Revision of South Australia’s In-channel, Floodplain and Coorong, Lower Lakes and Murray Mouth Environmental Water Requirements

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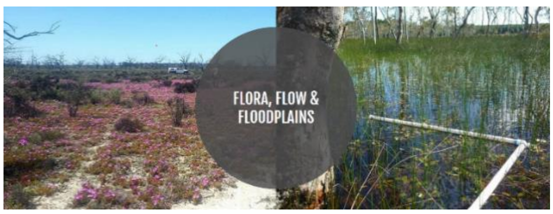

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Common Acronyms

ARI	Average Return Interval
CHM	Coorong Hydrodynamic Model
CLLMM	Coorong, Lower Lakes and Murray Mouth
CPUE	Catch Per Unit Effort
CSL	Coorong South Lagoon
DOC	Dissolved Organic Carbon
DTR	Diurnal Tide Ratio
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percent
EWR	Environmental Watering Requirement
FSL	Full Supply Level
FP	Floodplain
GL	Giga Litres
IC	In-channel
LCI	Lignum Condition Index
MDBA	Murray–Darling Basin Authority
ML	Mega Litres
NPL	Normal Pool Level
PEA	Priority Environmental Asset
QSA	Discharge (Q) at South Australia
SA LTWP	South Australian Long Term Watering Plan
TCI	Tree Condition Index
TLM	The Living Murray
WRP	Water Resource Planning
YOY	Young of Year

Glossary

Average Return Interval	The long-term average number of years between the occurrence of a flow event
Critical maximum interval	The maximum period between flow events before a significant decline in the asset condition is likely to occur. This period should not be exceeded wherever possible.
Discharge	The volumetric flow rate of water i.e. volume of flow over a given time. In South Australia, this is often represented as ML/day
Duration	The required duration (typically expressed as the number of consecutive days) for the flow threshold, or the duration over which the flow volume should be delivered (as the case requires). This is typically expressed as a minimum duration. Longer durations will often be desirable and deliver better ecological outcomes
Environmental water	Environmental water is 'held' or 'planned' environmental water, defined in the Water Act 2007. Held environmental water is available under a water access right for the purposes of achieving environmental outcomes; planned environmental water is committed to environmental outcomes and cannot be used for any other purpose
Environmental Water Requirements	The water regime needed to sustain the ecological values of aquatic ecosystems and biological diversity at a low level of risk (DEWNR 2014)
Flow rate (or total flow volume)	The required flow rate (typically ML/day) or flow volume (typically GL over a defined period of time) of the flow event
Frequency	The required frequency of return of the flow event
Managed floodplain	Part of the floodplain that may be influenced by active management of environmental water either through releases of held environmental water from storages or changes in dam storage operations. MDBA modelling indicates that QSA 80,000 ML/day is the maximum flow at which this can occur (subject to constraints measured in upstream areas). For the purposes of this document, the managed floodplain is equivalent to the floodplain priority environmental asset.
m AHD	metres Australian Height Datum (i.e. metres above sea level)
Maximum period	The maximum period between flow events before a significant decline in the asset condition is likely to occur. This period should not be exceeded wherever possible. For this project it is referred to as the Critical Maximum Interval (see above).
Normal Pool Level	River water levels when weir pools are at full supply (m AHD)
Priority Environmental Asset	Part of the environmental asset that can be managed with environmental water, identified in accordance with the Basin Plan (s8.49). For the purposes of this document, the floodplain priority environmental asset is equivalent to the managed floodplain.
QSA	River Murray's discharge (Q) at the New South Wales - Victorian - South Australian borders
SA LTWP	South Australian River Murray Long Term Environmental Watering Plan
Shedding floodplain	Defined here as that part of the floodplain that will shed water
Timing	The required timing (season, typically expressed as a range of months within a year) of the flow event

Executive Summary

The South Australian River Murray Long Term Environmental Watering Plan (SA LTWP) is being updated by the SA Department for Environment and Water (DEW) in line with the requirements of Chapter 8 of the Basin Plan. One focus for the update is to review and revise South Australia's existing Environmental Water Requirements (EWRs) for the three Priority Environmental Assets (PEAs) namely the:

1. South Australian River Murray In-channel (IC),
2. South Australian River Murray Floodplain (FP) and,
3. Coorong, Lower Lakes and Murray Mouth (CLLMM).

The aim of this project was therefore to revise the EWR metrics for the IC, FP and CLLMM PEAs based on consideration of how EWRs are applied, and new knowledge of modelled natural hydrology and eco-hydrological relationships for key biota/ecosystem processes outlined in the SA LTWP.

The approach involved *i*) consultation with River Murray practitioners about the application of EWRs *ii*) review and analysis of existing EWRs and the development of preliminary revisions and *iii*) expert engagement and input to proposed EWR revisions.

Consultation with River Murray practitioners involved in the management of the three PEAs, highlighted that EWRs are used in annual environmental water planning and are also used to infer ecological outcomes arising from EWR delivery. However, feedback on the use of existing EWRs highlighted certain issues and confusion, such as discharge ranges that overlapped in the existing IC EWRs.

To develop preliminary revisions to the existing EWRs, information obtained from the above consultation process, a review of the key technical documents outlining the development of the existing EWRs and other literature, was undertaken. River Murray experts and practitioners were then engaged for further input into the proposed revisions. A framework was developed to support an approach that allowed experts and/or practitioners to consider where there may be some flexibility around certain EWR metrics and where it was critical that there was absolutely no flexibility. A first step in developing these values was to characterise the target values for each EWR metric where it is anticipated that there is the greatest certainty that the associated ecological objectives/targets will be met. Following the workshop, further analysis was undertaken of the suggested revisions including a review of modelled natural hydrology and the modelled alignment between IC, FP and CLLMM EWRs. As a result of the process, suggested revisions to the target values are presented for the IC, FP and CLLMM EWRs.

Suggested revisions to the IC EWRs include:

- The consolidation of seven existing IC EWRs (IC1–IC7) to four revised IC EWRs (IC1–IC4) to remove confusing overlap in discharge variability,
- Target values for the duration metric of many of the revised IC EWRs were shortened (i.e. ≥60 days) to improve consistency,
- Target values for the timing window of the revised IC EWRs was contracted to Oct–Dec, compared to Sep–Mar in the existing IC EWRs, to coincide with ideal, warmer in-channel temperatures,

- Target values for the frequency metric of the revised IC EWRs were largely unchanged but expressed in a variety of ways (i.e. number of flows per Average Return Interval (ARI), percentage (%) of years, number of flows within a 10-year period) to improve consistency across EWRs for the three PEAs and minimise confusion,
- Target values for the maximum period between flows for the revised IC EWRs were more clearly specified as the *critical maximum interval* metric before a significant decline in IC PEA condition is expected to occur,
- Target values for the maximum rates of rise and fall in water level metrics were included in the revised IC EWRs.

Suggested revisions to the target metrics of the FP EWRs include:

- Target values for the duration metric of FP EWRs were generally shortened compared to duration values in the existing FP EWRs; except for FP1, where the duration was increased slightly.

Suggested revisions to the target metrics of the CLLMM EWRs include:

- Target values for the annual barrage outflow volumes metric were more explicitly clarified as the 'average' annual volume,
- A metric specifying the target total annual barrage flow (GL) over a rolling 3-year period has been included to provide greater clarity that EWR assessments must consider barrage outflow volumes of preceding years,
- Target values for the timing metric of peak barrage outflows were modified to occur a little earlier (i.e. Sep–Dec, compared to Oct–Dec in the existing CLLMM EWRs),
- A new metric regarding the intra-annual pattern for barrage flows has been included, specifying that the total barrage flow volume during the peak season (Sep–Dec) is greater than total barrage flow volume throughout the rest of the year (Jan–Aug),
- Target values for the timing metric of the maximum Lower Lakes (i.e. Lake Alexandrina and Lake Albert) water levels were modified to peak earlier (i.e. Sep–Dec, compared to Dec–Feb in the existing CLLMM EWRs),
- Target values for the minimum water levels metric of the Lower Lakes were increased to ≥0.5 m AHD (CLLMM 1 & 2) and to ≥0.6 m AHD (CLLMM 3 & 4) compared to 0.4 m AHD in the existing CLLMM EWRs,
- Target values for the peak conditions for the Coorong South Lagoon (CSL) for CLLMM 1 were modified to specify a target range of water levels between 0 to 0.1 m AHD for ≥90 days between Sep–Dec,
- Target values for the peak conditions for the CSL for CLLMM 2 were modified to specify a target range of water levels between 0.2 to 0.45 m AHD for ≥150 days between Sep–Jan,
- Target values for the peak conditions for the CSL for CLLMM 3 were modified to specify a target range of water levels between 0.2 to 0.45 m AHD for ≥180 days between Sep–Feb,
- Target values for the peak conditions for the CSL for CLLMM 4 were removed,
- Target values for the minimum CSL water levels, timing and duration metrics were removed for all the revised CLLMM EWRs.

To improve our understanding of the hydrological connectivity between three PEAs, further modelling was also undertaken to investigate how the revised IC and FP EWRs provide for CLLMM EWR requirement. In general, aligning the EWRs presents some challenges. One of the key assumptions for the modelling exercise was that outside periods a 'flow peak' is delivered with the revised IC or FP EWRs, there are periods of low base flows (equivalent to SA Entitlement only). The periods of low base flows outside of the IC/FP EWRs have a profound influence on meeting certain CLLMM metrics, such as total annual barrage outflow volumes.

Some key findings include:

- The timing of the revised IC and FP EWRs align well with the preferred timing of peak barrage outflows, however outside of these months, as a result of the return to Entitlement (i.e. low base flows), barrage outflows are significantly reduced, which impacts total annual outflow volumes,
- A revised IC3 EWR (>30,000 ML/day QSA) is required to meet the target average annual barrage volume requirement for CLLMM 1; however, IC3 would need to occur more frequently than currently specified (i.e. 65% of years) to meet the target frequency for the revised CLLMM1 EWR (i.e. 100% of years),
- A revised FP5 EWR (≥80,000 ML/day QSA) with a longer target duration (i.e. ≥30 days) is required to meet the target average annual barrage outflow volume for CLLMM4,
- The Coorong Hydrodynamic Model (CHM) outputs indicate that the target values for peak CSL water levels are either not achieved, or only somewhat achieved, for most of the modelled scenarios of the revised IC, FP and CLLMM EWRs.
- The CHM outputs also indicate that estuarine conditions within the Coorong North Lagoon may cease for short periods under the modelled scenarios for the revised IC and FP EWRs if there are sustained periods of low base flows outside of the EWR flow peaks.

The EWRs have been revised with reference to new ecological knowledge and expert opinion, and with the use of revised modelling outputs and/or new modelling tools. As new knowledge and assessment tools are continually being generated these EWRs should be periodically reviewed in line with adaptive management principles.

1 Introduction

1.1 Need for Review

The Long Term Environmental Watering Plan for the South Australian River Murray Water Resource Plan (hereafter referred to as the SA LTWP) was published in November 2015 (DEWNR 2015). It identifies three Priority Environmental Assets (PEAs):

1. *South Australian River Murray Channel (In-channel, IC)* - consists of the area between Wellington, South Australia, and the Victorian border – a total distance of approximately 560 River km. The lateral extent comprises the area inundated at flows up to 40,000 ML/day (QSA; discharge (Q) at the South Australian border) under normal River Murray operations (i.e. without weir pool manipulations or operation of environmental regulators)
2. *South Australian River Murray Floodplain (Floodplain, FP)* – an equivalent longitudinal extent to the In-channel PEA, extending from Wellington to the South Australian border, and consists of the area that is inundated when flows are between 40,000 ML/day QSA and 80,000 ML/day QSA, under normal River Murray operations (i.e. without weir pool manipulations or operation of environmental regulators)
3. *Coorong, Lower Lakes and Murray Mouth (CLLMM)* – the Lower Lakes, Coorong and Murray Mouth incorporates 'The Living Murray' Icon Site and the Ramsar Wetland of International Importance 'The Coorong, Lakes Alexandrina and Albert Wetland'

The three PEAs reflect the ecological importance of the mosaic of habitats that comprise the South Australian River Murray ecosystem, rather than focussing on discrete management units that represent only a relatively small portion of the Water Resource Planning Area. It also ensures that a holistic approach is taken to environmental water planning, delivery and evaluation, enabling the contribution of outcomes at smaller scales, towards the achievement of outcomes at the larger scale, to be considered.

For each PEA, the Environmental Watering Requirements (EWRs) are descriptions of the hydrological regimes required to achieve the ecological objectives and targets prescribed within the SA LTWP (DEWNR 2015). The ecological objectives provide a clear statement of what the EWR delivery is expected to achieve and there are a number of objectives for each PEA (Table 1 to Table 3), which focus on key biotic groups or ecosystem processes. Key biota within the three PEAs include water-dependent vegetation types, native fish, frogs, waterbirds, macroinvertebrates, as well as woodland-dependent birds, reptiles and mammals. Improvements in longitudinal and lateral connectivity facilitate key ecosystem processes such as in-stream hydraulic conditions, productivity, carbon and nutrients loads, and the transport of vegetation propagules, invertebrates, tadpoles and fish larvae (DEWNR 2015). Ecological targets are nested within an ecological objective, where there may be more than one target per objective (Table 1 to Table 3). Ecological targets provide a means of assessing the change in condition and progress towards achieving the anticipated ecological outcomes (DEWNR 2015).

The SA LTWP is being updated by the Environmental Watering Team within the SA Department for Environment and Water (DEW) in line with the requirements of Chapter 8 of the Basin Plan. The EWRs are a key input into annual planning and evaluation of water delivery and, through their practical application, opportunities to make improvements have been identified. This report is therefore focused on revising the EWRs for each of the PEAs (IC, FP and CLLMM) but also ensuring there is consistency between the EWRs for the three PEAs so that they can inform the coordinated management of environmental water throughout the system.

Any revision to the EWRs must ensure they remain consistent with the requirements described in s8.51 (Chapter 8 of the Basin Plan). Whilst these requirements set some statutory boundaries, they still allow scope to develop EWRs that are fit-for-purpose for the region. Additional considerations and definitions applied to EWRs in the SA LTWP are described below and remain valid for any improvements through this project. The SA EWRs in the SA LTWP:

- Describe the water regimes needed to sustain the ecological values of the PEAs at low levels of risk, which is consistent with the definition agreed by the (then) SA Department of Environment, Water and Natural Resources in 2014,
- Represent a long-term (>30 years), variable hydrological regime needed to support healthy, functioning ecosystems,
- Use appropriate metrics to describe the given asset requirements,
- Are based on the pre-development hydrological regime to inform timing and shape of the hydrograph and biotic requirements, but are not seeking to recreate natural/pre-development conditions,
- Are not constrained to what can be delivered under the Basin Plan (based on water recovery modelling) but have a degree of pragmatism applied.

This report provides a summary of the project: *i*) Introduction, *ii*) Methods, *iii*) Results and *iv*) Conclusions. Further technical information supporting this report are presented in the Appendices section.

Table 1: Ecological Objectives and Targets for the SA River Murray In-channel Priority Environmental Asset (modified from Wallace et al. 2014a)

Type	Ecological Objective	Ecological Target
Ecosystem processes	Provide for the mobilisation of carbon and nutrients from the floodplain to the river to reduce the reliance of in-stream food webs on autochthonous productivity.	Open-water productivity shows a temporary shift from near zero or autotrophic dominance (positive Net Daily Metabolism) towards heterotrophy (negative Net Daily Metabolism) when QSA >30,000 ML/day.
	Provide diverse hydraulic conditions over the range of velocity classes in the lower third of weir pools so that habitat and processes for dispersal of organic and inorganic material between reaches are maintained.	Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep–Mar, at a maximum interval of 2 years.
	Maintain a diurnally-mixed water column to ensure diverse phytoplankton and avoid negative water quality outcomes.	Thermal stratification does not persist for more than 5 days at any time.
	Ensure adequate flushing of salt from the River Murray to the Southern Ocean.	Basin Plan Objective: Salt export, averaged over the preceding 3 years, is ≥2 million tonnes per year.
	Maintain habitats and provide for dispersal of organic and inorganic material and organisms between the river channel and wetlands.	Inundation periods in temporary wetlands have unrestricted lateral connectivity between the river channel and wetlands in >90% of inundation events.
Water quality	Maintain water quality to support aquatic biota and normal biogeochemical processes.	Biovolume <4 mm3/L for all Cyanobacteria, where a known toxin producer is dominant.
		Biovolume <10 mm3/L for all Cyanobacteria, where toxins are not present.
		Basin Plan Target: Maintain dissolved oxygen above 50% saturation throughout water column at all times.
Groundwater and Soil	Throughout the length of the Channel asset (i.e. SA border to Wellington), establish and maintain groundwater and soil moisture conditions conducive to improving riparian vegetation.	Establish and maintain freshwater lenses in near-bank recharge zones.
		Maintain soil water availability, measured as soil water potential > -1.5 MPa at soil depth 20–50 cm, to sustain recruitment of long-lived vegetation across the elevation gradient in the target zone.
		Reduce soil salinity (measured as Electrical Conductivity (EC) 1:5) to <5000 µS/cm to prevent shifts in understorey plant communities to salt-tolerant functional groups across the elevation gradient in the target zone.
Biofilms	Promote bacterial rather than algal dominance of biofilms and improve food resource quality for consumers.	Annual median biofilm composition is not dominated (>80%) by filamentous algae.
		Annual median biofilm C:N ratios are <10:1.
Vegetation	Throughout the length of the Channel asset (i.e. SA border to Wellington), establish and maintain a	In standardised transects spanning the elevation gradient in the target zone, 70% of River Red Gums have a Tree Condition Index (TCI) score ≥ 10.

Type	Ecological Objective	Ecological Target
	diverse native flood-dependent plant community in areas inundated by flows of 10,000–40,000 ML/day QSA.	A sustainable demographic is established to match the modelled profile for a viable river red gum population in existing communities spanning the elevation gradient in the target zone.
		Species from the Plant Functional Group 'flood-dependent/responsive' occur in 70% of quadrats spanning the elevation gradient in the target zone at least once every 3 years.
	Throughout the length of the Channel asset (i.e. SA border to Wellington), establish and maintain a diverse macrophyte community in wetlands inundated by flows up to 40,000 ML/day QSA.	Native macrophytes from the emergent, amphibious and flood-dependent Plant Functional Groups occur in 70% of quadrats spanning the elevation gradient in the target zone at least once every 3 years.
Fish	Restore the distribution of native fish.	Expected species occur in each mesohabitat (channel, anabranch, wetlands) in each weir pool/reach.
	Restore resilient populations of Murray Cod (a long-lived apex predator).	Population age structure of Murray Cod includes recent recruits, subadults and adults in 9 years in 10.
		Population age structure of Murray Cod indicates a large recruitment event 1 year in 5, demonstrated by a cohort representing >50% of the population.
		Abundance (measured as Catch Per Unit Effort (CPUE)) of Murray Cod increases by ≥50% over a 10-year period.
	Restore resilient populations of Golden Perch and Silver Perch (flow dependent specialists).	Population age structure of Golden Perch and Silver Perch includes Young of Year (YOY) with sub-adults and adults in 8 years in 10.
		Population age structure of Golden Perch and Silver Perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.
		Abundance (measured as CPUE) of Golden Perch and Silver Perch increases by ≥30% over a 5-year period.
	Restore resilient populations of Freshwater Catfish.	Population age structure of Freshwater Catfish includes YOY, with sub-adults and adults in 9 years in 10.
		Population age structure of Freshwater Catfish indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.
		Abundance (measured as CPUE) of Freshwater Catfish increases by ≥30% over a 5-year period.
	Restore and maintain resilient populations of foraging generalists (e.g. Australian Smelt, Bony Herring, Murray Rainbowfish, Unspecked Hardyhead, Carp Gudgeons, Flathead Gudgeons).	The length-frequency distributions for foraging generalists include size classes showing annual recruitment.

Type	Ecological Objective	Ecological Target
	Minimise the risk of Common Carp recruitment.	The relative abundance and biomass of Common Carp does not increase in the absence of increases in abundance and biomass of flow-dependent native fish.

Table 2: Ecological Objectives and Targets for the SA River Murray Floodplain Priority Environmental Asset (modified from Kilsby and Steggles 2015)

Type	Ecological Objective	Ecological Target
Ecosystem processes	Provide for the mobilisation of carbon, nutrients and propagules from the floodplain to the river.	During inundation periods, record an increase in the abundance and diversity of invertebrate food resources, nutrients and dissolved organic carbon (DOC) relative to those available during base flow.
	Provide diverse hydraulic conditions and complex habitat for flow dependent biota and processes.	Deliver flows in a manner that reduces the proportion of slow flowing habitat and increases the proportion of moderate velocity habitat thereby reinstating a diversity of velocity classes representative of natural conditions.
	Implement a seasonal and multi-year hydrograph that encompasses variation in discharge, velocity and water levels.	Discharge, water level and duration metrics of planned environmental water represent a seasonally variable hydrograph.
Water Quality	Maintain water quality to support water dependent biota and normal biogeochemical processes.	Maintain dissolved oxygen above 50% saturation throughout the water column at all times, in connected waters.
Groundwater and Soil	Establish groundwater conditions conducive to maintaining diverse native vegetation .	Establish and maintain freshwater lenses in near-bank recharge zones.
	Establish soil conditions conducive to maintaining diverse native vegetation.	Maintain soil water availability, measured as soil water potential at soil depth 20-50cm, greater than -1.5 MPa in order to sustain the recruitment of long-lived vegetation.
		Reduce soil salinity (measured as EC 1:5) to below 5,000 µS/cm to prevent permanent shifts in understorey plant communities to salt tolerant functional groups.
		Maintain soil sodicity below the Exchangeable Sodium Percent (ESP) value of 15 (highly sodic).
	Maintain sedimentation and erosion processes within normal ranges during overbank flows.	Limit the maximum rate of drawdown (averaged over 3 consecutive days) to ≤0.025 m/day (0.05m/day in any one day) to minimise risk of bank failure.
Vegetation	Maintain a viable, functioning River Red Gum population.	In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all River Red Gum trees have a TCI ≥10.
		A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient.

Type	Ecological Objective	Ecological Target
	Maintain a viable, functioning Black Box population.	In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all Black Box trees have a TCI ≥10.
		A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient.
	Maintain a viable, functioning River Cooba population.	In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all trees have a TCI ≥10.
		A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient.
	Maintain a viable, functioning Lignum population.	In standardised transects that span the floodplain elevation gradient and existing spatial distribution, ≥70% of lignum plants have a Lignum Condition Index (LCI) score ≥6 for colour.
	Establish and maintain diverse water dependent vegetation within aquatic zones across the Floodplain PEA.	In aquatic zones, a minimum of 40% of cells are either inundated or dry containing inundation dependent or amphibious plant taxa once every two years on average with maximum intervals of no greater than 4 years. Native water dependent species richness is >30 across the Floodplain PEA.
		In aquatic zones, a minimum of 80% of cells are either inundated or dry containing native flood dependent or amphibious plant taxa once every four years on average with maximum intervals of no greater than 6 years. Native water dependent species richness is >50 across the Floodplain PEA.
	Establish and maintain diverse native vegetation comprising native flood dependent and amphibious species within the shedding floodplain zones across the Floodplain PEA.	In shedding floodplain zones, a minimum of 20% of cells contain native flood dependent or amphibious plant taxa once every three years on average with maximum intervals of no greater than 5 years. Native flood dependent and amphibious species richness is >20 across the Floodplain PEA.
		In shedding floodplain zones, 40% of cells contain native flood dependent or amphibious plant taxa once every five years on average with maximum intervals of no greater than 7 years. Native flood dependent and amphibious species richness is >30 across the Floodplain PEA.
		In shedding floodplain zones, 65% of cells contain native flood dependent or amphibious plant taxa once every seven years on average with maximum intervals of no greater than 10 years. Native flood dependent and amphibious species richness is >50 across the Floodplain PEA.
Fish	Restore resilient populations of circa-annual nesters/ spawners within the South Australian River Murray.	Population age structure of Murray Cod includes recent recruits, sub-adults and adults in 9 years in 10.
		Population age structure of Murray Cod indicates a large recruitment event 1 year in 5, demonstrated by a cohort representing >50% of the population.

Type	Ecological Objective	Ecological Target
		Abundance, as measured by CPUE, of Murray Cod increases by ≥50% over a 10-year period.
		Population age structure of Freshwater Catfish includes YOY, with sub-adults and adults in 9 years in 10.
		Population age structure of Freshwater Catfish indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.
		Abundance (measured as CPUE) of Freshwater Catfish increases by ≥30% over a 5-year period.
	Restore resilient populations of flow-dependent specialists	Population age structure of Golden Perch and Silver Perch includes YOY with sub-adults and adults in 8 years in 10.
		Population age structure of Golden Perch and Silver Perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.
		Abundance, as measured by CPUE, of Golden Perch and Silver Perch increases by ≥30% over a 5-year period.
	Restore resilient populations of wetland/floodplain specialists within aquatic zones across the Floodplain PEA during floodplain flow events.	The length-frequency distributions for wetland/floodplain (native fish) specialists within aquatic zones across the Floodplain PEA include size classes showing annual recruitment.
		Increase range and abundance of wetland/floodplain (native fish) specialists within aquatic zones across the Floodplain PEA.
	A low proportion of total fish community, measured as abundance and biomass, is comprised of non-native species.	The relative abundance and biomass of non-native species does not increase in the absence of increases in abundance and biomass of native fish.
Frogs	Provide habitat conducive to supporting diverse communities of riparian frogs.	Each of 8 riparian frog species present within the Floodplain PEA will be recorded across the floodplain in any three-year period.
		Tadpoles will be recorded from 8 species in later stages of metamorphosis across the Floodplain PEA in any three-year period.
Waterbirds	Create conditions conducive to successful, small scale breeding events for waterbirds.	Minimum inundation periods required for successful breeding by a range of water bird species are provided. Preliminary minimum 120 days.
	Provide refuge for the maintenance of adult populations of waterbirds.	During continental dry periods an increase in the observed to expected ratio of waterbird species occurs.
Other	Provide habitat conducive to supporting communities of native woodland birds, reptiles and mammals.	Each of the bird species known to utilise similar floodplain woodland habitats in the region will be recorded at 50% of sites across the Floodplain PEA in any three-year period.
		Each of the reptile species known to utilise similar floodplain/woodland habitats in the region will be recorded at 50% of sites across the Floodplain PEA in any three-year period.

Type	Ecological Objective	Ecological Target
		Each of the native mammal species known to utilise similar floodplain/woodland habitats in the region will be recorded at 50% of sites across the Floodplain PEA in any three-year period.

Table 3: Ecological Objectives and Targets for the SA River Murray Coorong, Lower Lakes and Murray Mouth Priority Environmental Asset (modified O'Connor et al. 2015)

Type	Ecological Objective	Ecological Target
Waterbirds	Maintain or improve waterbird populations in the Coorong and Lower Lakes.	Abundances, area of occupation and extent of occurrence of The Living Murray (TLM) target waterbird species to be above defined median reference values.
		Detect annual breeding activity in waterbird species that are expected to breed annually at the site and at least two breeding events in any four consecutive years in species that breed regularly at the site.
		Provide functional mudflat habitat to sustain active shorebird foraging behaviour during Nov-Mar with a foraging effort of <50%.
		Maintain abundances of 12 waterbird species at or above 1% of the total flyway population size.
Fish	Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the Lower Lakes and Coorong.	A spatio-temporally diverse fish community is present including all 23 fish families stated in the Ramsar site draft Ecological Character Description.
		Annual detection of juvenile catadromous fish at abundances greater than that of defined 'Recruitment Index' values.
		Annual detection of migration for anadromous species (e.g. Short-headed and Pouched Lamprey) at index values of >0.6.
		Maximise fish passage connectivity between the Lower Lakes and Coorong, and between the Coorong and the sea by allowing fishways to operate year-round.
		Maintain or improve abundances of Murray Hardyheads and Pygmy Perch so that 'Relative Abundance Index' values of ≥1 are achieved on an annual basis.
		Detect recruitment success of Murray Hardyheads and Pygmy Perch at least every second year.
		Maintain or improve abundances, distribution and recruitment of Black Bream and Greenback Flounder with a population condition score of ≥3.
		Facilitate regular recruitment and a broader distribution of juvenile Mulloway.
		Maintain an average CPUE of Small-mouthed Hardyhead sampled in spring/early summer of > 120 for adults, and >790 for juveniles.

Type	Ecological Objective	Ecological Target
		Maintain the proportional abundance of Small-mouthed Hardyhead juveniles at >60% in 75% of defined monitoring sites within the CLLMM.
Macroinvertebrates	Maintain or improve invertebrate communities in estuarine and lagoon sediments.	Macroinvertebrate taxonomic distinctness falls within the expected ranges of a regional reference.
		The distribution of macroinvertebrate species remains within or above the species-specific reference level for their index of occurrence.
		The area of occupancy where abundance and biomass are at or above the reference level should be >20% of the monitoring sites.
		The macroinvertebrate community has a higher multivariate similarity to the community present in years with flow than years without flow.
	Maintain habitable sediment conditions in mudflats.	The median grain size of sediments in the Coorong and Murray Mouth remains between 125 – 500 µm.
		The sediment organic matter content is between 1 and 3.5 % dry weight. in the Coorong and Murray Mouth
Vegetation	Restore *Ruppia tuberosa* colonisation and reproduction in the Coorong at a regional and local scale.	A continuous distribution of *Ruppia tuberosa* beds occur along a 50 km section of the southern Coorong (excluding outliers).
		Within the abovementioned distribution, 80% of the monitored sites should have *Ruppia tuberosa* plants present in winter and summer.
		50% of sites with *Ruppia tuberosa* exceed the local site indicators for a healthy *Ruppia tuberosa* population.
		Support a resilient *Ruppia tuberosa* population with seed densities of 2000 seeds/m2 by 2019 and 50% of sites having 60% cover in winter and a seed bank of 10,000 seeds/m2 by 2029 in the Coorong South Lagoon.
	Maintain or improve aquatic and littoral vegetation in the Lower Lakes.	Maintain or improve diversity of aquatic and littoral vegetation in the Lower Lakes as quantified using the LLCMM vegetation indices.
Water quality	Establish and maintain stable salinities in the Lower Lakes and a variable salinity regime in the Murray estuary and Coorong.	Barrage outflows are sufficient to maintain EC in Lake Alexandrina at a long term average of 700 µS/cm, below 1,000 µS/cm 95% of years and below 1,500 µS/cm 100% of the time.
		To support aquatic habitat salinity is maintained at a gradient from 0.5 ppt to 35 ppt between the Barrages and Murray Estuary area, <45ppt in the North lagoon, and from 60 ppt to 100 ppt in the South lagoon.
Ecosystem processes	Maintain a permanent Murray Mouth opening through freshwater outflows, with adequate tidal variations to improve water quality and maximise connectivity between the Coorong and the Southern Ocean.	Maintain an open Murray Mouth, as indicated when the Diurnal Tidal Ratio (DTR) at Goolwa exceeds 0.3, with minimum DTR values of 0.05 and 0.2 at Tauwitchere and Goolwa respectively.
		Maintain a minimum annual flow required to keep the Murray Mouth open (730—1,090 GL/yr)

1.2 Existing EWRS

The SA LTWP describes seven EWRs the SA River Murray In-channel PEA (Table 4), five EWRs for the SA River Murray Floodplain PEA (Table 5) and four EWRs for the SA Coorong, Lower Lakes and Murray Mouth (CLLMM) PEA (Table 6). Collectively, these EWRs outline the variable hydrological regime required to meet the SA LTWP ecological objectives and targets for the three assets.

The In-channel (IC) EWRS incorporate metrics associated with discharge calculated flow to South Australia (QSA ML/day), duration (days), timing (seasonality), average return frequency (years) and maximum interval between flow pulses (years) as described in the SA LTWP (DEWNR 2015) and associated technical documents (Wallace et al. 2014a,b).

Similarly, the Floodplain (FP) EWRs incorporate metrics associated with discharge calculated flow to South Australia (QSA ML/day), duration (days), timing (months), average return frequency (years), maximum interval (years) and maximum rates of rise and fall (m/day) as described in the SA LTWP (DEWNR 2015) and associated technical documents (Kilsby and Steggles 2015).

The CLLMM EWRs incorporate metrics associated with annual barrage flow volumes (GL/year) and barrage flow timing (months), Lower Lakes (i.e. Lake Alexandrina and Lake Albert) water levels (m AHD), Coorong South Lagoon levels (m AHD), the timing of peak and minimum water levels in both the Lower Lakes and Coorong South Lagoon (months) and the duration of Coorong South Lagoon peak water levels (days) as outlined in the SA LTWP (DEWNR 2015) and associated technical documents (O'Connor et al. 2015).

Table 4: Existing Environmental Water Requirements for the SA River Murray In-channel Priority Environmental Asset (Wallace et al. 2014a)

EWR #	Median discharge* (ML/day QSA)	Discharge variability (ML/day QSA)	Duration (days)	Preferred timing (months)	Average return frequency** (years)	Maximum interval*** (years)
IC1	10,000	7,000–12,000	60	Sep–Mar	1.05	2
IC2	15,000	15,000–20,000	90	Sep–Mar	1.33	2
IC3	20,000	15,000–25,000	90	Sep–Mar	1.8	2
IC4	25,000	20,000–30,000	60	Sep–Mar	1.7	2
IC5	30,000	25,000–35,000	60	Sep–Mar	1.8	2
IC6	35,000	30,000–40,000	60	Sep–Mar	1.8	2
IC7	40,000	35,000–45,000	90	Sep–Mar	2.1	3

*metric relates to the flow threshold, as per the Basin Plan
**metric relates to the required frequency of flow events, as per the Basin Plan
***metric relates to the maximum period between flow events, as per the Basin Plan

Table 5: Existing Environmental Water Requirements for the SA River Murray Floodplain Priority Environmental Asset (Kilsby and Steggles 2015)

EWR #	Median discharge* (ML/day QSA)	Discharge variability (ML/day QSA)	Duration (days)	Preferred timing	Average return frequency** (years)	Maximum interval*** (years)	Max rate of water level rise (m/day)	Max rate of water level fall (m/day)
FP1	50,000	45,000–55,000	30	Sep–Dec	1.6	5	0.05	0.025
FP2	60,000	55,000–65,000	30	Sep–Dec	2.0	5	0.05	0.025
FP3	70,000	65,000–75,000	30	Sep–Dec	2.6	5	0.05	0.025
FP4	80,000	75,000–85,000	30	Sep–Dec	3.6	5	0.05	0.025
FP5	80,000	75,000–85,000	60	Sep–Dec	7.6	8	0.05	0.025

*metric relates to the flow threshold, as per the Basin Plan
**metric relates to the required frequency of flow events, as per the Basin Plan
***metric relates to the maximum period between flow events, as per the Basin Plan

Table 6: Existing Environmental Water Requirements for the Coorong, Lower Lakes and Murray Mouth Priority Environmental Asset (O'Connor et al. 2015)

EWR#	**Average return interval* (years)**	**Maximum interval** (years)**	**Annual barrage flow*** (GL/yr)**	**Barrage flow timing (months)**	**Lower Lakes water level (m AHD)**	**Lower Lakes water level timing (months)**	**Coorong south lagoon water level (m AHD)**	**Coorong south lagoon water level timing (months)**	**Coorong south lagoon duration (days)**
CLLMM 1	1–in–1	N/A	>650^	Jul–Jun, with peak barrage outflows in Oct–Dec	0.4 –0.75	Maximum lake levels Dec–Feb and minimum lake levels in Mar–May	0.0 to 0.2	Sep–Nov	≥90
							–0.2 to –0.4	Feb–Mar	N/A
CLLMM 2	1–in–2	N/A	>3,150^^	Jul–Jun, with peak barrage outflows in Oct–Dec	0.4–0.83	Maximum lake levels in Dec–Feb, with minimum lake levels in Mar–May	0.35 to 0.45	Sep–Dec	≥120
							0 to –0.5	Mar–Apr	N/A
CLLMM 3	1–in–3	5	>6,000	Jul–Jun, with peak barrage outflows in Oct–Dec	0.4–0.83	Maximum lake levels in Dec–Feb and minimum lake levels in Mar–May	0.35 to 0.45	Sep–Jan	≥150
							0 to –0.5	Feb–Apr	N/A
CLLMM 4	1–in–7	17	>10,000	Jul–Jun, with peak barrage outflows in Oct–Dec	0.4–0.9	Maximum lake levels in Dec–Feb, with minimum lake levels in Mar–May	0.35 to 0.45	Sep–end Feb	≥180
							N/A	N/A	N/A

*metric relates to the required frequency of flow events as per the Basin Plan
**metric relates to the maximum period between flow events, as per the Basin Plan
***metric relates to the total flow volume, as per the Basin Plan
^A total average barrage outflow of 2,000 GL/yr over a three-year rolling period (i.e. not less than 6,000 GL over three years) and not less than 650 GL/yr in any one of the three years (Heneker 2010, Lester et al. 2011)
^^ A total average barrage outflow of 4,000 GL/yr over a three-year rolling period (i.e. not less than 12,000 over three years) and not less than 3,150 GL/yr in any one of the three years (Heneker 2010, Lester et al. 2011)

2 Methods

2.1 Application of EWRs

As a first step, River Murray practitioners involved in the management of the three Priority Environmental Assets were consulted through a series of meetings to determine how EWRs are used in annual environmental water planning (e.g. to influence the delivery of environmental water at appropriate spatial and temporal scales) and how EWRs may be used to infer ecological outcomes as a result of their delivery.

2.2 Preliminary analysis and revision of existing EWRs

To develop some preliminary revisions to the existing EWRs, the project team used the information obtained from the above consultation process, referred to key technical documents outlining the development of the existing EWRs (i.e. Wallace et al. 2014a, b; DEWNR 2015; Kilsby and Steggles 2015; O'Connor et al. 2015) and reviewed other literature (cited herein). This information was used to develop two discussion papers: one for the IC and FP EWRs (unpublished) and one for the CLLMM EWRs (*unpublished*), which were circulated to SA River Murray scientists and practitioners prior to a face-to-face workshop. The discussion papers provided workshop participants with:

- A summary of the project aims,
- An outline of the key issues regarding the practical application of the existing EWRs,
- Technical information regarding the development of the existing EWRs, and
- Some preliminary suggestions (from the project team) for revisions to the existing EWRs (with supporting analysis/rationale).

In the development of the preliminary revisions to the existing EWRs, the project team sought to identify the ecological significance of each EWR (and their individual metrics).

A framework (Table 7) was developed to support an approach that allowed experts and/or practitioners to consider where there may be some flexibility around EWR metrics and where it was critical that there was absolutely no flexibility. A first step in developing these values was to characterise:

- *Target* values, which provide an indication of ideal/optimal conditions and the greatest certainty of achieving the anticipated ecological outcomes,
- *Envelope* values, that provide an acceptable range of variability around the target values, but with reduced certainty of achieving all the anticipated ecological outcomes,
- *Sub-optimal* values, that provide a range of values that are still considered tolerable (i.e. have not exceeded upper and/or lower critical thresholds), but there is low certainty of achieving most of the anticipated ecological outcomes, and
- *Critical threshold* values, that represent upper and/or lower thresholds that have been exceeded and there is no confidence (or certainty) of achieving the anticipated ecological outcomes.

The target, envelope, sub-optimal and critical threshold values were used in the revision process to guide the assessment of whether *i*) the EWRs have been met, *ii*) whether the associated ecological outcomes are likely to occur and *iii*) to aid analysis and strengthen the justification for any changes to EWR metrics that were made. Although this assessment process provides indication of whether EWR metrics are achieved, they differ from targets and triggers identified in the Ramsar Management Plan and thresholds for Limits of Acceptable Change in the updated Ecological Character Description, as the latter are specific thresholds associated with critical indicators to detect potential change in the ecological character of the site. It was also acknowledged that the final contributions towards the suite of anticipated ecological outcomes associated with EWRs may also depend upon the relevant combinations of individual metrics (e.g. discharge, duration and season).

Table 7: Framework of metric categories, descriptions, certainties and potential metric response used as a framework to guide revision of South Australian Environmental Watering Requirements

Categories within EWR metric*	Description	Certainty of contribution towards ecological outcomes^	Evaluation response
Target	Optimal	Greatest certainty	Met
Envelope	Acceptable variability	Moderate certainty	Almost met
Sub-optimal	Sub-optimal/tolerable	Low certainty	Partially met
Critical Thresholds	Intolerable	No certainty	Not met

*metric bounds might not be relevant to all metrics
^the final contribution towards the suite of ecological outcomes associated with an EWR may depend on the certainty of the contribution from relevant combinations of individual metrics within a whole-of-EWR (e.g. discharge, duration and timing/season)

2.3 Workshop of expert elicitation of EWR Revisions

The project team invited all workshop participants to read through the two discussion papers (Section 2. 2) and provide comments and/or feedback on all preliminary EWR revisions (Figure 1) prior to a full day, face-to-face workshop, held in Adelaide on the 25th July 2019. Facilitated by Sarah Imgraben (DEW), the invited list of attendees included: Dr Qifeng Ye (SARDI Aquatic Sciences), Dr Jason Nicol (SARDI Aquatic Sciences), Chris Bice (SARDI Aquatic Sciences) , Dr Brenton Zampatti (CSIRO, formerly SARDI Aquatic Sciences), Professor Michelle Waycott (The University of Adelaide), Assoc. Prof David Paton (The University of Adelaide), Dr Scotte Wedderburn (The University of Adelaide), Dr Deborah Furst (The University of Adelaide), Dr Matt Gibbs (DEW), Rebecca Turner (DEW), Jan Whittle (DEW), Tumi Bjornsson (DEW), Adrienne Rumbelow (DEW) and Tracey Steggles (DEW).

EWR #	FP1
Descriptor	Small overbank
Primary function(s)	Promote habitat and flow heterogeneity (including velocity) Lateral connectivity Inundation and lateral recharge of frin[illegible]ng vegetation Support Golden Perch and Silver Perc[illegible] [illegible]opulation structure
Discharge (ML/day QSA)	Target: 50,000 Envelope: 45,000–55,000 Threshold: N/A Critical Limits: N/A
Duration (number of days^)	Target = 30 days, Envelope = 27–33 da[illegible] Threshold limits = 2[illegible] [illegible]120 Critical limits = <20 da[illegible] [illegible] N/A
Timing (months)	Target: Sep-Dec Envelope: Au[illegible] Threshold: J[illegible] Critica[illegible] [illegible]mits [illegible] N/A
Frequency	Target fre[illegible]ncy = ARI = 1.66 (60%) Envel[illegible] ARI [illegible] (55%) Thre[illegible]old [illegible] = 2.5 (50%) 4-6 [illegible]rs in [illegible]0
Maximum interval (years)	T[illegible]rget: [illegible] Env[illegible]e: ([illegible]–4.5) [illegible]reshold: (N/A – 5) C[illegible]al limit: >5 years

4.5.1 Comments on Flo[illegible]dp[illegible]n [illegible]WR FP1

If you have any comm[illegible] the proposed EWR metrics, please provide in the space below:

EWR FP1:

Figure 1: Example of questionnaire inviting feedback on suggested approach to revision of the existing South Australian Environmental Watering Requirements EWRs.

