Victorian Murray Floodplain Restoration Project

Desktop Groundwater Assessment - Lindsay Island

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Lower Murray Urban and Rural Water Corporation

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Program Manager:	John Myers
Author:	Alice Tyson, Erin McIntosh, Anastasia Rastorgueva
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Jacobs Group (Australia) Pty Limited and GHD Pty Ltd trading as R8 Joint Venture
ABN 37 001 024 095Floor 11, 452 Flinders Street
Melbourne VIC 3000
PO Box 312, Flinders Lane
Melbourne VIC 8009 Australia
T +61 3 8668 3000
F +61 3 8668 3001

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List of abbreviations and units

bgl	Below ground level
cm	Centimetres
EC	Electrical conductivity – measure of salinity
EVC	Ecological Vegetation Class
ha	Hectares
IFR	Issued for review
km	Kilometres
mAHD	Metres Australian Height Datum – reference point for elevation
MDBA	Murray Darling Basin Authority
mg/L	Milligrams per litre – unit of Total Dissolved Solids salinity
mS/cm	MilliSiemens per centimetre – unit of electrical conductivity – equal to 0.001 x µS/cm
R8	Joint venture between Jacobs and GHD
SEPP	State Environment Protection Policy under the Victorian *Environment Protection Act 1970*.
t/ha/m	Tonnes per hectare per metre depth of soil – unit of soil salt load
µS/cm	MicroSiemens per centimetre – unit of electrical conductivity – equal to 1000 x mS/cm
VAF	Victorian Aquifer Framework
VMFRP	Victorian Murray Floodplain Restoration Project
TDS	Total Dissolved Solids – measure of salinity
yr	Years

Executive Summary

Project background and description

This desktop groundwater assessment has been prepared for the Lindsay Island Floodplain Restoration Project (the project), to support the preparation of referrals under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and Victorian *Environment Effects Act 1978* (EE Act). The project is one of nine discrete environmental works projects being undertaken as part of the Victorian Murray Floodplain Restoration Project (VMFRP), which is being implemented as part of Victoria's obligations under the Murray Darling Basin Plan. Lower Murray Urban and Rural Water Corporation (LMW) has been nominated by the partnership established to deliver VMFRP, as the project proponent for the purpose of submitting referrals and approval applications.

The project involves works to facilitate managed inundation of approximately 4,845 ha of high ecological value floodplain in Victoria, mostly located on Lindsay Island and floodplain areas south of the Lindsay River, including Lake Wallawalla. In order to engage inflows to the Lindsay River, operation of the project would involve raising water levels along the Murray River behind Lock 7, which would also inundate some lower-lying billabongs and creeks on the NSW side of the Murray River. Approximately 263 ha of inundation would occur in NSW, most of which would be within the Murray River. The total inundation area for the project is 5,108 ha including inundation in Victoria and NSW. By proposing to restore a more natural inundation regime, the project aims to mimic the impact of prior to river regulation natural flood events, improving the condition of vegetation communities, and providing seasonal aquatic habitat for native fauna.

The project comprises six main water management areas (WMAs):

- Berribee WMA – comprises a 3,507 ha inundation area in Victoria and 263 ha of inundation in NSW
- Crankhandle WMA – comprises a 299 ha Upper Tier and a 17 ha Lower Tier inundation area
- Crankhandle West WMA comprises a 23 ha Upper Tier and a 72 ha Lower Tier inundation area
- Lindsay South WMA – comprises a 140 ha inundation area
- Wallawalla East WMA – comprises a 164 ha inundation area
- Wallawalla West WMA – comprises a 623 ha inundation area.

To facilitate environmental watering, the project involves construction of a large regulator on the Lindsay River near Berribee Homestead, additional regulators, containment banks and channels across the floodplain to distribute and retain floodwaters, two drop structures into the Lindsay River and one drop structure into the Murray River to enable controlled release of managed floodwaters, three temporary pump hardstands, a permanent pump suction line into Lake Wallawalla, along with access track works and temporary construction laydown areas near the Berribee Regulator. These project components are all included in the area of investigation assessed in this report.

In addition, a number of ancillary project components have also been identified as being required to facilitate the project works including the construction of boat ramps / barge wharves on the Lindsay River to facilitate construction of the Berribee Regulator, additional temporary laydown areas and temporary pump stations to source construction water supply at various locations, and installation of coffer dams to enable dewatering of work sites in the Lindsay River, Murray River and other locations where required to minimise the potential for inundation of work areas during construction. Where practicable, it is understood that these ancillary activities would be located within the area of investigation.

As discussed in the Flora and Fauna Assessment prepared for the project (R8, 2020a), it is expected that the reinstatement of a more natural flooding regime would be beneficial to vegetation within the managed inundation, as the vegetation communities modelled to occur are generally flood dependent. Although two non-flood-dependent EVCs have been modelled by DELWP (2005) as being present within the proposed inundation area (EVC 97: Semi-arid Woodland and EVC 98: Semi-arid Chenopod Woodland), targeted ground-truthing has confirmed that these EVCs are not present within or immediately adjacent to the modelled locations within the inundation area. The vegetation present in these areas was generally Riverine Chenopod Woodland (EVC 103), Lignum Shrubland (EVC 808) and occasionally Alluvial Plains Semi-arid Grassland (EVC 806). These EVCs are located on alluvial terraces and are prone to flooding and are therefore likely to benefit from environmental watering. Monitoring programs (such as The Living Murray) at Lindsay Island have shown positive responses to flooding for the flood-dependent EVCs modelled or mapped to occur within the proposed inundation area, whether it be landscape-scale overbank flooding or smaller scale events (e.g. watering of creeks, floodrunners and low-lying wetlands). The Flora and Fauna Assessment (R8, 2020a) and the EPBC Act and EE Act referral documentation provides further discussion of the expected ecological benefits for floodplain vegetation communities of reinstating a more natural flooding regime through environmental watering.

Reference to 'the project area' throughout this assessment includes both the construction footprint and the inundation area, as well as areas beyond these extents where groundwater impacts may conceivably occur.

Design is being refined as part of the design process and in response to environmental and heritage studies. The area of investigation that has been established provides a buffer around the current design of the development footprint and access tracks to allow for future changes. Any design changes requiring works outside of this area of investigation, or changes to the proposed operating scenarios and inundation area would require further assessment to identify their potential to impact on groundwater.

Key findings

The project area is underlain by shallow groundwater, typically between 3 – 6 m below ground level. The watertable aquifer is predominantly highly saline (>50 mS/cm), with fresher groundwater close to the Murray River and isolated sections of anabranches (<5 mS/cm). Soil salinity is also known to be very high. Groundwater is thought to be in direct connection with the Murray River and sections of the Lindsay River, which generally lose water to groundwater. Large areas of terrestrial vegetation, which are likely to have some reliance on groundwater, are present across the project area. No registered groundwater users (groundwater bores) were identified within the area of project influence.

Potential impacts associated with construction and operation of the project could arise through changes in groundwater level, flow and quality. This includes:

<u>Potential impacts from construction of the project</u>

- Potential for temporary, localised drawdown of groundwater levels from dewatering of construction excavations – not expected to significantly reduce groundwater availability to local ecosystems based on implementation of proposed mitigation measures.
- Disposal of saline waste groundwater from dewatering of construction excavations – not expected to significantly impact local ecosystems based on implementation of proposed mitigation measures.
- Potential for localised alteration of groundwater flow paths and levels from installation of permanent below-ground water barriers – not expected to significantly alter groundwater availability to local ecosystems based on implementation of proposed mitigation measures.

<u>Potential impacts from operation of the project</u>

- Potential for increased groundwater levels in inundated areas and some areas outside the managed inundation area to result in waterlogging if shallow groundwater persists in areas containing not flood-tolerant vegetation communities and species - further assessment (as outlined in Section 5.1) is required to fully understand this potential impact, with monitoring and adaptive management proposed to mitigate this potential impact. Within the managed inundation area, EVCs are flood tolerant and therefore unlikely to be affected by waterlogging from shallow groundwater.
- Potential for near-surface salinisation in some areas outside of the managed inundation area in the medium to long term - further assessment (as outlined in Section 5.1) is required to fully understand this potential impact, with monitoring and adaptive management proposed to mitigate this potential impact. Within the

managed inundation area, local ecosystems may benefit from slight reductions in groundwater salinity. NSW inundation areas are anticipated to have less of a need for management with respect to near-surface salinisation but will be included in the adaptive management framework.

- Potential increase to nutrient load in soil profile and groundwater from flood waters - not expected to adversely impact local ecosystems.
- Potential for increased salt load in the Lindsay River downstream of the project area from mobilisation of salt from soil and groundwater to surface water (salt wash-off) potentially affecting water dependent ecosystems, and water quality for downstream irrigators - further assessment (as outlined in Section 5.1) is required to fully understand this potential impact, with monitoring and adaptive management proposed to partly mitigate this potential impact.
- Potential secondary impact to cultural values from near-surface salinisation and waterlogging – additional assessment is being undertaken through the Cultural Heritage Management Plan (CHMP) to understand this potential impact and to identify management and mitigation measures if required.

In addition to the above, salinity discharges and any associated changes or impacts in the Murray River as a result of planned inundation of the Lindsay Island floodplain would be considered and assessed on a cumulative basis by the Murray Darling Basin Authority (MDBA) through the protocols of the Basin Salinity Management 2030 strategy (BSM2030). These protocols are yet to be finalised for floodplain restoration projects, but discharges from the Lindsay Island project would need to comply with these once finalised. This may involve the use of offsets or salinity credits from the Victorian salinity credit pool.

To address the potential impacts identified above, the following mitigation measures are proposed:

Construction

- Minimise the total volume and rate of groundwater extracted for construction purposes - plan construction to minimise dewatering, provide make-up or offset watering for affected vegetation during construction;
- Avoid disposal of groundwater from construction activities to land; and
- Manage disposal of waste groundwater to waterways to avoid significant impacts to water quality and to comply with EPA discharge requirements.

Operation

- Plan and monitor environmental watering events to avoid peak groundwater mound salt outflow coinciding with irrigation season;
- Monitor vegetation in areas surrounding inundated areas for signs of potential waterlogging. Implement adaptive management, potentially including amending operational schedules (e.g. reduce frequency/duration), to mitigate impacts if identified;
- Monitor groundwater levels and quality prior to, during and after an inundation event to monitor development of groundwater mounds within the areas identified as potentially impacted by near-surface salinisation (refer Section 4.2.1.2). Implement adaptive management, potentially including additional watering of these areas or amending operational schedules (e.g. reduce frequency/duration), to mitigate impacts if identified.

In addition, the following further assessment is recommended to understand and address the potential impacts of the project:

- Specific groundwater level and quality information is required for the site to form a baseline for the potential construction and operation impacts, as well as to monitor the effects of inundation outside of the inundation area. It is understood that one new groundwater monitoring bore was installed in mid-2020 (in Lindsay South area), however monitoring data from this site was not available at the time of this assessment. The remaining network of existing bores at Lindsay Island should be selectively included in the monitoring program. Existing groundwater bores with no available elevation information are required to be surveyed to enable groundwater elevation data to be gathered;

- Groundwater monitoring of mound rise targeting ‘areas of interest’ and in particular ‘areas of heightened interest’, prior to construction to gather baseline and then operational data. This would allow for adaptive management of the project operation to minimise the potential for EVCs and other assets to be impacted by near-surface salinisation; and
- A CHMP is currently being prepared for the project in consultation with the First People of the Millewa-Mallee Aboriginal Corporation to identify the impact on Aboriginal heritage places, including potential groundwater impacts, and to specify management and mitigation measures as required.

Site- specific Environmental Watering Management Plans and Operating Plans will be developed by VMFRP in consultation with DELWP, Parks Victoria, the Mallee Catchment Management Authority and other relevant agencies, prior to the commencement of works. The finalised plans will document all avoidance and mitigation measures to be implemented for the project during operations (including the planned timing of inundation events), as well as responsibilities for implementation.

Important note about your report

The purpose of R8's engagement under the Victorian Murray Floodplain Restoration Project (VMFRP) is to design infrastructure for the VMFRP including regulators, containment banks, roads, access tracks and culverts. The designs are required to be suitable for construction pricing to inform business case prioritisation. The purpose of this infrastructure is to allow floodplains to be watered at the hydraulic design levels nominated by VMFRP. R8 are also engaged to provide Regulatory Approvals and Cultural Heritage Services. The purpose of these services is to support VMFRP to lodge the necessary approvals documents for the project with the relevant approval authorities.

The sole purpose of this report and the associated services performed by R8 is to complete a Desktop Groundwater Assessment Report for VMFRP in accordance with the scope of services set out in the contract between R8 and VMFRP. That scope of services, as described in this report, was developed with VMFRP.

R8 has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. However, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

In preparing this report, R8 has relied on the information provided by VMFRP. In particular R8 is reliant on VMFRP's prior flood modelling work to define inundation levels and extents. R8 is not responsible for achievement of the project's desired operational ecological outcomes.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by R8 for use of any part of this report in any other context. This report has been prepared on behalf of, and for the exclusive use of VMFRP, and is subject to, and issued in accordance with, the provisions of the contract between R8 and VMFRP. R8 accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

1.1 Program overview

The Lindsay Island Floodplain Restoration Project (the project) is one of nine discrete environmental works projects being undertaken as part of the Victorian Murray Floodplain Restoration Project (VMFRP), which is being implemented as part of Victoria's obligations under the Murray Darling Basin Plan. The VMFRP aims to restore a more natural inundation regime across more than 14,000 ha of high ecological value Murray River floodplain in Victoria through the construction of new infrastructure and modification of existing infrastructure.

The VMFRP is being implemented in partnership between Lower Murray Urban and Rural Water Corporation (LMW), Goulburn Murray Rural Water Corporation (GMW), Mallee Catchment Management Authority (Mallee CMA), North Central Catchment Management Authority (North Central CMA), Parks Victoria and the Department of Environment, Land, Water and Planning (DELWP). LMW has been nominated by the partnership as the project proponent for the purpose of submitting referrals and approval applications.

R8 is a joint venture formed between Jacobs and GHD, which has engaged by LMW to deliver design, cultural heritage and approvals services for the VMFRP. This desktop groundwater assessment has been prepared for the project to support the preparation of referrals under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and Victorian *Environment Effects Act 1978* (EE Act).

1.2 Project description

The project is located in north west Victoria, approximately 75 km west north west of Mildura and 30 km east of Renmark, South Australia. The project involves works to facilitate managed inundation of approximately 4,845 ha of high ecological value floodplain in Victoria, mostly located on Lindsay Island. Lindsay Island is approximately 28 km long east to west and is enclosed by the Murray River in the north and the Lindsay River anabranch in the south. The project would also involve inundation of floodplain areas south of the Lindsay River, including Lake Wallawalla. In order to engage inflows to the Lindsay River, operation of the project would involve raising water levels along the Murray River behind Lock 7, which would inundate some lower-lying billabongs and creeks on the NSW side of the Murray River. Approximately 263 ha of inundation would occur within NSW, mostly along the Murray River and a number of billabongs on the northern side of the Murray River, however these inundation areas are not specifically targeted for restoration as part of the project.

Lindsay Island is part of the Chowilla-Lindsay-Wallpolla Icon Site, one of six icon sites identified under the Murray-Darling Basin Ministerial Council's 'The Living Murray Initiative'. The project builds on existing environmental works constructed under The Living Murray (TLM) Environmental Works and Measures Program, with the aim of providing greater flexibility to manage environmental flows into the floodplain.

A number of water management areas have been categorised for the project, namely Berribee (covering the majority of the central and north project area and Lake Wallawalla), and smaller zones covering Wallawalla West, Wallawalla East, Lindsay South, Crankhandle and Crankhandle West (refer Figure 1.1).

The project involves the construction of (refer to Figure 1.2):

- Four large regulators (Regulator BERR_A also referred to as Berribee Regulator, and Regulators BERR_F, CR_A and CW_B1)
- Sixteen small regulators (Regulators BERR_B, BERR_C, BERR_D, BERR_E, CR_B, CR_C, CR_D, CR_E, CR_F, CW_A, CW_B2, LS_A, LS_B, WE_A, WW_A1 and WW_A2)
- Two un-gated culverts (BERR_G, WE_D)
- Two drop structures into the Lindsay River (CW_A and CW_B1) and one drop structure into the Murray River (CR_D)
- Approximately 9 km of containment banks incorporating overflow spillways where required

- Approximately 1.6 km of new excavated channel (CR_G and CW_D)
- Three hardstands for temporary pumping (WE_D, WW_B, LS_C), and one permanent suction line into Lake Wallawalla (WW_B)
- Construction of approximately 5 km of new access track and maintenance / upgrades to up to 82 km of other existing access tracks
- A 50 m x 50 m secure, fenced compound on the northern bank of the Lindsay River at the Berribee Regulator site to provide for the storage of equipment and materials during maintenance and operation of the Berribee Regulator
- Three temporary laydown areas near the Berribee Regulator, two on the southern side of the Lindsay River and one on the northern side of the Lindsay River, which would provide the primary location for site offices, vehicle parking, storage of equipment and materials, during construction of the project.

The Berribee Regulator would extend across the full width of the Lindsay River. Temporary cofferdams are likely to be required at a number of work sites, including those sites located in the Lindsay River (including Berribee Regulator) and Murray River along with other sites where necessary to prevent inundation of the work sites during rainfall or flood flows. Dewatering of work areas, particularly for deeper excavations, is likely to necessitate the disposal of highly saline groundwater.

The design and location of project structures, laydown areas and extent of access track upgrades is yet to be confirmed and would be refined through the design process. In addition, the location of some other temporary construction activities is yet to be determined, including additional, smaller construction laydown areas likely to be required at other work sites, the location of boat ramps / barge wharves required for construction of the Berribee Regulator, and the location of temporary pump stations to supply water for construction purposes. Where practicable, it is understood that design changes to the proposed infrastructure and temporary construction activities would be contained within the area of investigation. However, where this is not able to be achieved, further groundwater assessment would be required.

The programme of flood frequency and duration for the project varies according to water management area (Figure 1.1), however these vary from 1 to 3 months of peak water elevations being held, and a frequency of between annually for watercourses to 2 in 10 years for less regularly watered areas. Preferred timing spans June to February depending on water management area. Most water management areas would be allowed to drain by gravity after the specified flood duration via the opening of regulator gates, except for the Crankhandle (Lower Tier) and Wallawalla West water management areas, as well as Lake Wallawalla, which would be allowed to evaporate and/or infiltrate after inundation based on the current proposed operating plans.

This assessment covers the hydrogeology of the floodplain of the Murray River at Lindsay Island, around 75 km west north west of Mildura, Victoria. The project area includes the waterways of Lindsay River, Lindsay South Creek, Mullaroo Creek, Little Mullaroo Creek and Lake Wallawalla, and floodplains at Crankhandle, Billgoes Billabong, Wallawalla east and west, and Lindsay south (refer Figure 1.1). The focus of this assessment is the hydrogeology on the Victorian side of the Murray River, whilst recognising that the aquifers in question have some limited hydraulic connection to the NSW side.

The project is expected to flood some land within NSW, mostly in the former Lake Victoria State Forest and including an anabranch of the Murray River, Horseshoe Billabong and a billabong immediately east of Lock 7 (refer Figure 1.3). The impacts from the project on these areas have also been considered.

The environmental water delivery infrastructure included in the development and construction footprints are based on the current design for the project. Refinement of the design of the infrastructure would be undertaken as part of the project's design process. As such, the construction element of the project included in this report is indicative but provided as a basis of assessing the potential impacts of the project during construction. An area of investigation has been considered in this report that provides a buffer on the current construction footprint to allow for potential changes.

This report has been prepared based on the Issue for Review (IFR) Design dated March 2020.

1.3 Terminology

The following terms are used throughout this report to describe the project:

- Area of investigation - this includes the development footprint, as well as a buffer around the construction footprint and access tracks.
- Development footprint - this is the area that the permanent project infrastructure (e.g. regulators, drop structures, pump hardstands, containment banks, spillways) would occupy, along with currently identified temporary construction laydown areas. No construction working buffer or access tracks are included in the development footprint.
- Construction footprint - this includes the project infrastructure as well as the land required to construct the infrastructure. This includes access tracks.
- Inundation area - area of land subject to flooding during managed events, up to a specific design water level.

