An investigation into the effects of climate change and groundwater development scenarios on the water resources of the Roper catchment using two finite element groundwater flow models

A technical report from the CSIRO Roper River Water Resource Assessment for the National Water Grid

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Important disclaimer

CSIRO Roper River Water Resource Assessment acknowledgements

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Aspects of the Assessment have been undertaken in conjunction with the Northern Territory Government.

The Assessment was guided by two committees:

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

ii. The Assessment's joint Roper and Victoria River catchments Steering Committee: Amateur Fishermen's Association of the NT; Austrade; Centrefarm; CSIRO, National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Cattlemen's Association; NT Department of Environment, Parks Australia; Parks and Water Security; NT Department of Industry, Tourism and Trade; Regional Development Australia; NT Farmers; NT Seafood Council; Office of Northern Australia; Roper Gulf Regional Council Shire

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 its release.

This report was reviewed by Luk Peeters and Warrick Dawes of 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.

CSIRO would also like to acknowledge useful technical discussions held with Des Yin Foo, Simon Cruickshank and Peter Waugh which partly guided the design of the scenario-based modelling and reporting.

Photo

Late dry-season flow across a tufa dam on the Roper River. Source: Sebastien Lamontagne, CSIRO.

Director’s foreword

Sustainable regional development is a priority for the Australian and Northern Territory governments. Across northern Australia, however, there is a scarcity of scientific information on land and water resources to complement local information held by Indigenous owners and landholders.

Sustainable regional development requires knowledge of the scale, nature, location and distribution of the likely environmental, social and economic opportunities and the risks of any proposed development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpins the resource security required to unlock investment.

In 2019 the Australian Government commissioned CSIRO to complete the Roper River Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to provide data and insight to support consideration of the use of land and water resources for development in the Roper catchment. While the Assessment focuses mainly on the potential for agriculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of regional-scale planning considerations by Indigenous owners, landholders, citizens, investors, local government and the NT and federal governments.

Importantly the Assessment will not recommend one development over another, nor assume any particular development pathway. 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.

Chris Chilcott

Project Director

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Shortened forms

SHORT FORM	FULL FORM
AHD	Australian Height Datum
BC	boundary condition
CLA	Cambrian Limestone Aquifer
DCA	Dook Creek Aquifer
DENR	Department of Environment and Natural Resources (NT)
DEPWS	Department of Environment, Parks and Water Security (NT)
DITT	Department of Industry Tourism and Trade (NT)
DOI	Digital Object Identifier
EPM	equivalent porous media
ET	evapotranspiration
FEFLOW	finite element subsurface flow simulation system
GCM	global climate model
LTWAP	Larrimah Tindall Water Allocation Plan
LWMZ	Larrimah Water Management Zone
MTLWAP	Mataranka Tindall Limestone water allocation plan
MTWAP	Mataranka Tindall Water Allocation Plan
MWMZ	Mataranka Water Management Zone
PET	potential evapotranspiration
SILO	Scientific Information for Land Owners (database of historical climate records)
WCD	water control district
WMZ	water management zone

Units

UNIT	DESCRIPTION
d	day
GL	gigalitre
km	kilometre
L	litre
m	metre
mAHD	metres above Australian Height Datum
mBGL	metres below ground level
s	second
y	year

Preface

Sustainable regional development is a priority for the Australian and Northern Territory governments. For example, in 2023 the NT Government committed to the implementation of a new Territory Water Plan. One of the priority actions announced by the government was the acceleration of the existing water science program ‘to support best practice water resource management and sustainable development’.

The efficient use of Australia’s natural resources by food producers and processors requires a good understanding of soil, water and energy resources so they can be managed sustainably. Finely tuned strategic planning will be required to ensure that investment and government expenditure on development are soundly targeted and designed. Northern Australia presents a globally unique opportunity (a greenfield development opportunity in a first-world country) to strategically consider and plan development. Northern Australia also contains ecological and cultural assets of high value and decisions about development will need to be made within that context. Good information is critical to these decisions.

Most of northern Australia’s land and water resources, however, have not been mapped in sufficient detail to provide for reliable resource allocation, mitigate investment or environmental risks, or build policy settings that can support decisions. Better data are required to 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.

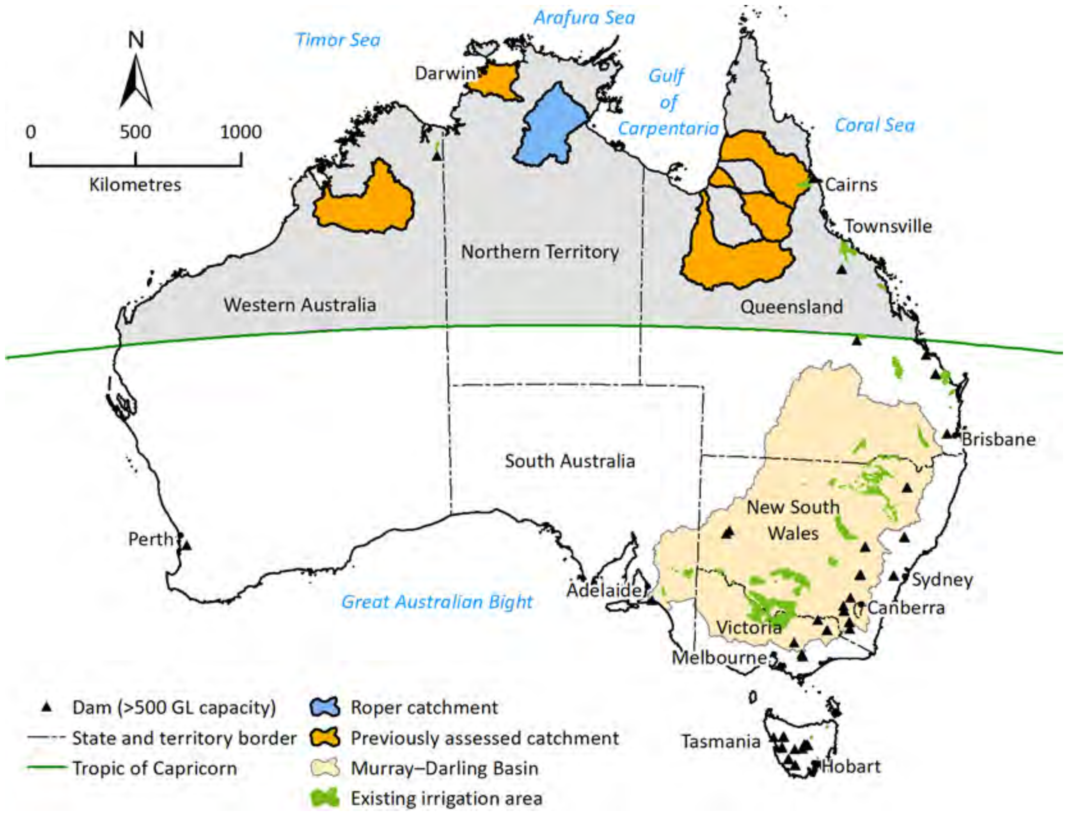
In consultation with the NT Government, the Australian Government prioritised the catchment of the Roper River for investigation (Preface Figure 1-1) and establishment of baseline information on soil, water and the environment.

Northern Australia is defined as the part of Australia north of the Tropic of Capricorn. The Murray–Darling Basin and major irrigation areas and major dams (greater than 500 GL capacity) in Australia are shown for context.

The Roper River Water Resource Assessment (the Assessment) provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development.

While agricultural developments are the primary focus of the Assessment, 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 and urban development and aquaculture, in relevant locations.

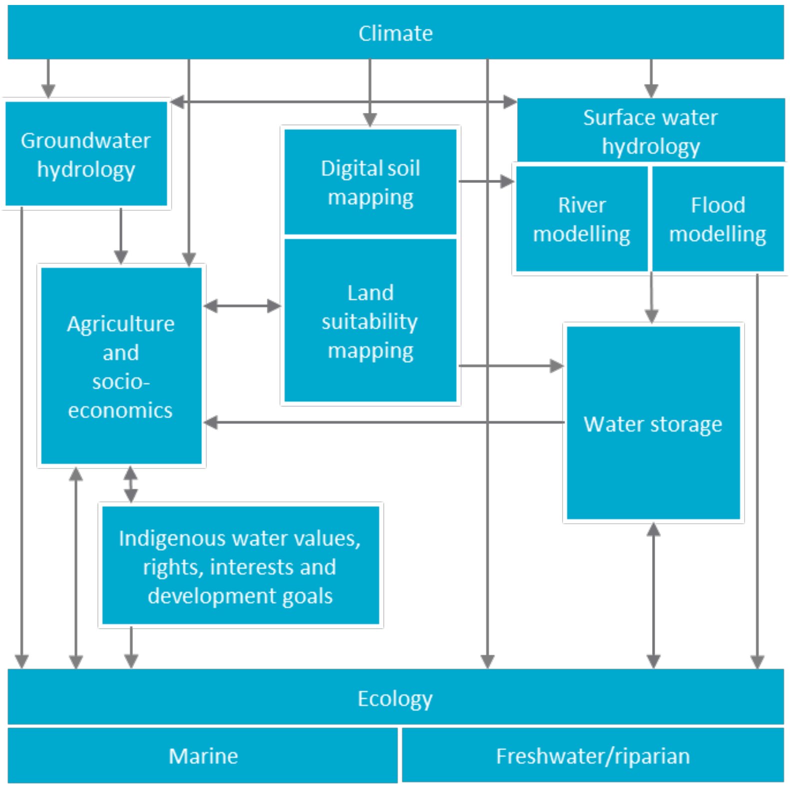
The Assessment was designed to inform consideration of development, not to enable any particular development to occur. As such, the Assessment informs – but does not seek to replace – existing planning, regulatory or approval processes. Importantly, the Assessment does not assume a given policy or regulatory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



Preface Figure 1-1 Map of Australia showing Assessment area

It was not the intention – 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.

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



Preface Figure 1-2 Schematic diagram of the high-level linkages between the eight activities 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 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; that present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the eight activities has one or more corresponding technical report.
- A Catchment report; that for the Roper catchment synthesises key material from the technical reports, providing well-informed (but not necessarily scientifically trained) readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture and other development options.
- A Summary report; that for the Roper catchment provides a summary and narrative for a general public audience in plain English.
- A Summary factsheet; that for the Roper catchment provides key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable the reader to better access information that is not readily available in a static form. All of these reports, information tools and data products are available online at https://www.csiro.au/roperriver. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

Executive summary

Background

The catchment of the Roper River has an area of approximately 77,400 km^2 and lies in the wet–dry tropics of northern Australia. The south-eastern portion of the Roper catchment is underlain by the regional-scale Cambrian Limestone Aquifer (CLA), which extends into the catchment of the Daly River and to the south-west as far as western Queensland. Northern parts of the Roper catchment are underlain by the intermediate-scale Dook Creek Aquifer (DCA). Most rainfall and runoff in the Roper catchment occurs from December to April (inclusive). During the dry season, the CLA and local-scale groundwater systems adjacent to the Roper River have been measured as supplying approximately 4 m^3/second of baseflow to the Roper River through the river bed and springs. Discharge from the CLA to the Roper River occurs in the upper reaches of the river. Groundwater also discharges from the DCA into the northern-most tributaries of the Roper River throughout the dry season. In the Mainoru and Wilton rivers and Flying Fox Creek, baseflow immediately downstream of these waterways' last contact with the DCA was measured to be about <0.1, 0.1 and 0.6 m^3/second, respectively. Groundwater discharge also occurs from discrete points in the landscape at springs (e.g. Top Spring, Lindsay Spring and Weemol Spring), and some diffuse discharge also occurs along portions of the rivers where they are in contact with outcropping sequences of the DCA.

The potential for increased groundwater development from these aquifers within the catchment for irrigation or other land use is likely to increase future demands on groundwater resources. Additional groundwater extraction from the high-transmissivity aquifers could lower groundwater levels and thereby reduce the baseflow of the rivers during the dry season. Groundwater models of each aquifer were used to evaluate the potential impacts of groundwater extraction from the CLA and DCA on groundwater levels and existing water users and groundwater baseflow. This report documents the use of these models and groundwater modelling scenarios investigated.

This study forms part of the CSIRO-led Roper River Water Resource Assessment.

Objectives and scope

The objectives of this modelling investigation were to assess the impacts of changes in rainfall and potential evaporation and/or potential increased groundwater resource development on the streamflow of the upper Roper River and some of its northern tributaries, groundwater levels in the vicinity of existing groundwater developments, and environmental receptors in the Mataranka and Bulman regions. To do this, a variety of scenarios were simulated using both the CLA and DCA groundwater models.

The CLA and DCA are regional-scale and intermediate-scale groundwater systems, respectively, so changes in climate and increases in groundwater extraction can take many hundreds of years to fully propagate through these systems. For this reason, the results are reported over two different time periods. The first involved running the model for 436 years to examine the impacts of changes in climate and increases in groundwater extraction at quasi-equilibrium conditions. (Quasi-equilibrium is used as a much longer time period than used for water resource management but is not run to steady state.) The second time period over which the results were reported involved running the model to 2070 (~50 years). This was considered a pragmatic time period over which to consider the impacts of changes in climate and groundwater extraction because i) it is equivalent to more than twice the length of the investment period of a typical agricultural enterprise; ii) it is about the service life of an appropriately constructed groundwater production bore; iii) it is five times the length of the current period over which NT water licences are assigned; and iv) it is consistent with the time period over which future climate projections have been evaluated. The quasi-equilibrium model runs are designated with a prime (′) to distinguish them from the 50-year trajectory model runs.

The future hypothetical development scenarios were developed where there is: (i) potentially suitable land for agricultural intensification; (ii) a suitable aquifer exhibiting a saturated thickness greater than 20 m; (iii) suitable groundwater quality for irrigation (≤1000 mg/L total dissolved solids (TDS)); (iv) indicative bore yields to suggest sufficient water could be extracted for groundwater-based irrigation (>15 L/s); (v) a threshold drilling depth to intersect the aquifer of less than 200 metres below ground level (mBGL); and (vi) a depth to groundwater of less than 100 mBGL. Each location was placed at a distance of more than 10 km from existing licensed water users and the other hypothetical development locations. The hypothetical developments were deemed large enough to support a viable irrigation enterprise.

The climate sequences and hypothetical development scenarios for the quasi-equilibrium (436 years) conditions are summarised below.

- **Scenario A′, historical climate and current development** – The historical climate from the 109-year period 1910 to 2019 repeated four times to create a 436-year climate sequence of historical climate. Current development of 32 GL of existing licensed extraction in the CLA and 0.1 GL in the DCA were simulated in the models.
- **Scenario B′, historical climate and future hypothetical development** – The same historical climate as Scenario A and three levels of hypothetical future development:
  - For CLA: Scenario B′35 includes the current development (32 GL/year) and an additional 35 GL/year hypothetical future development; Scenario B′70 includes the current development and an additional 70 GL/year of hypothetical future development; and Scenario B′105 includes the current development and an additional 105 GL/year of hypothetical future development.
  - For DCA: Scenario B′6 includes the current development (0.1 GL/year) and an additional 6 GL/year hypothetical future development; Scenario B′12 includes the current development and an additional 12 GL/year of hypothetical future development; and, Scenario B′18 includes the current development and an additional 18 GL/year of hypothetical future development.
- **Scenario C′, future climate and current development** – The same current development as Scenario A′ of 32 GL/year for CLA and 0.1 GL/year for DCA. The 436-year future climate has been created by scaling the Scenario A′ historical climate sequences informed by global climate model (GCM) outputs for dry, median and wet future climates nominally representative of projected 2070 conditions:
  - C′dry corresponds to a 10% reduction in mean annual rainfall and a 10% increase in potential evaporation relative to the historical climate (1910 to 2019).

- C′mid corresponds to a 2% reduction in mean annual rainfall and a 7.5% increase in potential evaporation relative to the historical climate (1910 to 2019).
- C′wet corresponds to a 10% increase in mean annual rainfall and a 5% increase in potential evaporation relative to the historical climate (1910 to 2019).

- **Scenario D′, future climate and future hypothetical development** – Uses the same three 436-year climate sequences as Scenario C′ and the same three levels of future hypothetical development as Scenario B′ for a total of nine variants:
  - For CLA: D′dry35, D′dry70, D′dry105, D′mid35, D′mid70, D′mid105, D′wet35, D′wet70 and D′wet105.
  - For DCA: D′dry6, D′dry12, D′dry18, D′mid6, D′mid12, D′mid18, D′wet6, D′wet12 and D′wet18.

The quasi-equilibrium results are reported relative to a Scenario A′N, which is the historical climate with no groundwater extraction.

To examine representative 2070 conditions, 119 years of historical climate data were used to prime the groundwater model to 2019 and thereafter:

- **Scenario A, historical climate and current development** – An ensemble of 11 × 50-year climate sequences (based on a 50-year sequence starting every 10 years over the 1910 to 2019 historical climate) – nominally representative of conditions to 2070 – and using current development of 32 GL/year of existing licensed extraction in the CLA and 0.1 GL/year in the DCA.
- **Scenario B, historical climate and future hypothetical development** – The same historical climate as Scenario A (ensemble of 11 × 50-year climate sequences) and three levels of hypothetical future development as per the quasi-equilibrium Scenario B′ model runs described above:
  - For CLA: B35, B70 and B105.
  - For DCA: B6, B12 and B18.
- **Scenario C, future climate and current development** – The same current development as Scenario A of 32 GL/year for CLA and 0.1 GL/year for DCA. The ensemble of 11 × 50-year future climate sequences were created by scaling the Scenario A historical climate sequences informed by GCM outputs for dry, median and wet future climates nominally representative of projected 2070 conditions: Cdry, Cmid and Cwet. The scaling factors used were the same as those described above under Scenario C′.
- **Scenario D, future climate and future hypothetical development** – The same three 11 × 50-year climate sequences as Scenario C and the same three levels of future hypothetical development as Scenario B for a total of nine variants:
  - For CLA: Ddry35, Ddry70, Ddry105, Dmid35, Dmid70, Dmid105, Dwet35, Dwet70 and Dwet105.
  - For DCA: Ddry6, Ddry12, Ddry18, Dmid6, Dmid12, Dmid18, Dwet6, Dwet12 and Dwet18.

The representative 2070 results are reported relative to a Scenario AN, which is the historical climate with no groundwater extraction.

Model description

The CLA and DCA groundwater models consist of three-dimensional finite element models developed using FEFLOW (finite element subsurface flow simulation system). The CLA and DCA groundwater models were first developed in 2009, and the CLA model was updated in 2018 (Knapton, 2009; Knapton, 2020). The interaction between groundwater and surface water occurs using the FEFLOW transfer boundary conditions (i.e. 3rd type Cauchy).

The FEFLOW groundwater model for the CLA, referred to as DR2, encompasses an area of approximately 159,000 km^2 and includes the entire extent of the CLA in the Daly Basin, the northern Wiso Basin and northern Georgina Basin.

The DR2 groundwater model was developed with all available river geometry and aquifer data. The DR2 groundwater model was calibrated with all available river flow and groundwater-level data (Knapton, 2020).

The FEFLOW groundwater model for the DCA, referred to as DC2, encompasses an area of approximately 22,220 km^2. It incorporates the entire mapped extent of the unconfined areas of the Dook Creek Formation and includes the entire catchments of Flying Fox Creek, Mainoru River, Wilton River, Guyuyu Creek and Goyder River.

The DC2 groundwater model was developed with available aquifer geometry and aquifer parameter information. The DC2 groundwater model was calibrated to all available river flow and groundwater-level data (Knapton, 2009).

The recharge inputs to both FEFLOW models for all scenarios were generated using the MIKE SHE recharge model (Knapton, 2009; Knapton, 2020).

Reporting areas

For the CLA model reporting, water management zones (WMZs) proposed by the NT Government are considered as they are currently the subject of a proposed water allocation plan: the Mataranka Tindall Limestone water allocation plan (MTLWAP). Water balances have been reported for two WMZs: the Mataranka Water Management Zone (MWMZ) which accounts for the Mataranka North and Mataranka South WMZs and the Larrimah Water Management Zone (LWMZ).

For the DCA, currently there is no water plan or WMZs and groundwater development is relatively low (i.e. Bulman community water supply ~0.1 GL/year).

Reported metrics

For the CLA:

- Water balances are documented for two areas within the model domain – the Mataranka area and Larrimah WMZs, respectively.
- Groundwater levels are documented for six sites: two in the Mataranka area, two in the Larrimah area, one in the south of the Roper catchment and one to the south of the Roper catchment.
- Groundwater discharge is reported at a site along the Roper River at Elsey Homestead (G9030013).

For the DCA:

- Water balances are documented for the portion of the model domain within the Roper catchment.
- Groundwater levels are documented for five sites: two near Flying Fox Creek, one near the Mainoru River and two near the Wilton River and Bulman.
- Groundwater discharge is reported at two sites – one along the upper reach of Flying Fox Creek (G9030108) and the other along the upper reach of the Wilton River (G9030003).

Results

The annual modelled recharge is highly variable in both model domains under the historical period of 1910 to 2019. In the CLA, recharge ranges from 2 to 23,743 GL/year with a mean and median of 995 and 469 GL/year, respectively. In the DCA, recharge ranges from 1 to 1328 GL/year with a mean and median modelled annual recharge of 231 and 138 GL/year, respectively. Under natural conditions this recharge is balanced by discharge as evapotranspiration, spring discharge and baseflow to streams both inside and outside the Roper catchment.

The water balance results for the MWMZ and the LWMZ in the CLA show that increased groundwater extraction will alter groundwater flow paths. Under the quasi-equilibrium no development scenario (A′N) for the MWMZ, inputs from recharge and flow from the north, west and south are balanced by discharge to the atmosphere as evapotranspiration and discharge to the Roper River. Under current levels of development (Scenario A′), discharge due to extraction is balanced by a reduction in discharge via evapotranspiration and discharge to the river. Under the highest simulated level of hypothetical future extraction (Scenario B′105), the increased extraction is outside the MWMZ, but evapotranspiration and discharge to the river are further reduced due to the MWMZ becoming a net exporting zone (compared to a net importing zone without extraction). The LWMZ does not discharge directly to evapotranspiration or streams as the watertable is too deep to interact with features at the land surface. Under natural conditions (Scenario A′N), inputs from recharge are exported out of the zone as lateral flow. At quasi-equilibrium, under all levels of simulated extraction (scenarios A′, B′35, B′70 and B′105), the direction of flow is reversed and the LWMZ becomes a net importing zone.

In DCA under the quasi-equilibrium no development scenario (A′N), inflows through recharge are balanced by discharge to evapotranspiration, rivers, springs and lateral flow out of the Roper catchment. Under the hypothetical future development scenarios (B′6, B′12 and B′18), the increased extraction is balanced by a reduction in all forms of discharge.

Under the dry and mid future climate scenarios, decreased rainfall and increased potential evapotranspiration are projected to result in a reduction in recharge. Under the wet future climate, recharge is projected to increase. These changes to recharge affect groundwater levels under the future climate scenarios. Groundwater levels are projected to decrease under scenarios Cdry and Cmid everywhere across both model domains. The drawdown contours continue to expand under the quasi-equilibrium C′dry and C′mid scenarios, indicating that 50 years is not enough time for either of these aquifers to come to a new equilibrium after a change in stress. Groundwater levels are projected to increase almost everywhere and to continue to increase to quasi-equilibrium under Scenario C′wet.

Changes due to drier or wetter future climates or groundwater extraction are most likely to affect assets of value to the community by changing groundwater discharge to streams, but these effects are unlikely to be noticed immediately due to the time lags involved in the regional groundwater systems. Under Scenario A, groundwater discharge to the Roper River is projected to reduce by 9% at 2070 relative to Scenario AN (Executive summary Table 1-1). Under Scenario B105, groundwater discharge is projected to reduce by 11% relative to Scenario AN. Fifty years is not long enough for the system to come to quasi-equilibrium, with the reduction in discharge projected to be 18% under Scenario B’105. Similar results are seen in Wilton River and Flying Fox Creek, which show a reduction in groundwater discharge of 11% under Scenario B18, increasing to 16% under Scenario B’18 (Executive summary Table 1-1). The largest reductions in groundwater discharge is modelled under Scenario Ddry105: the projected reduction in discharge to the Roper River is 33%, increasing to 66% under Scenario D’dry105. Similar results are seen in the DCA: under Scenario Ddry18 there is a reduction in groundwater discharge to the Wilton River of 34% and Flying Fox Creek of 54%, increasing to 59% and 69%, respectively, under Scenario D’dry18. Scenarios Dmid70 and Dmid12, the less extreme median future climate and medium future development models, see a projection of a reduction in discharge of 21%, 13% and 19% for the Roper River, Wilton River and Flying Fox Creek, respectively, at 2070.