2.4 Document rationale/justification

The purpose of the workshop was to elicit expert input to revisions and to document rationale/justifications to the proposed revisions to the SA EWRs and the individual metrics associated with each EWR. Following the workshop, further analysis was undertaken of the suggested revisions including a review of modelled natural hydrology (see Section 2.4.1 below and model outputs in Appendix 5.1) and the modelled alignment between IC, FP and CLLMM EWRs (see Section 2.4.2 below and model outputs in Appendix 5.2).

A first draft report was produced, outlining the proposed revisions made to the existing EWRs, supporting rationale/justifications and key findings/recommendations. This first draft was reviewed by the River Murray Scientists/practitioners, the DEW Environmental Water Team and the Project Working Group. A second draft of the report was reviewed by the DEW Environmental Water Team and Project Working Group only. A final review of the report was undertaken by the DEW Environmental Water Team and an independent reviewer. The revisions presented in this report are suggestions only and are subject to approval.

2.4.1 Review of modelled natural hydrology

Various In-channel (IC) and Floodplain (FP) EWR descriptions were trialled and assessed using the Freshchecker Tool (NSW OEH) and compared to natural modelled conditions (i.e. modelled without development data; years 1895–2009, MDBA). In addition, for the purposes of this review, observed QSA (ML/da) data were compared from two periods, where 1977 – 1995 represented a period of “less extensive development” and 1996 – 2017 represented a period of “more extensive development” (Appendix 5.1). The comparisons between the two periods of observed data were undertaken to highlight which EWRs (or individual metrics) may be most affected by the conditions experienced in recent decades to help guide water management in the long term. The analysis and development of revised EWR scenarios included inputs of values for specified EWR metrics (Table 8).

Table 8: Description of EWR metric Freshchecker inputs

Input	Description	Units
Discharge	Specified river discharge threshold value that flow event must be equal to, or greater than	ML/day
Maximum discharge	Maximum river discharge for flow event; but fixed at 10,000,000 ML/day to represent that no upper limit is defined	ML/day
Duration	Required duration (cumulative days) of flow event above discharge threshold	days
Timing	Required timing window that flow event must occur within.	months
Frequency	Required frequency of flow event return	% of years
Maximum interval	Duration of required maximum interval (dry spells) between flow events	days

The specified input values for each EWR were applied in combination (i.e. discharge × duration × timing × frequency × maximum interval). Modelled outputs for natural modelled (modelled without development), observed pre-development (1977–1996) and observed post-development (1997–2017) (Table 9) were provided. The EWR scenarios passed if the following conditions were met:

- Specified value of the EWR duration (days) was less than the median value for the duration of flows that occurred under natural modelled conditions,
- Specified value for the EWR frequency (% of years) was within 10% of the flow frequency that occurred under natural modelled conditions
- Specified maximum interval (i.e. duration of dry spell) of EWR scenarios were less than the 95th percentile value under natural modelled conditions.

Table 9: Description of Freshchecker outputs

Output	Description	Units
Frequency	Frequency of analogous flows compared to the specified EWR scenario that occurred within all years assessed	% of years
Median number of flow events within a year	The median number of analogous flows compared to the specified EWR scenario that occurred within a year	Median number of flows within a year
Range of flow events within year	Range of analogous flows compared to the specified EWR scenario that occurred within a year	Range of flows within a year
Median interval	Median duration of interval (dry spell) between analogous flows compared to the specified EWR scenario	days
95th percentile duration of interval	95th percentile duration of interval (dry spell) between analogous flows compared to the specified EWR scenario	days
Maximum interval	Maximum duration of interval (dry spell) between analogous flows compared to the specified EWR scenario	days
Median duration	Median duration of analogous flows compared to the specified EWR scenario; indicative of moderate water resource availability year	days

Output	Description	Units
25th percentile duration	25th percentile duration of analogous flows compared to the specified EWR scenario; indicative of low water resource availability year	days

2.4.2 Modelled alignment between revised IC, FP and CLLMM EWRs

To improve our understanding of the hydrological connectivity between the three PEAs, the alignment between the revised EWRs for the In-channel, Floodplain and CLLMM were assessed using the South Australian River Murray Source model (Beh et al. 2019). Alignment of the IC, FP and CLLMM EWRs will help to meet the ecological objectives and targets outlined in the SA LTWP (Table 1 to Table 3; DEWNR 2015) to promote integrated management across the SA River Murray Water Resource Planning area, inform the development of future regional multi-site watering actions and highlight where environmental trade-offs potentially need to be made.

Detailed methods, assumptions and outputs are described in Appendix 5.2.

Key questions investigated were:

1. Do the monthly flow volumes of the revised IC and FP EWRs align with the preferred delivery pattern of barrage outflows?
2. Does the timing of the revised IC and FP EWRs align with the preferred delivery pattern of barrage outflows?
3. Will the revised IC or FP EWRs meet the target barrage outflow volumes of the revised CLLMM EWRs?
4. Where IC and FP flow volumes and CLLMM barrage outflow volumes align, is there consistency between the target frequency values of the IC and FP EWRS and the target frequency values for the CLLMM EWRs?
5. Do the monthly flow volumes of the IC and FP EWRs align with the target range of peak/minimum Lower Lakes water levels?
6. Does the timing of the revised IC and FP EWRs align with the timing of peak/minimum Lower Lakes water levels?
7. For a given CLLMM EWR do barrage outflow metrics (volumes and timing) provide the revised target Coorong South Lagoon water levels, timing and duration metrics?

A hydrograph representing one hypothetical delivery pattern of a revised EWR scenario was developed for each IC and FP EWR and used to provide modelled predictions of the intra-annual pattern of flow (ML/day QSA) from the South Australian border through to Lock 1 and Wellington (accounting for travel time, diversions and losses and normal operations of weir pool levels) using the South Australian River Murray Source model (Beh et al. 2019). The hydrographs were also used to assess their alignment with the revised target CLLMM metrics for intra-annual water level (m AHD) patterns in Lake Alexandrina as well as the revised intra-annual patterns in barrage flow volumes (GL/month).

The modelled predictions of the IC and FP EWR target scenarios (derived from the SA River Murray SOURCE Model) were also used to investigate their influence on revised CLLMM metrics for the estuary and CSL using the Coorong Hydrodynamic Model (DEW). Parameters investigated included the CSL water levels (m AHD), CSL salinity (g/L) and the extent of estuarine conditions (km) within the Coorong North Lagoon. The Coorong Hydrodynamic Model incorporates the modelled barrage release patterns for each EWR scenario along with historical inputs relating to wind, sea level, evaporation and precipitation to represent the variation in the Coorong response to the EWR flow volumes.

3 Results

3.1 Practical application of IC and FP EWRs

Consultation with River Murray practitioners highlighted that EWRs are used in annual water planning and to describe ecological outcomes as a result of EWR delivery, but at present, neither the SA LTWP, nor any other related document, provides guidance (and/or a standardised process) for how to assess whether EWRs have been met because it is not required through relevant reporting processes.

Feedback on the utility of the IC and FP EWRs has emphasised certain issues. For example, the discharge (QSA) ranges in the existing IC EWRs tend to overlap (Table 4) causing some confusion when evaluating EWRs. Further consideration of the key issues with the existing IC and FP EWRs that were identified through the consultation, preliminary review/analysis of existing EWRs and the expert elicitation process are presented in Section 3.2. The final proposed revisions to the IC and FP EWRs are provided in Section 3.3.

3.2 Summary of considerations of existing IC and FP EWRs

3.2.1 Flow descriptor

A flow component descriptor was considered to provide context around the scale of the IC and FP EWRs and provide an indication of the physical character of the river-floodplain system (e.g. in-channel pulse, bankfull, connection to floodplain etc.). The hydrological descriptors are based on descriptions provided in Table 10. We note that as a result of the intensive regulation of the southern MDB, the low end of the scale is ‘very low flow’ to ‘baseflow’ (i.e. cease-to-flow does not occur in the main channel of the River Murray).

Table 10: Hydrological description of flow categories. Modified from Basin Wide Environmental Watering Strategy (MDBA 2014b).

Flow categories	Descriptions
Cease-to-flow	Partial or total drying of the channel. System contracts to a series of disconnected pools. No surface flows.
Very low flow	Minimum flow in a channel that prevents cease-to-flow conditions. Provides connectivity between some pools.
Baseflow	Long term seasonal flows that provide drought refuge between dry periods and contribute to nutrient dilution during wet periods or after a flood. Provides enough depth for fish movement along reaches.
Small fresh (pulse)	Improves longitudinal connectivity. Inundates lower banks, snags and woody debris, but flows are within the river channel. Maintains instream-habitat and cycles nutrients between parts of the river channel. May trigger aquatic animal movement and breeding. Flushes pools. May stimulate productivity/food webs.

Flow categories	Descriptions
Medium - Large fresh (pulse)	Inundates benches, snags, woody debris and inundation-tolerant vegetation higher in the channel. May connect wetlands and anabranches with low commence-to-flow thresholds. Supports productivity and transfer of nutrients, carbon and sediment. Provides fast-flowing habitat.
Bankfull flow	Inundates all in-channel habitats and connects many low-lying wetlands. Partial or full longitudinal connectivity. Drowns out most in-channel barriers and structures, such as weirs
Overbank flow	Overbank flows provide broad scale lateral connectivity with floodplains and wetlands. Supports nutrient, carbon & sediment cycling between the floodplain and channel. Promotes large-scale productivity. Overbank flows are used to describe flows above bankfull.

In the existing IC and FP EWRs there was a specified 'median' discharge and an associated range (i.e. minimum and maximum discharge values). In practice, there is some confusion as to whether *i*) the discharges must remain above the lower end of the specified range (i.e. the minimum values provided in 'Discharge Variability' metric), *ii*) remain at or above the specified 'median discharge' for the given number of days or *iii*) could exceed the maximum discharge value at any time during the event timeframe. It was proposed that the discharge variability metrics be removed from the EWRs to avoid this confusion and that only the specified target discharge values for each EWR be presented.

As a guideline, the discharge variability or 'flow bands' for all IC and FP EWRs were considered (see Table 11). The flow bands identified for each EWR are largely within incremental steps of 10,000 ML/day and correspond to the flow descriptors outlined in (Table 10).

Table 11: Discharge variability/flow bands in 10,000 ML/day incremental steps and corresponding flow component descriptors for IC and FP EWRs (modified from Kilsby et al. 2014).

Discharge variability/Flow band (ML/day QSA)	Target discharge (ML/day QSA)	Flow component descriptor	Revised EWR #
3,000–6,999	≥3,000	Very low baseflow (Entitlement Flow*)	EF
7,000–14,999	≥10,000	Baseflow	IC1
15,000–24,999	≥20,000	Small fresh	IC2
25,000–34,999	≥30,000	Large fresh	IC3
35,000–44,999	≥40,000	Bankfull flow	IC4
45,000–54,999	≥50,000	Low overbank flow	FP1
55,000–64,999	≥60,000	Low to moderate overbank flow	FP2
65,000–74,999	≥70,000	Moderate overbank flow	FP3
75,000–84,999	≥80,000	Moderate to large overbank flow	FP 4 and FP5

* QSA may be <3,000 ML/day during periods of extended dry

3.2.2 Discharge

The discharge/flow recorded over a specified time determines the magnitude of a flow event. Discharge affects flow velocity and stage (water level) (Wallace et al. 2014 a, b). Flow velocity represents the energy available for ecosystems processes, such as geomorphic processes (e.g. scouring, transport and deposition of sediments), the re-arrangement of biotic habitat (e.g.

macrophytes) and structural habitat (e.g. woody debris, rocks, gravel), the dispersal of material including biological propagules, and mixing energy to maintain non-buoyant propagules in suspension and prevent stratification. The magnitude of any given event may also directly or indirectly influence migration and spawning/breeding behavioural responses in channel and floodplain associated fauna.

Under unregulated conditions, the diversity and variability in flowing water conditions was a key feature of the River Murray, to which fish and other aquatic biota are adapted (Humphries et. al. 1999). Intensive river regulation has substantially reduced hydrodynamic complexity in the southern MDB (Bice et al.2017; Bice and Zampatti 2015; Mallen-Cooper et al. 2011; Maheshwari et al. 1995; Walker and Thoms 1993). For instance, historical operations of regulatory structures such as locks and weirs create still-water habitats, and removal of large wood reduces instream complexity (Mallen-Cooper and Zampatti 2015a). Many floodplain wetland systems have also suffered altered hydrology associated with river regulation, and destruction of habitat associated with land clearing and non-native species (Kingsford and Thomas 2004).

Kilsby and Steggles (2015) highlighted that there are distinct tipping points in discharge where certain ecological outcomes are maximised. For instance, modelling results indicate that when weir pools are at normal pool level (NPL) and flows are <5,000 ML/day, then the greatest proportion of in-channel velocities are slow flowing (<0.1 m/sec) (Table 12) (which is related to low hydraulic diversity). As flows increase, weir pool in-channel velocities increase (Table 12). When flows exceed 15,000 ML/day, there is a tipping point where a greater proportion of in-channel velocities within weir pools become moderate-fast-flowing (≥0.2 m/sec) (Table 12), providing medium-high hydraulic diversity. In the lower Murray, flows >15,000 ML/day and water temperature above ~20˚C are considered conducive to generating a spawning response for Golden Perch (*Macquaria ambigua*) (Mallen-Cooper and Stuart 2003, King et al. 2009). Eggs and larvae undergo downstream drift (Tonkin et al. 2007), and hence drift is reliant on hydraulic conditions that facilitate entrainment (prevent propagules from sinking out of suspension). Recruitment in the lower River Murray is typically observed following both in-channel flow pulses (e.g. 15,000–45,000 ML/day) (Zampatti and Leigh 2013b) and overbank floods (Zampatti and Leigh 2013a). Whilst Murray Cod (*Maccullochella peelii*) spawn annually in association with photoperiod and temperature cues irrespective of flow, broad-scale recruitment of Murray Cod typically occurs following years of elevated flow (e.g. >20,000 ML/day) (Ye and Zampatti 2007, King et al. 2009). For flows of 30,000 ML/day, the greatest proportion of in-channel velocities within weir pools become fast flowing (≥0.3 m/sec) (Table 12), which is related to high hydraulic diversity, providing an increased likelihood of outcomes for flow dependent specialist native fish and annual spawning nesters. Large freshes/flows that inundate floodplains (i.e. overbank flows) trigger a pulse of productivity and promote the exchange of nutrients and carbon between rivers and their floodplains (Junk et. al. 1989; Baldwin and Mitchell 2000), which in turn promotes food and breeding opportunities for aquatic biota (Geddes and Puckridge 1989, Balcombe et. al. 2012, Beesley et. al. 2011).

Table 12: The percentage of weir pool that is equal to, or above, the specified velocity class (m/sec) for a range of within channel discharges (ML/day). Please note values relate to when weir pool water level is at normal pool level (NPL) and that modelled velocity responses for all discharge ranges were not available for all weir pools.

Weir pool	NPL (m AHD)	Flow (ML/day)	Percentage of weir pool that is equal to or above the specified velocity class					
			≥ 0.05 (slow)	≥0.10 (slow)	>0.20 (moderate)	>0.3 (fast)	>0.4 (fast)	>0.5 (very fast)
1	3.2	10,000	100	98	35	16	1	1
1	3.2	20,000	100	100	99	59	25	9
2	6.1	3,000	93	25	2	0	0	0
2	6.1	5,000	100	63	9	0	0	0
2	6.1	7,000	100	97	27	4	0	0
2	6.1	10,000	100	100	74	30	8	1
2	6.1	20,000	100	100	100	95	49	14
2	6.1	30,000	100	100	100	100	94	48
2	6.1	40,000	100	100	100	100	99	93
3	9.8	5,000	98	47	26	9	0	0
3	9.8	10,000	100	98	47	31	13	1
3	9.8	15,000	100	100	89	49	27	6
3	9.8	20,000	100	100	98	69	37	11
3	9.8	30,000	100	100	100	97	76	25
3	9.8	40,000	100	100	100	100	93	52
3	9.8	50,000	100	100	100	100	97	70
4	13.2	5,000	100	36	0	0	0	0
4	13.2	10,000	100	100	32	3	0	0
4	13.2	15,000	100	100	83	30	5	0
4	13.2	20,000	100	100	100	49	25	4
4	13.2	30,000	100	100	100	100	66	27
4	13.2	40,000	100	100	100	100	92	42
5	16.3	5,000	98	45	2	0	0	0
5	16.3	10,000	100	96	21	1	0	0
5	16.3	15,000	100	100	77	17	1	0
5	16.3	20,000	100	100	96	49	9	0
5	16.3	30,000	100	100	99	95	53	15
5	16.3	40,000	100	100	100	99	91	46
5	16.3	50,000	100	100	100	98	94	47

For most of the IC and FP EWRs the discharge metrics were revised to specify a target value. Envelope values were also considered to help characterise an acceptable variability in discharge (Appendix 5.1) but were not provided in the proposed revisions as they still require further refinement and consideration. EWRs that meet the target discharge value (or more) provide high certainty of achieving the anticipated ecological outcomes. Flows within the envelope range are likely to achieve the outcomes, but at a reduced certainty. Discharge values that are above the minimum critical threshold discharge value, but do not meet the envelope value, may meet the outcomes associated with that EWR, but certainty of the positive contributions is lower.

In the existing IC2 EWR the minimum and median value were the same (Table 4), as it was viewed that the minimum value was ideally the desired “target” flow, meaning that if the discharge/flow fell below the “median/minimum” value it would be scored as a fail and therefore no lower limits were prescribed. In this instance, it was more appropriate for this Channel EWR (i.e. IC2) to be modified to target a higher discharge/flow value (e.g. target ≥20,000 ML/day with a minimum range of 15,000 ML/day) to increase the confidence that ecosystem processes and benefits to aquatic biota are maximised.

Discussions during the workshop supported the importance of QSA ≥ 15,000 ML/day as a critical shift from primarily lentic (still water) to lotic (flowing water) habitat. These discussions highlighted that QSA ≥15,000 ML/day is the minimum flow requirement to achieve most of the IC ecological objectives outlined in Table 1. Flows less than <15,000 ML/day but above the upper range of Entitlement Flows (i.e. IC1 = 7,000 to 15,000 ML/day) were deemed to provide minimal ecological outcomes and were better described as risk management flows (e.g. to be called upon as specific watering actions to address risks such as thermal stratification and algal blooms). Support for this decision came from expert experience and opinion (provided at the workshop) as well as monitoring and research evidence from Long Term Intervention Monitoring (LTIM) in the lower River Murray Selected Area (Ye et al. 2019). The IC1 EWR (7,000 to 15,000 ML/day) has been revised and retained, but it does come with the caveat that flows of this magnitude are only likely to provide minimal ecological outcomes and in particular, minimal benefits for flow-dependent fish recruitment. However, these flows may still be called upon to support risk mitigation/management.

The existing list of Channel EWRs is extensive with sometimes relatively minor incremental changes in discharge. We therefore consolidated the flow bands of the existing channel EWRs to align better with the flow categories identified in the Basin Plan (Table 10), resulting in the consolidation of seven existing IC EWRs into four revised IC EWRs (Table 11).

For floodplain EWRs, the area of shedding floodplain inundated increases with increasing flow bands (Figure 2; Kilsby and Steggles 2015), hence the proportion of vegetation types and/or temporary wetlands associated with shedding floodplain areas also increases with increasing flow. The proportion (%) of vegetation types and temporary wetlands inundated on the South Australian River Murray Floodplain within increasing flow bands (QSA, ML/day) was calculated according to the classifications outlined in Table 13, and demonstrate the continuing improvements in lateral connectivity associated with increased discharge rates and area of inundation. Descriptions of dominant species/stratum within the vegetation type classifications are provided in Table 14.

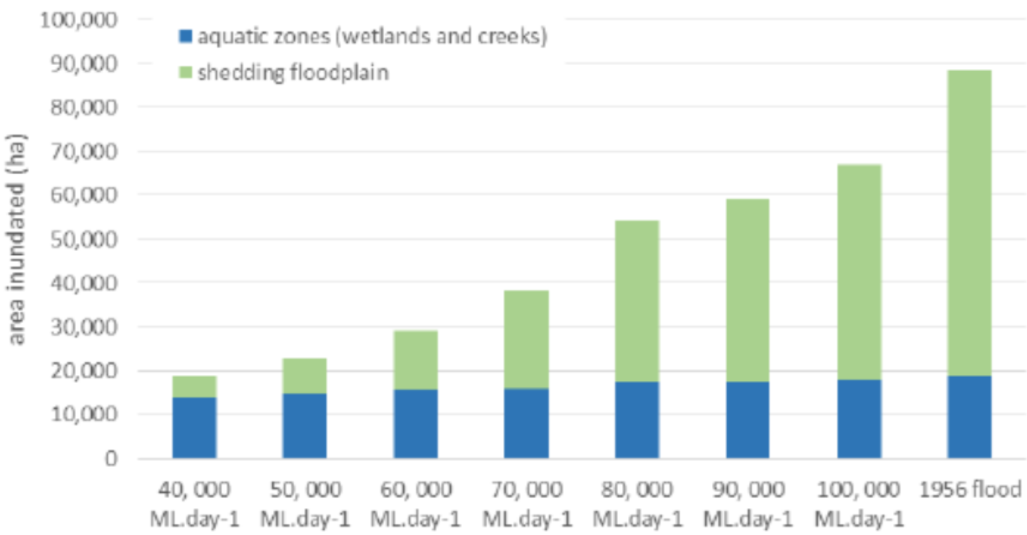

Figure 2: The area of aquatic zones (floodplain depressions, wetlands and creeks) and shedding floodplain inundated on the SARM by increasing discharges >40,000 ML/day. From Kilsby and Steggles (2015).

Table 13: Proportion (%) of vegetation and/or habitat types inundated on the South Australian River Murray Floodplain within increasing flow (QSA, GL/day). Best available data were provided from vegetation, temporary wetland and floodplain inundation spatial layers (i.e. provided by the DEW Environmental GIS team) and CSIRO FIM II model outputs for flows (20 to 100 GL/day).

Vegetation and/or Type Classifications	**Flow (QSA) (GL/day)**								
	20	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
River Red Gum woodland	8.4	9.7	11.0	20.7	30.1	44.9	62.0	69.1	76.5
Black Box woodland	1.0	1.1	1.5	3.2	5.5	12.6	27.0	38.2	45.7
Other woodland Forest	2.0	2.0	2.4	6.1	9.6	15.9	25.8	33.9	37.6
Lignum Shrubland	2.3	2.8	5.7	12.9	24.5	49.3	76.0	83.4	89.8
Other Shrubland	2.6	3.5	6.7	12.9	19.8	31.2	52.5	64.0	67.5
Forbland	0.3	0.3	0.5	4.3	6.2	15.6	26.3	33.3	34.7
Grassland	6.6	9.9	15.7	22.6	31.2	47.1	73.3	81.6	86.5
Sedgeland	47.7	49.5	56.2	65.4	71.0	78.0	83.7	84.3	86.1
Temporary wetlands	35.8	43.7	50.0	58.4	65.8	75.3	87.7	85.8	93.1

Table 14: Descriptions of dominant species/stratum within the vegetation type classifications. Plant names as provided by the DEW Environmental GIS team.

Vegetation Type Classification	**Dominant Species/Stratum**
Red Red Gum woodland	*Eucalyptus camaldulensis* var. *camaldulensis* (NC) woodland *Eucalyptus camaldulensis* var. *camaldulensis* (NC) forest *Eucalyptus camaldulensis* var. *camaldulensis* (NC) (mixed) woodland *Eucalyptus camaldulensis* var. *camaldulensis* (NC), *Acacia stenophylla* forest
Black Box woodland	*Eucalyptus largiflorens* woodland *Eucalyptus largiflorens*, *Acacia stenophylla* woodland
Other woodland	*Acacia stenophylla* woodland *Alectryon oleifolius* ssp. *canescens* woodland *Allocasuarina verticillata* woodland *Callitris gracilis* woodland *Eucalyptus brachycalyx* mallee woodland *Eucalyptus cyanophylla* mallee woodland *Eucalyptus dumosa* mallee forest *Eucalyptus gracilis* mallee woodland *Eucalyptus leptophylla* mallee woodland *Eucalyptus porosa*, *Acacia stenophylla* woodland *Eucalyptus viminalis* ssp. *cygnetensis* (mixed) woodland *Geijera linearifolia*,*Myoporum platycarpum* ssp. woodland *Melaleuca halmaturorum* forest *Melaleuca lanceolata* (mixed) forest *Melaleuca lanceolata* woodland *Myoporum platycarpum* ssp. woodland *Salix babylonica* (NC) forest
Lignum shrubland	*Duma florulenta* (mixed) shrubland >1m *Duma florulenta* shrubland >1m

Vegetation Type Classification	Dominant Species/Stratum
Other shrubland	*Atriplex lindleyi* ssp. *lindleyi* shrubland <1m *Atriplex rhagodioides* shrubland >1m *Atriplex stipitata* (mixed) shrubland <1m *Atriplex vesicaria* ssp. (mixed) shrubland <1m *Chenopodium nitrariaceum* shrubland >1m *Dodonaea viscosa* ssp. *angustissima* (mixed) shrubland >1m *Dodonaea viscosa* ssp. *angustissima* shrubland <1m *Dodonaea viscosa* ssp. *angustissima* shrubland >1m *Leucopogon parviflorus* (mixed) shrubland >1m *Lycium australe* (mixed) shrubland >1m *Maireana brevifolia* (mixed) shrubland <1m *Maireana pyramidata* (mixed) shrubland <1m *Maireana pyramidata* shrubland <1m *Maireana sedifolia* (mixed) shrubland >1m *Maireana sedifolia* shrubland <1m *Melaleuca brevifolia* shrubland >1m *Myoporum insulare* (mixed) shrubland >1m *Olearia axillaris* (mixed) shrubland >1m *Sarcocornia quinqueflora* (mixed) shrubland <1m *Sarcocornia quinqueflora* shrubland <1m *Sarcocornia* sp. (mixed) shrubland <1m *Sclerolaena tricuspis* shrubland <1m *Suaeda australis* shrubland <1m *Tecticornia arbuscula* shrubland <1m *Tecticornia halocnemoides* ssp. *halocnemoides* (mixed) shrubland <1m *Tecticornia halocnemoides* ssp. *halocnemoides*, *Tecticornia arbuscula* shrubland <1m *Tecticornia indica* ssp. *leiostachya* shrubland <1m *Tecticornia pergranulata* ssp. *pergranulata* (mixed) shrubland <1m *Tecticornia pergranulata* ssp. *pergranulata* shrubland <1m *Tecticornia* sp.,*Tecticornia* sp. shrubland <1m *Tecticornia triandra* shrubland <1m
Forbland	*Angianthus tomentosus* forbland *Disphyma crassifolium* ssp. *clavellatum* forbland *Polycalymma stuartii* forbland
Grassland	*Agrostis avenacea* var. *avenacea* (NC) grassland *Austrostipa stipoides* grassland *Enneapogon avenaceus* grassland *Eragrostis australasica*, *Duma florulenta* grassland *Lomandra effusa* (mixed) grassland *Phragmites australis* grassland *Phragmites australis*, *Typha domingensis* grassland *Spinifex sericeus* (NC) (mixed) grassland *Sporobolus virginicus* (mixed) grassland
Sedgeland	*Baumea juncea* sedgeland *Gahnia filum* (mixed) sedgeland

Vegetation Type Classification	**Dominant Species/Stratum**
	Gahnia filum sedgeland *Gahnia trifida* (mixed) sedgeland *Juncus kraussii* sedgeland *Typha domingensis* (mixed) sedgeland *Typha domingensis* sedgeland *Typha orientalis* sedgeland

3.2.3 Duration

The number of days a flow event remains at (or above) a specified discharge influences the extent of longitudinal and lateral connectivity created by the event. Long periods of high flow may promote productivity and access to feeding, breeding and nursery habitats (Bunn and Arthington 2002), although protracted inundation may cause waterlogging of soils and death of some floodplain/wetland vegetation types.

A key issue identified with the existing EWR duration metric was determining whether the anticipated ecological outcomes were achieved when the delivery of EWRs do not occur for the specified durations and/or there are rapid drops in flow peaks. In the existing IC and FP EWRs a single target duration value is specified (e.g. duration = 60 days; Table 4 and Table 5). Therefore, EWRs were only considered to have been met if continuous flow duration was equal (or above) that specified duration value. However, the EWR duration metrics recommended by Kilsby and Steggles (2015) list several key assumptions about durations that fall below the specified target values, which may still provide some ecological benefits/outcomes (Table 15). Therefore, the concept of envelope/sub-optimal values for the duration metric (Appendix 5.1) were considered to determine which outcomes may be achieved but with reduced certainty, however these values are not presented in the proposed revisions as they require further refinement and consideration.

Table 15: Important durations for key floodplain biota and processes (adapted from Kilsby and Steggles 2015)

Duration	Floodplain biota/processes
<30 days	Carbon, nutrient and propagules mobilization, transport and distribution.
30 days	Minimum requirements for River Red Gum and Black Box woodlands and Lignum shrublands for growth (assuming in current good condition), frog egg hatching, establishment and growth of amphibious/floodplain vegetation and circa annual and flow dependent fish spawning.
60 days	River Red Gum woodland, Black Box woodland, Lignum shrublands (longer durations preferable for condition improvement and maintenance), River Cooba woodlands.
≥90 days	Frog tadpole maturation.
≥120 days	Flows of greater magnitude are required to fill temporary wetlands. Some short-lived, ephemeral species will respond rapidly, but longer duration/retention times of temporary wetlands will allow for growth and development of vegetation, tadpoles and larval fish. Longer durations/retention times may also encourage breeding for some bird species (mainly some large wader and rallid species).

Flows of shorter durations will increase connectivity and may be sufficient to trigger faunal movement for the purposes of spawning, dispersal and foraging (Mallen-Cooper and Zampatti 2015b), but estimated time from spawning to full juvenile development for some native fishes ranges from 2 to 4 months (Cale 2009). King et al. (2003) suggested an optimum period of floodplain inundation would be several weeks to several months to cater for successful breeding of the fish species investigated, suggesting flows of longer duration provide greater certainty of meeting the ecological objectives to restore resilient populations of native fishes (Table 1 and Table 2).

Whilst there may be a preferred target duration which increases the confidence and certainty of achieving ecological outcomes, there is also an acceptable range of variability around this target value. Perhaps more importantly, there are likely to be critical thresholds that must be avoided to prevent detrimental effects. For example, some plant species may suffer from extended inundation, and therefore it may be desirable to specify a maximum duration, although it was felt that this is unlikely to be an issue in South Australia. More importantly, flow durations that are too short may mean that key outcomes, such as the completion of critical life history stages to ensure the viability of future generations (i.e. producing eggs or seed) are not met. A minimum flow duration of approximately 25 days was identified as the critical time required to ensure that microcrustaceans hatch out of the newly inundated sediments (i.e. emerge from inundated egg banks) and that the egg bank is replenished, thereby maintaining the abundance of microcrustacean diapause eggs within the egg bank for future inundation events (Deborah Furst, Adelaide University, *pers. comm*). A minimum duration of 25 days will ensure there is enough time for females to reach sexual maturity, to produce males for sexual reproduction, and for embryonic development following sexual reproduction, which will maintain the viability of the microcrustacean egg bank. Alternatively, a flow duration of 45 days will provide time for community succession to occur and a broader complement of zooplankton to produce an abundance of diapause eggs, improving the egg bank abundance and quality and therefore the potential response during future inundation events (Deborah Furst, Adelaide University, *pers. comm*). Identifying the critical thresholds of flow durations will make it easier to be more explicit about why ecological outcomes were either met, partially met or failed.

Durations provided for IC and FP EWRs are required flow pulse in-channel durations. Much of the floodplain topography in South Australia is characterised as shedding floodplain (Figure 2), therefore it is assumed there is minimal retention times (i.e. the length of time water is retained on floodplain topography) following inundation (i.e. outside the duration of the flow pulse). Retention times in floodplain wetlands are also difficult to verify as retention will depend upon a range of wetland specific factors such as volume/depth, wind and sun exposure, timing of filling and disconnection (i.e. seasonal evaporation) and wetland bed sediment types (i.e. infiltration rates). The distinction between flow pulse duration (i.e. duration of days above a specified discharge rate) and inundation retention time is an important consideration, particularly for biological responses on the floodplain that are strongly linked to long persistence (i.e. duration) of water such as tadpole metamorphosis and waterbird breeding (Table 15).

3.2.4 Timing

Seasonality influences temperature and day length, which in turn shapes fauna and flora life-history adaptations (Lytle and Poff, 2004), behavioural traits and metabolic (energetic) and endocrine (e.g. circadian rhythm) pathways (Bunn and Arthington, 2002). For instance, flow pulses (within channel or overbank) coinciding with warmer water temperatures are considered important in triggering spawning and facilitating dispersal of flow dependent fish specialists, such as golden and Silver Perch (Mallen-Cooper and Stuart 2003; Cheshire et. al. 2015; Zampatti et. al. 2015; Ellis et al. 2016). Temperature and day length effects biogeochemical rates, which also shape ecological patterns and processes in riverine ecosystems (Arthington et al. 2010; Lytle and Poff, 2004). For example, key biogeochemical processes are likely to be slowed if the water temperature is <15°C, whilst rising flows combined with appropriate, warmer temperatures and increased day length may cue reproduction (Bunn and Arthington, 2002). Peak abundance in zooplankton also frequently occurs between October and November in water temperatures between ~19–21 °C (Furst et al. 2017, 2018).

Review of eco-hydrological relationships and modelled natural hydrology (Appendix 5.1) highlight that there are target seasons and months that are ideal for maximising ecological outcomes. Peaks in flows may occur at times that were outside the preferred season, such as return flows from upstream watering actions or unregulated flow events. These discharge/flows that fall outside of ideal seasons and months, or anytime, may still provide benefits in mobilising and dispersing nutrients, in facilitating infiltration of surface water into the soil profile and replenishing low salinity lenses (LSL). Conversely, in certain circumstances, timing is considered critical (e.g. recruitment processes in flow dependent fishes). Therefore when evaluating EWRs, the target values represent meeting the ideal/optimal season and high likelihood of the full range of ecological outcomes, but ranges considered by envelope and/or sub-optimal values acknowledge that some outcomes may still be achieved (Appendix 5.1), although these values are still in development.

3.2.5 Frequency

The frequency of flows refers to the number of events of a given magnitude within a specified period. It is a function of flow magnitude and duration, with small flows typically having a relatively high return frequency. Events at different frequencies affect different biogeochemical and biological processes. Small to moderate events at high frequency are critical for maintaining connectivity, migration, dispersal, sediment and nutrient exchange and water quality. Less-frequent high flows may also reset ecological processes (Leigh et al. 2010). Extreme events (floods, droughts) are key processes driving mortality and recruitment (Lytle and Poff 2004).

The frequency of IC and FP EWRs has been reviewed to be expressed in three formats:

1. Number of flows per Average Return Interval (ARI),
2. Percentage (%) of years and
3. The number of flow years within a 10-year period.

These formats represent the same information; by providing all three formats we cater for differing preferences in format and ensure consistency in interpretation. Providing a range of frequencies (i.e. the number of flow years within a 10-year period) reflects factors such as the variability in population requirements, uncertainty in the knowledge base and variability in response during different climate scenarios (e.g. maintenance of populations during dry climate scenarios at the lower end of the range and population improvement and recovery during wet climate scenarios at the upper end of the range).

3.2.6 Critical maximum interval

When considering the maximum period between flows, experts were especially asked to consider the critical threshold value. Whilst the target frequency for flows (described above) essentially describes the target period between flows (i.e. that is within the tolerance of most biota), exceeding this target period between flows may trigger other risks, such as excessive build-up of organic matter. For example, a critical maximum interval of 5 years is significant for the build-up of standing leaf litter load (Wallace and Gibbs, *in prep*). The accumulation of organic matter may pose the risk of hypoxic blackwater events following inundation, particularly in river red gum dominated communities where litter fall rates are higher compared to litter fall rates in Black Box or mixed woodland types (Gibbs et al. 2020). At the lower elevations (FP1 to FP3: 45,000 to 65,000 ML/day), the critical maximum interval is also based on the water requirements of river red gums to avoid long term damage to their condition and/or viability. Therefore, for this metric it was important to identify a critical maximum interval between flows which may result in irreversible damage (e.g. death of long-lived vegetation) and a significant decline in FP PEA condition.

The two metrics (frequency and critical maximum interval) must be considered together when evaluating outcomes or managing systems. Achieving ecological objectives requires a sequenced pattern of events over time that achieves the average frequency and does not exceed the critical maximum intervals. Clustering of events over successive years can occur in response to climate patterns and may be important/desirable for the recovery and recruitment of native fish, vegetation and waterbird populations. However, extended dry periods between clustered events can be detrimental. Likewise, if the target frequencies are consistently not met, then the current ecological condition may not be sustainable.

3.2.7 Maximum rates of rise and fall

The rate of water level change (both the rising and falling limb of a hydrograph), is important for a variety of biota and processes (Thoms and Sheldon 2000). Existing conceptual models (Wallace et al. 2016) highlight that established stands of low-growing and emergent amphibious macrophytes may be vulnerable to rapid increases in water depth if they cannot maintain sufficient rates of photosynthesis and gas exchange to tolerate extended inundation (Siebentritt and Ganf 2000). In addition, full submergence (i.e. top flooding) can have drastic effects on some littoral plants like river clubrush (*Bolboschoenu*s spp.) or establishing seedlings. Drawdown rates of 1–3 cm/day have the most benefit for amphibious and floodplain plant communities (Nicol 2004) because many species only germinate as water levels recede, leaving areas with high soil moisture (Nicol 2004). Slower rates of recession also benefit breeding waterbirds (Rogers and Paton 2008), minimise bank slumping (Gippel et al. 2008) and minimise the risk of stranding fish in connected wetlands (Mallen-Cooper et al. 2008). Rapid rates of recession may induce saline inflows and potentially reduce the dilution capacity of the river when they occur (Telfer et al. 2012). Expert input from the workshop suggested that target and critical maximum rates of rise and fall be added as metrics to both the IC and FP EWR tables.

Critical maximum rates of rise and fall when flows are within channel (i.e. ≤45,000 ML/day) are:

- Maximum rate of rise - three-day average value of 0.075 m/day or 715 ML/day
- Maximum rate of fall - three-day average value of 0.05 m/day or 465 ML/day

Critical maximum rates of rise and fall when flows are outside of channel (i.e. >45,000 ML/day)

- Maximum rate of rise AND fall – three-day average value of 0.1 m/day or 930 ML/day

A preliminary assessment of rates of water level change relative to discharge under existing conditions was undertaken using data from the stations on the downstream side of the lock and weir structures 5 to 1 for the period 1994–2018 (data provided by Matt Gibbs, DEW). The assessment was based on NPL on the downstream side of weirs 5 to 1 being 13.2, 9.8, 6.1, 3.2 and 0.75 m AHD respectively (Figure 3, model data and analysis provided by Matt Gibbs, DEW). Noting that the assessment was preliminary, a linear fit to the respective data ($y= y0+a*x$) indicates that the rate of change downstream of the respective weirs is:

- Lock 5: 59 mm per 1,000 ML
- Lock 4: 94 mm per 1,000 ML
- Lock 3: 76 mm per 1,000 ML
- Lock 2: 93 mm per 1,000 ML
- Lock 1: 57 mm per 1,000 ML

The differences in the rate of change in water level is attributed to the different length and geomorphology of the weir pools (e.g. the distance from Lock 4 to Lock 5 is 46 km, distance from Lock 3 to 4 is 85 km).

An analysis of modelled natural data (QSA, 1900–2009) was undertaken to identify rates of change in discharge (Q; ML/day) and then estimate a natural rate of water level change (m). For each event during the model run period where Q >45,000 ML/day, a line of best fit was applied to both the rising and falling limb (Figure 3, model data and analysis provided by Matt Gibbs, DEW). If the linear fit to the period of change in water level was poor (i.e. r^2 <0.8) then those rates of rise and fall were excluded from further analysis. The average, median and 75th percentile values were subsequently calculated (Table 16).

Table 16: Average, median and 75th percentile rates of rise and fall where discharge (Q) >45,000 ML/day

Rate of rise		
Average	960	ML/day
Median	834	ML/day
75% percentile	1366	ML/day

Rate of fall		
Average	-2029	ML/day
Median	-1730	ML/day
75% percentile	-1029	ML/day

The results highlight that rates of rise and fall are highly variable and may be particularly rapid when flows are outside of the river channel. However, the 75th percentiles show that rates of rise were typically <1,400 ML/day, and rates of fall were typically <1,100 ML/day.

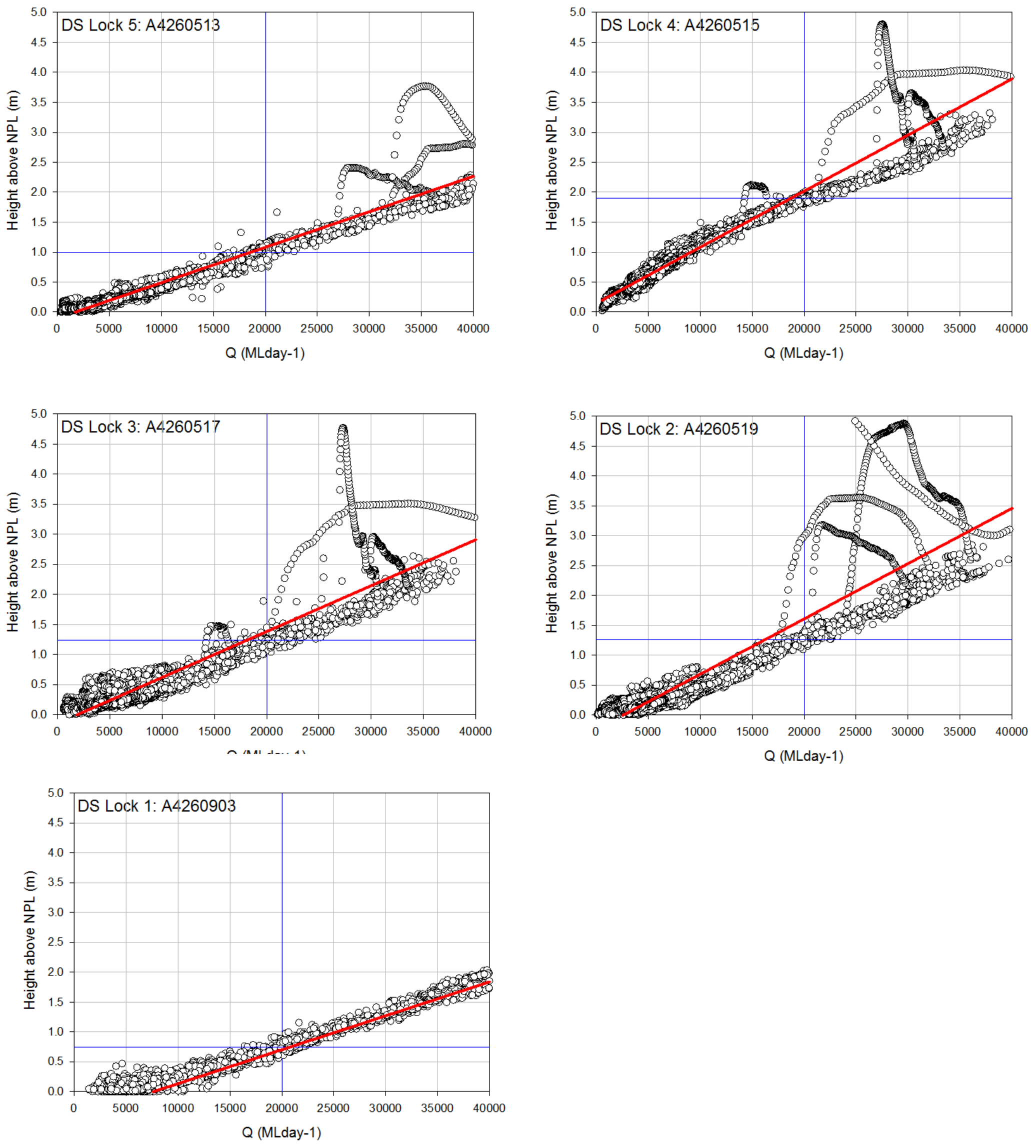

Figure 3: Relationship between downstream water level (m AHD) and discharge at the respective weir for Lock and Weir 5–1. Data from (1994–2018). Water level was determined as height (m AHD) above normal pool level (NPL).