Reference to 'the project area' throughout this assessment includes both the construction footprint and the inundation area, as well as areas beyond these extents where groundwater impacts may conceivably occur.

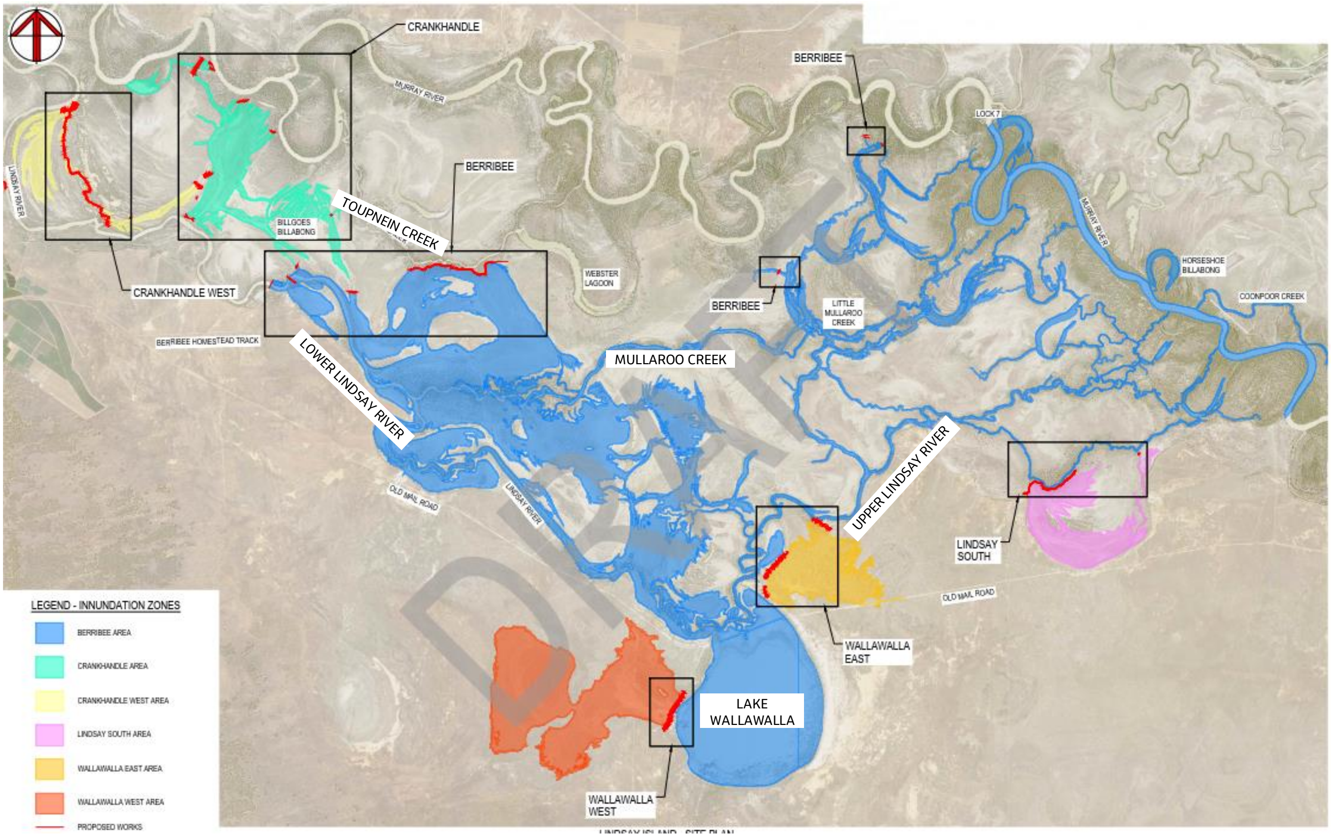

Figure 1.1: Draft indicative inundation extents classified into water management areas (R8 2020).

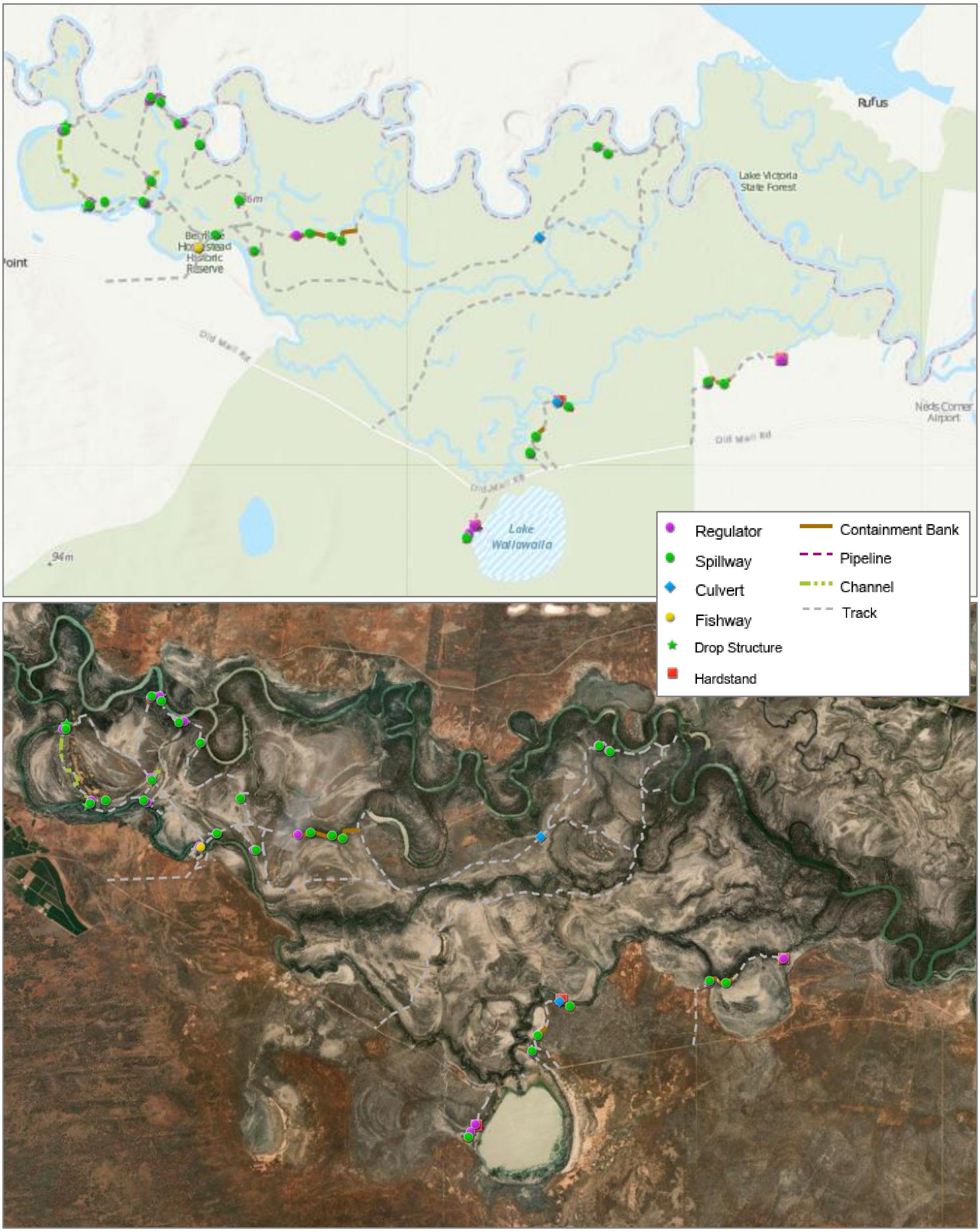

Figure 1.2: Indicative location of project works, over streetview (top) and satellite (bottom) basemaps (R8 mapping product).

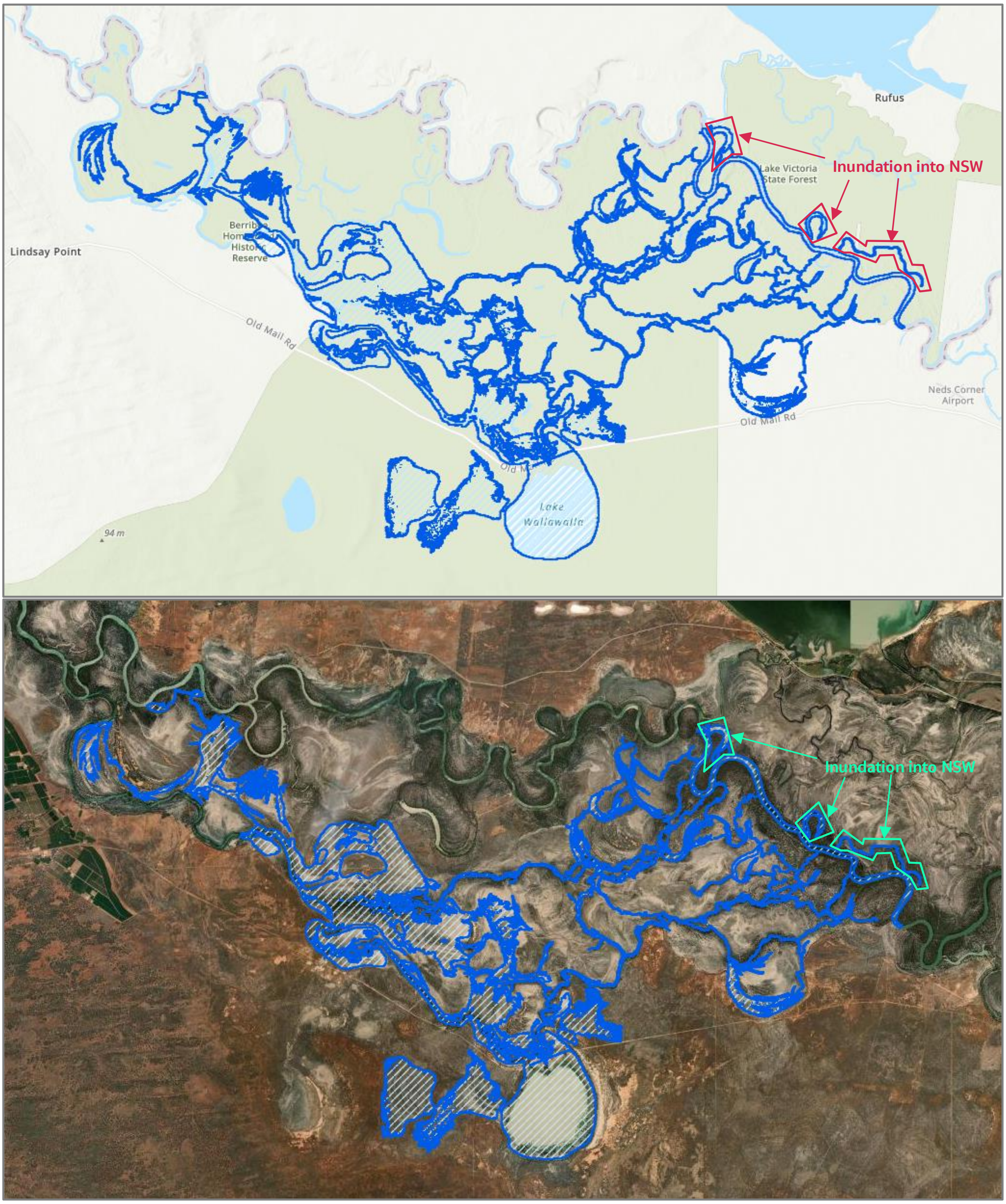

Figure 1.3: Inundation extent of environmental watering events under the project, over streetview (top) and satellite (bottom) basemaps, with NSW inundation (not including inundation within the Murray River) components marked (R8 mapping product).

1.4 Previous investigations

A considerable amount of work has been undertaken since the 1970s to study the hydrogeological system, and particularly the salinity processes, of Lindsay Island and the floodplain's impact on the salinity of the Murray River. The focus of the work has changed since these early investigations, which were concerned with high salinity in the Lindsay River impacting local irrigators. Through the late 1980s the direction of study shifted with the recognition of the contribution of groundwater salt loads to salinity in the Murray River, and the first focus on flora and fauna protection. This included the installation of a salt interception scheme at Rufus River, just north of the Lake Victoria State Forest (OoW 2013). A significant amount of work was done through the 1990s and early 2000s to understand the detailed hydrogeology, salinity processes and groundwater-surface water connection in the area. The current project falls under the most recent phase of work which would be characterised by a focus on environmental management. Since around 2005, studies have been centred on vegetation and wetland health and how groundwater impacts these (SKM 2014).

More recent investigations into environmental watering options for the Lindsay Island floodplain area were conducted in 2008 and 2010 (SKM) as part of The Living Murray program, and then in 2014 (SKM) under the Department of Sustainability, Environment, Water, People and Community (SEWPAC) works and measures program, all which focused on the salinity impact to the Murray River of an environmental watering scheme. These studies included an assessment of the impacts to NSW inundated areas with a rise in Lock 7 water levels (SKM 2010).

Previous studies that have considered impacts from projects similar to the current one, most recently SKM 2014, looked at effects on the hydrogeological system from the inundation of Lindsay Island and surrounds with regard to the salinity impact to the Murray River, albeit for a slightly different area of inundation and proposed environmental watering regime. While the hydrogeological processes causing the impacts are mostly still relevant, other groundwater receptors in the area (e.g. ecosystems) were not part of the scope of these previous projects as they are currently. Accounting for the potential salinity impact to Murray River water quality will likely be required as part of the current project, however the quantification of the potential impact is not within the scope of this assessment. Salinity discharges and any associated changes or impacts in the Murray River as a result of planned inundation of the Lindsay Island floodplain would be considered and assessed on a cumulative basis by the MDBA through the protocols of the Basin Salinity Management 2030 strategy (BSM2030). These protocols are yet to be finalised for floodplain restoration projects, but discharges from the Lindsay Island project would need to comply with these protocols once finalised.

Notwithstanding the significant amount of work undertaken to date, the complexity of the hydrogeological system across Lindsay Island means there are remaining uncertainties with regard to the exact mechanisms and quantification of salinity processes. The current assessment also does not attempt to re-quantify the likely salinity impact to the Murray River; rather it uses previous investigations to identify the issue for the purposes of referral and notes the need to address it in future work, associated with project development.

1.5 Purpose of this report

This report documents a desktop assessment of groundwater considerations associated with the Lindsay Island Floodplain Restoration Project and will feed into the referral documentation being prepared under the EE Act and EPBC Act.

1.6 Limitations

The following limitations apply to the assessment contained in this report:

- No site visit has been undertaken;
- Reports and records available on the public record have been used;
- Knowledge and experience of Jacobs staff have informed the assessment, including staff involved with SKM's 2014 salinity assessment;

- Detailed groundwater investigation and monitoring at the precise sites for the proposed works and at the specific areas of inundation are not available and so general understanding of the hydrogeology and sites has been used. It is possible that future detailed studies may revise the findings presented here, once in possession of site-specific information; and
- The report is based on the current design footprints and construction activities and information provided by VMFRP to define the proposed area of inundation and operating regime. This assessment is therefore preliminary only as changes to the scope and location of works and inundation may change the findings and recommendations in this report.

2. Key legislation

The following are the key legislation for this groundwater assessment. Other legislation may also apply:

- *Water Act 1989* – sets requirements for groundwater bore approval and licencing and regulates groundwater take and use from aquifers in Victoria. Groundwater users are regulated by this Act and impacts on users and the environment are also controlled. This Act would control groundwater monitoring works undertaken by the project.
- *Catchment and Land Protection Act 1994* – deals with diffuse source effects in catchment, such as recharge and water quality changes.
- *Water Act 2007* (Cwth) – deals with the management of salinity in the Murray River and sets the requirements for the Basin Plan, which includes groundwater management and sustainable diversion limits for aquifers (SDL).
- *Environment Protection Act 1970* – specifically the State Environment Protection Policy (Waters) (2018) which regulates the protection of surface water where groundwater may interact with surface water, including activities such as the disposal of groundwater into the environment from dewatering activities.

In addition to the relevant Acts, regulations under these acts are also important. Specifically, for groundwater, the protocols and agreements made under the Basin Salinity Management 2030 strategy (BSM2030) are important as they define the conditions and controls relating to salt discharge to the Murray River and anabranches.

3. Existing conditions

3.1 Regional hydrogeology

The Lindsay Island project area sits in the Murray Geological Basin. This basin was infilled with sediments during the Tertiary and Quaternary period. Figure 3.1 presents a generalised hydrogeological cross section for this area, identifying the main units and their relationship. The full geological sequence, running to a few hundred metres below ground surface is published by the Victorian Government through the Victorian Aquifer Framework and the 3D groundwater atlas of Victoria (see GHD & AWE, 2012). For this assessment, it is only the upper aquifer units that are of interest.

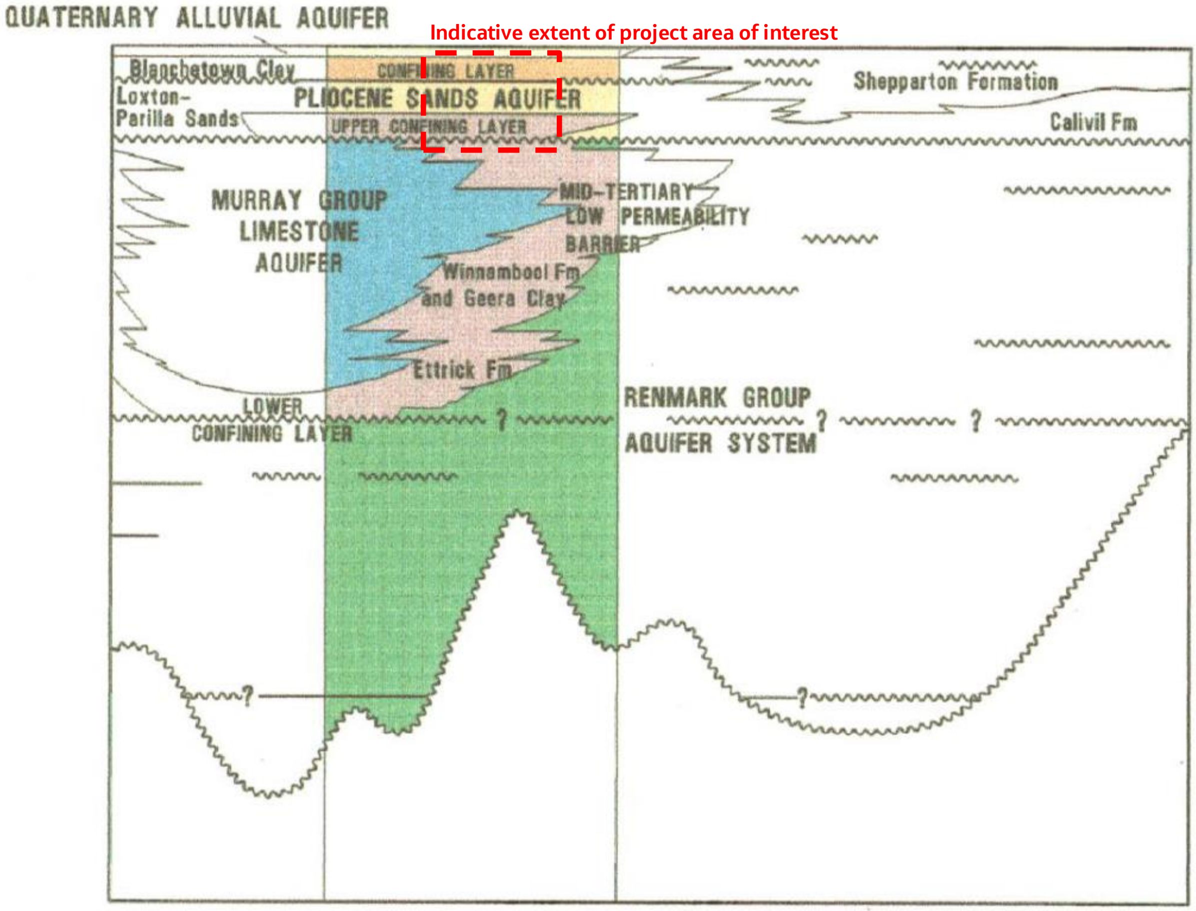

Figure 3.1: Regional hydrogeological units and their relationship within the Murray Geological Basin (indicative project area marked; after Thorne *et al.*, 1992).