Executive Summary Table 1-1 Change in mean discharge to the Roper River (G9030013) in the Cambrian Limestone Aquifer (CLA) and Wilton River (G9030003) and Flying Fox Creek (G9030108) in the Dook Creek Aquifer (DCA) under current and future climate and development scenarios relative to Scenario A’N

Scenario	Roper River (CLA)	Scenario	Wilton River (DCA)	Flying Fox Creek (DCA)
A (A’)	−9% (−9%)	**A (A’)**	0% (0%)	0% (0%)
B35 (B’35)	−10% (−12%)	**B6 (B’6)**	−3% (−5%)	−3% (−5%)
B70 (B’70)	−10% (−15%)	**B12 (B’12)**	−7% (−11%)	−7% (−11%)
B105 (B’105)	−11% (−18%)	**B18 (B’18)**	−11% (−16%)	−11% (−16%)
Cdry (C’dry)	−30% (−45%)	**Cdry (C’dry)**	−22% (−35%)	−45% (−57%)
Cmid (C’mid)	−19% (−26%)	**Cmid (C’mid)**	−6% (−8%)	−12% (−15%)
Cwet (C’wet)	+4% (+10%)	**Cwet (C’wet)**	+22% (+33%)	+54% (+66%)
Ddry35 (D’dry35)	−31% (−52%)	**Ddry6 (D’dry6)**	−26% (−42%)	−48% (−62%)
Ddry70 (D’dry70)	−32% (−59%)	**Ddry12 (D’dry12)**	−30% (−50%)	−51% (−66%)
Ddry105 (D’dry105)	−33% (−66%)	**Ddry18 (D’dry18)**	−34% (−59%)	−54% (−69%)
Dmid35 (D’mid35)	−20% (−31%)	**Dmid6 (D’mid6)**	−9% (−14%)	−16% (−20%)
Dmid70 (D’mid70)	−21% (−37%)	**Dmid12 (D’mid12)**	−13% (−19%)	−19% (−26%)
Dmid105 (D’mid105)	−22% (−44%)	**Dmid18 (D’mid18)**	−17% (−26%)	−23% (−31%)
Dwet35 (D’wet35)	+3% (+7%)	**Dwet6 (D’wet6)**	+19% (+29%)	+51% (+62%)

Scenario	Roper River (CLA)	Scenario	Wilton River (DCA)	Flying Fox Creek (DCA)
Dwet70 (D'wet70)	+3% (+4%)	**Dwet12 (D'wet12)**	+16% (+24%)	+48% (+58%)
Dwet105 (D'wet105)	+2% (+2%)	**Dwet18 (D'wet18)**	+13% (+19%)	+45% (+54%)

A/A' = Historical climate and current development; B6/B'6 = Historical climate and future development of 6 GL/year; B12/B'12 = Historical climate and future development of 12 GL/year; B18/B'18 = Historical climate and future development of 18 GL/year; Cdry/C'dry = Future dry climate sequences current development; Cmid/C'mid = Future mid climate sequences current development; Cwet/C'wet = Future wet climate sequences current development; Ddry6/D'dry6 = Future dry climate sequences current development and future development of 6 GL/year; Ddry12/D'dry12 = Future dry climate sequences current development and future development of 12 GL/year; Ddry18/D'dry18 = Future dry climate sequences current development and future development of 18 GL/year; Dmid6/D'mid6 = Future mid climate sequences current development and future development of 6 GL/year; Dmid12/D'mid12 = Future mid climate sequences current development and future development of 12 GL/year; Dmid18/D'mid18 = Future mid climate sequences current development and future development of 18 GL/year; Dwet6/D'wet6 = Future wet climate sequences current development and future development of 6 GL/year; Dwet12/D'wet12 = Future wet climate sequences current development and future development of 12 GL/year; Dwet18/D'wet18 = Future wet climate sequences current development and future development of 18 GL/year. A'N/AN = Historical climate and no development; B35/B'35 = Historical climate and future development of 35 GL/year; B70/B'70 = Historical climate and future development of 70 GL/year; B105/B'105 = Historical climate and future development of 105 GL/year; C'dry/Cdry = Future dry climate sequence with current development; C'mid/Cmid = Future mid climate sequence with current development; C'wet/Cwet = Future wet climate sequence with current development; D'dry35/Ddry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; D'dry70/Ddry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; D'dry105/Ddry105 = Future climate sequences with current development and additional future development of 105 GL/year; D'mid35/Dmid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; D'mid70/Dmid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; D'mid105/Dmid105 = Future mid climate sequences with current development and additional future development of 105 GL/year; D'wet35/Dwet35 = Future wet climate sequences with current development and additional future development of 35 GL/year; D'wet70/Dwet70 = Future wet climate sequences with current development and additional future development of 70 GL/year; D'wet105/Dwet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.

Conclusions

Two groundwater flow models were used to examine the effects of scenarios encompassing climate change and groundwater development on the water resources of the Roper River. From this analysis, the following key findings have emerged:

- Recent climate conditions have led to significantly higher recharge than the long-term mean.
- Using the historical climate to simulate the future climate to 2070, the mean annual water balances and mean discharge to the Roper River in the MWMZ suggest that extractions under the current allocations will result in a reduction of 9% relative to no extractions. Current extractions in the DCA are minimal and so have a negligible impact on streamflow.
- Hypothetical future groundwater developments under the historical climate will result in further reductions in discharge from the CLA to the Roper River and will reduce discharge from the DCA to the Wilton River and Flying Fox Creek.
- The extensive spatial coverage, thickness, and variable hydraulic properties of the two karstic groundwater systems significantly influence the time lags for hydrological impacts of both climate variability and groundwater extraction to propagate through each system. The full impacts of changes in stresses on the aquifer systems, caused by extraction or long-term changes in climate, are only partially evident after 50 years, and these groundwater systems require hundreds of years to reach a state of quasi-equilibrium.
- Increased groundwater extraction does not linearly correspond to a proportional decrease in groundwater discharge to rivers, especially in the case of the CLA. In the case of the CLA, this is because a large proportion of groundwater extraction is 'buffered' by reductions in discharge to evapotranspiration, capture of groundwater to the south-east of LWMZ and capture of

groundwater throughflow that would otherwise flow downgradient from the MWMZ and LWMZ.

- The potential impact of climate variability on water resources in the Roper catchment is more significant than that of current groundwater extraction due to the influence of climate on the spatial and temporal variability in groundwater recharge.
- Future climate projections range from an increase in recharge under a wetter future climate to a reduction in recharge under the median and dry future climates.
- Under the dry and median future climates, any hypothetical future development will lead to further reductions in discharge to the Roper River, Wilton River and Flying Fox Creek. Under Scenario Dwet, small increases in groundwater discharge to the Roper River are projected and a much greater increase in discharge to the Wilton River and Flying Fox Creek.

Contents

Figures

Tables

1 Introduction

1.1 Background

The Cambrian Limestone Aquifer (CLA) and Dook Creek Aquifer (DCA) are the two largest, most productive and potentially most promising aquifers for future groundwater-based development within and beneath the catchment of the Roper River (Bruwer and Tickell, 2015; Taylor et al., 2023; Tickell and Bruwer, 2018; Zaar and Tien, 2003). Parts of these aquifers coincide with land recently identified as potentially suitable for agricultural intensification (Thomas et al., 2023). To better understand the potential opportunities and risks associated with future groundwater resource development, water resource modelling was undertaken to provide new information that could potentially help inform future water resource planning, investment and management across parts of the CLA and DCA considered potentially suitable for groundwater-based irrigation. CSIRO engaged CloudGMS Pty Ltd to run, process and evaluate the results of multiple future hypothetical groundwater development and climate scenarios using existing finite element groundwater models of the CLA and DCA, respectively. This study is part of the Roper River Water Resource Assessment (RoWRA), which was commissioned by the Australian Government.

The specific objectives of this modelling investigation were to model the impacts of changes in rainfall and potential evaporation and hypothetical development of groundwater resources on the availability of groundwater for environmental requirements of surface water resources and existing licensed water users in key parts of the Roper catchment. The climate data used as input to the groundwater models was sourced from climate analyses undertaken in a companion technical report on the climate of the Roper catchment (McJannet et al., 2023). The locations for future hypothetical groundwater development were identified from analyses undertaken in a companion technical report on a hydrogeological assessment of both the CLA and DCA (Taylor et al., 2023).

Although metrics are reported for streamflow, hypothetical surface water developments are not considered in this report. Presently there are very few surface water extraction licences (DEPWS, 2018). However, a companion technical report on river system modelling by Hughes et al. (2023) provides scenario-based modelling of hypothetical surface water development and its potential impacts on changes in streamflow.

A companion technical report on ecological assets in the Roper catchment (Stratford et al., 2022) identified potential ecological assets in the Roper catchment that may be susceptible to changes in streamflow and groundwater levels. A second companion technical report on ecological modelling in the Roper catchment (Stratford et al., 2023) evaluated how changes in streamflow characteristics (including changes in baseflow arising from changes in groundwater discharge) may result in changes to flow dependencies of ecological assets in the Roper catchment.

The report is structured as follows. Chapter 2 provides an overview of the Roper catchment relevant to the groundwater modelling of the CLA and DCA. In Chapter 3, the numerical groundwater models used to represent groundwater flow in the CLA and DCA are described, followed by an outline of the scenario modelling approach in Chapter 4. The results of the quasi-equilibrium scenario modelling for the CLA are presented in Chapter 5, and Chapter 6 delves into the scenario modelling results for the CLA projected to 2059 to 2069. Chapter 7 presents the results of the quasi-equilibrium scenario modelling for the DCA, and Chapter 8 presents the scenario modelling outcomes for the DCA projected to 2059 to 2069. Finally, Chapter 9 presents a summarised overview of the key findings and conclusions drawn from the entire scenario modelling process.

2 Catchment overview

2.1 Location of the Roper catchment

The Roper catchment is in the wet–dry tropics of northern Australia approximately 300 to 400 km south-east of Darwin, the capital of the NT (refer to Figure 2-1).

The Roper River starts as Roper Creek (also called Little Roper River) and becomes the Roper River downstream of the Waterhouse River junction near Mataranka. The Elsey Creek system drains the large Sturt Plateau region, which is in the south-west of the catchment The Arnhem Land Plateau, rising to 440 m, and the Wilton River Plateau are located in the north of the catchment and consist predominantly of Kombolgie sandstone. The middle section of Roper River consists of a highly braided river channel. The Roper River flows generally in an easterly direction, although the geology of the catchment influences the direction of the drainage systems. The normal tidal limit of the Roper River is at Roper Bar Crossing (20 km upstream from Ngukurr). Below this crossing, the Roper River traverses the alluvial coastal plain eastward for 145 km before entering the Gulf of Carpentaria (CSIRO, 2009).

The connected Daly, Wiso and Georgina groundwater basins underlie the south-west of the Roper catchment. The basins have strong similarities in terms of their stratigraphy and architecture. The Wiso Basin underlies the most western part of the south-west portion of the catchment. The Palaeozoic platform succession is generally less than 300 m thick. The Daly Basin underlies the northern part of the south-west portion of the Roper catchment and is a north-west-trending intracratonic sedimentary basin up to 700 m thick. It contains the lower Palaeozoic Daly River Group comprising, in ascending order, the marine Tindall Limestone, mixed peritidal Jinduckin Formation and carbonate peritidal Oolloo Dolostone. The Tindall Limestone usually rests disconformably on the Lower Cambrian Antrim Plateau Volcanics and is the most prominent unit present in the Daly Basin beneath the Roper catchment. The Georgina Basin occurs in the south-eastern part of the south-west portion of the Roper catchment and contains a relatively thin stratigraphic succession, up to 450 m thick. It is deposited on a tectonically quiescent platform. Deposition in the central part of the basin commenced with a marine transgression in the early Middle Cambrian and may have extended into the Late Cambrian. The northern Georgina Basin is largely concealed beneath Cretaceous sediments (CSIRO, 2009).

The McArthur Basin, which underlies the central northern and eastern parts of the Roper catchment, is a Palaeoproterozoic to Mesoproterozoic intracratonic sedimentary basin comprised mostly of folded and faulted sandstones, siltstones and dolostones that in some places have been intruded by minor igneous rocks (Ahmad et al., 2013). The McArthur Basin has a maximum thickness of about 10 km and is bound to the north by the Arafura Basin and east by the Gulf of Carpentaria (Ahmad et al., 2013). It contains, in ascending order, the Palaeoproterozoic Katherine River Group and the Mesoproterozoic Mount Rigg and Roper Groups. The Katherine River Group is mostly comprised of the Kombolgie Subgroup. The Mount Rigg Group is mostly comprised of the Dook Creek Formation, and the Roper Group is comprised of a series of stacked sandstones interbedded with siltstones.

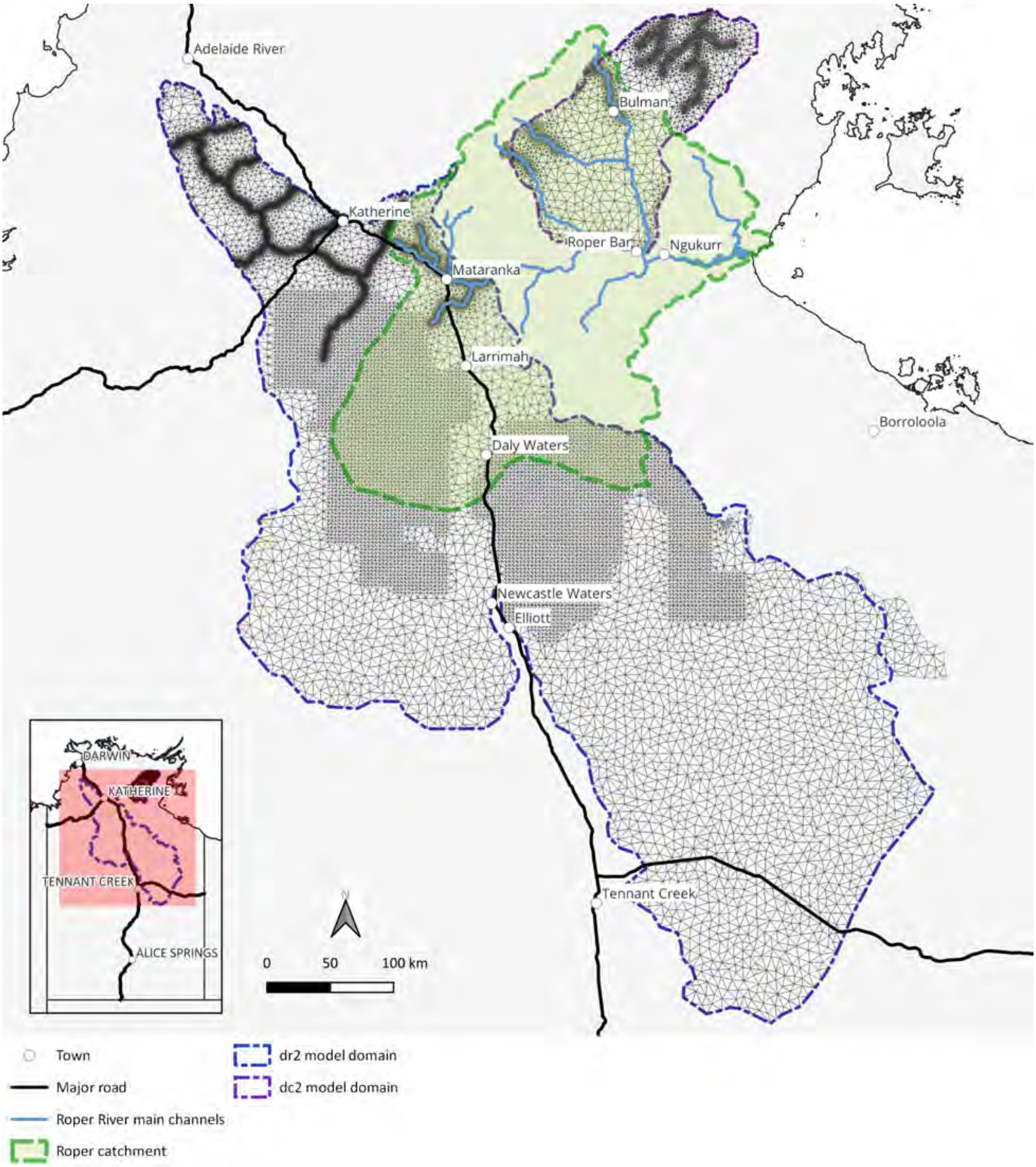


Figure 2-1 Location of the Roper catchment and its relationship to the groundwater systems of the Dook Creek Aquifer and the Cambrian Limestone Aquifer extending beyond the Roper catchment boundaries

2.2 Roper River

2.2.1 Flow regime

The Roper River is a perennial river with a catchment area of approximately 77,400 km^2. The river has a distinct seasonal flow regime of high-water levels and discharges during the wet season (November to April) and much lower water levels and discharges towards the end of the dry season (which is May to October). Several rivers and streams within the Roper catchment have persistent streamflow or baseflow, due to groundwater discharge from regional aquifers. Approximately 5 to 10% of the total annual runoff in the Roper catchment is baseflow.

The dry-season baseflow of the Roper River is sourced from the regional carbonate aquifers of the Daly and Georgina basins. The headwaters of the Roper River are incised into the Tindall Limestone. The limestone aquifers in the Daly Basin supply approximately 4 m^3/second of baseflow to the Roper River (Jolly et al., 2004).

Dry-season discharge from the upper Waterhouse Creek is between less than 0.01 and 1.0 m^3/second at G9030089. Discharge to the upper reaches of the Waterhouse Creek is sourced from Cretaceous sediments of sands, clayey sands and clay. The downstream reaches of the Waterhouse River incise into Tindall Limestone of the CLA where Rainbow Spring contributes 0.2 to 0.5 m^3/second (Jolly et al., 2004).

Groundwater also discharges from the DCA, providing dry-season baseflow to the tributaries of the Roper River: about <0.1 m^3/second at Mainoru River, 0.1 m^3/second at Wilton River and 0.6 m^3/second at Flying Fox Creek (George, 2001).

2.2.2 Groundwater contribution to surface flow

The major aquifers occurring beneath and beyond the Roper catchment are in the Tindall Limestone, Dook Creek Formation and Cretaceous sediments, and these are the primary source of dry-season flow in the perennial rivers of the Roper catchment (Kerle and Cruickshank, 2014; Wagenaar and Tickell, 2013; Waugh and Kerle, 2014).

Groundwater contributions to flow in the Roper River are clearly observed in the signal from the rated gauging stations located along the upper reaches of the Roper River. The exponential regressions of dry-season flows are evident as straight lines when plotted on a logarithmic scale representing typical storage characteristics of the karstic features in CLA close to Mataranka (Figure 2-2).

Groundwater discharge from the DCA provides the dry-season flow for the Mainoru and Wilton rivers and Flying Fox Creek. Discharge also occurs via preferential discharge through discrete springs (e.g. Top Spring, Lindsay Spring and Weemol Spring), and some diffuse discharge also occurs along portions of some of the rivers (Zaar and Tien, 2003).

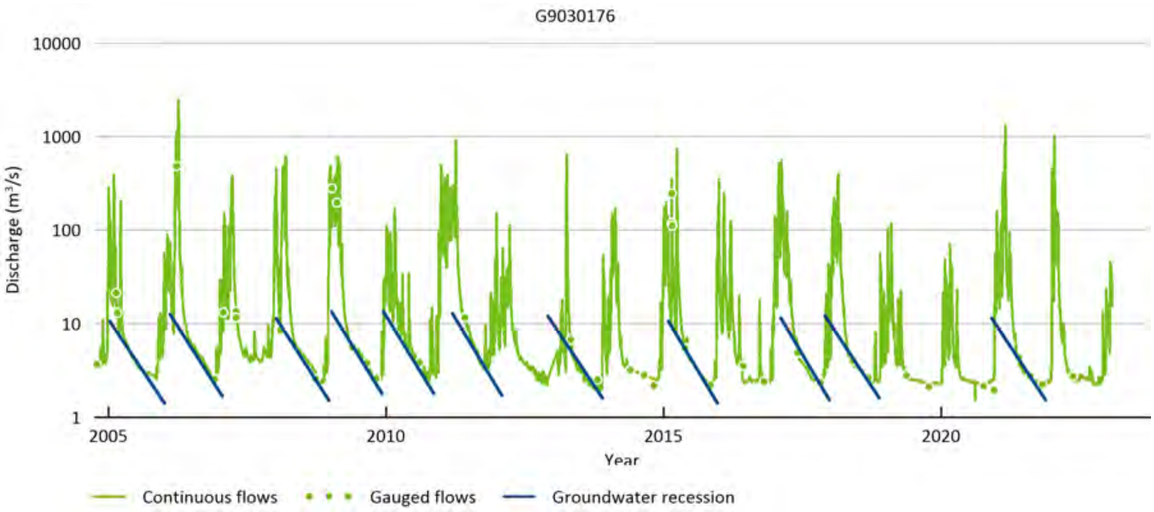


Figure 2-2 Demonstration of exponential regression of dry-season flows at G9030176 (Elsey National Park)

2.2.3 Surface water – groundwater connectivity

Surface water – groundwater connectivity is strongly controlled by the prevailing geological conditions. Regions where the carbonate sediments outcrop exhibit high connectivity with the rivers. Connectivity occurs via features associated with the karstic carbonate rocks of the Tindall Limestone and Dook Creek Formation. However, connectivity between the rivers and aquifers is reduced in areas where Cretaceous sediments overlie the CLA or where the Limmen Sandstone overlies the Dook Creek Formation. Areas with high connectivity between the surface water and groundwater are shown in Figure 2-3.

Perennial streamflow in the Roper River headwaters is fed by groundwater discharge from the CLA that originated as: (i) recharge and throughflow both within as well as from outside the Roper catchment, and (ii) localised recharge in the northern aquifer outcrops adjacent to streams (Bruwer and Tickell, 2015; Karp, 2008; Knapton, 2020; Tickell and Bruwer, 2018). The DCA, however, receives recharge in the outcropping–subcropping zone within the Roper catchment between Flying Fox Creek and Bulman. Groundwater recharged within the Roper catchment also contributes baseflow to other perennial rivers outside the Roper catchment in both the Daly and McArthur basins (Knapton, 2009, 2020; Williams et al., 2003; Zaar and Tien, 2003).

2.3 Hydrogeology

The Roper catchment has three major aquifer types: fractured rocks, Cretaceous sediments and karstic carbonate rocks. The karstic carbonate rocks are the Tindall Limestone and its equivalents (the Montejinni Limestone in the Wiso Basin and the Gum Ridge Formation in the northern part of the Georgina Basin); Jinduckin Formation and its equivalent (the Anthony Lagoon Beds in the northern part of the Georgina Basin); and Dook Creek Formation. The catchment’s formations are briefly described below, and their areal extent is shown in Figure 2-3.

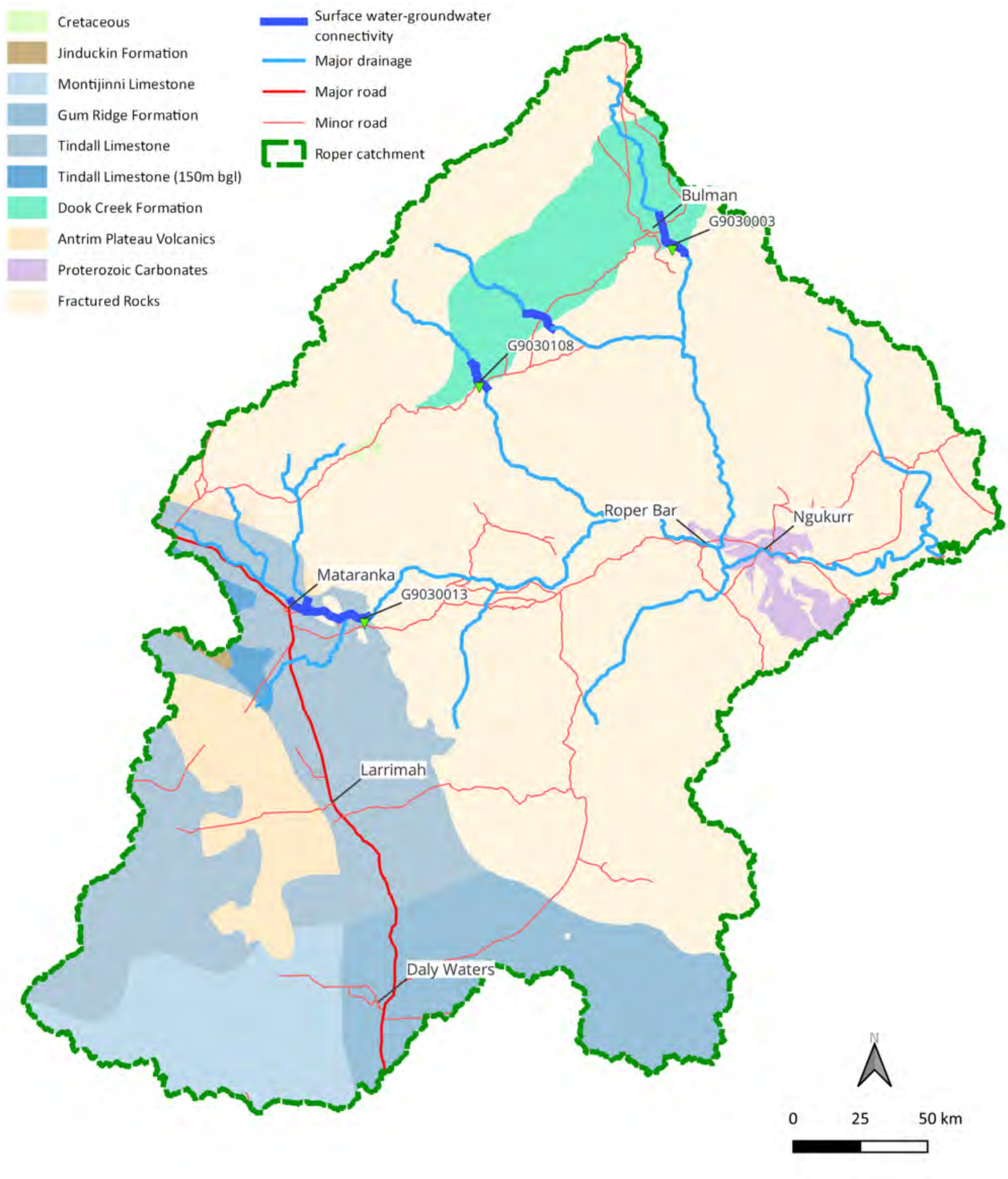


Figure 2-3 Hydrogeology of the Roper catchment and areas with high surface water – groundwater connectivity

The major hydrogeological feature in the southwest of the Roper catchment comprises the Cambrian–Ordovician southern Daly Basin, the northern Wiso Basin and the northern Georgina Basin. These basins host the CLA, which comprises the Tindall Limestone / Gum Ridge Formation / Montejinni Limestone and the Jinduckin Formation / Anthony Lagoon Beds. Early Cretaceous rocks overlie much of the Cambrian rocks (refer to Figure 2-3). Hydrogeological mapping of the Daly Basin, northern Georgina Basin and northern Wiso Basin is presented by Tickell (2005) and Bruwer and Tickell (2015). Mapping of the southern Georgina Basin to the Wonarah High is presented by Tickell and Bruwer (Tickell and Bruwer, 2018).

The major hydrogeological feature in the north of the Roper catchment comprises the Mesoproterozoic carbonates of the Dook Creek Formation.

Table 2-1 summarises the important hydrogeological units or hydrostratigraphy relevant to the Roper catchment.

Table 2-1 Hydrostratigraphic units of the Roper catchment

FORMATION	DISCHARGE	FORMATION CHARACTER	TRANSMISSIVITY RANGE (m^2/d)	STORAGE COEFFICIENT
Mesoproterozoic Dook Creek Formation	Wilton and Mainoru rivers and Flying Fox Creek	Karstic dolostone	600–7000	0.01–0.04
Cambrian Limestone Aquifer	Roper, Katherine, Flora, Douglas and Daly rivers	Karstic limestone	2000–5000	0.01–0.04
Jinduckin Formation / Anthony Lagoon Beds	NA†	aquitard	<100	0.001

†NA = not available.

