River model scenario analysis for the Southern Gulf catchments

A technical report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid

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Aspects of the Assessment have been undertaken in conjunction with the Northern Territory and Queensland governments.

The Assessment was guided by two committees:

i. The Governance Committee: CRC for Northern Australia/James Cook University; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Agriculture and Fisheries; Queensland Department of Regional Development, Manufacturing and Water

ii. The Southern Gulf catchments Steering Committee: Amateur Fishermen's Association of the NT; Austral Fisheries; Burketown Shire; Carpentaria Land Council Aboriginal Corporation; Health and Wellbeing Queensland; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Prawn Fisheries; Queensland Department of Agriculture and Fisheries; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Regional Development, Manufacturing and Water; Southern Gulf NRM

Responsibility for the Assessment's content lies with CSIRO. The Assessment's committees did not have an opportunity to review the Assessment results or outputs prior to their release.

This report was reviewed by Ashkan Shokri (CSIRO) and Mahdi Montazeri (CSIRO).

Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and pay our respects to their elders past and present.

Photo

Leichhardt River Source: CSIRO

Director's foreword

Sustainable development and regional economic prosperity are priorities for the Australian, Queensland and Northern Territory (NT) governments. However, more comprehensive information on land and water resources across northern Australia is required to complement local information held by Indigenous Peoples and other landholders.

Knowledge of the scale, nature, location and distribution of likely environmental, social, cultural and economic opportunities and the risks of any proposed developments is critical to sustainable development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpin the resource security required to unlock investment, while at the same time protecting the environment and cultural values.

In 2021, the Australian Government commissioned CSIRO to complete the Southern Gulf Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to generate data and provide insight to support consideration of the use of land and water resources in the Southern Gulf catchments. The Assessment focuses mainly on the potential for agricultural development, and the opportunities and constraints that development could experience. It also considers climate change impacts and a range of future development pathways without being prescriptive of what they might be. The detailed information provided on land and water resources, their potential uses and the consequences of those uses are carefully designed to be relevant to a wide range of regional-scale planning considerations by Indigenous Peoples, landholders, citizens, investors, local government, and the Australian, Queensland and NT governments. By fostering shared understanding of the opportunities and the risks among this wide array of stakeholders and decision makers, better informed conversations about future options will be possible.

Importantly, the Assessment does not recommend one development over another, nor assume any particular development pathway, nor even assume that water resource development will occur. It provides a range of possibilities and the information required to interpret them (including risks that may attend any opportunities), consistent with regional values and aspirations.

All data and reports produced by the Assessment will be publicly available.

C. Chilcott

Chris Chilcott

Project Director

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Shortened forms

SHORT FORM	FULL FORM
ADCFR	annual diversion commencement flow requirement
AMTD	adopted middle thread distance
APSIM	Agricultural Production Systems sIMulator
AWRA-R	Australian Water Resources Assessment – River
AWRC	Australian Water Resources Council
CMIP6	Coupled Model Intercomparison Project – Phase 6
DEM	Digital Elevation Model
EGM96	Earth Gravitational Model 1996
EOS	end-of-system
FSL	full supply level
GCM	global climate model
IPCC	Intergovernmental Panel on Climate Change
NAWRA	Northern Australia Water Resource Assessment
PET	potential evapotranspiration
SILO	Scientific Information for Land Owners
SRTM	Shuttle Radar Topographic Mission
SSP	Shared Socioeconomic Pathway

Units

Unit	Description
d	day
GL	gigalitre
ha	hectare
km	kilometre
m	metre
mEGM96	metres above Earth Gravitational Model 96 datum
ML	megalitre
mm	millimetre
s	second
y	year

Preface

Sustainable development and regional economic prosperity are priorities for the Australian, NT and Queensland governments. In the Queensland Water Strategy, for example, the Queensland Government (2023) looks to enable regional economic prosperity through a vision that states 'Sustainable and secure water resources are central to Queensland's economic transformation and the legacy we pass on to future generations.' Acknowledging the need for continued research, the NT Government (2023) announced a Territory Water Plan priority action to accelerate the existing water science program 'to support best practice water resource management and sustainable development.'

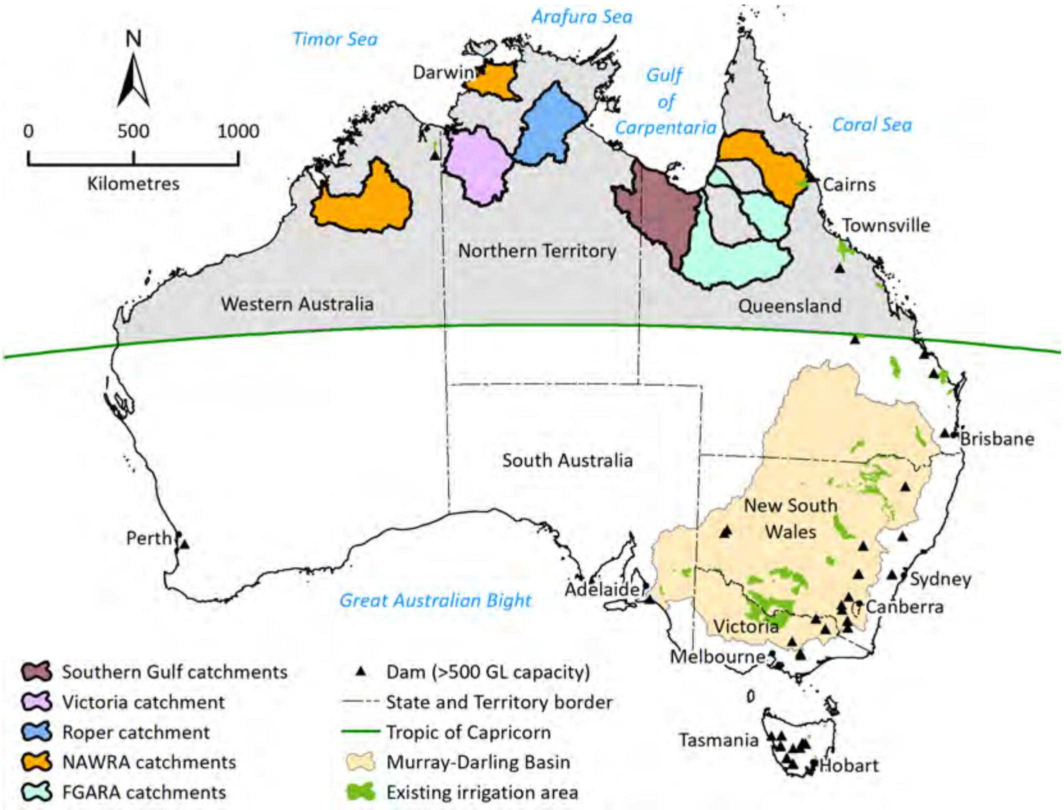
Governments are actively seeking to diversify regional economies, considering a range of factors, including Australia's energy transformation. The Queensland Government's economic diversification strategy for North West Queensland (Department of State Development, Manufacturing, Infrastructure and Planning, 2019) includes mining and mineral processing; beef cattle production, cropping and commercial fishing; tourism with an outback focus; and small business, supply chains and emerging industry sectors. In its 2024–25 Budget, the Australian Government announced large investment in renewable hydrogen, low-carbon liquid fuels, critical minerals processing and clean energy processing (Budget Strategy and Outlook, 2024). This includes investing in regions that have 'traditionally powered Australia' – as the North West Minerals Province, situated mostly within the Southern Gulf catchments, has done.

For very remote areas like the Southern Gulf catchments (Preface Figure 1-1), the land, water and other environmental resources or assets will be key in determining how sustainable regional development might occur. Primary questions in any consideration of sustainable regional development relate to the nature and the scale of opportunities, and their risks.

How people perceive those risks is critical, especially in the context of areas such as the Southern Gulf catchments, where approximately 27% of the population is Indigenous (compared to 3.2% for Australia as a whole) and where many Indigenous Peoples still live on the same lands they have inhabited for tens of thousands of years. About 12% of the Southern Gulf catchments are owned by Indigenous Peoples as inalienable freehold.

Access to reliable information about resources enables informed discussion and good decision making. Such information includes the amount and type of a resource or asset, where it is found (including in relation to complementary resources), what commercial uses it might have, how the resource changes within a year and across years, the underlying socio-economic context and the possible impacts of development.

Most of northern Australia's land and water resources have not been mapped in sufficient detail to provide the level of information required for reliable resource allocation, to mitigate investment or environmental risks, or to build policy settings that can support good judgments. The Southern Gulf Water Resource Assessment aims to partly address this gap by providing data to better inform decisions on private investment and government expenditure, to account for intersections between existing and potential resource users, and to ensure that net development benefits are maximised.



Preface Figure 1-1 Map of Australia showing Assessment area (Southern Gulf catchments) and other recent CSIRO Assessments

FGARA = Flinders and Gilbert Agricultural Resource Assessment; NAWRA = Northern Australia Water Resource Assessment.

The Assessment differs somewhat from many resource assessments in that it considers a wide range of resources or assets, rather than being a single mapping exercises of, say, soils. It provides a lot of contextual information about the socio-economic profile of the catchments, and the economic possibilities and environmental impacts of development. Further, it considers many of the different resource and asset types in an integrated way, rather than separately.

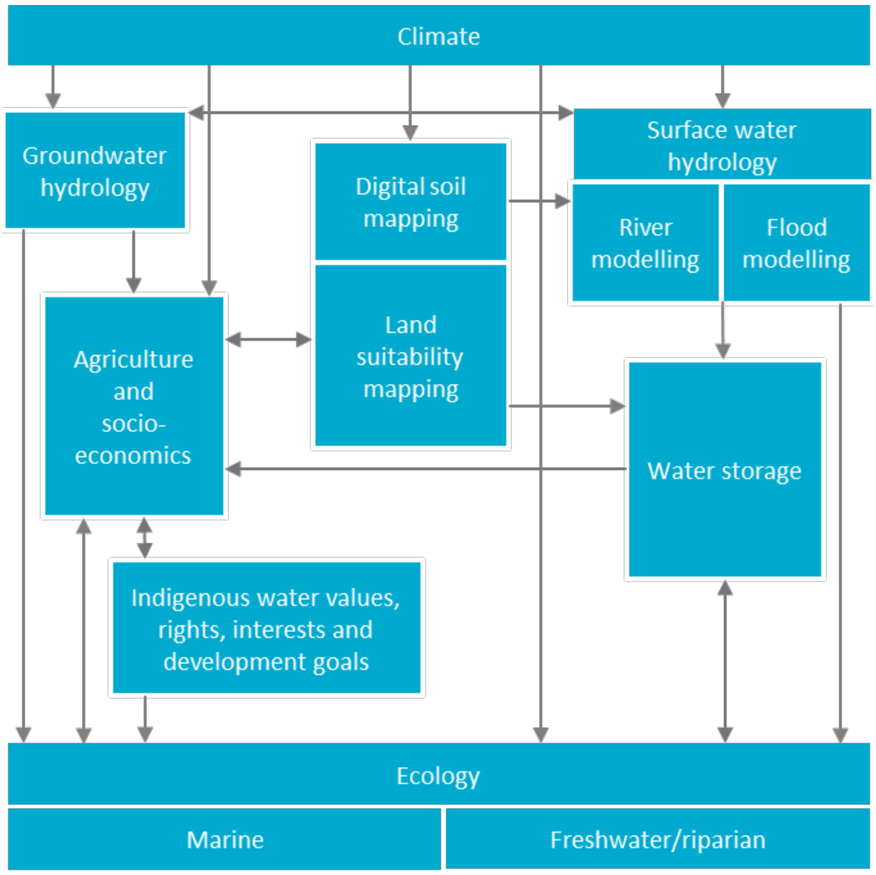
The Assessment has agricultural developments as its primary focus, but it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial, urban and aquaculture development, in relevant locations. The outcome of no change in land use or water resource development is also valid.

The Assessment was designed to inform consideration of development, not to enable any particular development to occur. As such, the Assessment informs – but does not seek to replace – existing planning, regulatory or approval processes. Importantly, the Assessment does not assume a given policy or regulatory environment. Policy and regulations can change, so this flexibility enables the results to be applied to the widest range of uses for the longest possible time frame.

It was not the intention of – and nor was it possible for – the Assessment to generate new information on all topics related to water and irrigation development in northern Australia. Topics not directly examined in the Assessment are discussed with reference to and in the context of the existing literature.

CSIRO has strong organisational commitments to Indigenous reconciliation and to conducting ethical research with the free, prior and informed consent of human participants. The Assessment allocated significant time to consulting with Indigenous representative organisations and Traditional Owner groups from the catchments to aid their understanding and potential engagement with its requirements. The Assessment did not conduct significant fieldwork without the consent of Traditional Owners. CSIRO met the requirement to create new scientific knowledge about the catchments (e.g. on land suitability) by synthesising new material from existing information, complemented by remotely sensed data and numerical modelling.

Functionally, the Assessment adopted an activities-based approach (reflected in the content and structure of the outputs and products), comprising activity groups, each contributing its part to create a cohesive picture of regional development opportunities, costs and benefits, but also risks. Preface Figure 1-2 illustrates the high-level links between the activities and the general flow of information in the Assessment.



Preface Figure 1-2 Schematic of the high-level linkages between the eight activity groups and the general flow of information in the Assessment

Assessment reporting structure

Development opportunities and their impacts are frequently highly interdependent and, consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports for each Assessment most reliably informs discussion and decisions concerning regional development when read as a whole.

The Assessment has produced a series of cascading reports and information products:

- Technical reports present scientific work with sufficient detail for technical and scientific experts to reproduce the work. Each of the activities (Preface Figure 1-2) has one or more corresponding technical reports.
- A catchment report, which synthesises key material from the technical reports, providing well-informed (but not necessarily scientifically trained) users with the information required to inform decisions about the opportunities, costs and benefits, but also risks, associated with irrigated agriculture and other development options.
- A summary report provides a shorter summary and narrative for a general public audience in plain English.
- A summary fact sheet provides key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable users to better access information that is not readily available in print format. All of these reports, information tools and data products are available online at https://www.csiro.au/southerngulf. The webpages give users access to a communications suite including fact sheets, multimedia content, FAQs, reports and links to related sites, particularly about other research in northern Australia.

Executive summary

There are substantial opportunities for targeted development in northern Australia, and access to the water resources of the region is integral to their success. However, extracting water from rivers, particularly for water-intensive industries such as irrigated agriculture, can result in large perturbations to streamflow, which can affect existing users and produce ecological change. Hydrological river modelling is commonly used to quantify the water resources of a catchment and examine the trade-offs associated with water regulation and extraction.

This report presents scenario analyses for the catchments of the Southern Gulf in north-west Queensland that explore current and projected future streamflow characteristics in the study area. The analyses investigate to what degree of reliability increasing volumes of water could potentially be extracted and how will streamflow be perturbed. The Southern Gulf catchments comprise four northerly draining catchments – defined by the Australian Water Resources Council (AWRC) river basin boundaries of Settlement Creek (17,600 km^2), Nicholson River (52,200 km^2), Leichhardt River (33,400 km^2), Morning Inlet (3700 km^2) – plus the islands within the AWRC Mornington Island Basin (total 1240 km^2). Gibbs et al. (2024) outlined the development of the river model for the Southern Gulf catchments that is used for this work.

Three initial scenarios were used to quantify past and current water availability: a representation of natural conditions, estimated current conditions in the catchments and conditions under the full use of existing entitlements (referred to as Scenario A). The results suggest a mean annual end-of-system volume across the Assessment area under Scenario A of 6759 GL/year. In the Leichhardt River catchment, where most existing users are located, Scenario A resulted in an 8% reduction in mean annual end-of-system volume compared to natural conditions.

Future water availability was informed by a suite of 32 global climate models (GCMs) from the Coupled Model Intercomparison Project – Phase 6 (CMIP6) for the Shared Socioeconomic Pathway (SSP) 2-4.5 in 2060, representing a 1.6 °C increase in temperature relative to a time slice centred around 1990. The climate models project a reduction in end-of-system streamflow as more likely than an increase for the Southern Gulf catchments: under Scenario Cmid (representing the median of GCMs) there is reduction of 3% to 14% (mean 9%) across the end-of-system flow metrics. However, the range in projections from the suite of GCMs is large. Scenario Cwet projected a 16% to 30% (mean 22%) increase compared to the 20% to 41% (mean 29%) decrease under Scenario Cdry. This wide range in results from the suite of GCM projections is a typical outcome, so a sensitivity-based approach was also used to provide additional information on hydrological responses to changes in annual rainfall and potential evaporation.

Two types of hypothetical future development scenario have been considered: large instream dams, and water harvest diversions directly from water courses to smaller off-stream storages. For each development type, a range of conditions were simulated, representing different water access conditions or mitigating strategies to reduce the effect on the downstream flow regime.

For water harvest development scenarios, at the smallest pump start threshold examined (200 ML/day, representing a lower physical pumping limit), approximately 300 GL of water can be extracted in the Southern Gulf catchments in 75% of years. However, this relatively low pump start threshold results in some impacts on existing downstream licence holders along the Leichhardt River. These impacts were mitigated with a pump start threshold of 600 ML/day, but that threshold reduced the volume of water that can be extracted in 75% of years to approximately 150 GL. Including an annual diversion commencement flow requirement to preserve the first flow event through the system was found to require large pumps to achieve volumes in this range; the large pumps were needed to provide the capacity to extract the annual reach target volume over 10 days.

Represented as a total mean annual volume extracted for water harvest (both hypothetical development scenario and full use of existing entitlements), the water harvest extraction volume is relatively insensitive to the range in projected climate from the conditions assumed. All GCMs fell within a 5% range in mean annual extraction volume compared to no change in climate.

The total divertible volume from seven short-listed dam sites (Yang et al., 2024) at a reliability of 85% and maintaining supply to downstream users was estimated to be 733 GL. However, most of this water yield was derived from the three dams that had the lowest cost per megalitre supplied. The combined yield from these three dams was 641 GL and resulted in a 14% reduction in median annual end-of-system volume from mainland catchments in the Assessment area. The yield from each individual dam was also estimated for a range of transparent flow releases, up to 50% of the mean daily inflow, to represent the trade-off between maximising yield from the storage and maintaining the persistence of low flows through the system. Transparent flow occurs when inflows below a given threshold are 'passed through' a dam to help mitigate potential ecological impacts.

The relative influence of the climate projections on the yield available from instream dams, and the resulting median annual volume released or spilling downstream, depends on the local topography and ability to capture inflows. The sensitivity of results for a hypothetical development including the three highest yielding dams indicated that 14 of 32 GCMs projected changes in climate that result in a total reduction in mean annual yield for all storages (both hypothetical and existing storages) of more than 5%. One of the GCMs projected an increase in mean annual yield greater than 5%, and the remaining 17 GCMs projected yields within 5% of values based on historical climate.

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Contents

Figures

Tables

Part I Main report

Nicholson River at Doomadgee in December 2022

Source: CSIRO

1 Introduction

Water supplied by regulated surface water resources in southern Australia meets about 70% of Australia's 25,000 GL mean annual water use (CSIRO, 2011). With substantial use of water resources in southern states coupled with governments seeking sustainable regional economic development, there is interest in developing the water resources of northern Australia. However, extracting water from rivers, particularly for water-intensive industries such as irrigated agriculture, can cause large perturbations to streamflow, which can affect existing industries and users and result in ecological change.

This report presents scenario analyses for the catchments of the Southern Gulf in north-west Queensland that explore current and projected future streamflow characteristics in the study area. The analyses investigate to what degree of reliability increasing volumes of water could potentially be extracted and how will streamflow be perturbed. The Southern Gulf catchments comprise four northerly draining catchments – defined by the Australian Water Resources Council (AWRC) river basin boundaries of Settlement Creek (17,600 km^2), Nicholson River (52,200 km^2), Leichhardt River (33,400 km^2) and Morning Inlet (3700 km^2) – plus the islands within the AWRC Mornington Island Basin (total 1240 km^2).

Gibbs et al. (2024) outlined the development of the river model for the Southern Gulf catchments in north-west Queensland that is used for this work. Henceforth, 'the model' refers to the Australian Water Resources Assessment River (AWRA-R) model developed in that work, for which the model subcatchments and node numbers are presented in Figure 1-1. This report uses the model to simulate a number of hypothetical scenarios, model assumptions, resulting extraction volumes and the associated reliability and changes in downstream flow. Gibbs et al. (2024) and companion reports provide more information on the study area, site characteristics, data availability, previous studies and model development.

1.1 Surface water activity objectives

The surface water hydrology activity uses a modelling framework to obtain water storage and flux estimates over various spatial and temporal scales across the Southern Gulf catchments. This report outlines how the model was used to simulate hypothetical scenarios in order to answer questions relevant to surface water development.

The key questions that this activity seeks to address in the Southern Gulf catchments include:

- How much water has discharged from the catchments over different time frames since 1890 and where is most runoff generated?
- What are the opportunities to use surface water for multiple uses?
- With what degree of reliability can water be extracted in different parts of the Southern Gulf catchments, how is the reliability of extraction affected by varying extraction conditions and how will streamflow be perturbed downstream?
- How would changes in projected future climate potentially affect streamflow and water resource development in the Southern Gulf catchments?

Figure 1-1 AWRA-R model nodes and subcatchment areas

See Gibbs et al. (2024) for detail on model configuration and calibration.

1.2 Hypothetical water resources development options considered

Yang et al. (2024) undertook a pre-feasibility-level assessment of four types of surface water storage options: (i) large dams that could supply water to multiple properties, (ii) farm-scale or on-farm dams that supply water to a single property, (iii) re-regulating structures such as weirs, and (iv) natural water bodies. This report considers the first two water storage options to assess the reliability with which increasing volumes of water could be extracted and how these types of hypothetical developments would perturb streamflow downstream.

Large dams and farm-scale dams can be further classified as either instream or offstream water storages. In the Assessment, instream water storages are defined as structures that intercept a drainage line (creek or river) and are not supplemented with water from other drainage lines. Offstream water storages are defined as structures that: (i) do not intercept a drainage line, or (ii) intercept a drainage line and are supplemented with water extracted from another larger drainage line. Ringtanks and turkey nest tanks are examples of offstream storages; both are formed by a continuous earth embankment.

An attraction of large dams is that, if the reservoir is large enough relative to the demands on the dam (i.e. water supplied for consumptive use, evaporation and seepage), when the reservoir is full water can last two or more years. This has the advantage of providing water during dry seasons and mitigating against years with low inflows to the reservoir. For this reason, large dams are sometimes referred to as carry-over storages.

Another advantage of large instream dams is that they provide a very efficient way of intercepting the flow in a river, effectively trapping all flow until the full supply level (FSL) is reached. However, this also means they are a very effective barrier to the movement of fish and other species within a river system, and they can also inundate large areas of land.

Offstream water storages can take the form of farm-scale ringtanks (e.g. 100 to 10,000 ML storage capacity) or large dam structures (>10,000 ML). The most suitable type of offstream water storage depends on factors such as topography, availability of suitable soils, excavation costs, frequency of flooding and source of water (e.g. groundwater or surface water pumping, flood harvesting). Properly designed offstream storages can cause less disruption of the natural flow regime than large instream dams.

Irrespective of the physical resources that may support water and irrigated agricultural development in the Southern Gulf catchments, if the future trajectory of irrigation development is similar to historical trends in the NT and Queensland the scale of future irrigation development in the Southern Gulf catchments is likely to be modest, unlikely to encompass large dam development. Based on recent patterns, development is likely to be incremental and small-scale involving off-stream storages, gully dams and groundwater. Nonetheless, large dams remain topical, and it is important that robust and independent analysis addresses the opportunities and the risks that large-scale dam developments present.

Similarly, large scale water harvest operations in the Southern Gulf catchments are unlikely, however, these scenarios are included to understand the opportunities and risks of development.

2 Overview of scenarios

Northern Australia experiences a highly seasonal climate, with most rain falling during a 4-month period from December to March. Unless specified otherwise, this Assessment defines the wet season as being the 6-month period from 1 November to 30 April and the dry season as the 6-month period from 1 May to 31 October. These definitions were chosen because they are the wettest and driest 6-month periods, respectively, for the study area. Note, however, that the transition from the dry to wet season typically occurs in October or November, and meteorologists commonly define the northern wet season used as 1 October to 30 April.

All results in the Assessment are reported over the water year, defined as the period 1 September to 31 August, unless specified otherwise. This allows each individual wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons). The water year is more appropriate than a calendar year for reporting climate statistics from a hydrological and agricultural assessment viewpoint.

The Assessment considered four scenarios, reflecting combinations of different levels of development and historical and future climates, much like those used in the Northern Australia Sustainable Yields projects (CSIRO, 2009a, 2009b), the Flinders and Gilbert Agricultural Resource Assessment (Petheram et al., 2013a, 2013b) and the Northern Australia Water Resource Assessments (Petheram et al., 2018a, 2018b, 2018c). This chapter provides a high-level summary of the scenarios and terminology used in this work. Table 2-1 summarises the different configurations and nomenclature used. Details of the implementation of the scenarios in the model is provided in Chapter 3.

2.1 Scenario A

Scenario A is historical climate and current development assumed over the full simulation period. The simulation period used was 1 January 1889 to 1 July 2023, representing all available data at the time of model development. Allowing time for the model to 'warm up', the reporting period adopted in the Assessment is from 1 September 1890 to 31 August 2022. Justification for use of this period is provided in the companion technical report on climate (McJannet et al., 2023). All results presented in this report are calculated over this assessment period unless specified otherwise. Full use of existing entitlements was assumed under Scenario A.

Two additional scenarios were included for context:

- Scenario A Existing (AE) represents the estimated current use of existing entitlements, as there is substantial underutilisation of entitlements in the Southern Gulf catchments (DRDMW, 2023). Scenario AE provides a representation of current streamflow characteristics in the study area.
- Scenario A Natural (AN) removes all storages and diversions from the model and hence best represents 'natural conditions' (assuming current relationship between rainfall and runoff), or conditions prior to European development.

2.2 Scenario B

Scenario B is historical climate and hypothetical future development. Scenario B used the same historical climate series as Scenario A. The model was modified to reflect potential hypothetical development options, and changes in outputs were used to assess the responses of hydrological, ecological and economic systems.

Two types of hypothetical future development are considered. The first is an increase to water harvest extraction directly from watercourses, typically assumed to supply water to nearby farm-scale developments. A number of access conditions were evaluated, including the maximum pump capacity, the minimum flow in the river at the location of the pump required for pumping to commence (termed pump start threshold), and volume required to flow past a particular location(s) before pumping can commence for the season (termed annual diversion commencement flow requirement (ADCFR).

The second hypothetical future development considered is the construction of large instream dams, typically assumed to supply water to large contiguous irrigation districts. Trade-offs between storing more inflows to a dam and providing different levels of transparent flows, by releasing inflows up to a given flow threshold, are explored.

The locations of existing and hypothetical water harvesting operations and hypothetical dams examined in this report are shown in Figure 2-1.

2.3 Scenario C

Scenario C is projected future climate and current levels of surface water and ground development (assuming full use of existing entitlements as under Scenario A) assessed at around 2060. It is based on the 132-year climate series (as in Scenario A) derived from global climate model (GCM) projections for an approximate 1.6 °C global temperature rise (at ~2060) relative to the 1990 scenario. This climate projection represents Shared Socioeconomic Pathway (SSP) 2-4.5, as defined in the United Nations Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report. McJannet et al. (2023) has more details on the definition and selection of SSPs. Three GCMs, selected to represent the range in projections, were used to modify the observed historical daily climate sequences. More details are provided in Section 3.3.

A Scenario CE has also been considered, assuming the same estimated current use of existing entitlements as under Scenario AE and same projected future climate as under Scenario C.

2.4 Scenario D

Scenario D is future climate and hypothetical future development. It used the same projected future climate series as Scenario C. Climate and river inflow were modified to reflect potential future development, as in Scenario B.