Regional groundwater flow is to the south-west (Thorne *et al.* 1992), and groundwater is typically highly saline (>30,000 mg/L), freshening close to rivers (SKM 2010).

Groundwater levels are influenced by the lock levels of the Murray River close to the river, and also by evapotranspiration processes in the floodplain which draw down the groundwater level. Groundwater recharge is via the Murray River and lower Lindsay River channels where they incise into the Channel Sands, and also vertical recharge from flooding and to a lesser extent rainfall, however the rate of vertical recharge is limited by the surface fine alluvium (Coonambidgal Formation; SKM 2010).

3.2 Project area hydrogeology

A generic cross section of the Lindsay Island floodplain is presented in Figure 3.2, which shows the relative position and indicative thickness of the key units. Further detailed cross sections at different points in the Victorian floodplain are included as Figure 3.4 and Figure 3.5. Note that the interaction of the rivers and creeks to groundwater is dependent on the current level of groundwater and may not be as represented in the figures (e.g. the Lindsay River is mostly thought to currently lose flow to groundwater; SKM 2010).

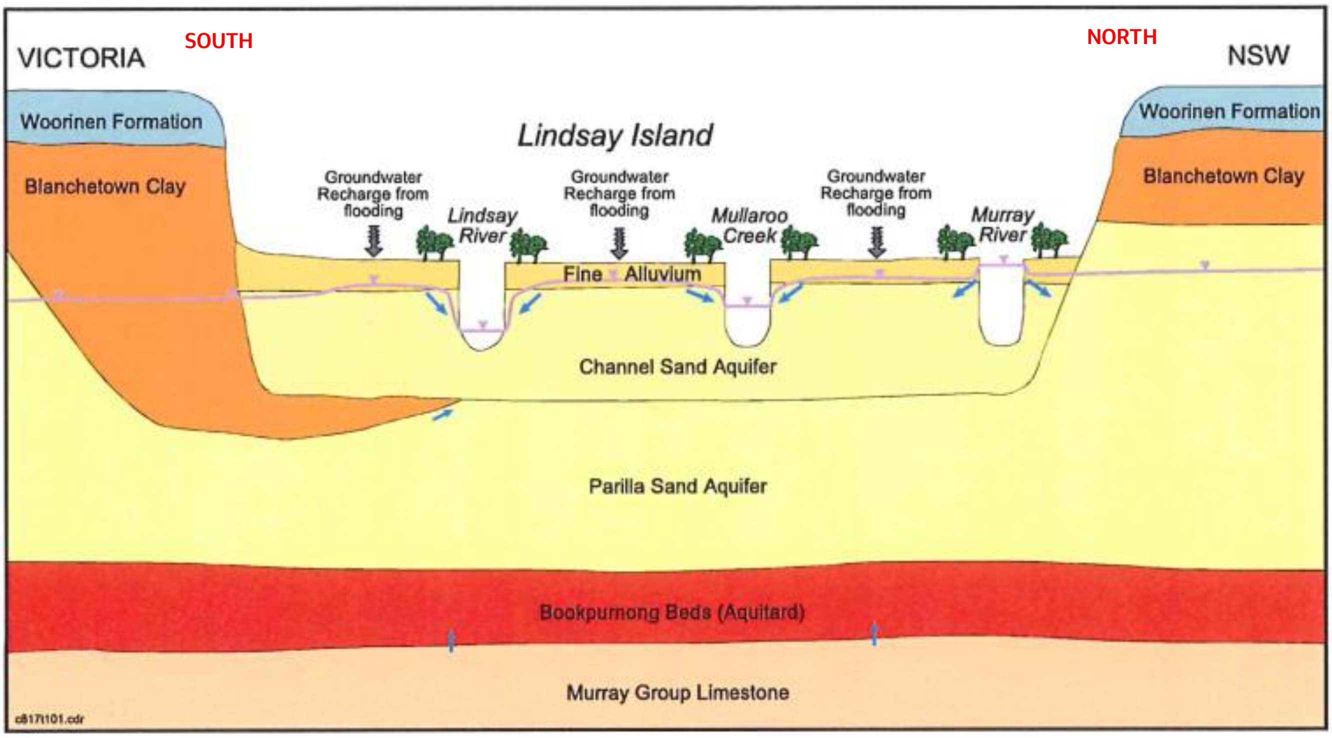

Figure 3.2: Typical indicative cross section of hydrogeological units across the Lindsay Island floodplain, running south to north across the section. Note that the "Fine Alluvium" on the section relates to the Coonambidgal Formation (SKM 2010).

A number of aquifer and confining (aquitard) units layer in the area to form a complex structure that is not uniform across the project area. The hydrogeological units relevant to the current study are listed in order of depth in Table 3.1 (from the surface down), with the relevant hydrogeological properties described.

Table 3.1: Summary of relevant hydrogeological units in project area (SKM 2008; 2009; 2010; 2014).

Hydrogeological unit	VAF^ Aquifer Number	Description	Expected thickness	Presence across project area	Aquifer nature
Coonambidgal Formation	100	Fine-grained recent Quaternary sedimentary deposit in the Murray Trench, consisting of silts and clays ("Fine Alluvium" on Figure 3.2). *Some vertical recharge through unit where it contains more sand, e.g. around the Mullaroo Wetlands.	2 - 10 m	Uniform	Aquitard *
Channel Sands (Monoman Formation)	100	Fine to medium-coarse grained Quaternary sedimentary deposit in the Murray Trench, consisting of predominantly of sand. Largely saturated across the project area, although the watertable sits within the upper extent in many areas.	5 – 20 m	Uniform	Aquifer

Hydrogeological unit	VAF^ Aquifer Number	Description	Expected thickness	Presence across project area	Aquifer nature
		Salinity is typically very saline, with limited flush zones of fresh water close to rivers.			
Blanchetown Clay	103	Quaternary clay unit, acting as a confining layer where present.	< 5 m	Localised to north of Lake Wallawalla (Figure 3.3)	Aquitard
Loxton Parilla Sand	104	A Pliocene sands aquifer, predominantly sand with minor silt and clay. Localised cemented layers limit vertical flow in places. Salinity is typically very saline, generally more so than the Channel Sands, with limited flush zones of fresh water close to rivers.	20 – 50 m	Uniform	Aquifer

^ Victorian Aquifer Framework Aquifer numbers.

The Blanchetown Clay unit acts as an aquitard separating the Channel Sands and the Loxton Parilla Sands where it is present. In the project area, the Blanchetown Clay is only interpreted to be very thin, less than 5 m, and present only to the north of Lake Wallawalla, where it underlies a few areas of planned inundation (refer Figure 3.3). There is also a small section of Blanchetown Clay underlying a planned inundation area at Lindsay South.

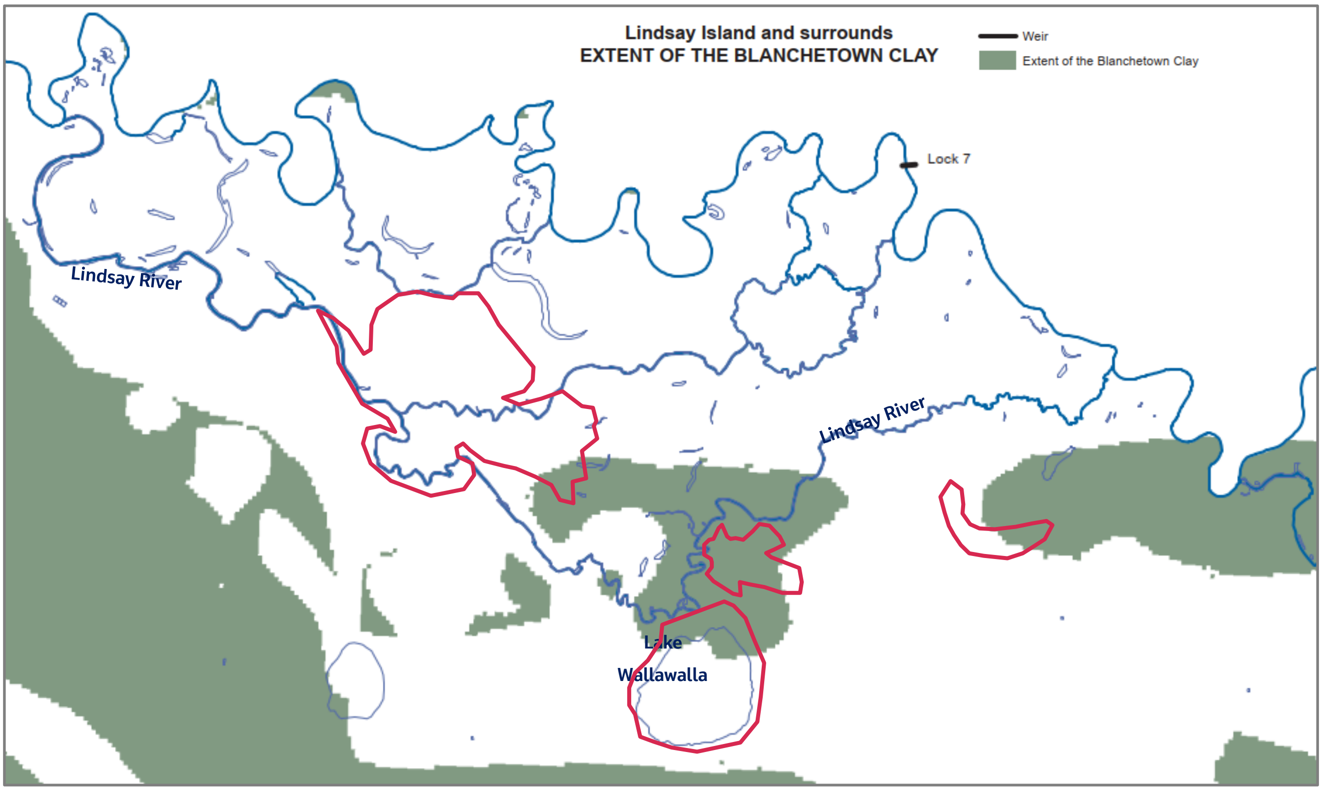

Figure 3.3: Interpreted extent of the Blanchetown Clay across the project area indicating where areas of planned floodplain inundation overlap (red polygons) (data from FedUni 2020, R8 mapping product).

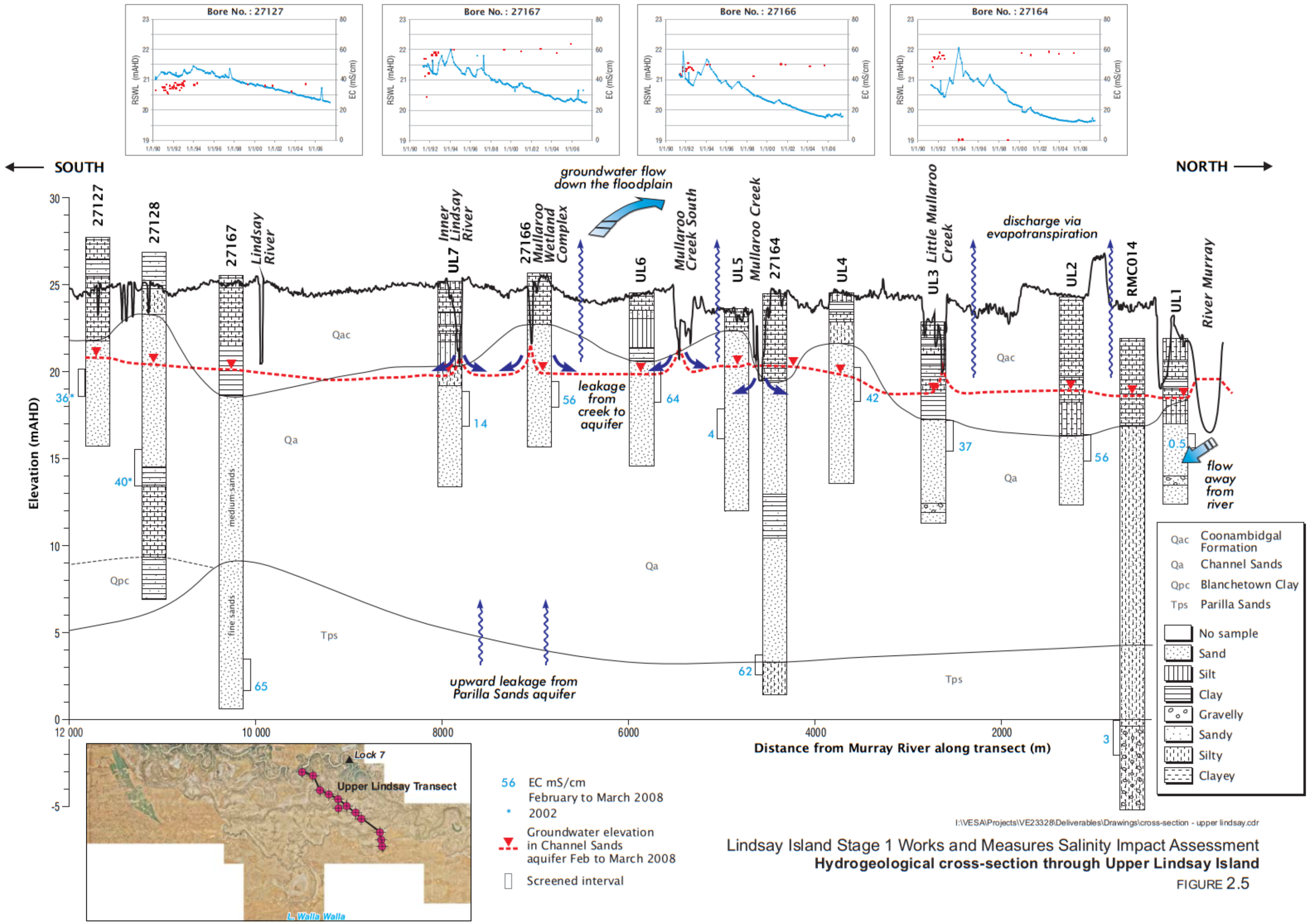

Figure 3.4: Cross section of the interpreted hydrogeological system through Upper Lindsay Island (SKM 2008).

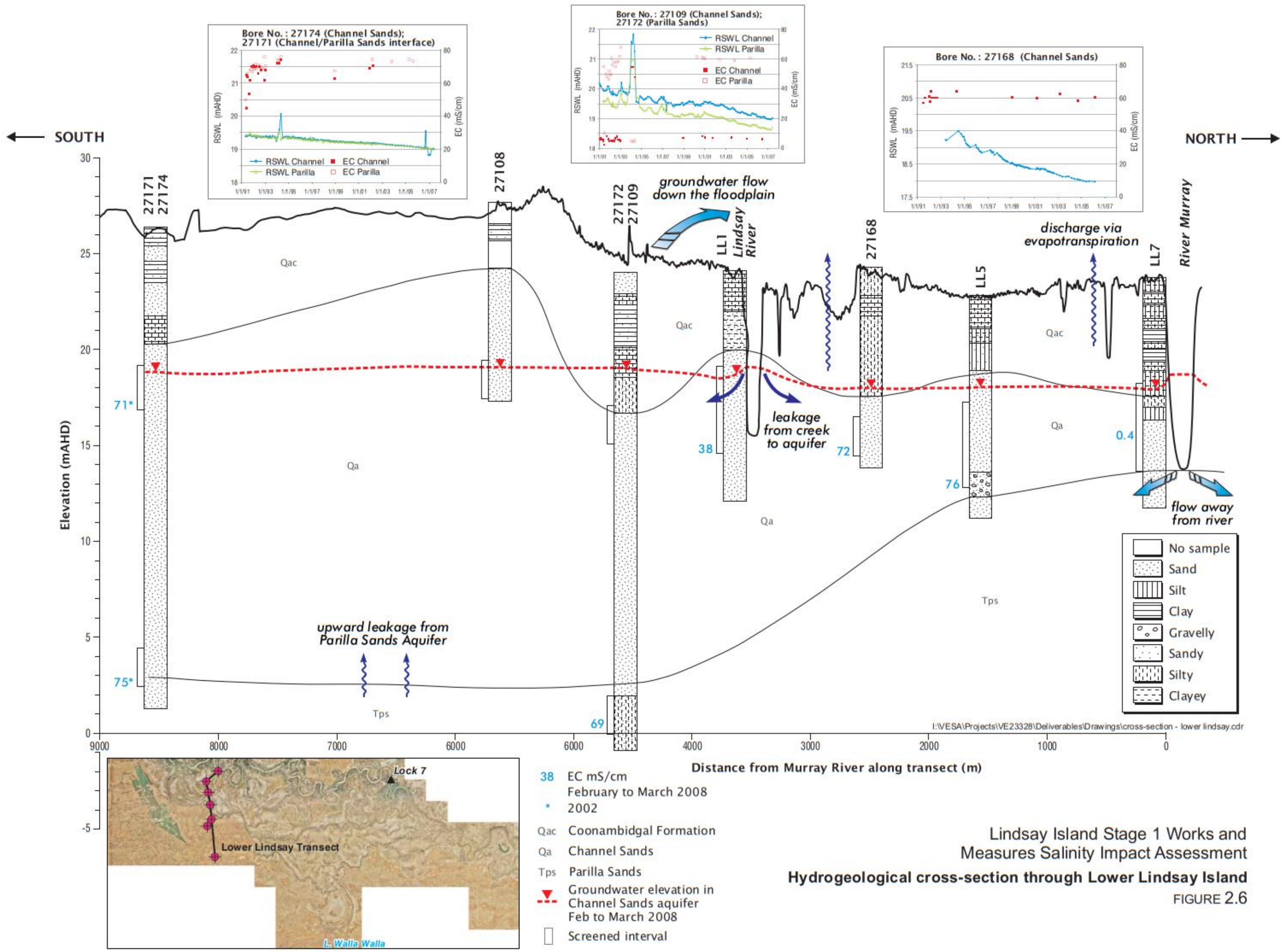

Figure 3.5: Cross section of the interpreted hydrogeological system through Lower Lindsay Island (SKM 2008).

3.2.1 New South Wales

The shallow hydrogeology in the Lake Victoria State Forest in NSW is very similar to that under Lindsay Island. The Coonambidgal Formation at the surface overlies the Channel Sands, known as the Monoman Formation in NSW. These are together around 10-12 m thick and are both in direct connection with Rufus River and the Murray River. Beneath the Quaternary alluvial is the Loxton Parilla Sand, as the Blanchetown Clay is not present in this area (refer Figure 3.6). Groundwater flow is south towards the Murray River, with the hydraulic head from Lake Victoria driving flow through the saline Loxton Parilla Sand into the Monoman Formation (Channel Sands) and discharging in the Murray River (OoW 2013).