2.3.1 Fractured rocks

A variety of Precambrian (older than 500 million years) rocks form the bedrock of the Roper catchment. These are mainly sedimentary but also include granite and volcanic rocks. Sandstone, siltstone and greywacke are the main sedimentary rock types. In some areas they are flat lying while in other areas they have been folded and faulted and show low-grade metamorphism.

In the Early Cambrian (500 million years ago), volcanic eruptions produced an extensive sheet of basalt flows, now known as the Antrim Plateau Volcanics of the Kalkarindji Igneous Province. These underlie the Daly, Wiso and Georgina basins.

Water is usually intersected in weathered fractured zones within the fractured rocks. Groundwater yields are controlled by the degree of fracturing of these units and are likely to be greater in areas located along large-scale joints and fault zones.

2.3.2 Karstic carbonate rock – Tindall Limestone / Gum Ridge Formation / Montejinni Limestone, Jinduckin Formation / Anthony Lagoon Beds and Mesoproterozoic carbonates (includes the Dook Creek Formation)

The major aquifers in beneath and extending beyond the Roper catchment occur within the carbonate rocks of the Daly and Georgina basins. These carbonate rocks are part of an extensive area that extends across a large part of the NT and into Queensland. The Tindall Limestone and its equivalents (the Montejinni Limestone in the Wiso Basin and the Gum Ridge Formation in the northern part of the Georgina Basin) host widespread karstic aquifers. These aquifers have very high permeabilities due to an extensive network of interconnected solution cavities and are referred to as the Cambrian Limestone Aquifer (CLA).

The Jinduckin Formation (and its equivalent, the Anthony Lagoon Beds in the northern part of the Georgina Basin) is mainly composed of siltstone. The formation contains thin, local aquifers in isolated limestone beds.

The aquifers of the CLA are typical of karstic aquifers where chemical weathering has produced widespread secondary porosity and permeability in the carbonates. The carbonate aquifers are expected to have greatest permeability within the weathered zone, up to a maximum of 200 m below the top of the formation. The karstic nature of the aquifers means that on a local scale groundwater flow is via preferential pathways. However, on a basin-wide scale the aquifers are considered to behave as an equivalent porous medium with very high transmissivities and a relatively low storage coefficient.

Lauritzen and Karp (1993) concluded that the Tindall Limestone karst aquifer developed before the Cretaceous period. The permeability of the karst aquifer has been further enhanced since then by the movement of acidic groundwater from the aquifer developed in the basal Cretaceous sandstone where it overlies the limestone.

The CLA karst aquifer is the main contributor to dry-season flow in the Roper River. The CLA is the aquifer of most interest to irrigators as it occurs beneath land suitable for irrigation and can yield high flow rates (greater than 50 L per second per bore) from relatively shallow depths.

The bulk of the Jinduckin Formation / Anthony Lagoon Beds is shale and siltstone with little fractured porosity. Minor cavernous and fractured rock aquifers are developed in the thicker dolostone beds. The Jinduckin Formation confines the CLA, and it is in these areas that the groundwater is considered to be ‘dead water’, with the majority of the inputs and outputs of the system occurring in the unconfined regions of the CLA at the edges of the Georgina Basin (Tickell and Bruwer, 2018).

The Mesoproterozoic Dook Creek Formation of the McArthur Basin is described as a dololutite, dolomitic sandstone and siltstone, stromatolitic and oolitic dolostone, chert, quartz sandstone, conglomerate, mudstone and siltstone. For the purposes of this Assessment, this formation is assumed to be represented as a single, extensive aquifer system and is referred to as the Dook Creek Aquifer (DCA).

The DCA has been intensely weathered and silicified to a depth of 20 m because of pre- and post-Cretaceous weathering. The outcropping and subcropping areas of the DCA is paralleled by a belt of sinkholes that developed in the carbonates because of the deep weathering (Sweet et al., 1999). The Dook Creek Formation is confined to the south-east by the Limmen Sandstone.

The DCA contributes significant dry-season flow to the upper reaches of the Wilton and Mainoru rivers and Flying Fox Creek, all of which are tributaries of the Roper River. Water supplies for Bulman and its neighbouring outstations are sourced from bores drilled into the DCA. Several large springs emanate from this aquifer (e.g. at Weemol).

Pumping tests conducted in the DCA have been completed in the Beswick and the Bulman areas. Both reports indicate that the transmissivity of the aquifer can be substantial with estimates averaging 700 m^2/day in the Beswick study (Yin Foo, 1983) and of the order of 6000 m^2/day in the Bulman study (Verma and Rowston, 1991). Both studies found that the high transmissivities are associated with secondary permeability developed in fault zones. The studies do, however, highlight that under suitable conditions high transmissivities can be expected in the DCA. Where extensive, this aquifer type has the potential to supply quite large amounts of water. Individual bore yields of up to 10 L/second are expected, although bores can be unsuccessful if cavities are not intersected. Drilling depths may be up to 80 m, depending on the local occurrence of suitable cavities (George, 2001).

2.3.3 Cretaceous sediments

The Cretaceous sediments form a mantle of lateritised claystone and sandstone covering much of the area. In Figure 2-3, the sediments have only been mapped where they are expected to form the major aquifer at that locality. However, the sediments overlay the karstic rock aquifers within and beyond the Roper catchment The beds are sub-horizontal and may be divided into an upper claystone and siltstone unit and a basal sandstone unit. Outcrop is generally sparse due to the soft nature of the rock but in places silicification has changed the outcrops to porcellanite and quartzite.

In the Wiso and Georgina basins, the formation may be up to 75 m thick with the clayey upper unit comprising 60 m of its thickness. The thickness of the sandy unit is variable and ranges from less than 5 m up to 25 m. Where the upper claystone is thin and eroded, the potential recharge to the underlying limestone aquifer is increased. In most places within the basins, the sediments lie above the regional water level.

The main influence of the Cretaceous sediments is to reduce the recharge to the CLA. The effect of reduced recharge is based on the lithology of the unit, which is predominantly clay / clayey sand and the subdued response of groundwater hydrographs for the bores located in areas where Cretaceous rocks cover the underlying carbonate aquifer.

2.4 Water management zones

In 2023, two water management zones (WMZs) within the Roper catchment are proposed under the NT Government’s Mataranka Tindall Limestone water allocation plan (DENR, 2017).

The first is the Mataranka Water Management Zone (MWMZ), in which north and south portions will be established to oversee the management of the water resources in the unconfined Tindall Limestone portion of the CLA where major groundwater recharge and discharge to the Roper River occurs. Groundwater in the CLA is sourced for large-scale irrigated agricultural developments in the Mataranka area, posing a significant risk to the ecology of the nearby Elsey National Park and the flow from the iconic Mataranka Hot Springs complex. Within the MWMZ are currently 18 licences totalling 23.8 GL/year (DEPWS, 2018).

The second is the Larrimah Water Management Zone (LWMZ), which will be established to oversee the management of water resources of the CLA to the south-east of the MWMZ and centred around Larrimah. The water allocation plan for this zone is currently under development. The extents of the two WMZs used to calculate groundwater balance information are presented in Figure 2-4. Within the LWMZ are currently 4 licences totalling 8 GL/year (DEPWS, 2018).

Currently there is no water management zone for the DCA and groundwater development is relatively low (i.e. Bulman community water supply using ~0.1 GL/year).

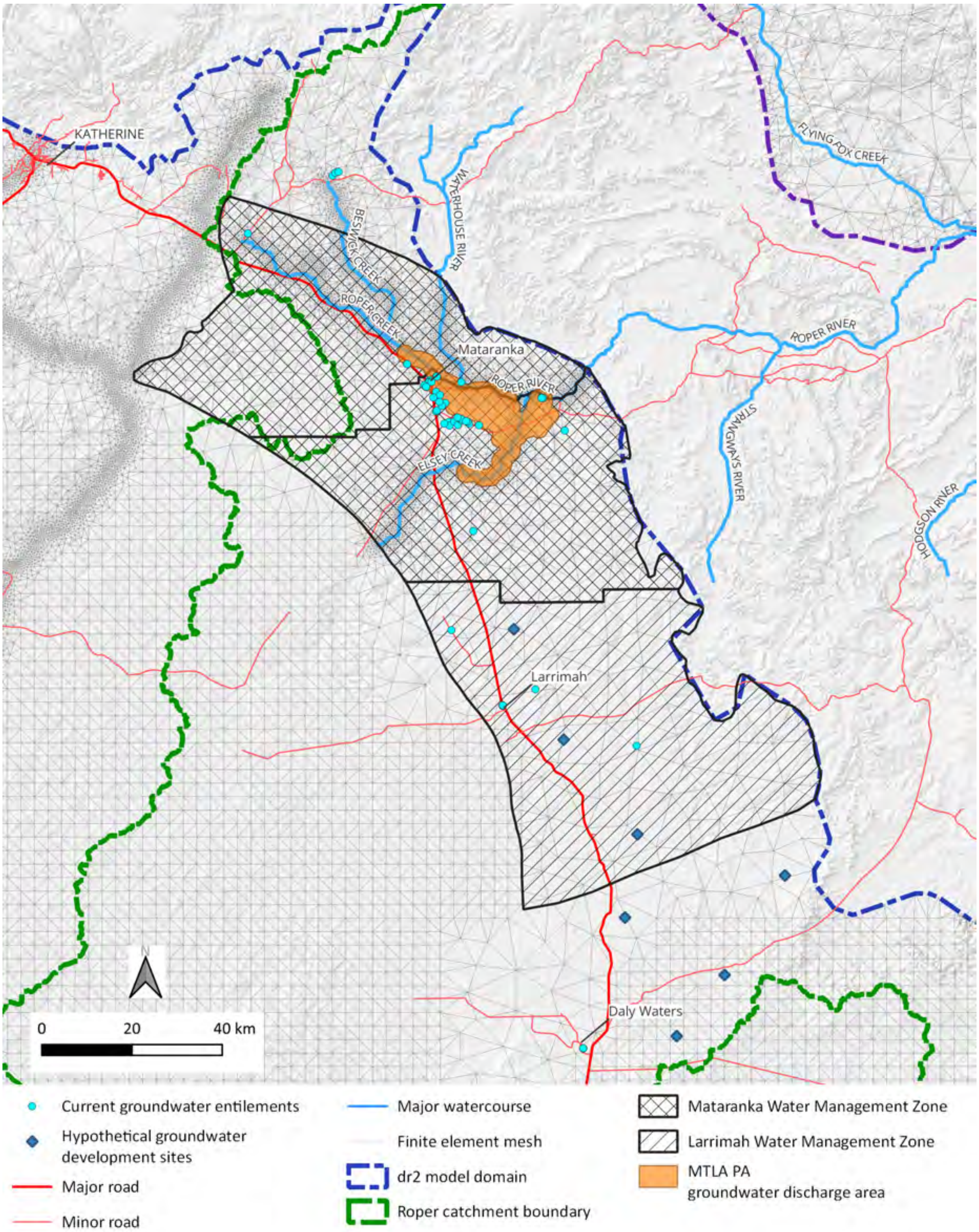


Figure 2-4 Water allocation plan management zones within the Roper catchment and positions of existing entitlements and future hypothetical groundwater developments

3 Groundwater flow model descriptions

3.1 Introduction

The groundwater flow in the CLA is modelled using the DR2 groundwater flow model as detailed in Knapton (2020), and the groundwater flow in the DCA is modelled using the DC2 groundwater flow model detailed in Knapton (2009). The two groundwater flow models are summarised in the following sections.

3.2 Previous modelling

Previous studies of groundwater modelling of the aquifers of the Roper River include groundwater modelling of the Tindall Limestone in the area of the Katherine River (Puhalovich, 2005; Water Studies, 2001) and groundwater modelling of the CLA of the Daly, Georgina and Wiso basins, the original flow model being referred to as 'DR1' (Knapton, 2006).

Knapton (2009) documented the recalibration of the DR1-coupled Daly catchment model and investigated the effects of future climate predictions and groundwater extraction development scenarios on groundwater levels and river flows as part of the Northern Australia Sustainable Yields Project (CSIRO, 2009).

The DR1 model was updated to facilitate the coupling of the Roper River (Knapton, 2009). This updated model is referred to as 'DR2'. Knapton (2020) documents the details of the recalibration of the DR2 groundwater flow model and the coupled Roper catchment model.

Knapton (2009) also details the development of a groundwater model of the DCA. The DCA system provides baseflow to the major tributaries to the north of the Roper River, namely Flying Fox Creek, Mainoru River, Wilton River and the Blyth and Goyder rivers, which drain north to the Arafura Sea.

The existing model conceptualisation and calibration of the DR2 and DC2 models are used in the current simulations (Table 3-1).

Table 3-1 Summary of existing DR2 and DC1 model development

	DR2	DC2
Area (km²)	159,000	22,220
Model layers	4	3
Elements (per layer)	46,197	NR†
Calibration period	1900–2018	1960–1988
GWL observation points	1713	8
Discharge observation points	6	5
Sy (-)	0.04	0.01
Ss (-)	1.00E-06	1.00E-04

	DR2	DC2
k (m/d)	0.100 to 572	0.000864 to 30.0
RMS error (m)	12.2	NR
Scaled RMS (%)	5	NR

GWL = groundwater level. Sy = specific yield. Ss = specific storage. K = hydraulic conductivity. RMS – root mean square.
†NR = not reported.

3.3 Conceptual models

The major aquifers in the CLA and DCA are karstic and are dominated by secondary porosity/permeability due to chemical weathering. The carbonate aquifers are expected to have greatest permeability within the weathered zone, up to a maximum of 100 to 150 m below the surface. The karstic nature of the aquifers means that, on a local scale, groundwater flow is via preferential pathways. However, previous modelling has demonstrated that, at a basin-wide scale, the aquifers are considered to behave as an equivalent porous medium (Abusaada and Sauter, 2013; Ghasemizadeh et al., 2012; Ghasemizadeh et al., 2015; Scanlon et al., 2003) with very high transmissivities (5000 m^2/day for the Cambrian limestone and 1000 m^2/day for the Dook Creek dolostone) and relatively low specific yield with estimates ranging from 0.01 to 0.06 (1 to 6%).

Key conceptual features of the karstic systems include:

- Increased permeability in areas where sinkhole development has occurred.
- Preferential flow occurs along major structural features such as the Bulman Fault for the DCA, where it discharges to springs located along its length.
- The location of the contact between the confined and unconfined sections of the DCA is at the surface contact between the underlying Dook Creek Formation and overlying Limmen Sandstone; this contact is roughly coincident with the Central Arnhem Highway.

Recharge and discharge are the dominant processes expected to occur within the unconfined portions of both the groundwater systems.

3.3.1 Recharge

Recharge occurs in the unconfined portion of the aquifer, with higher rates of recharge occurring in areas where sinkholes have developed.

Recharge beneath native vegetation is dominated by bypass flow rather than diffuse movement through soil horizons. The most likely mechanism for this is via stream sinks, sinkholes and/or macropores such as cracks and root holes in the soil. Sinkholes and stream sinks have been located over the CLA and the DCA.

The dominant recharge mechanism in the areas of outcropping Tindall Limestone is via preferential pathways; however, this mechanism is not well understood and is poorly represented numerically. Recharge was therefore estimated as diffuse recharge using a simple soil moisture deficit model based on rainfall and estimated evapotranspiration (Jolly et al., 2004). It has been found that this method has not quantified the increase in recharge during wetter periods in the rainfall record when compared to groundwater-level hydrographs and gauged flows. Recharge is also expected during periods when the river stage height is greater than the groundwater level adjacent to the river where the river overlies the aquifers, and the model simulates this process.

Recharge is thought to occur via four mechanisms:

- Diffuse direct recharge – where water is added to the groundwater in excess of soil water deficits and evapotranspiration by direct vertical percolation of precipitation through the unsaturated zone. This is thought to be the dominant mechanism in areas with Cretaceous cover.
- Macropores – where precipitation is preferentially 'channelled' through the unsaturated zone and has a limited interaction with the unsaturated zone.
- Localised indirect recharge – where surface water can be channelled into karstic features such as dolines (sinkholes). This is a poorly understood component of recharge.
- River recharge – when the stage height of the river exceeds the adjacent groundwater level in the aquifer. This is thought to be a minor component of the overall water budget.

Recharge to the groundwater of the outcropping carbonates is thought to be dominated by macropore and local indirect recharge. Water balance and hydrograph analysis have estimated that recharge to the CLA is about 19 to 144 mm/year in the MWMZ (Knapton, 2020). Calibration of the groundwater models with the estimated recharge rates has resulted in an accepted range of hydraulic parameters.

The Dook Creek Formation is also the source of dry-season flow in the Goyder River, which flows into the Arafura Swamp. Williams et al. (2003) estimated a mean annual recharge rate of about 90 mm/year (1884 to 1999) for the area of the Dook Creek Formation that provides the source of dry-season flows in the Goyder River. These rates of recharge are consistent with the range of values estimated for the aquifer using chloride mass balance and environmental tracers in Taylor et al. (2023).

3.3.2 Regional groundwater flow

The groundwater flow within the CLA is from the south to the north where it discharges to the lower section of Elsey Creek and the upper Roper River and its major tributaries (Roper Creek and Waterhouse River) in the Roper catchment and to the catchments of the Katherine, Flora and Douglas rivers along the beds of rivers and via discrete springs. Major discharges occur along the Roper River and Flora River as it intercepts the much larger groundwater flows from the Georgina Basin and Wiso Basin, respectively (refer to Figure 3-1).

The groundwater flow within the DCA is from the topographically high areas to topographically lower areas, generally from the south-west to the north-east. Discharge within the Roper catchment occurs in the areas where Flying Fox Creek and the Mainoru and Wilton Rivers incise into the dolostone aquifer. Discharge from the DCA also occurs at Guyuyu Creek and Goyder River to the north-east of the Roper catchment. Discrete springs occur where fractures in the Limmen Sandstone allow groundwater to flow to the surface under pressure (e.g. Lindsay, White Rock, Emu, Top and Weemol springs).

3.3.3 Groundwater discharge

Most of the groundwater discharge to the Roper River from the CLA occurs downstream of the gauging station G9030176 at Elsey National Park (refer to Figure 2-3).

Groundwater discharge from the DCA provides the dry-season flow for reaches of the Mainoru and Wilton rivers and Flying Fox Creek. Discharge is predominantly from discrete points at springs (e.g. Top, Lindsay and Weemol springs), some diffuse discharge also occurs along portions of some of the rivers.

A considerable volume of groundwater discharge occurs via evapotranspiration from the riparian zone along the rivers (Crosbie and Rachakonda, 2021; Jolly et al., 2004; Tickell, 2016).

Groundwater extraction can result in streamflow depletion at certain locations across the aquifers. However, the distance between a groundwater extraction site and a nearby river greatly affects the timing of its impacts on that river.

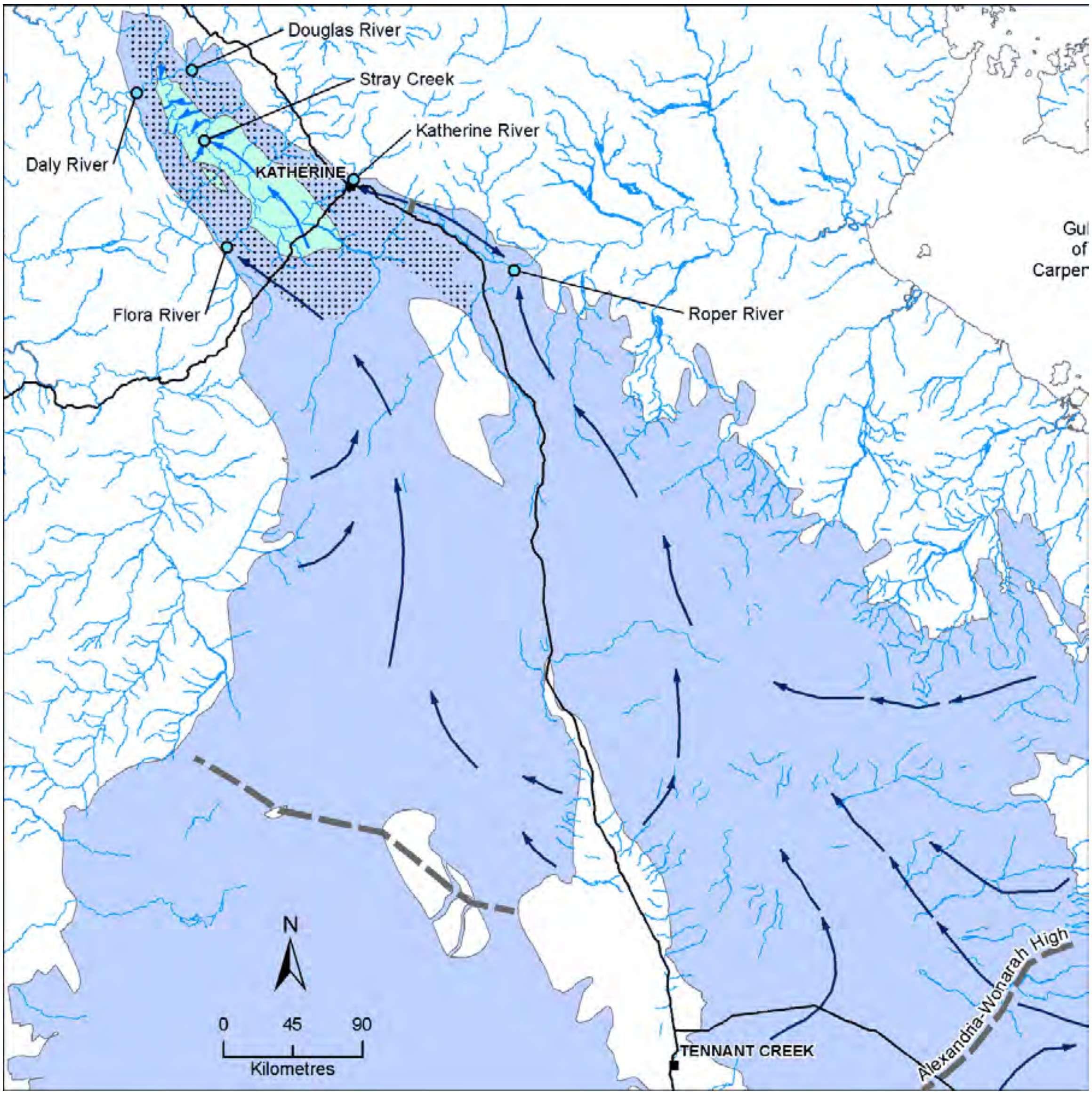


Figure 3-1 Regional Cambrian Limestone Aquifer groundwater flow paths

The stippled region identifies the areas where the Tindall Limestone Aquifer is confined by the Jinduckin Formation. The blue circles represent the location of active streamflow gauging stations.
Source: Knapton (2020)

3.3.4 Summary of CLA water budget components

The above calculations of storage, throughflow, usage and recharge are based on a range of independent investigations by the NT Department of Environment, Parks and Water Security (DEPWS) and others into the Assessment area hydrogeology. The results provide estimates of the parameters used for constraining the calibration of the groundwater flow model (Bruwer and Tickell, 2015; DENR, 2017; Jolly et al., 2004; Knapton, 2009, 2020; Tickell and Bruwer, 2018). These parameters include specific yield, transmissivity, the hydraulic gradient of the watertable, rainfall and the chloride content of rainfall and groundwater. Some parameters are derived from measured field data while others, such as specific yield, are estimates based on typical values for specific rock types. As a result, some of the figures obtained are only first-pass estimates, although they are considered the best available data at the time of model development.

A summary of the information relating to the water balance is provided diagrammatically in Figure 3-2.

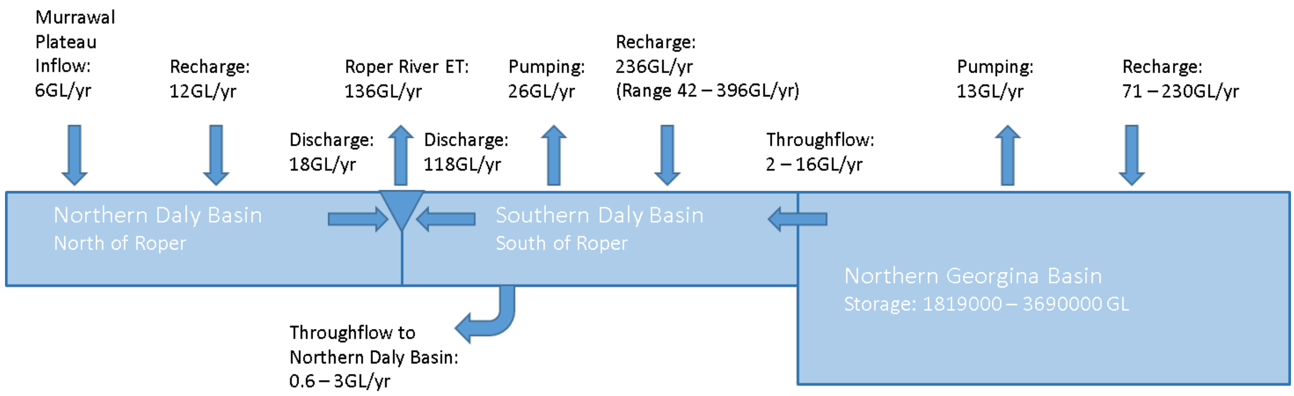


Figure 3-2 Diagrammatic representation of water balance for the Roper River groundwater catchment

Source: Knapton (2020)

3.4 DR2 (CLA) model description

The groundwater flow model of the CLA in the Roper catchment is based on a calibrated three-dimensional finite element groundwater model referred to as DR2 (Knapton, 2020).

The DR2 groundwater model covers an area of 159,000 km^2 and represents the unconfined and confined areas of the CLA in the Daly Basin, the Wiso Basin to the south and the Georgina Basin to the south-east (Figure 2-1).

The groundwater model was developed using finite element methods in the FEFLOW simulation code (Diersch, 2008) and consists of three layers. The CLA groundwater system is conceptually characterised as an equivalent porous medium. This simplification allows for the development of a more manageable and computationally efficient model while still capturing the essential characteristics of the groundwater system using calibrated regional aquifer parameters to reproduce the observed groundwater levels and discharge to the rivers. This assumption means that the actual flow paths cannot be modelled, and this model is not intended to be used for contaminant transport problems.