Figure 2-1 Locations of existing water users under Scenarios A and C, and additional hypothetical options considered under scenarios B and D

Existing supplemented demands represent water licences supplied from existing dams rather than existing water harvest licences supplied directly from the watercourse. The model has an additional hypothetical water harvest extraction at the same location as the existing water harvest licence at node 9139000 on the Leichhardt River. AMTD = adopted middle thread distance. FSL = full supply level.

Table 2-1 Summary of scenarios and nomenclature

SCENARIO	DESCRIPTION	ASSUMES FULL USE OF EXISTING LICENCES	TRANSPARENT FLOW THRESHOLD (% OF MEAN INFLOW)	TARGET EXTRACTION VOLUME (GL)	ANNUAL DIVERSION COMMENCEMENT FLOW REQUIREMENT (GL)	PUMP START THRESHOLD (ML/d)	PUMP CAPACITY (d)
Scenario A	**Historical climate and no hypothetical development**						
AN	Pre-European development	No (no use)	na§	0	na	na	na
AE	Current (2023) levels of development	No (current)	No	29.9†	0	86.4	38
A	Full use of existing entitlement	Yes	No	113.5†	0	variable	variable
Scenario B	**Historical climate and hypothetical future development**						
$B\text{-}D_{WR}T_{Q}$	Single hypothetical dam‡	Yes	Q = 0, 10, …, 40, 50	na‡	na	na	na
$B\text{-}D_3$	Three hypothetical dams, GR-H, GU, N‡	Yes	No	na‡	na	na	na
$B\text{-}W_{V}, E_{F}, P_{T}, R_{C}$	Water harvesting varying target extraction volume (V), system flow requirement (F), pump start threshold (T), and/or pump capacities (C)	Yes	na	V = 50, 100, …, 450, 500	F = 0, 50, …, 200, 250	T = 200, 300, …, 900, 1000	C = 10, 20, 30, 40, 50
Scenario C	**Future climate and current level of development**						
Cdry	Dry (10th percentile exceedance) GCM†† projection	Yes	No	113.5†	0	variable	variable
Cmid	Mid (50th percentile exceedance) GCM projection	Yes	No	113.5†	0	variable	variable
Cwet	Wet (90th percentile exceedance) GCM projection	Yes	No	113.5†	0	variable	variable
Scenario D	**Future climate and hypothetical future development**						
$Dclim\text{-}D_3$	Three hypothetical dams (same as $B\text{-}D_3$), for each Scenario C climate (clim = dry, mid, wet)	Yes	No	na‡	na	na	na
$Dclim\text{-}W_{150,F,600,c}$	Water harvesting with Scenario C climate	Yes	na	150	F = 0, 150	600	C = 10, 20

† This extraction volume represents existing users. The target volume for scenarios with hypothetical development (scenarios B and D) includes this Scenario A target volume.
§ na = not applicable.
‡ No target volume for hypothetical dam scenarios; instead a target extraction volume that could be met with 85% reliability was identified.
†† GCM = global climate model.

3 Methods

3.1 Scenario A

3.1.1 Scenario AN

All (existing) dams and diversions included in the model for calibration in Gibbs et al. (2024) were removed under Scenario AN. This only influences the catchment of the Leichhardt River in the model, as existing users in other catchments were not included in the calibration model due to the small volume of licences relative to streamflow and a lack of information on historical extraction volumes.

3.1.2 Scenario AE

The model as configured in Gibbs et al. (2024) was used for Scenario AE with modifications to the assumptions for two diversions in the Leichhardt River catchment:

- An existing user that was assumed to commence water harvest in 1999 for model calibration was simulated over the entire reporting period under Scenario AE.
- Demand from Lake Moondarra was reduced from to 11,365 to 9,525 ML/year over the entire reporting period to represent water saving measures at Mount Isa mines (DNRME, 2019).

3.1.3 Scenario A

All existing users were assumed to extract their full licence volume (where possible) under Scenario A. Information on existing licences was sourced from the Open Data Portal (Queensland Government (n.d.). Total number of water licences and nominal entitlement volumes identified aligns with that reported in Appendix B of DRDMW (2023). The existing users implemented in the model, including the model node used to locate the extraction and assumed licence conditions, is outlined in Table 3-1.

The existing Water Plan (Gulf) (Queensland Government, 2007) also includes a number of strategic water reserves in the Southern Gulf catchments. There are Indigenous reserves (Indigenous unallocated water) in Morning Inlet (50 ML), Settlement Creek (1.5 GL) and Gregory River (1 GL). There is 1.1 GL for any purpose reserved for the East Leichhardt Dam and 4.4 GL general purpose reserve in the Nicholson River subcatchment. State strategic reserves are 5 GL in the Gregory River, 15 GL in the lower Leichhardt River, 1 GL in Morning Inlet, 4.282 GL in the Nicholson River and 1 GL in Settlement Creek, for a total of 34.3 GL of strategic reserves. These reserves have not been represented explicitly in the model, but the hypothetical developments assumed as part of Scenario B could theoretically represent some of these strategic purposes.

Table 3-1 Assumed existing users in the Southern Gulf catchments under Scenario A

CATCHMENT AREA	MODEL NODE	ENTITLEMENT VOLUME (ML)	PUMP CAPACITY (ML/d)	PUMP START THRESHOLD (m^3/s)
Nicholson River	9121015	1,192	10.97	0
	9121070	24	0.52	0
	9121160	500	2.59	0
Gregory River	9121010	784	10.81	0
	9121030	1,802	17.28	0
	9121090	3,540	36.55	0.035
Upper Leichhardt River	9130010	1,500	4.23	0
	9130012	26	0.52	0
Lower Leichhardt River	9130040	442	8.21	0
	9130061	3,953	6.91	0
	9130110	1,600	8.64	1
	9130111	10,000	999.91	1
	9139000	13,000	510.28	1
Lake Julius	9130150	48,850	133.83	0
Lake Moondarra	9130011	26,300	72.05	0

3.2 Scenario B

Some hypothetical water harvest or instream dam scenarios under Scenario B are upstream of existing licences (Figure 2-1). Any impacts to these users, assuming full use of licence volumes, is considered in the analysis (i.e. relative to reliability of supply under Scenario A). All hypothetical developments under Scenario B are situated downstream of the existing storages simulated in the Leichhardt catchment.

3.2.1 Water harvest

Water harvest analysis is partly intended to explore the physical limits of supply across the catchments and how access conditions influence the reliability of supply, defined as the percentage of years that a given volume could potentially be diverted each year. Access conditions considered were:

- system target volume – the total volume across all water harvest nodes attempted to be extracted each year, which is then apportioned across the water harvest nodes to produce the reach target volume
- pump start threshold – a daily flow threshold flow rate above which pumping or diversion of water can commence. This condition represents a mitigation strategy to minimise the ecological impact of water harvesting and/or to minimise impacts to existing downstream users, but can also represent the physical threshold below which it is difficult to pump water from a natural waterhole

- pump capacity – the maximum extraction rate of the pump(s) in a reach, expressed as the number of days required to extract the reach target volume. A higher pump capacity (lower number of days) can divert more flow per day, potentially taking advantage of short duration flow pulses
- annual diversion commencement flow requirement (ADCFR) – the cumulative volume passing the most downstream nodes in catchments with water harvest (on the Leichhardt River node 9130071, Albert River node 9129040 and Nicholson River node 9121090) from the start of the water year required before water harvest pumping can commence. This condition represents a mitigation strategy to delay water extraction to allow the 'first flush' flow event through the system for ecological benefit.

The parameters analysed for each of the access conditions are given in Table 3-2. Note that these parameters do not account for other limits on diversion that may be apparent, or any other environmental, legal, social or economic reasons that may influence diversion of surface water.

Table 3-2 Parameters and values considered for water harvest analyses

WATER HARVEST PARAMETERS	VALUES ANALYSED	UNITS
System target volume	50, 100, 150, …, 400, 450, 500	GL/year
Pump start threshold	200, 300, …, 900, 1000	ML/day
Pump capacity	10, 20, 30, 40, 50	Days†
ADCFR‡ volume	0, 50, 100, 150, 200, 250	GL/year

† Pump capacity is the rate at which the pump(s) can operate to extract the reach annual irrigation target in the given number of days. Hence the pump capacity used by the simulation (m^3/s) will be a function of the system target volume and the reach proportions in Table 3-3.
‡ ADCFR = annual diversion commencement flow requirement.

The impact of pump start thresholds and ADCFR volumes on extraction reliability are explored because they are the least complex environmental flow provision to regulate and ensure compliance in remote areas. More-targeted environmental flow provisions may be possible, but they are inevitably more complicated for irrigators to adhere to (usually requiring many dozens of pump operations during a season) and more difficult for regulators to ensure compliance. Within each river reach, water could be harvested by one or more hypothetical water harvesters and the water nominally stored in ringtanks adjacent to the river reach.

Preliminary analysis determined that simulated flow regimes in the Settlement Creek, Morning Inlet and Mornington Island AWRC basins did not support substantial water harvest volumes, defined as greater than 1 GL/year extracted at 75% reliability with a pump capacity of 20 days and pump start threshold of 200 ML/day. One water harvest node is located on each of the Nicholson, Lawn Hill, and Gregory rivers and two nodes along the lower Leichhardt River (Figure 2-1). The locations were assigned based on joint consideration of crop versatility, broad-scale flooding, ringtank suitability and river discharge. The model nodes and assumed proportion of the system target volume are given in Table 3-3. Where relevant, hypothetical water harvest nodes were placed upstream of existing users in the same reach to ensure potential impacts to existing entitlement holders were conservatively evaluated.

Table 3-3 Proportion of the system target volume used to determine reach target volumes at hypothetical water harvest nodes under scenarios B and D

MODEL NODE	PROPORTION
9121052	0.3
9121161	0.125
9121033	0.075
9139000	0.25
9130070	0.25

Consideration of soil limitations

In some river reaches, soil suitable for irrigation and/or constructing ringtanks is the bio-physical limitation to water harvesting. The soil limitation in each reach was assessed to ensure the volume of water extracted did not exceed the area of land required to store the water or the volume required to irrigate all of the suitable soil along a river. An assessment of the soil-limited water harvest volume was calculated based on the volume of surface water available to each model node and the volume of water required to irrigate a reference crop on all suitable soils within the water harvest node reach. The soil-limited water harvest volume (e_{sw}) for the node was calculated as:

$$e_{sw} = min(e_{soil}, e_{rt}) \quad (1)$$

where:

e_{rt} is the volume of water that can be stored on ringtank-suitable soils within 5 km of the river, assuming 33% of the area of soils suitable for dry-season grain and fibre crops under spray irrigation will need to be reserved for water storage.

e_{soil} is the soil-limited water harvest annual volume (GL) and is calculated as follows:

1. Soil area per reach is defined as the area of soils suitable for dry-season grain and fibre crops under spray irrigation (Thomas et al., 2024) within 5 km of the main stream within each subcatchment. The area of suitable soil is then potentially further reduced when accounting for soil spatial continuity (i.e. some areas of Class 1 and 2 soils are isolated by areas of poor soil or topographic features such as larger streamlines) (Thomas et al., 2024).
2. Soil area is further reduced (by 33%) due to the need to build ringtanks close to the river on similar soils to those suitable for broadacre cropping. It is then further reduced (by 20%) due to other farm-related infrastructure requirements (channels, roads, buildings etc.).
3. Assuming that a dry-season crop with a medium growing season length requires 10 ML/ha on average (including transmission, storage and application losses), soil areas are converted to a mean annual water requirement.

This analysis found that e_{sw} was greater than the volume that could be supplied in 75% of years at each extraction point based on the locations and proportions assumed in Table 3-3, indicating that water availability, rather than soil availability, was likely to be the bio-physical limit on water harvest diversions in the study area.

3.2.2 Hypothetical water storages

Yang et al. (2024) used the DamSite model (Petheram et al., 2017) to objectively identify potential locations for hypothetical large instream dams based on topography, potential evaporation, rainfall and inflows across the Assessment area. Short-listed dams identified for additional assessment are presented in Table 3-4. For the dam located on the Gregory River adopted middle thread distance (AMTD) 174 km, an FSL of 138 m above Earth Gravitational Model 96 datum (mEGM96) is adopted by Yang et al. (2024) to avoid inundation of Boodjamulla (Lawn Hill) National Park. A dam at this location with higher FSL of 145 mEGM96 is also simulated for completeness. At this FSL, the cost of construction per megalitre of water supplied with a reliability of 85% of years is minimised, noting that a higher FSL can yield a higher volume with only a slight increase in cost per megalitre.

Table 3-4 Surface area and reservoir capacity at full supply level (FSL) of short-listed hypothetical dams simulated using river model

See Figure 2-1 for a map of locations.

DAM	CODE	MODEL NODE	RESERVOIR SURFACE AREA (ha)	RESERVOIR CAPACITY (GL)
Gregory River AMTD† 174 km (Dam 1) FSL 138 mEGM96	GR-L	9121050	2,622	118
Gregory River AMTD 174 km (Dam 1) FSL 145 mEGM96	GR-H	9121050	7,090	441
Gunpower Creek AMTD 66 km (Dam 28) FSL 186 mEGM96	GU	9130030	4,021	716
Nicholson River AMTD 198 km (Dam 3) FSL 108 mEGM96	N	9121070	12,417	1403
South Nicholson River AMTD 9 km (Dam 290) FSL 162 mEGM96	SN	9121075	4,923	382
Mistake Creek AMTD 60 km (Dam 165) FSL 149 mEGM96	M	9130080	2,320	158
Ewen Creek AMTD 6 km (Dam 275) FSL 217 mEGM96	E	9130040	2,515	245
Gold Creek AMTD 58 km (Dam 206) FSL 84 mEGM96	GO	9121097	756	119

† AMTD = adopted middle thread distance.

Relationships between the modelled volume and stage height and surface area for each hypothetical dam were developed based on the 1 second hydrological digital elevation model (DEM-H) (~30 m horizontal grid), derived from the Shuttle Radar Topographic Mission (SRTM) data. The resulting curves are provided in Appendix A.

The potential evapotranspiration (PET) inputs are calculated using the Morton's wet area algorithm (Morton, 1983). These and other typical potential evaporation estimates have been shown to differ from measured lake evaporation (see Figure 3-1) in some instances, for example, due to variable fetch conditions. Accordingly, lake evaporation is estimated using dynamic lake area (A_t) and monthly correction factors based on measured lake evaporation data collected at Lake Julius during the project (see Petheram et al. (2020) for more detail on method).

Figure 3-1 Floating evaporation pan used to determine water surface evaporation, Lake Julius on the Leichhardt River

Source: CSIRO – Nathan Dyer

The pattern of water use from each dam was assumed based on Agricultural Production Systems sIMulator (APSIM) modelling of an irrigated dry-season medium-length growing season grain and fibre crop (Webster et al., 2024). Typically, the soils downstream of hypothetical dam locations in the catchments of the Leichhardt and Nicholson–Gregory rivers are classified as heavy or brown Vertosol. For these soils, trafficability to plant a crop may be limited until mid-March over 50% of the time, using a metric of the modelled plant available water capacity below 70%. The resulting pattern of applied irrigation water for a crop planted on a Vertosol in mid-March was used to distribute the annual yield from the dam over the year. For more details on crop modelling used to develop the demand pattern, see Webster et al. (2024).

Releases of water from hypothetical instream dams in the model were managed to ensure no impact on existing downstream users. This was determined by simulating each dam individually in the model and comparing the reliability of supply for all users under Scenario A, as indicated by an exceedance curve of annual diverted volumes. If an impact to a downstream existing user was identified, the difference between the daily diversion volumes was calculated. The resulting shortfall was increased by a nominal 50% to account for modelled losses between the hypothetical dam and the downstream user. This nominal amount was found to be sufficient for all but two existing users, for whom the loss factor was increased further until the reliability impacts were mitigated. These releases were then included in the model for subsequent model runs and are accounted for in the simulated reservoir yield volumes.

Different assumptions for demand patterns and other input data (e.g. evaporation correction factors) and the representation of downstream existing users have resulted in slight differences between the yield volumes presented in this report and those in Yang et al. (2024).

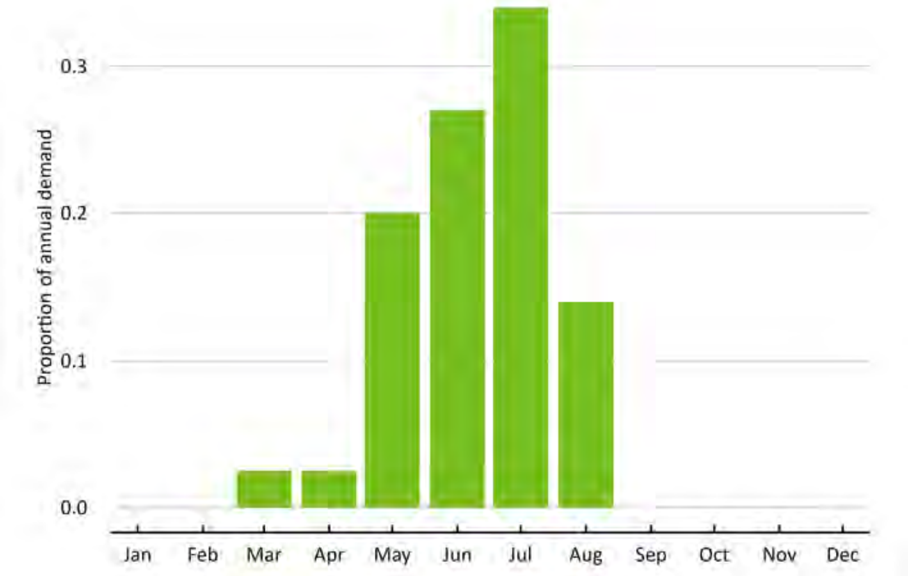

Figure 3-2 Assumed pattern of demand for Scenario B instream dams

Two main analyses were undertaken for the water storage modelling.

The first analysis is to assess the yield available from each hypothetical dam and the trade-off with providing transparent flows up to a maximum rate, Q_T, to mitigate the impact of the dam on streamflow downstream. Q_T was determined as a percentage of the mean daily inflow to the dam, $\bar{Q}$, and values of 0, 10, 20, 30, 40 and 50% of $\bar{Q}$ were trialled. The dam releases, Q_o, were then:

$$Q_o = \min(Q_I, Q_T) \quad (2)$$

where Q_I are the daily inflows to the dam. No transparent flow releases are made if there are no inflows. The resulting values for Q_T are outlined in Table 3-5.

Table 3-5 Transparent flow thresholds (m^3/s) tested for each short-listed dam

$\bar{Q}$ is the mean daily streamflow into the dam node.

DAM	$0.1\,\bar{Q}$	$0.2\,\bar{Q}$	$0.3\,\bar{Q}$	$0.4\,\bar{Q}$	$0.5\,\bar{Q}$
Gregory River AMTD† 174 km (Dam 1) FSL 138/145 mEGM96	1.5	3.0	4.5	6.0	7.5
Nicholson River AMTD 198 km (Dam 3) FSL 108 mEGM96	2.1	4.1	6.2	8.2	10.3
Gunpower Creek AMTD 66 km (Dam 28) FSL 186 mEGM96	0.6	1.2	1.8	2.4	3.0
South Nicholson River AMTD 9 km (Dam 290) FSL 162 mEGM96	0.4	0.8	1.2	1.6	2.0
Mistake Creek AMTD 60 km (Dam 165) FSL 149 mEGM96	0.3	0.5	0.8	1.0	1.3
Ewen Creek AMTD 6 km (Dam 275) FSL 217 mEGM96	0.7	1.4	2.0	2.7	3.4
Gold Creek AMTD 58 km (Dam 206) FSL 84 mEGM96	0.3	0.5	0.8	1.0	1.3

† AMTD = adopted middle thread distance.

The second analysis is to determine the potential total divertible volume in the Southern Gulf catchments Assessment area based on the short-listed dams. Dams were included in the model incrementally. The order was based on the modelled cost per megalitre of water available at the dam wall from Yang et al. (2024). The yield released from the dam at a reliability of 85% of years was determined, after accounting for any controlled releases to maintain reliability of supply to downstream users, as outlined above. The relatively high security of supply of 85% annual time reliability used for the dam yield analysis is likely suitable for high-value crops like horticulture. Other uses such as broadacre cropping may be viable with a higher volume of lower reliability water (e.g. the 75% annual time reliability nominally used for reporting of water harvest extractions).

3.3 Scenario C

Global climate models are an important tool for simulating global and regional climate. To simulate and assess the uncertainty of the range of future runoff projections, future climate projections from a large range of archived GCM simulations were downloaded from the Coupled Model Intercomparison Project – Phase 6 (CMIP6) website (https://pcmdi.llnl.gov/CMIP6/). Of the 92 available GCMs, 32 included the rainfall, temperature, solar radiation and humidity data required for the Southern Gulf catchments Assessment area AWRA-R hydrological model. For the purpose of the Assessment, the SSP2-4.5 from the Sixth Assessment Report (IPCC, 2022) was used to investigate the sensitivity of changes in rainfall and potential evaporation on streamflow at approximately the year 2060. SSP2-4.5 represents a scenario where emissions rise slightly before declining after 2050, but do not reach net zero by 2100. More details on SSPs and assumptions are provided in the companion technical report on climate (McJannet et al., 2023). At around 2060, SSP2-4.5 is representative of a 1.6 °C temperature rise relative to a time slice centred around 1990.

These direct GCM outputs provide information at a resolution that is too coarse to be used directly in catchment-scale hydrological modelling. McJannet et al. (2023) outlines the scaling approach used to make the climate projections suitable for the AWRA-R hydrological model, and a more detailed description can be found in Chiew et al. (2009). The seasonal pattern scaling (PS) method employed used output from the 32 GCMs to scale the historical daily rainfall, temperature, radiation and humidity sequences (i.e. SILO (Scientific Information for Land Owners) climate data), to construct the 32 sequences of future daily rainfall, temperature, radiation and humidity. Potential evaporation is also derived from these variables. The method comprised two broad steps. The first step involved estimating the seasonal scaling factors for four 3-month blocks (December to February, March to May, June to August and September to November) for the changes between two time slices centred around 1990 (1975 to 2005) and 2060 (2046 to 2075) from the GCMs. For each season and over each time slice, the total rainfall was calculated. Seasonal scaling factors were then calculated as the ratio of the total season's rainfall over the 2060 time slice divided by the total rainfall over the 1990 time slice. The historical climate sequence was then scaled using these seasonal scaling factors. The second step involved rescaling the entire series so that it matches the annual scaling factors, to maintain consistency with annual projected changes in the GCMs (Chiew et al., 2009; Petheram et al., 2012). The method was repeated for each climate parameter except for temperature, for which the difference rather than ratio between the two periods was used to scale the historical sequence. Using a pattern scaling method to transform broad-scale GCM outputs to catchment-scale variables is denoted herein as 'GCM-PS'.

The resulting percentage change in rainfall and potential evaporation spatially averaged across the Southern Gulf catchments under SSP2-4.5 at approximately 2060 from each GCM is shown in Figure 3-3. As outlined by McJannet et al. (2023), scenarios Cwet, Cmid and Cdry were selected to represent the range of projections from the 32 GCMs shown in Figure 3-3. They were selected as the 10th, 50th and 90th percentile exceedance change in rainfall. That is, the GCM-PS time series derived from the GISS-E2-1-G (3rd ranked GCM), UKESM1-0-LL (16th ranked GCM) and CMCC-ESM2 GCMs (29th ranged GCM) were used for the Cdry, Cmid and Cwet scenarios, respectively.

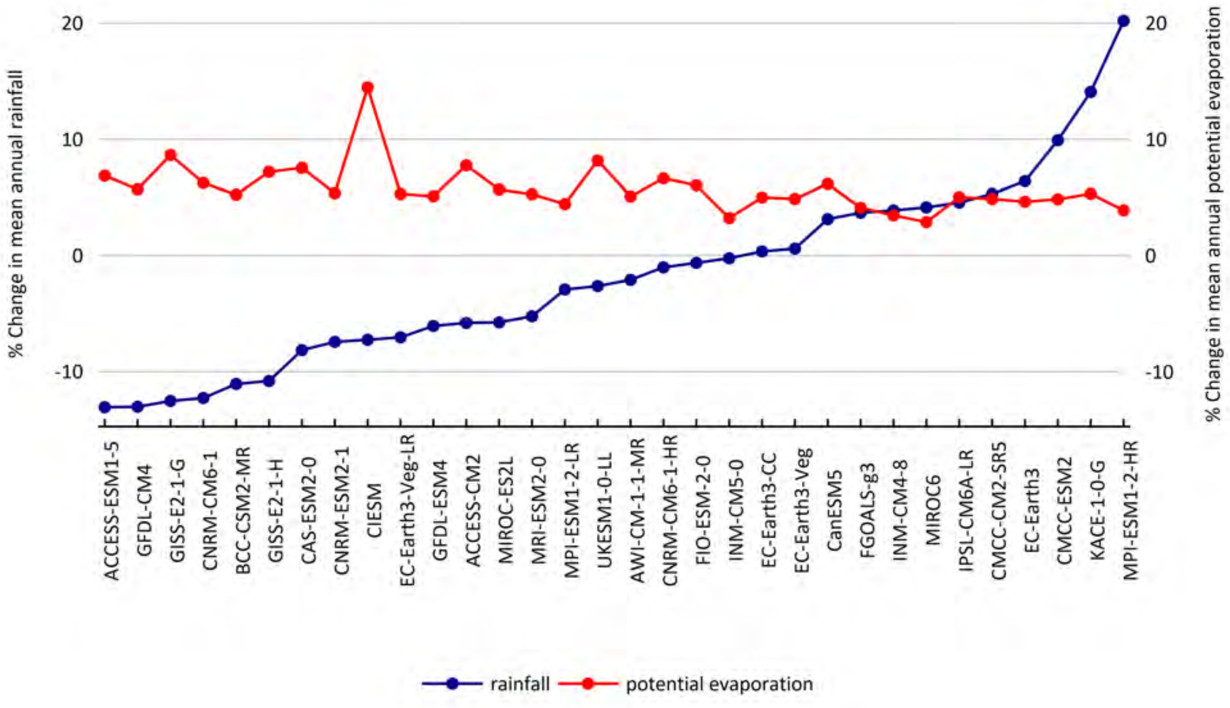

Figure 3-3 Percentage change in mean annual rainfall and potential evaporation under Scenario C relative to under Scenario A

Pattern scaling of rainfall and potential evaporation have been applied to global climate model output (GCM-PS). The GCMs were arranged by the resulting change in mean annual rainfall from the GCM-PS time series.

To evaluate the range in projections more fully, a scaling approach was also used to represent the sensitivity of the hydrological outputs to changes in climate. The range in mean annual rainfall and PET in Figure 3-3 was used to perturb the climate inputs by an annual scaling value. The ranges considered were from a 15% reduction to a 25% increase in mean annual rainfall, and from no change to a 15% increase in PET, both in increments of 2.5%, resulting in 119 simulations. This approach allows the sensitivity of the system to be represented and potential degrees of change resulting in undesirable changes to be identified, often referred to as a 'bottom up' approach. Metrics of mean annual end-of-system volume and mean annual diversions from both instream dams and water harvesting are reported.

3.4 Scenario D

Scenario D is future projected climate and hypothetical future development. The climate data produced above, both the GCM-PS time series for the Cdry, Cmid and Cwet scenarios, as well as the bottom-up sensitivity scaling approach, were used for Scenario D. Targeted hypothetical future development scenarios, based on the results from Scenario B, were selected for inclusion in Scenario D. No changes to the model configuration were made for Scenario D compared to Scenario B. For example, threshold flow rates were maintained as computed based on a percentage of Scenario A inflows to the dam (Table 3-5), and releases to maintain reliably of supply to existing users were the same as in Scenario B.