Based on this analysis, and the rate of change in water level relative to discharge (Q) calculated for Locks 1–5 (see preceding paragraph), the values outlined in Table 17 were used to develop the hypothetical representations of IC and FP EWR hydrographs to be used in the alignment modelling (Appendix 5.2).

Table 17: Calculated maximum rates of water level (m) change (i.e. rates of rise and fall) relative to changes in discharge (Q) when discharge was within channel (<45,000 ML/day) and/or outside of channel (>45,000 ML/day)

Rate of change	Max rate of (rise for all events)	Max rate of fall when flows are within channel (<45,000 ML/day)	Max rate of fall when flows are overbank (>45,000 ML/day)
m/day	0.075	0.05	0.10
ML/day	715	-465	-930

3.3 Proposed revisions to IC and FP EWRs

In view of the considerations outlined above, the proposed revisions for the EWRs are presented for IC (Table 18) and FP (Table 19) PEAs. The tables show the target values for the individual EWR metrics. These target values represent the hydrological conditions required to give the greatest certainty of achieving ecological outcomes along the SA River Murray.

The Entitlement Flow EWR has been included (Table 18). Under the terms of the *Murray–Darling Basin Agreement 2008,* South Australia is entitled to a maximum of 1850 GL/yr. The fixed monthly Dilution and Loss Entitlement (58 GL per month), combined with the variable monthly 'consumptive' Entitlement, provides lower flow volumes (3,000 ML/day) in the cooler months and peak flow volumes of 7,000 ML/day in the warmer months when consumptive demand is greater. Entitlement Flow is effectively a very low baseflow (see Table 10) and is primarily provided to meet 'consumptive' requirements rather than achieve ecological outcomes (see Table 1). However, Entitlement Flow can support ecological objectives such as avoiding the critical loss of foraging generalist fish species and maintaining key refuges during severe, unnaturally prolonged dry periods (Wallace et al. 2014a).

Table 18: Revised South Australian In-channel (IC) Environmental Watering Requirements (EWRs) showing the specified target values for individual metrics.

EWR #	EWR metrics						
	Target discharge (ML/day QSA)	**Duration (days)**	**Timing (months)**	**Frequency* (# flows-per-ARI; [% of years]; {#yr in 10-yr})**	**Critical Maximum Interval^ (years)**	**Rate of water level rise# (m/day or [ML/day])**	**Rate of water level fall (m/day or [ML/day])**
EF^^	≥3,000	365	All year	1-in-1 [100%] {10 yr in 10}	0	N/A	N/A
IC1	≥10,000	≥60	Sep–Mar	1-in-1.05 [95%] {9–10 yr in 10}	2	0.05 [465]	0.025 [232.50]
IC2	≥20,000	≥60	Oct–Dec	1-in-1.33 [75%] {6–7 yr in 10}	3	0.05 [465]	0.025 [232.50]
IC3	≥30,000	≥60	Oct–Dec	1-in-1.54 [65%] {5–6 yr in 10}	4	0.05 [465]	0.025 [232.50]
IC4	≥40,000	≥60	Oct–Dec	1-in-2.22 [45%] {4–5 yr in 10}	5	0.05 [465]	0.025 [232.50]

*Frequency is expressed as: 1) number of flows per Average Return Interval (ARI), 2) percentage of years and 3) the number of years that the EWR should occur within a 10-yr period.
^represents the critical maximum interval (years) between EWRs before a significant decline in IC condition is likely to occur. This period should not be exceeded wherever possible.
#rate of rise and fall presented as m/day or ML/day
^^EF = Entitlement Flow

Table 19: Revised South Australian Floodplain (FP) Environmental Watering Requirements (EWRs) showing the specified target values for individual metrics.

EWR #	EWR metrics						
	Target discharge (ML/day QSA)	**Duration (days)**	**Timing (months)**	**Frequency* (# flows-per-ARI; [% of years]; {#yr in 10-yr})**	**Critical Maximum Interval^ (years)**	**Rate of water level rise# (m/day or [ML/day])**	**Rate of water level fall (m/day or [ML/day])**
FP1	≥50,000	≥40	Sep–Dec	1-in-1.67 [60%] {5–7 yr in 10}	4	0.05 [465]	0.025 [232.50]
FP2	≥60,000	≥20	Sep–Dec	1-in-2.25 [45%] {4–5 yr in 10}	5	0.05 [465]	0.025 [232.50]
FP3	≥70,000	≥20	Sep–Dec	1-in-2.86 [35%] {3–4 yr in 10}	5	0.05 [465]	0.025 [232.50]
FP4	≥80,000	≥10	Sep–Dec	1-in-4.0 [25%] {2–3 yr in 10}	5	0.05 [465]	0.025 [232.50]
FP5	≥80,000	≥30	Sep–Dec	1-in-6.67 [15%] {1–2 yr in 10}	8.5	0.05 [465]	0.025 [232.50]

*Frequency is expressed as: 1) number of flows per Average Return Interval (ARI), 2) percentage of years and 3) the number of years that the EWR should occur within a 10-yr period.
^represents the critical maximum interval (years) between EWRs before a significant decline in FP condition is likely to occur. This period should not be exceeded wherever possible.
#rate of rise and fall presented as m/day or ML/day.

3.3.1 Summary of key revisions to IC EWRs

Key changes to the IC EWRs include that they were consolidated to remove confusing overlap in discharge variability, resulting in four revised IC EWRs (Table 18 and Table 19). The flow bands identified for each IC EWR were designed to capture the increasing in-channel hydrodynamic and hydraulic complexity that occurs with increasing discharge (Table 11 and Table 12). The specified target discharge values for all IC EWRs represent the discharge that provides the greatest certainty of achieving the respective ecological outcomes.

Duration metrics for some IC EWRs were shortened to ensure that the duration of flows for each IC EWR scenario did not exceed what may have occurred under natural modelled conditions when the combined constraints of all the individual, equally weighted target metric values (such as discharge, timing, return frequency and critical maximum interval) were applied during analysis (Appendix 5.1). In general there was a consensus reached amongst experts that ≥60 days was sufficient to meet most of the ecological targets ascribed to each IC EWR, with the acknowledgement that longer durations are likely to increase the certainty of maximising ecological outcomes and should be sought wherever possible. In addition, there is a need to test whether flow durations must be maintained continuously, or whether there is a permissible number of gap days (i.e. number of consecutive days discharge can fall below the relevant target value specified for the discharge metric).

The target timing for in-channel pulses was shortened to capture the importance of flow pulses that coincide with warmer water temperatures and maximise ecological objectives/ targets for biota and ecosystem functions (e.g. for Golden Perch spawning and larval recruitment).

For consistency across the EWRs across all three PEAs, frequency is expressed as: 1) number of flows per Average Return Interval (ARI), 2) percentage of years and 3) the number of years that the EWR should occur within a 10-yr period. With the consolidation of the IC EWRs, the target frequencies were revised to ensure they were within the bounds of natural modelled conditions (i.e. +/-10% of 'without development') for the relevant target discharge. An emphasis on the combination of discharge × duration was also used to help determine frequency. For example, if a shorter target duration was specified, then this may occur at a greater frequency (or vice versa).

The critical maximum interval between events were also revised. Ideally flow returns follow the desired period specified by the target frequency (e.g. IC1 EWR frequency is 1-in-1.05 or 95% of years,), but the critical maximum interval describes the maximum number of years between events (e.g. IC1 critical maximum dry spell is 2 years) before decline and potentially irreversible damage to IC PEA condition may occur.

Specified target values for rates of rise (e.g. 0.05 m/day) and fall (e.g. 0.025 m/day) were included for all IC EWRs. Specified target values for rates of rise (e.g. 465 ML/day) and fall (e.g. 232.50 M/day) in discharge units were also outlined, which will assist with the evaluation process (Table 17). It is anticipated that these rates would be calculated as a rolling average over three days. For many biota and ecosystem processes, the rate of rise and fall of water level influences the ecological response; for example, a rapid fall may cause desiccation of fish eggs and frog spawn, and may cause waterbirds to abandon their nests (Kilsby and Steggles 2015). A rapid drop in water level can also lead to bank failure.

3.3.1.1 IC1 EWR revisions/explanations

For the revised IC1 EWR, the target discharge QSA ≥10,000 ML/day is for ≥60 days, between Sep–Mar, in 95% of years with a critical maximum interval of 2 years (Table 18). Summary of the key revisions include:

- The flow band was expanded to 7–15,000 ML/day (previously 7–12,000 ML/day). The target value for the discharge metric is QSA ≥10,000 ML/day, which is the discharge that provides the greatest certainty that mean cross-sectional velocity in most, if not all, weir pools are within the slow flowing range (≥0.05 m/sec) or higher (see Table 12),
- Target value for the duration metric remains unchanged at ≥60 days,
- Target value for the timing metric remains unchanged (Sep–Mar), although it should be noted that one of the key ecological targets that an IC1 EWR can contribute to is minimising the likelihood of thermal stratification, which is more likely to happen in summer months (Dec–Feb). It is therefore recommended that where possible flows are delivered within the summer timing window,
- Target value for the frequency metric also remains unchanged at 95% of years,
- A critical maximum interval of 2 years remains unchanged,
- Target values for a rate of rise metric (0.05 m/day or 465 ML/day) and a rate of fall metric (0.025 m/day or 232.5 ML/day) were included for all IC EWRs.

3.3.1.2 IC2 EWR Revision/explanations

For the revised IC2 EWR, the target discharge QSA ≥20,000 ML/day is for ≥60 days, between Oct–Dec, in 75% of years with a critical maximum interval of 3 years (Table 18). Summary of the key revisions include:

- In the existing IC2 EWRs the minimum and median value for discharge were the same, which caused some confusion. The existing IC2 and IC3 have been consolidated so that the discharge variability between the two EWRs no longer overlaps,
- The minimum discharge for the existing IC2 EWR flow band (15–20,000 ML/day) did not align with the maximum discharge for the existing IC1 EWR (previously 7–12,000 ML/day), meaning flows that had a discharge >12,000 ML/day, but <15,000 ML/day did not fall into any EWR category, and therefore this omission has been corrected,
- Discharge QSA = 15,000 ML/day represents the tipping point where there is a shift from primarily lentic (still to slow water) to lotic (moderate-fast flowing water) habitat within weir pools (Wallace et al. 2014a; Ye et al. 2019). However, a discharge of QSA of ≥20,000 ML/day provides the greatest certainty that mean cross-sectional velocity in most, if not all, of the weir pools are within the moderate-fast flowing range (i.e. ≥0.2 m/sec) or higher (see Table 12),
- Flows with discharge ≥20,000 ML/day may be conductive to spawning and recruitment of flow dependent specialists, such as Golden Perch and Silver Perch (Ye et al. 2019). For instance, when temperature thresholds (≥20°C, i.e. spring to early summer) are met, flows of this magnitude may be expected to facilitate drift of larvae from upstream areas and potentially elicit a local spawning response (Gibbs et al. 2019). The target value for the discharge metric of the revised IC2 EWR is therefore QSA ≥20,000 ML/day,
- With consolidation of the existing IC2 and IC3 EWRs, the target value for the duration metric of revised IC2 was reduced to ≥60 days to be more consistent with the other revised IC EWRs,
- Target values for the timing metric have been modified to Oct–Dec when in-channel temperatures are likely to provide the greatest certainty of achieving many of the associated in-channel ecological outcomes,
- Target value for the frequency metric remain unchanged, with a target frequency of 75% of years,
- Critical maximum interval increased from 2 to 3 years,
- Target values for a rate of rise metric (0.05 m/day or 465 ML/day) and a rate of fall metric (0.025 m/day or 232.5 ML/day) were included for all IC EWRs.

3.3.1.3 IC3 EWR Revisions/explanations

For the revised IC3 EWR, the target discharge QSA ≥30,000 ML/day is for ≥60 days, between Oct–Dec, in 65% of years with a critical maximum interval of 4 years (Table 18). Summary of the key revisions include:

- The existing IC4 and IC5 EWRs were consolidated so that discharge variability did not overlap. The revised target discharge of QSA of ≥30,000 ML/day represents a tipping point where there is the greatest certainty that mean cross sectional velocity in most, if not all, weir pools would be fast-flowing (≥0.3 m/sec) or higher (see Table 12),

- Flows with discharge ≥30,000 ML/day also represent a tipping point where there is a marked increase in the riparian, off-channel and temporary wetland areas inundated, which corresponds with a marked increase in carbon and nutrients in the water column (Wallace et al. 2014a). Phytoplankton communities are more likely to be dominated by diatoms (Wallace et al. 2014a), which are nutritionally more valuable basal food resource than filamentous algae and cyanobacteria.
- Flows with discharge ≥30,000 ML/day are also considered to provide greater certainty of spawning and recruitment of flow dependent specialists, especially when temperature thresholds (≥20°C, i.e. spring to early summer) are met (Gibbs et al. 2020). The target value for the discharge metric for the revised IC3 EWR is therefore QSA ≥30,000 ML/day.
- With consolidation of the existing IC4 and IC5 EWRs, the target value of ≥60 days for the duration metric of the revised IC3 EWR remains unchanged,
- Target value for the timing metric of the revised IC3 EWR has been more modified to Oct–Dec when in-channel temperatures are likely to provide the greatest certainty of achieving many of the associated in-channel ecological outcomes,
- With the consolidation of the existing IC4 and IC4 EWRs the target frequency of the revised IC3 EWR has been reduced slightly to 65% of years,
- Critical maximum interval has increased from 2 to 4 years,
- Target values for a rate of rise metric (0.05 m/day or 465 ML/day) and a rate of fall metric (0.025 m/day or 232.5 ML/day) were included for all IC EWRs.

3.3.1.4 IC4 EWR Revisions/explanations

For the revised IC4 EWR, the target discharge QSA ≥40,000 ML/day is for ≥60 days, between Oct–Dec, in 45% of years with a critical maximum interval of 5 years (Table 18). Summary of the key revisions include:

- The IC6 and IC7 EWRs were consolidated so that discharge variability did not overlap. The target discharge QSA of ≥40,000 ML/day, represents the tipping point where there is greatest certainty that in-channel flows within most, if not all, weir pools are fast to very fast flowing (≥0.4 m/sec) (see Table 12).
- Flows with discharge ≥40,000 ML/day also represent a tipping point where there is a marked increase in the load of dissolved organic carbon (DOC) increase. Heterotrophic activity will become increasingly important in net ecosystem productivity. Whilst flows of >35,000 ML/day are considered conducive to spawning and recruitment of flow dependent specialists (Golden Perch and Silver Perch) and for promoting the recruitment of Murray Cod, the survival of individuals may improve with flows with discharge >40,000 ML/day (Wallace et al. 2014a). Strong age classes of Murray cod have been associated with years of flows with discharge >40,000 ML/day and flows of this magnitude may also stimulate upstream migration of reproductively mature fish (Wallace et al. 2014a). The target value for the discharge metric of the revised IC4 EWR is therefore QSA ≥40,000 ML/day.

- With consolidation of the existing IC6 and IC7 EWRs, the target value of the duration metric was reduced to ≥60 days,
- Target value for the timing metric has been more clearly specified as Oct–Dec, when in-channel temperatures are likely to provide the greatest certainty of achieving many of the associated in-channel ecological outcomes,
- With consolidation of the existing IC6 and IC7 EWRs, the target frequency is 45% of years,
- Critical maximum interval has increased from 3 to 5 years,
- Target values for a rate of rise metric (0.05 m/day or 465 ML/day) and a rate of fall metric (0.025 m/day or 232.5 ML/day) were included for all IC EWRs.

3.3.2 Summary of key revisions to FP EWRs

The existing discharge variabilities/ flow bands were used to retain the five FP EWRs (Table 19). The flow bands identified for FP 1–4 represent increasing lateral connectivity up to the maximum area that floodplain inundations can occur on the managed floodplain, with the managed floodplain being consistent with the definition used in the Basin-Wide Environmental Watering Strategy (i.e. 85,000 ML/day) (MDBA 2014).

The specified target value for the discharge metric for FP EWRs provides the greatest certainty of achieving anticipated ecological outcomes. For the FP5 EWR, the target value for the FP5 EWR discharge metric is equivalent to FP4, but the focus for FP5 is on extending the target value of the duration metric to maximise floodplain vegetation and productivity outcomes. In other words, FP4 has the same target value as the FP5 discharge metric, but occurs for shorter duration, with a greater frequency.

The target values for the duration metric of most FP EWRs were shortened, except for FP1 where the target value was extended. FP5 is retained with a longer duration than FP4, but the EWR has a lower frequency and greater critical maximum interval. Target duration metrics for the revised FP EWR scenarios were analysed to ensure they did not exceed what may have occurred under natural modelled conditions when the combined constraints of all the individual, equally weighted target metric values (e.g. discharge, timing, return frequency and critical maximum interval) were applied (Appendix 5.1).

The target values for the timing metric for the FP EWRs were retained in line with peak timing windows observed under natural modelled conditions (i.e. 'without development') (Appendix 5.1). Floodplain inundating flows tended to peak in September. The FP EWRs timing (Sep–Dec) is also consistent with the preferred timing for Lake Alexandrina barrage outflows to the Coorong (Lester et al. 2011 b; MDBA 2014a).

In some instances, target values for the frequency metrics of the FP EWRs were revised to ensure they did not exceed natural modelled conditions for the relevant target discharge. For any given target frequency value that was investigated, there was a pattern of decreasing flow duration with increasing discharge. For example, if a higher flow frequency was specified, then the trade-off may be that this occurs at a shorter flow duration (or vice versa).

The critical maximum intervals between flow events were also revised. Ideally flow return intervals follow the desired target values specified in the frequency metrics (e.g. FP1 EWR target frequency is 1-in-1.67 years) (Table 19) but the critical maximum interval describes the maximum number of years between events (e.g. i.e. FP1 critical maximum interval is 5 years) (Table 19) before a significant decline and potentially irreversible damage to FP condition is likely to occur. For the lower elevations (FP1 to FP3), the critical maximum interval is based on the water requirements of River Red Gums, which have the most demanding maximum interval requirements of 5 years. It was also identified in the workshop that a period of 5 years is a critical maximum interval for the build-up of standing leaf litter load (Wallace and Gibbs, *in prep*). The accumulation of organic matter may pose the risk of hypoxic blackwater events following inundation, particularly in River Red Gum dominated communities where litter fall rates are higher compared to litter fall rates in Black Box or mixed woodland types (Gibbs et al. 2020). For the higher elevations (FP4 and FP5) there was a trade-off between the shorter flow duration for FP4, with the critical maximum interval of 5 years, reflecting the requirements of River Red Gums, which are still present at this elevation. However, for FP5, a longer flow duration is prescribed, but with a critical maximum interval of 8 years. Whilst this is nearing the upper limit for most key plant species, it is assumed that vegetation will persist in sub-optimal conditions due to more frequent short-duration events, and that infrequent longer duration events will improve conditions and promote recruitment (Kilsby and Steggles 2015).

Specified target values for the rates of rise metric (0.05 m/day) and rates of fall metric (0.025 m/day) were retained for all FP EWRs. Specified target values for rates of rise (465 ML/day) and rates of fall (232.50 ML/day) as a measure of discharge, were also outlined. It is anticipated that these rates of rise and fall in discharge units (ML/day) would be calculated as a rolling average every three days. For many biota and ecosystem functions, the rate of rise and fall of water level influences the ecological response. For example, a rapid fall may cause desiccation of fish eggs and frog spawn, and may cause waterbirds to abandon their nests (Kilsby and Steggles 2015). A fast drop in water level can also lead to soil bank failure.

3.3.2.1 FP1 EWR Revisions/explanations

For the revised FP1 EWR, the target discharge QSA ≥50,000 ML/day is for ≥40 days, between Sep–Dec, in 60% of years with a critical maximum interval of 4 years (Table 19). Summary of the key revisions include:

- Target value for discharge metric remains unchanged,
- Target value for the duration metric was increased slightly from 30 days to ≥40 days,
- Target value for the timing metric has been retained (Sep–Dec),
- Target value for the frequency metric was increased slightly from an ARI of 1.6 to an ARI = 1.66 but falls within the range of 5–7 flows within a 10-year period,
- A critical maximum interval decreased from 5 years to 4 years,
- Target values for the maximum rates of rise/fall remain unchanged.

3.3.2.2 FP2 EWR Revisions/explanations

For the revised FP2 EWR, the target discharge QSA ≥60,000 ML/day is for ≥20 days, between Sep–Dec, in 45% of years with a critical maximum interval of 4 years (Table 19). Summary of the key revisions include:

- Target value for the discharge metric remains unchanged,
- Target value for the duration metric was reduced from 30 days to ≥20 days,
- Target value for the timing metric has been retained (Sep–Dec),
- Target value of the frequency metric was increased slightly from an ARI = 2.6 to an ARI = 2.85 but falls within the range of 3–4 flows within a 10-year period,
- A critical maximum interval of 5 years remains unchanged,
- Target values for the maximum rates of rise/fall remain unchanged.

3.3.2.3 FP3 EWR Revisions/explanations

For the revised FP3 EWR, the target discharge QSA ≥70,000 ML/day is for ≥20 days, between Sep–Dec, in 35% of years with a critical maximum interval of 5 years (Table 19). Summary of the key revisions include:

- Target value for the discharge metric remains unchanged,
- Target value for the duration metric was reduced from 30 days to ≥20 days,
- Target value for the timing metric has been retained (Sep–Dec),
- Target value for the frequency metric was increased slightly from an ARI = 2.6 to an ARI = 2.85 but falls within the range of 3–4 flows within a 10-year period,
- A critical maximum interval of 5 years remains unchanged,
- Target values for the maximum rates of rise/fall remain unchanged.

3.3.2.4 FP4 EWR Revisions/explanations

For the revised FP4 EWR, the target discharge QSA ≥80,000 ML/day is for ≥10 days, between Sep–Dec, in 25% of years with a critical maximum interval of 5 years (Table 19). Summary of the key revisions include:

- Target value for the discharge metric remains unchanged,
- Target value for the duration metric was reduced from 30 days to ≥10 days,
- Target value for the timing metric has been retained (Sep–Dec),
- Target value for the frequency metric was increased slightly from an ARI = 3.6 to an ARI = 4 but falls within the range of 2–3 flows within a 10-yr period,
- A critical maximum interval of 5 years remains unchanged,
- Target values for the maximum rates of rise/fall remain unchanged.

3.3.2.5 FP5 EWR Revisions/explanations

For the revised FP5 EWR, the target discharge QSA ≥80,000 ML/day is for ≥30 days, between Sep–Dec, in 15% of years with a critical maximum interval of 8.5 years (Table 19). Summary of the key revisions include:

- Target value for the discharge metric remains unchanged,
- Target value for the duration metric was reduced from 60 days to ≥30 days,
- Target value for the timing metric has been retained (Sep–Dec),
- Target value for the frequency metric was decreased from an ARI of 7.6 to 6.67 but falls within range of 1–2 flows within 10-year period.
- A critical maximum interval for the revised FP5 EWR increased slightly from 8 to 8.5 years,
- Target values for the maximum rates of rise/fall remain unchanged.

3.4 Modelled hydrology

Analysis of natural modelled and observed hydrology (Appendix 5.1) showed that flows analogous to the revised target EWR scenarios were achievable under natural modelled conditions (Appendix 5.1). This contrasts with the pre-development period (1977–1995) where flows analogous to the proposed envelope and sub-optimal EWR scenarios were met, but the proposed target EWR scenarios were not met (Appendix 5.1). Similarly, flows analogous to the revised target, envelope and sub-optimal EWR scenarios were not met during the post-development conditions (1996–2017). Analysis results also highlight that for many of the proposed EWR scenarios analysed, the likelihood of multiple EWR scenarios occurring within a year was also possible under natural modelled conditions (Appendix 5.1).

3.5 Application of CLLMM EWRs

Feedback on the practical application of the existing CLLMM EWRs (Table 6) highlighted a range of issues, such as the inter-relationships between CLLMM components (e.g. barrage outflows, Lakes and CSL levels), the narrow bands of optimal duration and/or water levels (e.g. CSL levels maintained within a narrow 20 cm range continuously for ≥90 days), and the perceived inability to influence certain metrics under particular discharge volumes. As they are currently described, the CLLMM EWRs represent key hydrological drivers for the asset, but they are very complex and with improved understanding of the system, some of the metrics may be revised to assist in the interpretation and evaluation of EWRs. Further examples of key issues that were identified through the consultation, preliminary review/analysis of existing EWRs and the expert elicitation process for the CLLMM EWRs are presented in Section 3.6. The final proposed revisions to the CLLMM EWRs are provided in Section 3.7.

3.6 Summary of considerations of existing IC and FP EWRs

3.6.1 Annual Barrage flow volumes

Barrage outflows are a key driver for managing salinity levels in Lake Alexandrina (Heneker 2010). Total annual barrage outflow volumes have historically varied considerably from year to year. Under unregulated conditions approximately 50% of annual barrage flows (~ 10,750 GL/yr) in the Murray–

Darling Basin reached the sea (and passed through the Coorong) and <1% of days were associated with zero flow (Kingsford et al. 2011). Modelled barrage outflows (from 1891 to 2006), demonstrate the barrage outflow volumes were highly variable, with outflow volumes ranging from 200 GL (2006/07) to 45,000 GL (1956/57) (Figure 4) but also an indication that there were years of zero barrage outflows (0 GL) during the Millennium Drought. Heneker (2010), considered the influence of high variability in inter-annual inflows and barrage outflows and showed that high inflows (and consequently high outflows) lowered salinity in Lake Alexandrina, but salinity levels in Lake Alexandrina rise quickly following years with low or no outflows. This occurs because Lake Alexandrina is primarily controlled by lake inflows and outflows through the barrages. The reduction in lake salinity that occurs during high flow years is subsequently overcome by input and evapo-concentration of salt that occurs within one or two years of low inflow and outflow conditions.

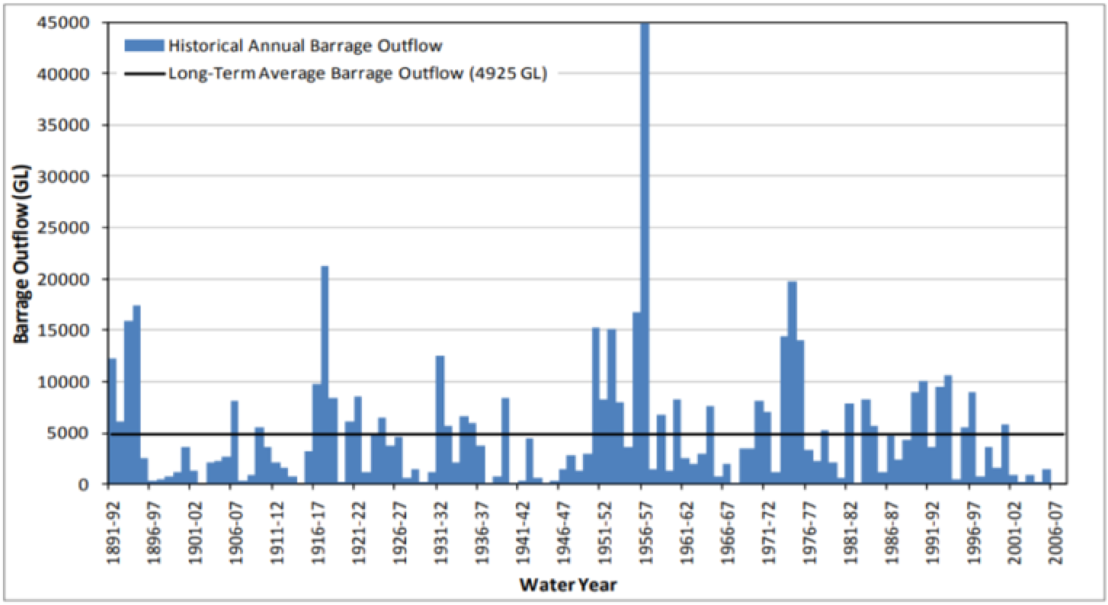

Figure 4: Annual variability in total annual barrage outflows (figure from Heneker 2010)

O'Conner et al. (2015) described desirable annual barrage outflow volumes to achieve salinity targets for Lake Alexandrina (Table 3), which are a key outcome for CLLMM 1 and 2. There is a marked increase in salinity as annual barrage outflow volumes fall below 2000 GL and three-year cumulative outflows fall below 6000 GL (Heneker 2010). The system must be managed to include a multi-year sequence of flows (e.g. one, two and three-year inflow sequences) to manage salinity within the Lower Lakes (O'Connor et al. 2015). There is a marked increase in salinity as annual barrage outflow volumes fall below 2000 GL and three-year cumulative outflows fall below 6000 GL (Heneker 2010). This presents challenges when evaluating whether EWRs have been met on an annual basis and highlights the need for annual evaluation to consider barrage outflows in preceding years.

Total modelled monthly barrage volumes from 1970 to 1999 (Figure 5 to Figure 7) highlight periods of successive months where no barrage outflows occur. These periods may influence fishway function, where as a guide barrage outflows ≥5.1 GL/month are specified as the minimum requirement to maintain fishways. However, management of the Lower Lakes water levels above the critical minimum threshold of ≥0.4 m AHD will also provide opportunities to discharge the Lower

Lakes water to maintain fishway operations. Minimum annual barrage outflows of approximately 500 GL/yr (variable as depends on timing and tides) are required to prevent salt incursion while total annual barrage flow volumes of 730 GL/yr (or 2000 ML/day) are required to maintain the existing level of openness at the mouth (Gibbs et al. 2017). For CLLMM 1, there is to be outflows of no less than 650 GL in a single year and no less than 6,000 GL over three years. Therefore, the target average annual barrage outflow volume has been more explicitly presented as 2000 GL/yr. Similarly, for CLLMM 2, there is to be outflows of no less than 3150 GL in a single year and no less than 12,000 GL over three years. Therefore, the target average annual barrage outflow volume has been explicitly presented as 4000 GL/yr. Annual flow volumes of ≤ 650 GL/year (minimum value for CLLMM 1 barrage outflows) must be avoided where possible if Basin Plan objectives for CLLMM are to be achieved. The Basin Plan identifies objectives to:

s8.06 (3) Protect and restore connectivity within and between water-dependent ecosystems by ensuring that:

> (c) The Murray Mouth remains open at frequencies, for durations, and with passing flows, sufficient to enable the conveyance of salt, nutrients and sediment from the Murray-Darling Basin to the ocean; and
>
> (d) The Murray Mouth remains open at frequencies, and for durations, sufficient to ensure that the tidal exchanges maintain the Coorong's water quality (in particular salinity levels) within the tolerance of the Coorong ecosystem's resilience;
>
> *Note: This is to ensure that water quality is maintained at a level that does not compromise the ecosystem and that hydrologic connectivity is restored and maintained*

The annual barrage flow metric has been modified to express a target value range, noting that there are critical minimum requirements both annually and across a three-year average for CLLMM 1 and 2. A framework for considering the annual barrage outflow variability and the corresponding CLLMM component descriptors for the revised CLLMM EWRs are presented in Table 20.

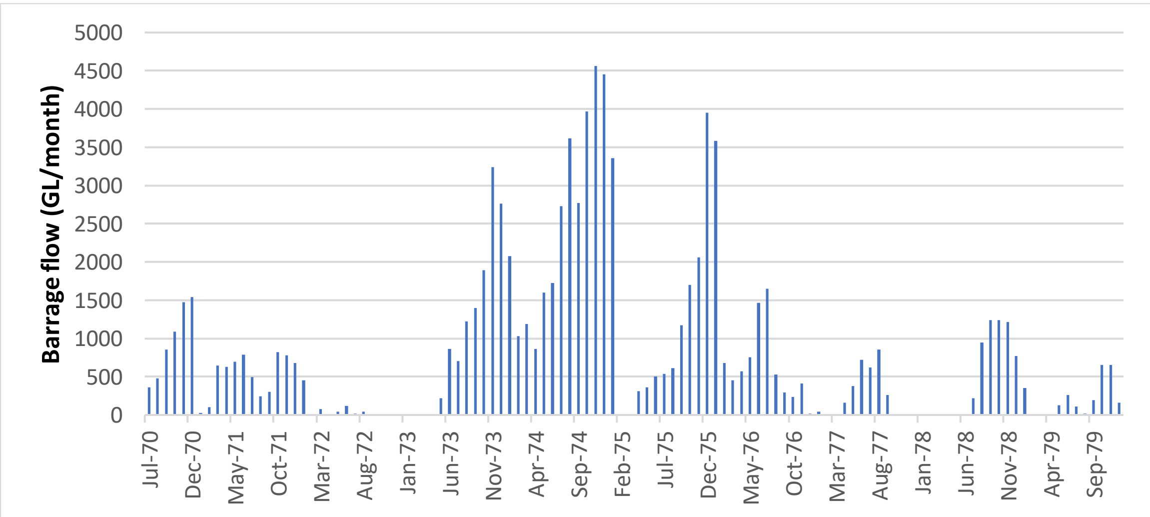

Figure 5: Modelled Total Barrage Flow (GL/month) from 1970 -1979.

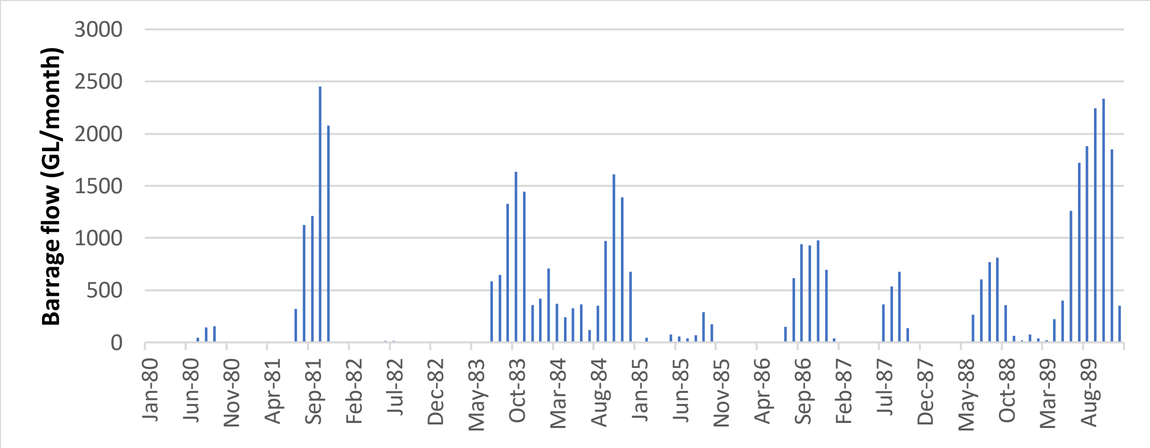

Figure 6: Modelled Total Barrage Flow (GL/month) from 1980-1989

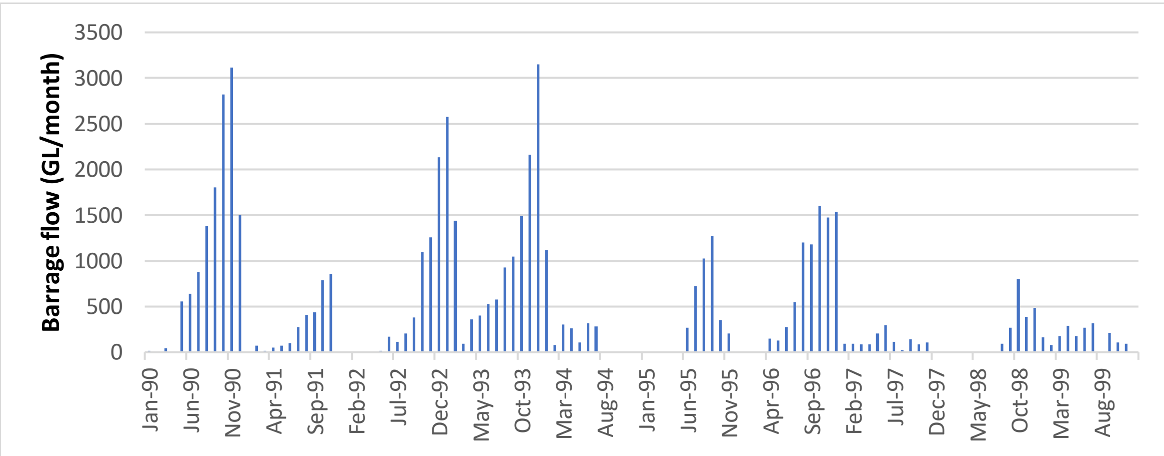

Figure 7: Modelled Total Barrage Flow (GL/month) from 1990 - 1999

Table 20: Framework for considering annual barrage outflow variability and corresponding integrated system component descriptors for the revised CLLMM EWRs.

Barrage outflow variability (GL/yr)	Target Barrage outflow (GL/yr)	Integrated systems descriptor	EWR #
0-649	N/A	No Murray Mouth discharge (Dredging likely required, Low Barrage outflows, Potential for very low to low Lower Lakes water levels, Critically low Coorong South Lagoon water levels	N/A
650–3,149	≥2,000	Murray Mouth potentially open (without dredging); Low Murray Mouth discharge, low tomoderate Lower Lakes water levels, low-moderate Coorong South Lagoon water levels	CLLMM1
3,150–5,999	≥4,000	Murray Mouth open (without dredging); Moderate Murray Mouth discharge, Moderate Lower Lakes water levels, Moderate Coorong South Lagoon water levels	CLLMM2

Barrage outflow variability (GL/yr)	Target Barrage outflow (GL/yr)	Integrated systems descriptor	EWR #
6,000–9,999	≥6,000	Murray Mouth open (without dredging); High Murray Mouth discharge, Moderate to high Lakes water levels, Moderate-High Coorong South Lagoon water levels	CLLMM3
≥10,000	≥10,000	Murray Mouth open (without dredging); High barrage outflows, High Lower Lakes water levels, High Coorong South Lagoon water levels,	CLLMM4

3.6.2 Barrage peak outflow timing

In regard to the peak timing of barrage outflows, modelled data of total monthly barrage flows (1977–2017) suggest that the timing of peak and/or minimum flows is highly variable both within and between years (Figure 5 to Figure 7). However, the hypothetical barrage flow operations for the existing CLLMM EWR scenarios (e.g. range of annual barrage volumes: 650 GL, 2000 GL, 4000 GL, 6000GL and 10000 GL) show there is a preferred peak timing of barrage flows for Oct–Dec, with minimum flow timing from May–Jul (Figure 8, O'Connor et al. 2015).

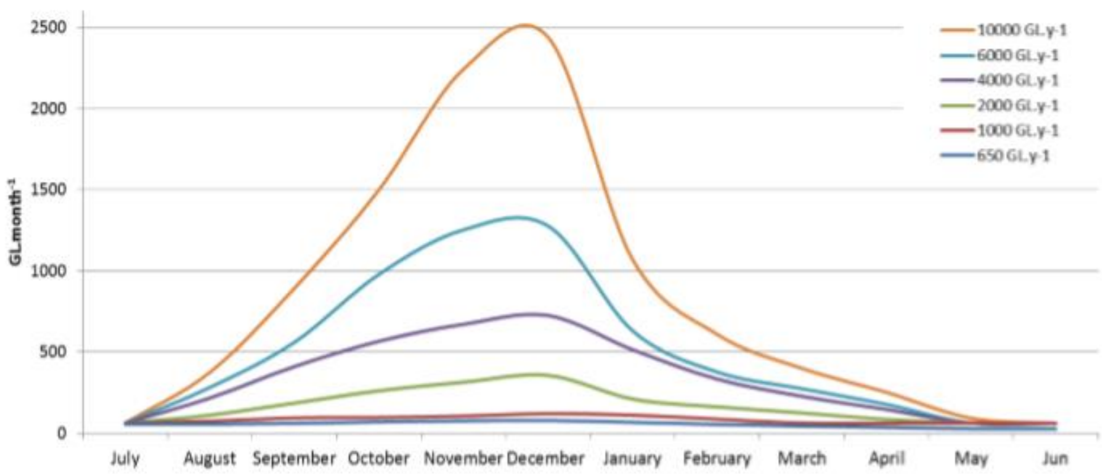

Figure 8: Hypothetical optimal peak timing (Oct–Dec) for barrage outflow operations for various annual CLLMM EWR flow scenarios from O'Connor et al. (2015).

Following consultation with experts at the workshop it was acknowledged that peak timing of barrage outflows that occur within a wider envelope of time (or anytime) may still provide some ecological benefits (e.g. winter peak barrage flows may encourage lamprey dispersal). However, a preferred inter-annual pattern of barrage operations for CLLMM EWRs was determined, where peak flows, of greater magnitude, occur in Sep–Dec as they align with target timing for peak Lower Lakes water levels (see Section 3.6.5). There was also a preference that a new metric was included into the CLLMM EWRs that specifies that for the intra-annual pattern in barrage flows, the total volume of barrage flows within the peak period (Sep–Dec) are ideally greater than the monthly volumes outside of the peak period (Jan–Aug) (Figure 9).

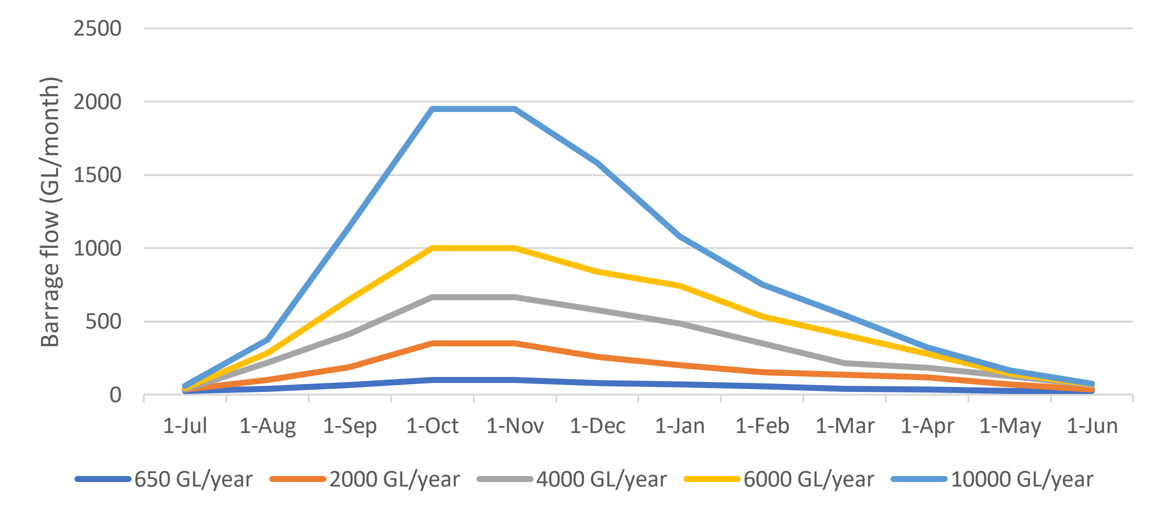

Figure 9: Revised hypothetical optimal peak timing (Sep–Dec) for barrage outflow operations for various annual CLLMM EWR flow scenarios

3.6.3 Frequency

The frequency metric of existing CLLMM EWRs are expressed as number of flows within a specified number of years (e.g. 1 in 1, 1 in 2, 1 in 3 and 1 in 7), to highlight that the 'patterned sequence of flows' is required to maintain key ecological outcomes, such as managing salinity levels in Lake Alexandrina.