Recharge is applied to the top slice of the groundwater model according to recharge zones based primarily on the mapped surface geology (Knapton, 2005; Knapton, 2006). The time series recharge flux estimates of recharge have been determined using MIKE SHE (DHI, 2008) and more recently the LUMPREM utility (Doherty, 2020). These are process-based models and include an estimate of preferential or bypass flow.

The modelled recharge is highly variable (Figure 3-3a) ranging from 2 to 23,743 GL/year across the model domain with a mean of 995 GL/year. The portion of the model domain within the Roper catchment is similar with a range from 1 to 2176 GL/year and a mean of 248 GL/year (Figure 3-3b). Despite the highest annual recharge being in 1974 (associated with Cyclone Tracy), the 21st century (mean of 1724 GL/year) has seen considerably higher recharge than the 20th century (mean of 832 GL/year).

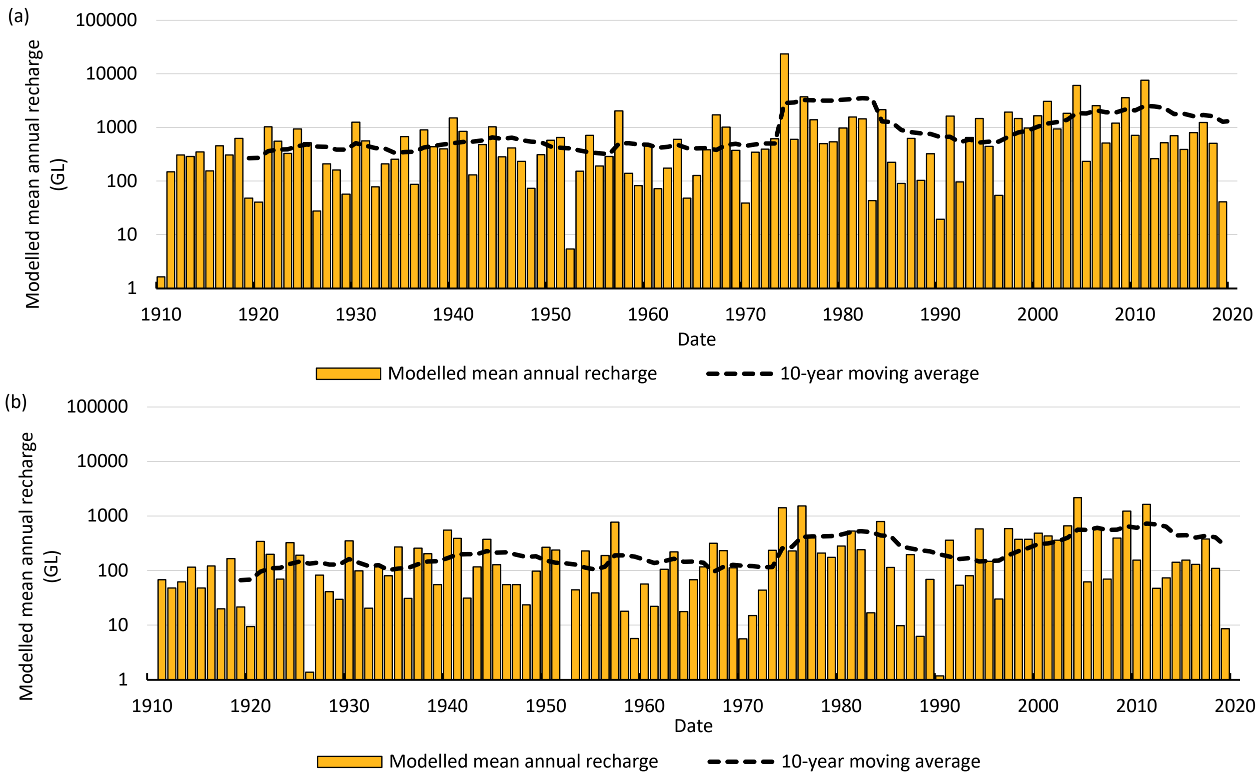


Figure 3-3 Modelled mean annual recharge for (a) the entire DR2 FEFLOW model domain for the Cambrian Limestone Aquifer (CLA) and (b) the spatial extent of the CLA within the Roper catchment

Dashed black line is the 10-year moving average. Modelled estimates are presented on a logarithmic scale.

The groundwater model includes boundary conditions (BCs) that define the interaction between the rivers and the groundwater system. Discharge from the rivers is implemented using Cauchy or transfer BCs (like river cells in ModFlow). The groundwater model assumes that recharge and/or discharge to the rivers where they are in connection with the aquifer is relatively uniform between adjacent nodes. The transfer in/out rates vary spatially across the model domain, and areas of preferential recharge and/or discharge along the rivers are simulated by adjusting the transfer in/out parameters. Springs are not included in the model as discrete pathways because they are too poorly understood and at a scale too small to be adequately represented. Extraction for stock and domestic and horticultural use is simulated from the model domain via well BCs at model nodes. Pumping rates were applied as a steady-state value equal to the annual pumped volume for the bore converted to m^3/day. The spatial extent of the CLA and its northerly flowing groundwater system form the boundary of the model domain where the Antrim Plateau Volcanics outcrop or occurs above the groundwater level and is therefore implemented as no-flow BC.

The method used to calibrate the DR2 groundwater model is documented in detail by Knapton (2020). The calibration process used a combination of pilot points (Doherty, 2003) and PEST, an automated nonlinear parameter estimation code (Doherty, 2004). Pilot points were strategically placed throughout the model domain to allow for flexible spatial parameterisation, capturing the spatial variability of hydraulic properties (i.e. hydraulic conductivity, storage coefficient and transfer in/out). PEST was then used to iteratively calibrate the model by adjusting the pilot point parameters and recharge parameters to minimise the objective function (i.e. discrepancies between observed and simulated data). The observed data used to define the objective function included available historical groundwater levels (9151 head observations) in the CLA and discharge measurements for the Roper, Flora, Katherine and Douglas rivers. The results of the calibration process are detailed in Knapton (2020).

The upper layer of the DR2 groundwater model is also capable of coupling to a MIKE11 river model of the Roper River. Groundwater – surface water interaction along the rivers occurs where the MIKE11 model is joined to the FEFLOW model at the transfer BCs.

3.5 DC2 (DCA) model description

The groundwater flow model of the DCA in the Roper catchment is based on a calibrated three-dimensional finite element groundwater model referred to as DC2 and is described in Knapton (2009).

The DC2 groundwater flow model encompasses an area of approximately 22,220 km^2. It incorporates the entire extent of the unconfined areas of the Dook Creek Formation and includes the entire catchments of the Flying Fox Creek, Mainoru River, Wilton River, Guyuyu Creek and Goyder River.

The groundwater model was developed using finite element methods in the FEFLOW simulation code (Diersch, 2008) and consists of three layers. The DCA groundwater system is conceptually characterised as an equivalent porous medium. This simplification allows for the development of a more manageable and computationally efficient model while still capturing the essential characteristics of the groundwater system using calibrated regional aquifer parameters to reproduce the observed groundwater levels and discharge to the rivers. This assumption means that the actual flow paths cannot be modelled, and this model is not intended to be used for contaminant transport problems.

Based on the conceptual model, the DCA groundwater system is unconfined to the north-west of the Central Arnhem Highway and confined beneath the Limmen Sandstone to the south-east. The extent of the confined region of the DCA model was arbitrarily defined using the subcatchments of the rivers which source flows from the Dook Creek Formation.

To represent recharge and evapotranspirational losses, the DC2 groundwater model uses areal flux BCs applied to the top slice of the model using a combination of element distributions and functions.

The modelled recharge is highly variable (Figure 3-4a) ranging from 0.5 to 1328 GL/year across the model domain with a mean of 231 GL/year. The portion of the model domain within the Roper catchment is similar with a range from 0.3 to 892 GL/year and a mean of 150 GL/year (Figure 3-4b). Similar to the CLA model domain, the 21st century has seen considerably higher recharge (mean of 392 GL/year) than the 20th century (mean of 194 GL/year).

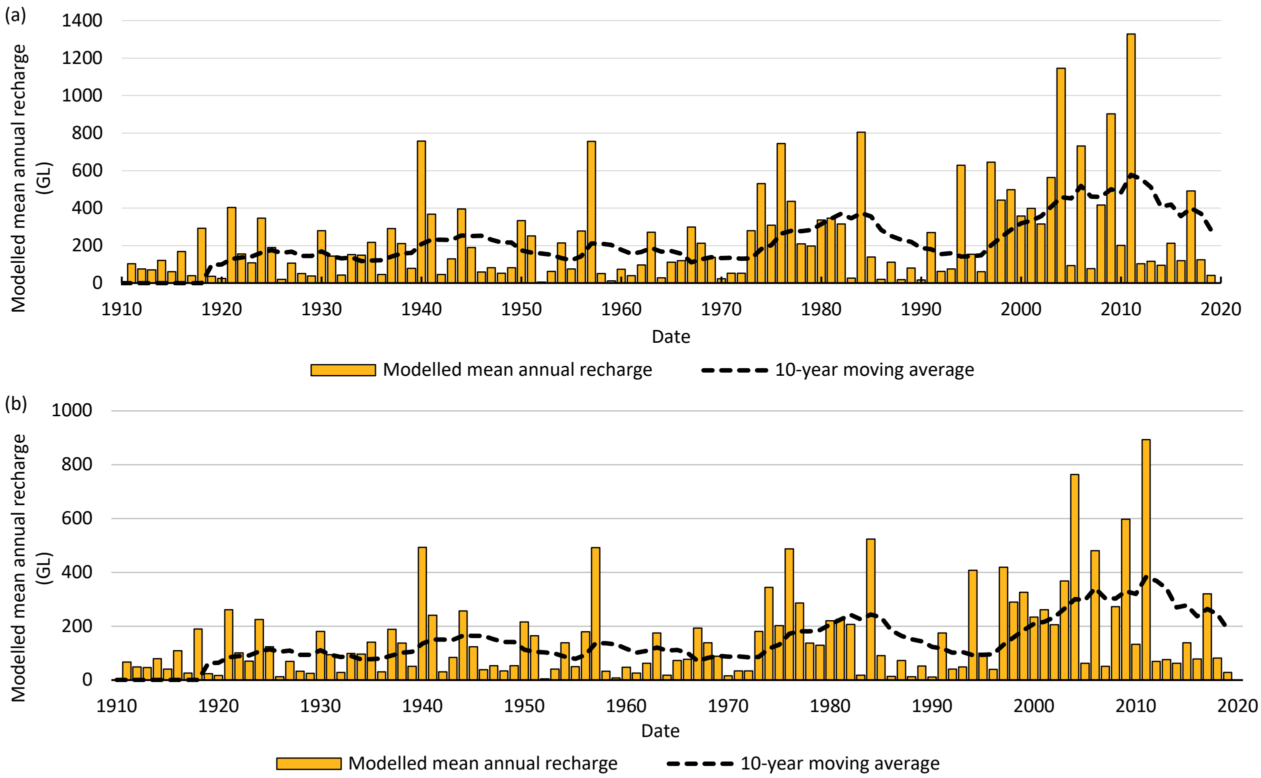


Figure 3-4 Modelled mean annual recharge for (a) the entire DC2 FEFLOW model domain for the Dook Creek Aquifer (DCA) and (b) the spatial extent of the DCA within the Roper catchment

Dashed black line is the 10-year moving average. Modelled estimates are presented on a logarithmic scale.

The DC2 groundwater model includes BCs that represent the discharge to the rivers, implemented using the Cauchy or transfer BCs (Diersch, 2008). The transfer BC describes a reference hydraulic head which has an imperfect hydraulic contact with the groundwater body caused by a colmation layer (related to the streambed conductance). Pumping bores for stock and domestic and horticultural use were implemented using multilayer well BC. Pumping rates were applied as a steady-state value equal to the annual pumped volume for the bore converted to m^3/day. Given that there has been very little development of the DCA groundwater resources in the Roper catchment, they are only relevant to scenario modelling to examine the effects of future development. Discrete springs discharging from the DCA through the confining Limmen Sandstone (e.g. Lindsay Spring and Top Spring) were simulated using constant head BC. The extent of the DCA forms the boundary of the model domain and is implemented as no-flow BC.

Calibration of the DC2 groundwater flow model is documented by Knapton (2009). Calibration was undertaken using the automatic calibration code PEST (Doherty, 2015). PEST uses the weighted sum of squared residuals to determine the objective function or ‘goodness of fit’ between the simulated response and the observed response (i.e. simulated and measured groundwater levels and groundwater discharge). PEST generates new model parameters as pilot point values (i.e. hydraulic conductivity, specific yield and transfer out distributions). The distribution of hydraulic conductivity, storage coefficient and transfer out pilot points values were interpolated to the model mesh.

3.6 Limitations

Current assumptions and limitations of the DR2 and DC2 models are:

- Equivalent porous media has been used to represent karstic systems. The regional equivalent porous media groundwater flow model only assumes approximate homogeneous isotropic conditions at element scales and is not suited to analysis of local karstic terrains (e.g. for tracking of pollutant flow).
- The runoff data used in the surface water modelling and the groundwater recharge are calculated using two different codes and are not interlinked. However, the models have been designed and calibrated to ensure that water inflows and outflows between the surface water and groundwater systems are appropriately accounted for and that there is no duplication or double accounting of water in the overall water balance.
- Recharge is assumed to be diffuse; however, bypass flow via macropores or sinkholes is also known to be a significant recharge mechanism in some areas. Although the codes used to calculate recharge include estimates of bypass flow, it is expected that for the years with above average rainfall, the MIKE SHE and LUMPREM recharge will under estimate actual recharge.
- There is no consideration of deep drainage from recycled irrigation associated with the future hypothetical groundwater developments.
- There is limited understanding of actual river–aquifer interactions, especially with respect to the flows from the river to the groundwater system.
- Individual springs are not considered in the DR2 model as the distributions of the discrete pathways are too poorly understood and at a scale too small to be adequately represented.

4 Scenario modelling

This section discusses the inputs to the scenarios used in the groundwater models.

The CLA and DCA are regional-scale and intermediate-scale groundwater flow systems, respectively, meaning a change in model state, such as climate or development, may take several hundreds of years before the system re-establishes a quasi-equilibrium state, where the groundwater flow patterns stabilise. Consequently, the impacts of hypothetical groundwater-based development or changes in future long-term climate will in part depend on the timescale over which the modelling results are reported. For the purposes of this report, the modelling results are reported over two timescales:

- Quasi-equilibrium, designated by a prime symbol (′), where the model was run once using 4 × 109-year climate sequences with only the results of the last 109-year sequence evaluated.
- Projected 2070 model state, where an ensemble of 11 × 50-year climate sequences (based on a 50-year moving window over the 1910 to 2019 historical climate) were run through the model, with the last 20 years evaluated – nominally representative of the range in conditions between 2060 and 2070.

The quasi-equilibrium timescale is representative of the climate and hypothetical development remaining unchanged over the entire timescale (which is unlikely). The projected 2070 model state is more representative of a result that is consistent with the time frames over which projected future climate scenarios were evaluated in the companion technical report on climate (McJannet et al., 2023) and time frames over which water planning and investment decisions are made. The 11-climate-sequence ensemble encapsulates the effects of inter-decadal variability.

For each evaluation timescale, five scenarios were assessed:

- Scenario AN – historical climate (1910 to 2019) and no groundwater development
- Scenario A – historical climate (1910 to 2019) and current levels of development
- Scenario B – historical climate (1910 to 2019) and hypothetical levels of future development
- Scenario C – future climate (dry, mid and wet) and current levels of development
- Scenario D – future climate (dry, mid and wet) and hypothetical levels of future development.

In considering changes to the hydrological regime under different scenarios, all results were assessed relative to Scenario AN.

The method by which future climate sequences were generated is outlined in Section 4.1. The method of establishing hypothetical developments is outlined in Section 4.2, and the adopted model scenarios and naming conventions are outlined in Section 4.3. The reporting metrics for each scenario are presented in Section 4.4.

4.1 Generation of future climate sequences

The potential impacts of future climate change were evaluated within a sensitivity analysis framework. Future climate sequences were evaluated using seasonal scaling factors from selected global climate models (GCMs), as described below, to scale the historical climate data. The entire climate sequence was then re-scaled using an annual scaling factor representative of a percentage change from the long-term annual rainfall and potential evaporation (PET), as detailed below. Percentage change in long-term annual rainfall and PET were based on the 10, 50 and 90% exceedance values shown in McJannet et al. (2023).

Scenario Cdry used the seasonal scaling factors from the ACCESS1-0 model (GCM with 10th % exceedance annual rainfall – see McJannet et al. (2023)) but had an annual scaling factor that reduced the long-term mean annual rainfall by 10% and increased the long-term mean annual PET by 10%.

Scenario Cmid used the seasonal scaling factors from the MRI-CGCM3 model but had an annual scaling factor that reduced the long-term mean annual rainfall by 2% and increased the long-term mean annual PET by 7.5%.

Scenario Cwet used the seasonal scaling factors from the FIO-ESM model but had an annual scaling factor that increased the long-term mean annual rainfall by 10% and increased the long-term mean annual PET by 5%.

Scenario D model runs use the same climate inputs as Scenario C with differing levels of hypothetical future development.

Rainfall (Figure 4-1) and potential evaporation (Figure 4-2) data at the six climate locations used in the groundwater model are provided for scenarios Cwet, Cmid and Cdry.

4.1.1 Rainfall

Historical rainfall data for the six representative climate sites used in the CLA groundwater model were downloaded from the Scientific Information for Land Owners (SILO) database (https://www.longpaddock.qld.gov.au/silo/), which is maintained and hosted by the Science and Technology Division of the Queensland Government's Department of Environment and Science. SILO is a comprehensive database and platform that provides climate data and related information for Australia (Jeffery et al., 2001).

The cumulative historical (SILO) rainfall and the three scaled future rainfall sequences (Cdry, Cmid, and Cwet) at the six representative sites used in the recharge models are presented in Figure 4-1.

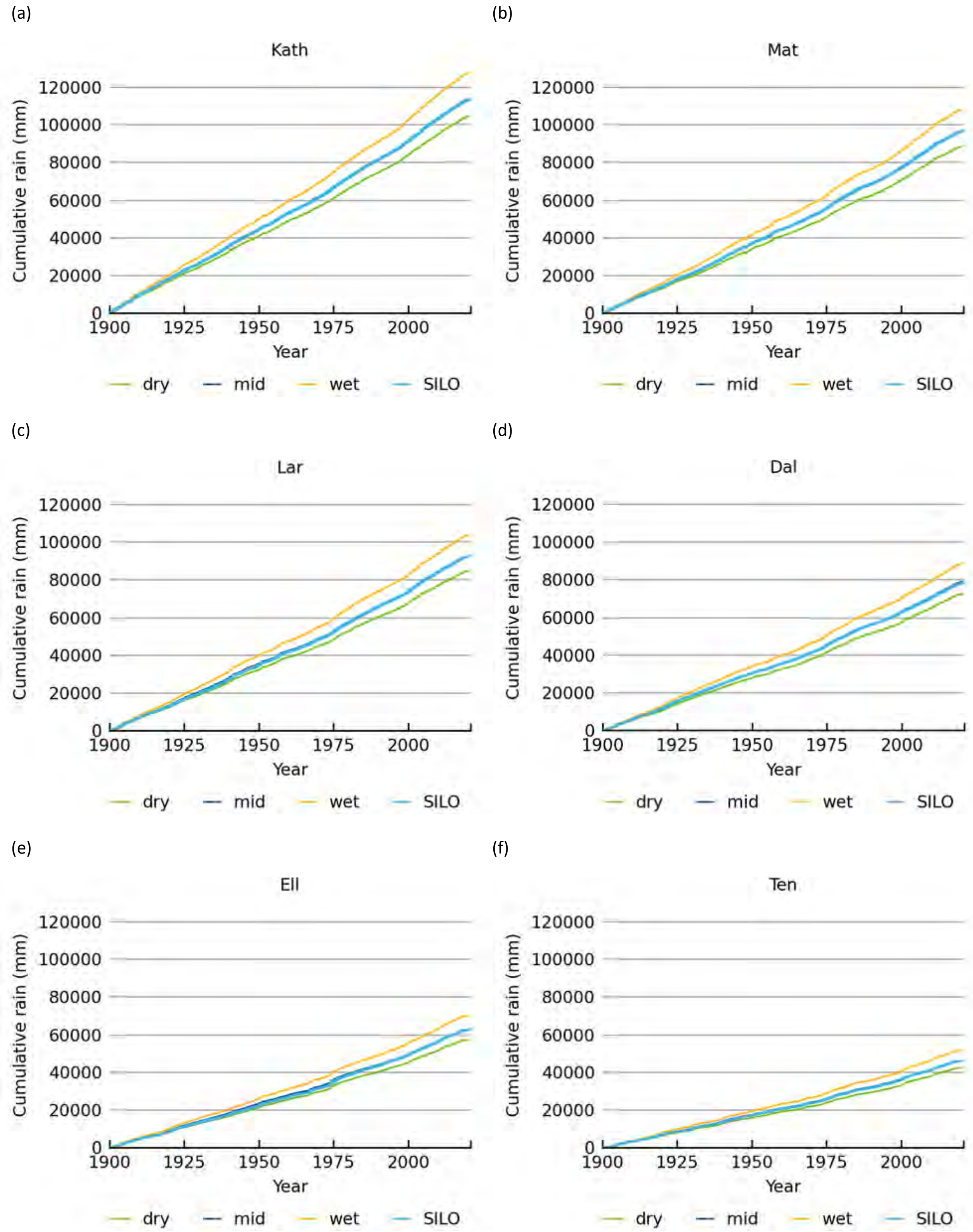


Figure 4-1 Cumulative rainfall for the dry, mid, and wet climate sequences and the SILO data drill at (a) Kath = Katherine, (b) Mat = Mataranka, (c) Lar = Larrimah, (d) Dal = Daly Waters, (e) Ell = Elliot and (f) Ten = Tennant Creek

Note: dry = Cdry scaled rainfall, mid = Cmid scaled rainfall and wet = Cwet scaled rainfall, SILO = historical rainfall retrieved from the SILO data drill.

4.1.2 Potential evaporation

The cumulative historical (SILO) PET and the three scaled future PET sequences (Cdry, Cmid and Cwet) at the six representative sites used in the recharge models are shown in Figure 4-2.

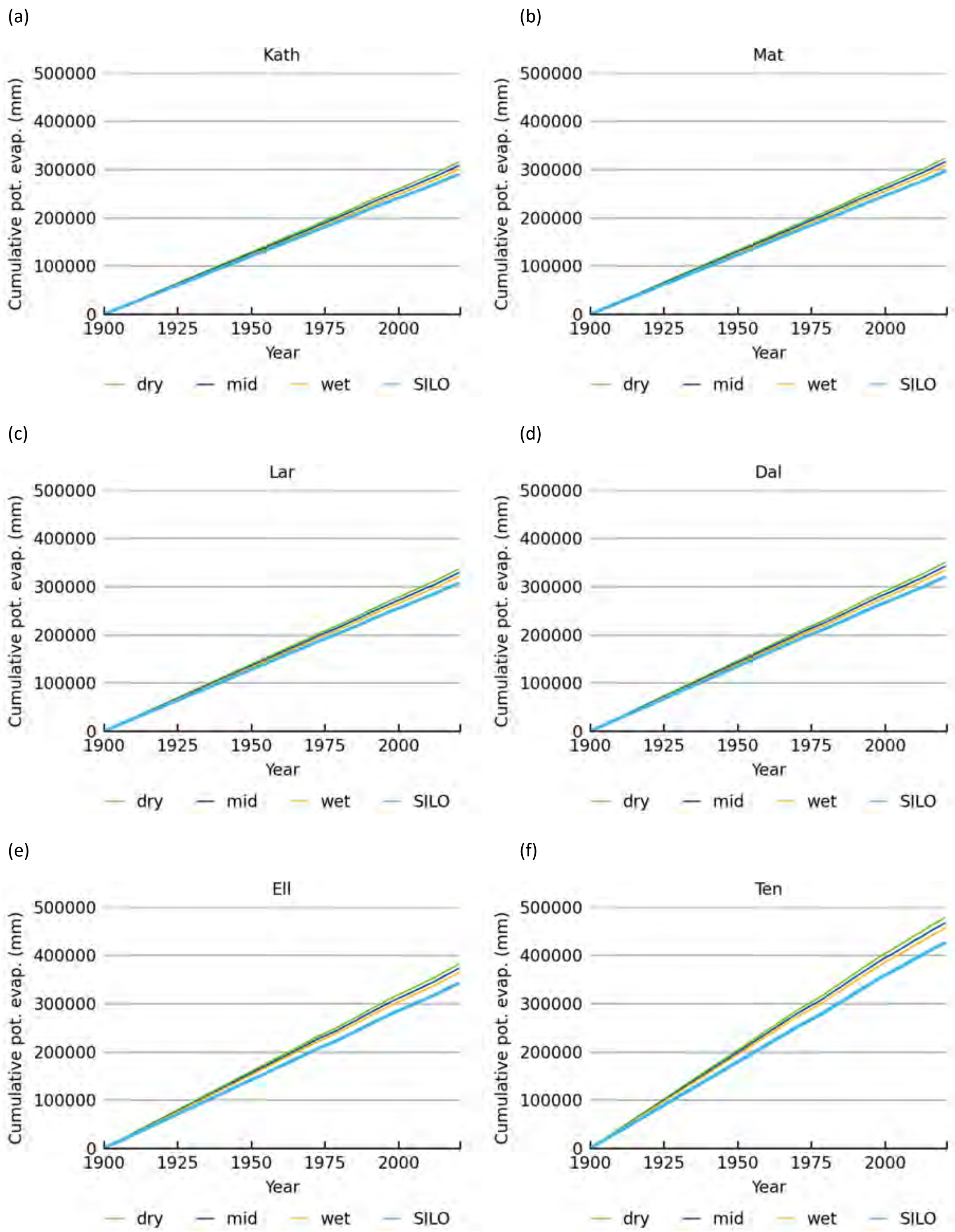


Figure 4-2 Cumulative potential evaporation for the dry, mid, and wet climate sequences and the SILO data drill at (a) Kath = Katherine, (b) Mat = Mataranka, (c) Lar = Larrimah, (d) Dal = Daly Waters, (e) Ell = Elliot and (f) Ten = Tennant Creek

Note: dry = Cdry scaled potential evaporation, mid = Cmid scaled potential evaporation and wet = Cwet scaled potential evaporation, SILO = historical potential evaporation retrieved from the SILO data drill.