4 Results

4.1 Scenario A

Summary statistics of annual end-of-system (EOS) flow volumes under scenarios AN, AE and A are presented in Table 4-1, with flow statistics for each node in the river model under scenarios A, AE and AN provided in Appendix B. For the Morning Inlet, Settlement Creek and Mornington Island AWRC basins, EOS flow volumes are the same under the three scenarios because the model did not include any storages or diversions in these basins. Existing users in the Nicholson River catchment were not represented in the model under Scenario AE due to limited information on historical demand volumes, so the results are the same under scenarios AE and AN. Full use of existing entitlements are included under Scenario A, so the EOS volume is lower under this scenario. For the Leichhardt River AWRC basin, the inclusion of five storages (Rifle Creek Dam, East Leichhardt Dam, Greenstone Creek Dam, Lake Moondarra and Lake Julius), and the associated use from these dams and one existing user, results in reduced EOS volumes under Scenario AE compared to Scenario AN. Assuming full use of existing entitlements (Scenario A) in the Leichhardt River AWRC basin further reduced the mean annual EOS volume by 53 GL.

Table 4-1 Scenario A annual end-of-system volume statistics for each Southern Gulf AWRC basin

	SCENARIO	LEICHHARDT RIVER	NICHOLSON RIVER	MORNING INLET	SETTLEMENT CREEK	MORNINGTON ISLAND
Mean annual flow (GL)	AN	1827	2476	307	2014	292
	AE	1730				
	A	1677	2469			
80% annual exceedance flow (GL)	AN	582	610	93	633	93
	AE	494				
	A	449	602			
Median annual flow (GL)	AN	1211	1873	195	1304	173
	AE	1111				
	A	1059	1865			
20% annual exceedance flow (GL)	AN	2640	3500	397	2507	469
	AE	2519				
	A	2463	3492			

4.2 Scenario B

4.2.1 Hypothetical water harvest

The sensitivity of the system to the different access conditions was assessed primarily by a series of 'heat map' plots that present the variation in annual reliability of supply for water harvest nodes with changes in two of the access conditions, while holding two others constant. All plots are provided separately as supplementary material, and salient examples in Figure 4-3 to Figure 4-8 illustrate key results.

Based on Scenario A output, the distribution of the date that a given ADCFR volume was met after the start of the water year on 1 September is presented in Figure 4-1. This result demonstrates the effect ADCFR volume on the commence-to-pump date for water harvest (assuming no other limiting factors such as pump start threshold). A relatively modest system flow requirement of 50 GL has a mode (peak of the distribution) of mid-November, delaying the pump start date 2.5 months in these years. There were relatively small differences between the irrigation start date and system flow requirement for volumes greater than 150 GL.

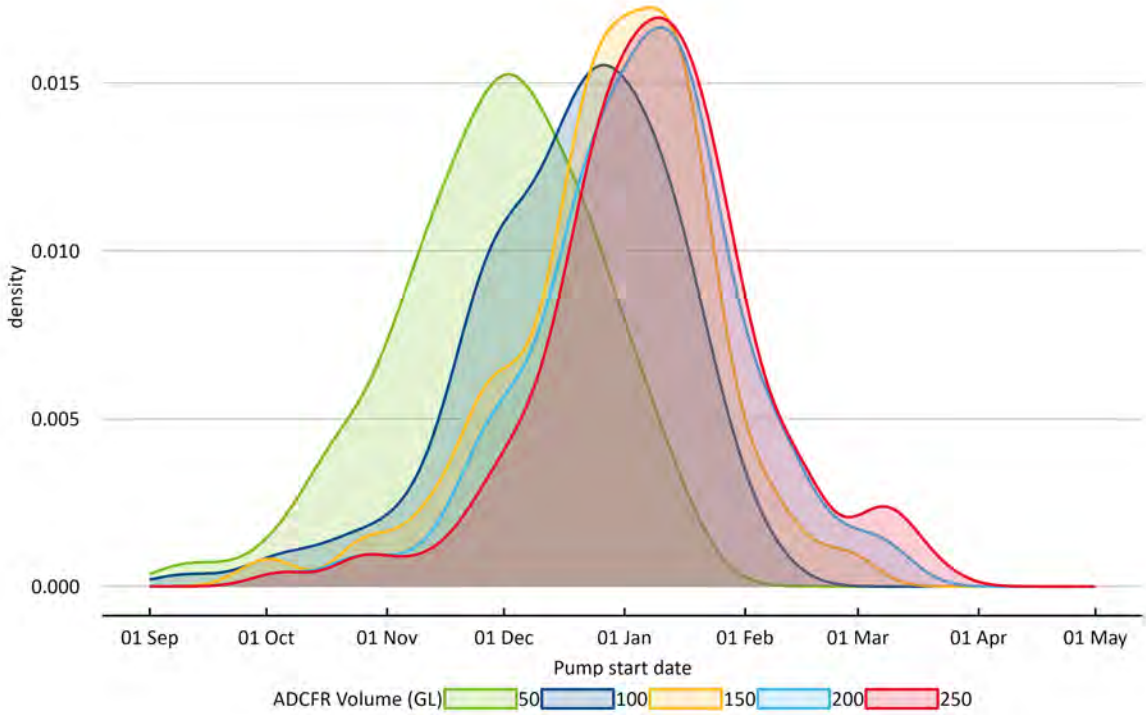

Figure 4-1 Influence of annual diversion commencement flow requirement (ADCFR) on commence-to-pump date

The start date is expressed as a frequency density over the 132 years of the historical climate. The cumulative volume each water year is based on catchments with water harvest nodes included in the model: the Gregory–Nicholson and Leichhardt rivers.

This analysis has used a total system ADCFR combined across the three end-of-system nodes downstream of water harvest diversions. A more refined approach could adopt an ADCFR for each river separately. To provide an indication of how the combined ADCFR relates to the flow in each river system, the proportion of the ADCFR requirement met by each node is presented in Figure 4-2, which simulates the variability across years. For the lowest ADCFR volume considered (50 GL), the more perennial system of the Nicholson River and a distributary of the Gregory River, the

Albert River, meet most of the ADCFR requirement; the Leichhardt River provides 9% of the volume in a median year (mean of 14%). As higher ADCFR volumes delay the commencement of pumping longer into the wet season (Figure 4-1), the proportion of the ADCFR volume met from the more seasonal Leichhardt River increases, for example, to 28% in a median year (mean of 29%) for an ADCFR volume of 250 GL.

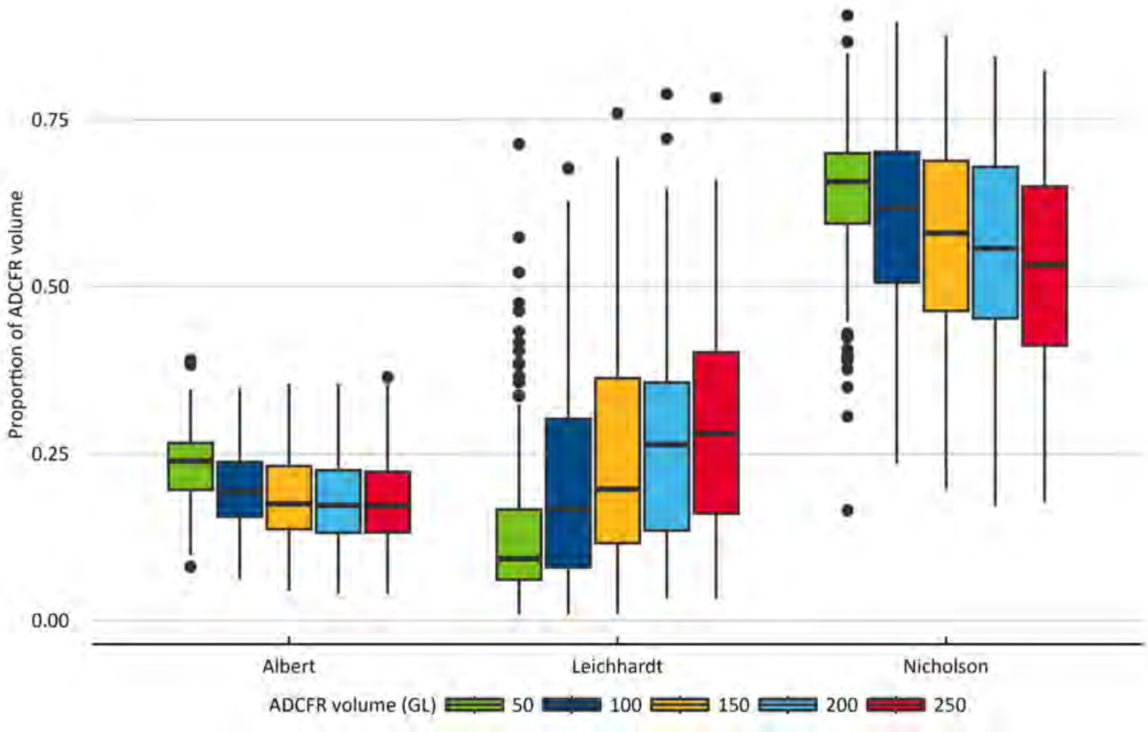

Figure 4-2 Proportion of the annual diversion commencement flow requirement (ADCFR) met by each end-of-system river node for increasing ADCFR volume

Each boxplot represents the variability over the 132 years of the historical climate, with the upper and lower bounds of each box corresponding to the 25th and 75th percentile exceedance proportions, and line within the box the median. Vertical lines (or 'whiskers') are defined as 1.5 time longer than the height of the box, and years that fall outside of the whiskers represented as dots.

Figure 4-3 can be used to explore the reliability at which increasing volumes of water can be extracted ('harvested') or diverted at five locations in the Southern Gulf catchments under varying pump start thresholds. The left *y*-axis indicates the system target volume, which is the maximum volume of water extracted across the Southern Gulf catchments each season (nominal catchment-wide entitlement volume). The right *y*-axis is the maximum volume of water extracted in that reach each season (nominal reach entitlement volume).

This example assumes a 20-day pump capacity; that is, pump capacities are set to enable the reach target volumes to be pumped in 20 days (not necessarily consecutively). This means an irrigator with a 4 GL ringtank has a pump capacity of 200 ML/day to fill their ringtank in 20 days. In this example there is no ADCFR to be met.

At the smallest pump start threshold examined (200 ML/day, nominally representative of a lower physical pumping limit), approximately 300 GL of water can be extracted in the Southern Gulf catchments in 75% of years. However, this relatively low pump start threshold results in some impacts on existing downstream licence holders along the Leichhardt River (see the grey contour lines on node 9139000 in Figure 4-3). This figure shows that, as the total system and reach targets increase, the reliability at which that volume can be fully extracted decreases. Similarly, as the pump start threshold increases, reducing the opportunities to extract water, the reliability at which the full system and reach targets can be extracted decreases. At a pump start threshold of 600 ML/day, which is required to ensure additional hypothetical diversions do not affect existing users, approximately 150 GL of water can be extracted in the Southern Gulf catchments when combined across extraction nodes in 75% of years with no ADCFR.

Figure 4-4 presents similar data to those shown in Figure 4-3 but imposes an additional extraction condition: a combined total of 150 GL has to flow past the outlets of the Gregory−Nicholson and Leichhardt rivers each wet season before any water can be extracted. Figure 4-4 shows that increasing the ADCFR reduces the reliability at which the system and reach targets can be extracted for different pump start thresholds. In Figure 4-5, the pumping capacity is increased by modifying the conditions so the target volume can be extracted in 10 days instead of 20 days, which increases the reliability of supply for a given target and pump start threshold. The relationship between pump capacity and reliability of extracting different volumes is shown in more detail in Figure 4-6, this time with pump rate in days on the *x*-axis instead of pump start threshold, which has been fixed to 600 ML/day. With a pump start threshold of 600 ML/day and an ADCFR of 150 GL, the highly variable nature of streamflow in these catchments means that large pump capacities (i.e. 20 days or less) are required to extract the system and reach targets in 75% of years or greater.

Figure 4-7 and Figure 4-8 indicate the post-extraction 50% and 80% annual flow exceedance combined across the outlets with water harvest extractions upstream as a proportion of change relative to under Scenario A. Median annual flow is relatively unaffected by the ADCFR volume (Figure 4-7). The ADCFR has the effect of ‘protecting’ streamflow during drier years, in which higher ADCFR volumes resulted in a higher proportion of the 80% annual flow exceedance volume being maintained under Scenario B compared to under Scenario A (Figure 4-8).

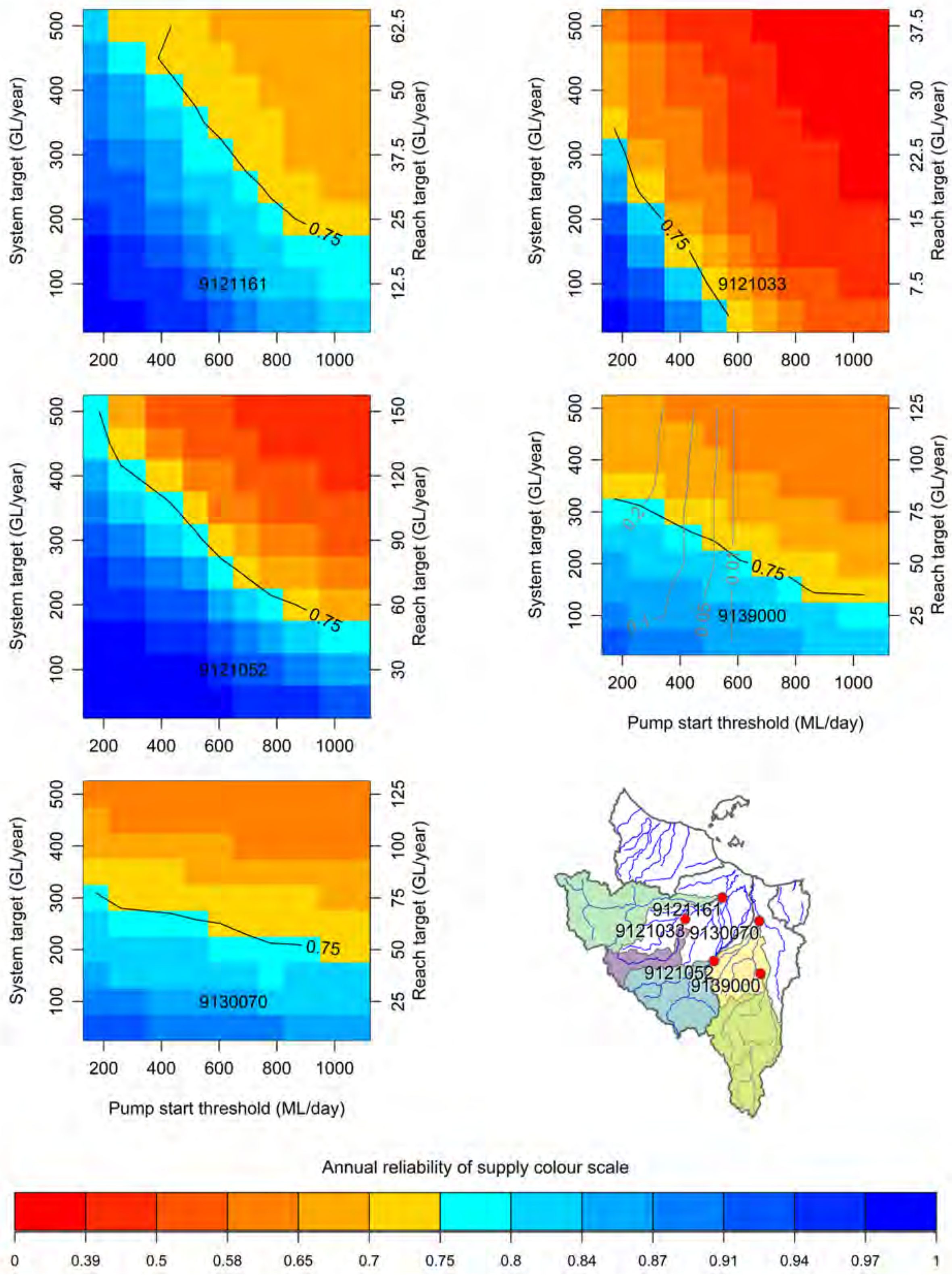

Figure 4-3 Annual reliability of diverting annual system and reach target volumes for varying pump start thresholds

No annual diversion commencement flow requirement volume before pumping can commence. Assumes a pumping capacity such that system and reach targets can be pumped in 20 days. Seven-digit numbers (black) refer to model node location. Black contour lines indicate the conditions that meet a 75% annual reliability of supply, and grey contour lines on node 9139000 indicate the proportion of years with a reduction in supply to existing users compared to Scenario A.

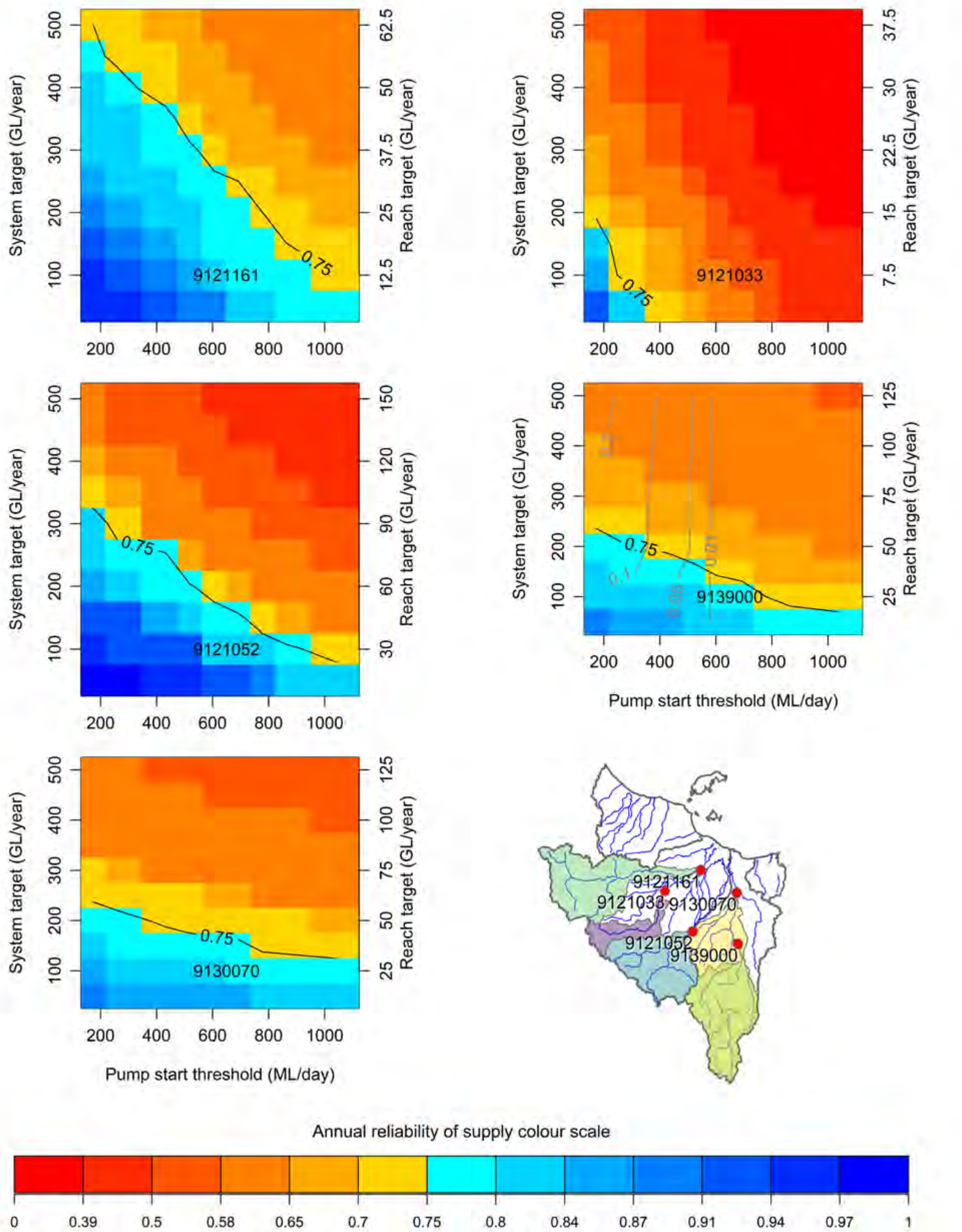

Figure 4-4 Annual reliability of diverting annual system and reach target volumes for varying pump start thresholds with annual diversion commencement flow requirement of 150 GL

Assumes pumping capacity of 20 days (i.e. system and reach targets can be pumped in 20 days). Seven-digit numbers (black) refer to model node location. Black contour lines indicate the conditions that meet a 75% annual reliability of supply, and grey contour lines on node 9139000 indicate the proportion of years with a reduction in supply to existing users compared to Scenario A.

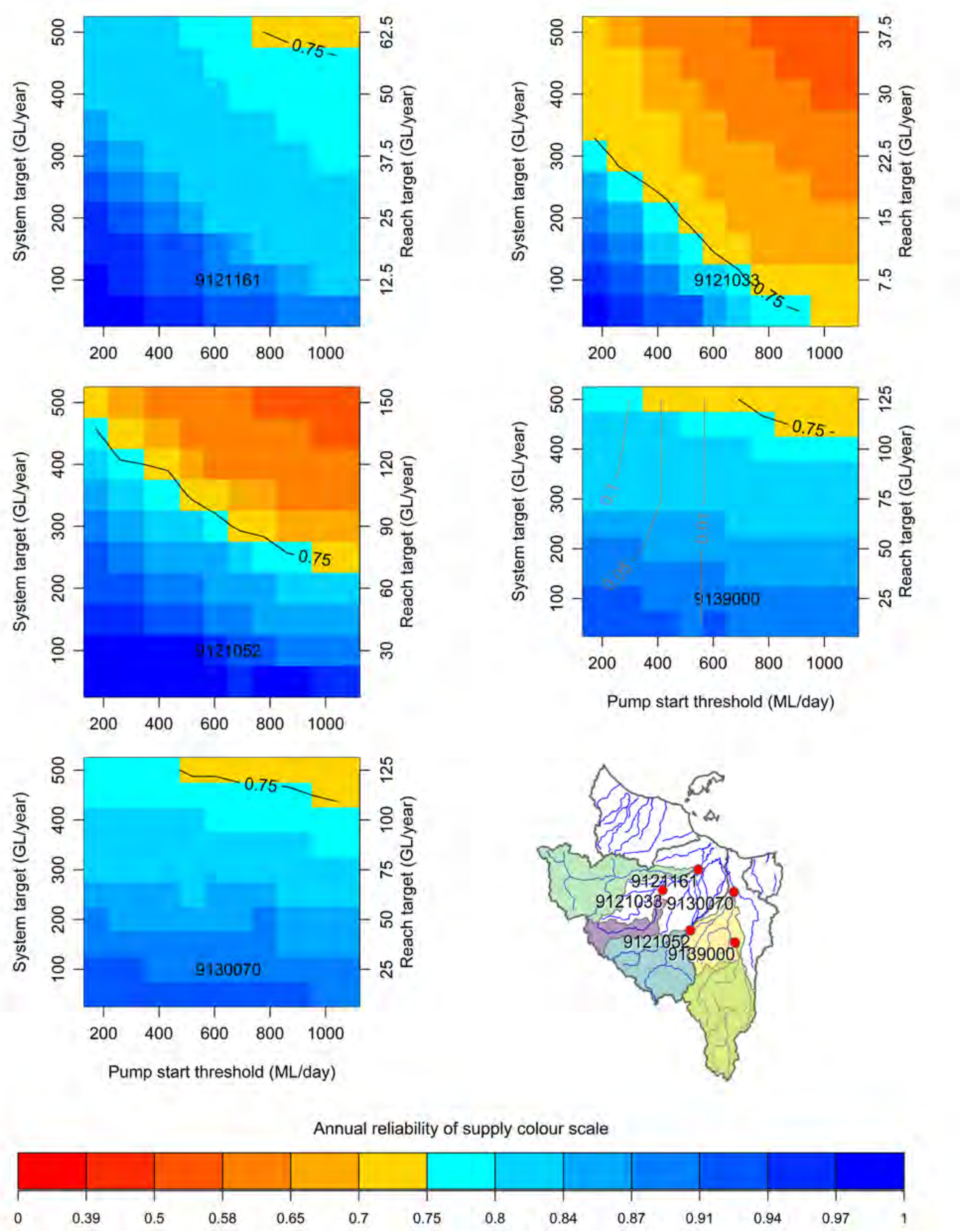

Figure 4-5 Annual reliability of diverting annual system and reach target volumes for varying pump start thresholds assuming pumping capacity of 10 days

Annual diversion commencement flow requirement of 150 GL before pumping can commence. Assumes a pumping capacity such that system and reach targets can be pumped in 10 days. Seven-digit numbers (black) refer to model node location. Black contour lines indicate the conditions that meet a 75% annual reliability of supply, and grey contour lines on node 9139000 indicate the proportion of years with a reduction in supply to existing users compared to Scenario A.

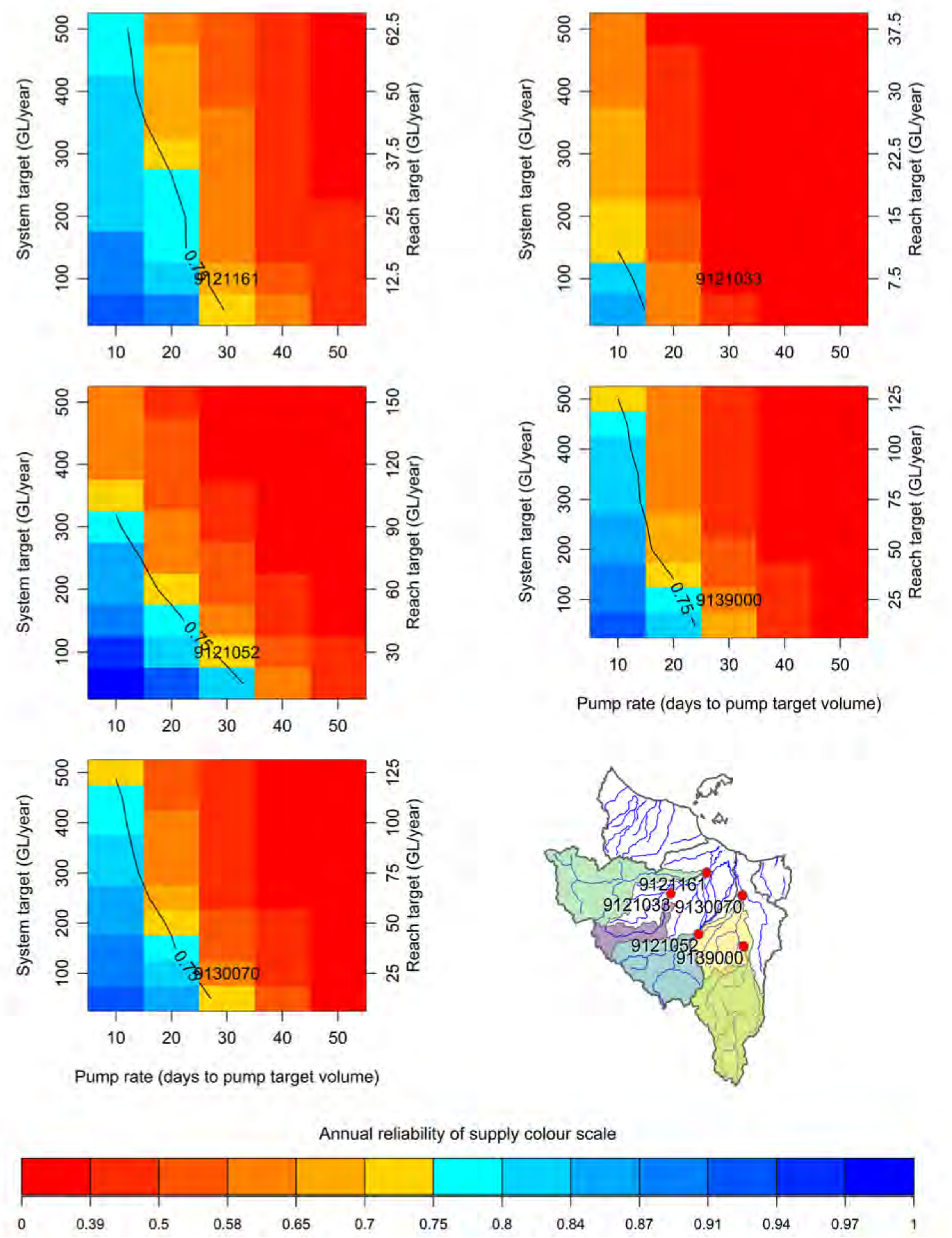

Figure 4-6 Annual reliability of diverting annual system and reach target volumes for varying pump rates assuming a pump start flow threshold of 600 ML/day

Annual diversion commencement flow requirement of 150 GL before pumping can commence. Seven-digit numbers (black) refer to model node location. Black contour lines indicate the conditions that meet a 75% annual reliability of supply, and the lack of grey contour lines on node 9139000 indicate that reliability of supply to existing users is not affected compared to Scenario A with a pump start threshold of 600 ML/day.