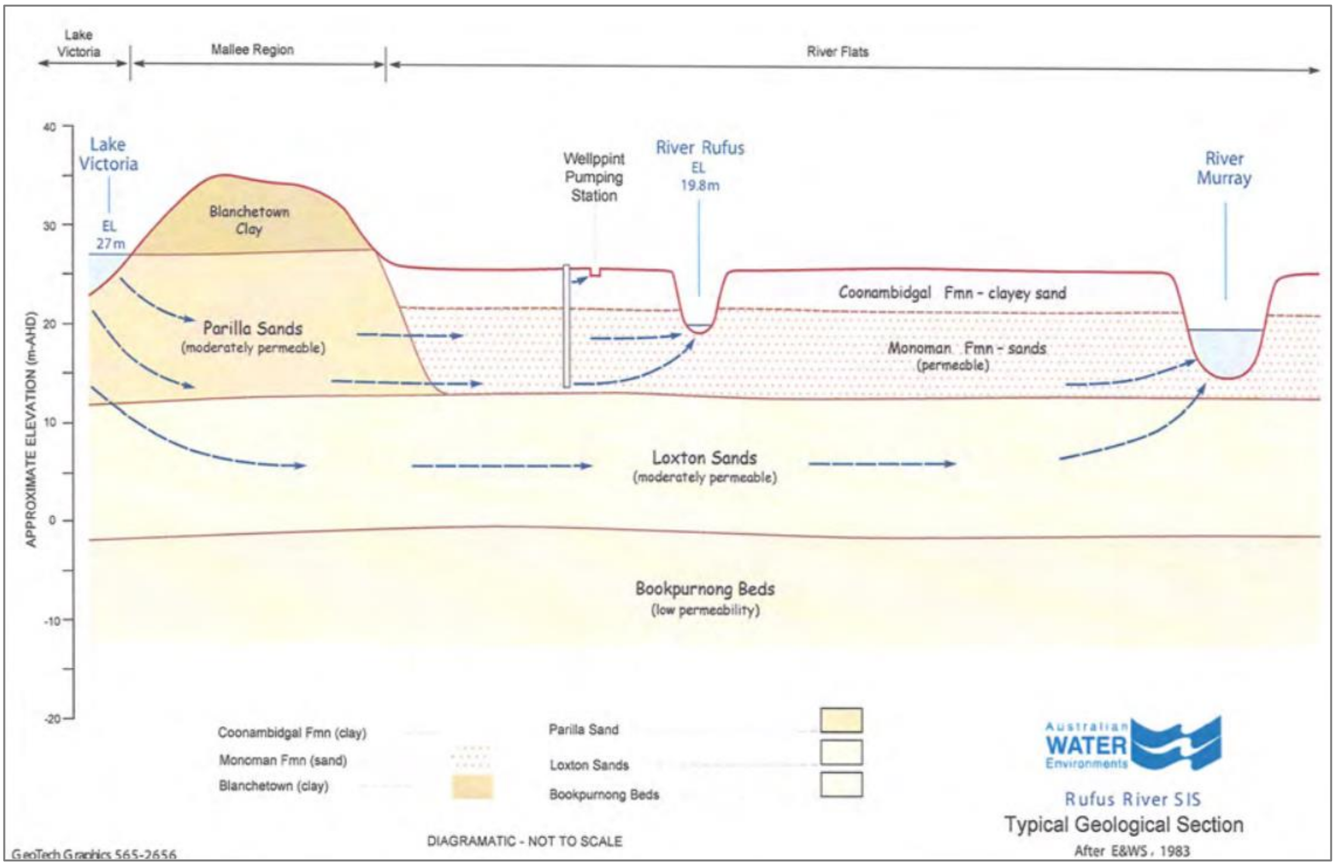

Figure 3.6: Indicative hydrogeological system under the Lake Victoria State Forest (OoW 2013)

3.2.2 Groundwater recharge

Previous studies have used an estimated recharge rate to the watertable (vertical infiltration) of between 0.03 and 1 mm/day (Overton and Jolly, 2004; SKM 2002), however recent investigations concerning salinity processes have considered 0.5 mm/day to be a reasonable estimate (SKM 2008; 2014). This is a source of uncertainty in the hydrogeological conceptualisation of the region as the actual recharge rate will depend on clay content of the surface unit. It is proposed that as part of the monitoring program for the watering operations, that better estimates of the infiltration in response to flood events and that these will lead to refinement of the estimated recharge rate. The uncertainty bounds on this are not considered to be detrimental to the project nor to imply that there is a lack of suitable understanding about the nature of the likely responses to flooding.

An additional and significant groundwater recharge pathway is via the stream bed of rivers and creeks when flowing, especially where channels cut into the Channel Sands aquifer. This is thought to be relevant for the Murray River, the Mullaroo Creek and the lower (downstream) Lindsay River. This is evident when noting halos of fresher groundwater around these waterways (flush zones; refer Section 3.4 below).

The presence of the Blanchetown Clay is likely limiting interaction between the Channel Sands and the underlying Loxton Parilla Sand where it is present.

3.3 Groundwater levels

A network of existing groundwater bores are present across the project area, which provide groundwater level data with a variable monitoring history, in both the Channel Sands and Loxton Parilla Sands aquifers at various depths. Depth to groundwater and watertable elevation contours have been developed for the Victorian project area using groundwater levels from selected bores based on an average of the last five years of records (data since 2015, DELWP 2020; Figure 3.8). NSW data was not available for this exercise. Individual bore results have been overlain on this map to indicate where localised groundwater levels differ slightly to this project-wide analysis.

The mapping suggests the watertable sits predominantly between 3 – 6 m below ground surface across the project area, with shallower areas at Lake Wallawalla and the Mullaroo Wetlands Complex, and across the floodplain in local depressions. The depth to groundwater is likely to be slightly deeper in the north-central Lindsay Island. Elevations of the watertable range between around 21.5 m AHD in the east to 18.5 m AHD in the west, and around 19.5-20 mAHD at Lake Wallawalla.

Groundwater levels are known to rapidly decline moving away from the Murray River and other permanently pooled areas into the floodplain (SKM 2010). This significant lowering of the watertable in the floodplain, up to 2-3 m lower than Murray River lock water levels, is occurring under both vegetated and open floodplain. This indicates that significant evapotranspiration processes are occurring on the floodplain, beyond what would be expected in this environment.

Hydrographs for selected groundwater bores show on Figure 3.8 have been prepared from the data record. Groundwater levels show lengthy recessions from flood peaks, evident after 2010 flood, as seen in the hydrographs for select bores in Figure 3.7. It is likely that current groundwater levels are still recovering (decreasing) from the elevated levels of the 2010 floods. Groundwater levels are significantly lower (1-1.5 m) than the peaks of the early 1990s before the Millennium drought. The impact of the drought in declining groundwater levels can be seen in the hydrographs in Figure 3.7 from around 1994 to 2010.

There has historically been upward vertical leakage from the Loxton Parilla Sand aquifer to the Channel Sands where the Blanchetown Clay is not present, particularly in the south-east of Lindsay Island, driven by an upward groundwater gradient between those aquifers (SKM 2010).

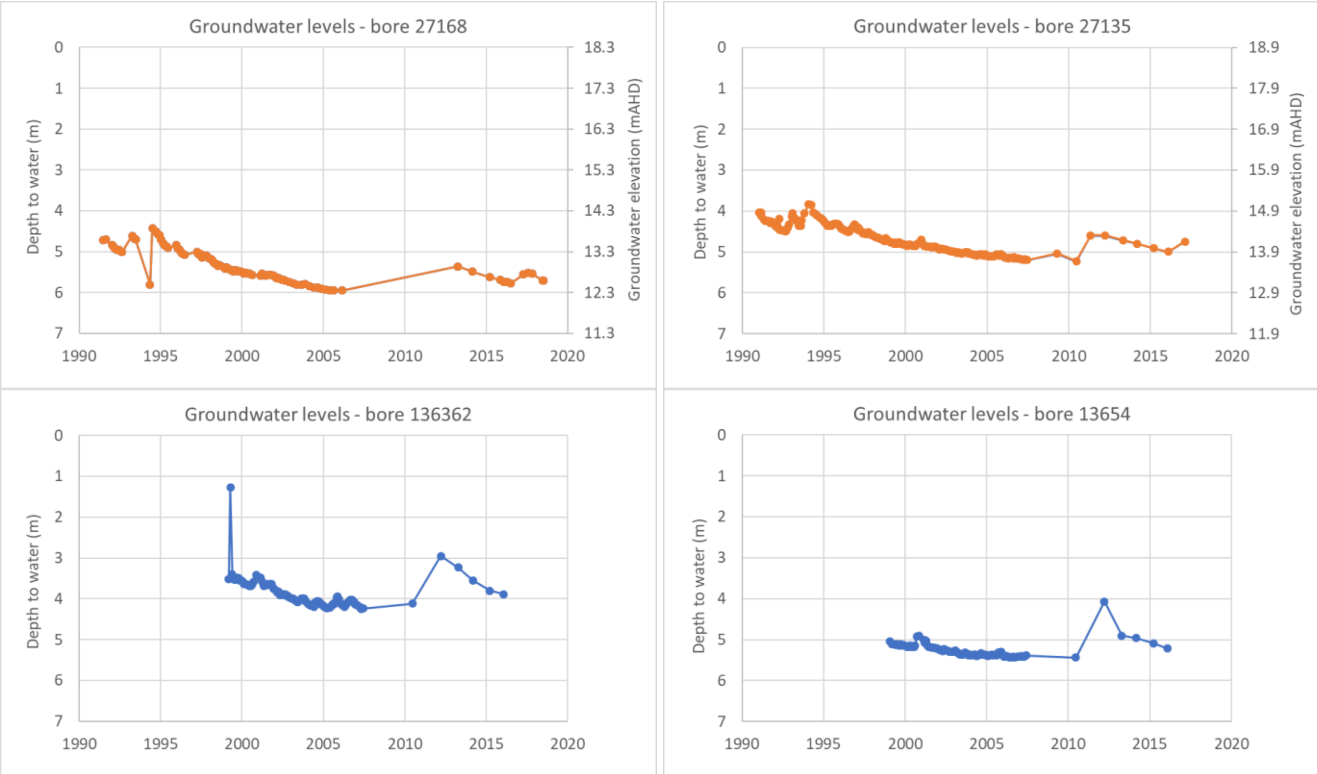

Figure 3.7: Hydrographs presenting depth to groundwater and groundwater elevation for selected bores in the project area (refer to Figure 3.8 for locations; DELWP 2020).

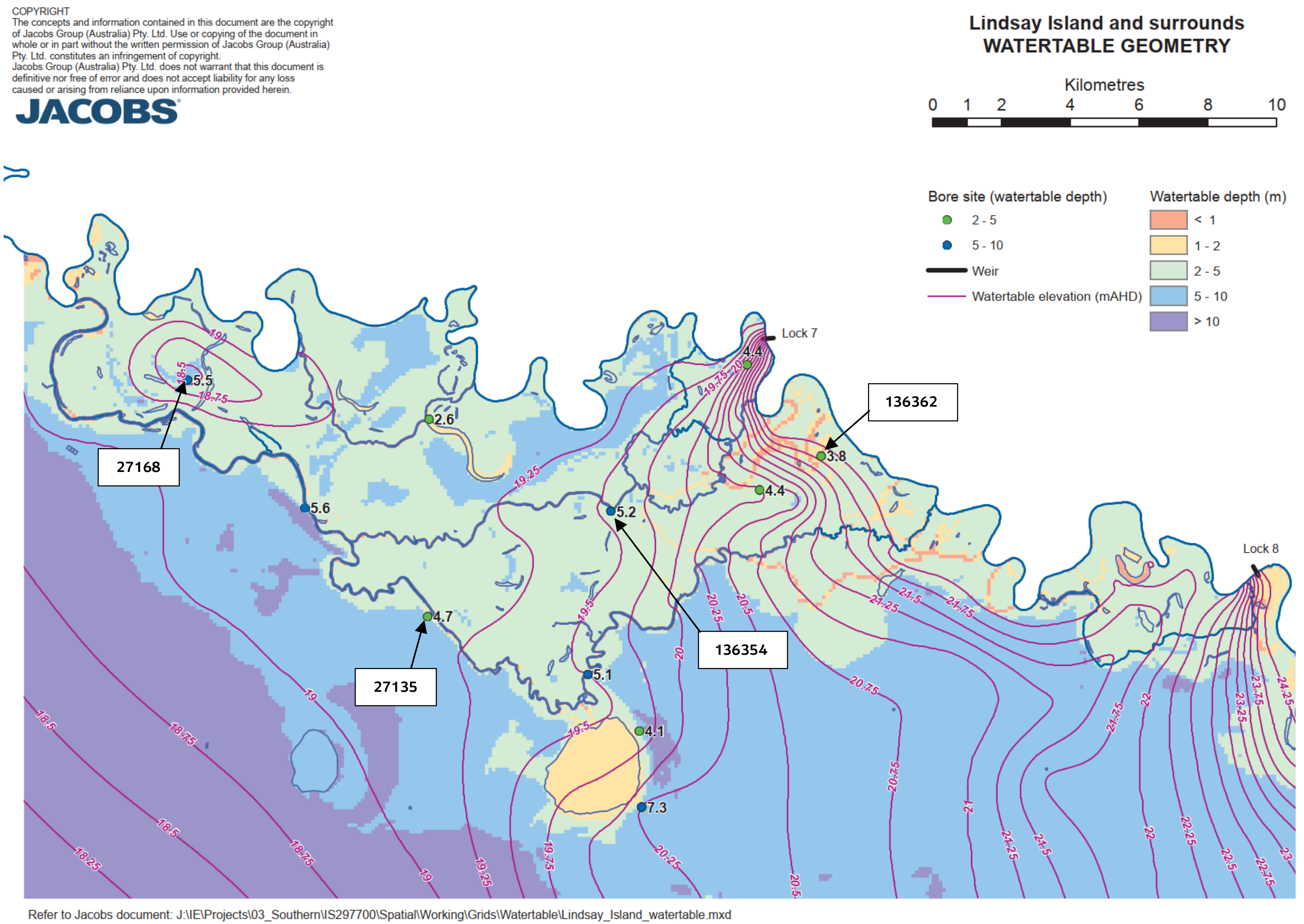

Figure 3.8: Interpreted geometry of the watertable across the project area (data from DELWP 2020).

3.3.1 NSW

Groundwater levels in the areas of NSW that would be inundated under this project would be very similar to the Murray River pool level at Lock 7, given the proximity of the areas to the river. This is around 19.5 m (average since 2015; WaterNSW 2020). In contrast to Victoria, where the watertable is lowered in the floodplain, groundwater in the former Lake Victoria State Forest is maintained by a driving hydraulic head from Lake Victoria to the north (refer Figure 3.6 above), and groundwater elevation is likely to increase away from the Murray River into NSW.

3.4 Groundwater salinity

Salt inflow to the Murray River in the Mallee tract (that is, downstream of Swan Hill) is a major source of salt load in the river, and land and water salinity issues in this region can be significant. Accordingly, soil and shallow groundwater salinity in the vicinity of the VMFRP sites and associated potential for near-surface salinity requires consideration in terms of ecosystems, vegetation and downstream surface water users.

The salinity of the Channel Sands aquifer (effectively the watertable) was interpreted in 2010 across the project area (SKM 2010). The variation in salinity as electrical conductivity is typically 200 to 90,000 µS/cm (SKM 2008) and is presented in Figure 3.9 (in mS/cm; 10 mS/cm = 10,000 µS/cm EC or around 6,000 mg/L total dissolved solids). Spot data from select groundwater bores has been plotted over the background salinity on this figure to give examples of point data (SKM 2010).

The salinity is highly variable, with the fresher flush zones evident close to waterways where there is regular flow. Note the absence of the flush zone in the upper Lindsay River and Mullaroo Creeks where flow is not as permanent. Most of the floodplain has very high groundwater salinities of between 50,000 to 90,000 µS/cm (or around 30,000 – 72,000 mg/L), with the flush zones recording much fresher water quality, from around close to river quality (typically <200 µS/cm) to around 5,000 µS/cm (around 3,000 mg/L). Airborne electromagnetic surveys (AEM) undertaken across the project area in 2008 show groundwater salinity at depth underground across Lindsay Island. The flush zones and very high salinity under the floodplain are clearly seen in the depth sections in the project area – a section north-south through Lock 7 in the east of the project area is show in Figure 3.10 (Cullen et al. 2008).

The deeper Loxton Parilla Sand aquifer is more saline than the Channel Sands, with some bores historically recording salinities of up to 200,000 µS/cm, however water quality in this aquifer too can vary significantly.

The SKM 2010 mapping also included the floodplain south of Lake Victoria into NSW, areas which the current project would be inundating. The groundwater in the relevant areas of NSW is mapped at between 35,000 to 50,000 µS/cm, however salinity is likely to be heavily impacted by the river flush zone.

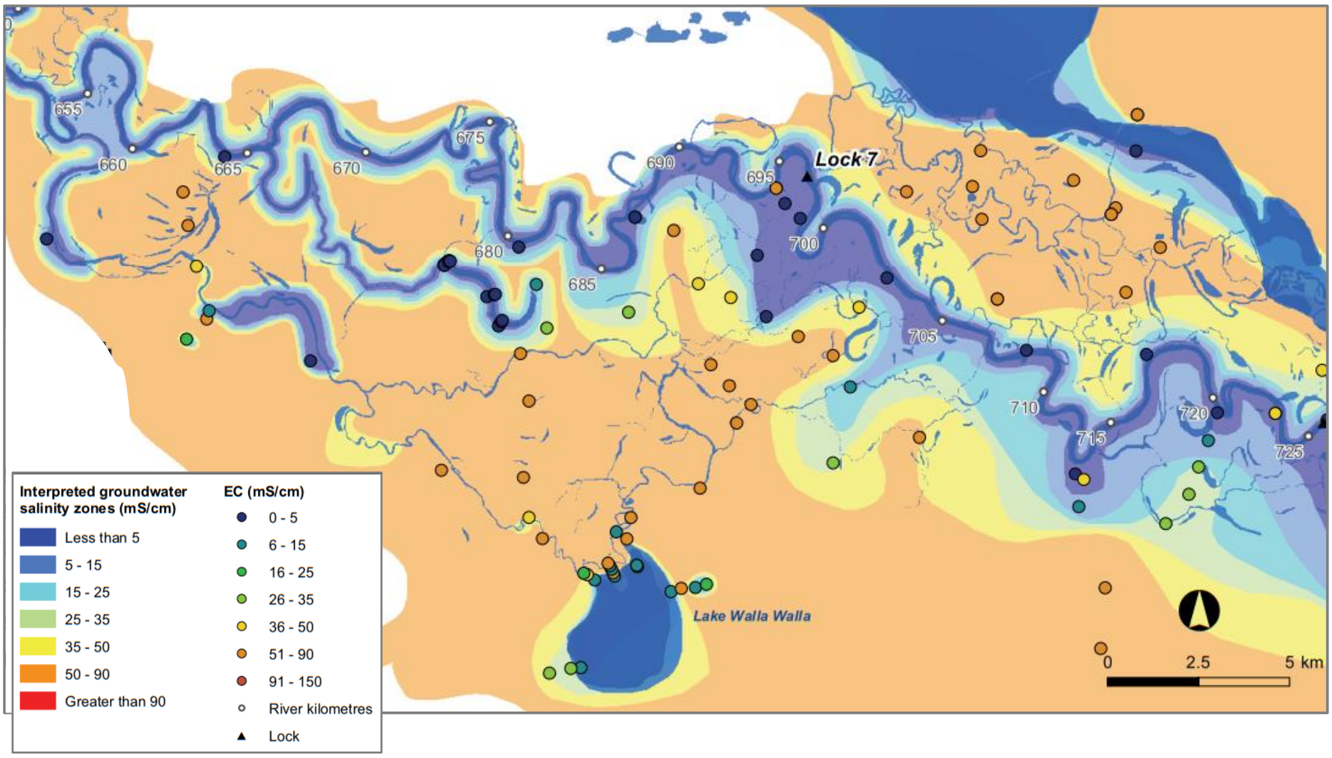

Figure 3.9: Interpreted groundwater salinity in the Channel Sands aquifer (after SKM 2010).

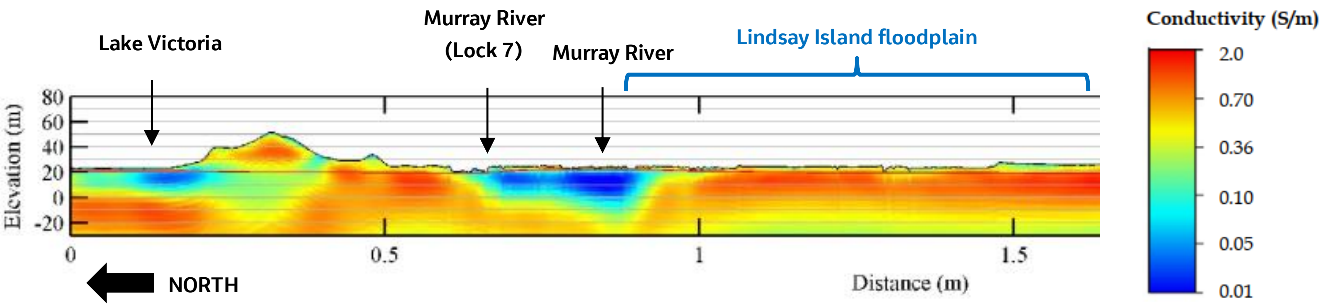

Figure 3.10: Interpreted ground salinity at depth under the floodplain – section runs through Lock 7, north-south (past Lindsay South) (after Cullen et al. 2008).