4.2 Establishment of groundwater development scenarios

4.2.1 Locations for hypothetical future groundwater development

Cambrian Limestone Aquifer

Locations for hypothetical groundwater development in the CLA were selected based on spatial analyses undertaken by Taylor et al. (2023). Land suitability grids derived by Thomas et al. (2022) were overlain on the: (i) spatial hydrogeology data (Department of Environment Parks and Water Security, 2008; Department of Industry Tourism and Trade, 2014), (ii) spatial water quality and bore yield data (Department of Environment Parks and Water Security, 2014), (iii) current and proposed spatial water management zones (Department of Environment Parks and Water Security, 2019), (iv) spatial licensed entitlement data (Department of Environment Parks and Water Security, 2018), and (v) major and minor road network. In addition, the DR2 (CLA) LeapFrog geological model was used to extract gridded depth to the top of the CLA and to groundwater as well as to extract multiple hydrogeological cross-sections to evaluate aquifer saturated thickness. From these spatial analyses based on potential water availability in the proposed Mataranka Tindall Limestone water allocation plan (Department of Environment and Natural Resources, 2017) and the current Georgina Wiso water allocation plan (Northern Territory Government, 2023), seven hypothetical locations were chosen. These locations have: (i) potentially suitable land for agricultural intensification, (ii) a suitable aquifer exhibiting a saturated thickness greater than 20 m, (iii) suitable groundwater quality for irrigation (≤1000 mg/L total dissolved solids (TDS)), (iv) indicative bore yields suggesting sufficient water could be extracted for groundwater-based irrigation (>15 L/second), (v) a threshold drilling depth to intersect the aquifer of less than 200 metres below ground level (mBGL), and (vi) a depth to groundwater of less than 100 mBGL. Each location was placed at a distance of greater than 10 km from existing licensed water users and each hypothetical development location (Figure 4-3).

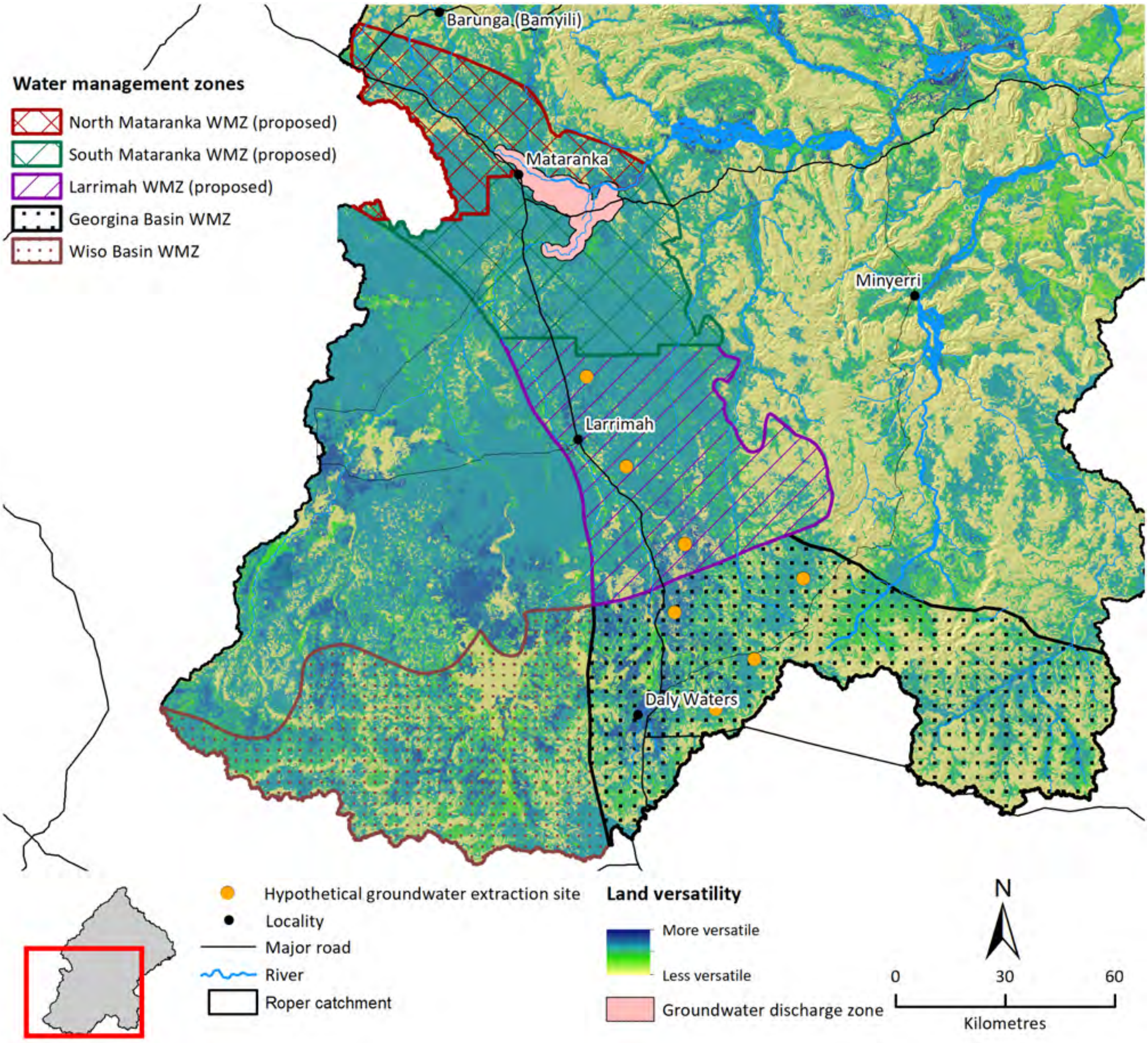


Figure 4-3 Locations of hypothetical groundwater development in the Cambrian Limestone Aquifer

Water management zones sourced from Department of Environment Parks and Water Security (2019)

Dook Creek Aquifer

Locations for hypothetical groundwater development in the DCA were selected based on spatial analyses similar to those specified above and undertaken by Taylor et al. (2023). There are slight differences, however. The same land suitability grids derived by Thomas et al. (2022) were overlain on the: (i) spatial hydrogeology data (Department of Environment Parks and Water Security, 2008; Department of Industry Tourism and Trade, 2014), and (ii) spatial water quality and bore yield data (Department of Environment Parks and Water Security, 2014). In addition, the DR2 (DCA) LeapFrog geological model was used to extract gridded depth to the top of the DCA and to groundwater. There is no licensed groundwater use across the DCA that coincides with the DC2 (DCA) model domain, and there are no WMZs as there is no water allocation plan for the groundwater resource. However, based on the spatial analyses and the scale (i.e. size and thickness of the aquifer), six hypothetical locations were chosen. These locations have: (i) potentially suitable land for agricultural intensification, (ii) a suitable aquifer exhibiting a saturated thickness greater than 20 m, (iii) suitable groundwater quality for irrigation (≤1000 mg/L TDS), (iv) indicative bore yields to suggest sufficient water could be extracted for groundwater-based irrigation (>15 L/s), (v) a threshold drilling depth to intersect the aquifer of less than 200 mBGL, and (vi) a depth to groundwater of less than 100 mBGL. Each location was placed at a distance of greater than 10 km from the Bulman community (the only water user) and each hypothetical development location (Figure 4-4).

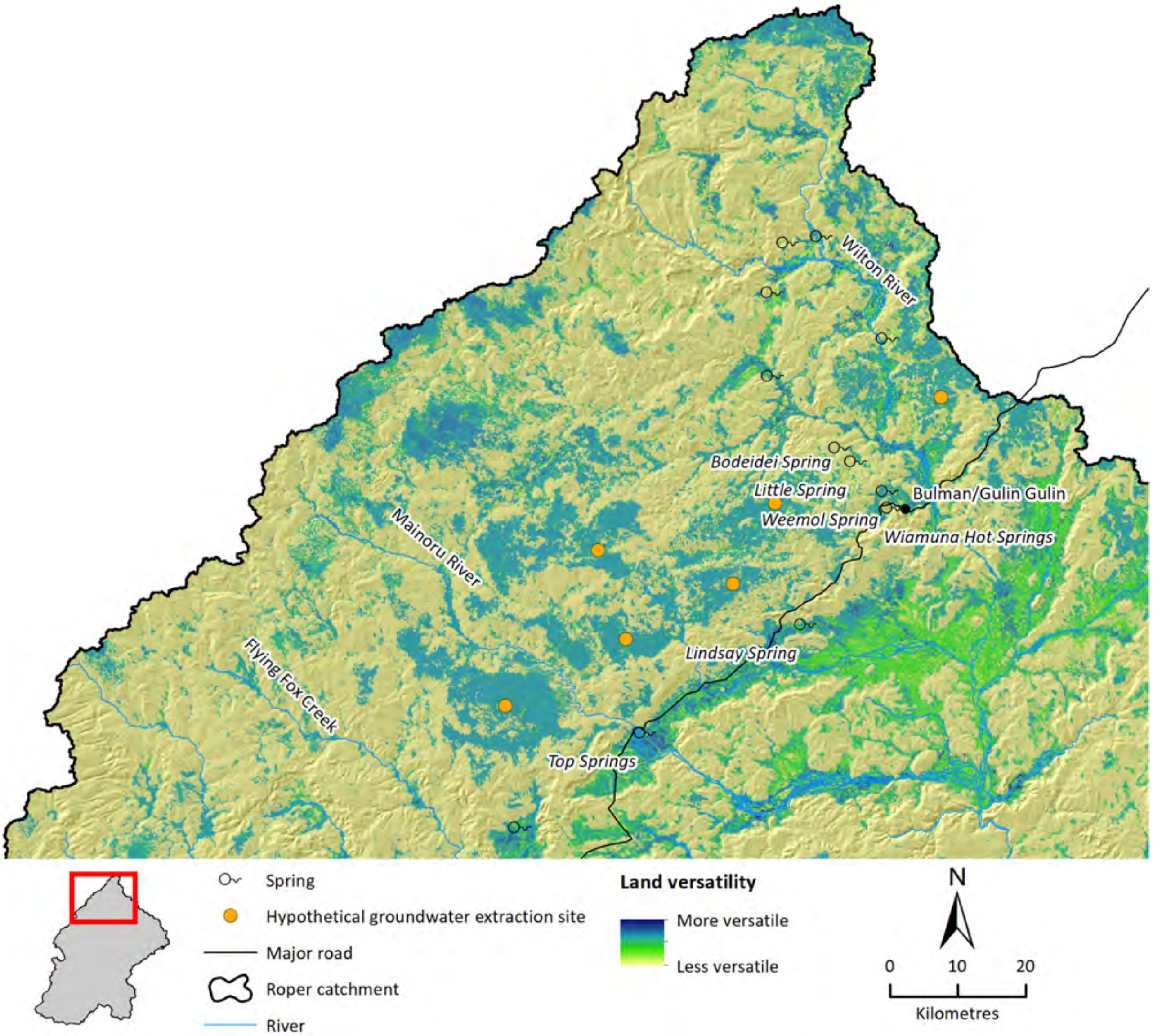


Figure 4-4 Locations of hypothetical groundwater development in the Dook Creek Aquifer

4.2.1 CLA groundwater development

The extraction regimes used for each CLA scenario were generated by identifying existing licensed bores used for horticulture supplies. Stock and domestic extraction is a small component of the total water extracted from the two areas. Stock and domestic use is approximately 5% of entitlements identified for horticultural use and has been omitted from this assessment.

Bores used for horticulture are licensed and have entitlements associated with each bore (DEPWS, 2018). Apart from scenarios A'N and AN, all the scenarios run assumed a pumping rate based on the entitlement specified in each extraction licence.

Scenarios A/A′ and C/C′ employed an extraction regime based on the documented entitlements for 2019 for both the MWMZ and the LWMZ. The mean annual rate was converted to a daily extraction rate in kilolitres per day and applied over the entire duration of each scenario. The mean annual extraction rates used for the two areas are presented in Table 4-1.

Scenarios B/B′ and D/D′ employed an extraction regime based on the current estimates of groundwater use and the hypothetical future groundwater development for both the MWMZ and the LWMZ. The mean rate was converted to a daily extraction rate and applied over the entire duration of each scenario. The mean annual extraction rates used for the two areas are presented in Table 4-1.

In the MWMZ, all scenarios have the same extraction. In the LWMZ, relative to Scenario A/A′ with 8 GL/year extraction, the three future hypothetical groundwater development levels in both Scenario B/B′ and Scenario D/D′ represent an increase in extraction of 15 GL/year (B35, D35), 30 GL/year (B70, D70), and 45 GL/year (B105, D105), or 190%, 375%, and 560%, respectively.

Table 4-1 Groundwater extraction rates (GL/year) for the Mataranka Water Management Zone (Mataranka Water Management Zone), Larrimah Water Management Zone (LWMZ), and 'Cambrian Limestone Aquifer (CLA) other' for the four scenarios investigated

AREA	AN	A	B35	B70	B105	C	D35	D70	D105
MWMZ	0.0	−23.8	−23.8	−23.8	−23.8	−23.8	−23.8	−23.8	−23.8
LWMZ	0.0	−8.0	−23.0	−38.0	−53.1	−8.0	−23.0	−38.0	−53.1
CLA other	0.0	−0.3	−20.4	−40.4	−60.4	−0.3	−20.4	−40.4	−60.4
Total	0.0	−32.1	−67.2	−102.2	−137.2	−32.1	−67.2	−102.2	−137.2

AN = Historical climate and no development; A = Historical climate and current development; B35 = Historical climate sequences with current development and additional future development of 35 GL/year; B70 = Historical climate sequences with current development and additional future development of 70 GL/year; B105 = Historical climate sequences with current development and additional future development of 105 GL/year; C = Future climate and current development; D35 = Future climate sequences with current development and additional future development of 35 GL/year; D70 = Future climate sequences with current development and additional future development of 70 GL/year; D105 = Future climate sequences with current development and additional future development of 105 GL/year.

4.2.2 DCA groundwater development

The DCA has very little groundwater development. Scenarios A and C only employed extraction for Bulman community (~0.1 GL/year). The mean rate was converted to a daily extraction rate in kilolitres per day and applied over the entire duration of each scenario. The mean annual extraction rates used for scenarios A and C are presented in Table 4-2.

Scenarios B and D employed an extraction regime based on the current estimates of extraction and hypothetical future groundwater development. The mean annual extraction rates used in scenarios B and D for the DCA are presented in Table 4-2.

Table 4-2 Groundwater extraction rates (GL/year) for the Dook Creek Aquifer (DCA) for the four scenarios investigated

AREA	AN	A	B6	B12	B18	C	D6	D12	D18
DCA	0.0	−0.1	−6.1	−12.1	−18.1	−0.1	−6.1	−12.1	−18.1

AN = Historical climate and no development; A = Historical climate and current development; B6 = Historical climate sequences with current development and additional future development of 6 GL/year; B12 = Historical climate sequences with current development and additional future development of 12 GL/year; B18 = Historical climate sequences with current development and additional future development of 18 GL/year; C = Future climate and current development; D6 = Future climate sequences with current development and additional future development of 6 GL/year; D12 = Future climate sequences with current development and additional future development of 12 GL/year; D18 = Future climate sequences with current development and additional future development of 18 GL/year.

4.3 Adopted model scenarios and naming conventions

4.3.1 Quasi-equilibrium conditions

The first set of scenarios examine the impacts of development assuming the groundwater system achieves quasi-equilibrium. These scenarios are designated with a prime (′) to distinguish their results from the results for the scenarios representative of 2059 to 2069 (nominally 2070) conditions (Table 4-3).

The first two scenarios (Scenario A′N and Scenario A′) are historical climate scenarios based on the 109-year historical climate sequence repeated four times to achieve quasi-equilibrium. The historical climate is taken as the observed climate (rainfall and PET) for water years (defined as the period 1 September to 31 August) from 1910 to 2019. Scenario A′N assumes no groundwater development and Scenario A′ assumes the current levels of groundwater development described in Section 4.2. Scenario A′N is used as the baseline against which the assessments of relative change are made.

Scenario B′ is also a historical climate scenario; it uses the current level and future level of groundwater development described in Section 4.2. Scenario B′ is therefore used to assess water availability assuming future development under historical climate used in Scenario A′N and Scenario A′ (Table 4-4).

Scenario C′ is a future climate and current development scenario. It was based on a 109-year climate series derived from scaling rainfall and PET as described in Section 4.1. Scenario C′ assumes the current level of groundwater development described in Section 4.2 (Table 4-5).

Scenario D′ is a future climate and future development scenario. It uses the same climate sequences as Scenario C′ but considers growth in groundwater use, assuming future development as described in Section 4.2 (Table 4-6).

To examine quasi-equilibrium conditions, modelled data from the last 109-year climate replica (based on the baseline period of 1910 to 2019) were evaluated for the CLA and the DCA for each of the scenarios detailed below.

Table 4-3 Model configurations under Scenario A′

4 × 109 years of historical climate and current development.

SCENARIO	CAMBRIAN LIMESTONE AQUIFER MODEL CONFIGURATION	SCENARIO	DOOK CREEK AQUIFER MODEL CONFIGURATION
A′N	Historical climate and no development	**A′N**	Historical climate and no development
A′	Historical climate and 32 GL/y current development	**A′**	Historical climate and 0.1 GL/y current development

Table 4-4 Model configurations under Scenario B′

4 × 109 years of historical climate and hypothetical future development.

SCENARIO	CAMBRIAN LIMESTONE AQUIFER MODEL CONFIGURATION	SCENARIO	DOOK CREEK AQUIFER MODEL CONFIGURATION
B′35	Historical climate and current development + 7 × 5 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 35 GL/y)	**B′6**	Historical climate and current development + 6 × 1 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 6 GL/y)
B′70	Historical climate and current development + 7 × 10 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 70 GL/y)	**B′12**	Historical climate and current development + 6 × 2 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 12 GL/y)
B′105	Historical climate and current development + 7 × 15 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 105 GL/y)	**B′18**	Historical climate and current development + 6 × 3 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 18 GL/y)

Table 4-5 Model configurations under Scenario C′

4 × 109 years of future climate and current development.

SCENARIO	CAMBRIAN LIMESTONE AQUIFER MODEL CONFIGURATION	SCENARIO	DOOK CREEK AQUIFER MODEL CONFIGURATION
C′dry	C′dry corresponding to a 10% reduction in mean annual rainfall and 10% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 32 GL/y current development	**C′dry**	C′dry corresponding to a 10% reduction in mean annual rainfall and 10% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 0.1 GL/y current development
C′mid	C′mid corresponding to a 2% reduction in mean annual rainfall and 7.5% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 32 GL/y current development	**C′mid**	C′mid corresponding to a 2% reduction in mean annual rainfall and 7.5% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 0.1 GL/y current development
C′wet	C′wet corresponding to a 10% increase in mean annual rainfall and a 5% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 32 GL/y current development	**C′wet**	C′wet corresponding to a 10% increase in mean annual rainfall and a 5% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 0.1 GL/y current development

Table 4-6 Model configurations under Scenario D'

4 × 109 years of future climate (Cdry, Cmid and Cwet) and hypothetical future development.

SCENARIO	CAMBRIAN LIMESTONE AQUIFER MODEL CONFIGURATION	SCENARIO	DOOK CREEK AQUIFER MODEL CONFIGURATION
D'dry35	C'dry climate and current development + 7 × 5 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to additional 35 GL/y)	**D'dry6**	C'dry climate and current development + 6 × 1 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to additional 6 GL/y)
D'dry70	C'dry climate and current development + 7 × 10 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums an additional 70 GL/y)	**D'dry12**	C'dry climate and current development + 6 × 2 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 12 GL/y)
D'dry105	C'dry climate and current development + 7 × 15 GL/y hypothetical future enterprises (i.e. total future extraction sums to an additional 105 GL/y)	**D'dry18**	C'dry climate and current development + 6 × 3 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 18 GL/y)
D'mid35	C'mid climate and current development + 7 × 5 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 35 GL/y)	**D'mid6**	C'mid climate and current development + 6 × 1 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 6 GL/y)
D'mid70	C'mid climate and current development + 7 × 10 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 70 GL/y)	**D'mid12**	C'mid climate and current development + 6 × 2 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 12 GL/y)
D'mid105	C'mid climate and current development + 7 × 15 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 105 GL/y)	**D'mid18**	C'mid climate and current development + 6 × 3 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 18 GL/y)
D'wet35	C'wet climate and current development + 7 × 5 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 35 GL/y)	**D'wet6**	C'wet climate and current development + 6 × 1 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 6 GL/y)
D'wet70	C'wet climate and current development + 7 × 10 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 70 GL/y)	**D'wet12**	C'wet climate and current development + 6 × 2 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 12 GL/y)
D'wet105	C'wet climate and current development + 7 × 15 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 105 GL/y)	**D'wet18**	C'wet climate and current development + 6 × 3 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 18 GL/y)

4.3.2 Projected 2059 to 2069 conditions

The second set of scenarios (Table 4-7 to Table 4-11) examines how different groundwater development scenarios might affect water resources in the CLA and DCA over a specific period in the future (2059 to 2069) using historical and future climate data as a basis for these projections. The historical and future climate inputs comprise 11 × 50-year historical climate sequences taken from the observed climate (rainfall and PET) using the water years (defined as the period 1 September to 31 August) from 1910 to 2019. The scenarios comprise a warm-up period of 109 years of historical climate data used to prime the CLA groundwater model to 2019 followed by the 50-year historical and future climate and groundwater development inputs to evaluate the 2059 to 2069 representative conditions (nominally representative of 2070 conditions).

The time periods for each of the 50-year climate sequences used in the 2019 to 2069 scenarios are summarised in Table 4-7.

Table 4-7 Period of historical record used to develop the climate sequences

CLIMATE SEQUENCE	DATE FROM	DATE TO
1	01/09/1910	31/08/1959
2	01/09/1920	31/08/1969
3	01/09/1930	31/08/1979
4	01/09/1940	31/08/1989
5	01/09/1950	31/08/1999
6	01/09/1960	31/08/2009
7	01/09/1970	31/08/2019
8	01/09/1980 to 31/08/2019	01/09/1900 to 31/08/1909
9	01/09/1990 to 31/08/2019	01/09/1900 to 31/08/1919
10	01/09/2000 to 31/08/2019	01/09/1900 to 31/08/1929
11	01/09/2010 to 31/08/2019	01/09/1900 to 31/08/1939

The first two scenarios represent 'recent climate' scenarios (Table 4-8) and are based on the 11 × 50-year historical climate sequences without development (Scenario AN) and current levels of groundwater development (Scenario A). Scenario AN will be used as the baseline against which assessments of relative change will be made.

The third group of scenarios (Scenario B) is also a 'recent climate' scenario (Table 4-9). It is based on the 11 × 50-year climate sequences used in scenarios AN and A. Scenario B uses the current level and future level of groundwater development described in Section 4.2. Scenario B is, therefore, used to assess water availability assuming hypothetical future groundwater development.

The fourth group of scenarios (Scenario C) is a future climate and current development scenario (Table 4-10). It is based on the 11 × 50-year climate sequences derived from scaling rainfall and PET as described in Section 4.1. Scenario C employs the current level of groundwater development.

The fifth group of scenarios (Scenario D) is a future climate and future development scenario (Table 4-11). It uses the same 11 × 50-year climate sequences as Scenario C but considers growth in groundwater use, assuming the hypothetical future development described in Section 4.2.

Table 4-8 Model configurations under Scenario A

11 × 50-year climate sequences (based on a 50-year moving window over the 1910 to 2019 historical climate) – nominally representative of conditions to 2070 and using current development.

SCENARIO	CAMBRIAN LIMESTONE AQUIFER MODEL CONFIGURATION	SCENARIO	DOOK CREEK AQUIFER MODEL CONFIGURATION
AN	Historical climate and no development	**AN**	Historical climate and no development
A	Historical climate and 32 GL/y current development	**A**	Historical climate and 0.1 GL/y current development

Table 4-9 Model configurations under Scenario B

11 × 50-year climate sequences – nominally representative of conditions to 2070 and using current and hypothetical future groundwater development.

SCENARIO	CAMBRIAN LIMESTONE AQUIFER MODEL CONFIGURATION	SCENARIO	DOOK CREEK AQUIFER MODEL CONFIGURATION
B35	Historical climate and current development + 7 × 5 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 35 GL/y)	**B6**	Historical climate and current development + 6 × 1 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 6 GL/y)
B70	Historical climate and current development + 7 × 10 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 70 GL/y)	**B12**	Historical climate and current development + 6 × 2 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 12 GL/y)
B105	Historical climate and current development + 7 × 15 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 105 GL/y)	**B18**	Historical climate and current development + 6 × 3 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 18 GL/y)

Table 4-10 Model configurations under Scenario C

11 × 50-year future climate sequences (based on a 50-year moving window over Scenario C climate) – nominally representative of conditions to 2070 and using current groundwater development.

SCENARIO	CAMBRIAN LIMESTONE AQUIFER MODEL CONFIGURATION	SCENARIO	DOOK CREEK AQUIFER MODEL CONFIGURATION
Cdry	Cdry corresponding to a 10% reduction in mean annual rainfall and 10% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 32 GL/y current development	**Cdry**	Cdry corresponding to a 10% reduction in mean annual rainfall and 10% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 0.1 GL/y current development
Cmid	Cmid corresponding to a 2% reduction in mean annual rainfall and 7.5% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 32 GL/y current development	**Cmid**	Cmid corresponding to a 2% reduction in mean annual rainfall and 7.5% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 0.1 GL/y current development
Cwet	Cwet corresponding to a 10% increase in mean annual rainfall and a 5% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 32 GL/y current development	**Cwet**	Cwet corresponding to a 10% increase in mean annual rainfall and a 5% increase in potential evaporation, relative to the historical climate (1910 to 2019) and 0.1 GL/y current development

Table 4-11 Model configurations under Scenario D

11 × 50-year future climate sequences (based on a 50-year moving window over Scenario C climate) – nominally representative of conditions to 2070 and using current and hypothetical future groundwater development.