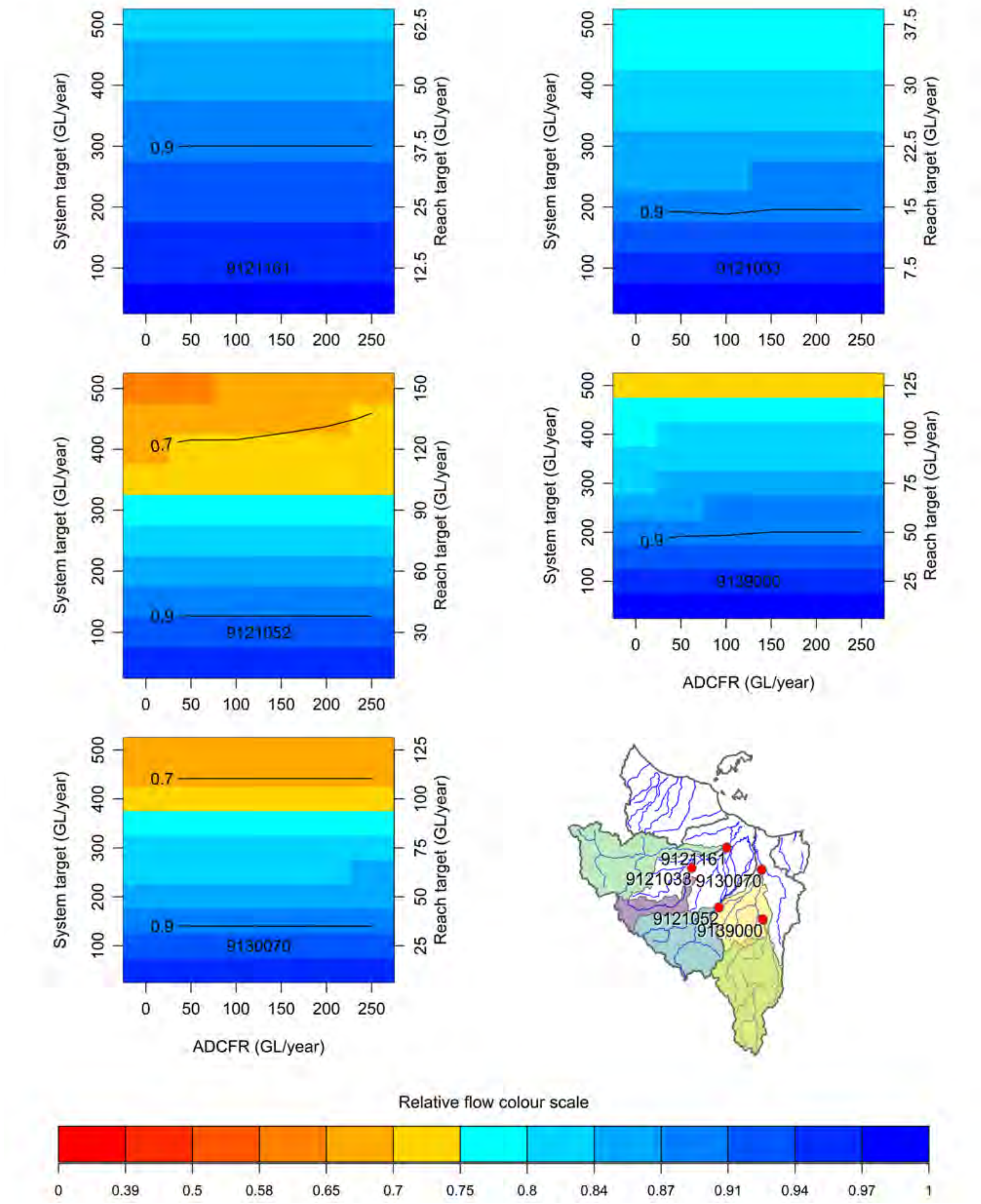

Figure 4-7 50% annual exceedance (median) streamflow relative to Scenario A for increasing annual diversion commencement flow requirement (ADCFR)

A pump start threshold of 600 ML/day and a pump capacity of 20 days is assumed. Seven-digit numbers (black) refer to model node location.

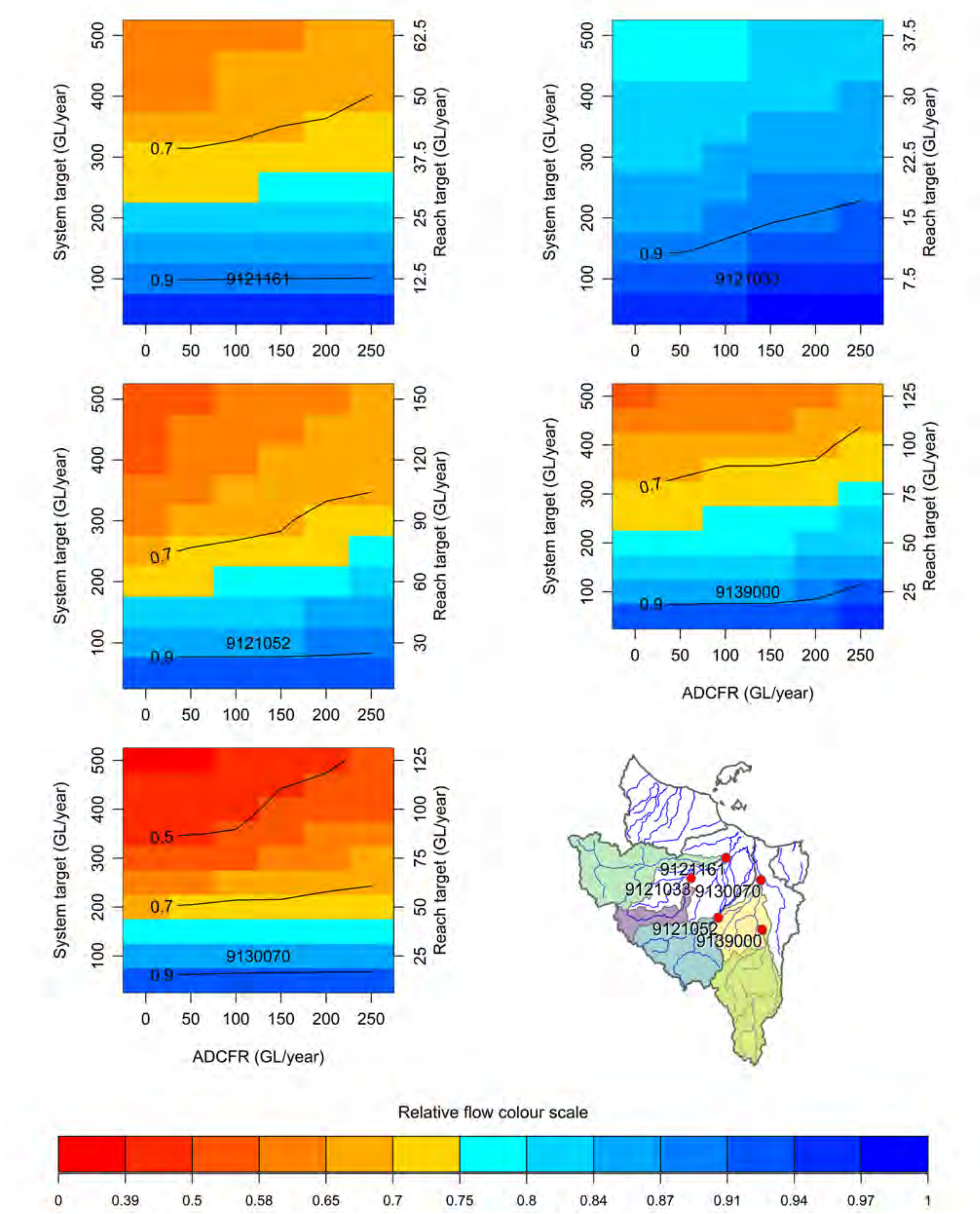

Figure 4-8 80% annual exceedance (median) streamflow relative to Scenario A for increasing annual diversion commencement flow requirement (ADCFR)

A pump start threshold of 600 ML/day and a pump capacity of 20 days is assumed. Seven-digit numbers (black) refer to model node location.

4.2.2 Hypothetical water storages

Single hypothetical dam sites

Each short-listed hypothetical dam was simulated individually to estimate the yield that could be extracted with a reliability of 85% of years with no transparent flow releases. Releases required to maintain reliability of supply to downstream users were included. The volumes released are summarised in Table 4-2, and the resulting reliability of supply for existing downstream user nodes is provided in separate supplementary material. For the purpose of this exercise, it was assumed that water released from the dam for irrigation or other consumptive purposes was diverted via a channel or pipeline rather than being released downstream along the main river channel.

In Figure 4-9 to Figure 4-17, the reservoir yield at the dam wall and median annual volume flowing downstream of the dam wall for the eight dams are shown for transparent flow releases ranging from 0 to 50% of the mean daily inflow. The reservoir yield at the dam wall reduces with transparent flow (a), with the volume of transparent flows 'passed through' the dam increases seen as an increase in median annual volume (b). The light-blue horizontal dashed line represents the value under Scenario A for comparison. The proportion of the median annual volume released as transparent flows downstream of the dam under Scenario B compared to under Scenario A varies across the eight hypothetical dam sites, depending on the characteristics of inflows, local topography for the dam site and ability to efficiently store and extract water. Depending on the site, larger volumes for the transparent flow threshold may be required to maintain flow persistence further downstream or maintain other ecological functions (flow pulses for example).

Table 4-2 Volume released to maintain downstream user reliability of supply

DAM	MEAN (GL/y)	MEDIAN (GL/y)	YEARS WITH RELEASE (%)	MEAN OF YEARS WITH RELEASE (GL/y)
Gregory River AMTD† 174 km (Dam 1) FSL 138 mEGM96	2.72	3.20	58	4.63
Gregory River AMTD 174 km (Dam 1) FSL 145 mEGM96	3.78	4.95	82	4.63
Gunpower Creek AMTD 66 km (Dam 28) FSL 186 mEGM96	0.45	0.00	25	1.81
Nicholson River AMTD 198 km **(Dam 3) FSL 108 mEGM96**	1.46	1.49	99	1.47
Gold Creek AMTD 58 km (Dam 206) FSL 84 mEGM96	0.00	0.00	0	0.00
Mistake Creek AMTD 60 km (Dam 165) FSL 149 mEGM96	0.07	0.00	17	0.38
Ewen Creek AMTD 6 km (Dam 175) FSL 217 mEGM96	0.03	0.00	16	0.19
South Nicholson River AMTD 9 km (Dam 290) FSL 162 mEGM96	0.01	0.00	41	0.03

† AMTD = adopted middle thread distance.

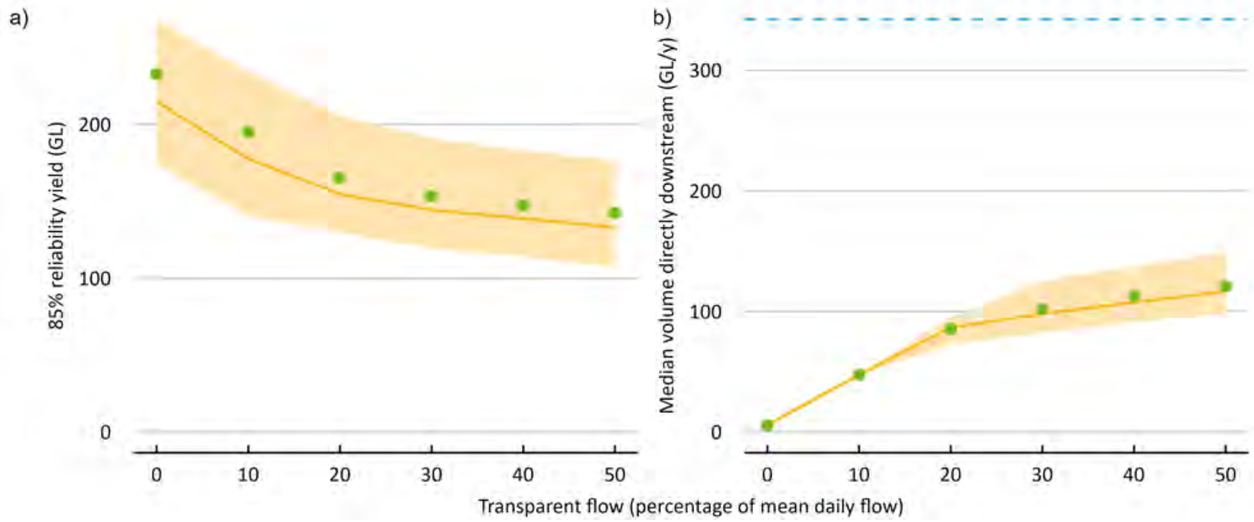

Figure 4-9 Annual yield and median downstream flow at dam wall for hypothetical dam on Gregory River AMTD 174 km (Dam 1) FSL 145 mEGM96 under different transparent flow thresholds

(a) Reservoir yield at 85% annual time reliability at dam wall and (b) median annual volume downstream of the dam wall (transparent flow, releases for downstream users and spills). Scenario B is represented by the green dots and Scenario D by the orange line (Cmid) and shaded area (upper limit Cwet and lower limit Cdry). Median annual downstream volume under Scenario A is represented by the light-blue dashed horizontal line (b).

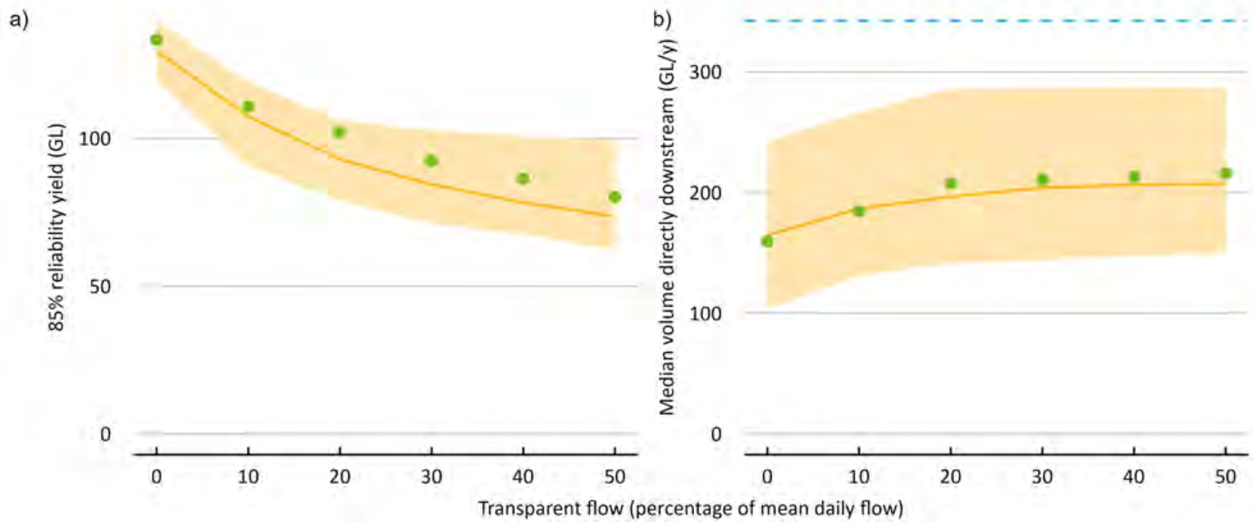

Figure 4-10 Annual yield and median downstream flow at dam wall for hypothetical dam on Gregory River AMTD 174 km (Dam 1) FSL 138 mEGM96 under different transparent flow thresholds

(a) Reservoir yield at 85% annual time reliability at dam wall and (b) median annual volume downstream of the dam wall (transparent flow, releases for downstream users and spills). Scenario B is represented by the green dots and Scenario D by the orange line (Cmid) and shaded area (upper limit Cwet and lower limit Cdry). Median annual downstream volume under Scenario A is represented by the light-blue dashed horizontal line (b).

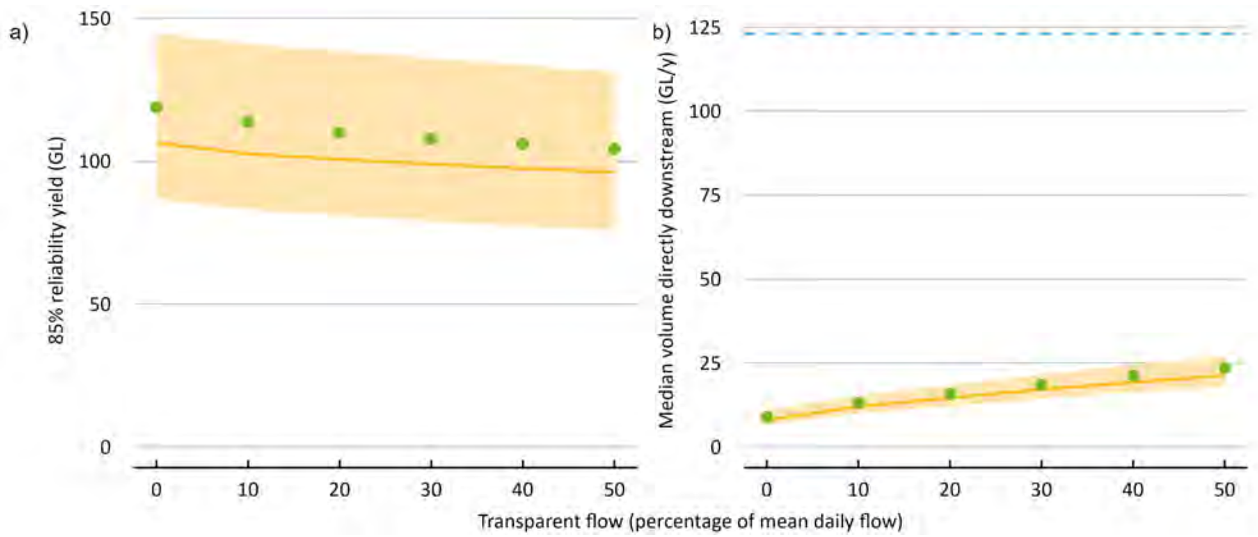

Figure 4-11 Annual yield and median downstream flow at dam wall for hypothetical dam on Gunpower Creek AMTD 66 km (Dam 28) FSL 186 mEGM96 under different transparent flow thresholds

(a) Reservoir yield at 85% annual time reliability at dam wall and (b) median annual volume downstream of the dam wall (transparent flow, releases for downstream users and spills). Scenario B is represented by the green dots and Scenario D by the orange line (Cmid) and shaded area (upper limit Cwet and lower limit Cdry). Median annual downstream volume under Scenario A is represented by the light-blue dashed horizontal line (b).

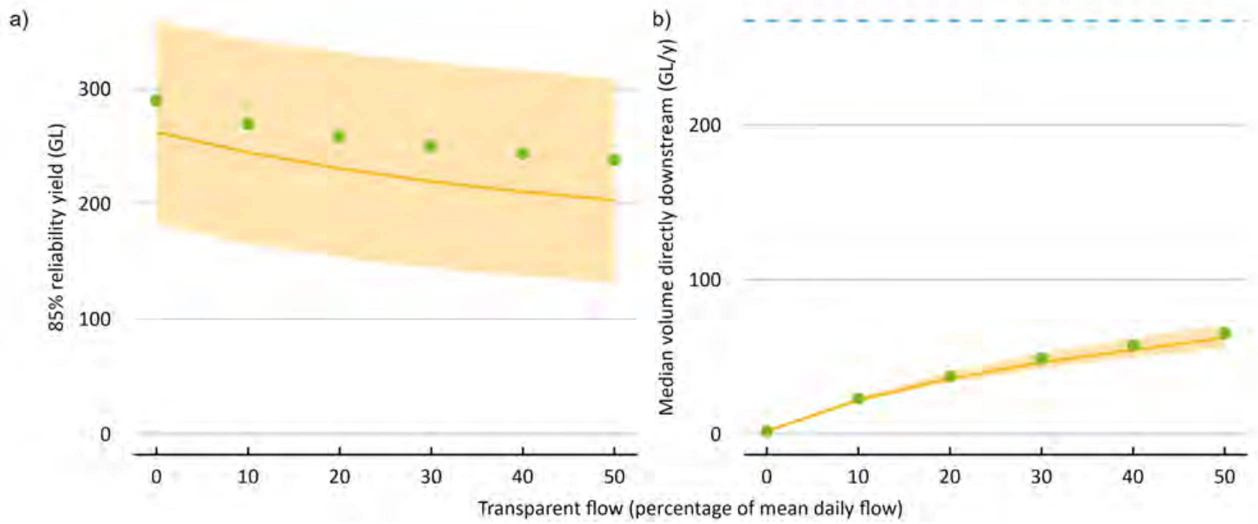

Figure 4-12 Annual yield and median downstream flow at dam wall for hypothetical dam on Nicholson River AMTD 198 km (Dam 3) FSL 108 mEGM96 under different transparent flow thresholds

(a) Reservoir yield at 85% annual time reliability at dam wall and (b) median annual volume downstream of the dam wall (transparent flow, releases for downstream users and spills). Scenario B is represented by the green dots and Scenario D by the orange line (Cmid) and shaded area (upper limit Cwet and lower limit Cdry). Median annual downstream volume under Scenario A is represented by the light-blue dashed horizontal line (b).

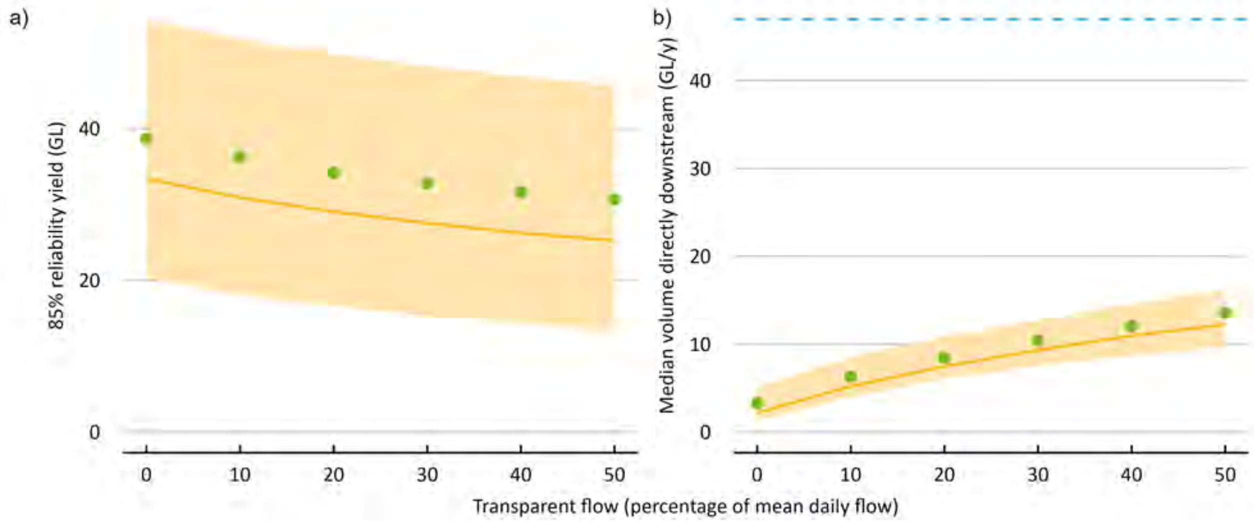

Figure 4-13 Annual yield and median downstream flow at dam wall for hypothetical dam for South Nicholson River AMTD 9 km (Dam 290) FSL 162 mEGM96 under different transparent flow thresholds

(a) Reservoir yield at 85% annual time reliability at dam wall and (b) median annual volume downstream of the dam wall (transparent flow, releases for downstream users and spills). Scenario B is represented by the green dots and Scenario D by the orange line (Cmid) and shaded area (upper limit Cwet and lower limit Cdry). Median annual downstream volume under Scenario A is represented by the light-blue dashed horizontal line (b).

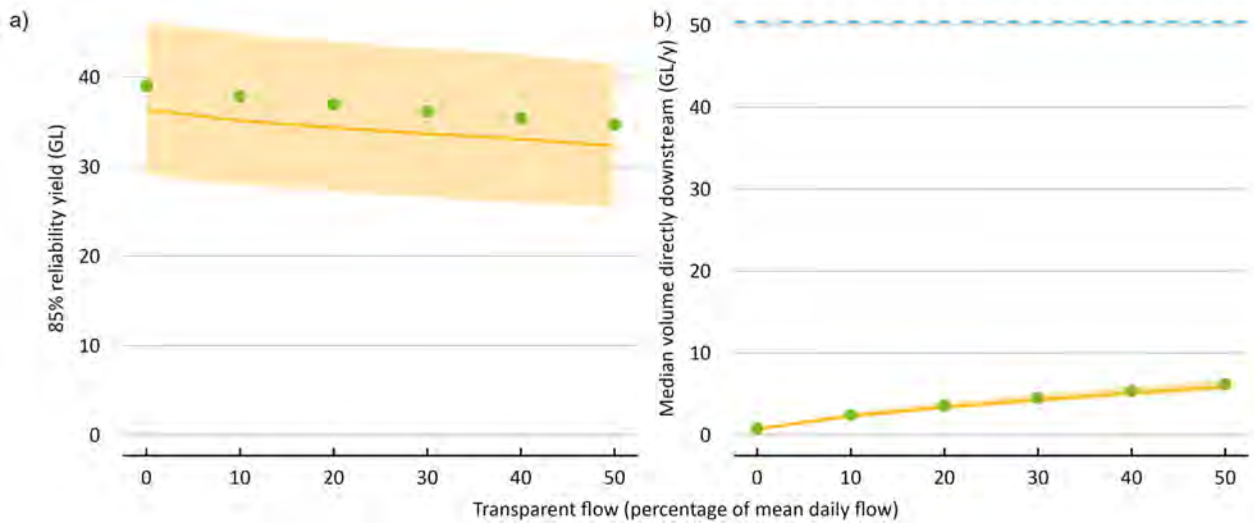

Figure 4-14 Annual yield and median downstream flow at dam wall for hypothetical dam on Mistake Creek AMTD 60 km (Dam 165) FSL 149 mEGM96 under different transparent flow thresholds

(a) Reservoir yield at 85% annual time reliability at dam wall and (b) median annual volume downstream of the dam wall (transparent flow, releases for downstream users and spills). Scenario B is represented by the green dots and Scenario D by the orange line (Cmid) and shaded area (upper limit Cwet and lower limit Cdry). Median annual downstream volume under Scenario A is represented by the light-blue dashed horizontal line (b).