The target frequency values have been retained in the revised CLLMM EWRs (O'Connor et al. 2015), but there was a lack of consistency between the way frequency was expressed compared to the IC and FP EWRs. Therefore, to provide consistency with the IC and FP EWRs, frequency has been explicitly expressed as:

- Number of flows per Average Return Interval (ARI) (e.g. 1-in-2),
- Percentage of years (e.g. 50% of years) and
- The number of years that the EWR should occur within a 10-yr period (e.g. 5 yr in 10).

3.6.4 Critical maximum interval

The critical maximum interval represents the maximum period between flow events before a significant decline in PEA condition is likely to occur. Ideally flow returns follow the desired target frequency outlined above (e.g. CLLMM1 EWR frequency is 1-in-1 or 100% of years); but the critical maximum interval describes the maximum number of years between flow events (e.g. dry spell) before significant decline occurs. Whilst critical maximum return intervals were specified for CLLMM 3 and 4 EWRS, they were not specified for CLLMM 1 and 2 EWRs. This was reconsidered as the two metrics (flow frequency and maximum interval) must be considered together when evaluating outcomes or managing systems. For example, clustering of events over successive years can occur in response to climate patterns. Clustering of flows may be ecologically desirable for the recovery and recruitment of native fish, vegetation and waterbird populations, however extended dry periods between clustered events can be detrimental. Likewise, if the return intervals are consistently not met, then current ecological condition may not be sustainable.

3.6.5 Timing for peak Lower Lakes water levels

Heneker (2010) modelled the intra-annual distribution of lake inflows to Lake Alexandrina. The averaged distribution of inflows to Lake Alexandrina compares well to the averaged distribution of both historical (recorded) and modelled natural QSA. Under modelled natural conditions, peak flows to South Australia tend to occur Aug–Dec, with minimum flows occurring Feb–May (Figure 10). However, the distribution of Entitlement Flow differs significantly, with peak timing occurring Dec–Feb, and minimum flow occurring May–Jun (Figure 10). Peak timing for Entitlement is based on maintaining sufficient supply volumes and acceptable salinity for irrigation and urban water supply and maintaining pool levels during periods of elevated evaporative losses, rather than a reflection of the pattern of unregulated flow events. This highlights that the delivery of targeted environmental water should not follow the timing of Entitlement but be representative of natural conditions if ecological outcomes are to be maximised.

Within the existing EWRs (Table 6), the Lower Lakes level timing metrics indicate that minimum Lakes levels should be achieved between Mar–May and maximum levels should be achieved between Dec–Feb (i.e. aligned with the preferred peak timing of Entitlement Flow). However, the recorded data shows maximum water levels often tend to occur in Aug–Dec (aligned with modelled natural flows) (Figure 10). Consequently, the existing EWR metrics (Table 6) do not reflect the preferred timing for maximum water levels in the Lower Lakes. Expert input from the workshop highlighted that peak timing for the Lower Lakes water levels should be shifted to earlier in the year to maximise vegetation responses. Seasonal water level fluctuations, peak water levels in spring and minimum water levels in autumn show improved native plant species richness (Nicol et al. 2019). The revised Lower Lakes level timing also better align with the revised intra-annual pattern of peak barrage outflow timing (Figure 9).

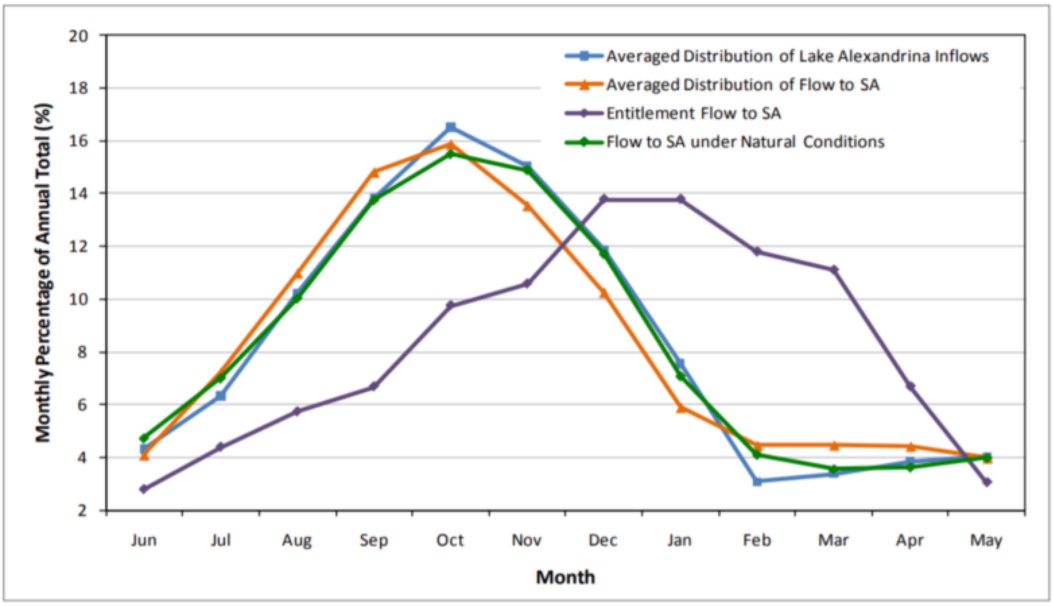

Figure 10: Average intra-annual distribution of Lake Alexandrina inflows (monthly percentage of annual total %) (from Heneker 2010).

3.6.6 Timing for minimum Lower Lakes water levels

The Lower Lakes level timing metric has been revised and split to include a peak Lakes water level season and the minimum Lakes water level season (see above).

3.6.7 Lower Lakes water level range

Variability for Lower Lakes levels is a desirable attribute, therefore the SA LTWP (DEWNR 2015) provides a specified range that Lakes water levels (m AHD) should remain within, throughout the year. However, it is not clear, particularly in relation to the maximum levels, if these are critical limits that if exceeded, should result in reporting non-achievement of the metric. For example, maximum Lake levels are given as 0.83 m AHD, however Lakes levels peaked at 1.06 m AHD in Oct 2016. Third-party impacts may occur if Lakes levels exceed 0.9 m AHD, so the Lakes are managed to be maintained around 0.83 m AHD whenever possible to mitigate these risks. Therefore, although there are no critical upper limits specified in the revised EWRs, target values for the peak timing in Lakes water levels for the various CLLMM EWRs have been revised to indicate that there is a target peak water level, but no maximum critical threshold (Figure 11).

For the Lakes water levels a minimum threshold of 0.4 m AHD is supported by Basin Plan objectives s8.06 (3) to protect and restore connectivity within and between water-dependent ecosystems by ensuring that:

> (e) The levels of the Lower Lakes are managed to ensure sufficient discharge to the Coorong and Murray Mouth and help prevent riverbank collapse and acidification of wetlands below Lock 1, and to avoid acidification and allow connection between Lakes Alexandrina and Albert, by:
>
> > (i) Maintaining levels above 0.4 metres Australian Height Datum for 95% of the time, as far as practicable; and
> >
> > (ii) Maintaining levels above 0.0 metres Australian Height Datum all of the time.

Workshop participants felt the recommended target minimum Lakes water levels be increased (Figure 11). For CLLMM 1 & 2, a target minimum Lakes level of 0.5 m AHD is recommended. Seasonal fluctuations, where Lakes water levels peak at 0.8 m AHD (or more) in spring and reach a minimum of >0.5 m AHD in autumn most years (i.e. CLLMM 1 & 2) are recommended for maintaining the submerged vegetation communities at lower elevations (<0.5 m AHD) and facilitating the establishment of amphibious plant taxa at slightly higher elevations (e.g. 0.6 m AHD) (Nicol et al. 2019). A minimum Lakes level greater than 0.6 m AHD is further recommended to occur at least once every 3 years (i.e. CLLMM 3 & 4) to maximise microcrustacean emergence from the soil eggbanks at higher elevations (Wedderburn et al. 2020; Deborah Furst, Adelaide University, pers. comm) and to provide greater habitat availability for threatened small-bodied fish species, such as Yarra Pygmy Perch through improved aquatic plant species richness and abundance (Wedderburn et al. 2020). The revised target values for the minimum Lakes water levels metric *i*) decrease the risk that Lakes levels cannot be maintained above 0.4 m AHD for 95% of the time, *ii*) maintain system connectivity and decrease the risk that lake-fringing wetlands are completely hydrologically disconnected when Lakes levels are below ~0.25 m AHD (Wedderburn et al. 2020) and *iii*) improve the likelihood of avoiding frequent barrage shutdown to avoid reverse head conditions (which is more common at a Lakes level of 0.4 m AHD compared to >0.5 m AHD). When barrage outflow volumes are <650 GL/year, maintenance of minimum Lakes levels >0.5 m AHD may not be practicable.

Whilst not included as a specific metric, rates of change in Lakes water levels is also significant. The ecological effects of lowering lake water levels too quickly are amplified in shallow fringing habitats (e.g. wetlands) where small changes *i*) influence water quality (e.g. salinity), *ii*) reduce habitat volumes, and *iii*) increase predation pressure (Leira and Cantonati 2008). There is also the possibility that important habitat dries completely (Wedderburn and Barnes 2019).

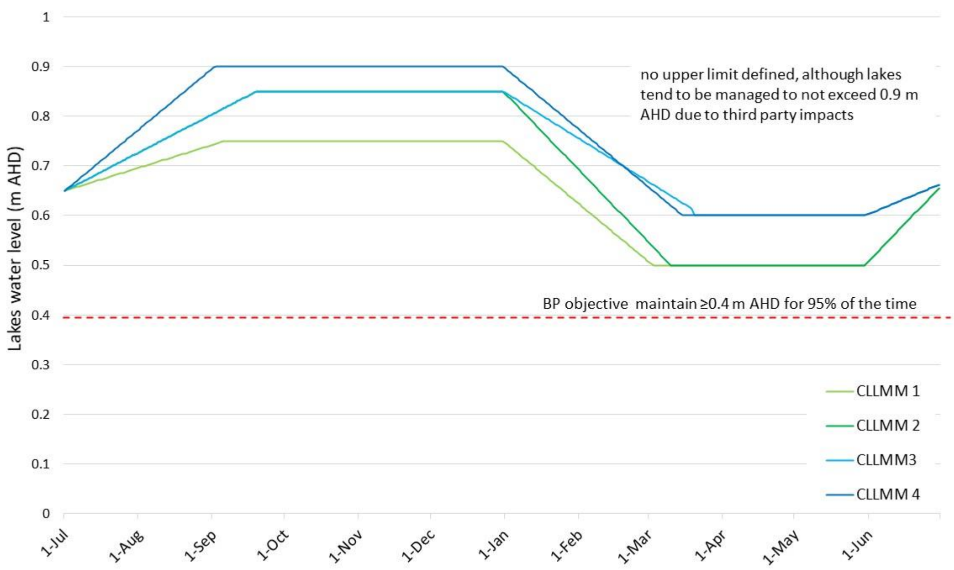

Figure 11: Revised hypothetical optimal intra-annual pattern of peak and minimum Lakes water level (m AHD) for various CLLMM EWR flow scenarios. Please note that +/- 5 cm variation is acceptable.

3.6.8 Peak Coorong South Lagoon water levels

The Coorong South Lagoon (CSL) water levels are influenced by barrage outflows, constriction of the Murray Mouth as well local sea level variation, wind patterns, evaporation and seasonal hydrologic disconnection between the North and South lagoon (Webster 2010).

The CSL EWR metrics set out in the existing CLLMM EWRs (Table 6) were primarily derived to maximise *Ruppia tuberosa* (hereafter referred to as Ruppia) outcomes. The annual growth cycle of Ruppia is that seeds and turions sprout in autumn, then grow, spread and ideally reproduce (either sexually through flowering, or asexually through turion formation) prior to senescence in late spring–early summer. Only dormant parts (i.e turions and seeds) survive the summer. Seeds are considered particularly important for recovery of ephemeral mudflats. Reproduction by seeds can increase Ruppia diversity and resilience (Collier et al. 2017).

Collier et al. (2017), specified suitability functions for Ruppia life stages in the development of the Ruppia Optimisation Habitat Model (Table 21). Optimal, sub-optimal and unsuitable CSL water levels were provided:

- To maintain Ruppia adult plant growth (i.e. vegetative) life stages between Jun–Sep, water levels >0.2 m AHD are optimal, whilst water levels that range between 0.1–0.2 m AHD are sub-optimal and water levels <0.1 m AHD are considered unsuitable.
- For successful flowering between Aug–Dec, water levels between 0.1 to 0.4 m AHD are optimal, whilst water levels that are within lower thresholds (0–0.1 m AHD) and upper thresholds (0.4–1.0 m AHD) are sub-optimal. Water levels that fall below 0 m AHD or exceed 1.0 m AHD throughout Aug-Dec, represent a critical threshold.
- For successful turion and seedbank production, water levels >0.1 m AHD are considered optimal, whilst water levels between 0–0.1 m AHD are considered sup-optimal and water levels that fall below 0 m AHD represent a critical threshold. Seed germination and turion sprouting occurs Apr-Jul (Collier et al. 2017). Permanently dry periods throughout these specified months are unsuitable and ideally water levels are maintained >0.2 m AHD for optimal turion sprouting, between 0–0.2 m AHD for sub-optimal outcomes and do not exceed 0 m AHD.

The target values for the peak Coorong South Lagoon water level metrics were revised at the workshop with expert input. The CLLMM 1 target values for the peak CSL water levels are between 0 to 0.1 m AHD and are focused on maintaining existing adult Ruppia populations. The target values for the peak CSL water level metrics for CLLMM 2 and 3 EWRs between 0.2 to 0.45 m AHD are focused on improving Ruppia populations by encouraging flower and seed/turion production. No target values for the peak CSL water level metrics were prescribed for CLLMM 4 as CSL water levels are likely to exceed the preferred CSL water envelope to improve Ruppia populations (i.e. between 0.2 to 0.45 m AHD) due to the magnitude of annual barrage volumes (i.e. >10,000 GL/yr).

Table 21: Suitability functions for Ruppia life stages used in the development of the Ruppia Optimisation Habitat model (modified from Collier et al. 2017).

Ruppia Life stage	Water level (m AHD)
Seed germination (Apr–Jul)	Permanently dry: unsuitable
	<15 days wet (95% of time): unsuitable
	15-42 days wet (95% of time: sub-optimal
	>42 days wet (>95% of time): optimal
	Permanently wet: optimal
Turion sprouting (Apr–Jul)	<0 unsuitable
	0 to 0.2 suboptimal
	>0.2 optimal
Adult plant growth (vegetative) (Jun–Sep)	<0.1 unsuitable
	0.1-0.2 suboptimal
	>0.2 optimal
Flowering (Aug–Dec)	<0 unsuitable
	0-0.1 suboptimal
	0.1 to 0.4 optimal
	0.4 to 1.0 suboptimal
	>1.0 unsuitable
Turion production (Aug–Dec)	<0 unsuitable
	0 to 0.1 suboptimal
	>0.1 optimal
Seedbank production (Aug–Dec)	<0 unsuitable
	0 to 0.1 suboptimal
	>0.1 optimal

To assess the proposed revisions to the CLLMM peak CSL water levels metric, the median values for water level (model data from the 1983–2017, model runs provided by Matt Gibbs, DEW) (Appendix 5.2) were compared to the revised target values for the CLLMM EWR 1 metric of 0.0–0.1 m AHD from Sep-Dec (Aug–Jan = sub-optimal), and the revised target values for CLLMM EWR 2 and 3 metric of 0.2–0.45 m AHD from Sep–Jan (Aug–Feb = sub-optimal). The results are summarised in Figure 12 (A–C) and indicate that none of the existing CLLMM EWR scenarios retain water level within the specified target range for the specified period (Figure 12A) . All the revised FP EWR scenarios cause water levels to be too high during Sep–Nov (Figure 12B) but the revised IC3 EWR scenario may represent the best “fit” within the target values specified for CLLMM EWR 2 and 3 (Figure 12C and Table 22).

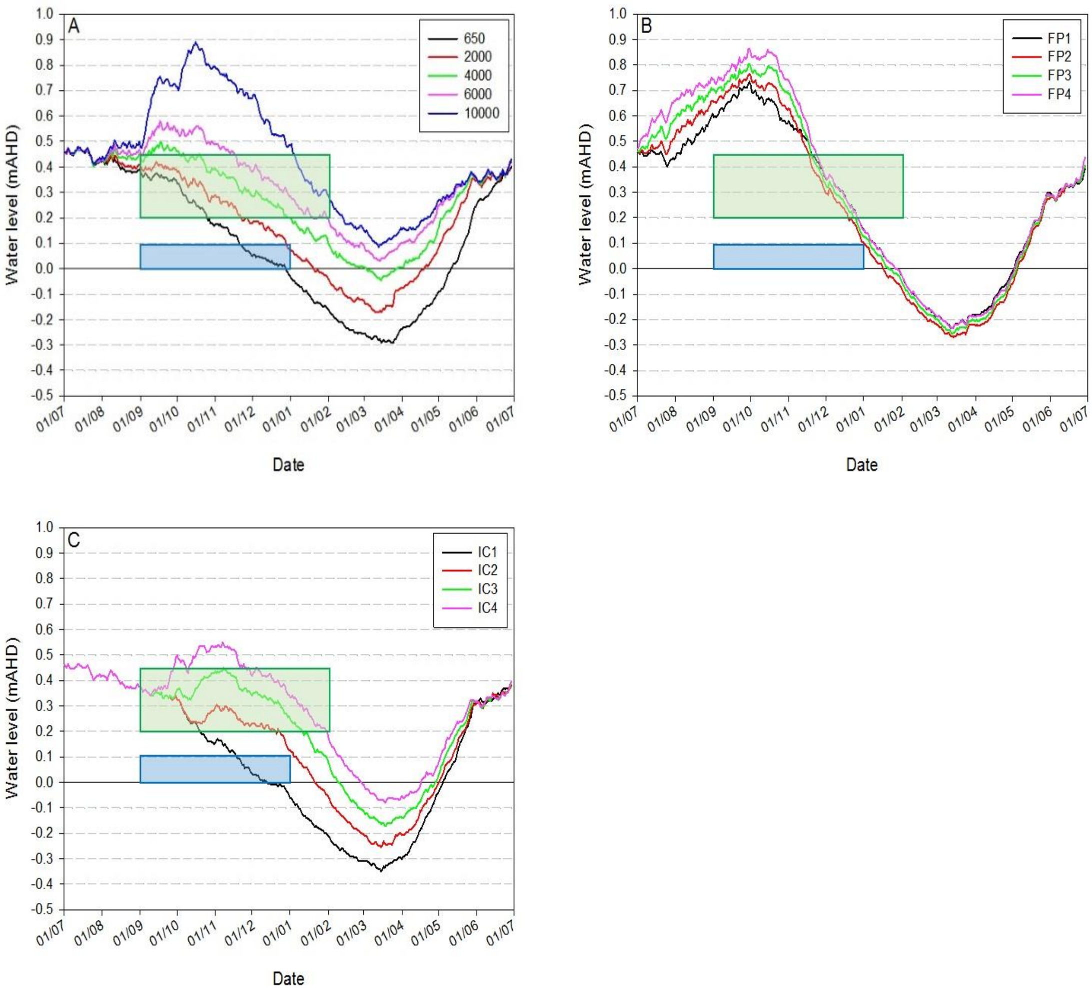

Figure 12: Modelled median water levels in the South Lagoon for [A] existing CLLMM EWRs, [B] revised FP EWRs, and [C] revised IC EWRs (Values for date are dd/mm). The green shaded area is the CLLMM EWR 2 metric of maintaining Coorong South Lagoon water level within the range 0.2 to 0.45 m AHD between September and January. The blue shaded area represents the revised target values for the CLLMM 1 EWR metric to maintain Coorong South Lagoon water levels within the range 0.0 to 0.1 m AHD between September and December.

Table 22: Modelled number of days the modelled existing and revised EWR scenarios maintain water level within the revised target values for the CLLMM 2 EWR to maintain Coorong South Lagoon water levels within the range of 0.2 to 0.45 m AHD between September and January for CLLMM 2.

Modelled EWR Scenario	Description	Modelled Equivalent annual barrage outflow (GL/yr)	Total N days	# of days water level metric is maintained	% of days water level metric is maintained
CLLMM 650	Existing CLLMM1 EWR	650	153	55	36
CLLMM 2000	Existing CLLMM1 EWR	2,000	153	85	56
CLLMM 4000	Existing CLLMM2 EWR	4,000	153	98	64
CLLMM 6000	Existing CLLMM 3 EWR	6,000	153	74	48
CLLMM 10000	Existing CLLMM4 EWR	10,000	153	28	18
FP1	Revised FP1 EWR	5,000	153	38	25
FP2	Revised FP2 EWR	5,500	153	33	22
FP3	Revised FP3 EWR	6,500	153	36	24
FP4	Revised FP4 EWR	8,000	153	33	22
IC1	Revised IC1 EWR	500	153	49	32
IC2	Revised IC2 EWR	1,200	153	113	74
IC3	Revised IC3 EWR	2,500	153	133	87
IC4	Revised IC4 EWR	4,000	153	99	65

Whilst the EWR metrics for the CSL are primarily focused on maximising Ruppia outcomes, another key consideration is the availability of mudflats, which provide highly productive feeding grounds for wading birds and attract large numbers of local and intercontinental species. Wader use of mudflat habitat in the Coorong peaks in summer (Jan–Feb) (Rogers and Paton 2009). Wader habitat in the Coorong has been defined as shallow depths between 0–0.12 m AHD, but individual species will use different ranges within this band depending on their body size and feeding habitats (Rogers and Paton 2009). Upper water level thresholds (>0.55 m AHD) are recognised due to the reduced availability of mudflat habitat for migratory shorebirds.

For the Coorong South and North Lagoons, mudflat availability at 0.1 m water level increments was assessed (Figure 13 and Figure 14; modelled data provided by Matt Gibbs (DEW)) (Appendix 5.2); showing the area (Ha) of available mudflats with changing water levels and the proportion (%) of available mudflats compared to the maximum available area (846.89 ha at 0.1 m AHD for the Coorong South Lagoon (Figure 13), 790.78 ha at 0.0 m AHD for the Coorong North lagoon (Figure 14)). The results demonstrate that as water level increases (or decreases) away from 0.0 m AHD, mudflat availability decreases.

The areas of mudflat that may be available in the CSL as a result of existing CLLMM EWRs and revised EWRs were compared (Table 23, Appendix 5.2). It was assumed that Nov–Mar is the optimal timing for provision of wading habitat for waterbirds (David Paton, *pers. comm*). For the CSL, only water levels between -0.1 and 0.2 m AHD provide ≥ 60% of mudflat availability. The results demonstrate that the modelled scenarios for the existing CLLMM1b and CLLMM2 EWRs maintain the highest availability of mudflats, whereas all of the revised FP EWR scenarios provide low mudflat availability (i.e. water levels are between -0.1 and 0.2 m AHD for only 30% of the time) (Table 23).

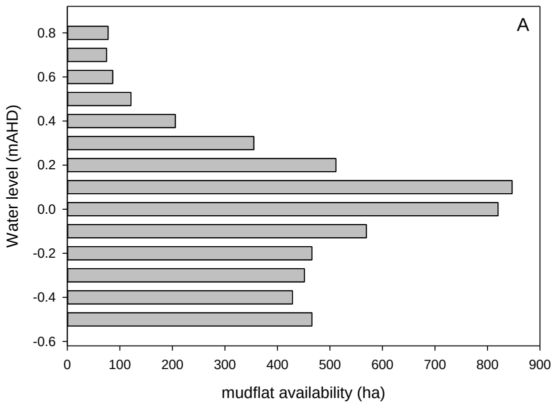

Figure 13: [A] mudflat availability (ha) in the Coorong South Lagoon with changing water level. [B] percent of mudflat available in the Coorong South Lagoon with changing water level.

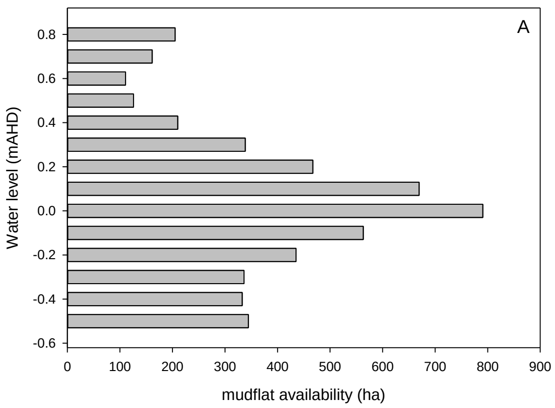

Figure 14: [A] mudflat availability (ha) in the Coorong North Lagoon with changing water level. [B] percent of mudflat available in the Coorong North Lagoon with changing water level.

Table 23: Modelled number of days water level is maintained between -0.1 and 0.2 m AHD between November and March in the Coorong South Lagoon (CSL) in order to maintain mudflat availability ≥60%.

Modelled EWR Scenario	Description	Modelled Equivalent annual barrage outflow (GL/yr)	Number of days between Nov and Mar that CSL water level is between -0.1 and 0.2 m AHD	% of days between Nov and Mar that CSL water level is between -0.1 and 0.2 m AHD
CLLMM650	Existing CLLMM1 EWR	650	77	51
CLLMM2000	Existing CLLMM1 EWR	2,000	91	60
CLLMM4000	Existing CLLMM2 EWR	4,000	92	61
CLLMM6000	Existing CLLMM 3 EWR	6,000	65	43
CLLMM10000	Existing CLLMM4 EWR	10,000	47	31
FP1	Revised FP1 EWR	5,000	47	31
FP2	Revised FP2 EWR	5,500	46	30
FP3	Revised FP3 EWR	6,500	46	30
FP4	Revised FP4 EWR	8,000	47	31
IC1	Revised IC1 EWR	500	69	46

Modelled EWR Scenario	Description	Modelled Equivalent annual barrage outflow (GL/yr)	Number of days between Nov and Mar that CSL water level is between -0.1 and 0.2 m AHD	% of days between Nov and Mar that CSL water level is between -0.1 and 0.2 m AHD
IC2	Revised IC2 EWR	1,200	49	32
IC3	Revised IC3 EWR	2,500	47	31
IC4	Revised IC4 EWR	4,000	60	40

3.6.9 Minimum Coorong South Lagoon water levels

The metric for the peak CSL water levels has been revised to define the target values (see above), but expert input from the workshop felt that values for the CSL minimum water level metric did not need to be defined and the metric has therefore been removed.

3.6.10 Timing of peak Coorong South Lagoon water levels

The CSL peak water level timing metric was revised and consolidated to concentrate on the peak season to achieve successful Ruppia growth and reproduction, which are a critical part of the Coorong food web (i.e. to support migratory bird populations). The timing of changes in water levels (particularly falling water levels) is essential for success of both sexual and asexual reproduction of Ruppia (Collier et al. 2017). Avoiding desiccation during the key reproduction period in spring/summer is crucial and maintaining ideal water levels for extended periods may enable a prolonged flowering season. Peak waterbird wading season is November to March and during this season water levels should not exceed 0.55 m AHD to ensure provision of mudflat habitat (David Paton, *pers. comm*).

3.6.11 CSL minimum water level timing

Target values for the timing of peak CSL water levels were revised (see above), but expert input from the workshop felt that values for the timing of the minimum CSL water levels did not need to be defined and the metric was therefore removed.

3.6.12 Duration of peak CSL water levels

The duration of peak CSL water levels metric was revised at the workshop with expert input. Changes in water level during spring can prevent Ruppia reproduction and maintaining peak water level durations during key growth stages is considered essential for maximising Ruppia outcomes. The shortest observed truncated Ruppia life cycle (in only a few plants) is ≥135 days (Michelle Waycott, *pers. comm.*), therefore a minimum peak water level duration of 150 days is required to provide subsistence seed-set to support populations the following year. Durations of <150 days are unlikely to support Ruppia reproduction and are only to maintain existing adult/perennial populations. Durations of ≥180 days provide greater certainty and greater magnitude of response (e.g. production of more seed).

3.6.13 Further considerations

3.6.13.1 Maintain salinity in the Coorong South Lagoon

Ecological targets that relate to maintaining salinity in the CSL (as per the SA LTWP target to maintain a salinity gradient from 60 ppt to 100 ppt) may also contribute to improving Ruppia outcomes (Collier et al. 2017). Hence the median values for salinity (model data from the 1983–2017 climate model runs provided by Matt Gibbs, DEW) (Appendix 5.2) were compared to the target of maintaining salinity within 60–100 ppt. The results are summarised in Figure 15 (A–C) and indicate that median salinity for the existing CLLMM 650 and CLLM10000 scenarios does not remain within the 60–100 ppt range for the entire year (Figure 15A). The CLLMM4 EWR median salinity falls below the minimum threshold (i.e. <60 ppt) during the specified target timing (Sep–Nov) when Ruppia are growing, but Collier et al. (2017) found that salinities of 35-65 ppt may still be suitable for Ruppia flowering. All of the revised FP EWR scenarios cause median salinity to fall below the 60 ppt envelope during Sep–Nov (Figure 15B) and in the revised IC1 and IC2 EWR scenarios, salinity increases above the 100 ppt during Jan–May (Figure 15C). The contribution was assessed on the period of time median salinity is maintained within the specified target range of 60–100 ppt (Table 24).

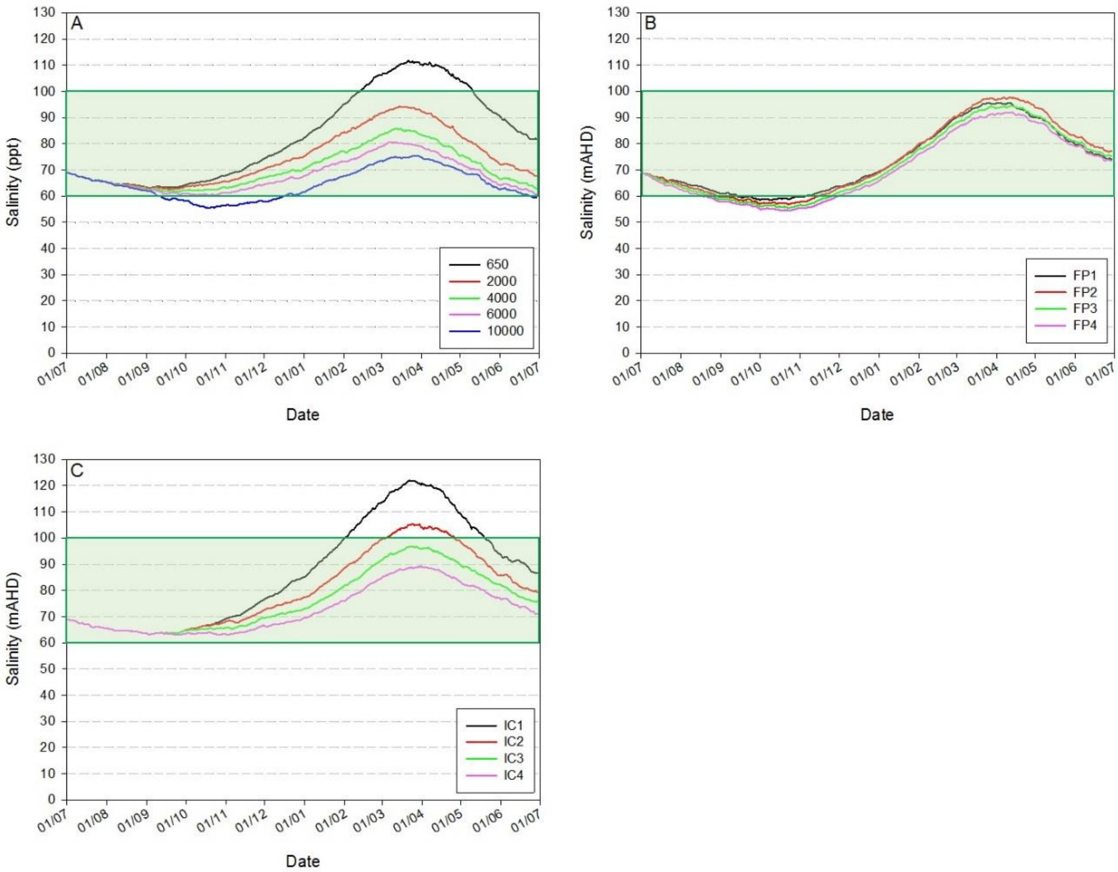

Figure 15: Modelled median salinity in the South Lagoon for [A] existing CLLMM EWRs, [B] revised FP EWRs, and [C] revised IC EWRs (Values for date are dd/mm). The green shaded area is the CLLMM EWR metric of maintaining salinity within the range 60–100 ppt.

Table 24: Modelled number of days the existing and revised EWRs maintain salinity within the envelope of 60–100 ppt.

Modelled EWR Scenario	Description	Modelled Equivalent annual barrage outflow (GL/yr)	# of days salinity is maintained within 60–100 ppt	% of days salinity is maintained within 60–100 ppt
CLLMM 650	Existing CLLMM1 EWR	650	278	76
CLLMM 2000	Existing CLLMM1 EWR	2,000	364	100
CLLMM 4000	Existing CLLMM2 EWR	4,000	364	100
CLLMM 6000	Existing CLLMM 3 EWR	6,000	364	100
CLLMM 10000	Existing CLLMM4 EWR	10,000	262	72
FP1	Revised FP1 EWR	5,000	311	85
FP2	Revised FP2 EWR	5,500	285	78
FP3	Revised FP3 EWR	6,500	272	75
FP4	Revised FP4 EWR	8,000	259	71
IC1	Revised IC1 EWR	500	256	70
IC2	Revised IC2 EWR	1,200	310	85
IC3	Revised IC3 EWR	2,500	364	100
IC4	Revised IC4 EWR	4,000	364	100

3.7 Proposed revisions to CLLMM EWRs

In view of the considerations outlined above, the proposed revisions for the CLLMM EWRs are presented in (Table 25). The table shows the target values for the individual EWR metrics. These target values represent the hydrological conditions required to give the greatest certainty of achieving ecological outcomes within the Coorong, Lower Lakes and Murray Mouth PEA.

Table 25: Revised South Australian Coorong, Lower Lakes and Murray Mouth (CLLMM) Environmental Watering Requirements (EWRs) showing the specified target values for individual metrics.

EWR #	EWR metrics									
	Average Annual Barrage flow (GL/yr)	**Total barrage flow over rolling 3-yr period (GL)**	**Barrage outflow annual pattern^**	**Frequency# (# flows-per-ARI; [% of years]; {#yr in 10-yr})**	**Critical Max Interval& (years)**	**Lakes water level (m AHD)**	**Lakes water level peak and/or minimum timing (months)**	**Coorong South Lagoon peak water level (m AHD)**	**Coorong South Lagoon peak water level timing (months)**	**Coorong South Lagoon peak water level duration (days)**
CLLMM1	≥2,000	≥6,000*	Total volume released in Sep–Dec > Total volume released in Jan–Aug	1-in-1 [100%] {10 yr in 10}	0	0.5 to ≥0.75		0.0 to 0.1	Sep–Dec	≥90
CLLMM2	≥4,000	≥12,000**	Total volume released in Sep–Dec > Total volume released in Jan–Aug	1-in-2 [50%] {5 yr in 10}	3	0.5 to ≥0.83	Peak: Sep–Dec Min: Mar–May	0.2 to 0.45	Sep–Jan	≥150
CLLMM3	≥6,000	N/A	Total volume released in Sep–Jan >Total volume released in Feb–Aug	1-in-3 [33.3%] {3–4 yr in 10}	5	0.6 to ≥0.83		0.2 to 0.45	Sep–Feb	≥180
CLLLMM 4	≥10,000	N/A	Total volume released in Sep–Jan >Total volume released in Feb–Aug	1-in-7 [14%] {1–2 yr in 10}	17	0.6 to ≥0.9		N/A	N/A	N/A

* CLLMM1 = no less than 650 GL in a single year, and no less than 6,000 GL over 3 years
** CLLMM2 = no less than 3150 GL in a single year, and no less than 12,000 over 3 years
^ see Figure A1_8 for hypothetical representation of annual barrage release pattern
#Frequency is expressed as: 1) number of flows per Average Return Interval (ARI), 2) percentage of years and 3) the number of years that the EWR should occur within a 10-yr period.
&represents the critical maximum interval (years) between EWRs before a significant decline in CLLMM condition is likely to occur. This period should not be exceeded wherever possible.

3.7.1 Summary of key revisions to CLLMM EWRs

The number of CLLMM EWRs remained the same (Table 25).

The target annual barrage outflow volumes (GL/yr) for the CLLMM EWRs have not specifically changed in the revision but it has been made more explicit that the target values are specified as 'average' annual barrage flow volumes with corresponding 3-year rolling barrage outflow requirements. This was for consistency with the floodplain EWRs, whilst retaining key specific rules from the operational formulas to ensure salinity thresholds are not exceeded (Heneker 2010; Lester et al. 2011). For CLLMM 1 there was a specified rule that there is to be no outflow less than 650 GL in a single year, and no less than a total of 6,000 GL over three years (therefore target average annual barrage flow volume is explicitly presented as 2000 GL/yr). Similarly, for CLLMM 2 there is to be no outflow less than 3150 GL in a single year and no less than a total of 12,000 GL over three years (therefore the target average annual barrage outflow volume is explicitly presented as 4000 GL/yr). Meeting the target 'average' annual barrage flow volume is likely to provide a higher degree of certainty of meeting the anticipated ecological outcomes. For example, targeting the CLLMM1 average barrage flow volume is especially important when 730–1090 GL/yr is the minimum volume required to minimise sand ingress and maintain Murray Mouth openness (MDBA 2014b).

The target values for the timing of peak barrage outflows were also revised to occur earlier (Sep–Dec compared to Oct–Dec) to line up with the revised peak Lower Lakes water level ranges (see below). A further metric was included to specify that for the intra-annual pattern in barrage flows, the total volume of barrage flows within the peak period (Sep–Dec) are greater than the total volumes outside of the peak period (Jan–Aug).

In the existing CLLMM EWRs, the frequency was expressed as the number of flows within a specified number of years. This was to highlight that a 'patterned sequence of flows' is required to meet the ecological objectives for managing salinity levels in Lake Alexandrina (Table 3). The target frequency values were not changed in the revised EWRs, but there was a lack of consistency between the way frequency for the CLLMM EWRs were expressed compared to the IC and FP EWRs. Therefore, to provide clarity and consistency, frequency has been expressed in the following:

1. Number of flows per Average Return Interval (ARI) (e.g. 1-in-2),
2. Percentage of years (e.g. 50% of years) and
3. The number of years that the EWR should occur within a 10-yr period (e.g. 5 yr in 10).

The critical maximum interval, or maximum period, between flow events were also revised. Ideally flow returns follow the desired target frequency outlined above (e.g. CLLMM3 EWR frequency is 1-in-3 or 33% of years); but the critical maximum interval describes the maximum number of years between events (e.g. dry spell) before significant decline and potentially irreversible damage, such as loss of populations occurs. Whilst critical maximum intervals were specified in the existing CLLMM 3 and 4, they were not specified for CLLMM 1 and 2. This was reconsidered as the two metrics (flow frequency and maximum interval) must be considered together when evaluating outcomes or managing systems. For example, the sequencing of larger flows over successive years can occur in response to climate patterns. This clustering pattern of flows may be ecologically desirable for the recovery and recruitment of native fish, vegetation and waterbird populations; however, extended dry periods between clustered events can be detrimental. Likewise, if the target frequencies are consistently not met, then ecological condition may not be sustainable.

The Lower Lakes water level timing metrics that specify the peak Lakes water level months (season) and the minimum Lakes water level months (season) were also revised. A significant revision was that the peak timing for Lakes water level occur earlier (Sep–Dec compared to Dec–Feb) based on modelled intra-annual distribution of lake inflows to Lake Alexandrina (Figure 10), which better align with historical and modelled natural QSA (and the target peak timing of IC and FP flows) as well as the requirements of littoral vegetation (Nicol et al. 2019) and small-bodied threatened fish (Wedderburn et al. 2020). The timing for minimum Lakes water level remained the same (i.e. Mar–May).

The target values for the Lower Lakes water level range were also reviewed for the CLLMM EWRs and remained largely unchanged apart from increasing the target minimum Lakes water level to maximise vegetation outcomes (for CLLMM1 & 2) (Nicol et al. 2017) and to improve habitat availability (i.e. increase diversity and abundance of aquatic plants) for threatened small-bodied fish species and encourage zooplankton productivity for CLLMM3 & 4 (Wedderburn et al. 2020).

The target values for the Coorong South Lagoon (CSL) peak water level range, timing and duration were also revised to better align with observed CSL water levels and modelling outcomes to maximise Ruppia and waterbird outcomes (Collier et al. 2017, Rogers and Paton 2009).

3.7.1.1 CLLMM1 EWR Revisions/explanations

For the revised CLLMM1 EWR, the target average annual barrage outflow volume is ≥2,000 GL/yr (or no less than 650 GL in a single year, and ≥6,000 GL over 3 years); with peak flows occurring Sep–Dec where total volumes of barrage flows in Sep–Dec are greater than the total volume of flows in Jan–Aug; occurs at a frequency of 1-in-1 (or 100% of years), critical maximum interval is 1 year, Lower Lakes water levels range between 0.5 to ≥0.75 m AHD, with peak Lakes water level timing Sep–Dec and minimum Lakes water level timing Mar–May; Coorong South Lagoon water level range between 0–0.1 m AHD, with peak CSL water level timing Sep–Dec for a duration of ≥90 days. Summary of key changes include:

- Target average annual barrage outflow remains unchanged (≥2,000 GL/yr), except that it has been more explicitly stated that this is the average volume,
- A metric specifying the target total annual barrage flow (GL) over a rolling 3-year period has been included to provide greater clarity that EWR assessments must consider barrage flows of preceding years (i.e. CLLMM1 ≥6,000 GL; no less than 650 GL in a single year, and no less than 6,000 GL over 3 years),
- A metric specifying the intra-annual pattern for barrage flows has been included, specifying that the total barrage flow volume during the peak season (Sep–Dec) is greater than total barrage flow volume throughout the rest of the year (Jan–Aug),
- The target frequency of 1-in-1 (100% of years) remains unchanged,
- A critical maximum interval value of 1 year has been included,
- The target value for the peak Lower Lakes water level timing was changed to Sep–Dec (compared to Dec–Feb),
- The target value for the timing of the minimum Lower Lakes water level (Mar–May) remains unchanged,
- The target value for peak Lower Lakes water level remains the same at ≥0.75 m AHD,

- The target value for the minimum Lower Lakes water level has increased from ≥0.4 to ≥0.5 m AHD, to maximise outcomes for vegetation, improve habitat availability for threatened small-bodied fish populations and encourage zooplankton productivity,
- The target value for the peak range of CSL water level changed to 0–0.1 m AHD, with a focus on maintaining existing adult Ruppia populations (i.e. vegetative growth) and maximising waterbird outcomes,
- The target value for the timing of peak CSL water levels has been expanded (Sep–Dec compared to Sep–Nov),
- The target value for the duration of peak CSL water levels remains unchanged at ≥90 days.