SCENARIO	CAMBRIAN LIMESTONE AQUIFER MODEL CONFIGURATION	SCENARIO	DOOK CREEK AQUIFER MODEL CONFIGURATION
Ddry35	Cdry climate and current development + 7 × 5 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 35 GL/y)	**Ddry6**	Cdry climate and current development + 6 × 1 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 6 GL/y)
Ddry70	Cdry climate and current development + 7 × 10 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 70 GL/y)	**Ddry12**	Cdry climate and current development + 6 × 2 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 12 GL/y)
Ddry105	Cdry climate and current development + 7 × 15 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 105 GL/y)	**Ddry18**	Cdry climate and current development + 6 × 3 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 18 GL/y)
Dmid35	Cmid climate and current development + 7 × 5 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 35 GL/y)	**Dmid6**	Cmid climate and current development + 6 × 1 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 6 GL/y)
Dmid70	Cmid climate and current development + 7 × 10 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 70 GL/y)	**Dmid12**	Cmid climate and current development + 6 × 2 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 12 GL/y)
Dmid105	Cmid climate and current development + 7 × 15 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 105 GL/y)	**Dmid18**	Cmid climate and current development + 6 × 3 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 18 GL/y)
Dwet35	Cwet climate and current development + 7 × 5 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 35 GL/y)	**Dwet6**	Cwet climate and current development + 6 × 1 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 6 GL/y)
Dwet70	Cwet climate and current development + 7 × 10 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 70 GL/y)	**Dwet12**	Cwet climate and current development + 6 × 2 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 12 GL/y)
Dwet105	Cwet climate and current development + 7 × 15 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 105 GL/y)	**Dwet18**	Cwet climate and current development + 6 × 3 GL/y hypothetical future enterprises (i.e. total hypothetical future extraction sums to an additional 18 GL/y)

4.4 Reported metrics

4.4.1 Mean annual water balances

Mean annual water balances are documented for the two management zones (MWMZ and LWMZ) within the CLA model domain and for the entire DCA model domain within the Roper catchment (refer to Section 2.4). Mean annual water balances are reported for both the quasi-equilibrium and projected 2059 to 2069 timescales, and water balance components are reported in gigalitres per year. The quasi-equilibrium mean annual water balances are calculated for the last 109-year climate sequence replicate, whereas the projected 2059 to 2069 annual water balances are calculated for the final 10-year period from 2059 to 2069 (nominally representative of 2070 conditions).

4.4.2 Groundwater-level metrics

CLA groundwater levels are documented for six sites as shown in Figure 4-5:

- RN035796 is in the MWMZ and is representative of areas with outcropping Tindall Limestone near the Roper River.
- RN019012 is in the MWMZ and is representative of areas with Cretaceous cover.
- RN028082 and RN029013 are in the Gum Ridge Formation in the LWMZ.
- RN024536 is located in the Gum Ridge Formation near the southern extent of the Roper catchment and about 30 km east of Daly Waters.
- RN005621 is located about 100 km south of the Roper catchment.

DCA groundwater levels are documented for five sites as shown in Figure 4-5:

- RN006546 represents impacts at Mountain Valley homestead.
- RN027811 represents impacts at the Bulman groundwater supply borefield.
- RN028226 represents impacts at the downstream extent of groundwater discharge to Wilton River.
- RN031983 represents impacts at the downstream extent of groundwater discharge to Flying Fox Creek.
- RN036302 represents impacts at Mainoru Station near Mainoru River.

The mean groundwater level for each site was calculated to provide a simple measure of the effects of each scenario on the groundwater systems of the CLA and DCA. The mean groundwater level for the quasi-equilibrium conditions was calculated for the fourth (i.e. last) 109-year climate sequence replicate. The mean groundwater level for each of the projected 2059 to 2069 scenarios was calculated from the last 10 years of all 11 × 50-year sequences (nominally representative of 2070 conditions).

4.4.3 Groundwater drawdown

To demonstrate the spatial extent of the effects associated with each scenario, the groundwater drawdown has been calculated for the final time step of each scenario and presented as contours. Drawdowns calculated for all scenarios use the final time step of Scenario AN or A’N as the reference head.

A single set of drawdown contours is presented for each quasi-equilibrium scenario at the final time step. The drawdowns from the 11 sets of projected 2059 to 2069 results at the final time step are summarised as percentiles with contours representing p5, p50 and p95 conditions.

4.4.4 Groundwater discharge metrics

Groundwater discharges to rivers are presented as hydrographs in cubic metres per second for selected gauge sites along the upper Roper River (G9030013, CLA model), Flying Fox Creek

(G9030108, DCA model) and Wilton River (G9030003, DCA model). These sites are considered to represent the dry-season flow dynamics of the Roper River and its tributaries, especially with respect to the impacts of pumping on dry-season low flows. The gauging sites and the corresponding river branch are presented in Table 4-12. The discharge at each site was calculated by summing fluxes at the Cauchy BC nodes assigned upstream of each site.

Mean groundwater discharge at the gauge sites along the Roper River, Flying Fox Creek and Wilton River have also been calculated to provide simple measures that reflect changes to the discharge regime under each scenario. The mean groundwater discharge for the quasi-equilibrium scenarios was calculated from the fourth (i.e. last) 109-year climate sequence replicate. The mean groundwater discharge for the projected 2059 to 2069 scenarios was calculated from the last 10 years of all 11 × 50-year sequences (nominally representative of 2070 conditions).

Table 4-12 Gauging sites and the corresponding river branch name

GAUGE SITE	BRANCH
G9030013	Roper River at Elsey Homestead
G9030003	Wilton River at Bulman Waterhole
G9030108	Flying Fox Creek at Central Arnhem Road

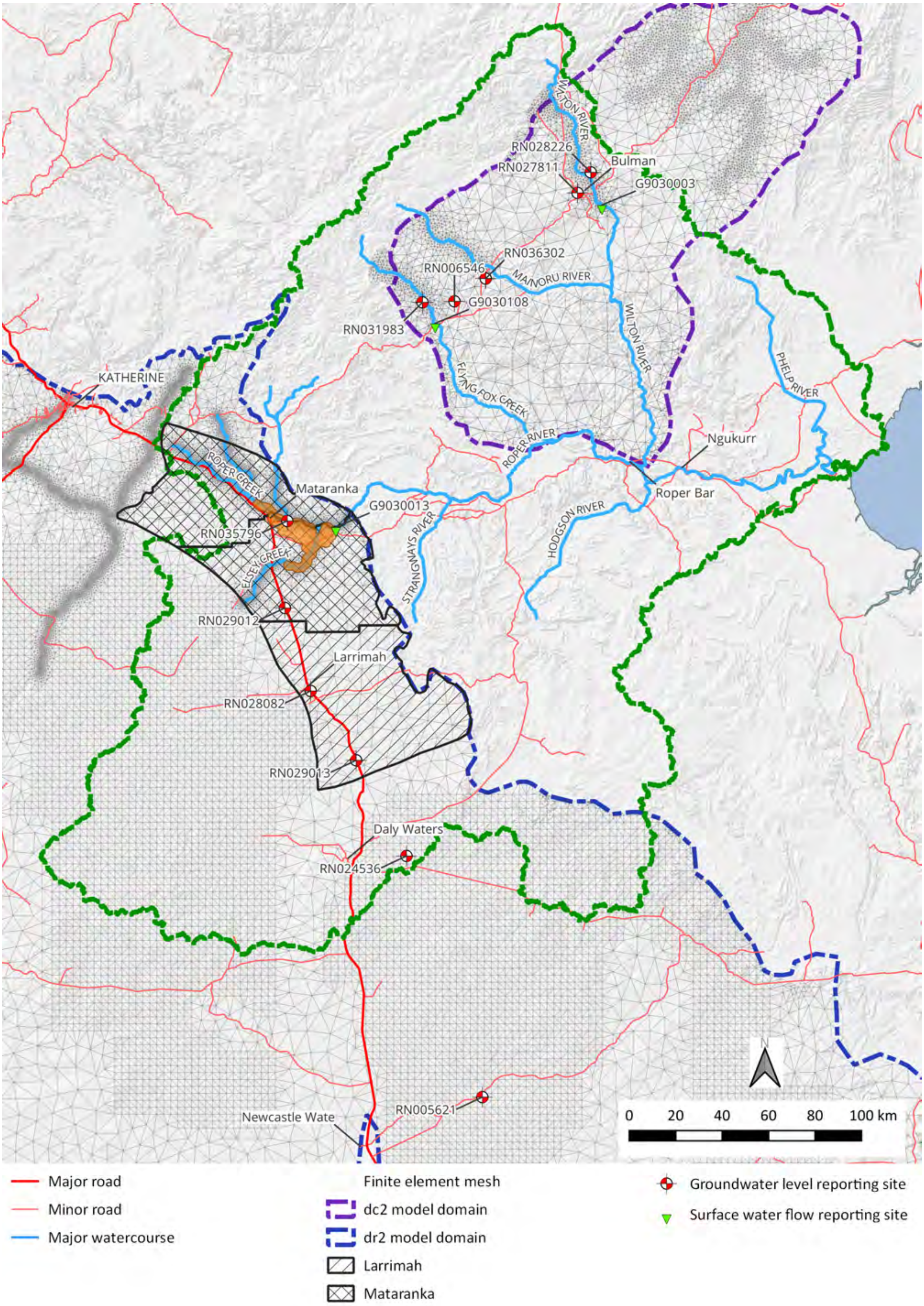


Figure 4-5 Water balance areas, groundwater-level sites and groundwater discharge sites used for reporting the scenario modelling results

5 Cambrian Limestone Aquifer quasi-equilibrium results (436 years)

5.1 Historical climate (scenarios A′ and B′) 436 years

5.1.1 Scenarios A′ and B′ – mean annual water balances

The mean annual groundwater balances for the last 109-year climate sequence replicate under scenarios A′N, A′ and B′35, B′70 and B′105 are presented for the MWMZ (Table 5-1) and the LWMZ (Table 5-2).

None of the hypothetical groundwater development sites are in the MWMZ. Nevertheless, there is a decrease in groundwater discharging as evapotranspiration (ET) (reductions relative to Scenario A′N for A′ = −12%, B′35 = −21%, B′70 = −29% and B′105 = −37%) and as discharge to the Roper River (reductions from Scenario A′N for A′ = −9%, B′35 = −12%, B′70 = −15% and B′105 = −18%).

The net inflow/outflow to the MWMZ also undergoes change, shifting from approximately 30 GL/year inflow under Scenario A′N to a net outflow of 13 GL/year under Scenario B′105. The reductions in ET, discharge to the rivers and groundwater inflows to the MWMZ are due to the increase in groundwater extraction associated with the hypothetical future groundwater developments in the LWMZ and to the south of the LWMZ.

The increase in groundwater extraction in the LWMZ (Table 5-2) is balanced by inflows from the release of groundwater from storage and inflows to the LWMZ. The net flow to the LWMZ undergoes a change, shifting from approximately -5 GL/year outflow under Scenario A′N to +46 GL/year inflow under Scenario B′105.

Table 5-1 Mean annual water balances (GL/year) under scenarios A′ and B′ for the last 109-year climate sequence replicate (2237 to 2346) for the Mataranka Water Management Zone

	A′N	A′	B′35	B′70	B′105
Inflow (gains)					
Recharge (diffuse)	201.8	203.3	204.2	205.3	206.5
Release from storage	189.5	188.8	188.7	188.9	189.5
From river	1.7	2.2	2.2	2.0	1.7
Sub-total	**393.0**	**394.3**	**395.1**	**396.2**	**397.7**
Outflow (losses)					
Evapotranspiration	105.8	92.9	84.0	74.8	66.2
Extraction	0	23.8	23.8	23.8	23.8
Capture into storage	194.8	194.2	194.1	193.9	193.8
To rivers	122.6	111.7	108.3	104.6	100.6
Sub-total	**423.2**	**422.6**	**410.2**	**397.1**	**384.4**

	A′N	A′	B′35	B′70	B′105
Net flow In (+ve) / out (-ve)	**30.2**	**28.4**	**15.0**	**0.9**	**–13.3**

A′N = Historical climate and no development; A′ = Historical climate and current development; B′35 = Historical climate sequences with current development and additional future development of 35 GL/year; B′70 = Historical climate sequences with current development and additional future development of 70 GL/year; B′105 = Historical climate sequences with current development and additional future development of 105 GL/year.

Table 5-2 Mean annual water balances (GL/year) under scenarios A′ and B′ for the last 109-year climate sequence replicate (2237 to 2346) for the Larrimah Water Management Zone

	A′N	A′	B′35	B′70	B′105
Inflow (gains)					
Recharge (diffuse)	8.28	8.28	8.28	8.28	8.28
Release from storage	5.61	5.75	6.37	7.07	7.92
From river	na†	na†	na†	na†	na†
Sub-total	**13.89**	**14.03**	**14.65**	**15.35**	**16.20**
Outflow (losses)					
Extraction	0	8.02	23.03	38.04	53.05
Capture into storage	9.23	9.17	9.04	8.95	8.88
To rivers	na†	na†	na†	na†	na†
Sub-total	**9.23**	**17.19**	**32.08**	**46.99**	**61.93**
Net flow In (+ve) / out (-ve)	**–4.66**	**3.16**	**17.42**	**31.64**	**45.73**

A′N = Historical climate and no development; A′ = Historical climate and current development; B′35 = Historical climate sequences with current development and additional future development of 35 GL/year; B′70 = Historical climate sequences with current development and additional future development of 70 GL/year; B′105 = Historical climate sequences with current development and additional future development of 105 GL/year.
†na = not applicable.

5.1.2 Scenarios A′ and B′ – groundwater levels

The groundwater levels for the six reported sites are presented in Figure 5-1 (in metres above Australian Height Datum (mAHD)). Each hydrograph reflects the different recharge conditions prevailing in the vicinity of that reporting site.

The groundwater levels under scenarios A′N and A′ show an upward trend for all sites over the 436-year model run from 1910 to 2346.

RN035796 is near the Roper River (refer to Figure 4-5), and the groundwater hydrograph reflects the connectivity of the surface water and the groundwater. The lower level of the hydrograph is controlled by the water level in the river during the dry season, resulting in a relatively steady trend in the overall level.

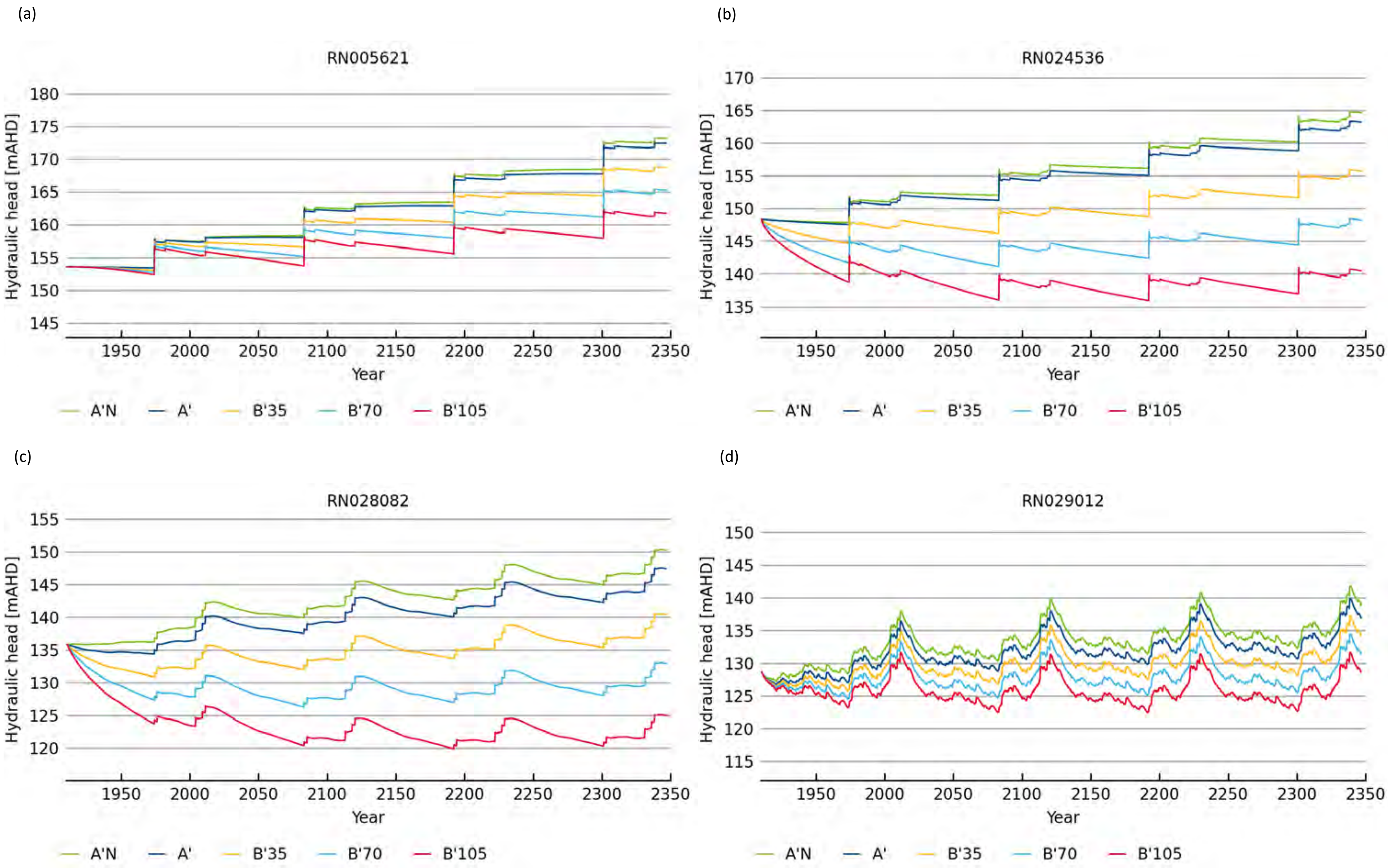
The mean groundwater levels over the last 109-year climate sequence replicate for each site were determined to provide a simple indicator of the effects of each scenario (Table 5-3). The difference in mean groundwater levels from the Scenario A′N baseline results reflects the gain or loss of groundwater from storage over this period associated with the other scenarios.

Table 5-3 Mean groundwater levels (mAHD) for quasi-equilibrium scenarios A′ and B′ for the last 109-year period (2237 to 2346) for the six reporting sites

SCENARIO	RN005621	RN024536	RN028082	RN029012	RN029013	RN035796
A′N	170.3	161.8	146.7	135.3	154.4	119.0
A′	169.5	160.5	144.0	133.6	152.3	118.5
B′35	166.3	153.4	137.1	131.1	143.9	118.4
B′70	163.1	146.2	129.9	128.5	135.2	118.2
B′105	159.9	138.9	122.2	125.8	125.9	118.0

A′N = Historical climate and no development; A′ = Historical climate and current development; B′35 = Historical climate sequences with current development and additional future development of 35 GL/year; B′70 = Historical climate sequences with current development and additional future development of 70 GL/year; B′105 = Historical climate sequences with current development and additional future development of 105 GL/year.

(a) (b) (c) (d)


RN005621
RN024536
RN028082
RN029012
Hydraulic head [mAHD]
Year
A'N
A'
B'35
B'70
B'105

(e) (f)

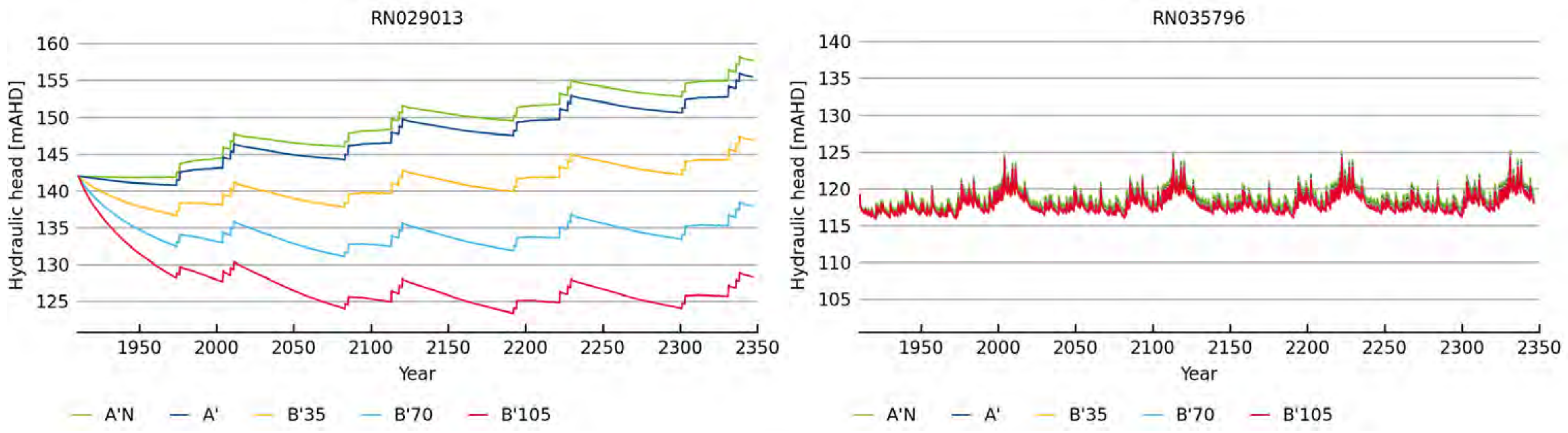


Figure 5-1 Hydrographs of groundwater level under scenarios A′ and B′ at the six reporting sites: (a) RN005621, (b) RN024536, (c) RN028082, (d) RN029012, (e) RN029013 and (f) RN035796

5.1.3 Scenario A′ and B′ – 436-year groundwater drawdown contours

The drawdown contours at 31/8/2346 under scenarios A′ and B′35 are presented in Figure 5-2a and Figure 5-2b, respectively. The Scenario A′ maximum drawdown (<5 m) is centred roughly on the Larrimah water control district (WCD), and the 1 m drawdown extends about 110 km south of the Larrimah WCD (or 210 km south-east of the Roper River).

Under Scenario B′35, maximum drawdown (<15 m) is centred roughly on the southern portion of the Larrimah WCD, and the 1 m drawdown contour extends about 310 km south of the Larrimah WCD (or 410 km south-east of the Roper River).

The drawdown contours under Scenario B′70 at 31/8/2346 assuming current and future groundwater extraction of 70 GL/year are presented in Figure 5-2c. The maximum drawdown (<25 m) is centred roughly on the southern boundary of the Larrimah WCD, and the 1 m drawdown contour extends 360 to 370 km south of the Larrimah WCD (or 460 to 470 km south-east of the Roper River).

The drawdown contours under Scenario B′105 at 31/8/2346 assuming current and future groundwater extraction of 105 GL/year are presented in Figure 5-2d. The maximum drawdown (<35 m) is centred roughly on the southern boundary of the Larrimah WCD, and the 1 m drawdown contour extends 380 to 390 km south of the Larrimah WCD (or 480 to 490 km south-east of the Roper River).