3.5 Soil salinity

Soil salinity in the saturated and unsaturated zones were mapped over the project area and for the riverine corridor by AEM (Cullen et al. 2008). Figure 3.11 shows the interpreted soil salt loads in the unsaturated soil profile across most of the inundated project area to be very high, over 100 t/ha/m, and over 200 t/ha/m in areas of central Lindsay Island, Crankhandle, Wallawalla West and Wallawalla East. Salt store in the top 5 m of the watertable mapped under the AEM survey also indicates significant areas of high salt load in the groundwater at a detail not captured in the groundwater salinity mapping (SKM 2010). Note the different legend salt store categorisation between the saturated and unsaturated maps. Small sections of central-south Lindsay Island and South Lindsay have a very significant salt store in the saturated zone, above 200 t/ha/m.

The AEM project also identified the inundated extents of the project area to have a moderate to very high surface salinity hazard rating (Cullen et al. 2008).

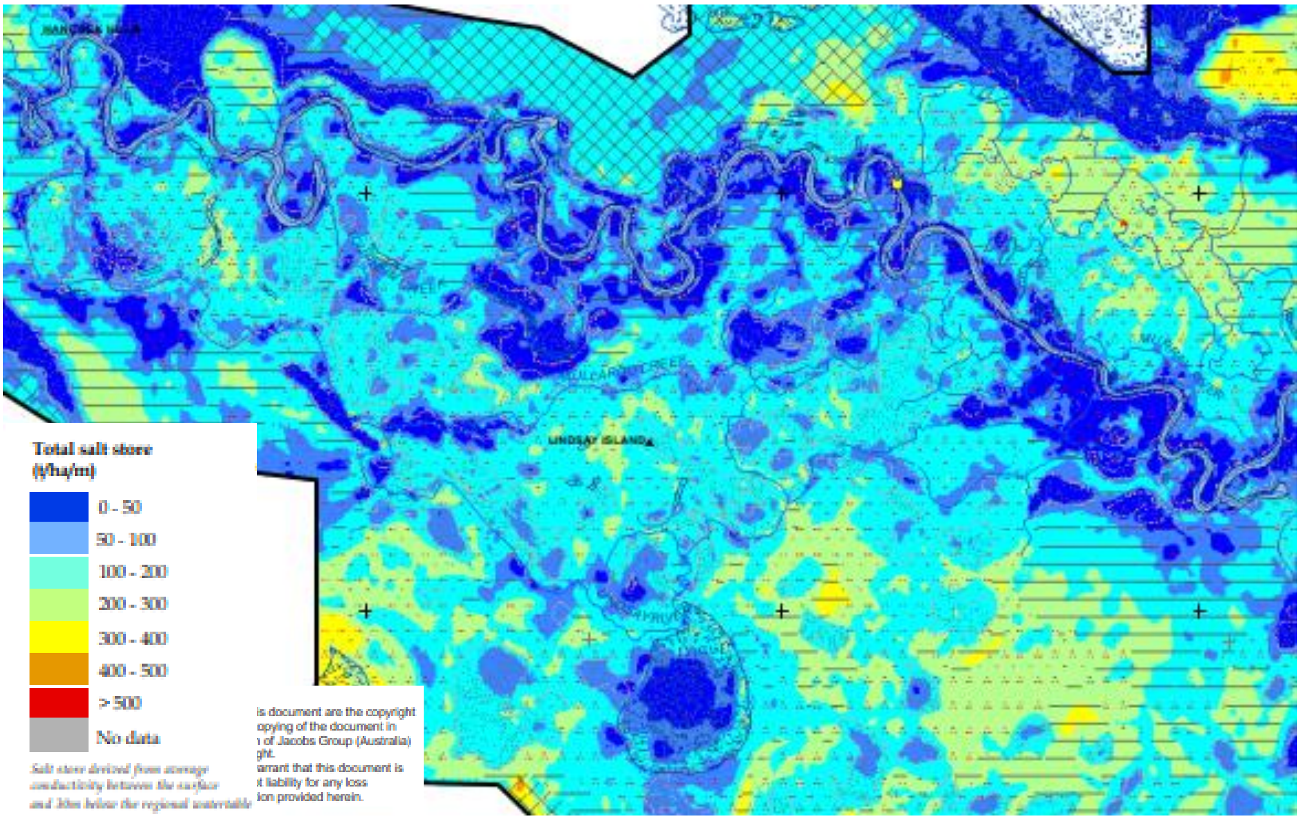

Figure 3.11: Interpreted unsaturated zone soil salt store from AEM survey across the project area (Cullen et al. 2008).

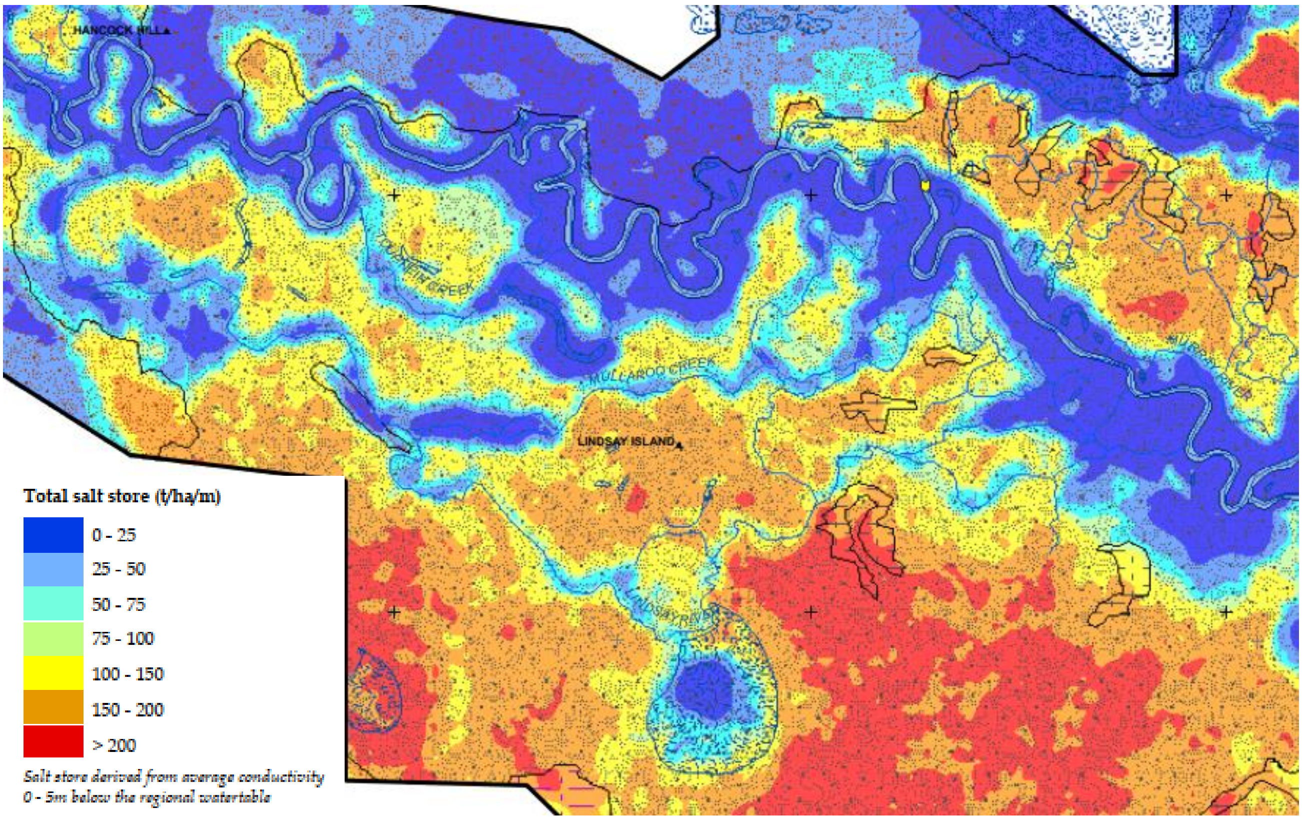

Figure 3.12: Interpreted saturated zone soil salt store 0-5m below regional watertable from AEM survey (Cullen et al. 2008).

3.6 Groundwater-surface water connectivity

Most waterways in the project area are thought to be losing streams, being that they lose water into the local groundwater system. Stretches of the Murray River and Rufus River are the exception, as they are thought to be gaining streams. Figure 3.13 presents the interpreted groundwater-surface water connectivity of waterways in the project area (SKM 2010). The Murray River, Mullaroo Creek and lower Lindsay River are thought to be incised through the Coonambidgal formation and into the Channel Sands, while the upper Lindsay River may not incise consistently through the surface aquitard unit.

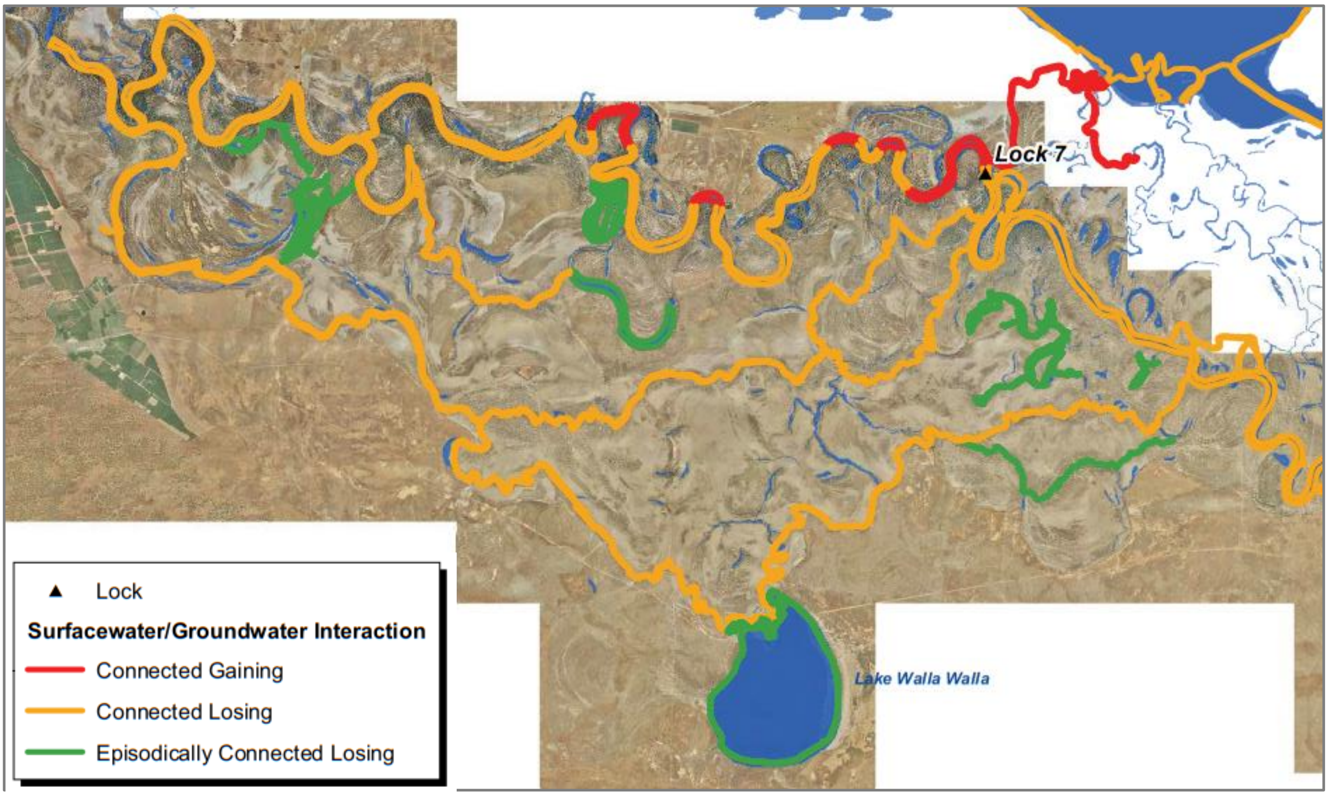

Figure 3.13: Interpreted groundwater-surface water connectivity in the project area (after SKM 2010).

3.7 Beneficial uses of groundwater

The quality of groundwater in Victoria is protected under the 2018 State Environment Protection Policy (SEPP) (Waters) (SEPP Waters), issued under the *Environment Protection Act 1970* and administered by EPA Victoria. The SEPP (Waters) defines a range of protected beneficial uses for defined segments of the groundwater environment, which are based on groundwater salinity. Beneficial uses of groundwater are considered to be precluded when relevant groundwater quality thresholds set out in the SEPP (Waters) for those beneficial uses have been exceeded.

The groundwater at the project area falls within segments B to F of the SEPP (Waters), however the majority of the groundwater across the floodplain areas falls well into the highest SEPP segment (F). Accordingly, the groundwater beneficial uses listed below are protected in the project area under the SEPP (Waters). Water quality standards are described for most of these beneficial uses and are provided in the SEPP (Waters).

- Water dependent ecosystems and species;
- Potable mineral water supply – likely protected in flush zones only;
- Agriculture and irrigation (irrigation) – likely protected in flush zones only;
- Agriculture and irrigation (stock watering) – likely protected in flush zones only;

- Industrial and commercial– likely protected in flush zones only;
- Water-based recreation (primary contact recreation);
- Traditional Owner cultural values;
- Cultural and spiritual values;
- Buildings and structures; and
- Geothermal properties.

3.7.1 Private groundwater use

There is only one registered stock and domestic bore within 5 km of the project area and no registered irrigation bores in the vicinity. The stock and domestic bore (8003691) is located around 3.5 km west of the Crankhandle West component of the area inundated by the project (refer Figure 3.14; FedUni 2020). The bore was constructed in 2008 and is screened 23-32 m below ground level and is therefore likely to be sourcing water from the regional Loxton Parilla Sand aquifer (FedUni 2020).

The absence of widespread groundwater use in the area is likely to be due to the high salinity of the regional aquifers and the proximity to fresh water from the Murray River and Lower Lindsay River.

Figure 3.14: Extreme north-west inundation area for the project, showing the location of bore 8003691 and the Lindsay Point irrigation area (dark green vegetated plots) (R8 mapping product and FedUni 2020).

Saline groundwater has been known to enter the Lindsay River and increase the salinity of the river, which has been an issue for irrigators farming almonds in the Lindsay Point area (Figure 3.14). In the early 1990s when the watertable was higher than current levels, the lower Lindsay River was thought to be a gaining stream, which allowed for a significant salt load from groundwater to enter the waterway. Since groundwater levels dropped through the Millennium drought, the Lower Lindsay River has become a predominantly 'losing stream' for most of the year (refer Section 3.6 above), where water quality and level in the river is generally maintained by the backing up of Lock 6 pool level on the Murray River (much less saline than groundwater). This is the case except for the recession limb of a flood event, where the elevation of the river drops after a flood, but the groundwater mound created from flood infiltration across the floodplain pushes more saline groundwater into the river, increasing its salinity for a period of time. This mechanism of salt delivery to the Lindsay River and eventually Murray River when groundwater levels are high is a potential issue for the current project.

3.7.2 Ecological vegetation classes

Groundwater plays an important role in sustaining aquatic and terrestrial ecosystems. A number of Ecological Vegetation Classes (EVCs) are mapped across the project area as identified in Figure 3.15, some of which are thought to contain species that are at least partially reliant on groundwater, namely:

- Riverine Chenopod Woodland (EVC 103)
- Grassy Riverine Forest (EVC 106)
- Grassy Riverine Forest / Floodway Pond Herbland Complex (EVC 811)
- Intermittent Swampy Woodland (EVC 813)
- Shrubby Riverine Woodland (EVC 818), and
- Lignum Swampy Woodland (EVC 823) (R8 2020a).

These EVCs include a number of present or possibly present rare or threatened species (R8 2020a).

As identified in the Flora and Fauna Assessment prepared for the project (R8, 2020a) there are two non-flood dependent EVCs (EVC 97: Semi-arid Woodland and EVC 98: Semi-arid Chenopod Woodland) modelled (DELWP modelled 2005 EVCs) to occur in the inundation area. However, targeted ground-truthing has confirmed that there is no Semi-arid Woodland (EVC 97) or Semi-arid Chenopod Woodland (EVC 98) within the inundation areas where these EVCs were modelled to occur. The vegetation found to be present in these areas is Riverine Chenopod Woodland (EVC 103), Lignum Shrubland (EVC 808) and occasionally Alluvial Plains Semi-arid Grassland (EVC 806). These EVCs are located on alluvial terraces and are prone to flooding and are therefore unlikely to be adversely affected by environmental watering to reinstate a more natural flooding regime.

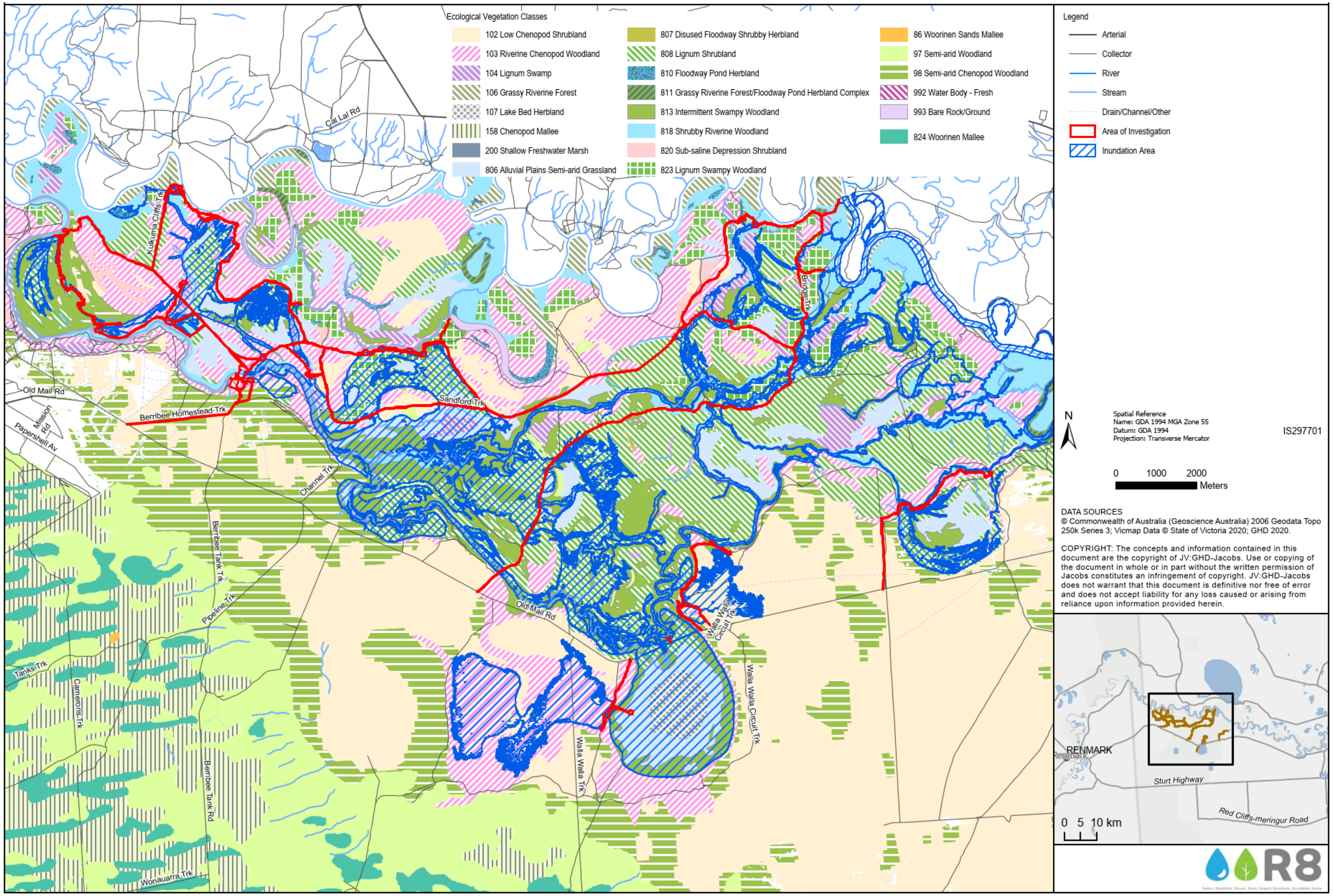

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Figure 3.15: Ecological Vegetation Classes present within the project area, as mapped by R8 (after R8, 2020a).