3.7.1.2 CLLMM2 EWR Revisions/explanations

For the revised CLLMM2 EWR, the target average annual barrage flow is ≥4,000 GL/yr (or no less than 3,150 GL in a single year, and ≥12,000 GL over 3 years); with peak flows occurring Sep–Dec where total volumes of barrage flows in Sep–Dec are greater than the total volume of flows in Jan–Aug; occurs at a frequency of 1-in-2 (or 50% of years), critical maximum interval is 3 years, Lower Lakes water levels range between 0.5 to ≥0.83 m AHD, with peak Lakes water level timing Sep–Dec and minimum Lakes water level timing Mar–May; Coorong South Lagoon water level range between 0.2–0.45 m AHD, with peak CSL water level timing Sep–Jan for a duration of ≥150 days. Summary of key changes include:

- Target average barrage outflow volumes remain unchanged (≥4,000 GL/yr) except that it has been more explicitly stated that this is the average volume,
- A metric specifying the target total barrage outflow volume over a rolling 3-year period has been included to provide greater clarity that EWR assessments must consider barrage flows of preceding years (i.e. CLLMM2 ≥12,000 GL; no less than 3,150 GL in a single year, and no less than 12,000 GL over 3 years),
- A metric specifying the intra-annual pattern for barrage flows has been included, specifying that the total barrage outflow volume during the peak season (Sep–Dec) is greater than total barrage flow volume throughout the rest of the year (Jan–Aug),
- The target frequency of 1-in-2 (50% of years) remains unchanged,
- A critical maximum interval value of 3 years has been included,
- Target value for the timing of peak Lakes water level was changed to Sep–Dec (compared to Dec–Feb),
- Target value for the timing of minimum Lower Lakes water level timing (Mar–May) remains unchanged,
- Target value for the peak Lower Lakes water level remains unchanged at≥0.83 m AHD,
- Target value for the minimum Lower Lakes water level has increased from ≥0.4 to ≥0.5 m AHD to maximise outcomes for vegetation, improve habitat availability for threatened small-bodied fish populations and encourage zooplankton productivity,
- The target value for peak range of CSL water changed to 0.2–0.45 m AHD, with a focus on improving Ruppia populations by encouraging flowering and seed/turion production. A critical upper threshold of ≤0.55 m AHD is required to ensure provision of mudflat habitat availability,
- The target value for the timing of peak CSL water levels has been expanded (Sep–Jan compared to Sep–Dec),

- The target value for the peak CSL water level duration has been increased from ≥120 days to ≥150 to ensure Ruppia life cycle is complete.

3.7.1.3 CLLMM3 EWR Revisions/explanations

For the revised CLLMM3 EWR, the target average annual barrage flow is ≥6,000 GL/yr; with peak flows occurring Sep–Dec where total volumes of barrage flows in Sep–Dec are greater than the total volume of flows in Jan–Aug; occurs at a frequency of 1-in-3 (or 33% of years), critical maximum interval is 5 years, Lower Lakes water levels range between 0.6 to ≥0.83 m AHD, with peak Lakes water level timing Sep–Dec and minimum Lakes water level timing Mar–May; Coorong South Lagoon water level range between 0.2–0.45 m AHD, with peak CSL water level timing Sep–Feb for a duration of ≥180 days. Summary of key changes include:

- Target average barrage outflow volume remains unchanged (≥6,000 GL/yr) except that it has been more explicitly stated that this is the average volume,
- A metric specifying the target total barrage outflow (GL) over a rolling 3-year period has been included to provide greater clarity that EWR assessments must consider barrage flows of preceding years, but note that for CLLMM3 this is not applicable,
- A metric specifying the intra-annual pattern for barrage flows has been included, specifying that the total barrage flow volume during the peak season (Sep–Dec) is greater than total barrage flow volume throughout the rest of the year (Jan–Aug),
- The target frequency of 1-in-3 (33% of years) remains unchanged,
- A critical maximum interval of 5 years remains unchanged,
- The target value for the timing of peak Lakes water level was changed to Sep–Dec (compared to Dec–Feb),
- The target value for the timing of minimum Lower Lakes water level (Mar–May) remains unchanged,
- The target value for the peak Lower Lakes water level remains unchanged at ≥0.83 m AHD,
- The target value for the minimum Lower Lakes water level has increased from ≥0.4 to ≥0.6 m AHD, to maximise outcomes for vegetation, improve habitat availability for threatened small-bodied fish populations and encourage zooplankton productivity,
- The target value for peak range of CSL water levels has changed to 0.2–0.45 m AHD, with a focus on improving Ruppia populations by encouraging flower and seed/turion production. A critical upper threshold of ≤0.55 m AHD is required to ensure provision of mudflat habitat availability,
- The target value for the timing of peak CSL water levels has been expanded (Sep–Feb compared to Sep–Jan),
- The target value for the duration of peak CSL water levels has increased from ≥180 days to provide greater certainty that Ruppia life cycle is completed, and seed replenishment is enhanced.

3.7.1.4 CLMM4 EWR Revisions/explanations

For the revised CLLMM4 EWR, the target average annual barrage outflow is ≥10,000 GL/yr with peak flows occurring Sep–Dec where total volumes of barrage outflows in Sep–Dec are greater than the total volume of flows in Jan–Aug; occurs at a frequency of 1-in-7 (or 14% of years), critical maximum interval is 17 years, Lower Lakes water levels range between 0.6 to≥0.90 m AHD, with peak Lakes water level timing Sep–Dec and minimum Lakes water level timing Mar–May. Summary of key changes include:

- Target average barrage outflow volume remains unchanged (≥10,000 GL/yr) except that it has been more explicitly stated that this is the average volume,
- A metric specifying the target total barrage outflow volume over a rolling 3-year period has been included to provide greater clarity that EWR assessments must consider barrage flows of preceding years, but note that for CLLMM4 this is not applicable,
- A metric specifying the intra-annual pattern for barrage flows has been included, specifying that the total barrage flow volume during the peak season (Sep–Dec) is greater than total barrage flow volume throughout the rest of the year (Jan–Aug),
- The target frequency of 1-in-7 (14% of years) remains unchanged,
- A critical maximum interval of 17 years remains unchanged,
- The target value for the timing of peak Lakes water levels was changed to Sep–Dec (compared to Dec–Feb),
- The target value for the timing of minimum Lakes water level (Mar–May) remains unchanged,
- The target value for peak Lakes water levels remains unchanged at ≥0.9 m AHD,
- The target value for minimum Lakes water levels has increased from ≥0.4 to ≥0.6 m AHD, to maximise outcomes for vegetation, improve habitat availability for threatened small-bodied fish populations and encourage zooplankton productivity,
- The metrics for peak CSL water levels, timing and duration were removed as water levels are likely to exceed the target peak CSL water level range due to the magnitude of the annual barrage outflow volume (≥10,000 GL).

3.8 Modelled alignment between revised IC, FP and CLLMM EWRs

Detailed evaluation of the modelling alignment outcomes is provided in Appendix 5.2.

In general, aligning the revised IC and FP EWRs with the revised CLLMM EWRs presents some challenges. One of the key assumptions for the modelling exercise was that outside periods of the 'flow peak' delivered with the revised IC or FP EWRs, there are periods of low base flows (equivalent to SA Entitlement only). This appears to have a profound influence on meeting certain CLLMM metrics. Some key findings include:

- The timing of the revised IC and FP EWRs align well with the preferred timing of peak barrage outflows, however outside of these months, as a result of the return to Entitlement (i.e. low base flows), barrage outflows are significantly reduced, which impacts total annual outflow volumes (Table 26) (Appendix 5.2),
- A revised IC3 EWR (>30,000 ML/day QSA) is required to meet the target average annual barrage volume requirement for CLLMM 1; however, IC3 would need to occur more

frequently than currently specified (i.e. 65% of years) to meet the target frequency for the revised CLLMM1 EWR (i.e. 100% of years) (Table 26) (Appendix 5.2),

- A revised FP5 EWR (≥80,000 ML/day QSA) with a longer target duration (i.e. ≥30 days) is required to meet the target average annual barrage outflow volume for CLLMM4 (Table 26) (Appendix 5.2),
- The Coorong Hydrodynamic Model (CHM) outputs indicate that the target values for peak Coorong South Lagoon water levels are either not achieved, or only somewhat achieved, for most of the modelled scenarios of the revised IC, FP and CLLMM EWRs (Appendix 5.2),
- The CHM outputs also indicate that estuarine conditions within the Coorong North Lagoon may cease for short periods under the modelled scenarios for the revised IC and FP EWRs if there are sustained periods of low base flows outside of the EWR flow peaks (Appendix 5.2).

Table 26: Ability of the revised In-channel (IC) and Floodplain (FP) EWRs to achieve the target annual barrage outflow volume (GL/yr) metric and frequency (% of years) metrics for the Coorong, Lower Lakes and Murray Mouth (CLLMM) EWRs. Green cells indicate that target annual barrage volumes for the CLLMM EWRs were met. Blue indicates volumes were sub-optimal. Red indicates volumes were below the critical threshold.

	EWR - CLMM 1		CLLMM 2		CLLMM 3		CLLMM 4	
EWR #	Volume >2000	ARI (100%)	Volume >4000	ARI (50%)	Volume >8000	ARI (33%)	Volum e >10000	ARI (14%)
IC1 - target	470	95%	470	95%	470	95%	470	95%
IC2 - target	1317	75%	1317	75%	1317	75%	1317	75%
IC3 - target	2567	65%	2567	65%	2567	65%	2567	65%
IC4 - target	4174	45%	4174	45%	4174	45%	4174	45%
FP1 - target	5115	60%	5115	60%	5115	60%	5115	60%
FP2 - target	5513	45%	5513	45%	5513	45%	5513	45%
FP3 - target	6659	35%	6659	35%	6659	35%	6659	35%
FP4 - target	7923	25%	7923	25%	7923	25%	7923	25%
FP5 – target*	√	15%	√	15%	√	15%	√	15%

*FP5 EWR scenario was not modelled, but due to the longer duration (compared to FP4) it is assumed that all target annual barrage volumes for the CLLMM EWRs are met

The detailed modelled historical flows for the revised IC EWR scenarios in relation to the preferred Lower Lakes level envelope are provided in Appendix 5.2. Results indicate that:

- For a revised IC1 EWR, median flows are likely to align well with the preferred Lower Lakes peak season timing (Sep–Dec) and target water level ranges. However, flows are highly variable, and rate of rise in drier years may be much slower, peak later in the year (Dec–Jan) and reach maximum water level of ~0.7 m AHD, before receding quite rapidly. Flows in wetter years may rise more rapidly, peak earlier (Sep–Oct) and maintain maximum peak water levels for longer,
- For revised IC2 and IC3 EWRs, median flows are likely to align well with the preferred Lower Lakes peak season timing (Sep-Dec) and peak water levels. In drier years, rates of rise may be slower and peak later (Oct), and recede to minimum Lakes levels slowly. Flows in wetter years are likely to rise more rapidly and peak earlier (Sep) and maintain peak water levels for longer,

- For the revised FP1–FP 4 EWRs, median flows also align well with preferred Lower Lakes peak season timing and water levels, although flows in drier years may similarly have slower rates of rise.

Detailed Coorong Hydrodynamic Model (CHM) analysis summary and outputs are found in Appendix 5.2. In general, the modelled outputs indicate that the target metrics for the Coorong South Lagoon water levels do not align with most of the revised IC and FP EWR scenarios.

- For the revised IC1 EWR, the median CSL water levels are likely to vary between 0.4 to -0.1m AHD across Aug–Jan, with target peak CSL water levels (0 to 0.1 m AHD) only occurring Nov and Dec; indicating the revised target CLLMM 1 EWR metrics are somewhat met,
- For the revised IC2 EWR, median CSL water levels vary between 0.2 to 0.45 m AHD from Aug until late Dec. Water levels then decrease to -0.2 m AHD by the end of Feb indicating that the revised target CSL metrics for CLLMM 2 EWR are somewhat met,
- For the revised IC3 EWR, median water levels vary between 0.2 to 0.45 m AHD from Aug to early Jan. Water levels then decrease to 0 m AHD by early Feb, and to -0.1 m AHD by mid-Mar, indicating that revised target CSL metrics for CLLMM 2 are somewhat met,
- For the revised IC4 EWR, median CSL water levels vary between 0.37 to 0.55 m AHD between Aug–Jan, then fall to approximately 0.2 m AHD by Feb. Median water levels may exceed the target peak CSL water level (i.e. 0.45 m AHD) during Oct–late Nov,
- For all revised FP EWRs, the median CSL water levels exceed the revised target values for the CLLMM CSL water level metrics,
- For the modelled existing CLLMM 1 scenario that represents a barrage outflow of 650 GL/yr (i.e. CLLMM 650) the median CSL water levels range from 0.2 to 0.45 m AHD between Sep and mid-Oct, hence this scenario would not meet the target metrics for the revised CLLMM 1 EWR,
- For the existing CLLMM 1 scenario that represents a barrage outflow volume of 2,000 GL/yr (i.e. CLLMM 2000) the median CSL water levels stay within the desired range (0.2 to 0.45 m AHD) between Aug–Dec, indicating that the target metrics for the revised CLLMM 2 EWR may be somewhat met,
- For the existing CLLMM 2 scenario (4,000 GL/yr; CLLMM 4000), median CSL water levels stay within the desired range (0.2 to 0.45 m AHD) indicating that the target metrics for the revised CLLMM2 EWR may be met,
- For the existing CLLMM 3 scenario (6,000 GL/yr; CLLMM 6000), and the existing CLLMM 4 scenario (10,000 GL/yr; CLLMM 10000) the median CSL water levels exceed the target upper boundary of 0.45 m AHD across the desired period.

The modelled outputs for the estuarine extent (i.e. within the Coorong North Lagoon; where 0 km represents the Murray Mouth and 60 km represents Parnka Point) were analysed to determine when estuarine conditions may cease for short periods of time as a result of the modelled scenarios for the revised IC and FP EWR (Appendix 5.2).

- For the revised IC1 EWR, estuarine conditions may cease from mid-Aug to late Oct, and again in late Jan,
- For the revised IC2 EWR, estuarine conditions may cease between mid Aug to early Oct,
- For the revised IC3 EWR, estuarine conditions may cease mid-Aug,
- For the revised IC4 EWR, estuarine conditions may cease for a short period between mid Aug–early Sep,
- For the revised FP2, FP3 and FP4 EWRs, estuarine conditions may also cease during Feb–Apr,

- For the existing CLLMM EWR (i.e. with barrage outflow volumes of 650, 2000, 4000, 6000 and 10000 GL/yr) estuarine conditions persist all year round.

3.9 Revised contribution towards ecological targets

We have provided an updated assessment of anticipated contributions of the revised EWRs towards the ecological targets for the IC, FP and CLLMM EWRs (DEWNR 2015). The updated contributions are on a 5-point scale and represent the potential/likely contribution to the target: unlikely to contribute (U); difficult to detect (D); low contribution (L); moderate contribution (M); and high contribution (H). Updated contributions to ecological targets are presented for In-Channel (Table 27), Floodplain (Table 28) and CLLMM (Table 29).

*Table 27: Contributions of the revised In-channel (IC) EWRs towards the ecological targets outlined for the channel in the SA LTWP. Red cells = **U**nlikely to contribute; Orange Cells = **D**ifficult to detect contribution; Yellow cells = **L**ow contribution; Light Green cells = **M**oderate contribution and Dark Green cells = **H**igh contribution.*

In-channel Ecological Targets (DEWNR 2015)	EF	IC1	IC2	IC3	IC4
Open-water productivity shows a temporary shift from near zero or autotrophic dominance (positive Net Daily Metabolism) towards heterotrophy (negative Net Daily Metabolism) when QSA >30,000 ML/day.	U	U	L	M	H
Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep–Mar, at a maximum interval of 2 years.	U	D	L	M	H
Thermal stratification does not persist for more than 5 days at any time.	L	M	H	H	H
Basin Plan Objective: Salt export, averaged over the preceding 3 years, is ≥2 million tonnes per year.	U	L	M	H	H
Inundation periods in temporary wetlands have unrestricted lateral connectivity between the river and wetlands in >90% of inundation events.	U	L	L	M	H
Biovolume <4 mm^3/L for all Cyanobacteria, where a known toxin producer is dominant.	L	M	H	H	H
Biovolume <10 mm^3/L for all Cyanobacteria, where toxins are not present.	L	M	H	H	H
Basin Plan Target: Maintain dissolved oxygen above 50% saturation throughout water column at all times.	L	M	M	H	H
Establish and maintain freshwater lenses in near-bank recharge zones.	U	U	L	M	H
Maintain soil water availability, measured as soil water potential > -1.5 MPa at soil depth 20–50 cm, to sustain recruitment of long-lived vegetation across the elevation gradient in the target zone.	U	U	L	M	H
Reduce soil salinity (measured as EC 1:5) to <5000 $\mu S.cm^{-1}$ to prevent shifts in understorey plant communities to salt-tolerant functional groups across the elevation gradient in the target zone.	U	U	L	M	H
Annual median biofilm composition is not dominated (>80%) by filamentous algae.	U	D	M	M	H
Annual median biofilm C:N ratios are <10:1.	U	D	M	M	H
In standardized transects spanning the elevation gradient in the target zone, 70% of River Red Gums have a Tree Condition Index score ≥ 10.	U	U	L	M	H
A sustainable demographic is established to match the modelled profile for a viable River Red Gum population in existing communities spanning the elevation gradient in the target zone.	U	U	L	M	H
Species from the Plant Functional Group ‘flood-dependent/responsive’ occur in 70% of quadrats spanning the elevation gradient in the target zone at least once every 3 years.	U	U	L	M	H

In-channel Ecological Targets (DEWNR 2015)	EF	IC1	IC2	IC3	IC4
Native macrophytes from the emergent, amphibious and flood- dependent functional groups occur in 70% of quadrats spanning the elevation gradient in the target zone at least once every 3 years.	U	U	L	M	H
Expected fish species occur in each mesohabitat (channel, anabranch, wetlands) in each weir pool/reach.	U	U	L	M	H
Population age structure of Murray Cod includes recent recruits, subadults and adults in 9 years in 10.	U	L	M	H	H
Population age structure of Murray Cod indicates a large recruitment event 1 year in 5, demonstrated by a cohort representing >50% of the population.	U	L	M	H	H
Abundance (measured as CPUE) of Murray Cod increases by ≥50% over a 10-year period.	U	L	M	H	H
Population age structure of Golden Perch and Silver Perch includes YOY with sub-adults and adults in 8 years in 10.	U	U	L	M	H
Population age structure of golden perch and Silver Perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.	U	U	L	L	M
Abundance (measured as CPUE) of Golden Perch and Silver Perch increases by ≥30% over a 5-year period.	U	U	L	L	M
Population age structure of freshwater catfish includes YOY, with sub-adults and adults in 9 years in 10.	U	U	L	M	H
Population age structure of freshwater catfish indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.	U	U	D	M	H
Abundance (measured as CPUE) of freshwater catfish increases by ≥30% over a 5-year period.	U	U	D	M	H
The length-frequency distributions for foraging generalists include size classes showing annual recruitment.	H	H	M	L	L
The relative abundance and biomass of common carp does not increase in the absence of increases in abundance and biomass of flow-dependent native fish.	H	H	L	H	H

*Table 28: Contributions of the revised Floodplain (FP) EWRs towards the ecological targets outlined for the channel in the SA LTWP. Red cells = **U**nlikely to contribute; Orange Cells = **D**ifficult to detect contribution; Yellow cells = **L**ow contribution; Light Green cells = **M**oderate contribution and Dark Green cells = **H**igh contribution.*

Floodplain Ecological Targets (DEWNR 2015)	FP1	FP2	FP3	FP4	FP5
During inundation periods, record an increase in the abundance and diversity of invertebrate food resources, nutrients and DOC relative to those available during base flow.	M	H	H	H	H
Deliver flows in a manner that reduces the proportion of slow flowing habitat and increases the proportion of moderate velocity habitat thereby reinstating a diversity of velocity classes representative of natural conditions.	H	H	H	H	H
Discharge, water level and duration metrics of planned e-water represent a seasonally variable hydrograph.	H	H	H	H	H
Maintain dissolved oxygen above 50% saturation throughout water column at all times, in connected waters.	H	H	H	H	H
Establish and maintain freshwater lenses in near-bank recharge zones.	H	H	H	H	H
Maintain soil water availability, measured as soil water potential at soil depth 20–50cm, greater than -1.5 MPa in order to sustain the recruitment of long-lived vegetation.	M	M	H	H	H

Floodplain Ecological Targets (DEWNR 2015)	FP1	FP2	FP3	FP4	FP5
Reduce soil salinity (measured as EC 1:5) to below 5,000 $\mu S.cm^{-1}$ to prevent permanent shifts in understorey plant communities to salt tolerant functional groups.	M	M	H	H	H
Maintain soil sodicity below the exchangeable sodium percent (ESP) value of 15 (highly sodic).	M	M	H	H	H
Limit the maximum rate of drawdown (averaged over 3 consecutive days) to ≤0.025 m/day (0.05m/day in any one day) to minimise risk of bank failure.	H	H	H	H	H
In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all RRG trees have a Tree Condition Index Score (TCI) ≥10.	D	D	L	M	H
A sustainable demographic that matches the modelled profile for a RRG viable population is established within existing communities across the floodplain elevation gradient.	D	D	L	L	M
In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all BB trees have a TCI ≥10.	U	D	D	L	M
A sustainable demographic that matches the modelled profile for a viable Black Box population is established within existing communities across the floodplain elevation gradient.	U	D	D	D	L
In standardised transects that span the Floodplain PEA elevation gradient and existing spatial distribution, >70% of all River Cooba trees have a TCI ≥10.	D	D	D	L	L
A sustainable demographic that matches the modelled profile for a viable River Cooba population is established within existing communities across the floodplain elevation gradient.	D	D	D	D	L
In standardised transects that span the floodplain elevation gradient and existing spatial distribution, ≥70% of Lignum plants have a Lignum Condition Score (LCI) ≥6 for colour.	D	D	L	H	H
In aquatic zones, a minimum of 40% of cells either inundated or dry containing inundation dependent or amphibious plant taxa once every two years on average with maximum interval no greater than 4 years. Native water dependent species richness >30 across the Floodplain PEA.	D	L	M	M	H
In aquatic zones, a minimum of 80% of cells either inundated or dry containing native flood dependent or amphibious plant taxa once every four years on average with maximum interval no greater than 6 years. Native water dependent species richness >50 across the Floodplain PEA.	D	D	L	M	H
In shedding floodplain zones, a minimum of 20% of cells containing native flood dependent or amphibious plant taxa once every three years on average with maximum interval no greater than 5 years. Native flood dependent and amphibious species richness >20 across the Floodplain PEA.	L	L	M	M	H
In shedding floodplain zones, of 40% of cells containing native flood dependent or amphibious plant taxa once every five years on average with maximum interval no greater than 7 years. Native flood dependent and amphibious species richness >30 across the Floodplain PEA.	D	L	M	M	H
In shedding floodplain zones, of 65% of cells containing native flood dependent or amphibious plant taxa once every seven years on average with maximum interval no greater than 10 years. Native flood dependent and amphibious species richness >50 across the Floodplain PEA.	D	D	L	M	H

Floodplain Ecological Targets (DEWNR 2015)	FP1	FP2	FP3	FP4	FP5
Population age structure of Murray Cod includes recent recruits, sub-adults and adults in 9 years in 10.	M	M	H	H	H
Population age structure of Murray Cod indicates a large recruitment event 1 year in 5, demonstrated by a cohort representing >50% of the population.	M	M	H	H	H
Abundance (measured as CPUE) of Murray Cod increases by ≥50% over a 10-year period	M	M	H	H	H
Population age structure of freshwater catfish includes YOY, with sub-adults and adults in 9 years in 10.	M	M	H	H	H
Population age structure of freshwater catfish indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.	M	M	H	H	H
Abundance (measured as CPUE) of freshwater catfish increases by ≥30% over a 5-year period.	M	M	M	H	H
Population age structure of Golden Perch and Silver Perch includes YOY with sub-adults and adults in 8 years in 10.	M	M	M	H	H
Population age structure of Golden Perch and Silver Perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.	H	H	H	H	H
Abundance, as measured by CPUE, of Golden Perch and Silver Perch increases by ≥30% over a 5-year period.	H	H	H	H	H
The length-frequency distributions for wetland/floodplain (native fish) specialists within aquatic zones across the Floodplain PEA include size classes showing annual recruitment.	L	L	M	H	H
Increase range and abundance of wetland/floodplain (native fish) specialists within aquatic zones across the Floodplain PEA.	L	L	M	H	H
The relative abundance and biomass of non-native species does not increase in the absence of increases in abundance and biomass of native fish.	M	M	H	H	H
Each of 8 riparian frog species present within the Floodplain PEA will be recorded across the floodplain in any three-year period.	M	H	H	H	H
Tadpoles will be recorded from 8 species in later stages of metamorphosis across the Floodplain PEA in any three-year period.	M	M	H	H	H
Minimum inundation periods required for successful breeding by a range of water bird species are provided. Preliminary minimum 120 days.	D	L	M	H	H
During continental dry periods an increase in the observed to expected ratio of waterbird species.	M	M	H	H	H
Each of the bird species known to utilise similar floodplain woodland habitats in the region will be recorded at 50% sites across the Floodplain PEA in any three-year period.	D	D	L	M	H
Each of the reptile species known to utilise similar floodplain/woodland habitats in the region will be recorded at 50% sites across the Floodplain PEA in any three-year period.	D	D	L	M	H
Each of the native mammal species known to utilise similar floodplain/woodland habitats in the region will be recorded at 50% sites across the Floodplain PEA in any three-year period.	D	D	L	M	H

*Table 29: Contributions of the revised Coorong, Lower Lakes and Murray Mouth (CLLMM) EWRs towards the ecological targets outlined for the channel in the SA LTWP. Red cells = **U**nlikely to contribute; Orange Cells = **D**ifficult to detect contribution; Yellow cells = **L**ow contribution; Light Green cells = **M**oderate contribution and Dark Green cells = **H**igh contribution.*

CLLMM Ecological Targets (DEWNR 2105)	Revised CLLMM EWR #			
	1	2	3	4
Abundances, area of occupation and extent of occurrence of TLM target waterbird species to be above defined median reference values (median of data from the 15 years between 2000 and 2014).	L	H	H	M
Detect annual breeding activity in waterbird species that are expected to breed annually at the site and at least two breeding events in any four consecutive years in species that breed regularly at the site.	L	H	H	M
Provide functional mudflat habitat to sustain active shorebird foraging behaviour during November-March with a foraging effort of <50%.	L	H	H	M
Maintain abundances of 12 waterbird species at or above 1% of the total flyway population size.	L	H	H	M
A spatio-temporally diverse fish community is present including all 23 fish families stated in the Ramsar site draft Ecological Character Description.	M	H	H	H
Annual detection of juvenile Catadromous fish at abundances ≥ that of defined 'Recruitment Index' values (44.5 for Congolli, and 6.1 for Common galaxias).	M	H	H	H
Annual detection of migration for Anadromous species (short-headed and pouched lamprey) at index values of >0.6.	L	H	H	H
Maximise fish passage connectivity between the Lower Lakes and Coorong, and between the Coorong and the sea by allowing fishways to operate year-round.	H	H	H	H
Maintain or improve abundances of Murray hardyheads so that 'Relative Abundance Index' values of ≥1 are achieved on an annual basis.	M	M	M	M
Maintain or improve abundances of pygmy perch so that 'Relative Abundance Index' values of ≥1 are achieved on an annual basis.	H	H	H	H
Detect recruitment success of Murray hardyheads at least every second year.	M	M	M	M
Detect recruitment success of pygmy perch at least every second year.	H	H	H	H
Maintain or improve abundances, distribution and recruitment of black bream with population condition score ≥3.	M	H	H	H
Maintain or improve abundances, distribution and recruitment of greenback flounder with population condition score ≥3.	M	H	H	H
Facilitate regular recruitment and a broader distribution of juvenile mulloway.	D	L	M	H
Maintain an average CPUE of small-mouthed hardyhead sampled in spring/early summer of >120 for adults, and >790 for juveniles.	M	H	H	H
Maintain the proportional abundance of small-mouthed hardyhead juveniles at >60% in 75% of defined monitoring sites within the CLLMM.	H	H	H	H
Macroinvertebrate taxonomic distinctness falls within the expected ranges of a regional reference - Lower Lakes.	M	M	M	M
Macroinvertebrate taxonomic distinctness falls within the expected ranges of a regional reference - Coorong.	M	H	H	M
The distribution of macroinvertebrate species remains within or above the species-specific reference level for their index of occurrence - Lower Lakes.	M	M	M	M
The distribution of macroinvertebrate species remains within or above the species-specific reference level for their index of occurrence – Coorong.	M	H	H	M
The area of occupancy where abundance and biomass are at or above the reference level should be >20% of the monitoring sites – Coorong.	M	H	H	H
The macroinvertebrate community has a higher multivariate similarity to the community present in years with flow than without flow - Lower Lakes.	M	M	M	M

CLLMM Ecological Targets (DEWNR 2105)	Revised CLLMM EWR #			
	1	2	3	4
The macroinvertebrate community has a higher multivariate similarity to the community present in years with flow than without flow – Coorong.	M	H	H	M
Median grain size of sediments in the Coorong and Murray Mouth will remain between 125–500 µm.	M	H	H	M
Sediment organic matter content between 1 and 3.5 % dry weight in the Coorong and Murray Mouth.	H	H	M	M
A continuous distribution of *Ruppia tuberosa* beds along a 50 km section of the southern Coorong (excluding outliers).	L	M	H	H
Within the abovementioned distribution, 80% of the monitored sites should have *Ruppia tuberosa* plants present in winter and summer.	L	M	M	H
50% of sites with *Ruppia tuberosa* to exceed the local site indicators for a healthy *Ruppia tuberosa* population.	D	L	M	H
Support a resilient *Ruppia tuberosa* population with seed densities of 2000 seeds/m^2 by 2019 and 50% of sites having 60% cover in winter and a seed bank of 10,000 seeds/m^2 by 2029 in the Coorong South Lagoon.	L	M	H	H
Maintain or improve diversity of aquatic and littoral vegetation in the Lower Lakes as quantified using the CLLMM vegetation indices.	H	H	H	H
Barrage outflows sufficient to maintain electrical conductivity in Lake Alexandrina at a long-term average of 700 $\mu S.cm^{-1}$, below 1,000 $\mu S.cm^{-1}$ 95% of years and below 1,500 $\mu S.cm^{-1}$ 100% of the time.	M	H	H	H
To support aquatic habitat: maintain a salinity gradient from 0.5 ppt to 35ppt between the Barrages and Murray Estuary area, <45 ppt in the North lagoon, and from 60 ppt to 100 ppt in the South lagoon.	H	H	H	H
Maintain an open Murray Mouth, as indicated when the Diurnal Tidal Ratio (DTR) at Goolwa exceeds 0.3, with minimum DTR values of 0.05 and 0.2 at Tauwitchere and Goolwa respectively.	H	H	H	H
Maintain a minimum annual flow required to keep the Murray Mouth open (730—1,090 GL/yr).	H	H	H	H

4 Conclusions

The EWRs have been revised with reference to new knowledge, expert opinion and with the use of revised modelling outputs and/or new modelling tools to maximise the likelihood of achieving the ecological objectives and targets outlined in the SA LTWP. It should be noted that EWRs attempt to define flows for a complex assemblage of species, ecosystem processes and conditions with the broad objective of achieving a 'healthy, functioning system'. The EWRs have been revised using the best available information. As new knowledge and tools are continually being generated these EWRs should be periodically reviewed in line with adaptive management principles.

Feedback on the application of IC and FP EWRs has emphasised certain issues, mostly concerning the confusion where discharge (Q) ranges in the existing IC EWRs tended to overlap. Overall the revisions to the IC and FP EWRs were minor, and primarily focused on explicitly specifying the target discharge values that will provide the greatest likelihood of maximising ecological objectives, especially those related to stepped, incremental improvements in longitudinal connectivity, in-channel velocities and lateral connectivity. Within South Australia, there is a marked disparity between the natural modelled conditions and observed flow conditions of the last four decades. Annual flow volumes tend to be much less than natural (Thoms et al. 2001), with a much greater frequency of low base flows (<10,000 ML/day) compared to unregulated conditions. Flows between 30,000 and 60,000 ML/day (i.e. represented by IC3–FP2 EWRs) inundate between 11–30% River Red Gum woodlands, 3–25% lignum shrublands, 50–70% of sedgelands and 44–66% temporary wetlands but now occur much less frequently in recent decades, compared to unregulated conditions.

Another issue identified was determining whether the anticipated ecological outcomes were likely to be achieved if EWRs delivery occurred for shorter durations and/or there were rapid drops in flow peaks. There was acknowledgement from the experts that longer durations are likely to increase the certainty of maximising the anticipated ecological outcomes and should be sought, wherever possible. However, EWR/flow metrics interact and there are trade-offs between natural modelled duration in relation to the other flow metrics (and vice versa). Based on expert elicitation, the target discharge values that were specified relative for each EWR, and the changes to timing, frequency and critical maximum interval periods, were often viewed as posing a potentially greater risk than shortened flow durations. For instance, the median duration of flows between 30,000 and 60,000 ML/day have almost halved in recent decades compared to natural modelled conditions, whereas the median flow durations of larger floodplain inundating events (>70,000 $ML.day^{-1}$) are more similar to unregulated conditions but the frequency of these higher flows has markedly decreased, resulting in increased periods of time the river is disconnected from the floodplain (Thoms et al. 2000). Ideally, further research would be undertaken to compare the trade-off outcomes between the duration and frequency of EWRs.

Another key area of uncertainty regarding flow durations is around the relationship between the duration of the flow pulse (measured in-channel as the number of days flows are above a specified discharge) and the duration of inundation (i.e. water retention) on corresponding parts of the floodplain. For example, does a specified FP EWR flow pulse duration equal the number of days water is retained on a shedding floodplain? The distinction between flow pulse duration and inundation retention time is an important consideration, particularly for biological responses on the floodplain that are strongly linked to long persistence (i.e. duration) of water, such as tadpole metamorphosis and waterbird breeding. Further research linking in-channel flow pulse duration to inundation retention time on floodplain assets would be valuable.

The target timing for IC EWRs were contracted (i.e. revised from Sep–Mar to Oct–Dec) to maximise anticipated ecological outcomes because flow pulses that occur with warmer water temperatures are important in triggering spawning and facilitating dispersal of flow dependent fish specialists such as Golden Perch and Silver Perch (Mallen-Cooper and Stuart 2003; Cheshire et. al. 2015; Zampatti et. al. 2015). Alternatively, the target timing for FP EWRs has remained the same (Sep–Dec), especially in view of the fact that the peak timing of larger floodplain inundating flows under current conditions has shifted slightly (Aug–Sep) compared to under unregulated conditions (Sep–Oct) (Thoms et al. 2000). The existing EWRs specified a wider timing window to account for the contributions that earlier or later flows may provide. For instance, the Darling River historically contributed regular summer flows to the Lower Murray (Thoms et al. 2000). It is anticipated that further development of EWR evaluation criteria, such as defining envelope and critical threshold values for all EWR individual metrics, would allow a process for evaluating the contribution of flows that occur later (or earlier) than the specified target timing.

Another key assumption for IC and FP EWRs are that if the desired rates of rise and fall in flow and water level are met, then durations for any of the higher FP EWRs (e.g. FP2, duration ≥20 days) will correspond with longer durations for the next lower EWR (e.g. FP1, duration ≥40 days); however this assumption needs to be validated.

Feedback on the practical application of the existing CLLMM EWRs highlighted a range of issues, such as the complex inter-relationships between CLLMM components (e.g. barrage outflows, Lower Lakes and CSL levels), the narrow bands of optimal duration for the CSL water levels and the perceived inability to influence certain metrics under particular discharge volumes.

The CLLMM presents several challenges with annual environmental water planning, as the system must be managed to include a multi-year sequence of flows, hence the total barrage outflow volumes of the preceding years must be considered. Whilst there were no proposed major revisions to the annual barrage outflow volumes, the proposed target values were more explicitly clarified as the average barrage outflow volume required each year to maximise connectivity between the Lower Lakes, Murray Mouth and Coorong components and ensure that the multi-year total barrage outflow volumes are met.

The timing of the Lower Lakes levels metrics was revised to so that water levels peak in spring-early summer and reach a minimum in autumn to early winter. This annual cycle is representative of natural conditions (as opposed to following the timing of Entitlement delivery) and is likely to improve vegetation responses (Nicol et al. 2019) and improve habitat and resource availability for small-bodied fish populations (Wedderburn and Barnes 2019). The intra-annual pattern of peak barrage outflow timing was also aligned with the revised Lower Lakes level timing.

In the existing CLLMM EWRs, the CSL EWR metrics were primarily derived to maximise Ruppia outcomes. With improved knowledge, the CLLMM 1 peak CSL water levels were revised to explicitly focus on maintaining existing adult Ruppia populations as well as maximising waterbird outcomes due to improved mudflat habitat availability. The CSL water level metrics for CLLMM 2 and CLLMM 3 EWRs were revised to improve Ruppia populations by encouraging flower and seed/turion production. Target values for the CLLMM 4 CSL water level metrics were removed due to likelihood of water levels exceeding the optimal water level range because of the magnitude of total annual barrage volumes.

In general, aligning the EWRs also presents some challenges with one of the key assumptions being that outside of an EWR 'flow peak' there are periods of low base flows (equivalent to SA Entitlement only). When modelled, this flow regime appears to have a profound influence on meeting certain CLLMM metrics, such as annual barrage outflow volumes, or that the target values for the Coorong South Lagoon water levels will be achieved and that extent of estuarine conditions in the Coorong North Lagoon can be maintained throughout the year. It is proposed that more EWR scenarios be modelled and that the optimal flow regime required to support Coorong South Lagoon outcomes be further investigated.

As part of this project, when revising the EWRs we sought to provide a transparent framework to evaluate the success of meeting individual metrics through the development of target, envelope, sub-optimal and critical threshold values, which were used in the revision process to strengthen the justification for any changes to EWR metrics that were made. For example, instead of focusing on an evaluation approach of a binary met/not met; we shifted our focus to considering values that may potentially assist in evaluating whether individual EWR metrics have been met (success), mostly met, somewhat met, or not met (failed). The development of evaluation criteria for individual EWR metrics provides a first step in the evaluation process, but the evaluation of 'whole-of-EWR' comprises an amalgamation of evaluation responses to individual metrics within that EWR. On a sliding scale of EWR = met → EWR = not met, the extreme ends are clear (e.g. all metrics within an EWR are met = EWR met/success; or all metrics within an EWR are not met = EWR not met/fail). However, the gradient from 'mostly met' → 'mostly failed' can be quite large and comprised of various combinations of met, mostly met, somewhat met and not met. The 'whole-of-EWR' evaluation therefore requires determining whether ALL metrics must be met to pass, or whether some metrics are more critical than others and should therefore be weighted accordingly. In relation to CLLMM EWRs additional consideration needs to be given to 'representativeness' of the components of CLLMM (i.e. metrics relating to barrage outflows, Lower Lakes and the Coorong South Lagoon). For example, would at least one metric need to be met from each of the three CLLMM components for the EWR to pass? Or would the overall score need to reflect the outcomes for CLLMM as a whole? Hence, the evaluation process needs to be incorporated within a hierarchical framework for assessing EWRs according to: *i*) individual metrics; *ii*) whole-of-EWRs; *iii*) Priority Environmental Assets (PEAs); and *iv*) whole-of-system (South Australia) across both annual and multi-year timeframes. Whilst values were used throughout the revision process to assist in our analysis and to strengthen the justification of the proposed revisions; we strongly recommend that the development and use of envelope, sub-optimal and critical threshold values (as examples) require ongoing refinement, as per adaptive management principles.

Areas to focus attention on in the next review of the SA LTWP include: *i*) refining the process for evaluating EWRs in a consistent, transparent and automated fashion, *ii*) reviewing the alignment between IC,FP EWRs and CLLMM EWRs (incorporating any improvements in monitoring or modelling outcomes) and *iii*) reviewing individual metrics in light of new knowledge.

5 Appendices

5.1 Freshchecker outputs

Various In-channel (IC) and Floodplain (FP) EWR scenarios were trialled and assessed using the Freshchecker Tool (NSW Office of Environment and Heritage 2019) and compared to natural modelled conditions (i.e. modelled without development data; years 1895–2009, MDBA). In addition, observed QSA (ML/da) data were compared from two periods, where 1977 – 1995 represented a period of “less extensive development” and 1996 – 2017 represented a period of “more extensive development” (Table A 1 to Table A 9).

The analysis and development of revised EWR scenarios included inputs of the following specified EWR metrics (Table 8). The specified values for each individual EWR metric were applied in combination (i.e. discharge × duration × timing × frequency × maximum interval). For each EWR scenario, the model provided outputs for a range of parameters calculated from natural modelled (modelled without development), observed pre-development (1977–1996) and observed post-development (1997–2017) (Table 9). The EWR scenarios passed if the following conditions were met:

- The specified value of the EWR duration (days) was less than the median value for the duration of flows that occurred in natural modelled conditions,
- The specified value for the EWR frequency (% of years) was within 10% of the flow frequency that occurred under natural modelled conditions
- The specified maximum interval (i.e. duration of dry spell) of EWR scenarios were less than the 95th percentile value under natural modelled conditions.