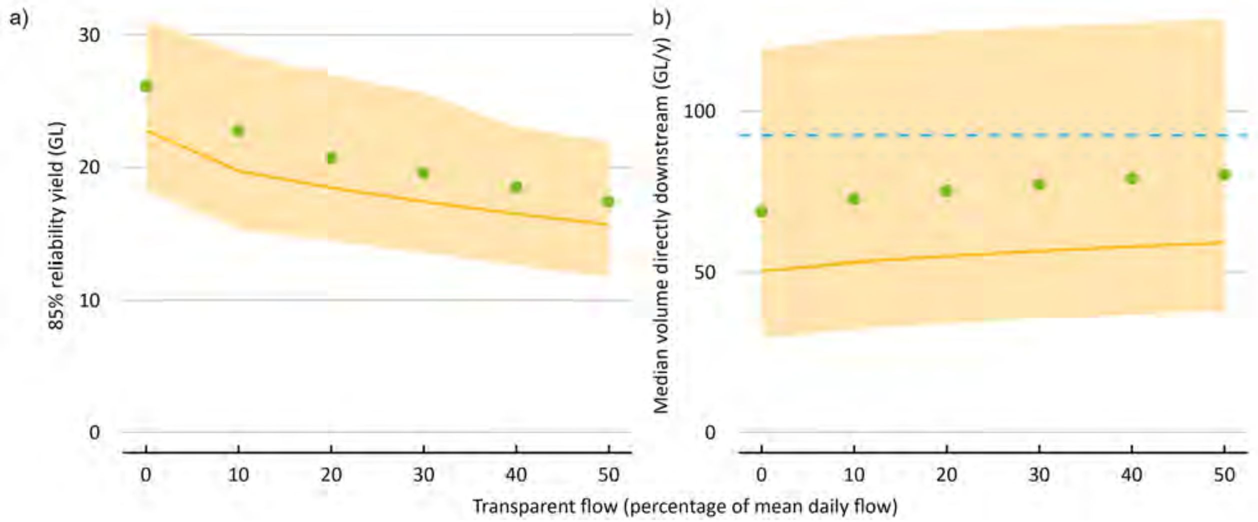

Figure 4-15 Annual yield and median downstream flow at dam wall for hypothetical dam on Ewen Creek AMTD 6 km (Dam 275) FSL 217 mEGM96 under different transparent flow thresholds

(a) Reservoir yield at 85% annual time reliability at dam wall and (b) median annual volume downstream of the dam wall (transparent flow, releases for downstream users and spills). Scenario B is represented by the green dots and Scenario D by the orange line (Cmid) and shaded area (upper limit Cwet and lower limit Cdry). Median annual downstream volume under Scenario A is represented by the light-blue dashed horizontal line (b).

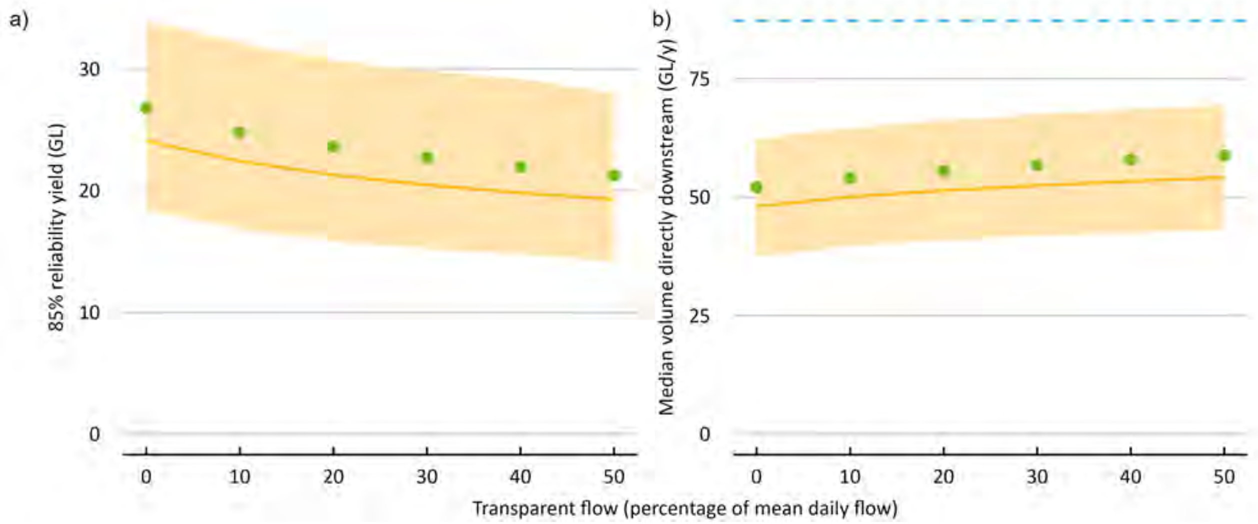

Figure 4-16 Annual yield and median downstream flow at dam wall for hypothetical dam on Gold Creek AMTD 58 km (Dam 206) FSL 84 mEGM96 under different transparent flow thresholds

(a) Reservoir yield at 85% annual time reliability at dam wall and (b) median annual volume downstream of the dam wall (transparent flow, releases for downstream users and spills). Scenario B is represented by the green dots and Scenario D by the orange line (Cmid) and shaded area (upper limit Cwet and lower limit Cdry). Median annual downstream volume under Scenario A is represented by the light-blue dashed horizontal line (b).

Cumulative yield of multiple hypothetical dams in the Southern Gulf catchments

This analysis examined the combined or cumulative yield of multiple dams in the Southern Gulf catchment and the resulting impact to end-of-system flows. To undertake this analysis, the most promising hypothetical dam sites (in terms of lowest cost per megalitre at the dam wall) were incrementally included in each river model simulation. Cumulative yields are reported at the dam wall and do not include transmission and conveyance losses. Releases for existing downstream entitlement holders were included in under this scenario, but no threshold flows were included to maximise the yield estimated. Similarly, the hypothetical dam Gregory River AMTD 174 km was only evaluated at a FSL of 145 mEGM96.

The results are presented in Figure 4-17, which represents cumulative yield (left *y*-axis) from sequential dams as triangles. The cumulative yield after adding the more upstream hypothetical dam South Nicholson River AMTD 9 km reduced due to interception of inflows to a hypothetical dam on the Nicholson River AMTD 198 km, so the upstream dam is not included in Figure 4-17.

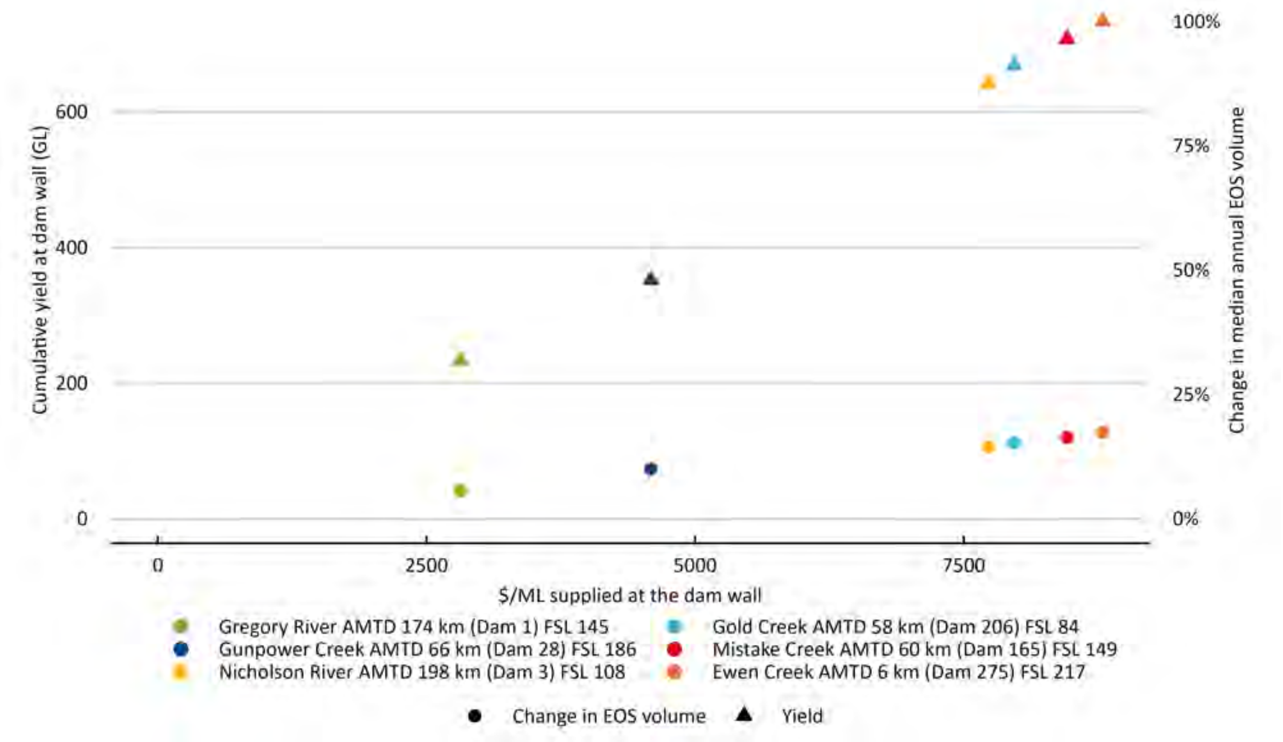

Figure 4-17 Cumulative yield at 85% annual time reliability versus cumulative cost of water in $/ML and change in the end-of-system (EOS) volume in the Southern Gulf catchments

Yield is reported at the dam wall under the historical climate. Triangles indicate combined water yield at 85% annual time reliability of one or more dams, and the colour of the dot indicates the most recently included dam in the cumulative yield calculation. Circles indicate change in median annual streamflow at the end-of-system for all mainland catchments compared to under Scenario A.

The total yield at the dam wall at an annual time reliability of 85% while also maintaining supply to existing entitlement holders downstream of all six instream dams is 733 GL. However, after the hypothetical dam Nicholson River AMTD 198 km, the cost per megalitre supplied increases for limited increase in yield. The combined yield from the first three dams is 641 GL. The percentage change in median annual EOS volume is represented as circles on the right *y*-axis in Figure 4-17. Here the EOS volume has been calculated as all nodes discharging to the Gulf of Carpentaria from the mainland catchments (i.e. Mornington Island was excluded).

4.3 Scenario C

Metrics of the annual end-of-system volumes (80th percentile annual exceedance, median, mean and 20th percentile annual exceedance) for Scenario C are shown as volumes in Figure 4-18 and as percentage change from the Scenario A value in Figure 4-19. Figure 4-18 also includes results for Scenario CE as hollow circles, most notable for the Leichhardt River catchment. The climate models tend to project a reduction rather than an increase in end-of-system streamflow. Under Scenario Cmid (representing the median of GCM-PS projections), there is reduction of 3% to 14% (mean 9%) across the different streamflow metrics and across the catchments of the Southern Gulf. However, the range in projections from the suite of GCMs is large. Under Scenario Cwet, streamflow metrics were projected to increase 16% to 30% (mean 22%), while under Scenario Cdry, streamflow metrics were projected to decrease 20% to 41% (mean 29%).

This wide range in results from the suite of GCM projections is typical for northern Australia. It has led to the adoption of sensitivity-based approaches for climate impact studies designed to identify the degree of change that may result in undesirable system change. The sensitivity of total end-of-system volume (combined across the Assessment area) to potential changes in rainfall and PET is shown in Figure 4-20, which is overlaid by the individual GCM projections. Figure 4-20 also shows the mean annual diversions from existing dams and water harvest licences, as implemented under Scenario A (Table 3-1). The same results are shown as a percentage change from Scenario A in Figure 4-21.

End-of-system volume is more sensitive than the diversion volumes to changes in climate, as the existing dams such as Lake Julius and Lake Moondarra provide carry-over storage to supply the existing supplemented water users. For existing water harvest diversions, the low (or in most cases no) pump start thresholds assumed for existing water harvest users allow these nodes to access water even when flows are reduced. Eight of the 32 GCMs project a reduction in mean annual diversions from storages of greater than 5% (Figure 4-21b). While diversions do not exceed the annual licence volume in the model, only one of the 32 GCMs project an increase in diversions of greater than 5%. In comparison, over half the GCMs (19 of 32) project changes in climate that result in a greater than 5% reduction in end-of-system mean annual volume (Figure 4-21a).

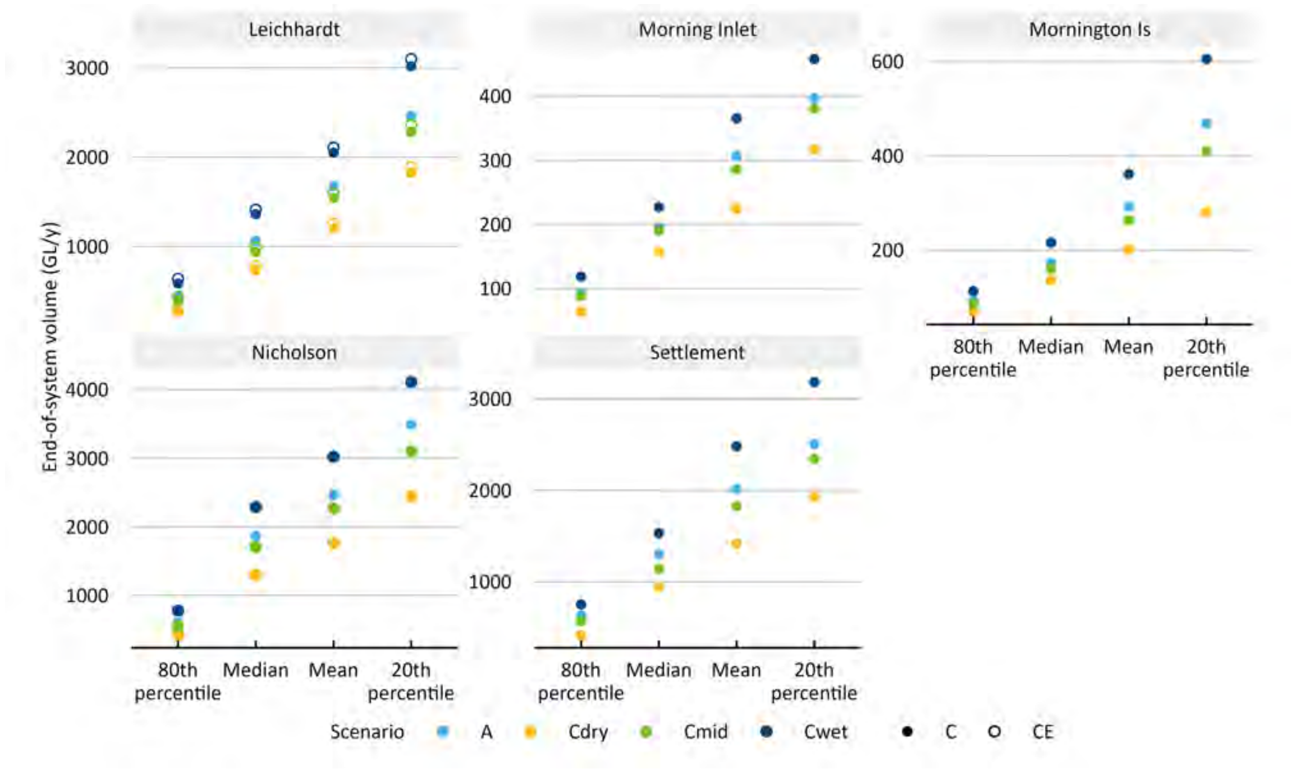

Figure 4-18 Metrics of AWRC basin end-of-system annual volumes under Scenario C compared to under Scenario A

Volumes under Scenario CE (existing levels of extraction) also shown as hollow circles, compared to Scenario C as solid circles. There is no difference between Scenario CE and C for Settlement Creek, Morning Inlet and Mornington Island basins, and the most noticeable differences in the Leichhardt Basin.

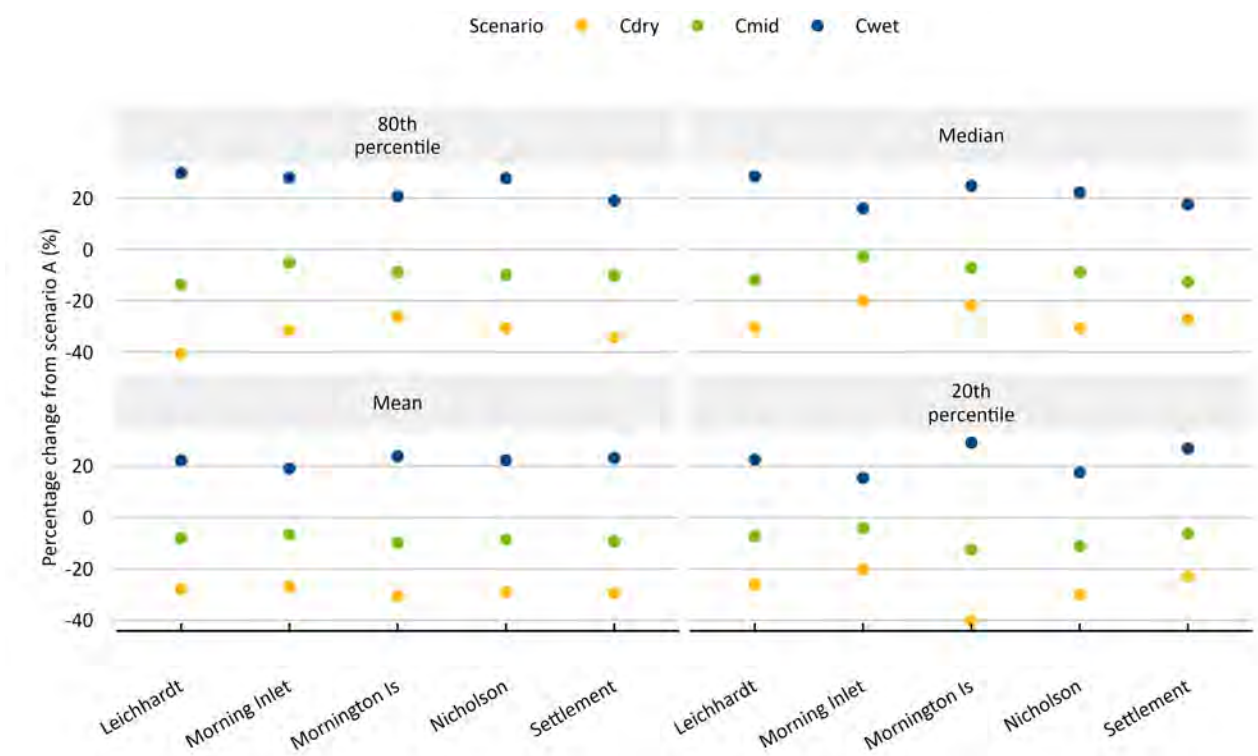

Figure 4-19 Percentage change in end-of-system annual volume metrics under Scenario C relative to under Scenario A

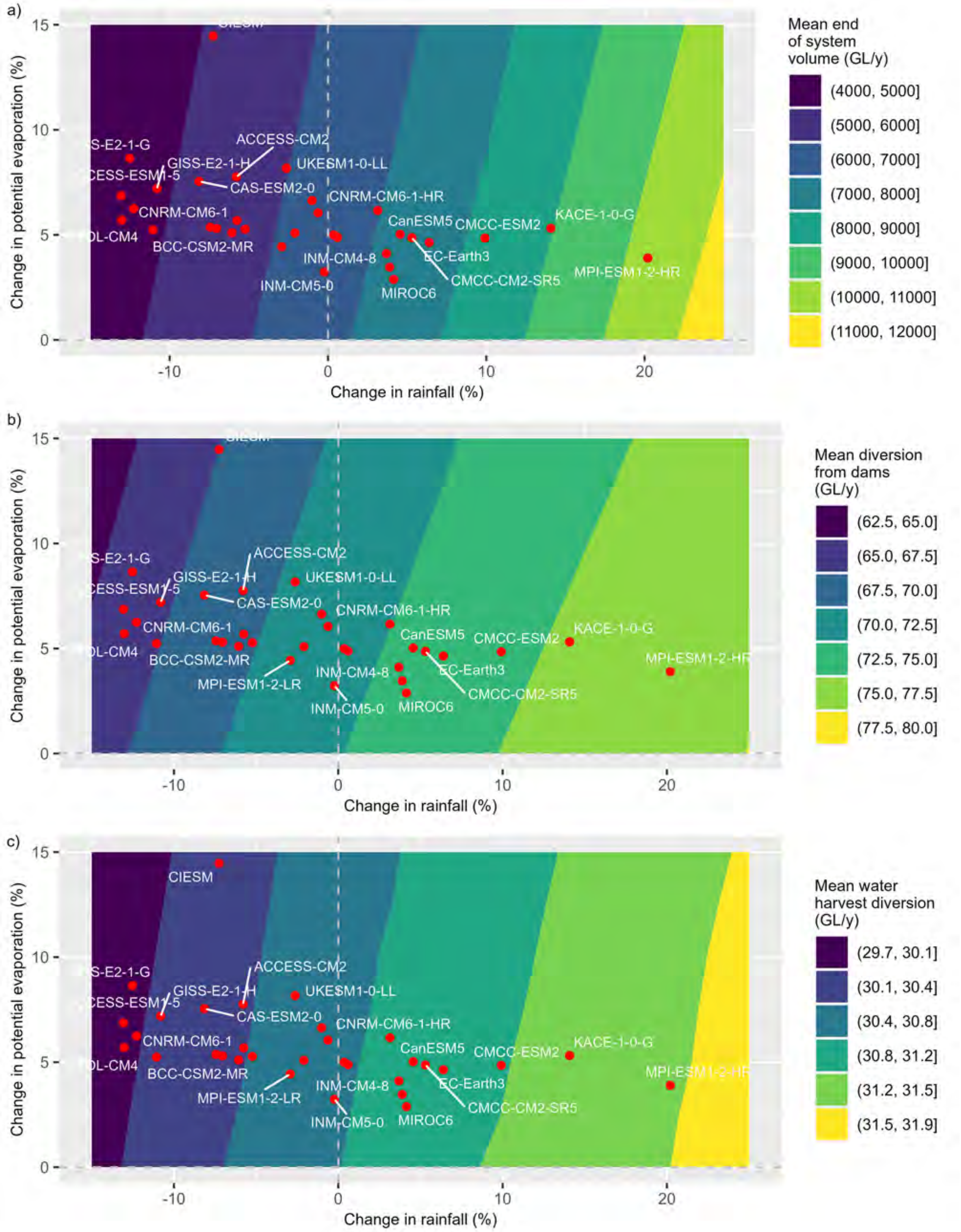

Figure 4-20 Sensitivity of the Assessment area (a) end-of-system, (b) dam diversion and c) water harvest diversion volumes to potential changes in rainfall and potential evaporation

Red circles represent annual scaling factors of the 32 CMIP6 GCMs under SSP2-4.5 at approximately the year 2060. Dashed grey lines represent no change in rainfall (vertical line) and PET (horizontal line on the *x*-axis). Under Scenario C, dam and water harvest diversions assume full use of existing entitlements.

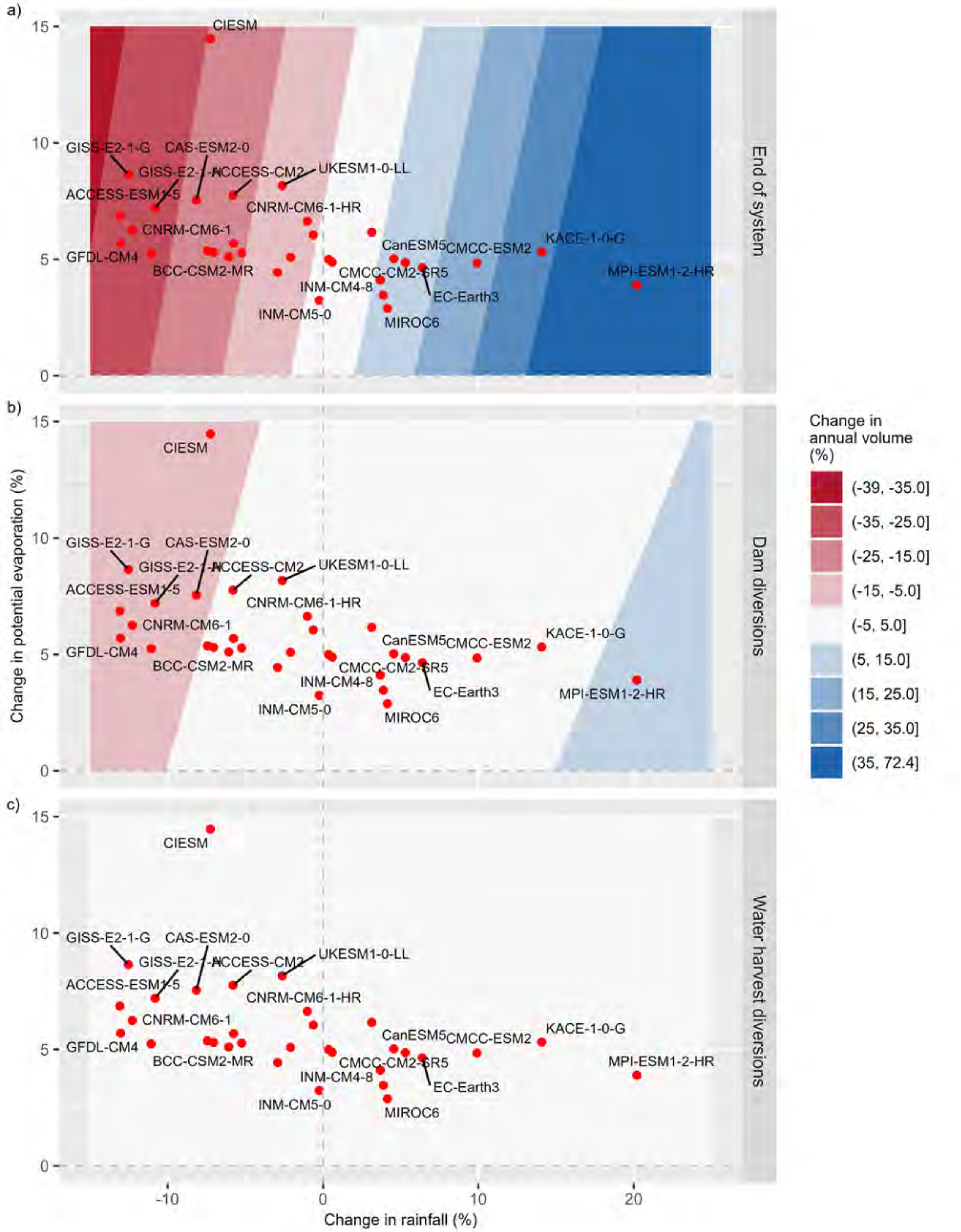

Figure 4-21 Sensitivity of the Assessment area (a) end-of-system, (b) dam diversion and c) water harvest diversion volumes to potential changes in rainfall and potential evaporation, as a percentage change from historical climate

Red circles represent annual scaling factors of the 32 CMIP6 GCMs under SSP2-4.5 at approximately the year 2060. Dashed grey lines represent no change in rainfall (vertical line) and PET (horizontal line on the *x*-axis). Under Scenario C, dam and water harvest diversions assume full use of existing entitlements.

4.4 Scenario D

4.4.1 Hypothetical water harvest

The Scenario C climate has been applied to a subset of the water harvest options. How the ability to supply the system target volume for different pump start thresholds varies, assuming no ADCFR and a 20-day pump capacity, under scenarios Cdry, Cmid and Cwet can be seen in Figure 4-22, Figure 4-23 and Figure 4-24, respectively. These results can be compared to Figure 4-3, which presents the same water harvest settings under Scenario B.