4. Potential effects

As discussed in the Flora and Fauna Assessment prepared for the project (R8, 2020a), it is expected that reinstatement of a more natural flooding regime would be beneficial to vegetation within the managed inundation areas. In 2014, Ecological Associates identified the water requirements for each of the water regime classes (based on EVCs) across the Lindsay Island floodplain. These water regime classes and their associated hydrological requirements, were then used to identify a preferred frequency, duration and timing of inundation for each water regime class. Ecological objectives were developed by Ecological Associates (2014) in relation to the water regime classes occurring in the managed inundation area, along with targets to measure progress towards achieving the ecological objectives. The ecological objectives and targets were then refined as part of the VMFRP Monitoring Evaluation and Reporting (MER) Plan (ARI, 2020) to provide more specific objectives and targets against which progress can be measured and to support quantification of the degree of environmental benefit expected from the project. The Flora and Fauna Assessment (R8, 2020a) and the EPBC Act and EE Act referral documentation provides further discussion of the expected ecological benefits for floodplain vegetation communities of reinstating a more natural flooding regime through environmental watering.

Notwithstanding the proposed ecological benefits of the project, there is potential for the project to have some adverse groundwater impacts as a result of changes to the level, flow and quality of the groundwater in and around the project area. However, the assessment of these potential impacts is complicated by the fact that the hydrogeological processes that the project would trigger, also occur in times of natural floods and therefore extracting the 'background' processes from those that are due to the project, is not straightforward. This issue is discussed below.

The potential groundwater effects are framed in terms of potential impact to specific receptors of groundwater rather than to the hydrogeological system itself (e.g. impact on ecosystems). In summary, the following potential effects may result from the construction and operation of the project:

Construction

- Temporary and localised drawdown of groundwater levels from dewatering construction excavations;
- Disposal of saline waste groundwater from dewatering of construction excavations; and
- Localised alteration of groundwater flow paths and levels from installation of permanent below-ground structures.

Operation

- Increase in groundwater levels from environmental watering of inundation areas (issues of waterlogging and salt movement within groundwater and soil profile (near-surface salinisation));
- Modified groundwater quality in inundated areas from infiltration of river water (salt and nutrients); and
- Mobilisation of salt from soil or groundwater to surface water (salt wash-off).

The sections below provide discussion of these potential impacts and likely effects on specific groundwater receptors in and around the project area.

4.1 Potential effects from project construction

4.1.1 Drawdown in groundwater level (physical works)

The works under this project include construction of below-ground infrastructure. The larger structures, those constructed more than around 5 m below ground surface, are likely to require temporary dewatering of excavations during construction. Based on the interpreted groundwater level across the project area (refer to Section 3.3 above) and the construction documentation (IFR dated March 2020), a number of project works are anticipated to require excavations below the watertable, the major site being Regulator BERR_A (the Berribee Regulator).

Regulator BERR_A is planned to cross the Lindsay River in the west of the project area. Construction drawings indicate construction of concrete piers below the regulator would extend to around 12 mAHD across the river channel (approx. 80 m wide). Drawings indicate sheet pile extends below this elevation, which is assumed to be pushed into the ground rather than excavated. Groundwater in the immediate vicinity of Regulator BERR_A is estimated to be at the Lock 6 weir pool level, around 19.3 mAHD (average last 5 years) (as the Lindsay River at this point is maintained from Lock 6 Murray River levels). This puts the excavated construction approximately 7.5 m below both surface water and groundwater level.

While the Regulator BERR_A location would require water management to control both surface water and groundwater intrusion to the works area, the location of the regulator actually reduces the potential for impacts to groundwater. This is because the surface water in the immediate vicinity of the excavations would provide a constant water source to replace extracted groundwater. Groundwater is also much fresher at this location than in the floodplain (i.e. due to flush zones). As such, the net impact to groundwater levels around these works is expected to be negligible, with groundwater levels around the barrier potentially rising slightly and the barrier increasing the water head in the river and driving more water into the watertable (as discussed in the next section). Any impact to groundwater level from these works is expected to be temporary, likely up to eighteen months, and physically localised; potentially tens of metres from the structure.

Any groundwater ingress into excavations for smaller excavations, extending up to a few metres below the watertable that are not open for long periods, is likely to be able to be managed through standard techniques (e.g. small sump pump in open excavations) with negligible impact to the local groundwater system. It is expected that all containment banks and most other smaller structures (e.g. box culvert regulators) would not be excavated below groundwater level.

4.1.2 Disposal of saline waste groundwater level

Impacts to local ecosystems from changes to the watertable level from the dewatering of project excavations are expected to be negligible, however there is the potential for interaction with terrestrial and aquatic ecosystems from disposal of waste groundwater. Disposal of groundwater extracted from excavations should be considered carefully, particularly where extraction is occurring in areas away from flush zones of rivers as background groundwater quality outside these flush zones is highly saline. Groundwater very close to the Murray River or lower Lindsay River is expected to be only slightly more saline than river water. Disposal to land should be avoided, and disposal to waterways should be managed so as to not significantly impact water quality. For the more significant excavations where a large volume of groundwater extraction is expected, a waste groundwater management plan should be considered, including assessment of likely volumes and quality, and options for disposal.

Design of structures that are altered or included in the design such that they require groundwater dewatering during construction should consider the potential impact on local groundwater levels and appropriate groundwater disposal.

4.1.3 Alteration of flow paths (physical works)

The project includes construction of below-ground permanent structures which are designed to disrupt groundwater flow below and around the waterway channel so as to reduce bypass of channel barrier structures. The impact to the flow path and subsequently the level of groundwater in localised areas, while part of the design, may have a negative impact on local ecosystems that are groundwater dependent. This is particularly relevant to structures that are close to or within waterways, where groundwater below creek or river bed often flows parallel to the waterway underground.

In several locations across the project area, including BERR_A, BERR_F, CR_A and CW_B1, sheet piles are planned to be installed as part of regulator structures between around 3 and 10 m below interpreted groundwater level in order to block bypass flow in the groundwater around the regulator. The impermeable barrier extends across the watercourse from between around 20 – 80 m. This impediment to groundwater flow is expected to back up groundwater on the upstream side of the structure, slightly raising groundwater levels there, and reducing groundwater levels slightly downstream of the structure. The impact to groundwater would extend out around the sides of the structure, likely for tens of metres, in a similar flow pattern to what occurs around locks in the Murray River (refer Figure 3.8 above). The magnitude of the change in groundwater elevations would be based on the local hydrogeological system and the dimensions of the particular barrier. The duration of the impact is uncertain, however in a well-defined groundwater flow system or watercourse, the impact may be permanent.

The impact of this process is predominantly dependent on the presence of surface water at the site. In areas where there is permanent or semi-permanent surface water, such as in the lower Lindsay River where Regulator BERR_A is planned, the significant structure being installed (over 7.5 m below the watertable and 80 m wide across the waterway) is considered unlikely to adversely impact aquatic and terrestrial ecosystems. This is because of the presence of surface water generating a flush zone into the groundwater of less saline water that would likely extend upstream and to the edges of the structure, mitigating the threat of a rise in saline groundwater in the short term.

In areas adjacent to permanent or semi-permanent surface water, such as where Regulators CR_A and CW_B1 are planned, the potential impact is likely greater but still low. These structures are planned to sit in typically dry watercourses within around 100 m of the lower Lindsay River, and are significantly smaller (less than 20 wide) in scale and depth (less than 3 m depth) than Regulator BERR_A. Because the structures sit within the flush zone of the river, groundwater backing up behind them would be much less saline than across the floodplain and should not cause a significant issue for local ecosystems that may otherwise be susceptible to near-surface salinisation.

In areas away from permanent or semi-permanent surface water, like where Regulator WW_A1 is planned to separate Lake Wallawalla with the floodplains to the west, the impact mechanism is likely to be similar, but the freshening effect of the surface water flush zone is significantly less or not present. Outside of flood events, if groundwater is flowing toward Lake Wallawalla locally, it would likely back up behind the structure and potentially raise groundwater levels in the floodplain to the west of the lake. Groundwater salinity in this area is estimated at between 35,000 – 50,000 µS/cm. These areas, while localised, have a higher requirement for adaptive management to mitigate near-surface salinisation.

The impacts would likely be moderated by the fact that much of the backed-up area would be inundated with flood water during watering events, so any saline groundwater build up would be likely diluted during flood events. However, in areas which are unlikely to be inundated, groundwater backing up and flowing around the side of the regulator structures has the potential to increase the elevation of saline groundwater locally. Where there is potential for this to occur, depending on background groundwater salinity and the specific dynamics of the location, adaptive management may be required and will be undertaken as part of project implementation.

The impact of permanent, below water table structures like these is lessened by the flat groundwater gradient across the project area, which means that any backing up of groundwater behind structures would likely only cause a small head increase in the upstream of structure groundwater levels. Even if the cumulative impact of the project is to raise groundwater across the project area and surrounds (refer Section 4.2.1), the additional increase in groundwater levels around the project structures is expected to be minor and thus the additional impacts to ecosystems is likely to be low. The impact is expected to be significantly less than what occurs around locks on the Murray River, which are not actively managed for this issue.

The potential impacts as described are not certain, as local groundwater flow paths and exact elevations of the watertables in the specific locations of proposed structures are unknown. Further investigation would be required to understand the potential changes to groundwater flow paths and levels at individual sites, specifically those noted above, and it is recommended that adaptive management be considered at these locations to identify and address potential adverse impacts. The discussion above goes to communicate areas where adaptive management is likely to be required, not to describe the magnitude of potential groundwater changes at individual sites.

4.2 Potential effects from project operation

4.2.1 Increase in groundwater levels (inundation)

As the project area is flooded, the flood water infiltrates into the soil and into the watertable, causing a rise in the groundwater level under the inundated area. The raised groundwater level under the flooded area causes a mound in the groundwater and pushes groundwater out into the surrounding area, raising groundwater levels in areas that are not inundated. The amount of groundwater rise in and around the inundated areas is dependent on the duration the water is held at flood levels, as well as soil type, depth to groundwater, and other hydrogeological and physical parameters.

Available hydrograph data within the project area has demonstrated rising groundwater levels in response to increased rainfall (specifically, the recent shallow groundwater levels that are likely associated with the breaking of the Millennium drought in 2010, see Section 3.3) and so it is expected that similar trends would be observed following sustained managed inundation events. This infiltration, while part of the purpose of the works themselves, i.e. to provide additional water to ecosystems to improve ecological condition, does create a potential for negative impacts for local ecosystems. These potential impacts are waterlogging and near-surface salinisation of groundwater and soil.

4.2.1.1 Waterlogging

Shallow groundwater in the vicinity of vegetation may occur for extended periods of time during and immediately after flooding. Vegetation that is exposed to shallow groundwater level for extended periods can become waterlogged and be harmed. This may be because of flood waters being held on the floodplain for extended periods or taking time to infiltrate, or groundwater mound rise next to inundated areas causing the watertable to rise.

While noted as a potential issue for the project, it is anticipated that the vegetation types in the floodplain area often rely on periods of inundation for optimal health, and that evapotranspiration across the region is very high, indicating that there is a low probability of vegetation in the managed inundation area being impacted by waterlogging. Even so, vegetation in inundated areas as well as in areas surrounding inundated areas, should be monitored for potential waterlogging and adaptive management should be implemented in areas found to be at risk of waterlogging. Appropriate adaptive management may include amending operational schedules and aerating soils. A separate assessment of the impacts to vegetation and ecological systems from the project has been undertaken for the Lindsay Island Floodplain Restoration Project in the form of the *Flora and Fauna Assessment Report – Lindsay Island* (R8, 2020a).

4.2.1.2 Near-surface salinisation

Saline groundwater rising to shallow depths brings with it dissolved salts already in the groundwater and also mobilises salt in the soil profile, bringing it closer to the surface. When the groundwater recedes, from mound rise recession and evapotranspiration, salt is left behind in the soil. Much of the project area will be regularly flushed with fresh flood water and this is expected to counter rising groundwater salinity under these areas.

However, areas where near-surface salinisation may have an impact on ecosystems is surrounding the managed inundation area - where the watertable is within approximately 3 m – 4m of the surface (I&I 2009). In moderate instances of near-surface salinisation, permanent, regular or temporary shallow saline groundwater can damage ecosystems and vegetation, even if these are not groundwater dependent (however groundwater dependent ecosystems are likely to be among the first to be impacted by this process). In severe instances, if highly saline groundwater is very near the ground surface, salt is deposited in the very top of the soil profile. Over time this can lead to dryland salinity, which can be particularly harmful to resident ecosystems and enhance erosion processes.

In the project area, there are several areas of widespread inundation of the floodplain which are likely to see moderate groundwater mound rise beneath them. These are highlighted in Figure A.1 in Appendix A. The areas with the potential for near-surface salinisation due to project works are likely to be within a few hundred metres of the edge of these extents where soil and/or groundwater salinity is high and where the soil profile is not being flushed of salt by the inundation.

An estimation of mound rise under the areas of inundation has been undertaken to assess the likely magnitude of potential groundwater level rise under the floodplain, and to understand whether and to what distance from inundated areas shallow groundwater levels may be produced by mound rise. The calculation was based on the Hantush equation for groundwater infiltration basins (1967) using the available data, information on the proposed environmental watering schedule and estimates of parameters where required. This is the method used to estimate similar processes in the previous work done by SKM (2014). Details of the mound rise analysis are presented in Appendix A, with a summary of results included in Table 4.1. It should be noted that approximate inundation areas based on a circular extent have been used to inform the estimates, for the purposes of modelling an irregular flooded area using a circular extent. The results of the calculations are intended to provide an indication of magnitude of potential response rather than exact figures, for the purposes of referral. As the project proceeds, it is expected that more detailed assessment will be undertaken to help plan monitoring and any other responses.

Mound rise after individual inundation events under Lake Wallawalla and Wallawalla West inundation extents may be around 1.5 m, while under other project inundation areas mound rise may be expected to be below half a metre. At 100 m from the edge of inundation, the groundwater may rise to between 0.5 and 1 m around Lake Wallawalla and its western floodplains and less than 30 cm around other areas.

Table 4.1: Results of Hantush equation mound rise calculations for selected inundation extents

Location	Watering plan	Approx. area of max inundation (for calculation purposes) (ha)	Max. mound rise under inundated area (m)	Max. groundwater level rise at 100 m (m)	Est. groundwater depth at 100 m (m bgl)	Max. groundwater level rise at 500 m (m)	Est. groundwater depth at 500 m (m bgl)
Berribee							
- central-north	Drained	950	0.6	0.2	3.3	0.1	3.4
- central-south	Drained	830	0.5	0.2	3.3	0.1	3.4
- central-southeast	Drained	160	0.3	0	3.5	0	3.4
- south	Drained	220	0.3	0.2	3.1	0.1	3.2
Lake Wallawalla and Wallawalla West	Left to infiltrate	2000	1.5	0.7	2.8	0.4	3.1
Wallawalla East *	Drained	260	0.3	0.1	4.3	0	4.4
Lindsay South	Drained	200	0.2	0.1	2.9	0.1	2.9
Crankhandle^	Left to infiltrate	320	0.6	0.3	1.1	0.2	1.2

* Mound influenced by the presence of the Blanchetown Clay acting as an aquitard beneath the Channel Sands that significantly reduces the thickness of the effective aquifer.
^ The area left to infiltrate for Crankhandle Lower was estimated and will need to be further refined as the project progresses.

The results of this analysis indicate that the design of the watering regime plays a key role in the magnitude of the mound and therefore its impact on the surrounding groundwater. At Lake Wallawalla, Wallawalla West and a small part of Crankhandle, the flood water is planned to be left to dissipate through evaporation and seepage rather than being drained by opening regulator gates on completion of a managed event. This extends the duration over which the mound can form and therefore increases its height. The inundation at Lake Wallawalla and Wallawalla West are of most concern because of the effective duration of retention of the water in the basins but also the large inundated area, particularly as the zones are most likely to be flooded concurrently.

Both the soil and groundwater across the Lindsay Island floodplain is highly saline. Areas of land that are planned to be regularly inundated would be flushed with fresher water and have less salt entrainment potential. It is the areas just outside the planned inundation that are not flushed, which have the potential to be impacted by near-surface salinisation driven by mound rise. The rise in groundwater levels outside of the inundated areas from the mound rise coincides with already shallow groundwater (<5m) and patches of significant groundwater and soil salt store. It is here that the potential for impact to ecosystems and vegetation arises.

To attempt to identify the areas which:

a) should be monitored for developing shallow saline groundwater, considered 'of interest'; and

b) have likely groundwater dependent EVCs present which may be sensitive to changing groundwater level and salinity, considered 'of heightened interest',

the available relevant data was reviewed.

This data included groundwater level and quality information, lithology, soil salinity and EVC presence (refer Figure 4.2 and Figure 3.15 in Section 3.7.2). Project areas that had the following characteristics were considered of interest:

- Within 300 m of the edge of a moderate to large inundated expanse[1] (indicative potential long-term impact zone, not intended to be a maximum or minimum of impacts), and
- Existing shallow groundwater less than 5 m below ground level, and
- Groundwater salinity of above 35,000 µS/cm, or
- Saturated zone salt store of greater than 100 t/ha/m, or
- Unsaturated zone salt store of greater than 100 t/ha/m.

Areas that satisfied the above criteria which also had likely groundwater dependent EVCs present (refer Section 3.7.2) were considered of heightened interest. These are also identified in Figure 4.1.

As identified above, it is not expected that the parts of the project area that are within the inundation extent will experience any increased groundwater salinity because of the salt flush and wash off effect of flood water in these areas. Areas with existing groundwater depth below 5 m were considered unlikely to be affected by changing salinity from the project works as the groundwater in these areas is too deep for the likely mound rise to reach sensitive depths for near surface salinisation or impact relevant EVCs.

The project areas considered of interest for near-surface salinisation are shown on Figure 4.1 and include:

- North of Lindsay South inundated area;
- Patches of floodplain around Crankhandle inundated area;
- Patches of floodplain around Lindsay Island (Berribee) inundated area; and
- West of Lindsay South inundated area.

Project areas where there are areas of heightened interest for near-surface salinisation because of the presence of potentially sensitive EVCs include (also on Figure 4.1):

- East of Crankhandle West inundated area;
- Patches of floodplain around Crankhandle inundated area;

[1] Where this buffer is intercepted by a creek or river, the groundwater mound is expected to be drained by the waterway and the buffer is not continued across the waterway.

- Patches of floodplain around Lindsay Island (Berribee) inundated area;
- South-west of Wallawalla East inundated area;
- South of Lake Wallawalla; and
- North of Lindsay South inundated area.

Just as irregular, mostly minor to moderate natural flood events are not currently presenting a risk of near-surface salinisation to most of Lindsay Island, an individual planned inundation event is unlikely to place local ecosystems at risk of high salt exposure. However increased frequency, duration and extent of inundation events, as planned under the project, increases the probability of development of near-surface salinisation through a cumulative effect on groundwater levels.

As such, it is recommended that groundwater monitoring of mound rise be implemented, targeting areas of interest and in particular areas of heighted interest, prior to construction to gather baseline and then operational data. This would allow for adaptive management of the project operation to minimise the potential for EVCs and other assets to be impacted by near-surface salinisation

There is expected to be a gradual, cumulative effect on groundwater levels from an enhanced watering regime across the project area from the process of mound rise. Estimating the magnitude of the medium to long term impact on groundwater levels from this project requires further study, however it could be expected that groundwater may return to levels similar to those experienced in the area prior to the Millennium drought when the climate was wetter and the groundwater system much more 'full' of water. In the early 1990s, groundwater levels in the area were 1-1.5 m shallower than currently and consequently the floodplain was predominantly a salt-deposition environment (refer to hydrographs in Figure 3.7). This situation would present a significant risk to both groundwater dependent and non-dependent ecosystems outside of the inundated areas from exposure to high levels of salt in the groundwater and soil profile. The areas identified in Figure 4.1 are considered to be of particular risk of near-surface salinisation from cumulative groundwater rise driven by mound rise.