Table A 1: Freshchecker input/output values for revised In-channel (IC1) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario IC1	Input values							Output values							
				Timing							Maximum interval			Duration	
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Start month	End month	Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Median	95%ile	Maximum	Median	25%ile
								Modelled natural conditions (without development model)							
Target	10,000	10,000,000	60	Sep	Mar	95	365	96%	1	1-2	176.5	279	586	151	45
Envelope*	9,000	10,000,000	30	Aug	Apr	90	548	99%	1	1-2	92	203	527	166	40
Sub-optimal*	7,000	10,000,000	25	Jul	Jun	85	730	99%	1	1-4	42	154	473	212	48
								Observed data 1977–1996 (less extensive development period)							
Target	10,000	10,000,000	60	Sep	Mar	95	365	43%	1	1-1	163.5	832.5	1007	7	2
Envelope*	9,000	10,000,000	30	Aug	Apr	90	548	90%	1	1-4	99	322	606	18	3
Sub-optimal*	7,000	10,000,000	25	Jul	Jun	85	730	95%	2	1-5	55.5	316.25	622	4	2
								Observed data 1997–2017) more extensive development period)							
Target	10,000	10,000,000	60	Sep	Mar	95	365	35%	1	1-2	250	2506.4	3516	3	1
Envelope*	9,000	10,000,000	30	Aug	Apr	90	548	50%	1.5	1-3	92	1642	1774	5	1
Sub-optimal*	7,000	10,000,000	25	Jul	Jun	85	730	70%	1	1-3	108	1031.7	1488	3	1

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

Table A 2: Freshchecker input/output values for revised In-channel (IC2) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario IC2	**Input values**							**Output values**								
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Timing		Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Maximum interval			Duration	
				Start month	End month						Median	95%ile	Maximum	Median	25%ile
								Modelled natural conditions (without development model)							
Target	20,000	10,000,000	60	Oct	Dec	75	730	84%	1	1-1	274	639.25	660	92	80.5
Envelope*	19,000	10,000,000	30	Sep	Mar	70	913	95%	1	1-2	216	341	961	125	35
Sub-optimal*	15,000	10,000,000	25	Jul	Jun	65	1095	99%	2	1-4	67	226	496	92	26
								Observed data 1977–1996 (less extensive development period)							
Target	20,000	10,000,000	60	Oct	Dec	75	730	24%	1	1-1	163.5	883.15	1037	32.5	22
Envelope*	19,000	10,000,000	30	Sep	Mar	70	913	62%	1	1-2	123	635.5	974	37	11.5
Sub-optimal*	15,000	10,000,000	25	Jul	Jun	65	1095	86%	1	1-3	131	442.05	613	47	15
								Observed data 1997–2017) more extensive development period)							
Target	20,000	10,000,000	60	Oct	Dec	75	730	10%	1	1-1	3470	4703	4840	18.5	6.5
Envelope*	19,000	10,000,000	30	Sep	Mar	70	913	35%	1	1-2	238	2427.3	3555	34	7
Sub-optimal*	15,000	10,000,000	25	Jul	Jun	65	1095	35%	2	1-3	72	2098.35	3431	12	3

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

Table A 3: Freshchecker input/output values for revised In-channel (IC3) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario IC3	Input values							Output values							
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Timing		Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Maximum interval			Duration	
				Start month	End month						Median	95%ile	Maximum	Median	25%ile
								Modelled natural conditions (without development model)							
Target	30,000	10,000,000	60	Oct	Dec	65	913	72%	1	1-1	279.5	815.15	1027	87	59
Envelope*	29,000	10,000,000	30	Sep	Mar	60	1095	87%	1	1-2	244	620	642	102	32.75
Sub-optimal*	25,000	10,000,000	25	Jul	Jun	55	1460	92%	1	1-3	157	500.2	618	77	19
								Observed data 1977–1996 (less extensive development period)							
Target	30,000	10,000,000	60	Oct	Dec	65	913	19%	1	1-1	169	898.9	1037	27	11.25
Envelope*	29,000	10,000,000	30	Sep	Mar	60	1095	52%	1	1-2	158	881.6	1007	28	8
Sub-optimal*	25,000	10,000,000	25	Jul	Jun	55	1460	81%	1	1-4	118	575.8	651	30.5	10
								Observed data 1997–2017) more extensive development period)							
Target	30,000	10,000,000	60	Oct	Dec	65	913	10%	1	1-1	3486	4733.4	4872	13.5	4.5
Envelope*	29,000	10,000,000	30	Sep	Mar	60	1095	15%	1	1-1	1415	4526.3	4872	9	3.75
Sub-optimal*	25,000	10,000,000	25	Jul	Jun	55	1460	25%	1	1-2	164	2911.1	3566	17	8

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

Table A 4: Freshchecker input/output values for revised In-channel (IC4) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario IC4	**Input values**							**Output values**								
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Timing		Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Maximum interval			Duration		
				Start month	End month						Median	95%ile	Maximum	Median	25%ile
								Modelled natural conditions (without development model)								
Target	40,000	10,000,000	60	Oct	Dec	45	1278	55%	1	1-1	638	1344.2	1751	71	35.5
Envelope*	39,000	10,000,000	30	Sep	Mar	40	1460	78%	1	1-2	262	653.45	1017	88	40.25
Sub-optimal*	35,000	10,000,000	25	Jul	Jun	35	1825	85%	1	1-3	216	612.1	889	84	18.5
								Observed data 1977–1996 (less extensive development period)								
Target	40,000	10,000,000	60	Oct	Dec	45	1278	10%	1	1-1	169	1037	1419	27	11.5
Envelope*	39,000	10,000,000	30	Sep	Mar	40	1460	48%	1	1-2	158	888.4	1007	27	11
Sub-optimal*	35,000	10,000,000	25	Jul	Jun	35	1825	62%	1	1-3	148.5	635.7	768	27	8.75
								Observed data 1997–2017) more extensive development period)								
Target	40,000	10,000,000	60	Oct	Dec	45	1278	5%	1	1-1	7038	7038	7038	21	14
Envelope*	39,000	10,000,000	30	Sep	Mar	40	1460	15%	1	1-1	1453	4542.7	4886	33	13
Sub-optimal*	35,000	10,000,000	25	Jul	Jun	35	1825	20%	1	1-1	880	4366.45	4882	24	15

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

Table A 5: Freshchecker input/output values for revised In-channel (FP1) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario FP1	**Input values**							**Output values**							
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Timing		Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Maximum interval			Duration	
				Start month	End month						Median	95%ile	Maximum	Median	25%ile
								Modelled natural conditions (without development model)							
Target	50,000	10,000,000	40	Sep	Dec	60	1095	58%	1	1-2	315	1024.5	1888	76.5	36
Envelope*	49,000	10,000,000	30	Aug	Mar	50	1278	67%	1	1-2	282	996	1442	68	21.5
Sub-optimal*	45,000	10,000,000	25	Jul	Jun	45	1460	74%	1	1-3	263	911.1	986	64	21
								Observed data 1977–1996 (less extensive development period)							
Target	50,000	10,000,000	40	Sep	Dec	60	1095	38%	1	1-1	163.5	1014.85	1419	24.5	9
Envelope*	49,000	10,000,000	30	Aug	Mar	50	1278	43%	1	1-2	163.5	984.4	1013	28	14
Sub-optimal*	45,000	10,000,000	25	Jul	Jun	45	1460	48%	1	1-2	153.5	729.65	1012	29.5	17.5
								Observed data 1997–2017) more extensive development period)							
Target	50,000	10,000,000	40	Sep	Dec	60	1095	5%	1	1-1	7062	7062	7062	39	26
Envelope*	49,000	10,000,000	30	Aug	Mar	50	1278	10%	1	1-1	3466	4750.3	4893	12.5	8.75
Sub-optimal*	45,000	10,000,000	25	Jul	Jun	45	1460	15%	1	1-1	1615	4563.4	4891	17	4

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

Table A 6: Freshchecker input/output values for revised In-channel (FP2) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario FP2	**Input values**							**Output values**								
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Timing		Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Maximum interval			Duration		
				Start month	End month						Median	95%ile	Maximum	Median	25%ile
								Modelled natural conditions (without development model)								
Target	60,000	10,000,000	20	Sep	Dec	45	1278	60%	1	1-2	328	1050.7	1490	63	29.75
Envelope*	59,000	10,000,000	15	Aug	Mar	40	1460	61%	1	1-3	311	1008.2	1489	60	25.75
Sub-optimal*	55,000	10,000,000	10	Jul	Jun	30	1825	67%	1	1-3	262	995.8	1452	65	31.5
								Observed data 1977–1996 (less extensive development period)								
Target	60,000	10,000,000	20	Sep	Dec	45	1278	38%	1	1-2	158	1049.6	1419	29	18.5
Envelope*	59,000	10,000,000	15	Aug	Mar	40	1460	38%	1.5	1-2	148.5	1010.5	1419	24	10
Sub-optimal*	55,000	10,000,000	10	Jul	Jun	30	1825	48%	1.5	1-2	158	726.6	1012	24	8
								Observed data 1997–2017) more extensive development period)								
Target	60,000	10,000,000	20	Sep	Dec	45	1278	10%	1	1-1	3524.5	4766.95	4905	24	15.5
Envelope*	59,000	10,000,000	15	Aug	Mar	40	1460	10%	1.5	1-2	2050	4618.6	4904	16	2.5
Sub-optimal*	55,000	10,000,000	10	Jul	Jun	30	1825	20%	1	1-1	1453	3333.4	3631	38	10

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

Table A 7: Freshchecker input/output values for revised In-channel (FP3) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario FP3	Input values							Output values							
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Timing		Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Maximum interval			Duration	
				Start month	End month						Median	95%ile	Maximum	Median	25%ile
								Modelled natural conditions (without development model)							
Target	70,000	10,000,000	20	Sep	Dec	35	1460	46%	1	1-2	609	1431.7	1888	48	27
Envelope*	69,000	10,000,000	15	Aug	Mar	30	1643	50%	1	1-3	329	1385.5	1869	52	28
Sub-optimal*	65,000	10,000,000	10	Jul	Jun	25	1825	59%	1	1-3	320	1019	1499	52.5	24.5
								Observed data 1977–1996 (less extensive development period)							
Target	70,000	10,000,000	20	Sep	Dec	35	1460	24%	1	1-2	169	1288	1419	22	17
Envelope*	69,000	10,000,000	15	Aug	Mar	30	1643	29%	2	1-2	158	1057.6	1419	21	17.75
Sub-optimal*	65,000	10,000,000	10	Jul	Jun	25	1825	33%	1	1-2	158	1053.6	1419	21.5	9.25
								Observed data 1997–2017) more extensive development period)							
Target	70,000	10,000,000	20	Sep	Dec	35	1460	5%	1	1-1	7077	7077	7077	32	32
Envelope*	69,000	10,000,000	15	Aug	Mar	30	1643	10%	1	1-1	3503	4806.2	4951	52	42.5
Sub-optimal*	65,000	10,000,000	10	Jul	Jun	25	1825	10%	1.5	1-2	2041	4627.6	4915	22.5	7.75

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

Table A 8: Freshchecker input/output values for revised In-channel (FP4) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario FP4	**Input values**							**Output values**								
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Timing		Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Maximum interval			Duration		
				Start month	End month						Median	95%ile	Maximum	Median	25%ile	
								Modelled natural conditions (without development model)								
Target	80,000	10,000,000	10	Sep	Dec	25	1460	42%	1	1-2	346.5	1440.6	3716	33	18.5	
Envelope*	79,000	10,000,000	8.5	Aug	Mar	20	1643	45%	1	1-2	340.5	1397.25	2393	34	19	
Sub-optimal*	75,000	10,000,000	7	Jul	Jun	15	1825	47%	1	1-2	308.5	1374.65	1875	38.5	24	
								Observed data 1977–1996 (less extensive development period)								
Target	80,000	10,000,000	10	Sep	Dec	25	1460	24%	2	1-2	148.5	1249.15	1419	27.5	18	
Envelope*	79,000	10,000,000	8.5	Aug	Mar	20	1643	24%	2	1-2	158	1263.1	1419	30	15	
Sub-optimal*	75,000	10,000,000	7	Jul	Jun	15	1825	29%	2	1-2	158	1063.2	1419	20	13	
								Observed data 1997–2017) more extensive development period)								
Target	80,000	10,000,000	10	Sep	Dec	25	1460	5%	1	1-1	7082	7082	7082	25	25	
Envelope*	79,000	10,000,000	8.5	Aug	Mar	20	1643	10%	1	1-1	3525	4820.1	4964	28.5	27.25	
Sub-optimal*	75,000	10,000,000	7	Jul	Jun	15	1825	10%	1.5	1-2	2061	4669.2	4959	18	5.5	

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

Table A 9: Freshchecker input/output values for revised In-channel (FP5) EWR scenarios. Suggested target (blue) and envelope/sub-optimal (grey) input vales were analysed. Output values represent analysis of observed River Murray discharge (QSA, ML/day) data from the South Australian Border gauge (#4261001) compared to natural modelled conditions (i.e. 'modelled without development' data, years 1895–2009). Dark green cells denote the metric has passed. Red denote the metric has failed.

EWR scenario FP5	**Input values**							**Output values**								
	Discharge (ML/day)	Maximum Discharge (ML/day)	Duration	Timing		Frequency (% years)	Maximum interval (days)	Frequency (% of years)	Median # events per year	Range # events per year	Maximum interval			Duration		
				Start month	End month						Median	95%ile	Maximum	Median	25%ile	
								Modelled natural conditions (without development model)								
Target	80,000	10,000,000	30	Sep	Dec	15	2738	30%	1	1-2	629	2954.2	4116	33	18.5	
Envelope*	79,000	10,000,000	25	Aug	Mar	10	2920	37%	1	1-2	612	2320	4072	34	19	
Sub-optimal*	75,000	10,000,000	20	Jul	Jun	5	3103	46%	1	1-2	334.5	1382.45	1875	38.5	24	
								Observed data 1977–1996 (less extensive development period)								
Target	80,000	10,000,000	30	Sep	Dec	15	2738	14%	1	1-1	178.5	1315.45	1419	27.5	18	
Envelope*	79,000	10,000,000	25	Aug	Mar	10	2920	24%	1	1-1	178.5	1315.45	1419	30	15	
Sub-optimal*	75,000	10,000,000	20	Jul	Jun	5	3103	24%	2	1-2	148.5	1247.45	1419	20	13	
								Observed data 1997–2017) more extensive development period)								
Target	80,000	10,000,000	30	Sep	Dec	15	2738	0%	#NUM!	N//A	N/A	N//A	N/A	N//A	N/A	
Envelope*	79,000	10,000,000	25	Aug	Mar	10	2920	10%	1	1-1	3525	4820.1	4964	28.5	27.25	
Sub-optimal*	75,000	10,000,000	20	Jul	Jun	5	3103	10%	1	1-1	3515	4814.6	4959	18	5.5	

*Please note that the envelope/sub-optimal values (grey) require further refinement/agreement.

5.2 Alignment modelling for revised EWRs

Environmental Water Requirement Alignment
Source and CHM Modelling

Prepared by: Tom Stewart - Science, DEW Reviewed by: Matt Gibbs

30/10/19

Source Modelling

The South Australian River Murray Source Model (Beh et al. 2019), based on the Source Murray Model (MDBA, 2015), was used to examine a set of Environmental Water Requirement (EWR) flow to South Australia (SA) scenarios. The model accounts for travel time, diversions and losses from the SA border to the barrages, based on given weir pool and lower lake target levels and minimum barrage releases. The Source model was run repeatedly with the fixed diversion pattern and historical climate data (rainfall and evaporation) from 1978/79–2018/19 to represent the range in evaporative losses that could be expected within South Australia. The model was run from 01 July to 30 June for each year in the multi-history period.

Flow to SA

The Department for Environment and Water Environmental Water team provided eight EWR target flow to SA scenarios. The monthly volumes (GL/month) and daily flow to SA disaggregated from the monthly volumes (ML/day) hydrographs for each scenario are presented in Table A2-1 and Figure A2-1, respectively.

Table A2_1. Monthly pattern of delivery summary of EWR scenarios, GL/month

	IC1	IC2	IC3	IC4	FP1	FP2	FP3	FP4
Jul	109	109	109	109	231	420	647	891
Aug	124	124	124	135	862	1107	1354	1637
Sep	135	150	285	560	1416	1713	2009	2290
Oct	262	538	848	1161	1525	1539	1690	1846
Nov	300	600	900	1200	1116	984	1075	1151
Dec	307	549	859	1169	714	577	671	750
Jan	219	242	454	764	301	238	276	324
Feb	194	194	194	313	194	194	194	194
Mar	186	186	186	186	186	186	186	186
Apr	135	135	135	135	135	135	135	135
May	93	93	93	93	93	93	93	93
Jun	90	90	90	90	90	90	122	240
Total	**2154**	**3009**	**4277**	**5914**	**6864**	**7275**	**8451**	**9738**

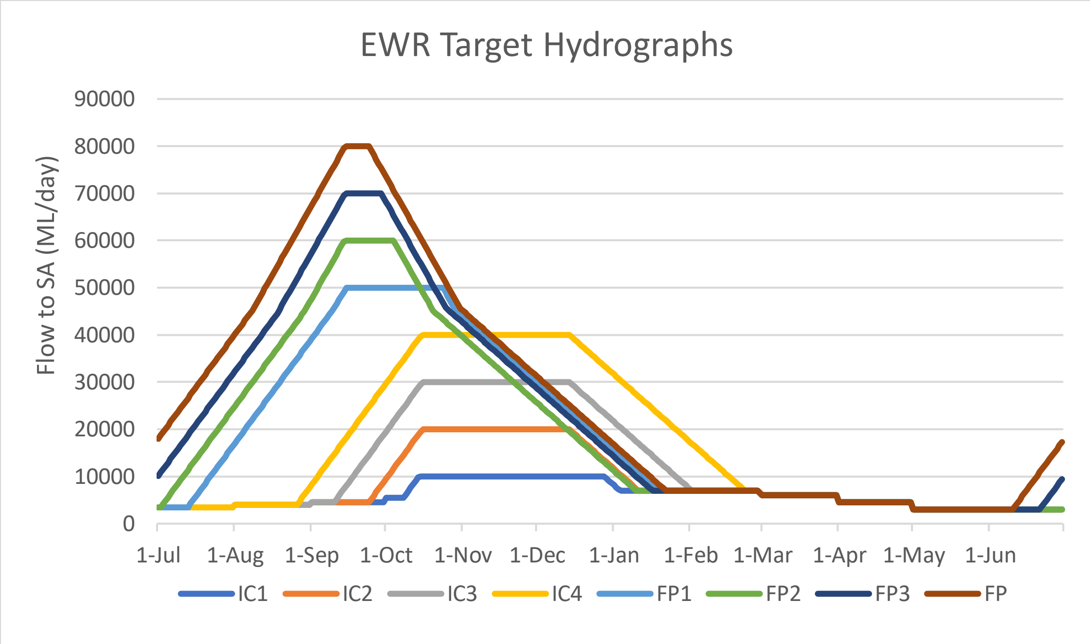

Figure A2_1 Daily Flow to SA under various EWR target scenarios.

Climate

The total rainfall and evaporation each month, derived from the historical climate record has been applied as a constant rate for each month to reduce the effect of large rainfall events on the modelled results. All other inputs remain unchanged (flow to SA and diversion volumes), so the ranges presented are due only to net evaporation losses within South Australia based on the period considered. Climate data (rainfall and Lake evaporation) from the following stations are used: 24004 (Chowilla), 24007 (Loxton), 24517 (Mannum Council Depot), 24518 (Meningie), 24564 (Blanchetown Lock 1), 24578 (Morgan), 23718 (Goolwa Council Depot), 24539 (Narrung), 24521 (Murray Bridge), 24536 (Tailem Bend), 24537 (Meningie), 24547 (Nildottie), 24008 (Lyrup), 24012 (Overland Corner), 24016 (Renmark), 24572 (Wellington), and 24576 (Milang).

Diversions within the Source model

For country towns the full 50 GL has been treated as a diversion under the assumption that this is either pumped or traded out of the state. A monthly pattern of Metro Adelaide diversions totalling 140 GL for the 2019/20 year was provided by SA Water on September 13, 2019.

All of the EWR scenarios exceed full Entitlement flow (1,850 GL) and therefore no scaling was applied under the SA Water Allocation Framework. Under a full Entitlement scenario, All Purpose entitlements, mainly for irrigation but also including stock and domestic and industrial, total 652 GL in the model. The Commonwealth (161 GL) and TLM (45 GL) held components, as advised by the CEWH (June 2019), are assumed to be part of these All Purpose entitlements but are not diverted. To account for this portion of environmental water within South Australia's Entitlement flow, the total volume to be diverted was reduced to 446 GL to preserve the Commonwealth and TLM components (206 GL) in the river. The remaining 446 GL is assumed to be fully utilised (either taken or deferred as private carryover) and is distributed based on a fixed annual pattern derived from historical pumping records from the Central and Renmark Irrigation Trusts.

Target lake level and weir pool manipulation

- Initial lake levels in the Source model were set to 0.7 m AHD on July 1
- All Locks were set to normal operational pool levels.

Scenario Summary Table & Barrage Release rules

Eight flow to SA scenarios were modelled (Figure A2-1). Each flow scenario was modelled under a target Lakes level profile, which reduced barrage flows to 170 ML/day (the equivalent of fishways only) when Lakes levels are below the target. No barrage releases occur for Lake levels below 0.4 m AHD. The EWR target scenarios and corresponding Lakes level profiles are provided in Table A2-2 and proposed revised target values for Lakes level profiles for CLLMM 1 & 2 and CLLMM 3 & 4 are presented in Figure A2-2.

Table A2_2. EWR target scenarios and corresponding Lakes level target used in the Source model.

	IC1	IC2	IC3	IC4	FP1	FP2	FP3	FP4
Lake Level Target Profile	CLLMM 1 & 2	CLLMM 1 & 2	CLLMM 1 & 2	CLLMM 1 & 2	CLLMM 1 & 2	CLLMM 3 & 4	CLLMM 3 & 4	CLLMM 3 & 4

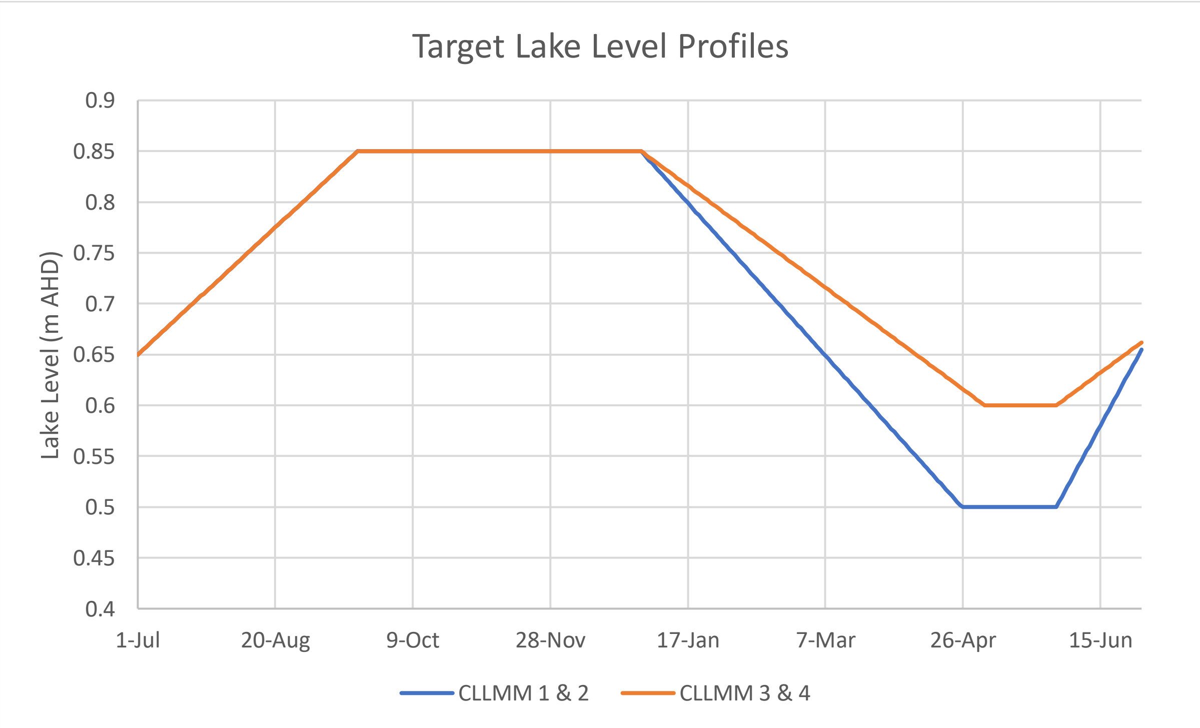

Figure A2_2. Target lake level profiles CLLMM 1 & 2, and CLLMM 3 & 4.

Source model results

Results for each of the revised EWR scenarios considered are presented below. A 30-day rolling average has been applied to the barrage flow results, as small changes in Lakes level can result in the model producing large barrage flows for a short period, which is not reflective of typical barrage operations. The variability in results produced by the historical net evaporation losses are presented as the median each day (as a line), and the shaded area represents the range between the 10th and 90th percentiles. This means 10% of the results are above, and 10% below, this band each day. These results are provided for the purpose of comparing environmental water volumes and barrage release scenarios.

For comparison, a summary of nominal spring peak barrage release patterns (solid lines) overlaid with modelled 30-day rolling average barrage releases from corresponding EWR target scenarios are presented in Figure A2-3 and Table A2-3.

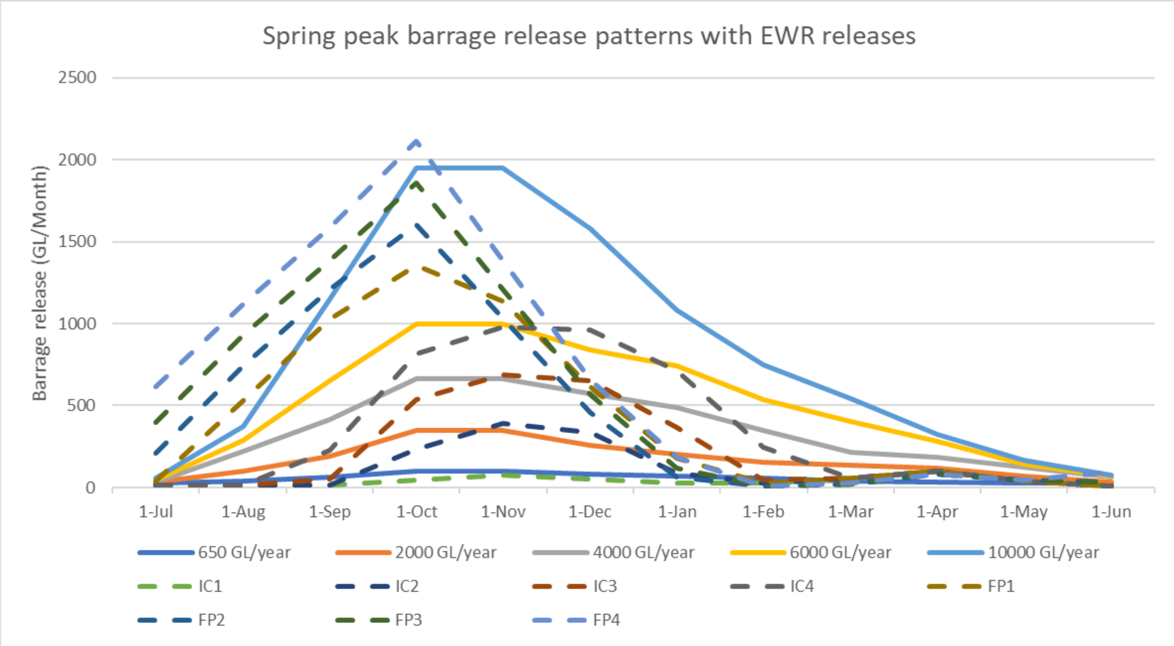

Figure A2_3. Monthly barrage release summary hydrograph for revised EWR target scenarios – nominal vs modelled (GL/month.).

Table A2_3. Mean monthly barrage discharge summary for modelled EWR target scenarios (GL/month).

	IC1	IC2	IC3	IC4	FP1	FP2	FP3	FP4
Jul	15.2	15.2	15.2	15.2	38.2	208.7	396.1	617.3
Aug	14.7	14.7	14.7	14.8	533.0	745.1	931.2	1120.7
Sep	16.0	16.1	48.5	228.8	1028.6	1211.6	1385.1	1586.0
Oct	45.0	230.8	536.7	816.4	1355.4	1605.3	1858.5	2112.3
Nov	76.4	388.7	684.9	978.5	1137.9	1033.3	1206.7	1383.7
Dec	50.0	337.5	651.3	961.2	616.3	460.0	566.5	657.6
Jan	29.1	86.5	366.3	710.1	175.9	61.9	119.7	185.2
Feb	24.2	25.2	46.4	243.6	26.7	8.3	9.4	10.6
Mar	53.8	56.4	57.2	60.2	56.8	21.1	23.3	25.3
Apr	100.4	100.5	100.5	100.5	100.5	78.8	80.7	82.1
May	39.4	39.4	39.4	39.4	39.4	47.4	47.4	47.4
Jun	5.9	5.9	5.9	5.9	5.9	31.7	34.0	95.1
Total	**470.1**	**1317.0**	**2567.0**	**4174.7**	**5114.8**	**5513.1**	**6658.7**	**7923.2**

Barrage Release Comparison Charts

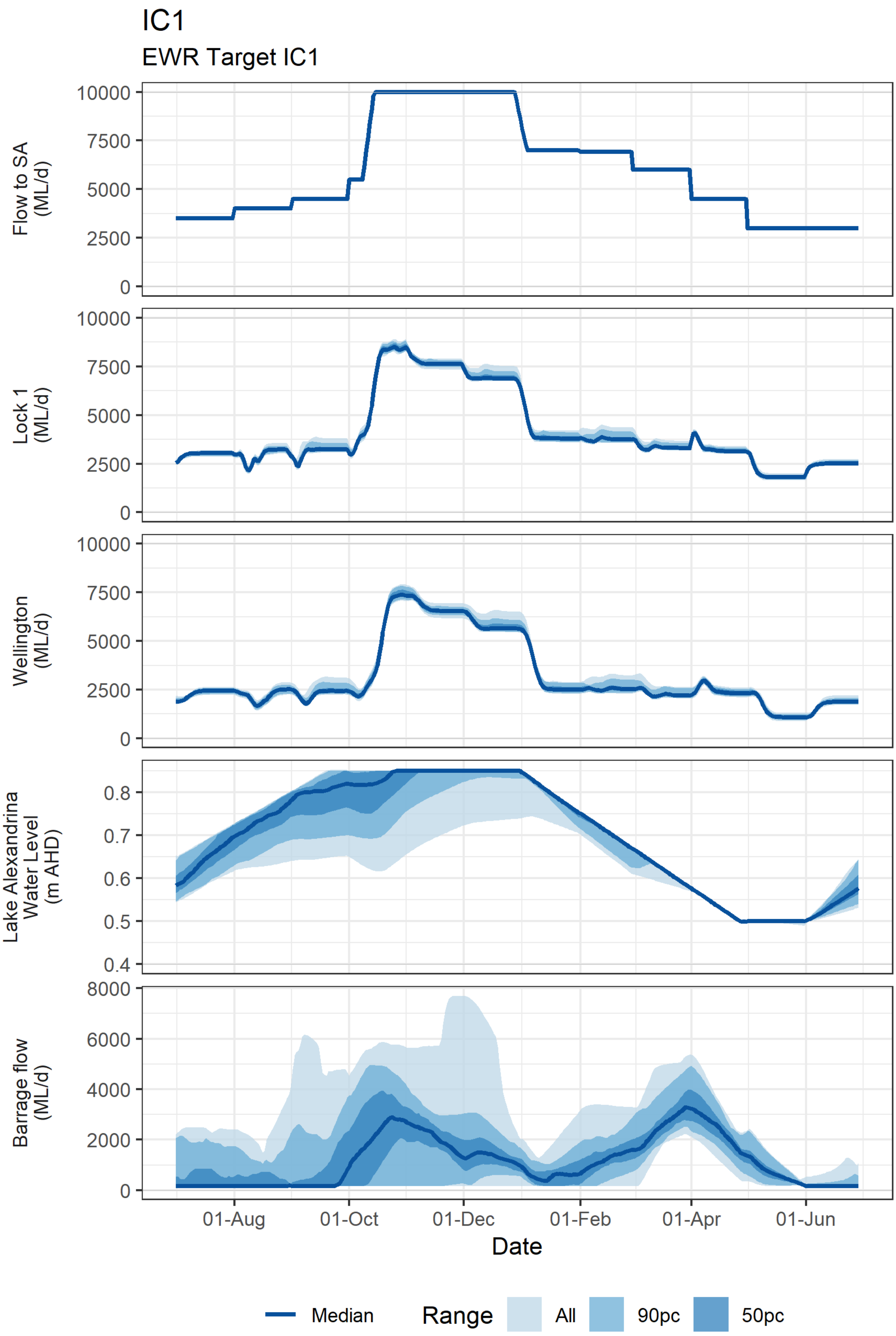

Figure A2_4. Flow, lake level, and barrage release results for the EWR IC1 target flow historical ranges.

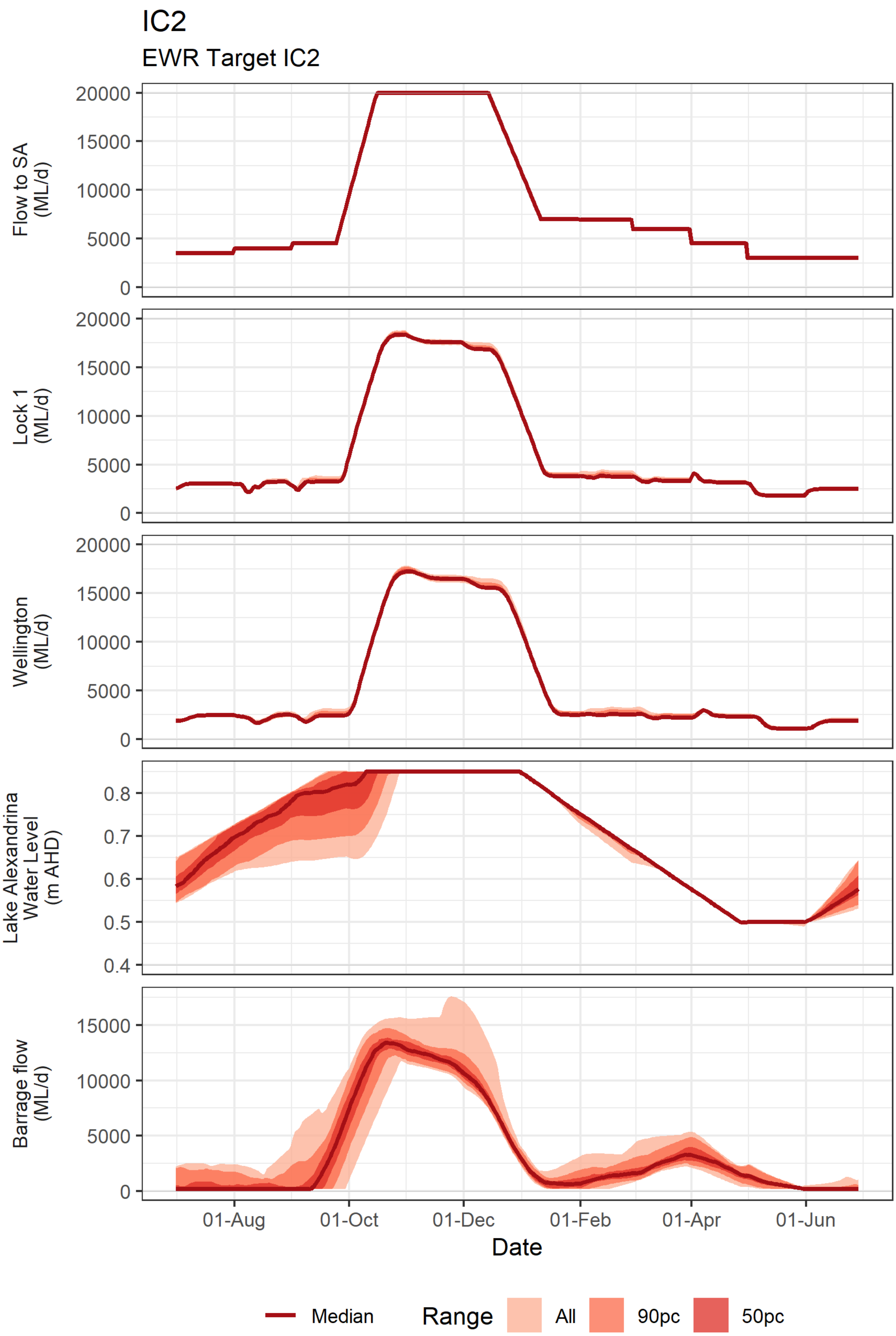

Figure A2_5: Flow, lake level, and barrage release results for the EWR IC2 target flow historical ranges.

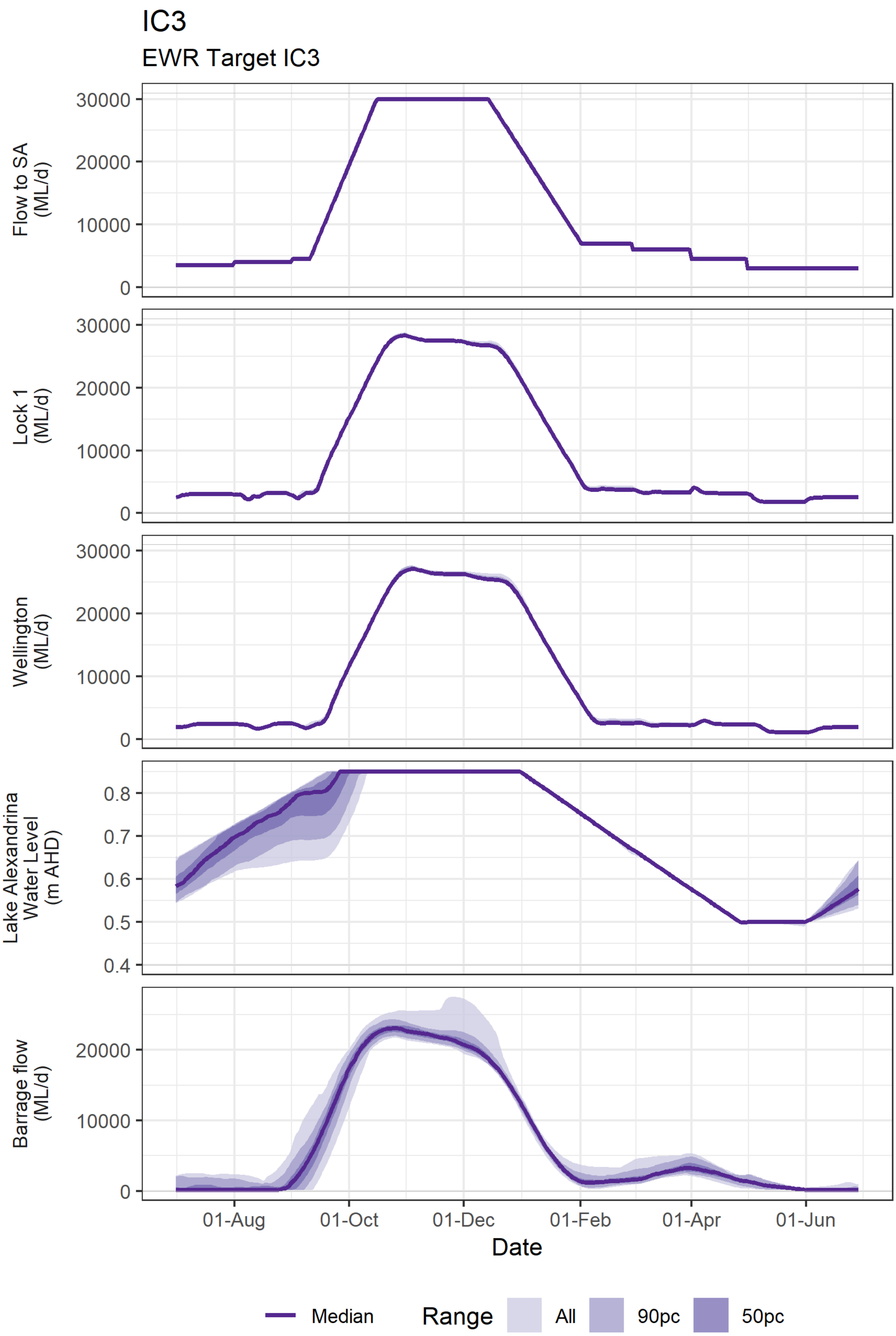

Figure A2_6. Flow, lake level, and barrage release results for the EWR IC3 target flow historical ranges.

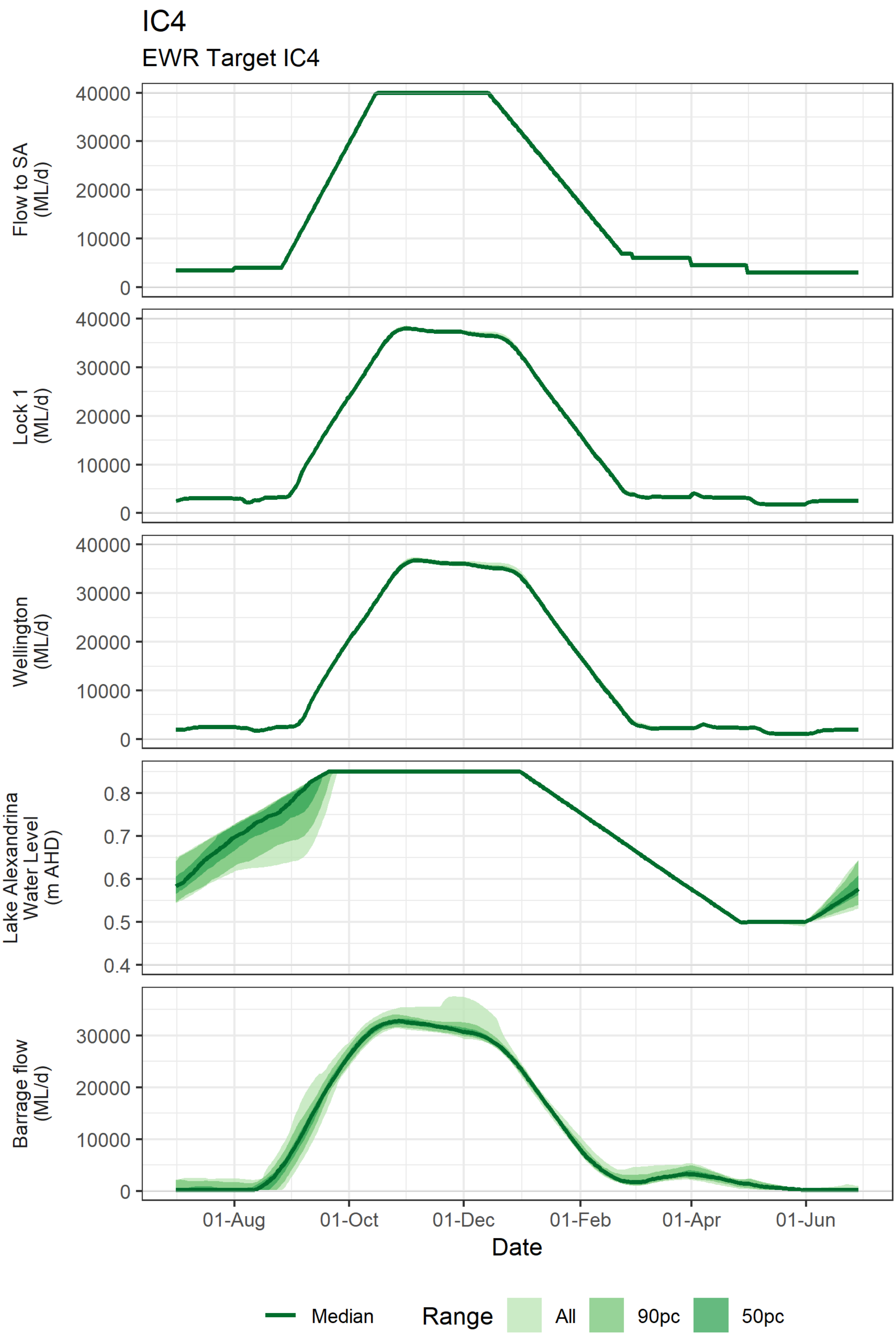

Figure A2_7. Flow, lake level, and barrage release results for the EWR IC4 target flow historical ranges.