The sensitivity of the water harvest volume to changes in climate has been assessed for the points in Figure 4-22, Figure 4-23 and Figure 4-24 corresponding to a system target volume of 150 GL and pump start threshold of 600 ML/day. The results are shown as volumes in Figure 4-25 and a percentage change from the historical climate in Figure 4-26. A comparison of the Cdry, Cmid and Cwet climates shows the wetter scenarios have higher reliability (Figure 4-22 to Figure 4-24). However, when represented as a total mean annual volume extracted for water harvest (both hypothetical development scenario and full use of existing entitlements), the mean annual water harvest yield is relatively insensitive to the projected changes in rainfall and potential evaporation evaluated: all projected changes in streamflow are within 5% of the mean annual extraction volume under Scenario B (Figure 4-26). Sensitivity plots for a water harvest scenario that assumes an ADCFR of 150 GL and increased pump capacity to pump the reach target volume in 10 days (for the same system target volume and pump start threshold) are provided in Appendix C. They also show that the mean annual water harvest volume is insensitive (less than 5% change) to the range in climate projections considered (Figure C-1 and Figure C-2).

4.4.2 Hypothetical water storage

For each individual short-listed dam considered, the change in yield at the dam wall at 85% annual time reliability for increasing transparent flow threshold under scenarios Cdry, Cmid and Cwet is included in Figure 4-9 to Figure 4-16. As was the case under Scenario C, a larger number of streamflow projections suggest a reduction in yield than an increase in yield under Scenario D. Under Scenario Cmid the reservoir yield is less than the reservoir yield under Scenario B yield for each dam and each transparent flow threshold. The relative influence of the climate projections on the yield available from a hypothetical dam and the median annual volume downstream depends on the inflow characteristics, local topography, and the ability to capture inflows.

The sensitivity of results for a hypothetical development including the three hypothetical dams with the lowest cost per megalitre supplied at the dam wall (see Figure 4-17) is explored in Figure 4-27, and the percentage change from Scenario B in Figure 4-28. Fourteen of the 32 GCMs project changes in climate that result in a projected reduction in mean annual diversion volume from all storages (including existing storages) of more than 5%, with one of the GCMs an increase in mean annual diversion volume from all storages of more than 5%.

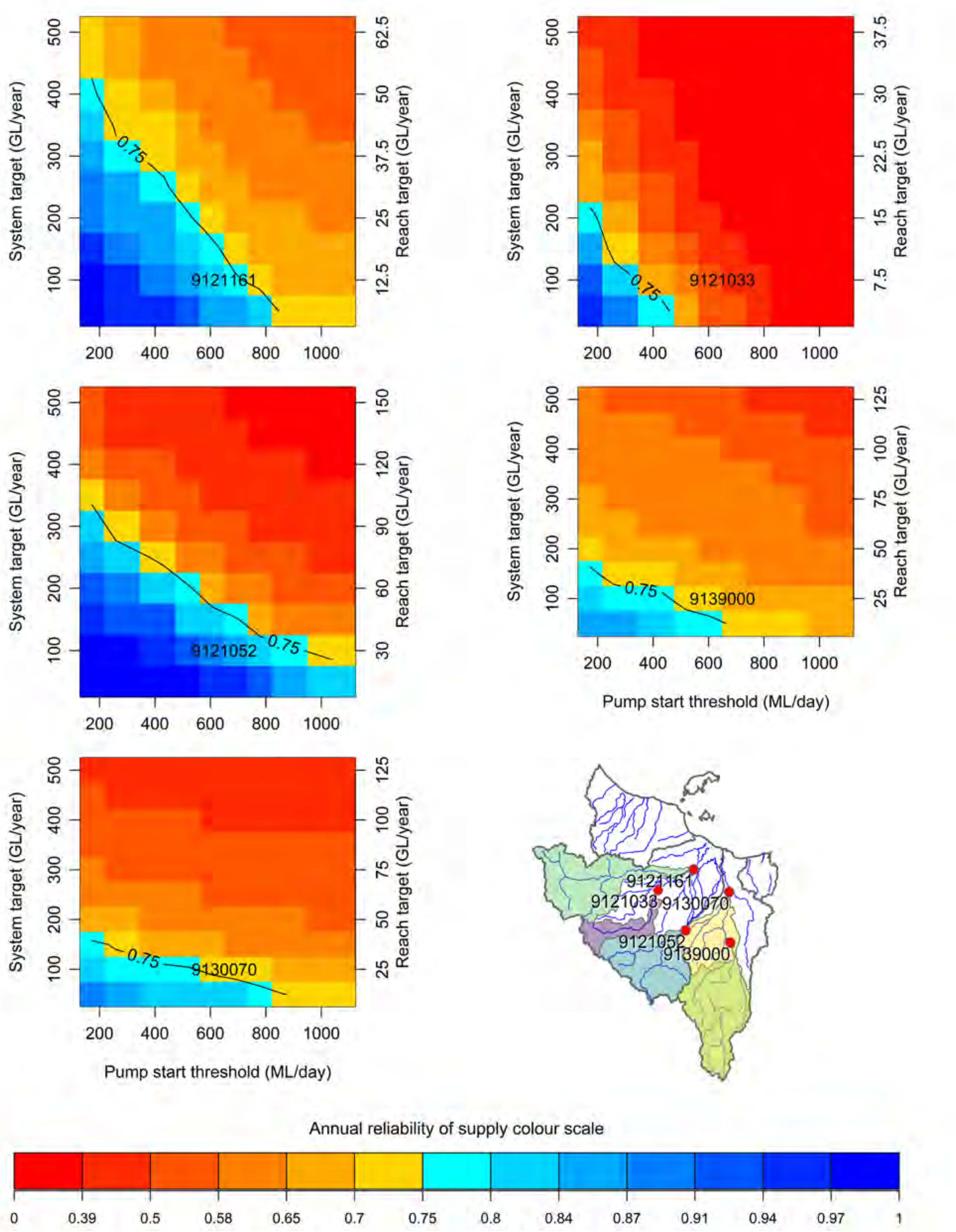

Figure 4-22 Annual reliability of diverting annual system and reach target volumes for varying pump start thresholds under Scenario Cdry

No annual diversion commencement flow requirement volume before pumping can commence. Assumes a pumping capacity such that system and reach targets can be pumped in 20 days. Seven-digit numbers (black) refer to model node location. Black contour lines indicate the conditions that meet a 75% annual reliability of supply.

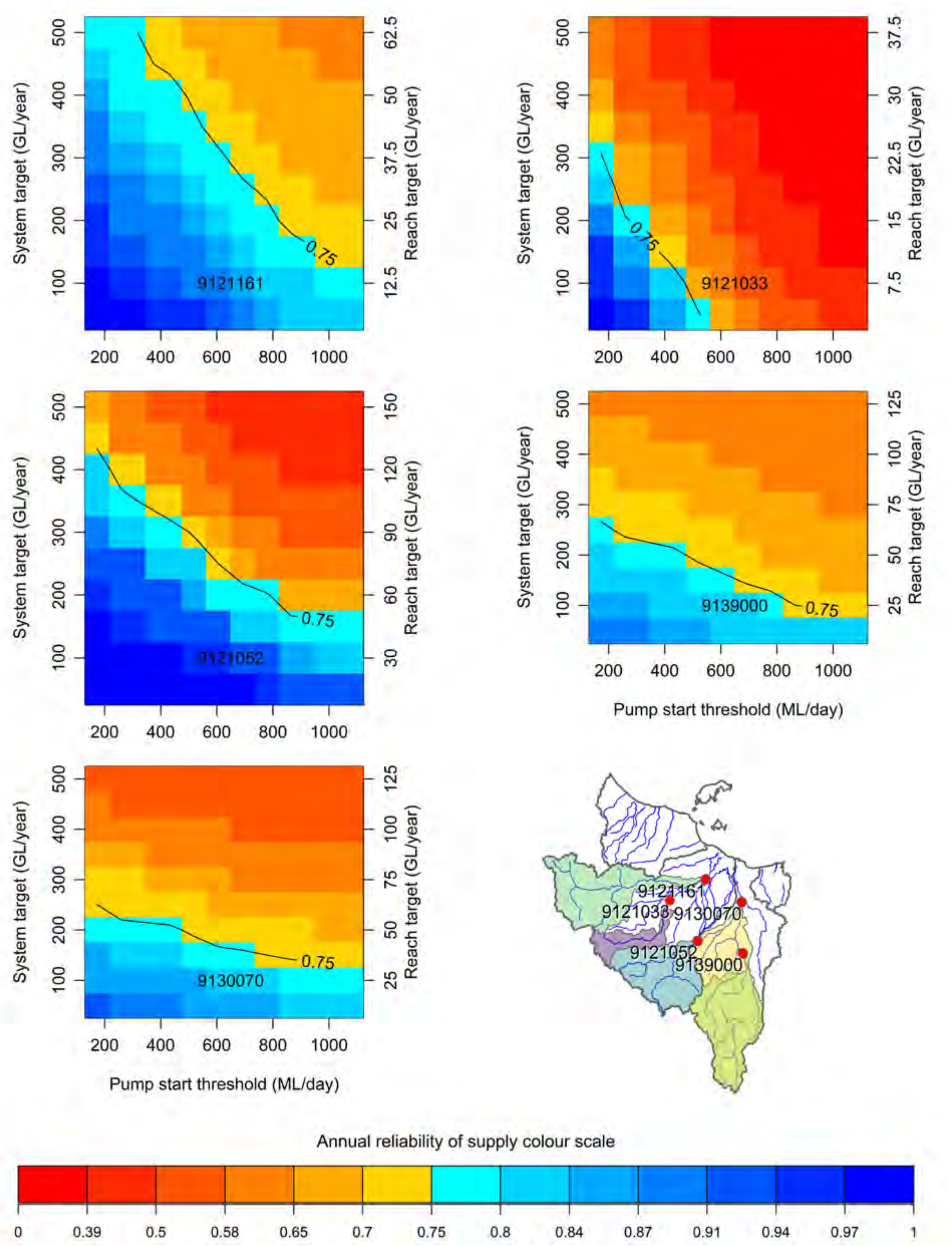

Figure 4-23 Annual reliability of diverting annual system and reach target volumes for varying pump start thresholds under Scenario Cmid

No annual diversion commencement flow requirement volume before pumping can commence. Assumes a pumping capacity such that system and reach targets can be pumped in 20 days. Seven-digit numbers (black) refer to model node location. Black contour lines indicate the conditions that meet a 75% annual reliability of supply.

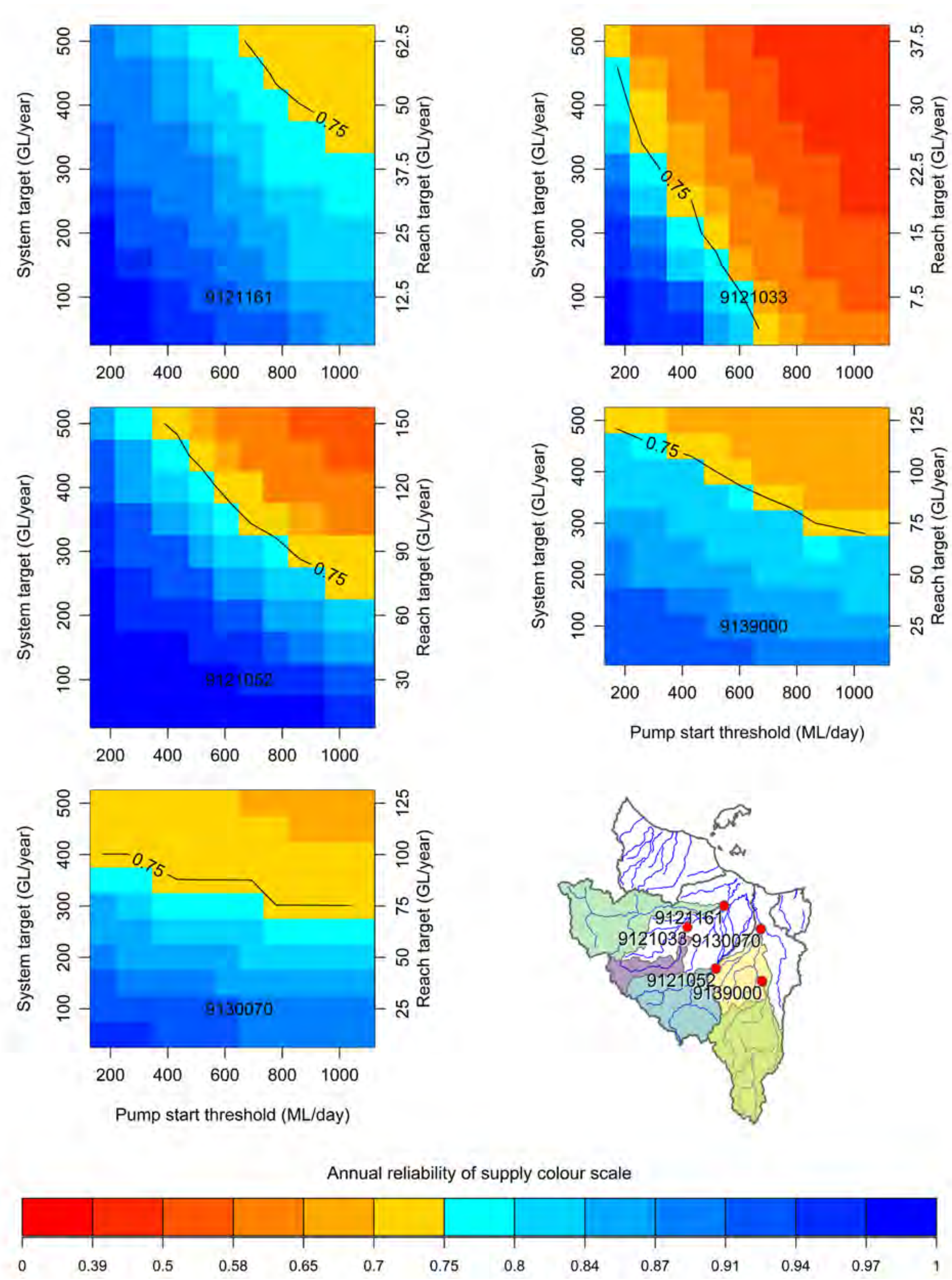

Figure 4-24 Annual reliability of diverting annual system and reach target volumes for varying pump start thresholds under Scenario Cwet

No annual diversion commencement flow requirement volume before pumping can commence. Assumes a pumping capacity such that system and reach targets can be pumped in 20 days. Seven-digit numbers (black) refer to model node location. Black contour lines indicate the conditions that meet a 75% annual reliability of supply.

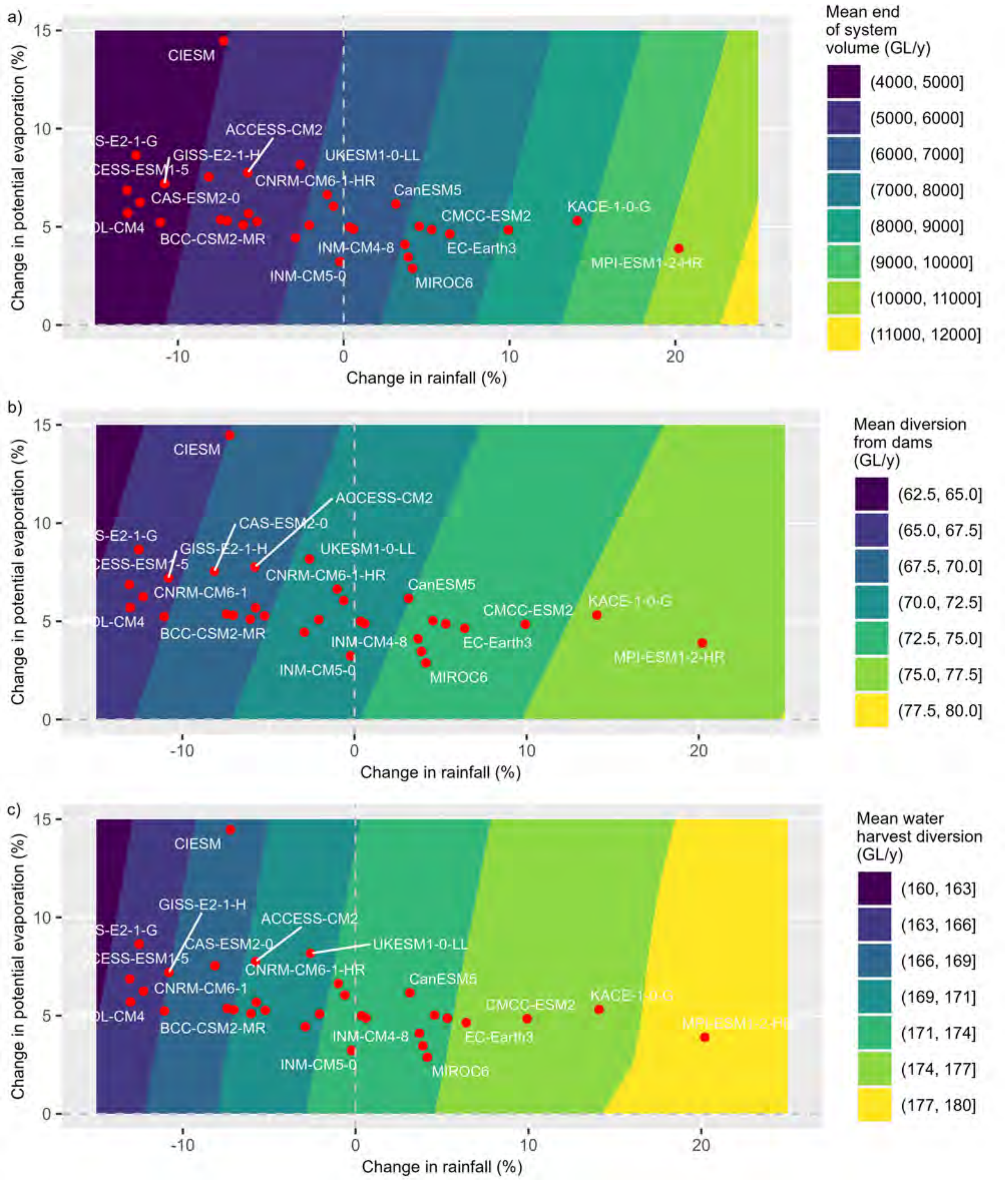

Figure 4-25 Sensitivity of the Assessment area (a) end-of-system, (b) dam diversion and c) water harvest diversion volumes to potential changes in rainfall and potential evaporation under Scenario D with hypothetical water harvest

Assuming 150 GL system target volume, 600 ML/day pump start threshold, 20-day pump capacity and no annual diversion commencement flow requirement volume for hypothetical water harvest. Mean diversion volumes include existing users, and this result includes existing dams only. Red circles represent annual scaling factors of the 32 CMIP6 GCMs under SSP2-4.5 at approximately the year 2060. Dashed grey lines represent no change in rainfall (vertical line) and PET (horizontal line on the *x*-axis).

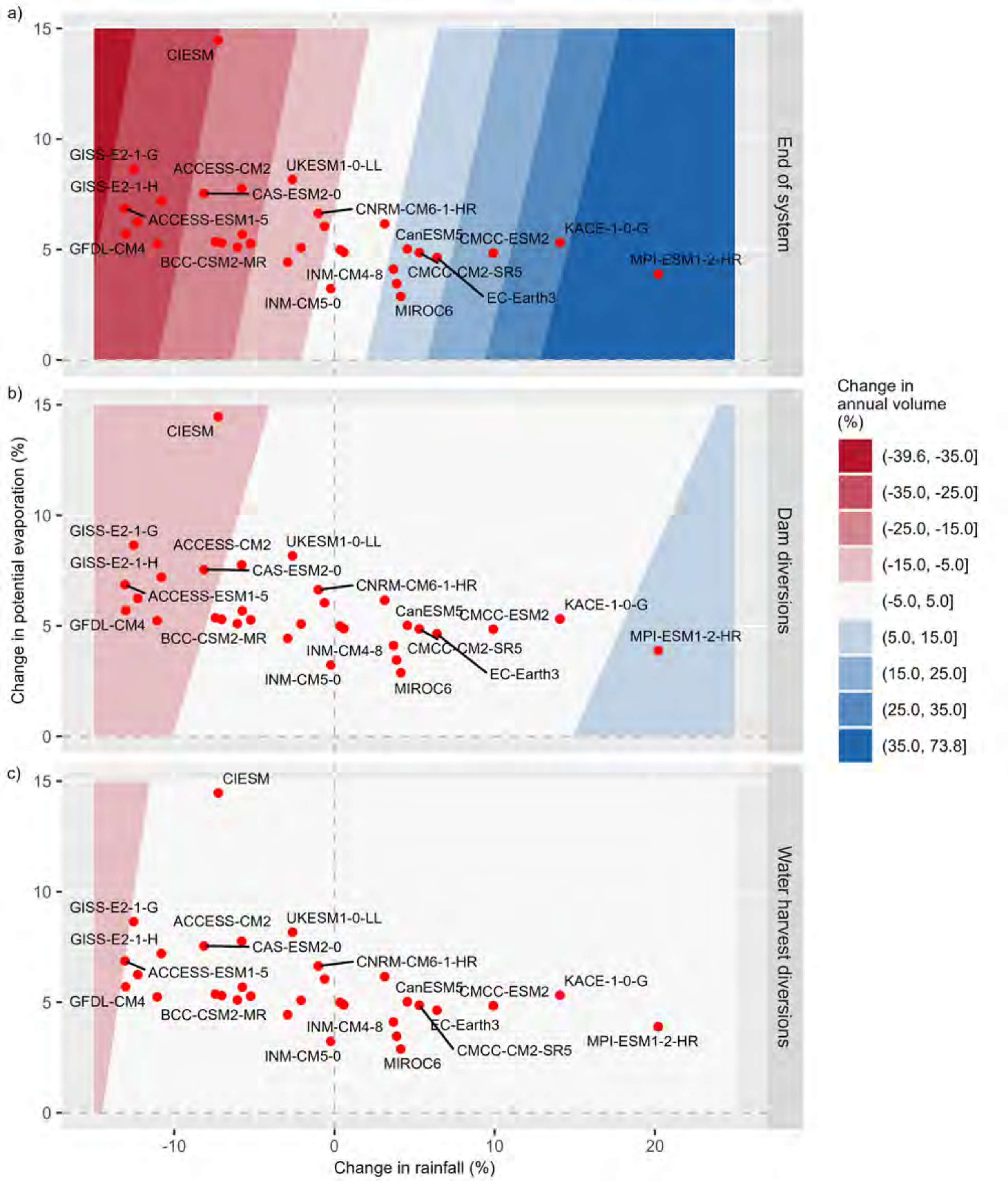

Figure 4-26 Sensitivity of the Assessment area (a) end-of-system, (b) dam diversion and c) water harvest diversion volumes to potential changes in rainfall and potential evaporation under Scenario D with hypothetical water harvest, as a percentage change from under Scenario B

Assuming 150 GL system target volume, 600 ML/day pump start threshold, 20-day pump capacity and no annual diversion commencement flow requirement volume for hypothetical water harvest. Red circles represent annual scaling factors of the 32 CMIP6 GCMs under SSP2-4.5 at approximately the year 2060. Dashed grey lines represent no change in rainfall (vertical line) and PET (horizontal line on the *x*-axis).

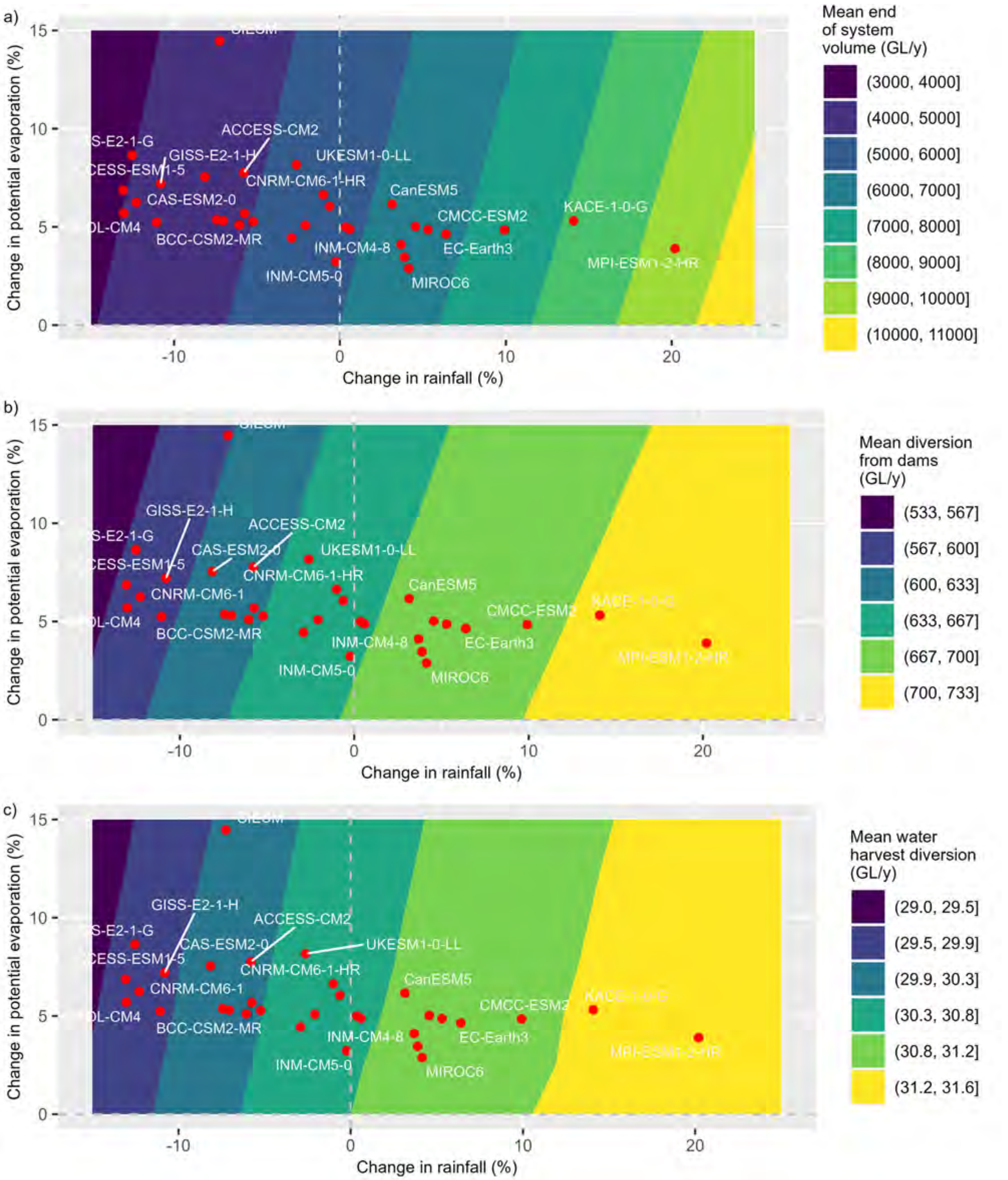

Figure 4-27 Sensitivity of the Assessment area (a) end-of-system, (b) dam diversion and c) water harvest diversion volumes to potential changes in rainfall and potential evaporation under Scenario D with hypothetical water storages

Assuming three hypothetical dams: GR-H, GU and N. Diversion volumes include volumes of water diverted by existing users. Red circles represent annual scaling factors of the 32 CMIP6 GCMs under SSP2-4.5 at approximately the year 2060. Dashed grey lines represent no change in rainfall (vertical line) and PET (horizontal line on the *x*-axis).