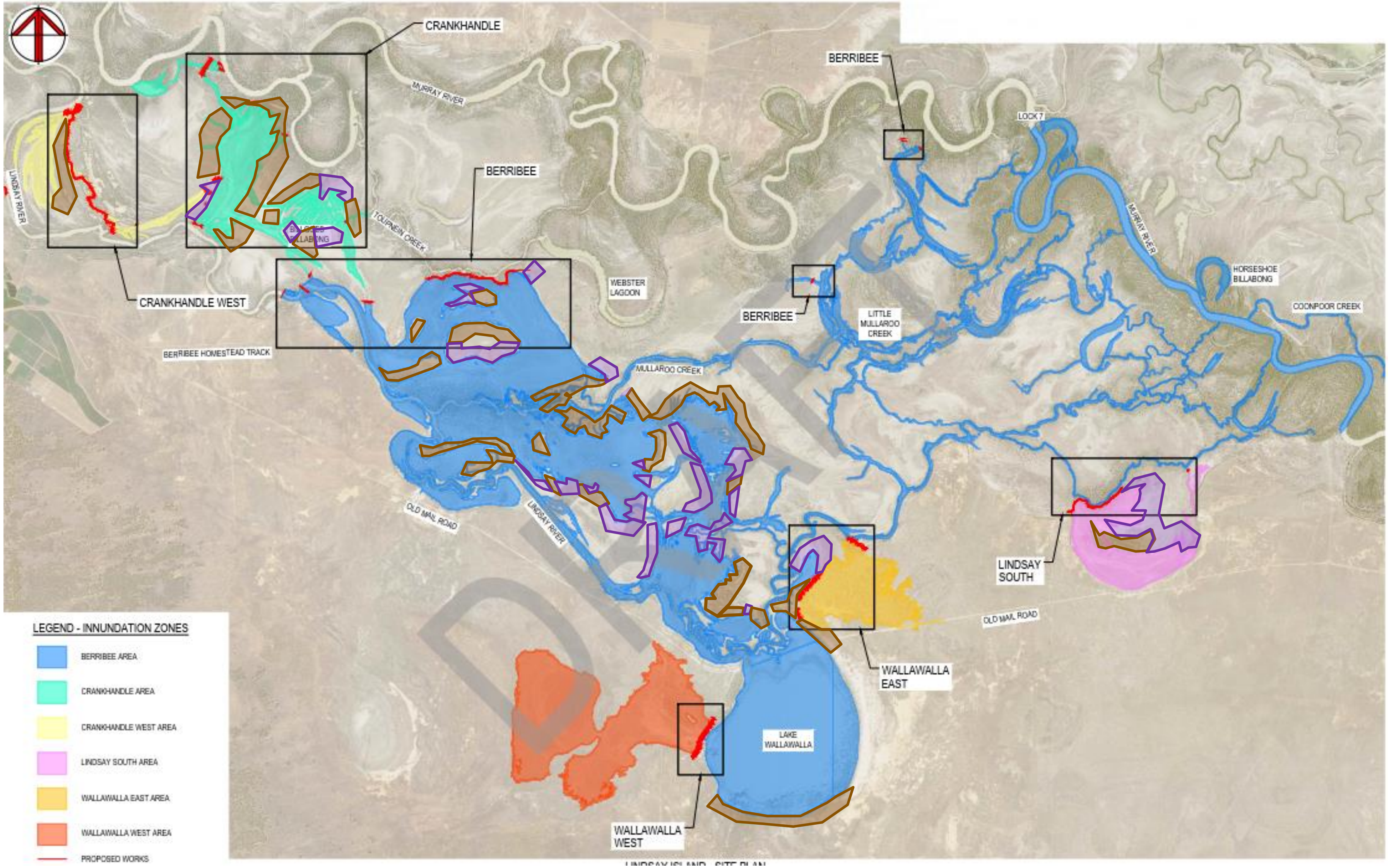


Figure 4.1: Indicative locations of areas of interest (purple shading) and heightened interest (brown shading) in terms of near-surface salinisation from project works (adapted from R8 mapping product).)

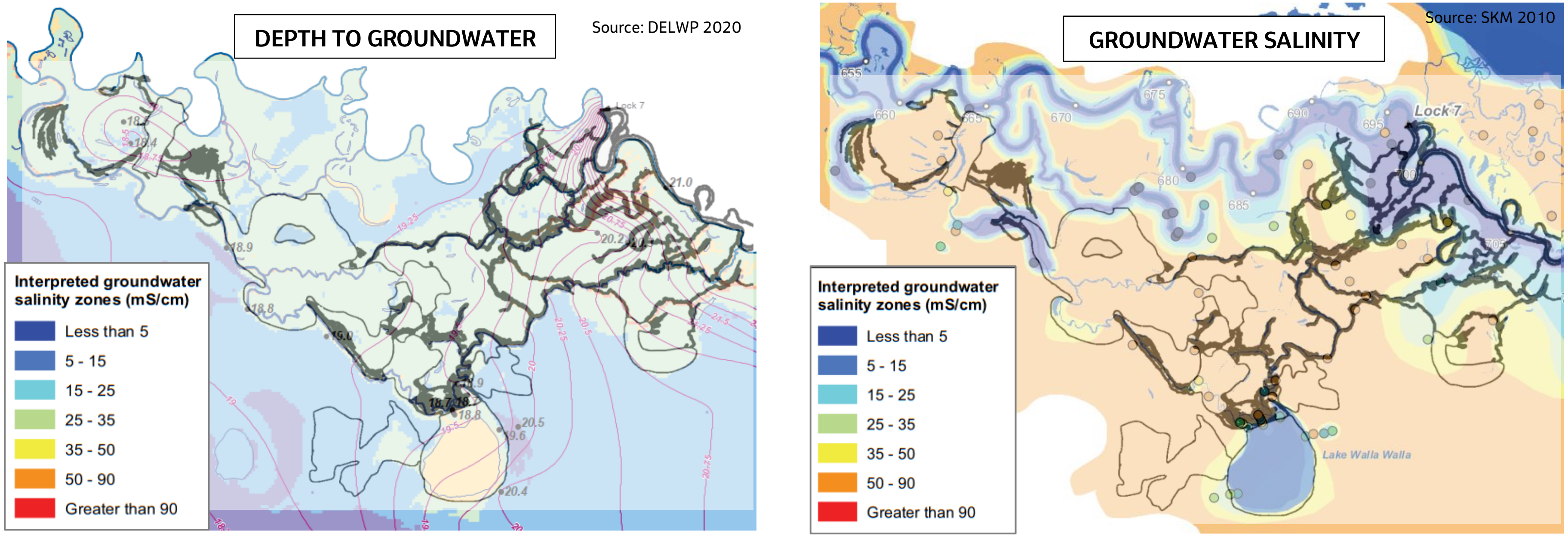
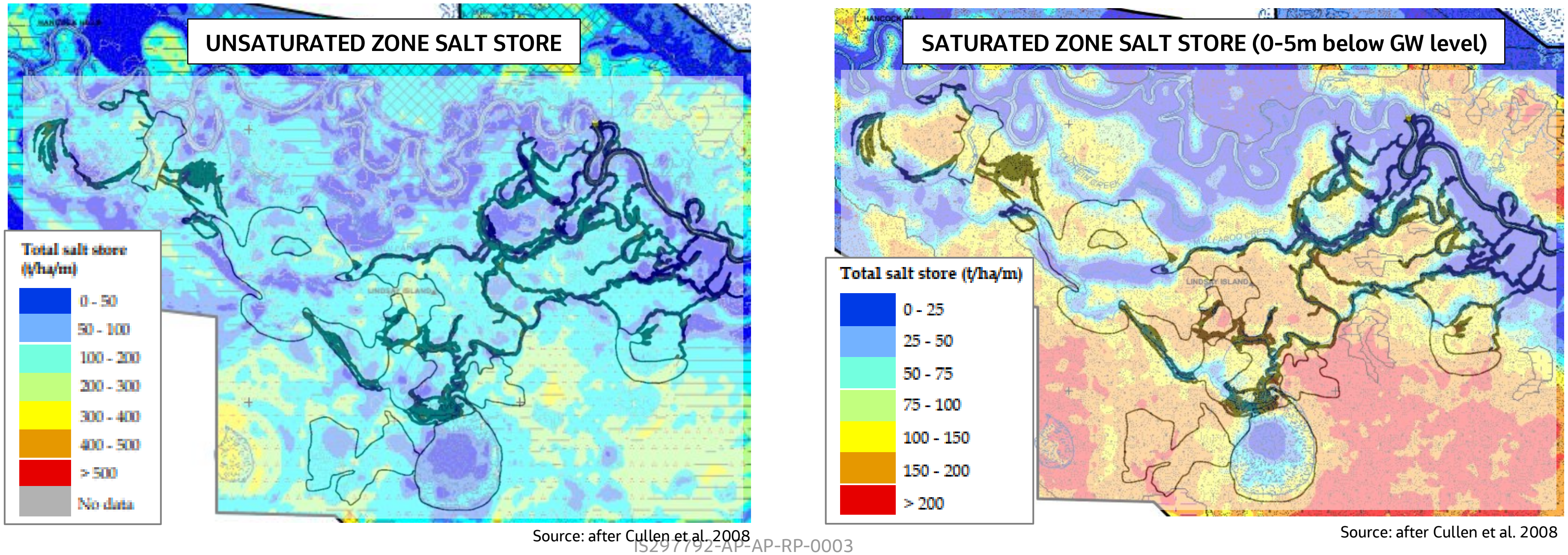


Figure 4.2: Mapping presenting contributing risk factors for near-surface salinisation overlayed with indicative project inundation extent (black outline).



4.2.1.3 Salt load entering waterways

Groundwater mound rise that occurs near waterways can cause saline groundwater to flow into the creeks and rivers and impact on surface water quality. A process called salt wash off, where the floodwater picks up salt entrained in the shallow soil profile and washes it into a waterway upon flood recession, is also known to deliver significant quantities of salt in environments such as Lindsay Island. The impact to surface water quality is temporary (weeks to months), however can be significant to downstream users, for example the irrigators at Lindsay Point if the salt load occurs during irrigation season and potentially to salinity in the Murray River.

Salt impact on the Murray River was considered extensively in SKM (2014), although based on a different watering program, notably a significantly reduced duration, and inundation extent. The current project design is different enough in environmental watering extent and timing/duration such that the conclusions from SKM (2014) cannot be directly applied. The study concluded that planned environmental watering of Lindsay Island and Lake Wallawalla had the potential to increase the salinity in the Murray River at Morgan in South Australia (the standard measurement point) by around 7 µS/cm electrical conductivity (EC).

The MDBA governs salt load delivery to the Murray River under a salinity accountability framework which tracks salinity credits and debits to the river. The threshold for entry onto Register A under the framework is +/-0.1 µS/cm impact to Murray River salinity, which suggests that salt load generated by the project has the potential to require deliberate consideration as a form of salinity debit. Salinity discharges and any associated changes or impacts in the Murray River as a result of planned inundation of the Lindsay Island floodplain would be considered and assessed on a cumulative basis by the MDBA through the protocols of the Basin Salinity Management 2030 strategy (BSM2030). These protocols are yet to be finalised for floodplain restoration projects, but discharges from the project would need to comply with these once finalised. This may involve the use of offsets or salinity credits from the Victorian salinity credit pool.

Site-specific Environmental Watering Management Plans and Operating Plans would be developed by VMFRP in consultation with DELWP, Parks Victoria, the Mallee Catchment Management Authority and other relevant agencies, prior to the commencement of works. The finalised plans would document all avoidance and mitigation measures to be implemented for the project during operations (including the planned timing of inundation events), as well as responsibilities for implementation.

4.2.2 Modified groundwater quality

Flood water is typically fresher (less saline) and also contains macronutrients from farmland. This water quality is different from the background groundwater quality of the floodplains which is more saline and nutrient poor.

4.2.2.1 Less saline flood water

The quality of water in the Murray River is significantly fresher than the background salinity of the watertable across Lindsay Island (around 100 µS/cm compared to 50,000+ µS/cm). This fresher water infiltrates into the floodplain over inundated areas, and through channel leakage from increased surface water head in waterways, diluting groundwater salinity. The effect is most obvious in the flush zones around losing rivers, such as large sections of the Murray River and lower Lindsay River (refer Figure 3.9). Infiltrating water on the floodplain can pick up entrained salt in the soil profile and carry it into the aquifer, however in the project area, this is not thought to overcome the freshening effect of flood water infiltration. This is a process that occurs with every flood event (natural and managed), and is virtually impossible to mitigate against, however it is also a positive effect, as most if not all groundwater receptors, including flora, fauna, and ground- and surface water consumptive users, prefer fresher water to saline.

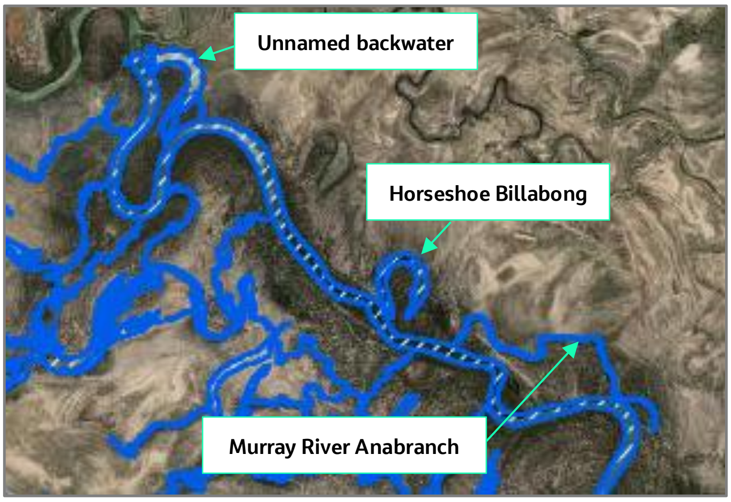
4.2.2.2 Higher nutrient load flood water

This is an analogous response to the salinity change noted above. Trace amounts of contaminants (such as nutrients) that are present in the flood water may enter groundwater during inundation. This process occurs naturally with all floods, but the delivered mass of nutrients would be greater from the operation of the project.

There is little published information on the impact of this in groundwater and it has generally been considered that the impact is negligible. This is considered the case for the Lindsay Island project.

4.2.3 New South Wales project areas

The potential consequences to the local groundwater system from inundation associated with the project in New South Wales are discussed below. The three inundation areas are relatively small, and so are covered individually. A study undertaken in 2008 (SKM), and added to in 2010 (SKM), considered the hydrogeological impacts of raising the Lock 7 weir pool to 22.6 m AHD on these same NSW features. The current proposed Lock 7 level is estimated at around 23.2 m AHD, however the inundation extent into NSW is similar between the 2010 project and the current one.



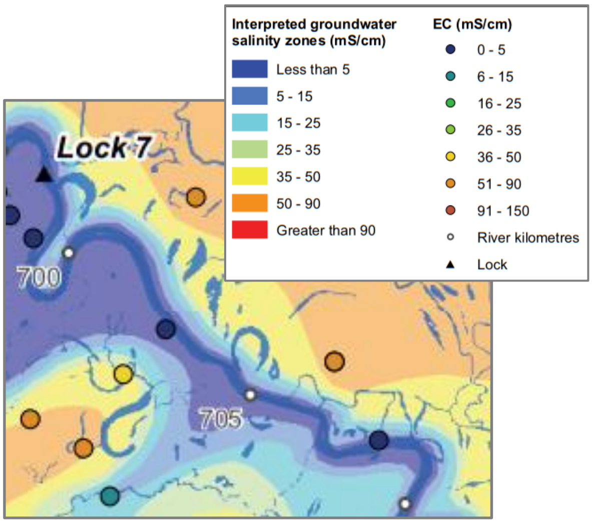


Figure 4.3: LHS: Inundation extent into NSW from project works, in the north-eastern corner of the project area (R8 mapping product), RHS: interpreted groundwater salinity in the same area (SKM 2010).

Unnamed backwater

This unnamed backwater sits immediately east of Lock 7, connected to the Murray River upstream of Lock 7 by an 800 m channel. The water quality is likely to be high salinity as it is not flushed by through flow from the Murray River, but regularly fed with inflow, suggesting evapotranspiration would be driving salinity in the pool. Any flood water fed into this pool would increase the hydraulic head and push any groundwater mound under the backwater toward the Murray River in the west and south, the Rufus River in the north and the floodplain in the east.

The sides of the backwater adjacent to waterways are expected to have relatively low groundwater salinity compared with regional groundwater quality, as there is thought to be a steep groundwater gradient toward the floodplain causing a flush zone of fresher water (SKM 2010). The groundwater salinity to the east of the backwater is expected to be between 35,000 to 50,000 µS/cm (SKM 2010). It is likely that any flow of moderately saline groundwater driven by a mound under the backwater would be overwhelmed by the increased rate of loss of river water to groundwater from the elevated river level upstream of Lock 7. The potential for impact to ecosystems outside of the inundated area from a rise in saline groundwater level at this site are therefore expected to be negligible to low.

Horseshoe Billabong

This billabong is assumed to act like an evaporation basin for Murray River flood waters. The billabong is only regularly connected to the Murray River on one end, and as such would not be flushed in floods. Depth to groundwater is estimated at less than 2 m below ground level close to the Murray River, decreasing away from the river (SKM 2010). Because of these shallow groundwater levels, SKM (2010) identified that raising Murray River levels (without inundating the billabong) would likely push saline groundwater into the basin. However, the current inundation extent that floods Horseshoe Billabong would mitigate this potential issue and provide some flush to the typically unsaturated, likely relatively saline, soil profile.

The pooling of flood water on the billabong would, however, be expected to generate a small groundwater mound under the inundated area. Infiltration of the flood water is likely to dissolve entrained salt in the soil profile and allow it to enter the groundwater. With background groundwater salinity at around 35,000 to 50,000 µS/cm (SKM 2010), the groundwater mound would be expected to push saline groundwater slightly into the floodplain to the north and east, closer to the ground surface. The gradient of groundwater levels in this area and the small scale of the inundation and likely groundwater mound, suggests that the potential for development of near-surface salinisation and therefore threats to local ecosystems in the area is low.

Murray River Anabranch

This anabranch of the Murray River slightly upstream of Horseshoe Billabong is fully connected to the Murray River at both ends and would be expected to be flushed by typical river as well as flooding flows. The impact to the surrounding groundwater would likely to be limited to an increase in the gradient of fresher river water into the floodplain watertable. The potential for impact to ecosystems outside of the inundated area from a rise in saline groundwater level at this site are therefore expected to be negligible.

4.2.4 Impacts to cultural values

Lindsay Island is known to be a significant location for Traditional Owners and holds cultural and spiritual values. A CHMP is currently being prepared for the project in consultation with the Traditional Owners to identify the impact on Aboriginal heritage places, and to specify management and mitigation measures as required.

As part of the CHMP, altered hydrological conditions within the inundation areas would be assessed. This would inform the assessment of impacts to Aboriginal cultural heritage as a result of inundation activities. The inundation assessment would be staged to assess:

- Hydrological change resulting from the operation of the infrastructure, relative to how the area currently floods and the benefits and risks that are associated with the changes in environmental watering regime. Hydrological change assessment would consider each of the operating phases; filling, holding and emptying. The assessment would focus on changes in velocity, shear stress, water depths and inundation extents across the floodplain areas;
- Geomorphological change which would include assessment of possible erosion risk areas and capacity of soil types to withstand shear stresses; and
- Aboriginal cultural heritage impacts which may result from the hydrological and geomorphological changes.

4.3 Summary of potential effects

The potential effects of the project on groundwater receptors from changes to the hydrogeological system in the project area are summarised below and in Table 4.2:

<u>Potential impacts from construction of the project</u>

- Potential for temporary, localised drawdown of groundwater levels from dewatering of construction excavations – not expected to significantly reduce groundwater availability to local ecosystems based on implementation of proposed mitigation measures.
- Disposal of saline waste groundwater from dewatering of construction excavations – not expected to significantly impact local ecosystems based on implementation of proposed mitigation measures
- Potential for localised alteration of groundwater flow paths and levels from installation of permanent below-ground water barriers – not expected to significantly alter groundwater availability to local ecosystems based on implementation of proposed mitigation measures.