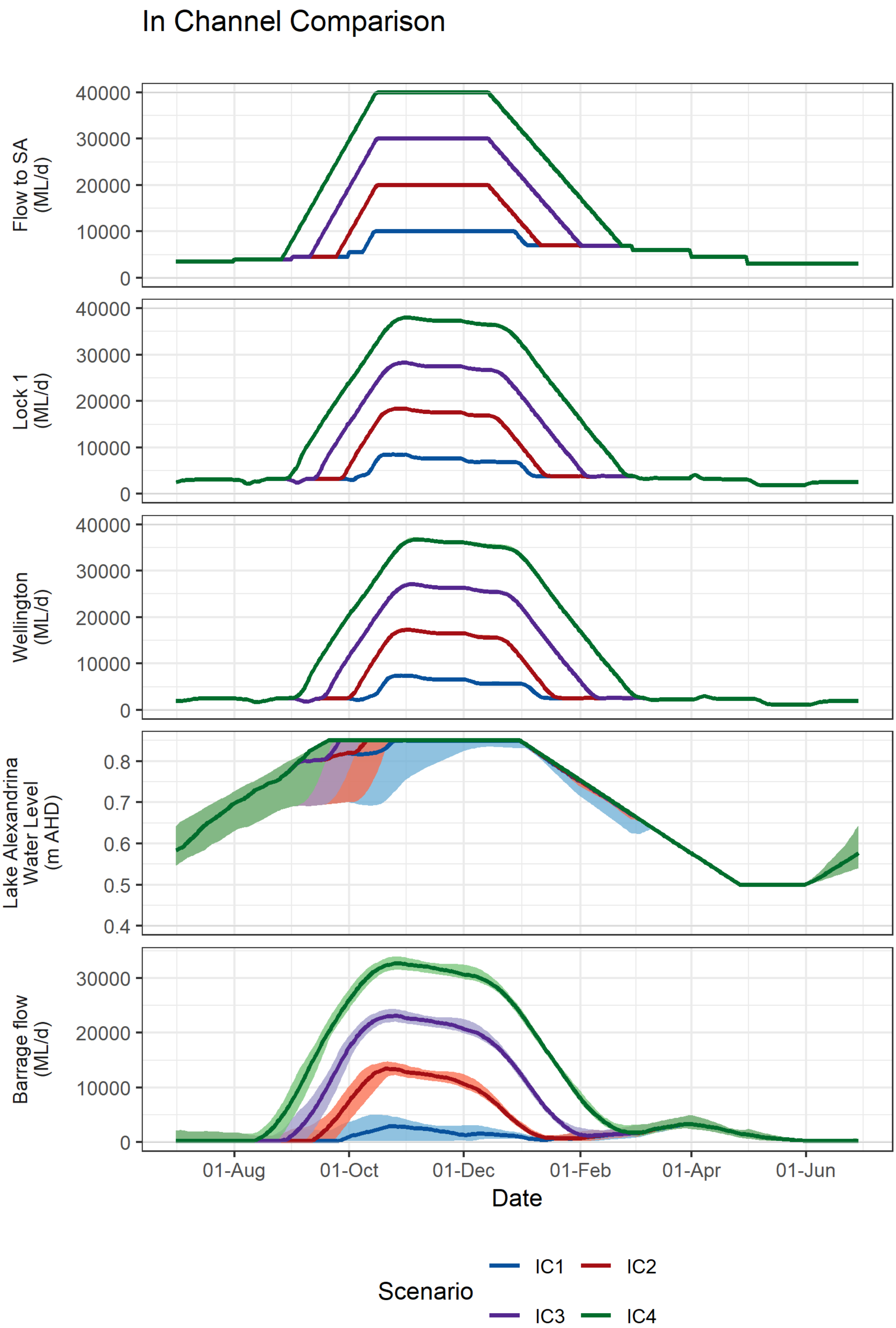

Figure A2_8. Comparison of EWR IC target scenarios.

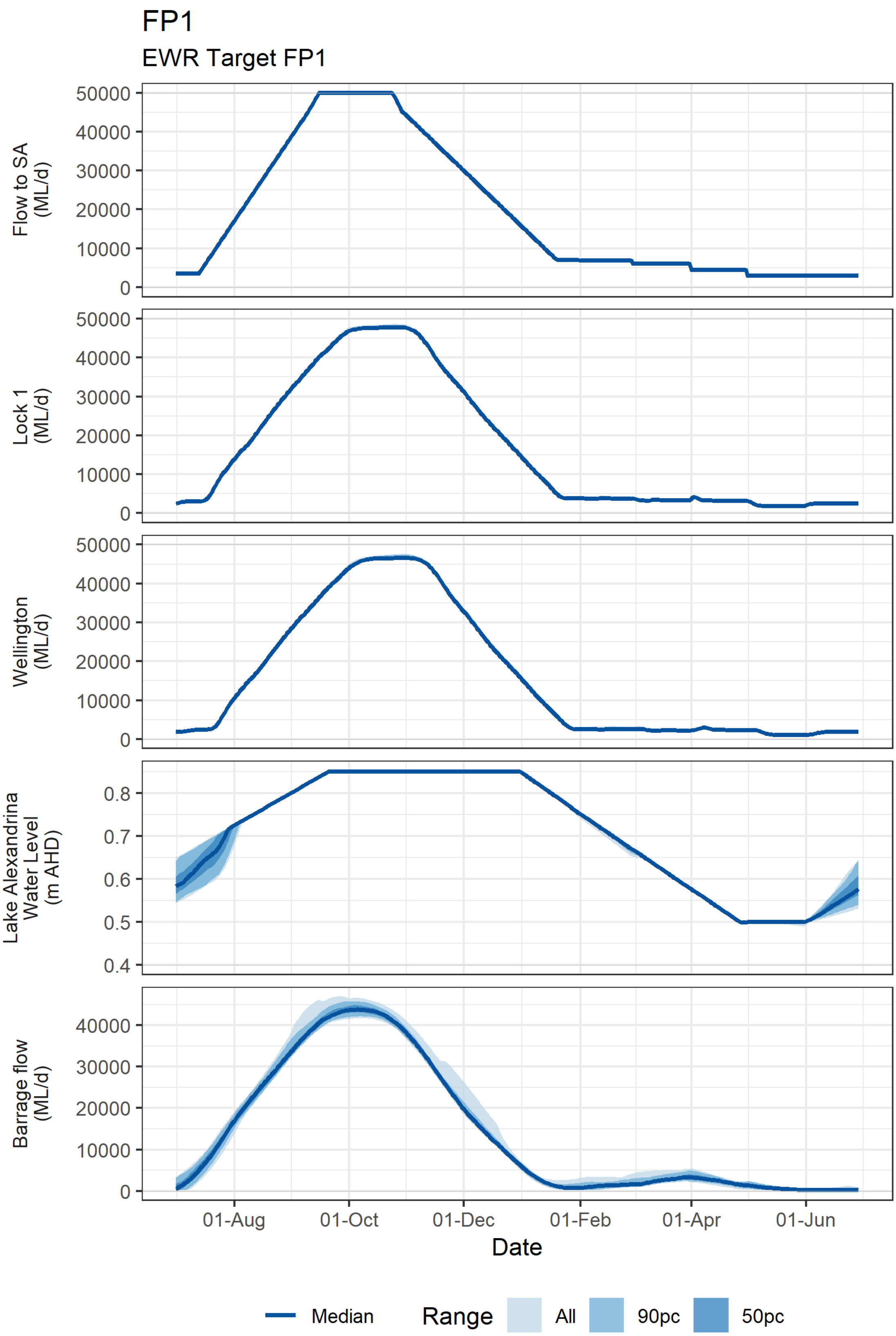

Figure A2_9. Flow, lake level, and barrage release results for the EWR FP1 target flow historical ranges.

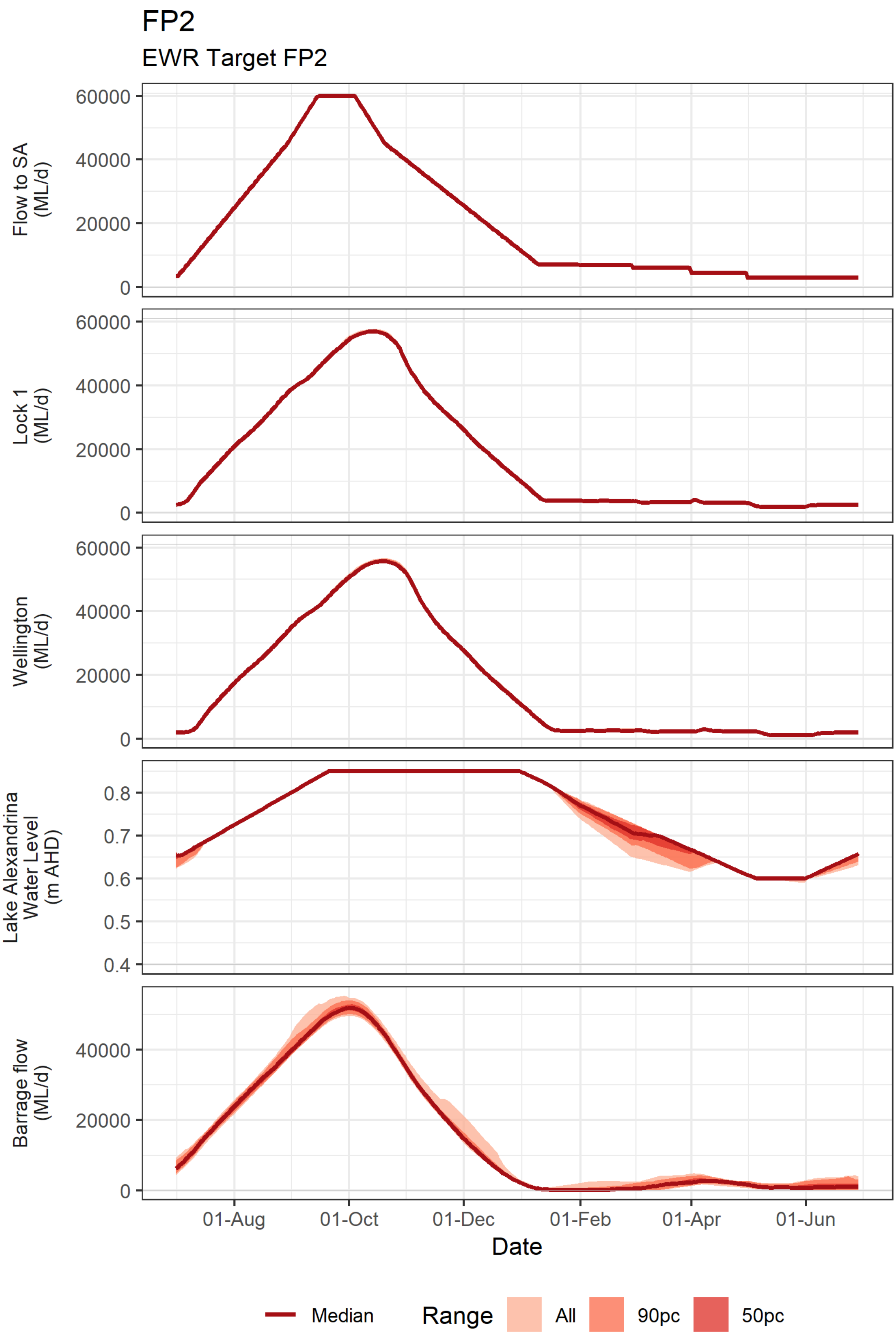

Figure A2_10. Flow, lake level, and barrage release results for the EWR FP2 target flow historical ranges.

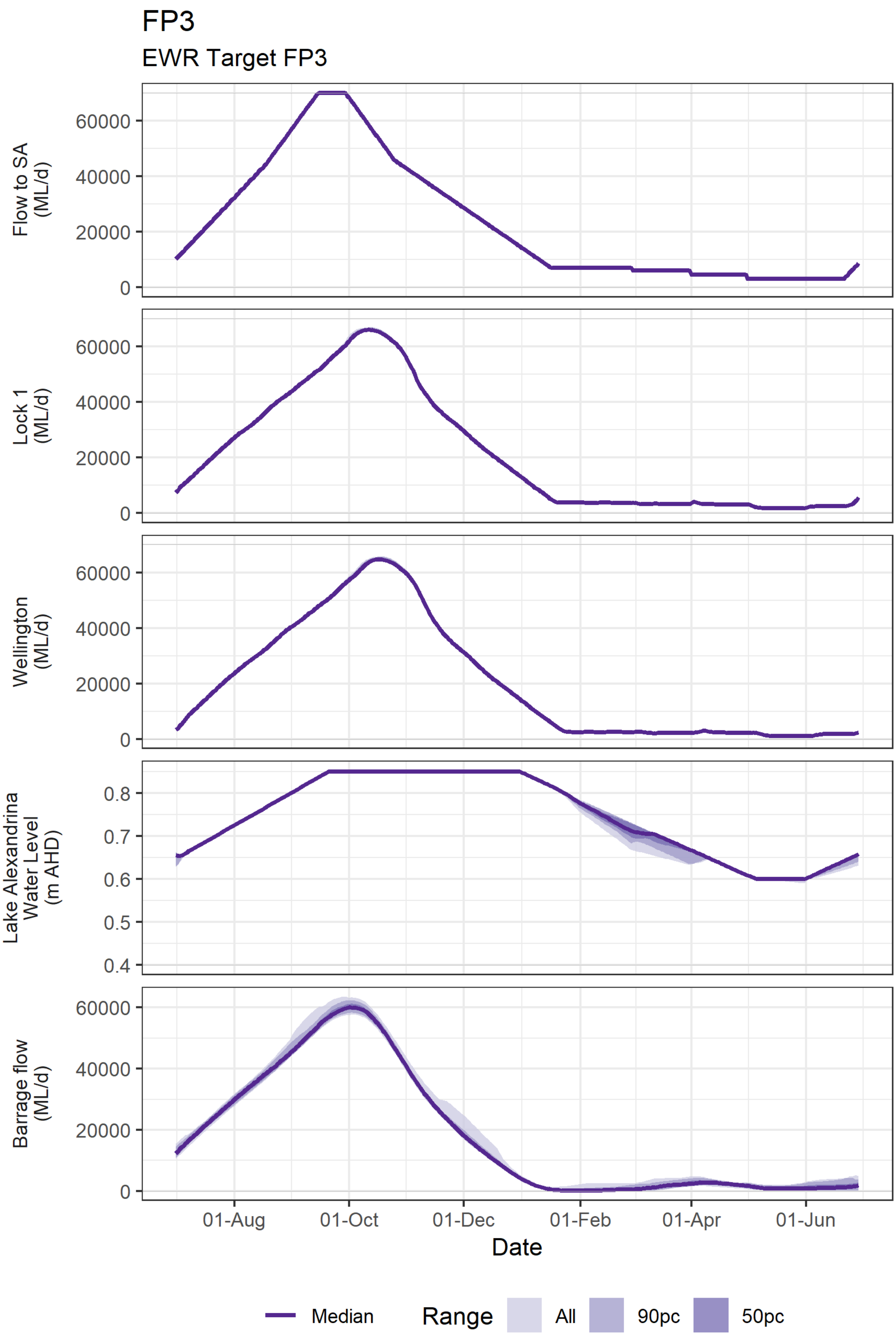

Figure A2_11. Flow, lake level, and barrage release results for the EWR FP3 target flow historical ranges.

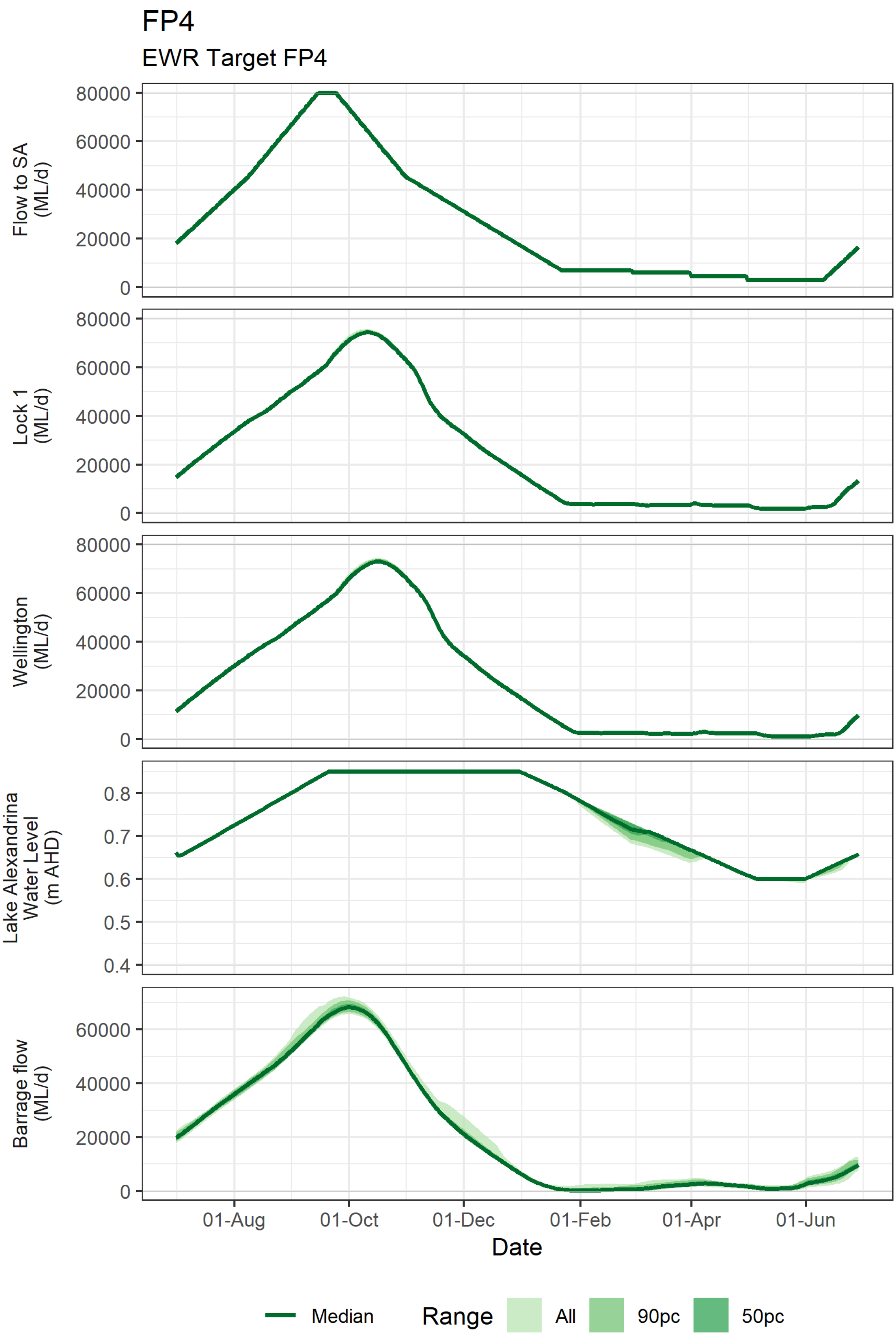

Figure A2_12. Flow, lake level, and barrage release results for the EWR FP4 target flow historical ranges.

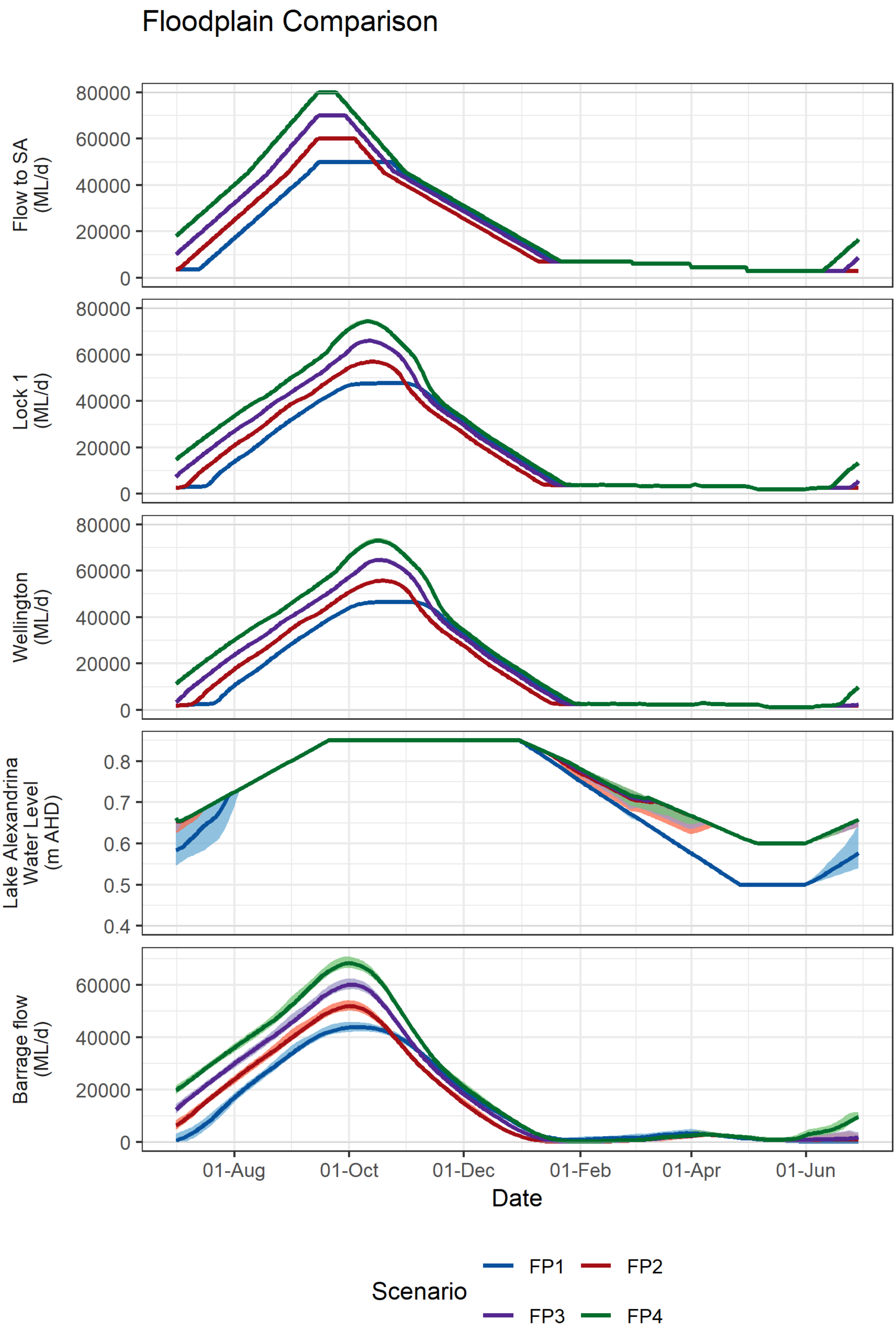

Figure A2_13. Comparison of EWR FP target scenarios.

Coorong Modelling

Hydrodynamic model inputs and initial conditions

Wind

The wind record for the initial observed period from January 1983 to June 2008 consisted of wind stresses calculated from twice daily measurements of wind speed and direction at Meningie. The wind record was extended to June 2017 using wind speed and direction at the Pelican Point AWS (A4260603).

Sea level

The sea level record for the period January 1983 to April 2012 was specified as measured water level at Victor Harbor with a 0.137 m offset factor applied to account for the difference in datum between water levels measured in the Coorong and at Victor Harbor, The record was extended to June 2018, with Victor Harbor tide data downloaded from the HydroTel web server maintained by Flinders Ports.

Meteorology

The pan evaporations and precipitation record was obtained from a SILO climate data site near Parnka Point for the record between January 1983 to July 2008. Thereafter, SILO data from the Bureau of Meteorology Goolwa site (23849) was used to extend the record until June 2018.

Initial values

The following values were used to initialise the mode. These values represent long term averages and were generated from observed data from the monitoring sites shown in Table A2-4. Water level and salinity values were averaged over an 8 day period (26-06 to 03-07) for the years 2012 to 2019. The initial mouth depth was set to -2.0 m AHD and the model was run with a flexible mouth depth, where the Murray Mouth varies dynamically throughout the modelled period.

Table A2_4. Coorong monitoring sites for data to initialise the Coorong Hydrodynamic Model.

<table>
<tr><th colspan="2">Goolwa Channel</th><th colspan="2">North Lagoon</th><th colspan="2">South Lagoon</th></tr>
<tr><th>Site no.</th><th>Site name</th><th>Site no.</th><th>Site name</th><th>Site no.</th><th>Site name</th></tr>
<tr><td rowspan="3">A4261036</td><td rowspan="3">Goolwa Channel at beacon 12</td><td>A4261134</td><td>Pelican Point</td><td>A4260633</td><td>Parnka Point</td></tr>
<tr><td rowspan="2">A4261135</td><td rowspan="2">Long Point</td><td>A4261209</td><td>NW Snipe Island</td></tr>
<tr><td>A4261165</td><td>Woods Well</td></tr>
<tr><th>Water Level (m AHD)</th><th>Salinity (g/L)</th><th>Water Level (m AHD)</th><th>Salinity (g/L)</th><th>Water Level (m AHD)</th><th>Salinity (g/L)</th></tr>
<tr><td>0.34</td><td>21.1</td><td>0.39</td><td>25.19</td><td>0.47</td><td>69.0</td></tr>
</table>

CHM Results

The results presented in Figures A2-14 to A2-23 represent the variation in response of the Coorong to the historical climate 1983-2017. A threshold of 35 ppt was set to illustrate the extent of estuarine conditions (km) within the north lagoon for each day in the model period, where 0 km represents the Murray Mouth and 60 km representing Parnka Point. For example, a median point of 20 km would indicate that estuarine conditions (i.e. below 35 ppt) occur from 0 to 20 km within the north lagoon. The variation in Coorong response to the preferred CLLMM barrage releases are presented in Figures A2-24 to A2-29.

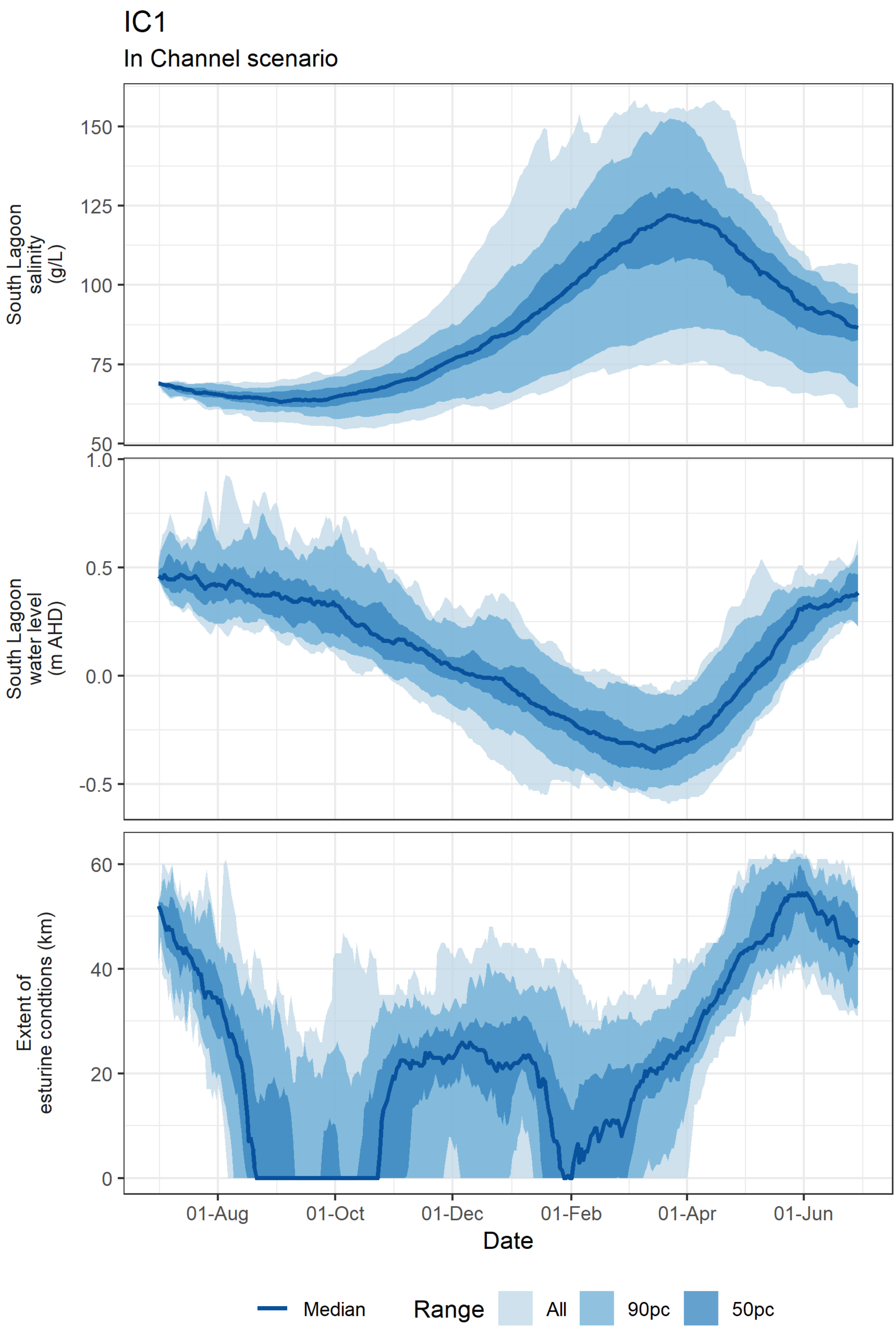

Figure A2_14. Salinity, level, and extent of estuarine conditions for EWR Scenario IC1.

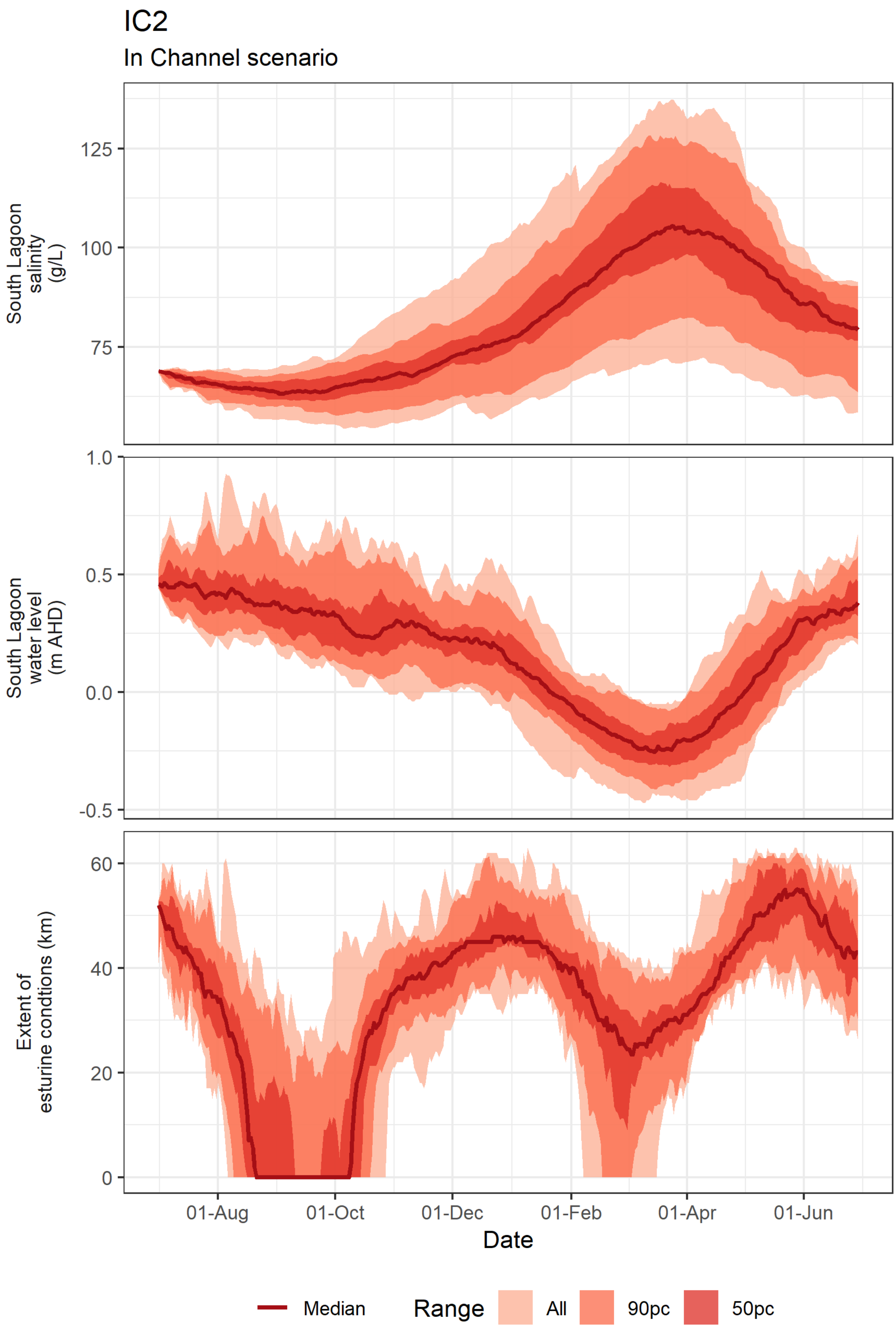

Figure A2_15. Salinity, level, and extent of estuarine conditions for EWR Scenario IC2.

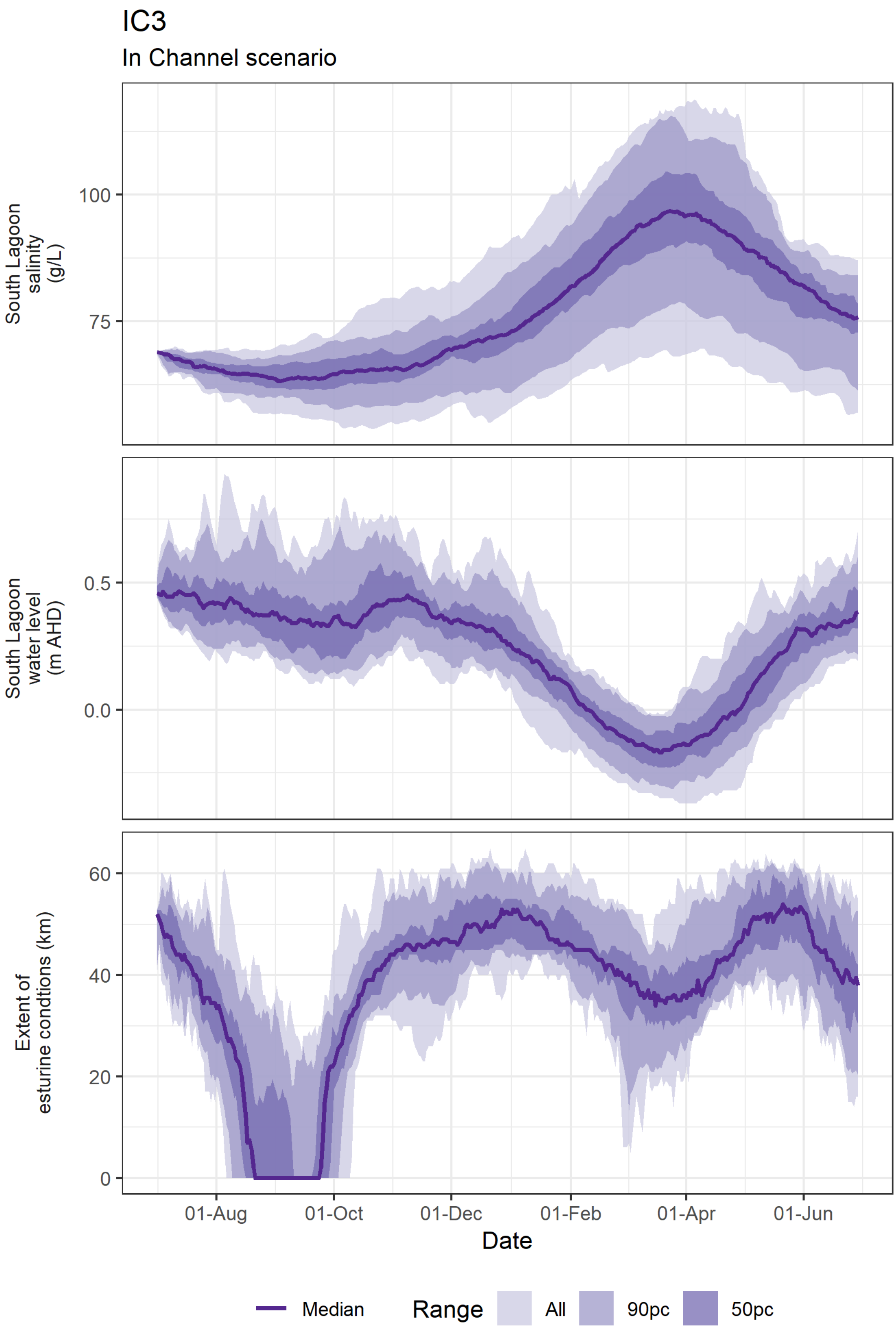

Figure A2_16. Salinity, level, and extent of estuarine conditions for EWR Scenario IC3.

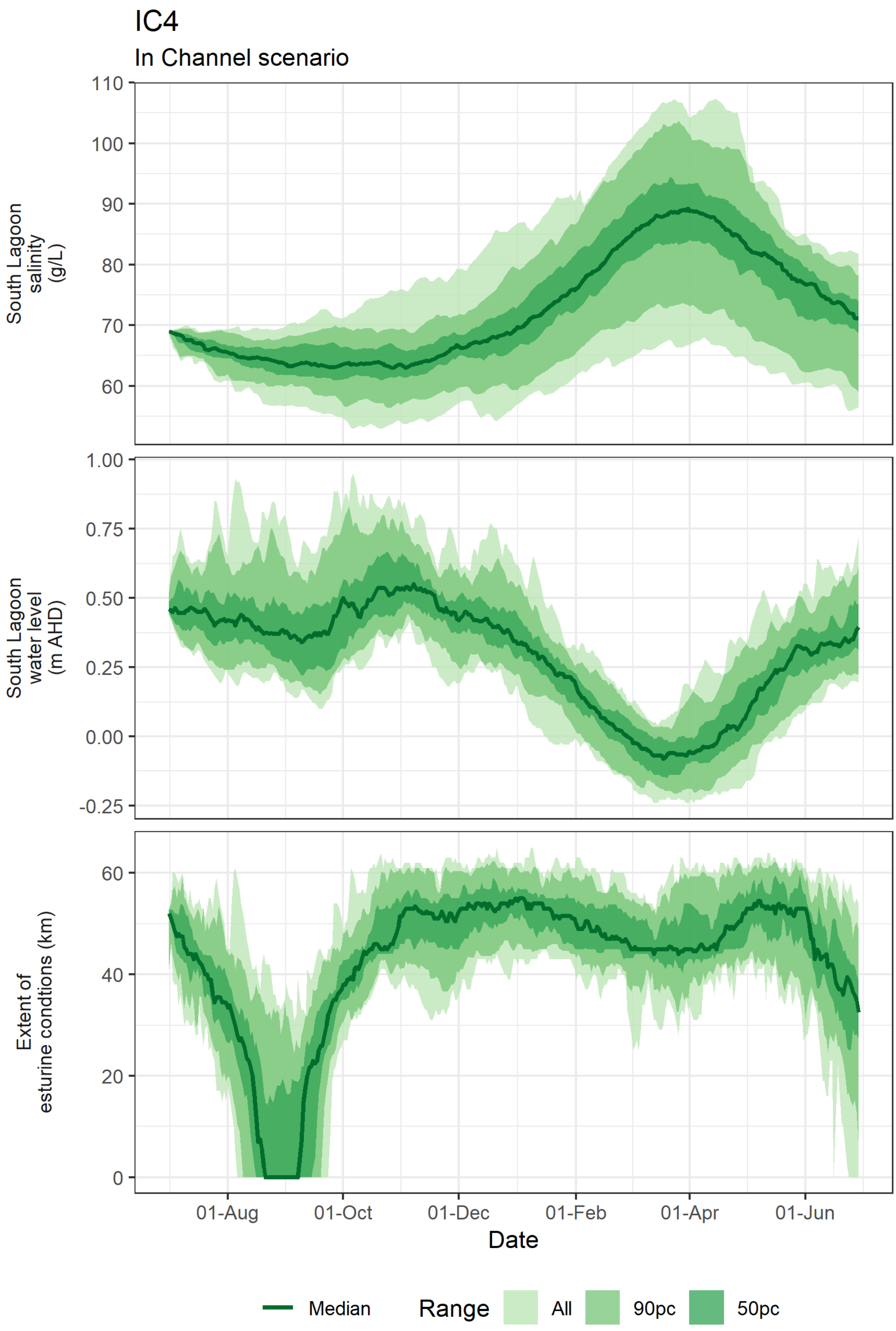

Figure A2_17. Salinity, level, and extent of estuarine conditions for EWR Scenario IC4.

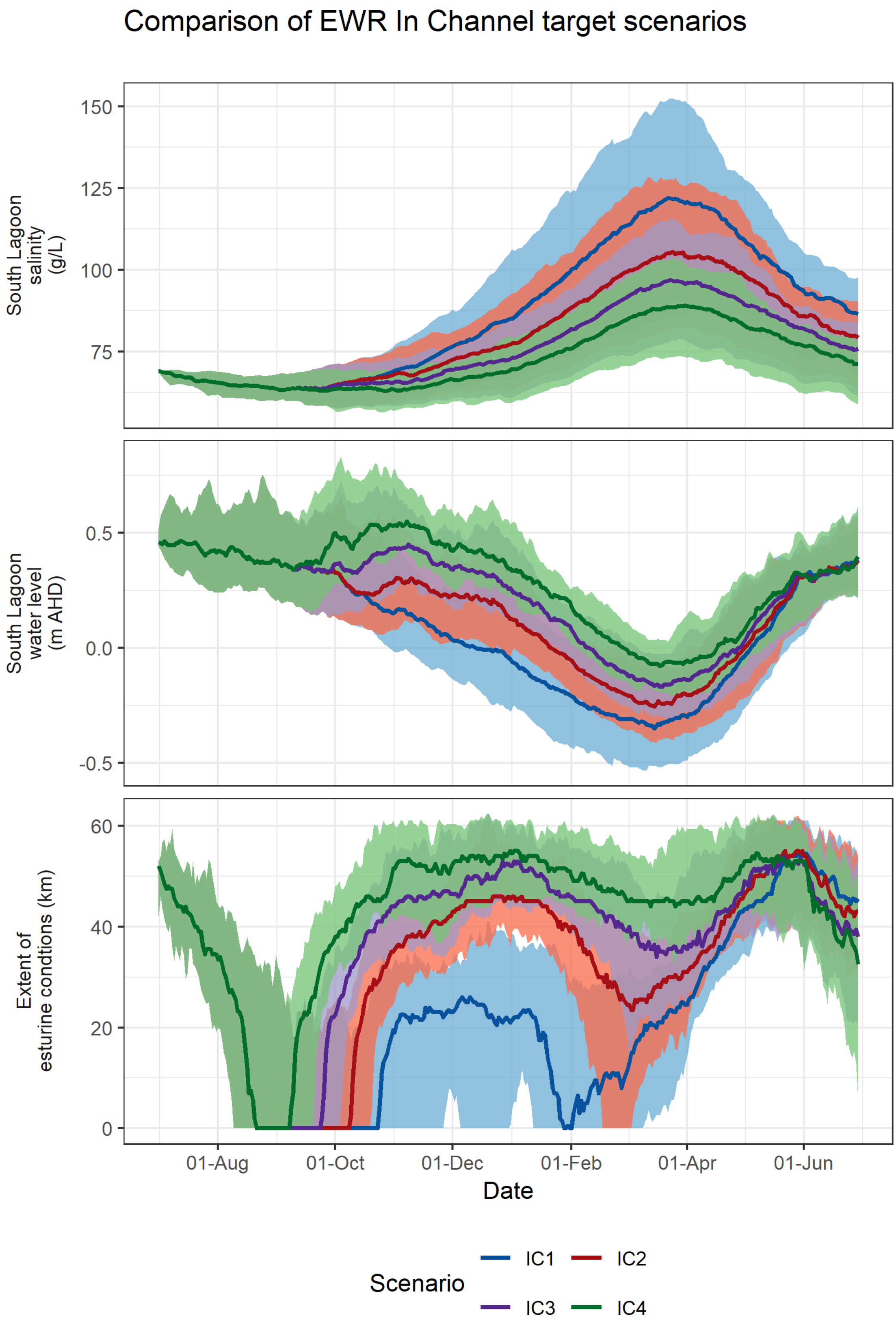

Figure A2_18. Comparison of salinity, level, and extent of estuarine conditions for 'In Channel' EWR scenarios.