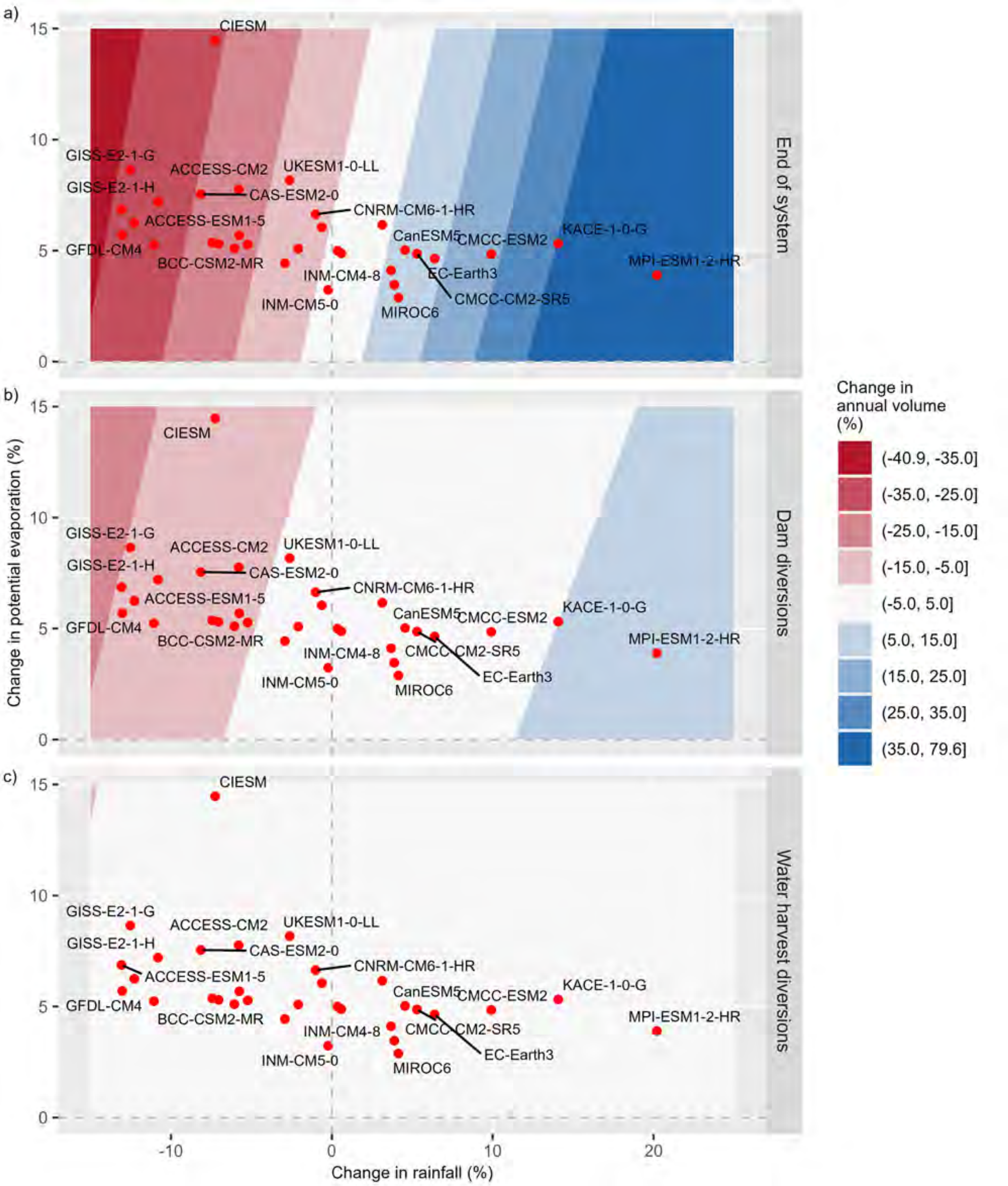

Figure 4-28 Sensitivity of the Assessment area (a) end-of-system, (b) dam diversion and c) water harvest diversion volumes to potential changes in rainfall and potential evaporation under Scenario D with hypothetical water storages, as a percentage change from under Scenario B

Assuming three hypothetical dams constructed: GR-H, GU and N. Diversion volumes include volumes of water diverted by existing users. Red circles represent annual scaling factors of the 32 CMIP6 GCMs under SSP2-4.5 at approximately the year 2060. Dashed grey lines represent no change in rainfall (vertical line) and PET (horizontal line on the *x*-axis).

5 Discussion and conclusion

Two types of hypothetical future development scenario have been considered: large instream dams, and water harvest diversions directly from water courses to smaller off-stream storages. For each development option, a range of conditions were simulated, representing different water access conditions or mitigating strategies to reduce the effect on the downstream flow regime. The underlying hydrological model, its assumptions and accuracy are outlined in detail in Gibbs et al. (2024), and the reader is directed to this companion report for further information.

For water harvest development scenarios, a relatively high pump start threshold of 600 ML/day is required to prevent any reduction in reliability of supply to existing entitlement holders. For this preliminary level of evaluation, one constant pump threshold has been assumed across the study area for each analysis, although in practice this threshold may be tailored to each river based on local requirements. Including an ADCFR volume to preserve the first flow events was found to require large pumps (i.e. with the capacity to extract the target volume in 10 days) to achieve a system target volume of approximately 150 GL at 75% annual time reliability. One option for the spatial distribution of hypothetical extraction locations was assumed. However, different locations and assigning different proportions of extraction to each location may influence the results.

The total divertible volume from seven hypothetical short-listed dam sites (Yang et al., 2024) at an annual time reliability of 85% and maintaining supply to existing downstream entitlement holders was estimated to be 761 GL/year. However, most of this yield was derived from the three dams that had the lowest cost per megalitre released at the dam wall. The combined yield from these three dams was 670 GL/year and resulted in a 15% change in median annual end-of-system volume from catchments of the Southern Gulf (excluding islands). The yield from each individual dam was also estimated for a range of transparent flow releases, up to 50% of the mean daily inflow, to represent the trade-off between maximum yield from the storage and maintaining the persistence of low flows through the system.

The results suggest the potential yields from large instream dams are greater than that from water harvesting, even assuming a higher reliably of supply for the dams (85% for dams compared to 75% for water harvest). This is likely due to the high pump start threshold required to maintain existing user reliability of supply and the short duration of flow events. These short events can be captured in instream storages, but only a proportion of the events could be extracted by water harvesting, even using large-capacity pumps. However, water harvesting has much smaller infrastructure requirements and in some cases may causes less disruption of the natural flow regime than large instream dams when properly designed. Note that these volumes and calculations do not consider other implications and restrictions arising from environmental, cultural, socio-economic or legislative (e.g. land tenure) considerations that may influence the suitability of the developments and resulting yields presented here.

The reliability of supply to existing licences have been considered in this work, assuming full use of these entitlements. DRDMW (2023) report relatively low use of entitlement from storages (11% to 29% used from Julius Dam and 52% to 66% from Moondarra Dam), so maintaining reliability of supply to existing licences includes some growth in use compared to current conditions in the

Assessment area. Strategic reserves in the Water Plan (Gulf) (Queensland Government, 2007) have not been explicitly represented. While not bound by specific volumes or uses, under Scenario B hypothetical developments could theoretically represent some of these strategic purposes. The volume of diversions from water harvest or instream dams is larger than the existing strategic reserves. However, the focus of this work has been on exploring the physical limits to water supply; other considerations (e.g. social, economic, environmental) are likely to provide lower limits to sustainable water supply. The companion technical report on ecological modelling in the Southern Gulf catchments (Ponce Reyes et al., 2024) uses the results of this analysis to explore potential ecological change.

The relative influence of potential changes to future long-term climate on the reservoir yield available from instream dams, and the resulting median annual volume released or spilling downstream, depends on inflow characteristics, local topography and ability to capture inflows. The sensitivity of results for a hypothetical development including the three highest yielding dams indicated that 14 of the 32 GCMs projected changes in climate that result in a projected reduction in mean annual yield for all storages (both hypothetical and existing storages) of more than 5%; one of the GCMs projected an increase of more than 5%. The mean annual water harvest extraction volume is relatively insensitive to the range in future climate projections from the different GCMs for the conditions assumed: all GCMs fell within 5% of the mean annual extraction volume under no change in climate. This result may be a function of the conditions assumed, whereby diversion volumes were limited by the system target and did not increase if streamflow volumes increased. If streamflow volumes decreased, large pump capacities made it still possible to opportunistically divert the reach and system target volumes over short events for hypothetical water harvest diversions. Furthermore, low pump start thresholds for existing water licences still allowed extraction of water at lower flow rates in the model.

References

Chiew FHS, Teng J, Vaze J, Post DA, Perraud JM, Kirono DGC and Viney NR (2009) Estimating climate change impact on runoff across southeast Australia: method, results, and implications of the modeling method. Water Resources Research 45(10), W10414. DOI: 10.1029/2008WR007338.

CSIRO (2009a) Water in the Flinders-Leichhardt region. In: CSIRO Water in the Gulf of Carpentaria Drainage Division. A report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, Australia, 189–276.

CSIRO (2009b) Water in the South-West Gulf region. In: CSIRO Water in the Gulf of Carpentaria Drainage Division. A report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, Australia, 121–185.

CSIRO (2011) Water: science and solutions for Australia. CSIRO Land and Water.

DNRME (2019) Mount Isa regional water supply security assessment. Department of Natural Resources, Mines and Energy, Queensland Government.

DRDMW (2023) Water Plan (Gulf) 2007 Minister's Performance Assessment Report. Department of Regional Development Manufacturing and Water, Queensland Government.

Gibbs M, Hughes J and Yang A (2024) River model calibration for the Southern Gulf catchments. A technical report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid. CSIRO, Australia.

IPCC (2022) Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA.

McJannet D, Yang A and Seo L (2023) Climate data characterisation for hydrological and agricultural scenario modelling across the Victoria, Roper and Southern Gulf catchments. A technical report from the CSIRO Victoria River and Southern Gulf Water Resource Assessments for the National Water Grid. CSIRO, Australia.

Morton FI (1983) Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. Journal of Hydrology 66, 1–76.

Petheram C, Bruce C, Chilcott C and Watson I (eds) (2018a) Water resource assessment for the Fitzroy catchment. A report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments. CSIRO, Australia.

Petheram C, Chilcott C, Watson I and Bruce C (eds) (2018b) Water resource assessment for the Darwin catchments. A report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments. CSIRO, Australia.

Petheram C, Gallant J and Read A (2017). An automated and rapid method for identifying dam wall locations and estimating reservoir yield over large areas. Environmental modelling and software 92, 189–201.

Petheram C, Read A, Hughes J, Stokes C, Philip S, Peake A, Marvanek S, Yang A, Devlin K, Wilson P, Baynes F, Podger G, Macintosh A, Stratford D, Potter N, Kim S, Tredger R, Barber M, Wang B, McJannet D, Jarvis D, Vanderbyl T, Watson I and Chilcott C (2020) An assessment of the historic Bradfield Scheme to divert water inland from north Queensland. CSIRO, Australia. DOI: 10.25919/hvb8-g289.

Petheram C, Rustomji P, McVicar TR, Cai W, Chiew FHS, Vleeshouwer J, Van Niel TG, Li L, Cresswell RG, Donohue RJ, Teng J and Perraud J-M (2012) Estimating the Impact of Projected Climate Change on Runoff across the Tropical Savannas and Semiarid Rangelands of Northern Australia. Journal of Hydrometeorology 13(2), 483-503. DOI: 10.1175/jhm-d-11-062.1.

Petheram C, Watson I and Stone P (2013a) Agricultural resource assessment for the Flinders catchment. A report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy. CSIRO Water for Healthy Country and Sustainable Agriculture flagships, Australia.

Petheram C, Watson I and Stone P (2013b) Agricultural resource assessment for the Gilbert catchment. A report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy. CSIRO Water for Healthy Country and Sustainable Agriculture flagships, Australia.

Petheram C, Watson I, Bruce C and Chilcott C (eds) (2018c) Water resource assessment for the Mitchell catchment. A report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments. CSIRO, Australia.

Ponce Reyes R, Stratford D, Linke S, Merrin L, Kenyon R, Buckworth R, Deng RA, Hughes J, McGinness H, Pritchard J, Seo L and Waltham N (2024) Assessment of the potential ecological outcomes of water resource development in the Southern Gulf catchments. A technical report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid. CSIRO, Australia.

Queensland Government (n.d.) Attributes for active water licences. Queensland Government Open Data Portal. Viewed 21 March 2024, https://www.data.qld.gov.au/dataset/water-entitlements/resource/a512e9a8-c374-4416-a77d-1be85f3c796e.

Queensland Government (2007) Water Plan (Gulf). Office of the Queensland Parliamentary Counsel, State of Queensland, Queensland, Australia. Viewed 11 Nov 2023, https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2007-0268.

Thomas M, Philip S, Zund P, Stockmann U, Hill J, Gregory L, Watson I and Thomas E (2024) Soils and land suitability for the Southern Gulf catchments. A technical report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid. CSIRO, Australia.

Webster A, Jarvis D, Jalilov S, Philip S, Oliver Y, Watson I, Rhebergen T, Bruce C, Prestwidge D, McFallan S, Curnock M and Stokes C (2024) Financial and socio-economic viability of irrigated agricultural development in the Southern Gulf catchments. A technical report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid. CSIRO, Australia.

Yang A, Petheram C, Marvanek S, Baynes F, Rogers L, Ponce Reyes R, Zund P, Seo L, Hughes J, Gibbs M, Wilson PR, Philip S and Barber M (2024) Assessment of surface water storage options in the Victoria and Southern Gulf catchments. A technical report from the CSIRO Victoria River and Southern Gulf Water Resource Assessments for the National Water Grid. CSIRO Australia

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Part II Appendices

Appendix A Storage relationships

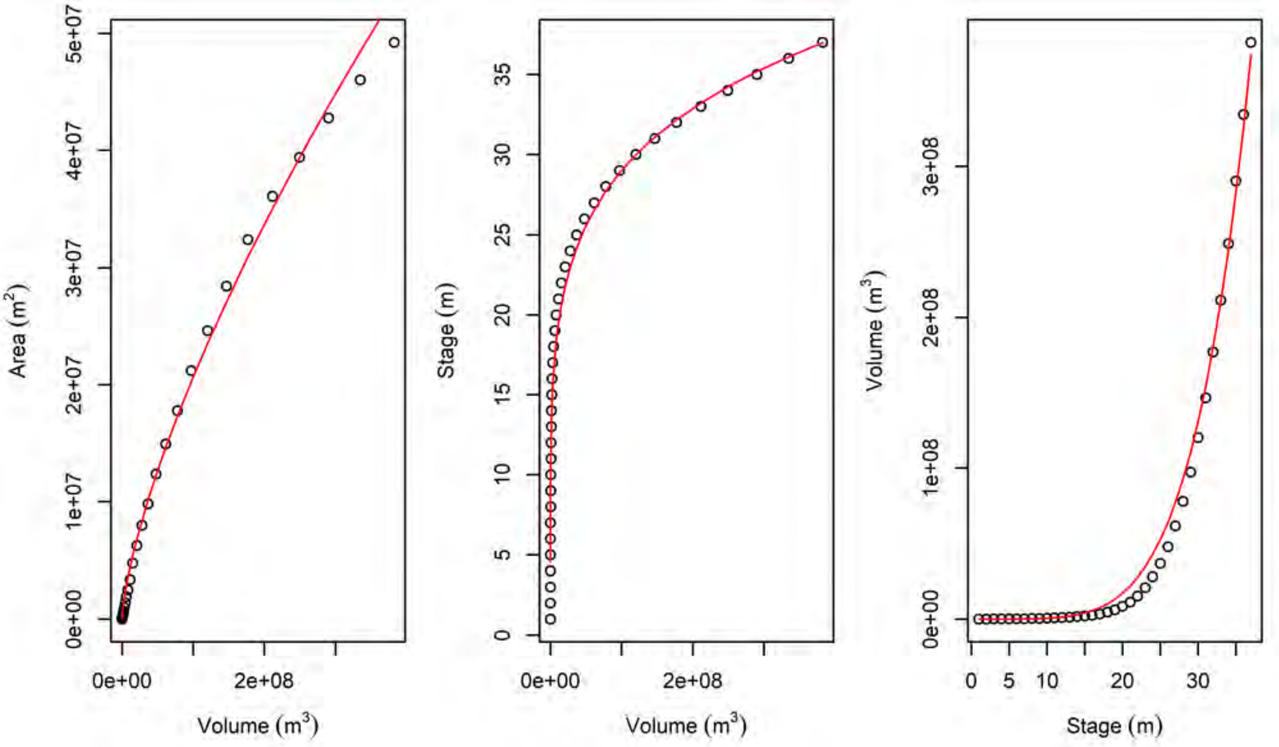

Figure A-1 Area, stage and volume relationships used for South Nicholson River AMTD 9 km (Dam 290) FSL 162 mEGM96

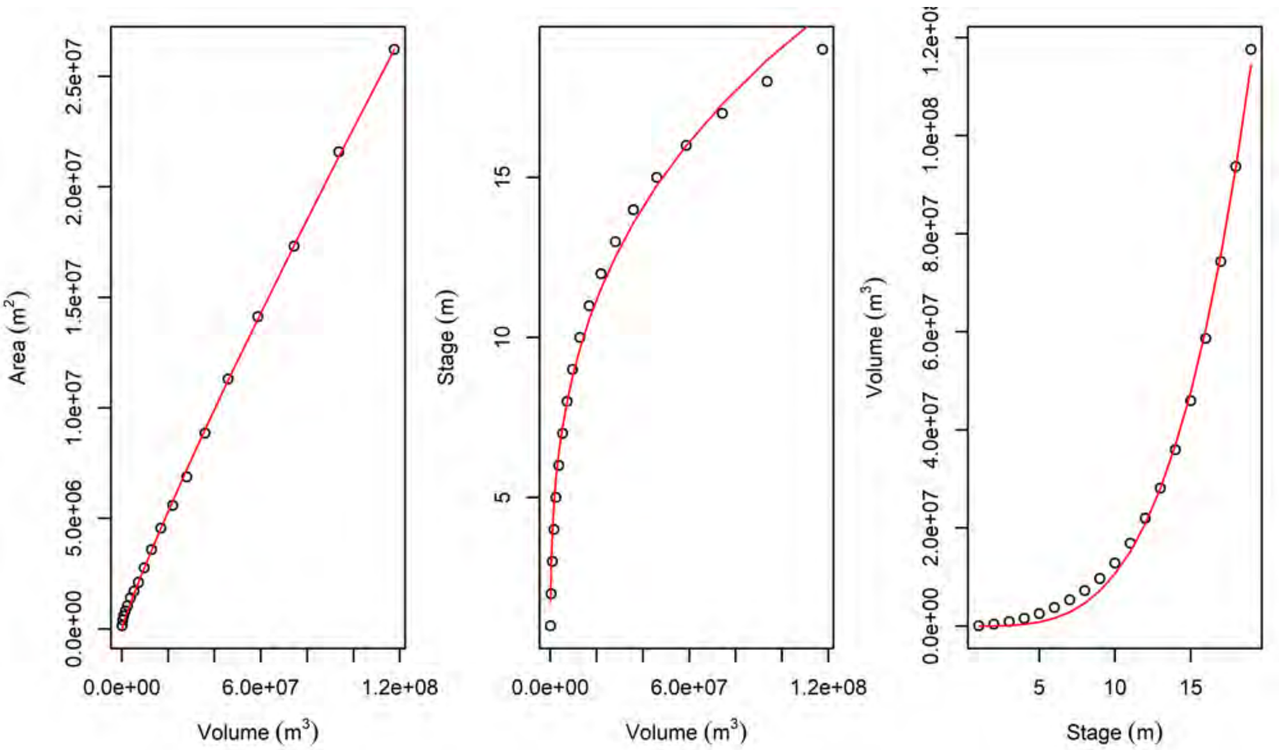

Figure A-2 Area, stage and volume relationships used for Gregory River AMTD 174 (Dam 1) FSL 138 and 145 mEGM96

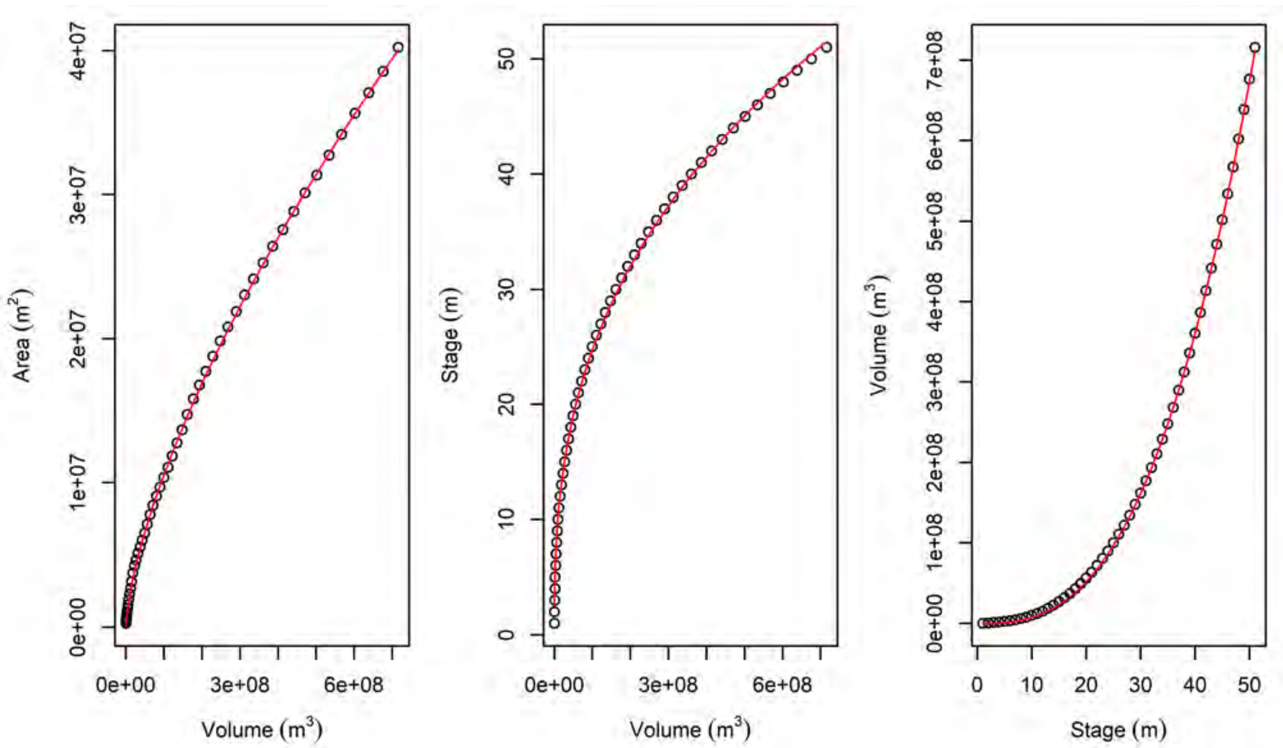

Figure A-3 Area, stage and volume relationships used for Gunpower Creek AMTD 66 km (Dam 28) FSL 186 mEGM96

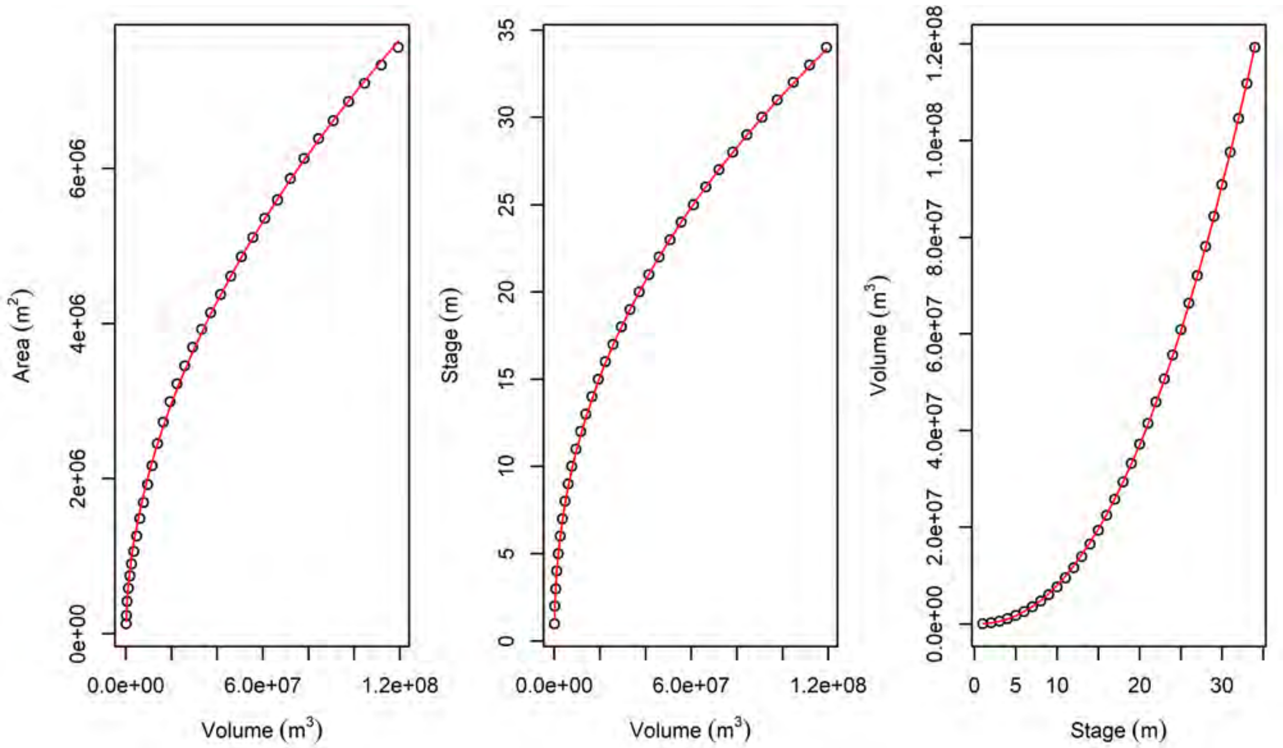

Figure A-4 Area, stage and volume relationships used for Gold Creek AMTD 58 km (Dam 206) FSL 84 mEGM96