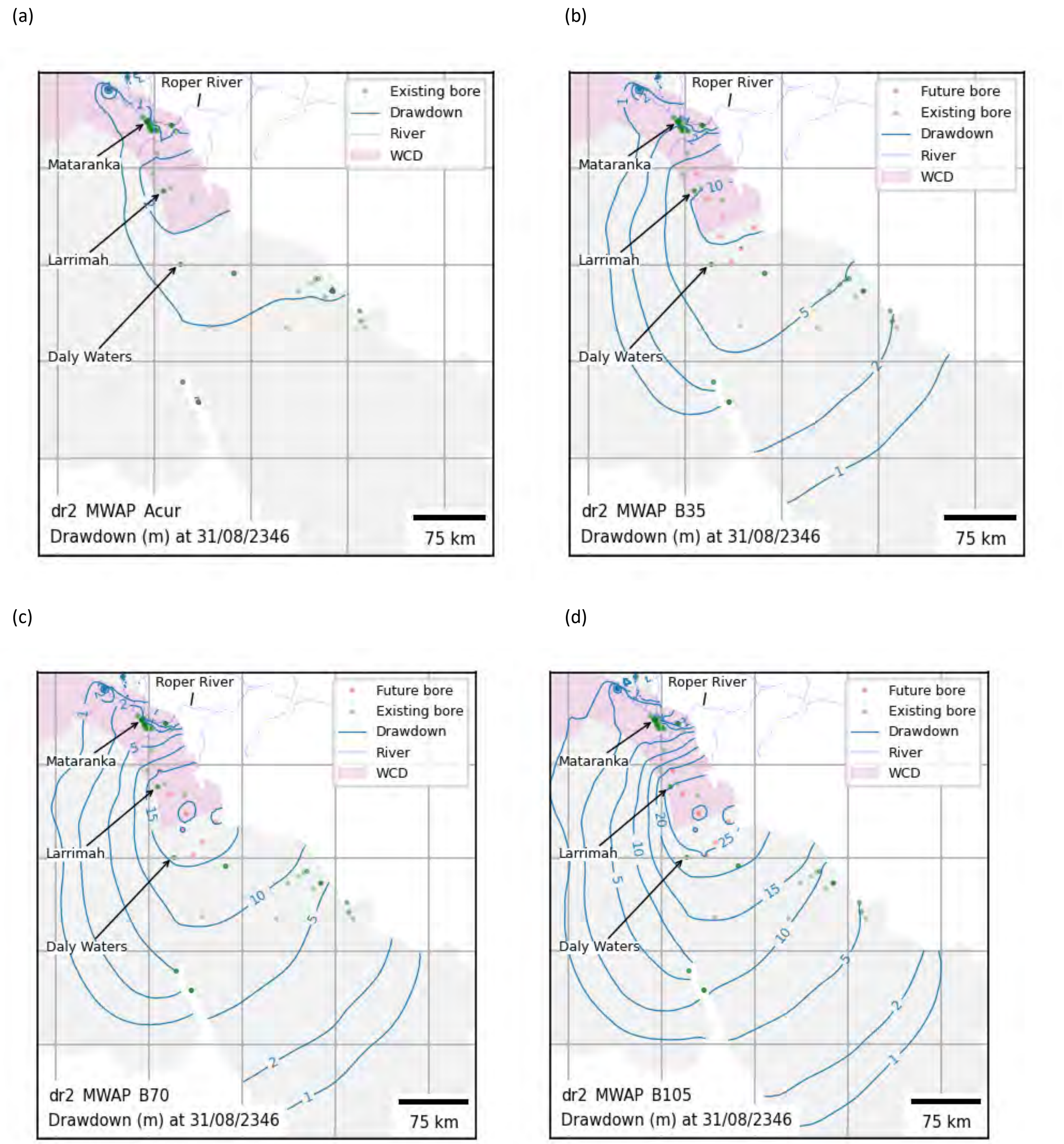
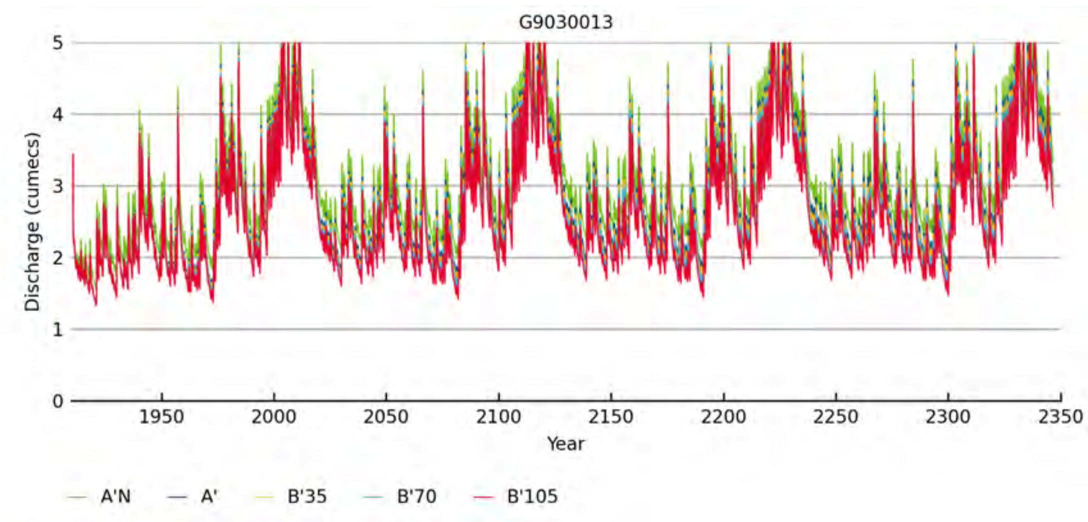


Figure 5-2 Drawdown contours relative to Scenario A′N at the end of the final climate sequence replicate under scenarios (a) A′, (b) B′35, (c) B′70 and (d) B′105

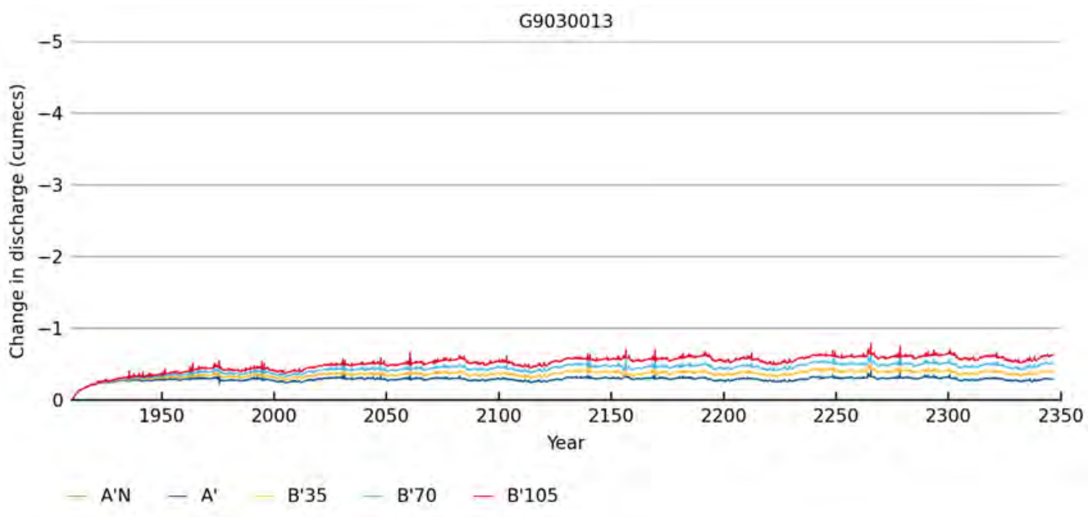
5.1.4 Scenarios A′ and B′ – groundwater discharge

Groundwater discharges to the Roper River at G9030013 (Elsey Homestead) under scenarios A′ and B′ are presented in Figure 5-3a. The groundwater discharge range at each of the sites has been clipped to accentuate the range where dry-season discharges dominate. The differences between the Scenario A′N results and the scenarios A′, B′35, B′70 and B′105 results are presented in Figure 5-3b. The differences are also presented as percentage change from Scenario A′N under scenarios A′, B′35, B′70 and B′105 in Figure 5-3c. The mean discharge for the last 109-year period from 2237 to 2346 is presented in Table 5-4.

a)



b)



c)

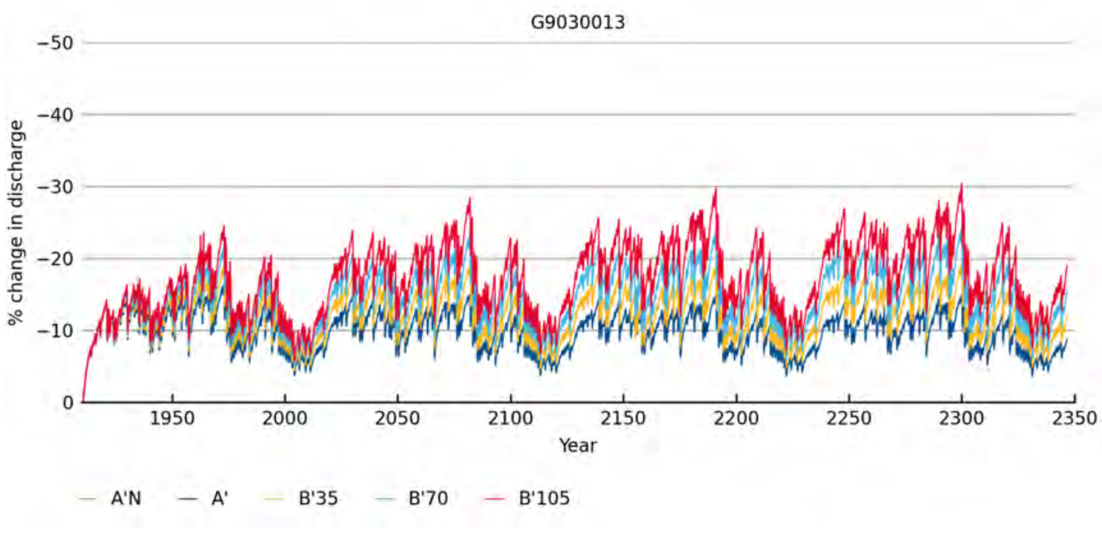


Figure 5-3 Hydrographs at G9030013 (Elsey Homestead) showing (a) groundwater discharge under scenarios A′ and B′, (b) differences between Scenario A′N and scenarios A′, B′35, B′70 and B′105 and (c) percentage change from Scenario A′N to scenarios A′, B′35, B′70 and B′105

Table 5-4 Mean groundwater discharges at the gauging site on the Roper River (G9030013) for the last 109-year climate replicate (2237 to 2346)

SCENARIO	DISCHARGE (m^3/s)	% CHANGE FROM A'N
A'N	3.3	na†
A'	3.0	−9
B'35	2.9	−12
B'70	2.8	−15
B'105	2.7	−18

A'N = Historical climate and no development; A' = Historical climate and current development; B'35 = Historical climate sequences with current development and additional future development of 35 GL/year; B'70 = Historical climate sequences with current development and additional future development of 70 GL/year; B'105 = Historical climate sequences with current development and additional future development of 105 GL/year.
†na = not applicable.

5.2 Quasi-equilibrium future climate (scenarios C' and D')

Two scenarios (C' and D') were used to examine the effects of current and future entitlements in conjunction with the three future climate sequences on the catchment water balance, groundwater levels and discharge to the river. The three input climate sequences (dry, mid and wet) represent changes in the mean annual rainfall of approximately −10, −2 and +10% and in PET of +10, +7.5 and +5%, respectively, from the historical climate sequence employed in Scenario A'N.

5.2.1 Scenarios C' and D' – last 109-year water balances (2327 to 2436)

The mean annual water balances under scenarios C' and D' s for the last 109-year replicate of the 436-year future climate sequence are presented for the MWMZ in Table 5-5 and for the LWMZ in Table 5-6.

Because none of the hypothetical development sites are in the MWMZ, scenarios D'35, D'70 and D'105 have the same extraction as the A' and C' scenarios (i.e. 23.8 GL/year). Three of the hypothetical future groundwater development sites are in the LWMZ and four are in the southern portion of the Roper catchment.

The mean annual water balances under each future climate sequence (i.e. scenarios C' and D') indicate that, although the future rainfall for the mid climate sequences is similar to the historical rainfall (Section 4.1.1), the Scenario C'mid recharge value is less than the Scenario A'N recharge because the Scenario C'mid climate sequence has a 7.5% higher PET rate, resulting in less deep drainage by the recharge models.

The discharge of groundwater as ET relative to Scenario A'N decreases under scenarios C'dry and C'mid and increases under Scenario C'wet (relative to Scenario A'N, change under C'dry = −67%, C'mid = −55% and C'wet = +3%). Similar changes are seen in discharge to the Roper River (relative to Scenario A'N, change under C'dry = −45%, C'mid = −27% and C'wet = +8%).

The net inflow to the MWMZ decreases from 30.2 GL/year under Scenario A'N to 7.1 GL/year under C'dry and 18.2 GL/year inflow under C'mid. Under Scenario C'wet the net inflow increases to 64.6 GL/year.

The net inflow to the MWMZ reverses to net outflow under Scenario D′dry, −5 GL/year under Scenario D′dry35 up to -27 GL/year under Scenario D′dry105. This is due to the hypothetical future groundwater extraction inducing groundwater flows from the MWMZ into the LWMZ to the south-east.

The reductions in ET, discharge to the rivers and groundwater inflows to the MWMZ are due to the increase in groundwater extraction associated with the hypothetical future groundwater developments in and to the south of the LWMZ.

In the LWMZ, scenarios D′35, D′70 and D′105 represent 15, 30 and 45 GL/year increases, respectively, in extraction over Scenario C′. The water balances for the Larrimah region are presented in Table 5-6. Note that there are no flows to or from rivers or to ET in the Larrimah region. This is because there are no rivers connected to groundwater in this region and because the depth of the water is greater than the depth at which ET processes operate.

Under natural conditions (i.e. Scenario A′N), groundwater flow out of LWMZ with a net inflow of -4.7 GL/yr. However, under all scenarios with either current or hypothetical future groundwater development (i.e. scenarios C′ and D′), the regime changes where groundwater flow is induced into the LWMZ. Under Scenario C′, the net inflow to the LWMZ ranges from approximately 7 GL/year under Scenario C′dry to 4 GL/year under Scenario C′wet. Under the D′ group of scenarios, the additional groundwater extraction results in a relatively consistent increase in the net inflows to the LWMZ: Scenario D′dry ranges from +21 to +49 GL/year, D′mid ranges from +20 to +48 GL/year and D′wet ranges from +18 to +47 GL/year.

Table 5-5 Mean annual water balances (GL/year) under scenarios C′ and D′ for the last 109-year climate sequence replicate (2237 to 2346) for the Mataranka Water Management Zone

	C′DRY	C′MID	C′WET	D′DRY35	D′DRY70	D′DRY105	D′MID35	D′MID70	D′MID105	D′WET35	D′WET70	D′WET105
Inflow (gains)												
Recharge (diffuse)	118.3	143.0	202.3	118.6	118.8	118.9	143.7	144.2	144.6	203.0	203.6	204.4
Release from storage	89.9	108.5	160.7	90.5	91.0	91.3	109.2	109.7	110.3	160.7	160.7	160.9
From river	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
Sub-total	**208.5**	**251.8**	**363.2**	**209.3**	**210.0**	**210.4**	**253.1**	**254.2**	**255.1**	**363.9**	**364.6**	**365.6**
Outflow (losses)												
Evapotranspiration	34.6	47.8	108.9	32.1	30.3	28.8	42.0	38.0	35.3	100.5	91.7	82.4
Extraction	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8
Capture into storage	89.6	108.7	162.8	89.7	89.6	89.6	109.0	109.3	109.4	162.5	162.3	162.2
To rivers	67.6	89.7	132.3	58.9	49.8	41.6	83.7	76.1	67.8	128.7	125.3	121.8
Sub-total	**215.6**	**270**	**427.8**	**204.5**	**193.5**	**183.8**	**258.5**	**247.1**	**236.2**	**415.4**	**403.1**	**390.1**
Net flow In (+ve) / out (-ve)	**+7.1**	**+18.2**	**+64.6**	**−4.8**	**−16.5**	**−26.6**	**+5.4**	**−7.0**	**−18.9**	**+51.5**	**+38.4**	**+24.5**

C′dry = Future dry climate sequence with current development; C′mid = Future mid climate sequence with current development; C′wet = Future wet climate sequence with current development; D′dry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; D′dry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; D′dry105 = Future dry climate sequences with current development and additional future development of 105 GL/year; D′mid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; D′mid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; D′mid105 = Future mid climate sequences with current development and additional future development of 105 GL/year; D′wet35 = Future wet climate sequences with current development and additional future development of 35 GL/year; D′wet70 = Future wet climate sequences with current development and additional future development of 70 GL/year; D′wet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.

Table 5-6 Mean annual water balances (GL/year) under scenarios C′ and D′ for the last 109-year climate sequence replicate (2237 to 2346) for the Larrimah Water Management Zone

	C′DRY	C′MID	C′WET	D′DRY35	D′DRY70	D′DRY105	D′MID35	D′MID70	D′MID105	D′WET35	D′WET70	D′WET105
Inflow (gains)												
Recharge (diffuse)	1.6	4.3	11.6	1.6	1.6	1.6	4.3	4.3	4.3	11.6	11.6	11.6
Release from storage	1.6	2.6	4.6	2.4	3.5	4.2	3.4	4.3	5.2	5.3	5.8	6.3
From river	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†
Sub-total	**3.1**	**7.0**	**16.2**	**4.0**	**5.1**	**5.7**	**7.7**	**8.6**	**9.6**	**16.9**	**17.4**	**17.9**
Outflow (losses)												
Evapotranspiration	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†
Extraction	8.0	8.0	8.0	23.0	38.0	53.1	23.0	38.0	53.1	23.0	38.0	53.1
Capture into storage	2.3	4.8	12.0	2.1	1.9	1.9	4.7	4.6	4.5	11.8	11.7	11.7
To rivers	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†
Sub-total	**10.3**	**12.8**	**20.0**	**25.1**	**40.0**	**54.9**	**27.7**	**42.6**	**57.6**	**34.8**	**49.7**	**64.7**
Net flow In (+ve) / out (-ve)	**+7.1**	**+5.8**	**+3.7**	**+21.1**	**+34.9**	**+49.2**	**+20.0**	**+34.0**	**+48.0**	**+17.9**	**+32.3**	**+46.8**

C′dry = Future dry climate sequence with current development; C′mid = Future mid climate sequence with current development; C′wet = Future wet climate sequence with current development; D′dry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; D′dry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; D′dry105 = Future dry climate sequences with current development and additional future development of 105 GL/year; D′mid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; D′mid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; D′mid105 = Future mid climate sequences with current development and additional future development of 105 GL/year; D′wet35 = Future wet climate sequences with current development and additional future development of 35 GL/year; D′wet70 = Future wet climate sequences with current development and additional future development of 70 GL/year; D′wet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.
†na = not applicable.

5.2.2 Scenarios C′ and D′ – groundwater levels

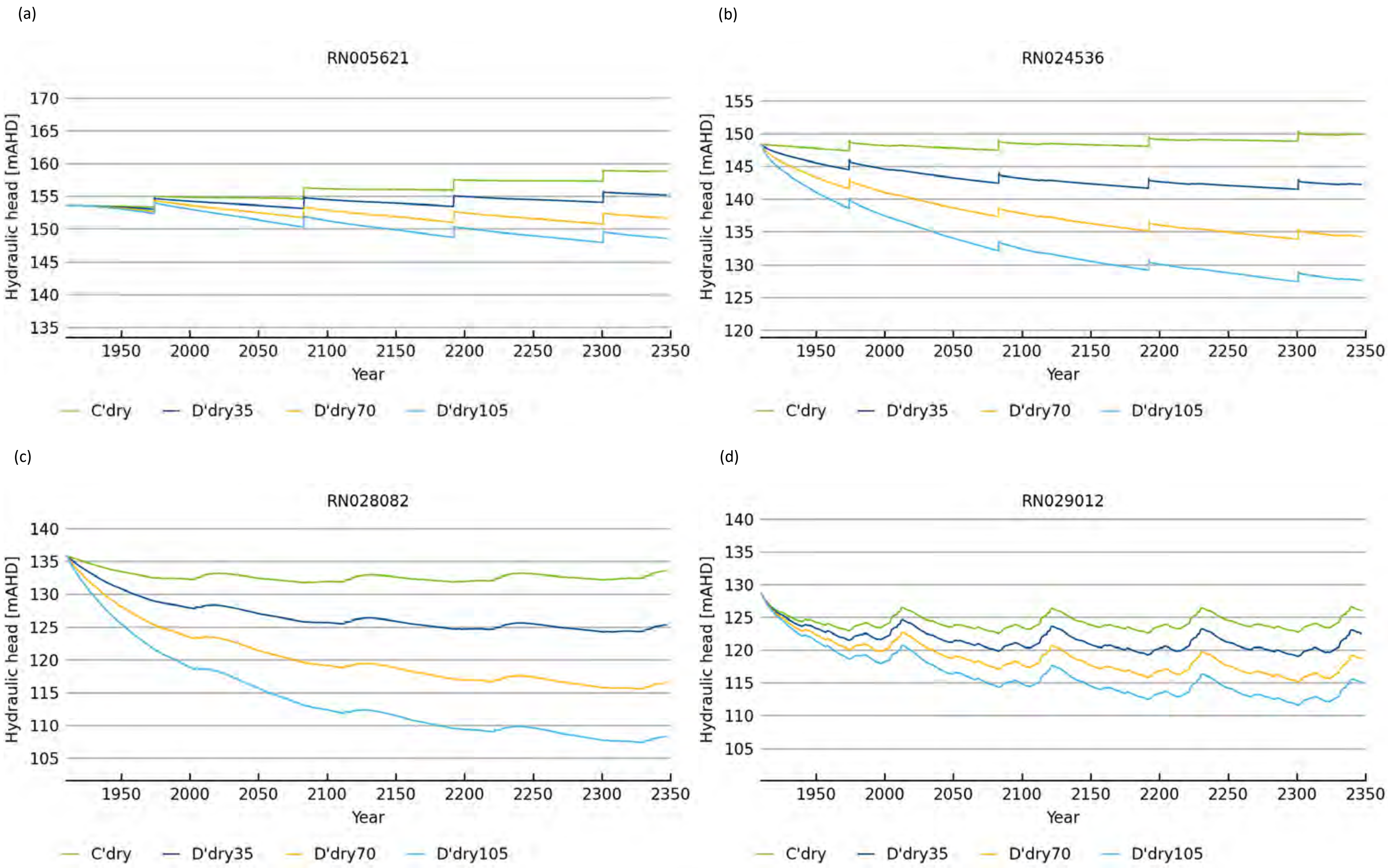
Hydrographs of groundwater levels at the six reporting sites are presented for scenarios C′dry and D′dry (Figure 5-4), scenarios C′mid and D′mid (Figure 5-5) and scenarios C′wet and D′wet (Figure 5-6). The groundwater-level hydrographs respond in the expected manner for the three climate sequences; that is, the dry sequences show the lowest groundwater levels, the wet sequences show the highest groundwater levels and the mid sequences groundwater levels sit somewhere in between the two extremes.

Groundwater levels decrease as groundwater development increases. Groundwater levels under Scenario D′dry are much lower than any recorded historical levels. Mean groundwater levels for the C′ and D′ scenarios are presented in Table 5-7.

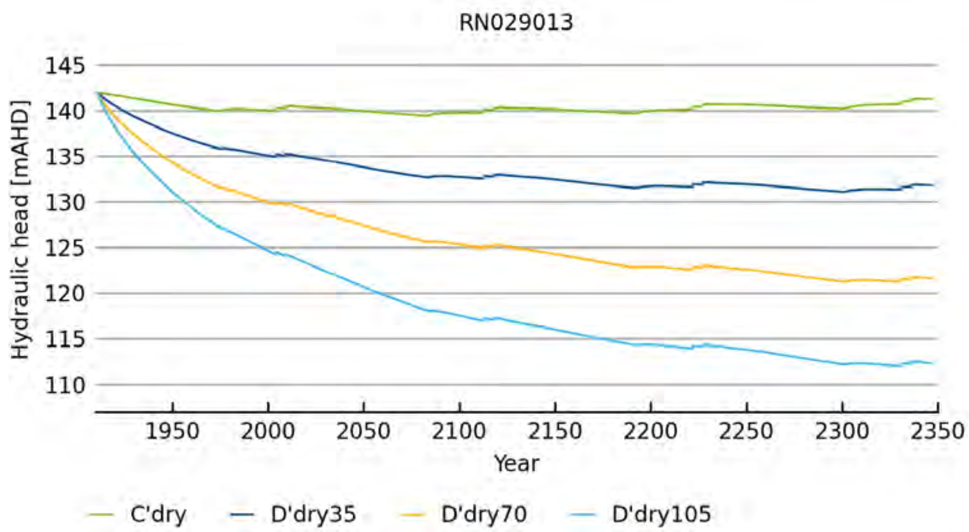
Table 5-7 Mean groundwater levels (mAHD) under scenarios C′ and D′ for the last 109-year climate sequence replicate (2237 to 2346)

SCENARIO	RN005621	RN024536	RN028082	RN029012	RN029013	RN035796
A′	169.5	160.5	144.0	133.6	152.3	118.5
C′dry	158	149.4	132.7	124.1	140.6	116.8
C′mid	164.1	154.8	137.5	127.8	145.9	117.8
C′wet	186.1	173.7	151.2	135.4	162.6	119.7
D′dry35	154.8	142.1	124.8	120.6	131.6	116.4
D′dry70	151.6	134.6	116.3	116.8	121.8	115.9
D′dry105	148.8	128.1	108.4	113.3	112.8	115.4
D′mid35	160.8	147.7	130.1	124.7	137.2	117.6
D′mid70	157.6	140.3	122.1	121.2	127.9	117.2
D′mid105	154.5	133.0	113.6	117.7	118	116.8
D′wet35	182.8	166.6	144.6	132.9	154.6	119.6
D′wet70	179.6	159.6	137.7	130.4	146.3	119.4
D′wet105	176.4	152.5	130.4	127.8	137.7	119.3

A′N = Historical climate and no development; C′dry = Future dry climate sequence with current development; C′mid = Future mid climate sequence with current development; C′wet = Future wet climate sequence with current development; D′dry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; D′dry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; D′dry105 = Future climate sequences with current development and additional future development of 105 GL/year; D′mid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; D′mid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; D′mid105 = Future mid climate sequences with current development and additional future development of 105 GL/year; D′wet35 = Future wet climate sequences with current development and additional future development of 35 GL/year; D′wet70 = Future wet climate sequences with current development and additional future development of 70 GL/year; D′wet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.