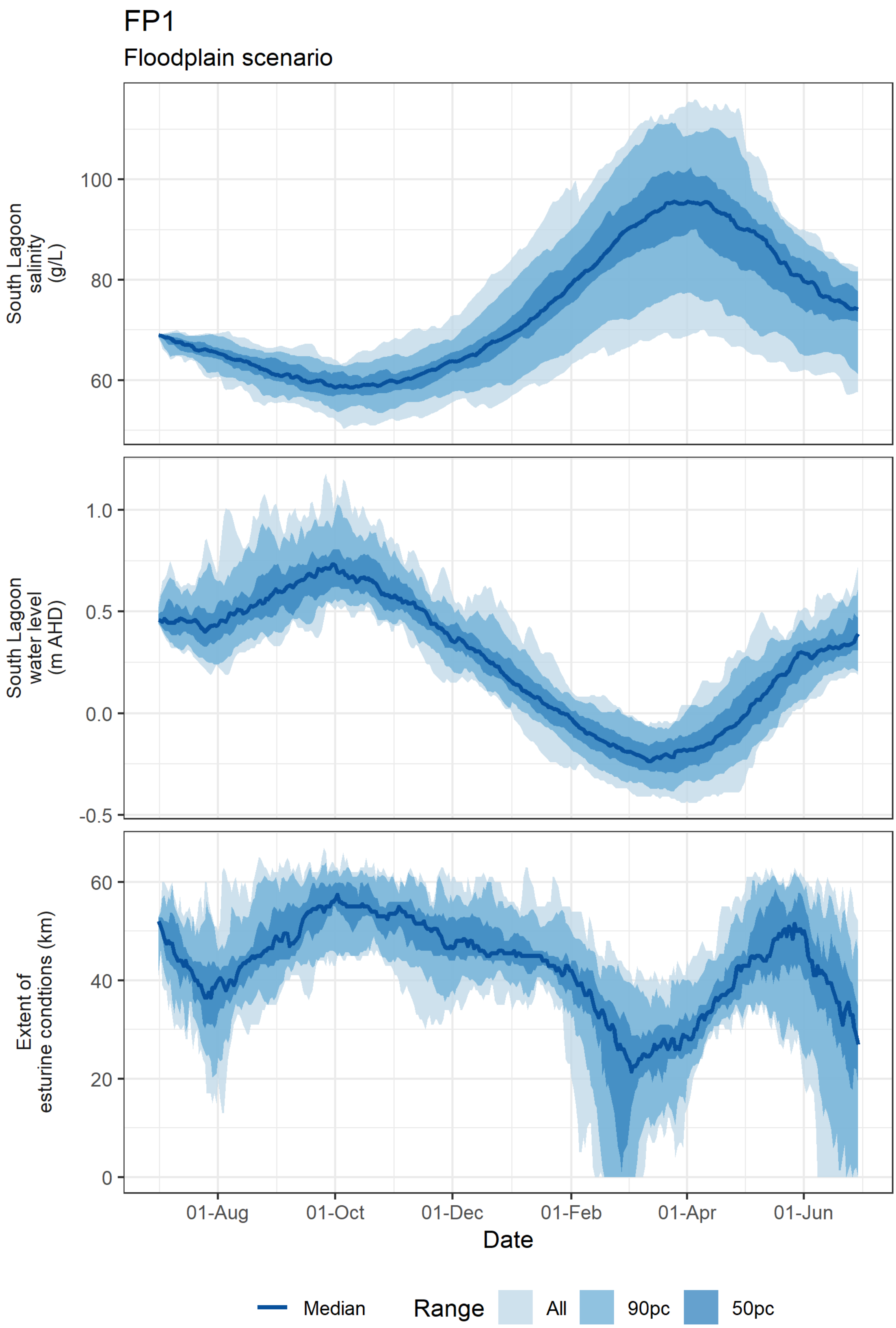

Figure A2_19. Salinity, level, and extent of estuarine conditions for EWR Scenario FP1.

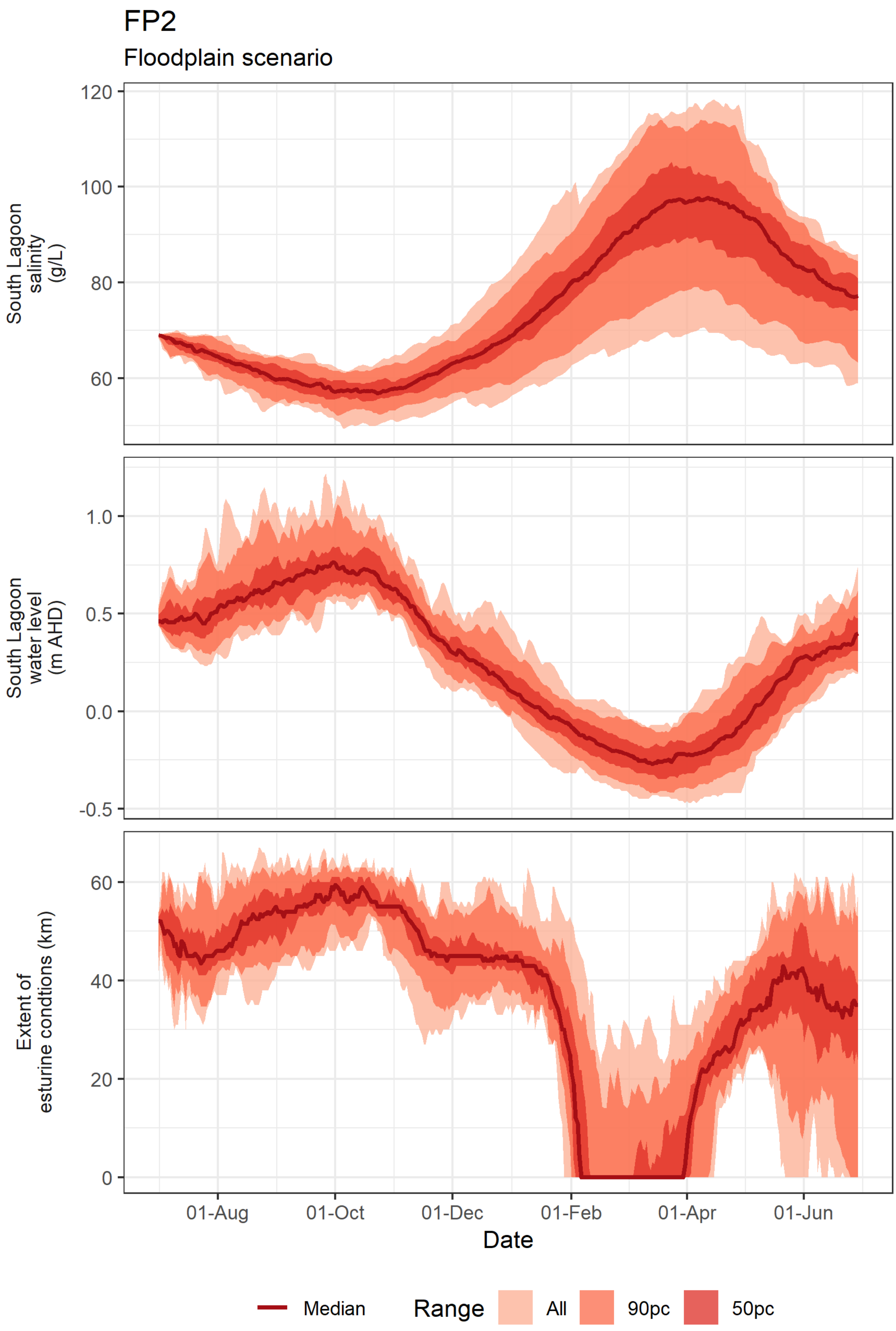

Figure A2_20. Salinity, level, and extent of estuarine conditions for EWR Scenario FP2.

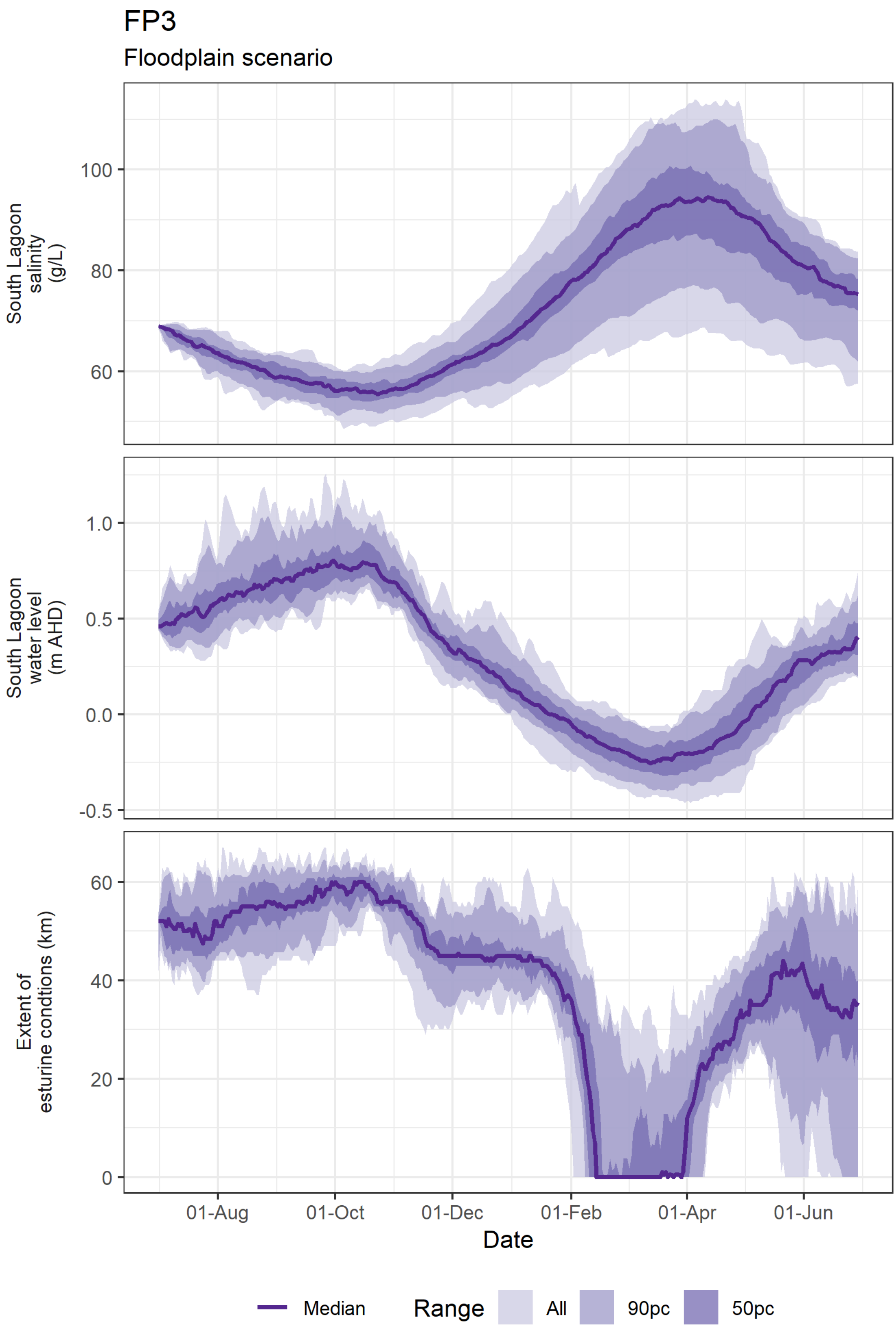

Figure A3_21. Salinity, level, and extent of estuarine conditions for EWR Scenario FP3.

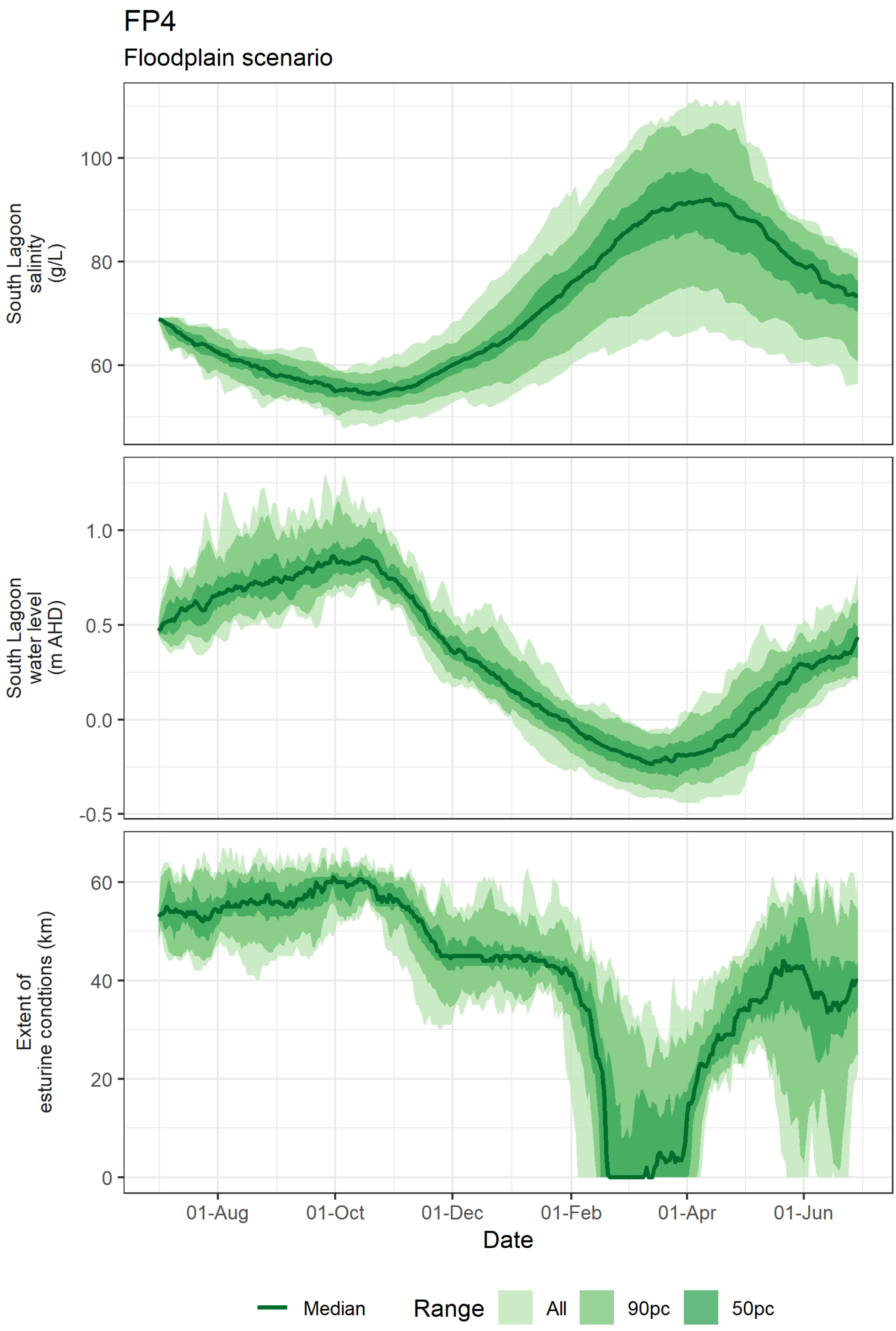

Figure A2_22. Salinity, level, and extent of estuarine conditions for EWR Scenario FP4.

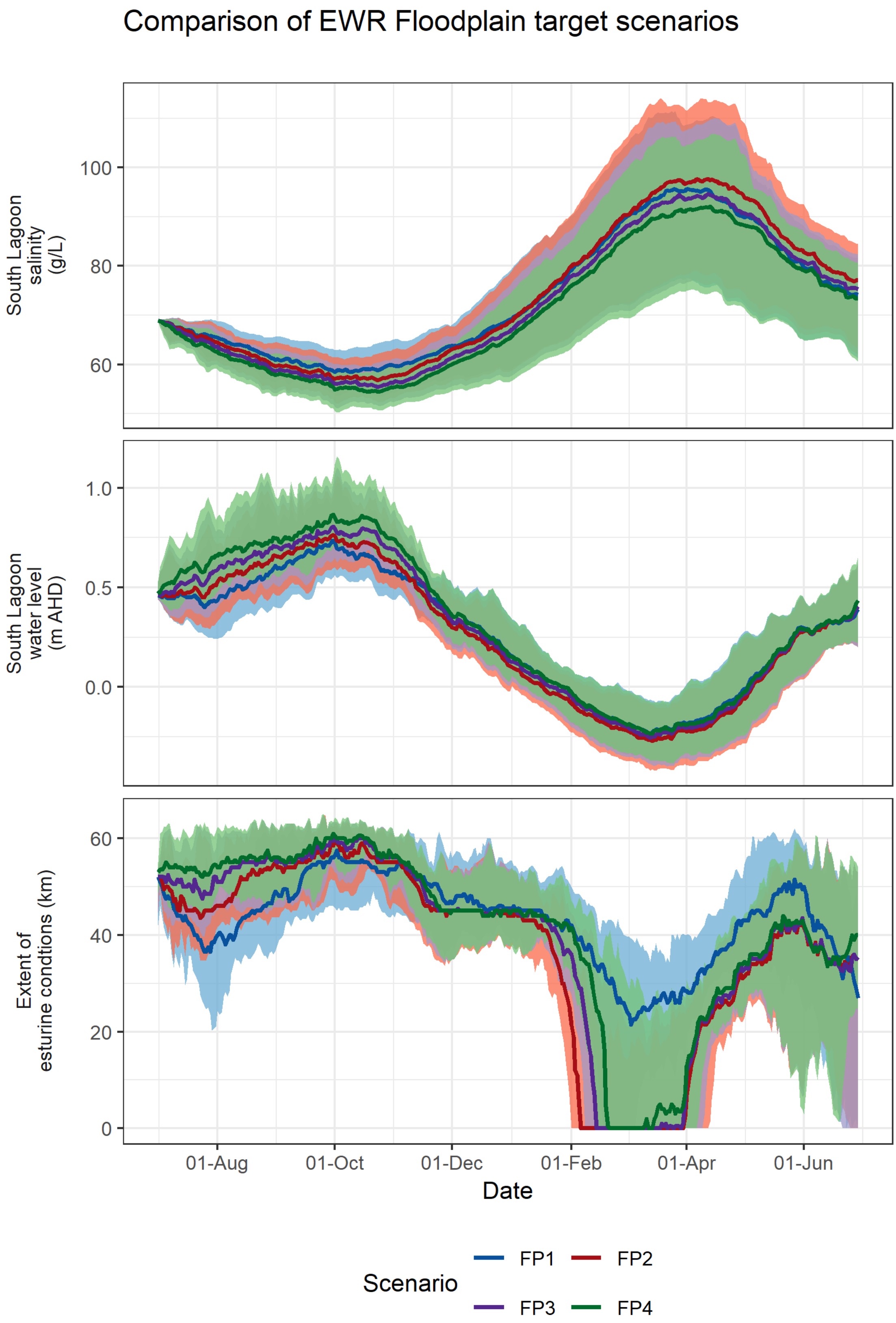

Figure A2_23. Comparison of salinity, level, and extent of estuarine conditions for 'Floodplain' EWR scenarios.

Preferred CLLMM Target Barrage Releases

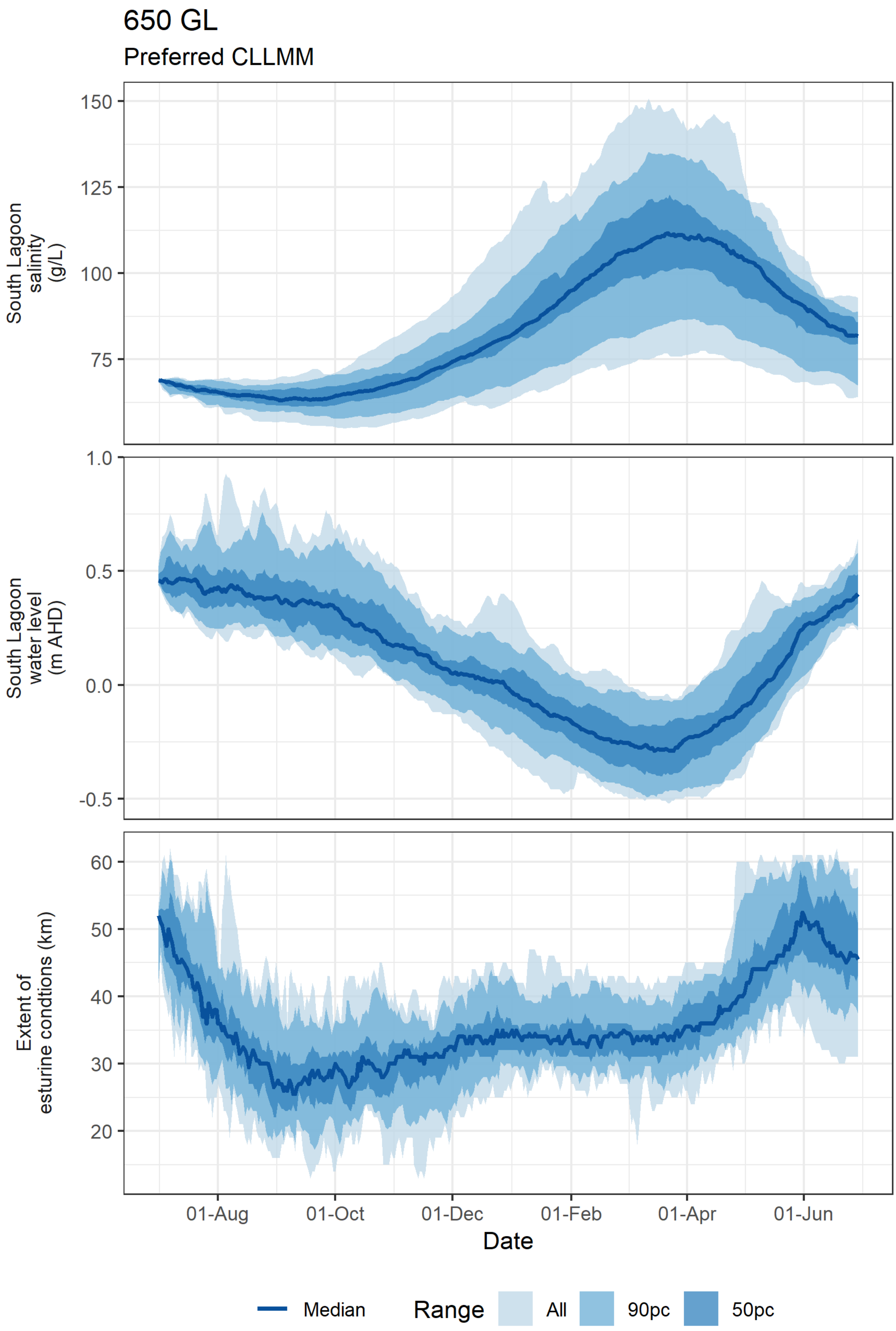

Figure A2_24. Salinity, level, and extent of estuarine conditions for preferred CLLMM target flow of 650 GL.

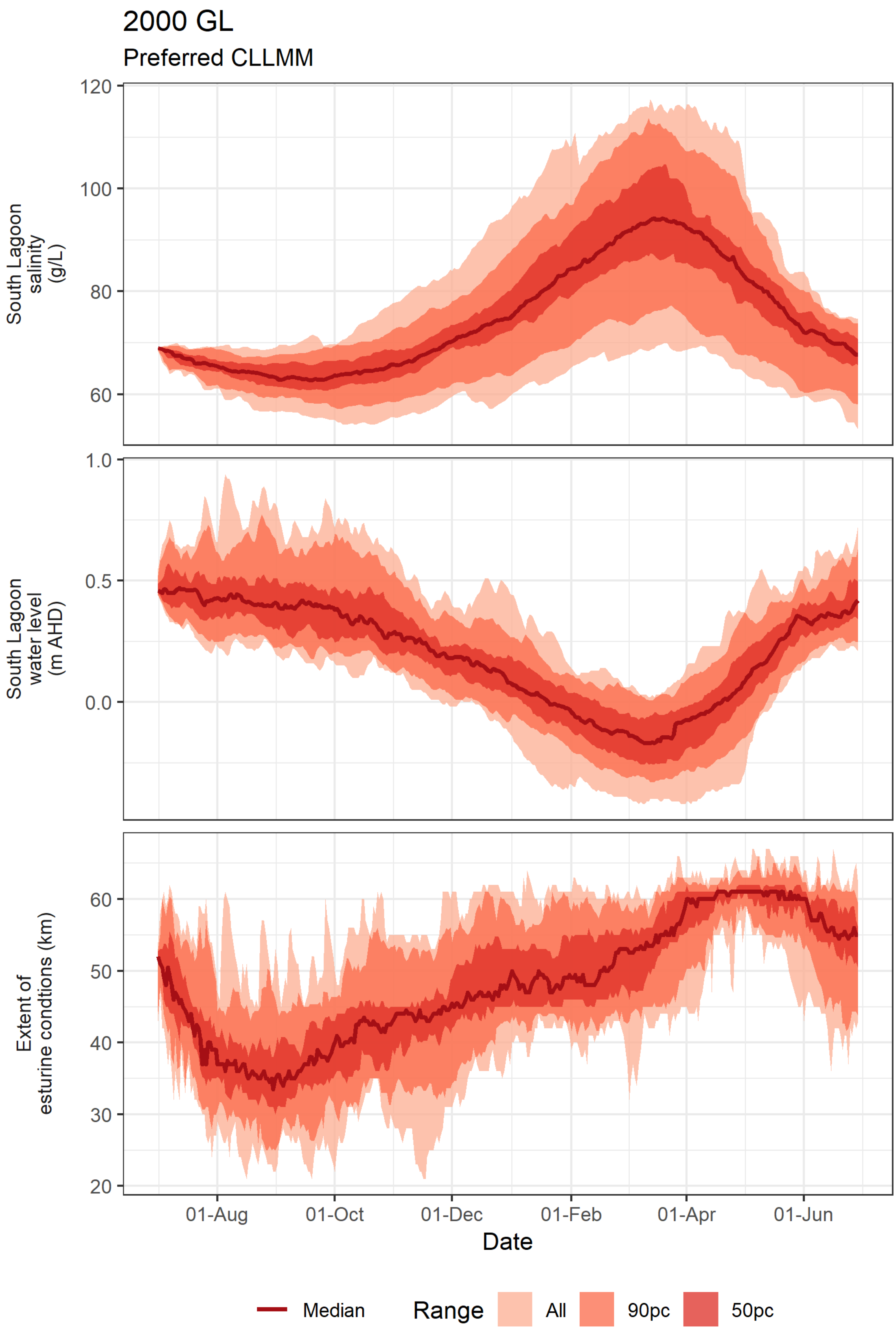

Figure A2_25. Salinity, level, and extent of estuarine conditions for preferred CLLMM target flow of 2000 GL.

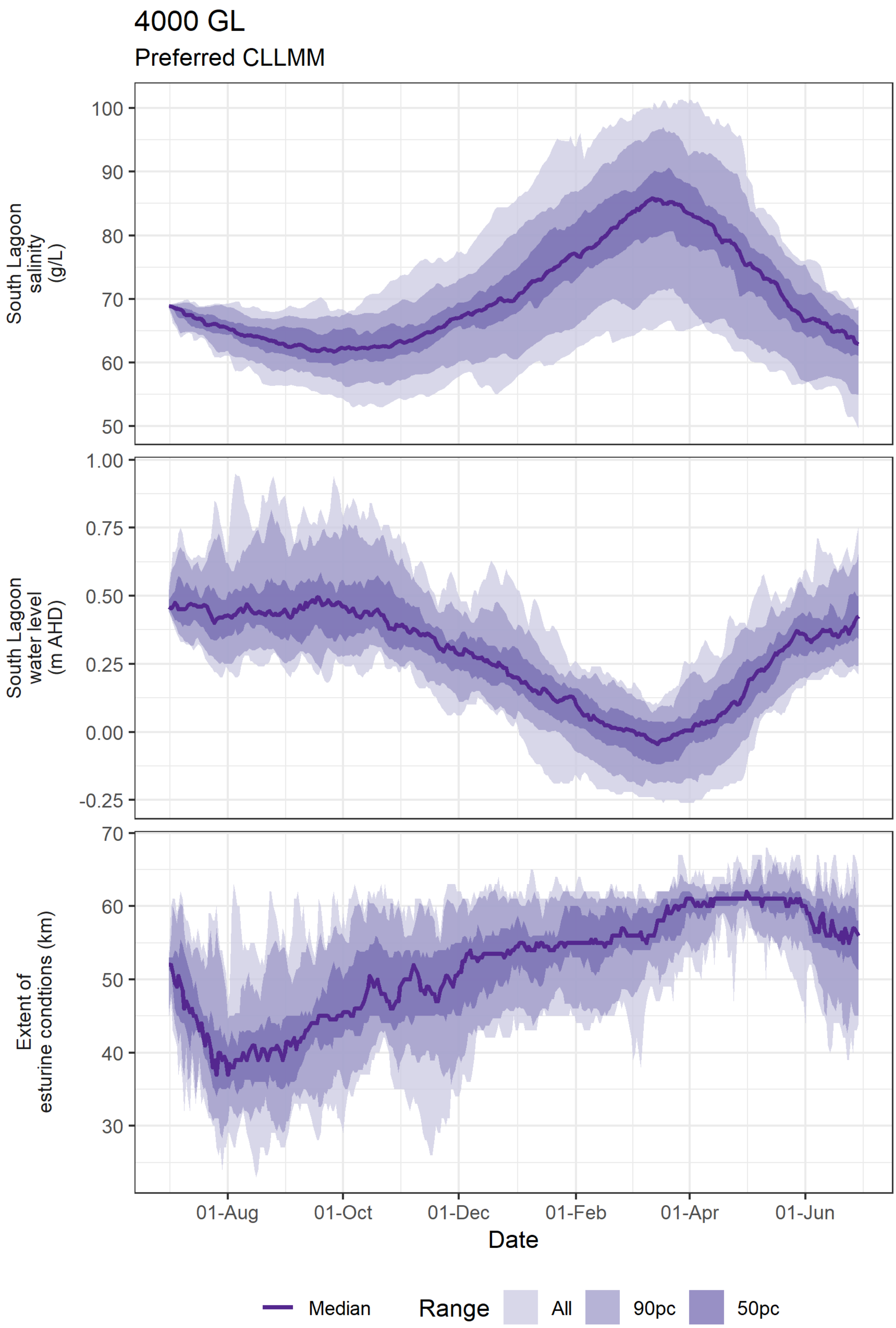

Figure A2_26. Salinity, level, and extent of estuarine conditions for preferred CLLMM target flow of 4000 GL.

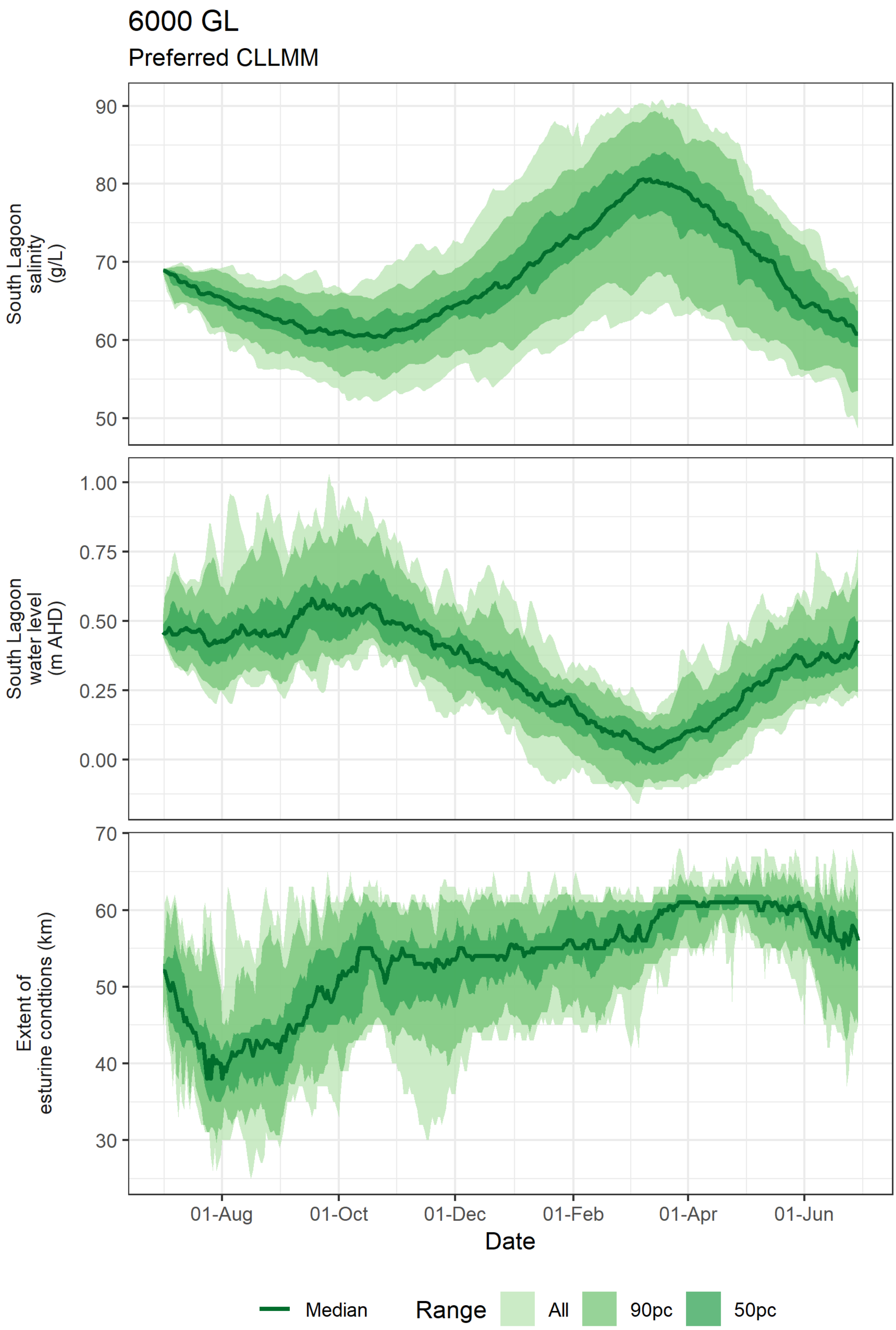

Figure A2_27. Salinity, level, and extent of estuarine conditions for preferred CLLMM target flow of 6000 GL.

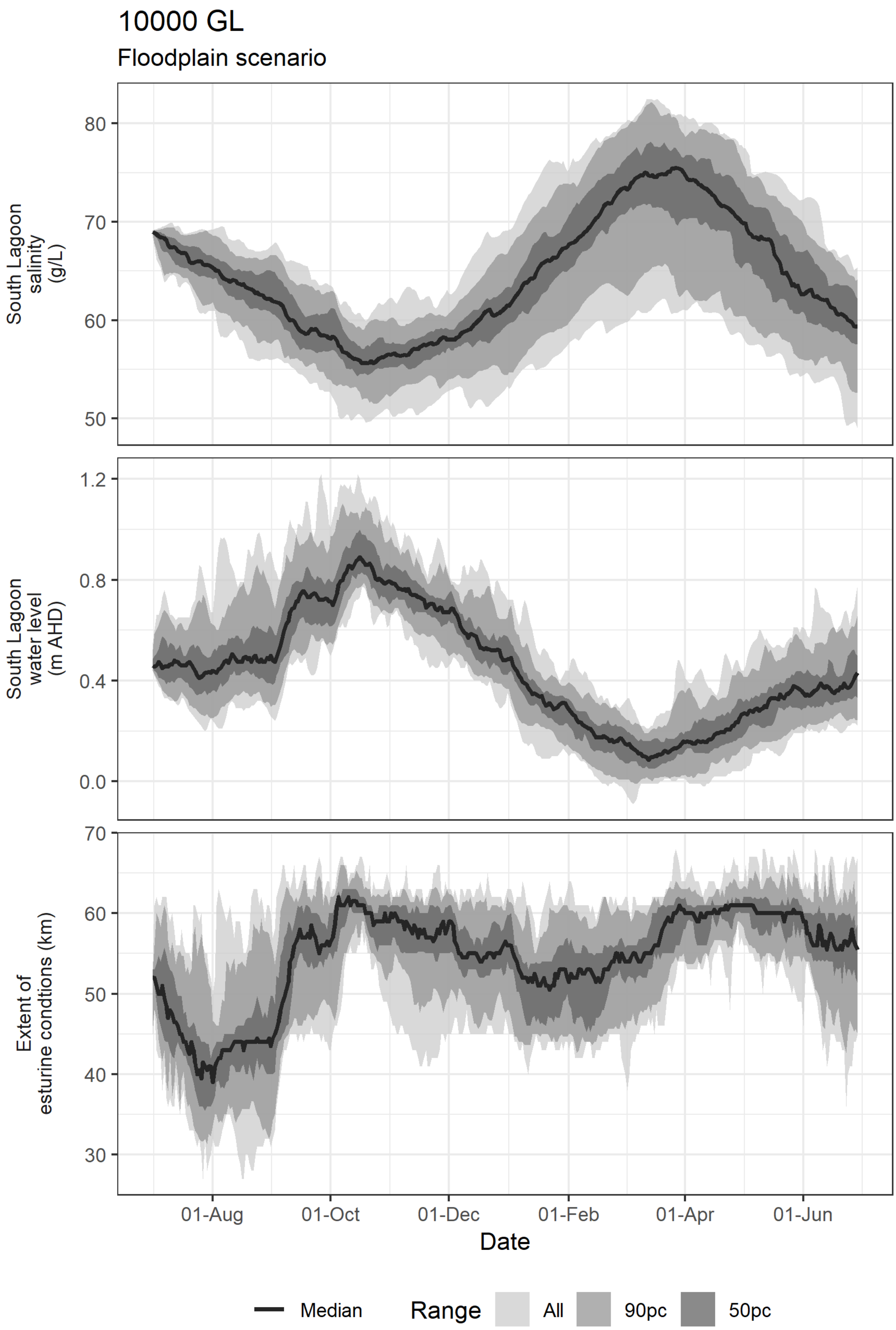

Figure A2_28. Salinity, level, and extent of estuarine conditions for preferred CLLMM target flow of 10000 GL.

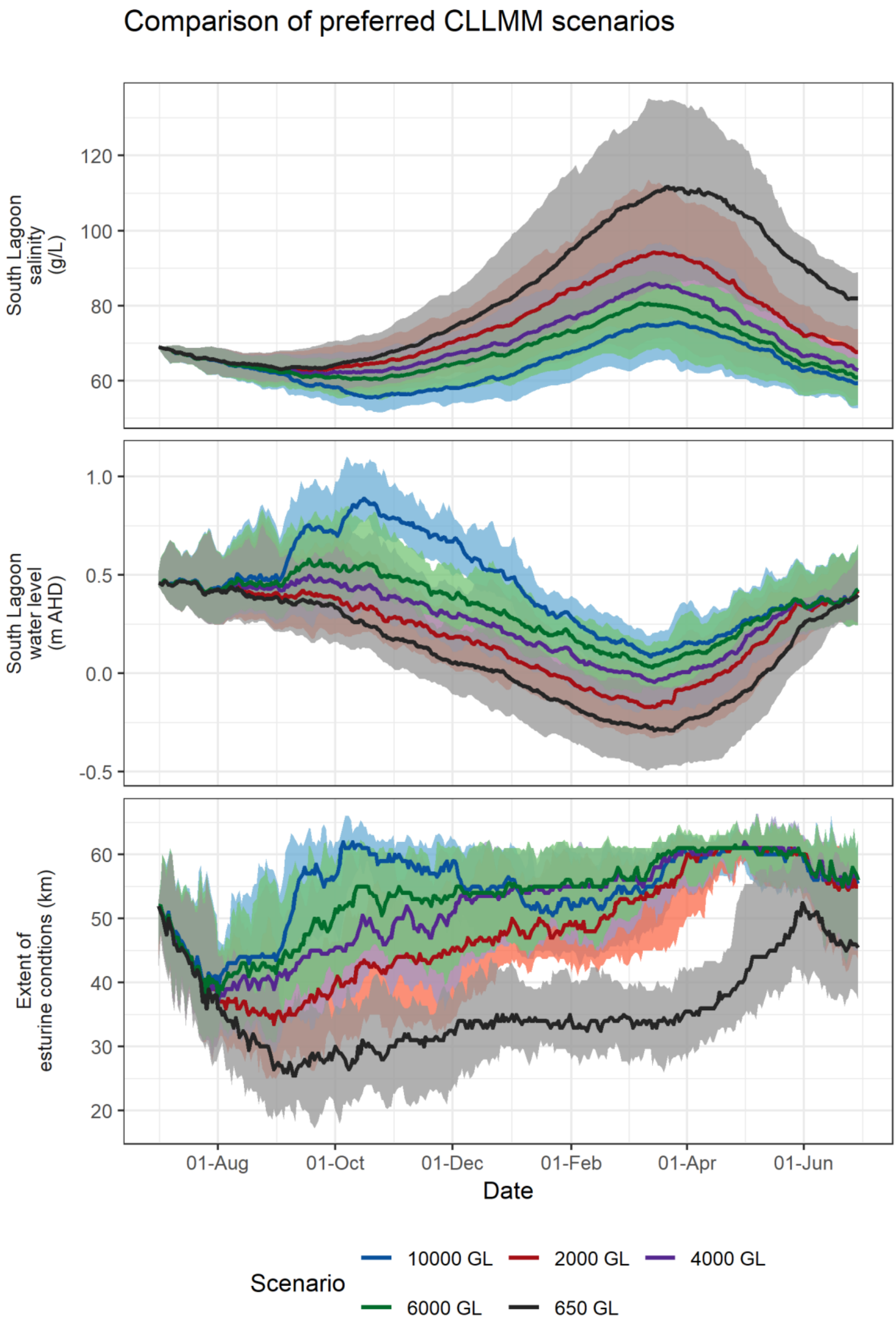

Figure A2_29. Comparison of salinity, level, and extent of estuarine conditions for preferred CLLMM scenarios.

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