Potential impacts from operation of the project

- Potential for increased groundwater levels in inundated areas and some areas outside the managed inundation area to result in waterlogging if shallow groundwater persists in areas containing not flood-tolerant vegetation communities and species - further assessment (as outlined in Section 5.1) is required to fully understand this potential impact, with monitoring and adaptive management proposed to mitigate this potential impact. Within the managed inundation area, EVCs are flood tolerant and therefore unlikely to be affected by waterlogging from shallow groundwater.
- Potential for near-surface salinisation in some areas outside of the managed inundation area in the medium to long term - further assessment (as outlined in Section 5.1) is required to fully understand this potential impact, with monitoring and adaptive management proposed to mitigate this potential impact. Within the managed inundation area, local ecosystems may benefit from slight reductions in groundwater salinity. NSW inundation areas are anticipated to have less of a need for management with respect to near-surface salinisation but will be included in the adaptive management framework.
- Potential increase to nutrient load in soil profile and groundwater from flood waters - not expected to adversely impact local ecosystems
- Potential for increased salt load in the Lindsay River downstream of the project area from mobilisation of salt from soil and groundwater to surface water (salt wash-off) potentially affecting water dependent ecosystems, and water quality for downstream irrigators - further assessment (as outlined in Section 5.1) is required to fully understand this potential impact, with monitoring and adaptive management proposed to partly mitigate this potential impact.
- Potential secondary impact to cultural values from near-surface salinisation and waterlogging – additional assessment is being undertaken through the CHMP to understand this potential impact and to identify management and mitigation measures if required.

In addition to the above, salinity discharges and any associated changes or impacts in the Murray River as a result of planned inundation of the Lindsay Island floodplain would be considered and assessed on a cumulative basis by the Murray Darling Basin Authority (MDBA) through the protocols of the Basin Salinity Management 2030 strategy (BSM2030). These protocols are yet to be finalised for floodplain restoration projects, but discharges from the Lindsay Island project would need to comply with these once finalised. This may involve the use of offsets or salinity credits from the Victorian salinity credit pool.

Table 4.2: Summary of potential effects on groundwater beneficial uses from the Lindsay Island Floodplain Restoration Project

Beneficial Use	**Potential Effect**
Water dependent ecosystems and species	Net beneficial effect expected in areas of planned inundation. Potential for impact to water dependent ecosystems and species outside of inundated areas from near-surface salinisation driven by groundwater mound rise under inundated areas. Potential for impact to water dependent ecosystems and species from increased salt load in the Lindsay River and Murray River downstream of project area from salt removed from project area, although the impact to Murray River salinity would be considered by the MDBA through the protocols of the Basin Salinity Management 2030 strategy.
Potable mineral water supply	Not applicable - The groundwater does not classify as mineral water.

Beneficial Use	Potential Effect
Agriculture and irrigation (irrigation)	No known current use of groundwater for irrigation in impacted area. Potential for impact to water quality in the Lindsay River (used by Lindsay Point irrigators) and Murray River downstream of project area from increased salt load, although the impact to Murray River salinity would be considered by the MDBA through the protocols of the Basin Salinity Management 2030 strategy.
Agriculture and irrigation (stock watering)	No known current use of groundwater for stock watering in impacted area. Potential for impact to water quality in the Lindsay River and Murray River downstream of project area from increased salt load, although the impact to Murray River salinity would be considered by the MDBA through the protocols of the Basin Salinity Management 2030 strategy.
Industrial and commercial	No known current use of groundwater for industrial and commercial purposes in the project area. Potential for impact to water quality in the Lindsay River and Murray River downstream of project area from increased salt load, although the impact to Murray River salinity would be considered by the MDBA through the protocols of the Basin Salinity Management 2030 strategy.
Water-based recreation (primary contact recreation)	Potential effect. The water quality in the Lindsay River may temporarily but regularly become more saline as a result of project works. The availability should not change.
Traditional Owner cultural values	Potential impacts being considered through project engagement with Traditional Owners.
Cultural and spiritual values	Potential impacts being considered through project engagement with Traditional Owners.
Buildings and structures	No effect expected. The water quality and availability for this beneficial use would not alter.
Geothermal properties	No effect expected. The water temperature at the surface is below the threshold for geothermal water and no effects are expected at depth.

5. Recommended mitigation measures

The following mitigation measures are recommended during the construction and operation of the project:

Construction

- Minimise the total volume and rate of groundwater extracted for construction purposes - plan construction to minimise dewatering, provide make-up or offset watering for affected vegetation during construction;
- Avoid disposal of groundwater from construction activities to land; and
- Manage disposal of waste groundwater to waterways to avoid significant impacts to water quality and to comply with EPA discharge requirements.

Operation

- Planning and monitoring of environmental watering events to avoid peak groundwater mound salt outflow coinciding with irrigation season;
- Monitor vegetation in areas surrounding inundated areas for signs of potential waterlogging. Implement adaptive management, potentially including amending operational schedules (e.g. reduce frequency/duration), to mitigate impacts if identified;
- Monitor groundwater levels and quality prior to, during and after an inundation event to monitor development of groundwater mounds within the areas identified as potentially impacted by near-surface salinisation (refer Section 4.2.1.2). Implement adaptive management, potentially including additional watering of these areas or amending operational schedules (e.g. reduce frequency/duration), to mitigate impacts if identified.

A set of draft mitigation measures has been developed as part of the draft Environmental Management Framework. Additional mitigation measures around the discharge of salt and associated impacts to the Lindsay River and Murray River from the project will be detailed when the Environmental Watering Management Plan and Operating Plan are developed for Lindsay Island.

5.1 Further work

The following aspects should be considered further to reduce uncertainty around potential project impacts:

- Specific groundwater level and quality information is required for the site to form a baseline for the potential construction and operation impacts, as well as to monitor the effects of inundation outside of the inundation area. It is understood that one new groundwater monitoring bore was installed in mid-2020 (in Lindsay South area), however monitoring data from this site was not available at the time of this assessment. The remaining network of existing bores at Lindsay Island should be selectively included in the monitoring program. Existing groundwater bores with no available elevation information are required to be surveyed to enable groundwater elevation data to be gathered;
- Groundwater monitoring of mound rise targeting 'areas of interest' and in particular 'areas of heightened interest', prior to construction to gather baseline and then operational data. This would allow for adaptive management of the project operation to minimise the potential for EVCs and other assets to be impacted by near-surface salinisation; and
- A CHMP is currently being prepared for the project in consultation with the Traditional Owners to identify the impact on Aboriginal heritage places, including potential groundwater impacts, and to specify management and mitigation measures as required.

Salinity discharges and any associated changes or impacts in the Murray River as a result of planned inundation of the Lindsay Island floodplain would be considered and assessed on a cumulative basis by the Murray Darling Basin Authority (MDBA) through the protocols of the Basin Salinity Management 2030 strategy (BSM2030). These protocols are yet to be finalised for floodplain restoration projects, but discharges from the project would need to comply with these once finalised. This may involve the use of offsets or salinity credits from the Victorian salinity credit pool.

Site-specific Environmental Watering Management Plans and Operating Plans would be developed by VMFRP in consultation with DELWP, Parks Victoria, the Mallee Catchment Management Authority and other relevant agencies, prior to the commencement of works. The finalised plans will document all avoidance and mitigation measures to be implemented for the project during operations (including the planned timing of inundation events), as well as responsibilities for implementation.

6. References

Department of Environment, Land, Water and Planning (DELWP), Victoria, 2020. Water Management Information System. Online data portal. Accessed 5/5/20. Available online: http://data.water.vic.gov.au/.

Kristen Cullen, Heike Apps, Larysa Halas, K.P. Tan, Colin Pain, Ken Lawrie, Jonathan Clarke, David Gibson, Ross C Brodie and Vanessa Wong, 2008. “Atlas – Boundary Bend to Speewa, River Murray Corridor AEM Salinity Mapping Project” Geoscience Australia, GEOCAT 68790.

GHD & AWE, 2012. “Report on the development of 3D aquifer surfaces”.

Industry and Investment, NSW, 2009. Primefacts – Dryland salinity, causes and impacts. NSW Government, October 2009. Primefact 936.

Jacobs 2019. Groundwater salinity monitoring bore specification for SDL project – Drilling specification. Report to Mallee CMA, May 2019.

Office of Water (OoW), NSW, 2011. Western Murray Porous Rock and Lower Darling Alluvium Groundwater Sources – Groundwater Status Report 2011. Department of Primary Industries, NSW.

R8, 2020a. Flora and Fauna Assessment Report – Lindsay Island. R8 is a Jacobs and GHD joint venture. Report for Lower Murray Urban and Rural Water Corporation.

R8, 2020b. Historical Heritage Assessment Report – Lindsay Island. R8 is a Jacobs and GHD joint venture. Report for Lower Murray Urban and Rural Water Corporation.

SKM, 2008. Semi-quantitative assessment of Living Murray works and measures: Salinity impacts at Lindsay, Mulcra and Wallpolla Islands. Prepared for the Mallee Catchment Management Authority.

SKM, 2010. Lindsay Island Stage 1 Works and Measures. Semi-quantitative salinity impact assessment of works and measures of the Living Murray. Report for the Victorian Department of Sustainability and Environment, March 2010.

SKM, 2014. Preliminary Salinity Impact Assessment for Mallee Environmental Watering Projects - Lindsay Island, Final Report. Prepared for the Mallee CMA, November 2014.

Thorne, R., Pratt, M., Hoxley, G., McAuley. C., and Chaplin, H (1992) Mildura 1:250,000 Scale Hydrogeological Map, Commonwealth of Australia.

Thorne, Hoxley, Chaplin, 1990. “Nyah to the South Australian Border Hydrogeological Project” Rural Water Commission of Victorian Investigations Branch Report 1988/5.

Victorian Government, 2018. State Environment Protection Policy (Waters), under the Environment Protection Act 1970. Victorian Government Gazette No. S 499, Tuesday 23 October 2018.

WaterNSW, 2020. Real Time Water Data. Online data portal. Accessed 5/5/20. Available online: https://realtimedata.waternsw.com.au/water.stm

Appendix A. Mound rise analysis

Mound rise under the larger inundated expanses (Figure A.1) was estimated using the Hantush equation for theoretical groundwater mounding beneath a circular infiltration basin (1967, from Walton 1988) in a spreadsheet model. Input parameters are presented in Table A.1, and results are included in Table A.2. The following hydrogeological parameters were standard for the analysis:

- Recharge rate – 0.5 mm/day
- Specific yield – 0.05
- Hydraulic conductivity – 10 m/day

An example of the spreadsheet is included as Figure A.2.

It should be noted that approximate inundation areas based on a circular extent have been used to inform the estimates, for the purposes of modelling an irregular flooded area using a circular extent. The results of the calculations are indented to provide an indication of magnitude of potential response rather than exact figures.

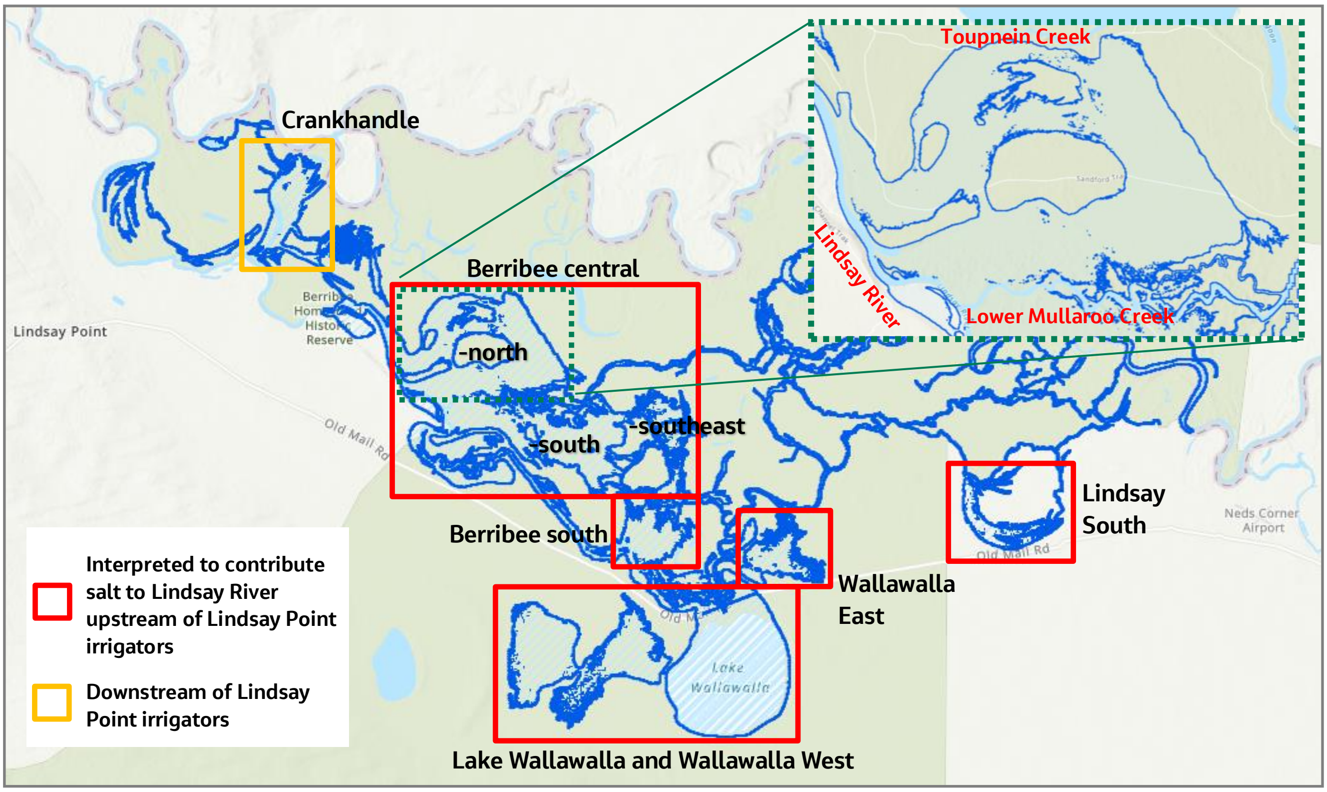


Figure A.1: Inundation extent of environmental watering events under the project, noting areas of extended floodplain inundation. Inset: close up of the northern component of the central Berribee inundated area (R8 mapping product).

Table A.1: Input parameters for Hantush equation mound rise calculations for selected inundation extents

Inundated area	Duration of inundation [1]	Initial GW level (mAHD)	Base of wetland (mAHD)	Inundation radius (m)	Initial aquifer thickness (m) [2]
Berribee					
- central-north	60 days	18.8	22.3	1,700	47.5
- central-south	60 days	18.8	22.3	1,600	47.5
- central-southeast	60 days	18.8	22.3	700	47.5

Inundated area	Duration of inundation [1]	Initial GW level (mAHD)	Base of wetland (mAHD)	Inundation radius (m)	Initial aquifer thickness (m) [2]
- south	60 days	19.2	22.5	800	47.7
Lake Wallawalla and Wallawalla West	60 days + assumed 4 mths infiltration	19.5	23.0	2,500	47.5
Wallawalla East [3]	30 days	19.1	23.5	800	10.6
Lindsay South	30 days	20.8	23.8	800	48.0
Crankhandle	80 days + assumed 2 mths infiltration	18.5	22.0	1,000	47.5

[1] Where inundated areas were not drained, an assumption was made to estimate how long flood water would take to dissipate into the environment (i.e. still be providing a water source for mound rise). It was assumed a larger and therefore likely deeper basin would take longer to infiltrate/evapotranspirate flood water.
[2] Includes estimated saturated thickness of both Channel Sands and Loxton Parilla Sand aquifers where present. Where the Blanchetown Clay is present at Wallawalla East, the effective aquifer thickness is reduced.
[3] Mound influenced by the presence of the Blanchetown Clay acting as an aquitard beneath the Channel Sands that significantly reduces the thickness of the effective aquifer.

Table A.2: Results of Hantush equation mound rise calculations for selected inundation extents

Location	Watering plan	Approx. area of max inundation (ha)	Max. mound rise under inundated area (m)	Max. groundwater level rise at 100 m (m)	Est. groundwater depth at 100 m (m bgl)	Max. groundwater level rise at 500 m (m)	Est. groundwater depth at 500 m (m bgl)
Berribee							
- central-north	Drained	950	0.6	0.2	3.3	0.1	3.4
- central-south	Drained	830	0.5	0.2	3.3	0.1	3.4
- central-southeast	Drained	160	0.3	0	3.5	0	3.4
- south	Drained	220	0.3	0.2	3.1	0.1	3.2
Lake Wallawalla and Wallawalla West	Left to infiltrate	2,000	1.5	0.7	2.8	0.4	3.1
Wallawalla East*	Drained	260	0.3	0.1	4.3	0	4.4
Lindsay South	Drained	200	0.2	0.1	2.9	0.1	2.9
Crankhandle ^	Left to infiltrate	320	0.6	0.3	1.1	0.2	1.2

* Mound influenced by the presence of the Blanchetown Clay acting as an aquitard beneath the Channel Sands that significantly reduces the thickness of the effective aquifer.

^ The area left to infiltrate for Crankhandle Lower was estimated and will lend to significant uncertainty around the resultant mound rise for this area.

Groundwater mound rise - Berribee central-north inundation

Calculate watertable mound (unconfined rise) from circular (vertical) recharge area

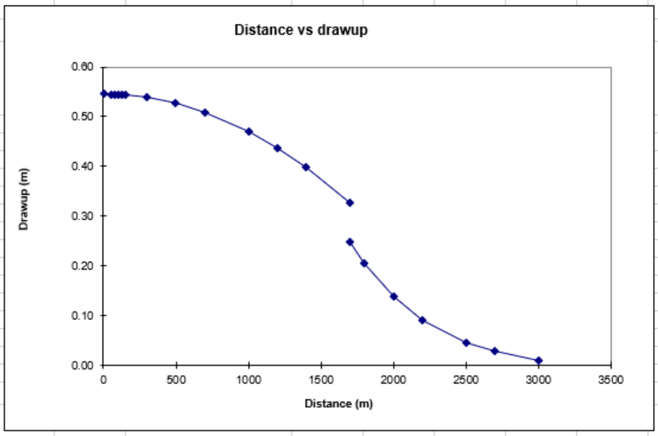
(from Walton, 1988, formulae from Hantush, 1967)

	INPUTS
Radius of circular recharge area = Rm (m):	1700
Recharge Rate (m/day):	0.0005
Hi = initial height of watertable above aquiclude (m):	47.5
average height of Hi and Hm (iterative)	48.5
Specific Yield:	0.05
Kh:	10
time of calculation (days):	60

Area of circle (ha)		**ha**
Area of circle (m2)		**m2**
Radius of circular recharge area = Rm (m):	1700	**m**

for r < Rm

Distance (r) from centre of mound (m)	u0	W(u)	gw level	gw level change (m)	GW level (mAHD)
1	1.24E+00	1.48E-01	48.0	**0.5453**	20.6253
50	1.24E+00	0.14841344	48.0	0.5451	20.6251
75	1.24E+00	0.14841344	48.0	0.5449	20.6249
100	1.24E+00	0.14841344	48.0	0.5446	20.6246
125	1.24E+00	0.14841344	48.0	0.5442	20.6242
150	1.24E+00	0.14841344	48.0	0.5436	20.6236
300	1.24E+00	0.14841344	48.0	0.5386	20.6186
500	1.24E+00	0.14841344	48.0	0.5265	20.6065
700	1.24E+00	0.14841344	48.0	0.5085	20.5885
1000	1.24E+00	0.14841344	48.0	0.4701	20.5501
1200	1.24E+00	0.14841344	47.9	0.4370	20.5170
1400	1.24E+00	0.14841344	47.9	0.3978	20.4778
1700	1.24E+00	0.14841344	47.8	0.3276	20.4076



for r >= Rm

Distance (r) from centre of mound (m)	u	W(u)	gw level	gw level change (m)		
1700	1.24E+00	0.14841344	47.7	0.2486	19.2486	
1800	1.39E+00	0.117697933	47.7	0.2064	19.2064	+100m
2000	1.72E+00	0.072740343	47.6	0.1398	19.1398	
2200	2.08E+00	0.04386534	47.6	0.0923	19.0923	+500m
2500	2.68E+00	0.019483703	47.5	0.0470	19.0470	
2700	3.13E+00	0.010542154	47.5	0.0286	19.0286	
3000	3.87E+00	-0.000586307	47.5	0.0094	19.0094	

Figure A.2: Example Hantush spreadsheet model of mound rise after *n* days.