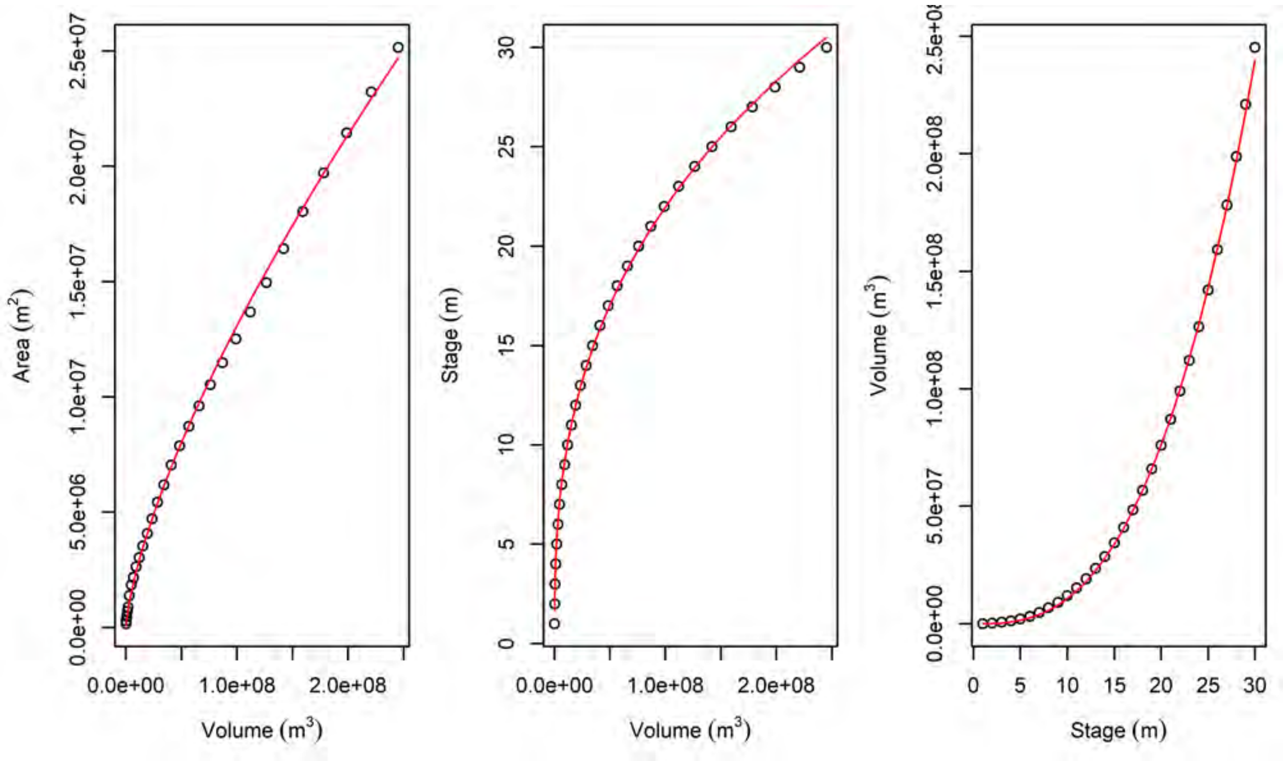

Figure A-5 Area, stage and volume relationships used for Ewen Creek AMTD 6 km (Dam 275) FSL 217 mEGM96

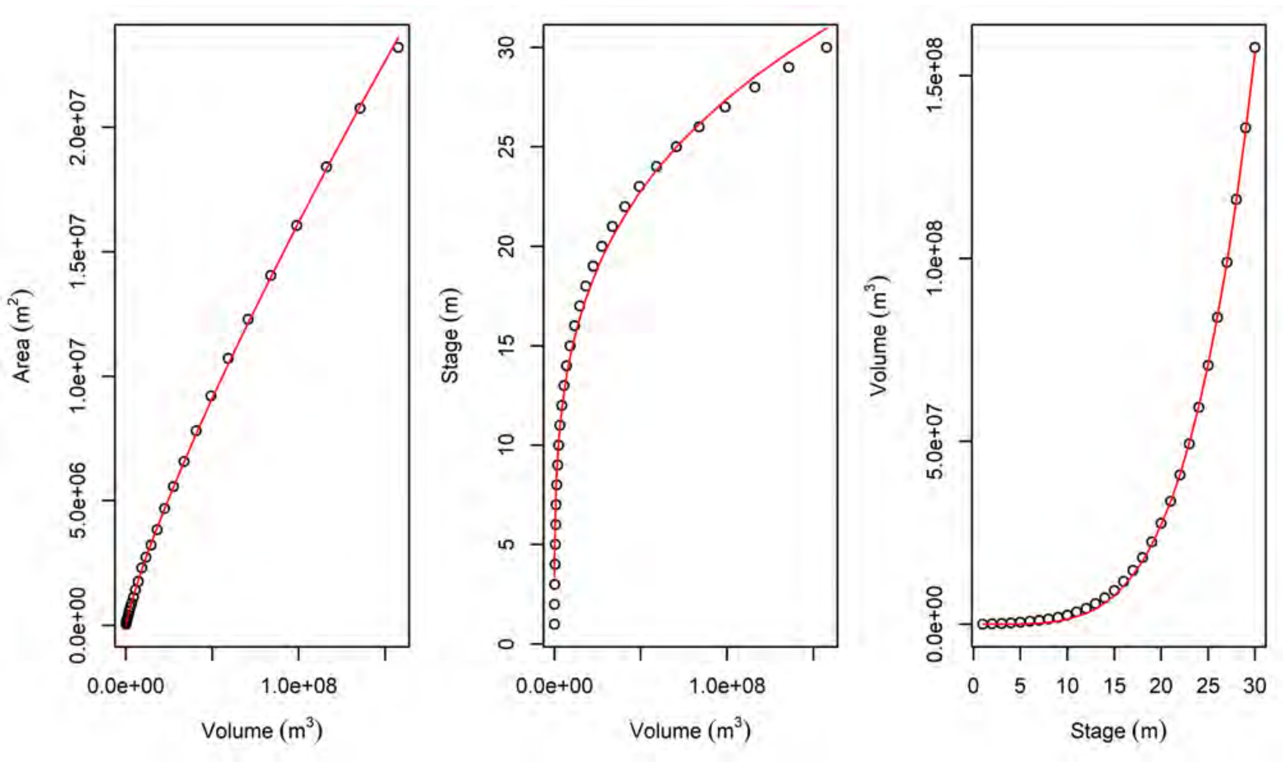

Figure A-6 Volume, stage and area relationships used for Mistake Creek AMTD 60 km (Dam 165) FSL 149 mEGM96

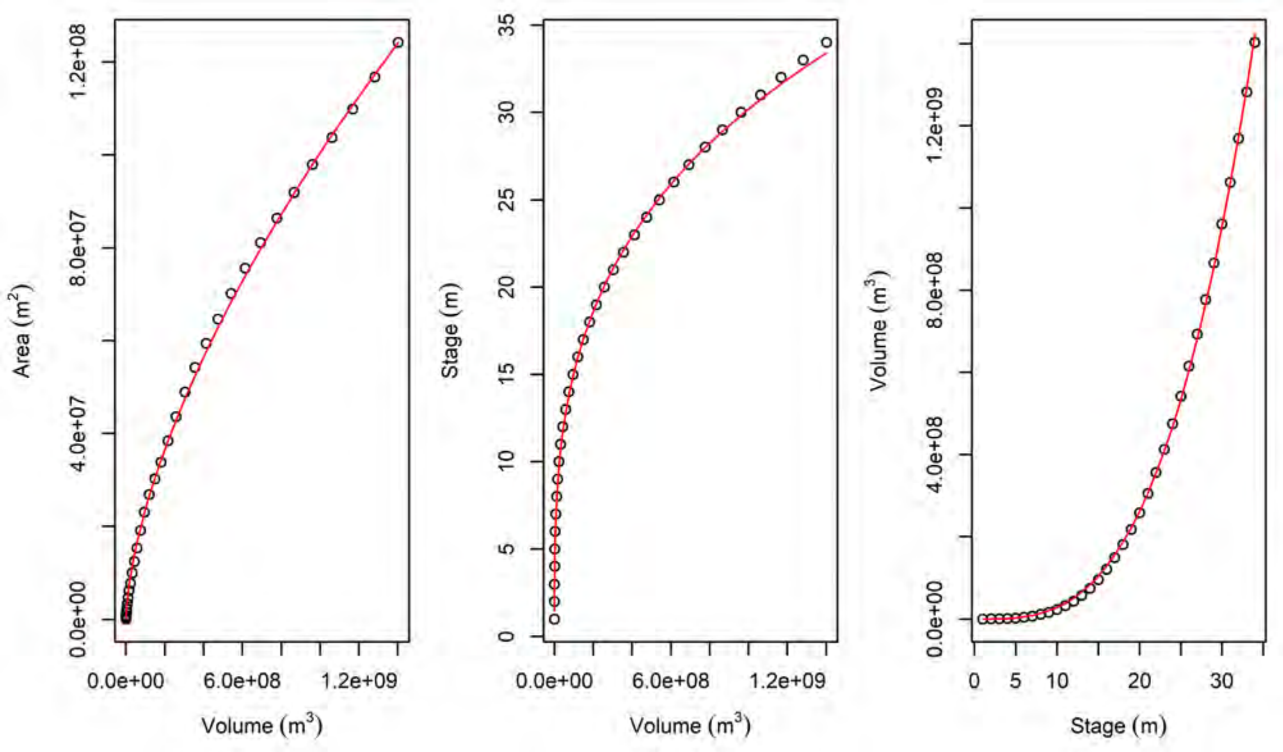

Figure A-7 Volume, stage and area relationships used for Nicholson River AMTD 198 km (Dam 3) FSL 108 mEGM96

Appendix B Flow statistics for all model nodes under Scenario A

Table B-1 Flow statistics for all model nodes under Scenario AN

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9121010	507	227	364	709	459	0.09
9121011	268	96	176	384	459	0.05
9121012	376	121	254	529	551	0.05
9121013	45	12	33	61	539	0.08
9121014	75	18	59	100	547	0.08
9121015	152	74	119	205	560	0.07
9121016	73	13	61	105	473	0.01
9121020	202	95	148	279	446	0.09
9121030	165	61	118	220	474	0.09
9121031	111	39	73	148	459	0.08
9121032	2	0	1	3	532	0.08
9121033	201	72	143	274	487	0.09
9121034	23	4	18	34	495	0.01
9121035	36	6	31	52	583	0.09
9121040	1	0	1	2	541	0.08
9121041	29	4	19	44	559	0.09
9121050	475	213	343	681	454	0.09
9121051	36	10	23	50	498	0.11
9121052	535	232	381	757	459	0.09
9121053	50	10	35	76	537	0.22
9121060	72	12	37	116	522	0.08
9121061	96	15	50	158	530	0.08
9121070	649	82	268	1092	546	0.09
9121071	615	77	253	1044	543	0.08
9121072	536	65	218	900	548	0.11
9121073	353	40	137	614	538	0.09
9121074	37	7	22	52	601	0.12
9121075	125	13	47	194	512	0.07
9121080	238	103	179	334	455	0.09
9121090	2016	484	1429	2898	548	0.13

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9121092	123	35	85	145	777	0.13
9121093	691	254	436	854	879	0.14
9121094	141	42	89	176	804	0.13
9121095	328	65	203	450	748	0.13
9121096	235	38	129	319	757	0.14
9121097	146	32	87	195	820	0.15
9121098	282	67	170	368	828	0.14
9121099	68	24	43	83	860	0.14
9121100	75	29	54	105	460	0.10
9121101	31	13	23	42	448	0.09
9121102	31	11	20	43	490	0.10
9121110	41	19	30	58	430	0.09
9121111	162	75	120	226	440	0.09
9121120	19	6	12	26	500	0.11
9121130	34	3	16	57	560	0.09
9121131	44	5	24	71	564	0.09
9121132	51	8	33	74	586	0.09
9121150	17	7	13	22	425	0.09
9121151	65	29	50	89	437	0.09
9121152	78	35	60	108	439	0.09
9121160	731	98	325	1187	553	0.09
9121161	787	123	372	1253	558	0.09
9129040	460	138	362	617	514	0.04
9129042	65	12	48	91	633	0.10
9130010	4	1	3	5	417	0.10
9130011	48	16	37	68	422	0.10
9130012	2	1	2	3	438	0.11
9130013	0	0	0	0	454	0.12
9130030	197	68	130	278	490	0.11
9130040	335	102	232	429	468	0.12
9130050	16	6	11	25	469	0.11
9130060	128	42	85	171	482	0.11
9130061	13	4	8	18	507	0.12
9130070	1298	412	868	1896	509	0.11
9130071	1827	582	1211	2640	535	0.11
9130072	114	35	72	150	700	0.11
9130073	193	57	130	247	731	0.11

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9130080	82	23	50	111	525	0.13
9130090	11	4	9	16	430	0.10
9130091	26	8	19	38	432	0.11
9130100	41	12	27	55	516	0.11
9130110	220	63	152	315	584	0.09
9130111	321	82	236	446	593	0.09
9130140	169	51	126	238	441	0.11
9130150	244	79	178	327	454	0.11
9131000	264	82	156	443	1147	0.22
9131001	28	9	17	36	975	0.18
9139000	903	269	579	1217	494	0.12
9139000	903	269	579	1217	494	0.12
9139000	903	269	579	1217	494	0.12

Table B-2 Flow statistics for all model nodes under Scenario AE

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9121010	507	227	364	709	459	0.09
9121011	268	96	176	384	459	0.05
9121012	376	121	254	529	551	0.05
9121013	45	12	33	61	539	0.08
9121014	75	18	59	100	547	0.08
9121015	152	74	119	205	560	0.07
9121016	73	13	61	105	473	0.01
9121020	202	95	148	279	446	0.09
9121030	165	61	118	220	474	0.09
9121031	111	39	73	148	459	0.08
9121032	2	0	1	3	532	0.08
9121033	201	72	143	274	487	0.09
9121034	23	4	18	34	495	0.01
9121035	36	6	31	52	583	0.09
9121040	1	0	1	2	541	0.08
9121041	29	4	19	44	559	0.09
9121050	475	213	343	681	454	0.09
9121051	36	10	23	50	498	0.11

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9121052	535	232	381	757	459	0.09
9121053	50	10	35	76	537	0.22
9121060	72	12	37	116	522	0.08
9121061	96	15	50	158	530	0.08
9121070	649	82	268	1092	546	0.09
9121071	615	77	253	1044	543	0.08
9121072	536	65	218	900	548	0.11
9121073	353	40	137	614	538	0.09
9121074	37	7	22	52	601	0.12
9121075	125	13	47	194	512	0.07
9121080	238	103	179	334	455	0.09
9121090	2016	484	1429	2898	548	0.13
9121092	123	35	85	145	777	0.13
9121093	691	254	436	854	879	0.14
9121094	141	42	89	176	804	0.13
9121095	328	65	203	450	748	0.13
9121096	235	38	129	319	757	0.14
9121097	146	32	87	195	820	0.15
9121098	282	67	170	368	828	0.14
9121099	68	24	43	83	860	0.14
9121100	75	29	54	105	460	0.10
9121101	31	13	23	42	448	0.09
9121102	31	11	20	43	490	0.10
9121110	41	19	30	58	430	0.09
9121111	162	75	120	226	440	0.09
9121120	19	6	12	26	500	0.11
9121130	34	3	16	57	560	0.09
9121131	44	5	24	71	564	0.09
9121132	51	8	33	74	586	0.09
9121150	17	7	13	22	425	0.09
9121151	65	29	50	89	437	0.09
9121152	78	35	60	108	439	0.09
9121160	731	98	325	1187	553	0.09
9121161	787	123	372	1253	558	0.09
9129040	460	138	362	617	514	0.04
9129042	65	12	48	91	633	0.10
9130010	1	0	0	0	417	0.02

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9130011	10	0	0	0	422	0.02
9130012	2	1	2	3	438	0.11
9130013	0	0	0	0	454	0.12
9130030	192	64	125	272	490	0.11
9130040	250	38	136	325	468	0.09
9130050	16	6	11	25	469	0.11
9130060	128	42	85	171	482	0.11
9130061	7	0	2	12	507	0.07
9130070	1200	342	741	1744	509	0.10
9130071	1730	494	1111	2519	535	0.10
9130072	114	35	72	150	700	0.11
9130073	193	57	130	247	731	0.11
9130080	82	23	50	111	525	0.13
9130090	11	4	9	16	430	0.10
9130091	14	0	5	22	432	0.06
9130100	41	12	27	55	516	0.11
9130110	220	63	152	315	584	0.09
9130111	321	82	236	446	593	0.09
9130140	119	27	72	159	441	0.08
9130150	159	14	83	207	454	0.07
9131000	264	82	156	443	1147	0.22
9131001	28	9	17	36	975	0.18
9139000	812	204	484	1121	494	0.11

Table B-3 Flow statistics for all model nodes under Scenario A

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9121010	506	226	363	708	459	0.09
9121011	267	96	175	383	459	0.05
9121012	376	121	253	528	551	0.05
9121013	45	12	33	61	539	0.08
9121014	75	18	59	100	547	0.08
9121015	150	72	118	203	560	0.07
9121016	73	13	61	105	473	0.01
9121020	202	95	148	279	446	0.09

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9121030	164	59	116	219	474	0.09
9121031	111	39	73	148	459	0.08
9121032	2	0	1	3	532	0.08
9121033	199	71	141	272	487	0.09
9121034	23	4	18	34	495	0.01
9121035	36	6	31	52	583	0.09
9121040	1	0	1	2	541	0.08
9121041	29	4	19	44	559	0.09
9121050	475	213	343	681	454	0.09
9121051	36	10	23	50	498	0.11
9121052	535	232	381	757	459	0.09
9121053	50	10	35	76	537	0.22
9121060	72	12	37	116	522	0.08
9121061	96	15	50	158	530	0.08
9121070	649	82	268	1092	546	0.09
9121071	615	77	253	1044	543	0.08
9121072	536	65	218	900	548	0.11
9121073	353	40	137	614	538	0.09
9121074	37	7	22	52	601	0.12
9121075	125	13	47	194	512	0.07
9121080	238	103	179	334	455	0.09
9121090	2010	478	1423	2893	548	0.13
9121092	123	35	85	145	777	0.13
9121093	691	254	436	854	879	0.14
9121094	141	42	89	176	804	0.13
9121095	328	65	203	450	748	0.13
9121096	235	38	129	319	757	0.14
9121097	146	32	87	195	820	0.15
9121098	282	67	170	368	828	0.14
9121099	68	24	43	83	860	0.14
9121100	75	29	54	105	460	0.10
9121101	31	13	23	42	448	0.09
9121102	31	11	20	43	490	0.10
9121110	41	19	30	58	430	0.09
9121111	162	75	120	226	440	0.09
9121120	19	6	12	26	500	0.11
9121130	34	3	16	57	560	0.09

NODE ID	MEAN ANNUAL FLOW (GL)	80% ANNUAL EXCEEDANCE FLOW (GL)	MEDIAN ANNUAL FLOW (GL)	20% ANNUAL EXCEEDANCE FLOW (GL)	MEAN ANNUAL RAINFALL (mm)	RUNOFF COEFFICIENT
9121131	44	5	24	71	564	0.09
9121132	51	8	33	74	586	0.09
9121150	17	7	13	22	425	0.09
9121151	65	29	50	89	437	0.09
9121152	78	35	60	108	439	0.09
9121160	730	98	325	1186	553	0.09
9121161	787	122	371	1253	558	0.09
9129040	459	137	361	615	514	0.04
9129042	65	12	48	91	633	0.10
9130010	1	0	0	0	417	0.02
9130011	6	0	0	0	422	0.01
9130012	2	1	2	3	438	0.11
9130013	0	0	0	0	454	0.12
9130030	190	64	123	270	490	0.11
9130040	213	27	92	277	468	0.08
9130050	16	6	11	25	469	0.11
9130060	128	42	85	171	482	0.11
9130061	6	0	0	10	507	0.06
9130070	1157	308	693	1670	509	0.10
9130071	1677	449	1059	2463	535	0.10
9130072	114	35	72	150	700	0.11
9130073	193	57	130	247	731	0.11
9130080	82	23	50	111	525	0.13
9130090	11	4	9	16	430	0.10
9130091	14	0	5	22	432	0.06
9130100	41	12	27	55	516	0.11
9130110	220	63	152	314	584	0.09
9130111	311	72	226	436	593	0.08
9130140	115	27	72	153	441	0.07
9130150	122	0	41	163	454	0.06
9131000	264	82	156	443	1147	0.22
9131001	28	9	17	36	975	0.18
9139000	774	182	447	1072	494	0.10

Appendix C Climate sensitivity for water harvest scenario

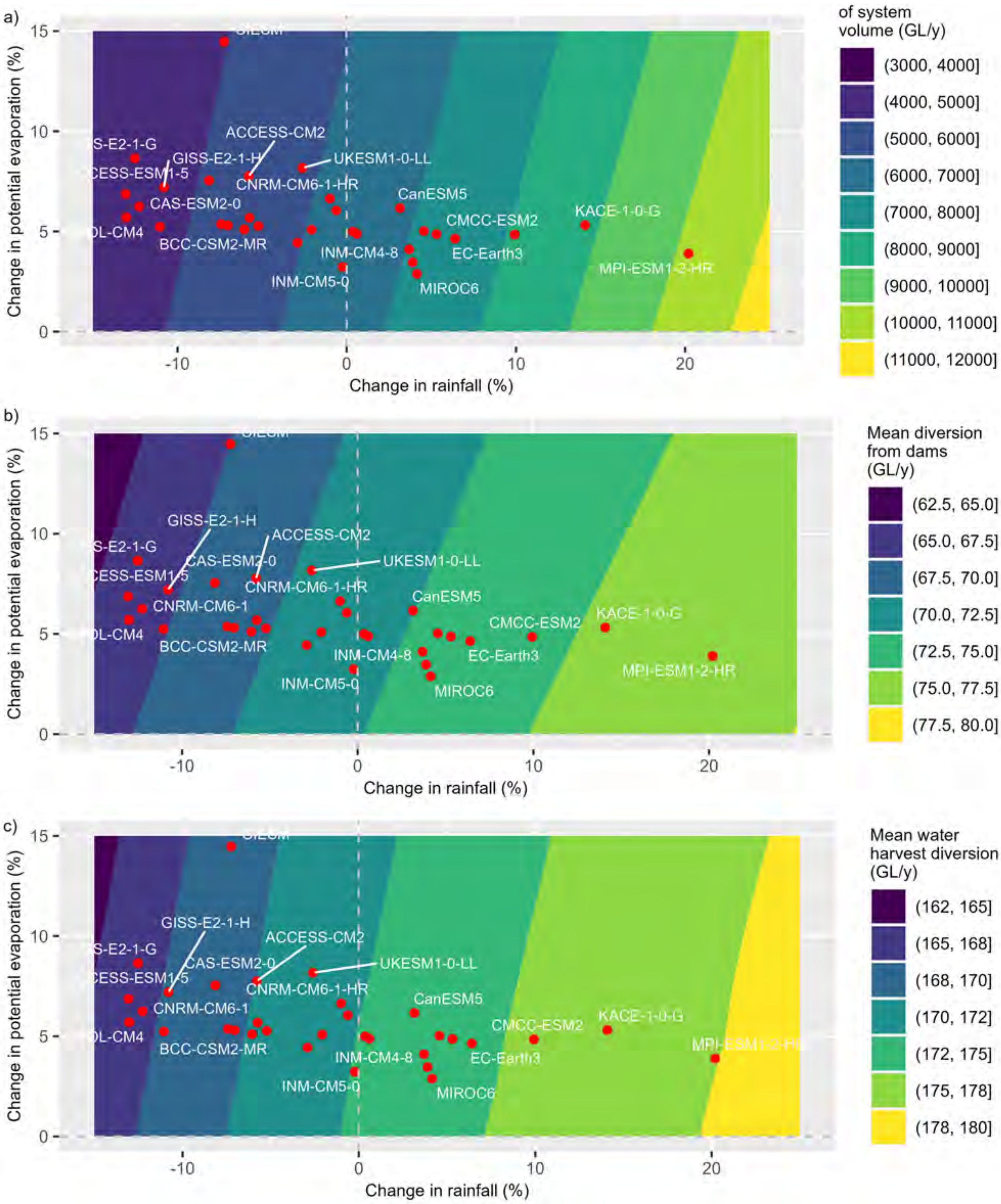

Figure C-1 Sensitivity of the Assessment area (a) end-of-system, (b) dam diversion and c) water harvest diversion volumes to potential changes in rainfall and potential evaporation under Scenario D with hypothetical water harvest

Assuming 150 GL system target volume, 600 ML/day pump start threshold, 10-day pump capacity and ADCFR of 150 GL. Diversion volumes include existing users. Red circles represent annual scaling factors of the 32 CMIP6 GCM under SSP2-4.5 at approximately the year 2060. Dashed grey lines represent no change in rainfall (vertical line) and PET (horizontal line on the *x*-axis).

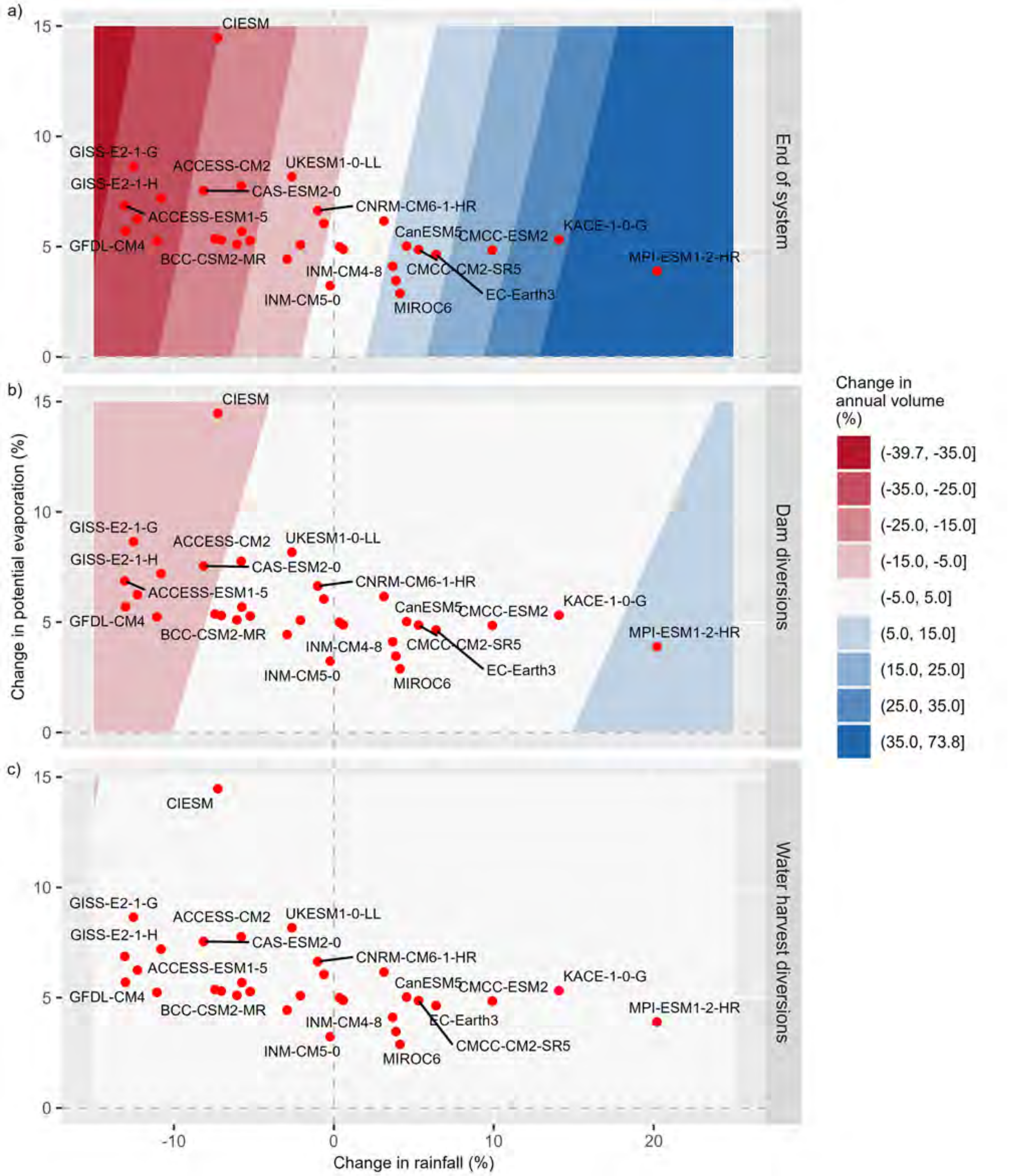

Figure C-2 Sensitivity of the Assessment area (a) end-of-system, (b) dam diversion and c) water harvest diversion volumes to potential changes in rainfall and potential evaporation under Scenario D with hypothetical water harvest, as a percentage change from historical climate

Assuming 150 GL system target volume, 600 ML/day pump start threshold, 10-day pump capacity and ADCFR of 150 GL. Red circles represent annual scaling factors of the 32 CMIP6 GCM under SSP2-4.5 at approximately the year 2060. Dashed grey lines represent the no change in rainfall (vertical line) and PET (horizontal line on the *x*-axis).

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