(a)
RN005621
Hydraulic head [mAHD]
Year
C'dry
D'dry35
D'dry70
D'dry105
(b)
RN024536
Hydraulic head [mAHD]
Year
C'dry
D'dry35
D'dry70
D'dry105
(c)
RN028082
Hydraulic head [mAHD]
Year
C'dry
D'dry35
D'dry70
D'dry105
(d)
RN029012
Hydraulic head [mAHD]
Year
C'dry
D'dry35
D'dry70
D'dry105

(e)



(f)

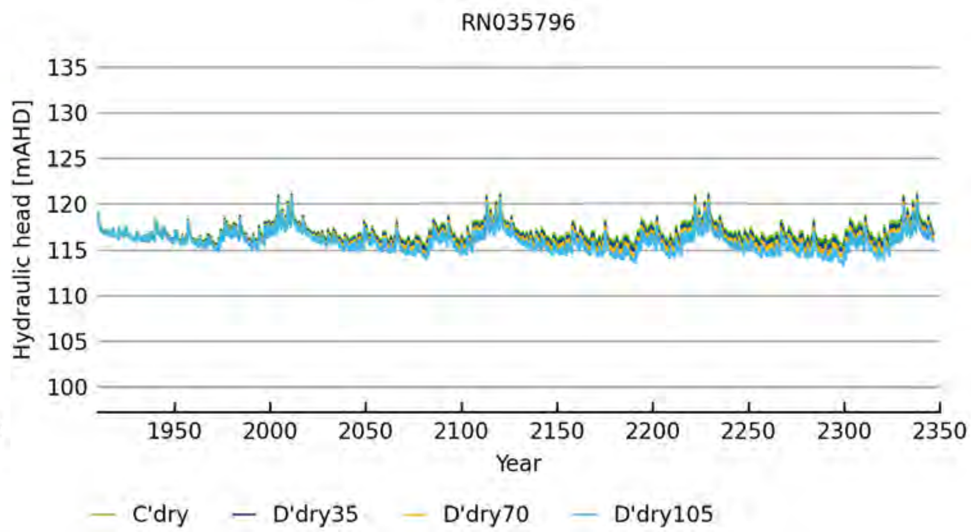
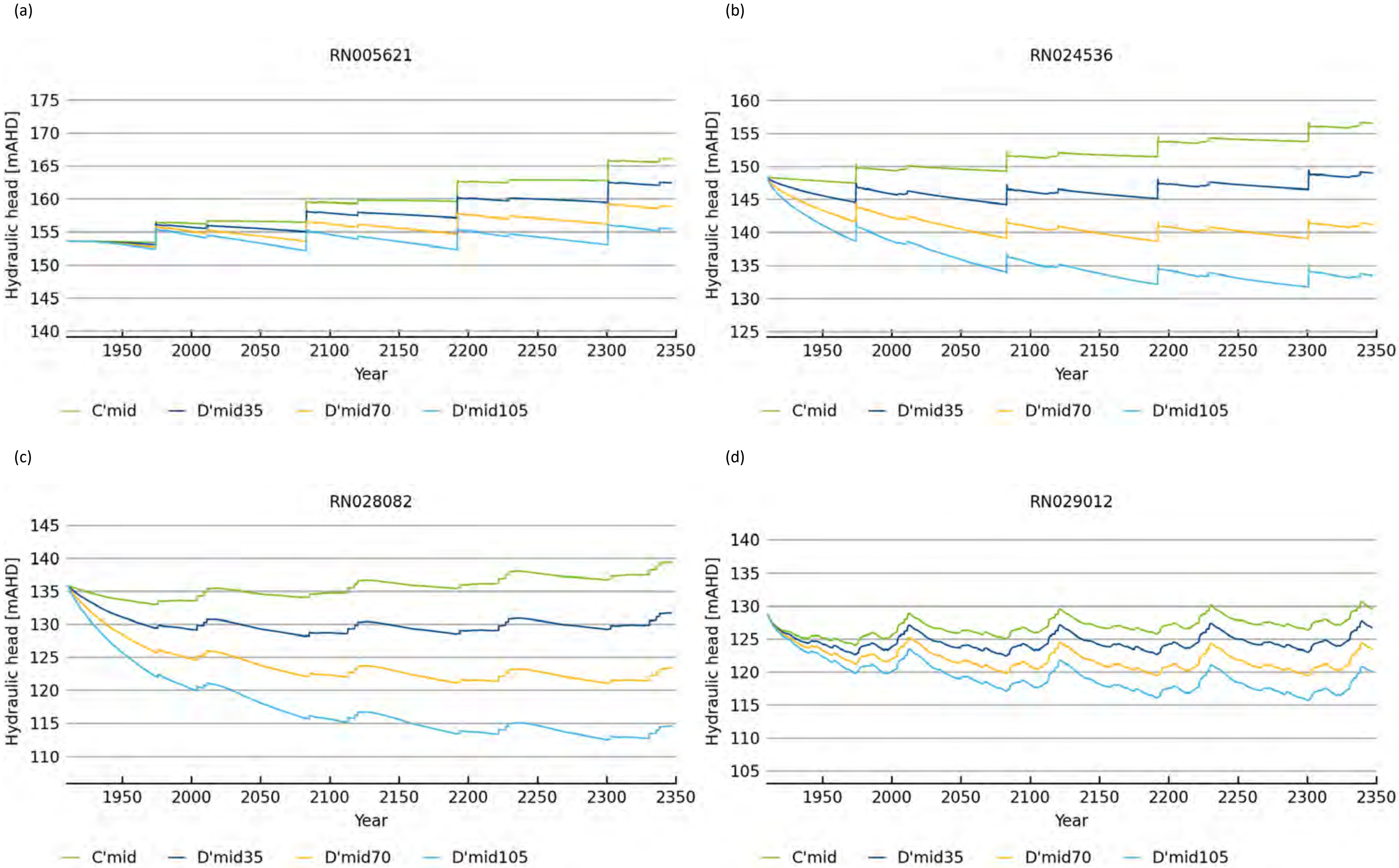


Figure 5-4 Hydrographs of groundwater level (mAHD) under quasi-equilibrium scenarios C'dry and D'dry at the six reporting sites: (a) RN005621, (b) RN024536, (c) RN028082, (d) RN029012, (e) RN029013 and (f) RN035796


(a)
RN005621
Hydraulic head [mAHD]
175
170
165
160
155
150
145
140
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
C'mid
D'mid35
D'mid70
D'mid105
(b)
RN024536
Hydraulic head [mAHD]
160
155
150
145
140
135
130
125
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
C'mid
D'mid35
D'mid70
D'mid105
(c)
RN028082
Hydraulic head [mAHD]
145
140
135
130
125
120
115
110
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
C'mid
D'mid35
D'mid70
D'mid105
(d)
RN029012
Hydraulic head [mAHD]
140
135
130
125
120
115
110
105
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
C'mid
D'mid35
D'mid70
D'mid105

(e) (f)

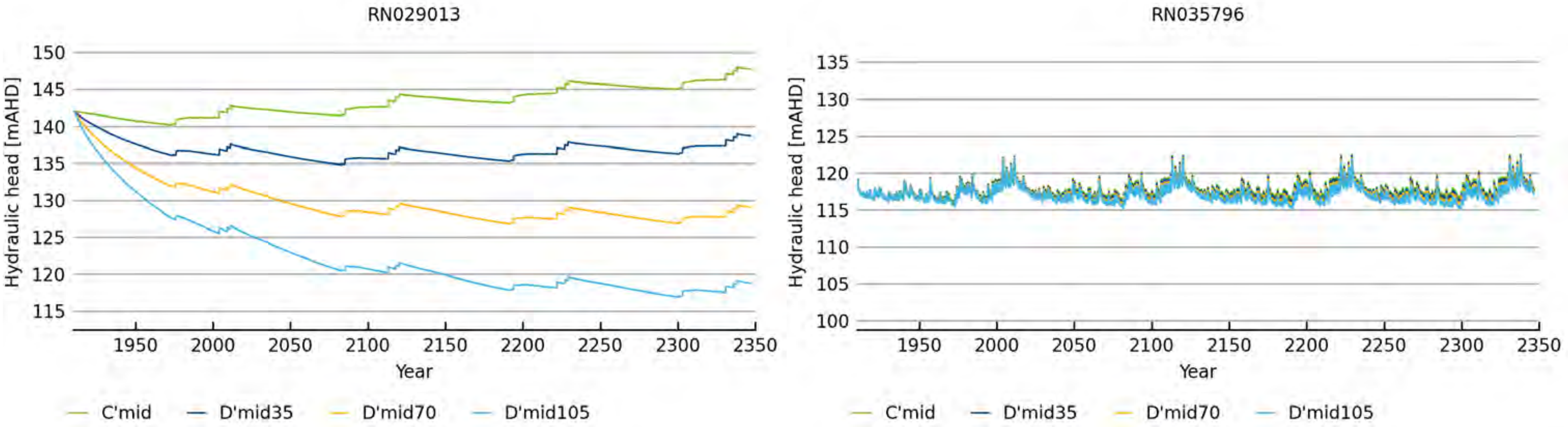
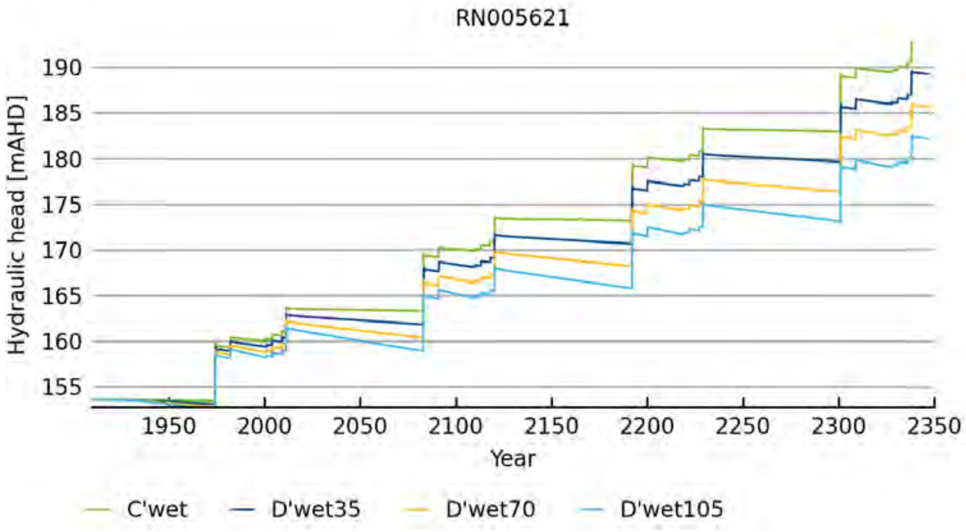


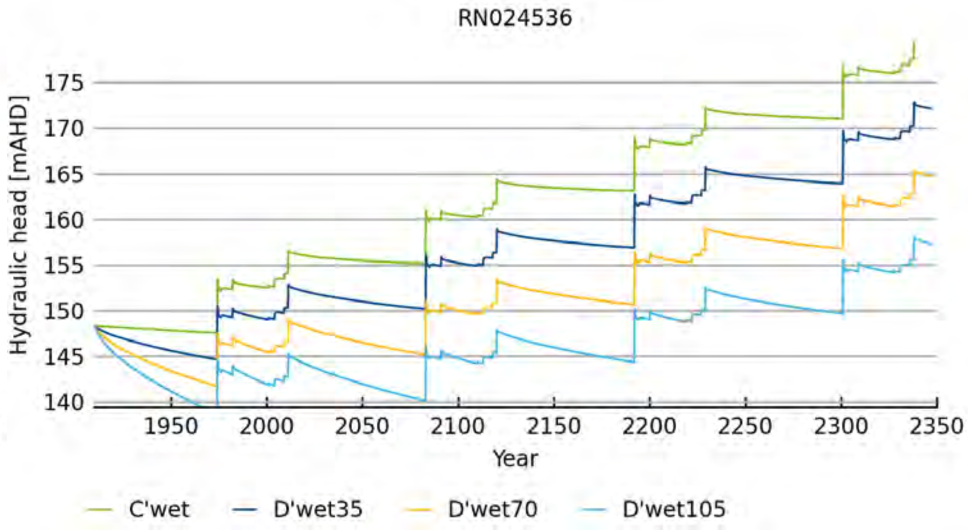
Figure 5-5 Hydrographs of groundwater level (mAHD) under quasi-equilibrium scenarios C'mid and D'mid at the six reporting sites: (a) RN005621, (b) RN024536, (c) RN028082, (d) RN029012, (e) RN029013 and (f) RN035796

(a)



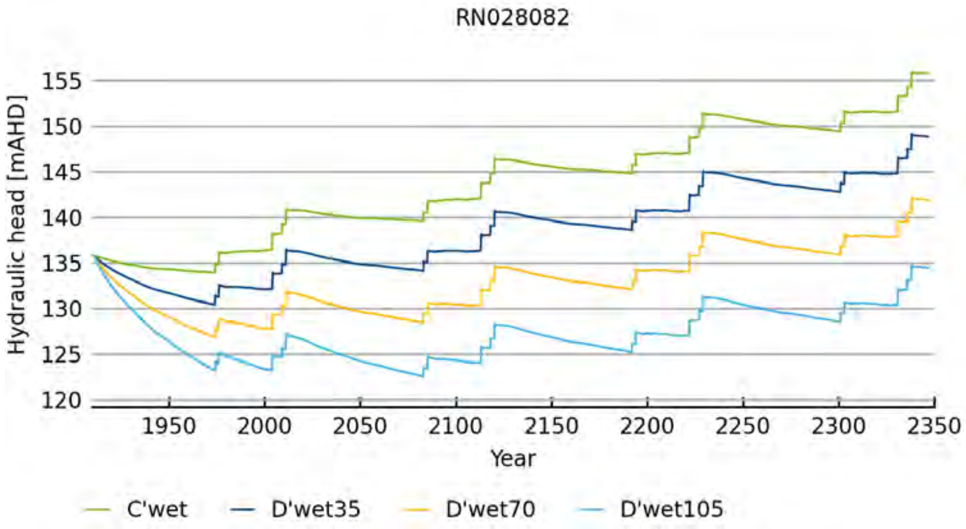
RN005621
Hydraulic head [mAHD]
190
185
180
175
170
165
160
155
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
C'wet
D'wet35
D'wet70
D'wet105

(b)



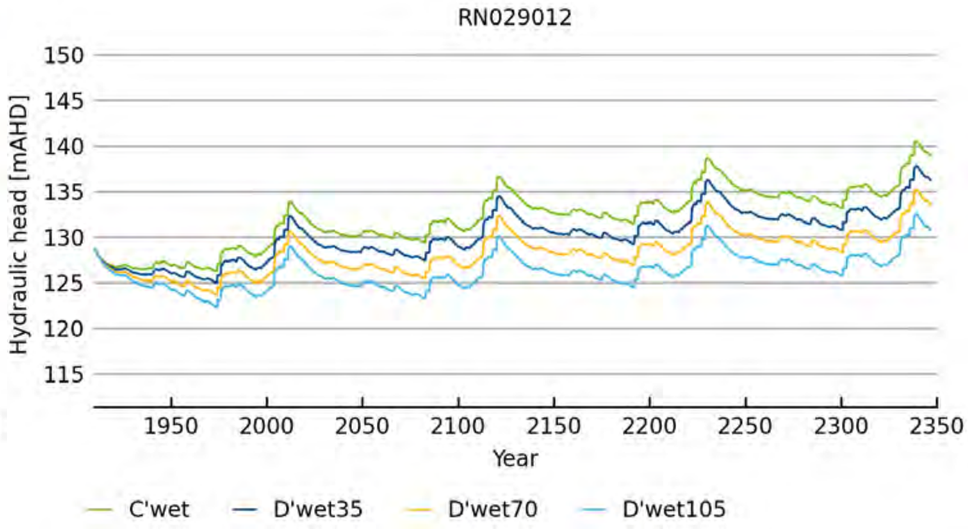
RN024536
Hydraulic head [mAHD]
175
170
165
160
155
150
145
140
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
C'wet
D'wet35
D'wet70
D'wet105

(c)



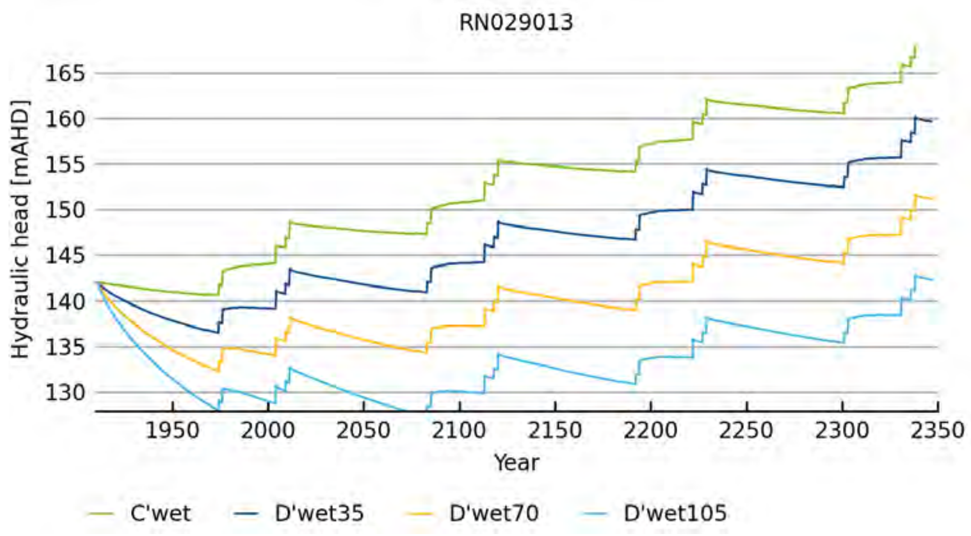
RN028082
Hydraulic head [mAHD]
155
150
145
140
135
130
125
120
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
C'wet
D'wet35
D'wet70
D'wet105

(d)



RN029012
Hydraulic head [mAHD]
150
145
140
135
130
125
120
115
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
C'wet
D'wet35
D'wet70
D'wet105

(e)



(f)

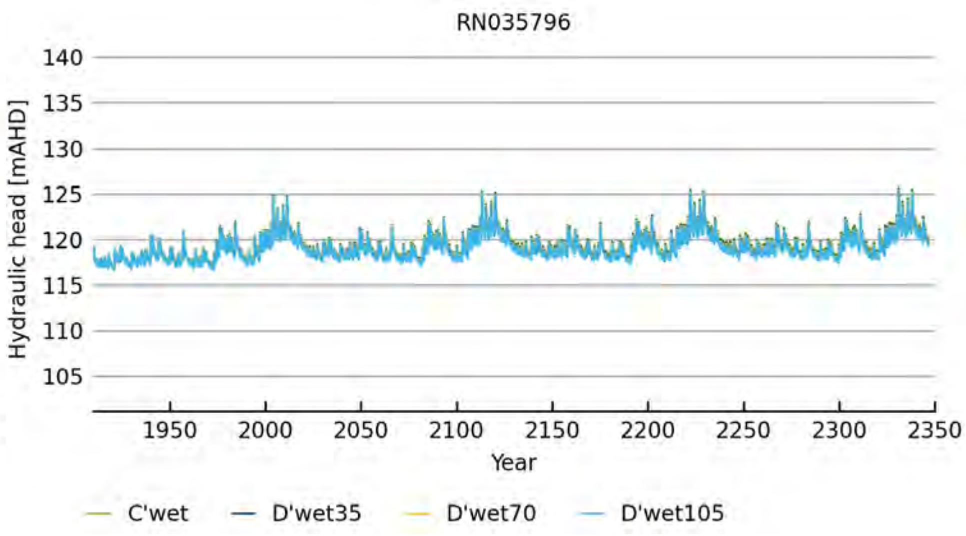


Figure 5-6 Hydrographs of groundwater level (mAHD) under quasi-equilibrium scenarios C'wet and D'wet at the six reporting sites: (a) RN005621, (b) RN024536, (c) RN028082, (d) RN029012, (e) RN029013 and (f) RN035796

5.2.3 Scenarios C′ and D′ – 436-year groundwater drawdown contours relative to A′N

The drawdown contours under scenarios C′dry, D′dry35, D′dry70 and D′dry105 are presented in Figure 5-7a, Figure 5-7b, Figure 5-7c, and Figure 5-7d, respectively. The maximum drawdown under Scenario C′dry is greater than 40 m and is centred in the south-east of the model domain far removed from any effects of groundwater extraction. The drawdown contours under Scenario D′dry35 are similar to Scenario C′dry but the impact of the additional extraction in the LWMZ is apparent. The drawdown in the LWMZ becomes greater with increased extraction under scenarios D′dry70 and D′dry105.

The drawdown contours under scenarios C′mid, D′mid35, D′mid70 and D′mid105 are presented in Figure 5-8a, Figure 5-8b, Figure 5-8c, and Figure 5-8d, respectively. The maximum drawdown under Scenario C′mid is greater than 15 m in the south-east of the model domain and reflective of the reduced recharge. There is increasing drawdown centred on the LWMZ as increasing future hypothetical development is simulated under scenarios D′mid35, D′mid70 and D′mid105.

The drawdown contours under scenarios C′wet, D′wet35, D′wet70 and D′wet105 are presented in Figure 5-9a, Figure 5-9b, Figure 5-9c and Figure 5-9d, respectively. Scenario C′wet shows an increase in groundwater level (negative drawdown) almost everywhere in the model domain with a maximum of greater than 50 m increase in groundwater levels in the south-east of the model domain. There is increasing drawdown centred on the LWMZ as increasing future hypothetical development is simulated under scenarios D′mid35, D′mid70 and D′mid105.

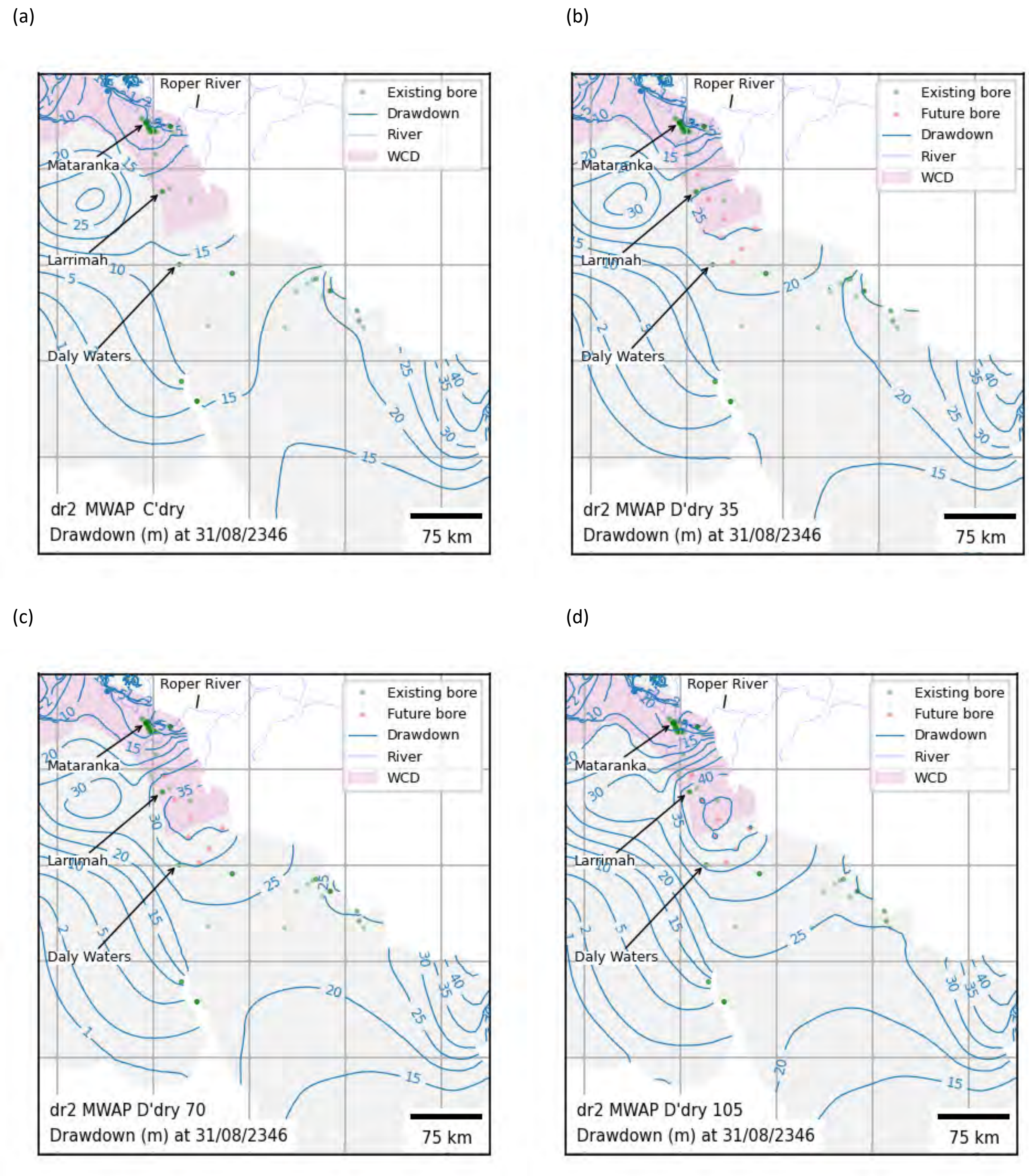


Figure 5-7 Drawdown contours relative to A'N at the end of the 436-year dry climate sequences under scenarios (a) C'dry (b) D'dry35, (c) D'dry70 and (d) D'dry105

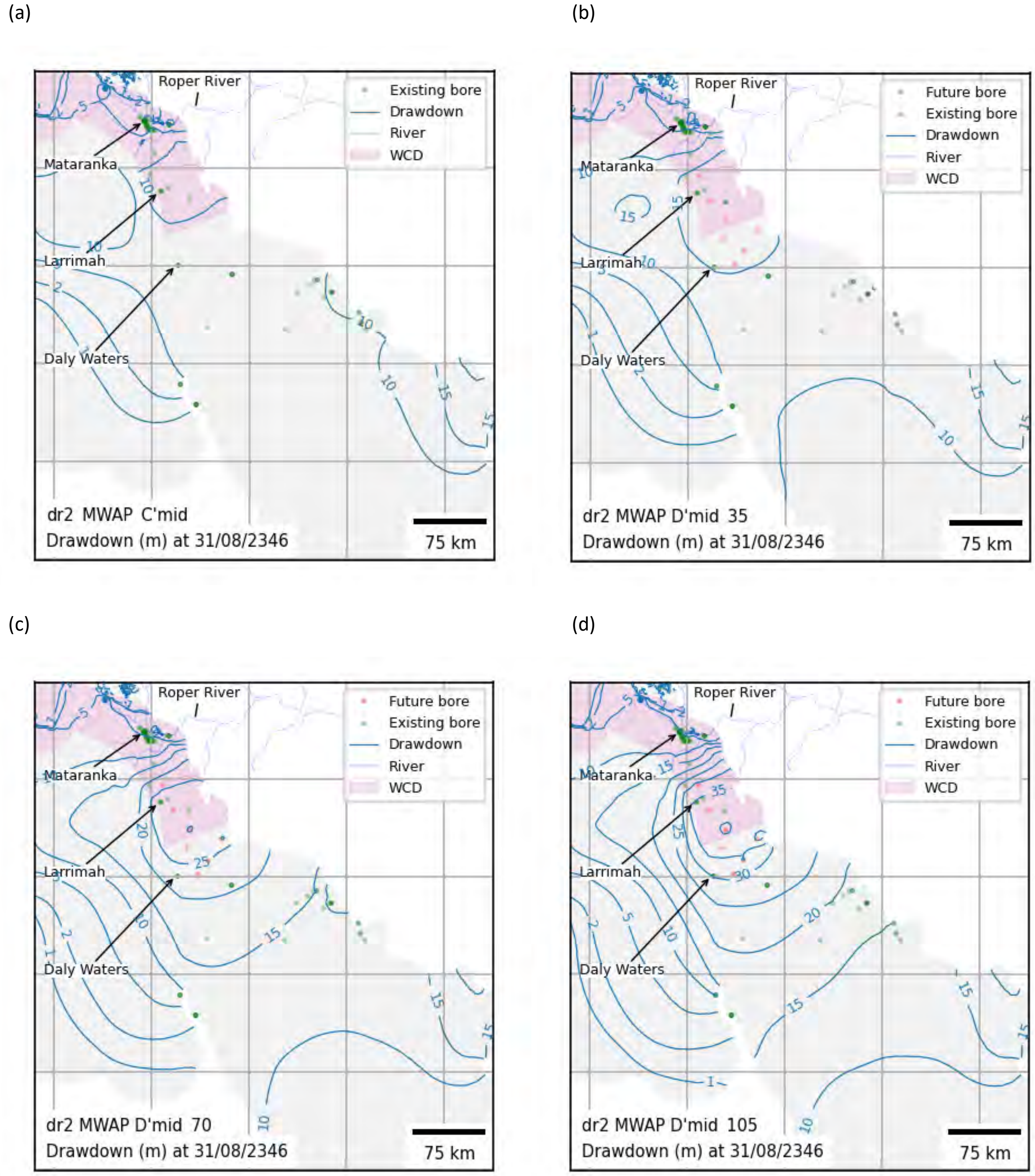


Figure 5-8 Drawdown contours relative to A'N at the end of the 436-year mid climate sequences under scenarios (a) C'mid (b) D'mid35, (c) D'mid70 and (d) D'mid105

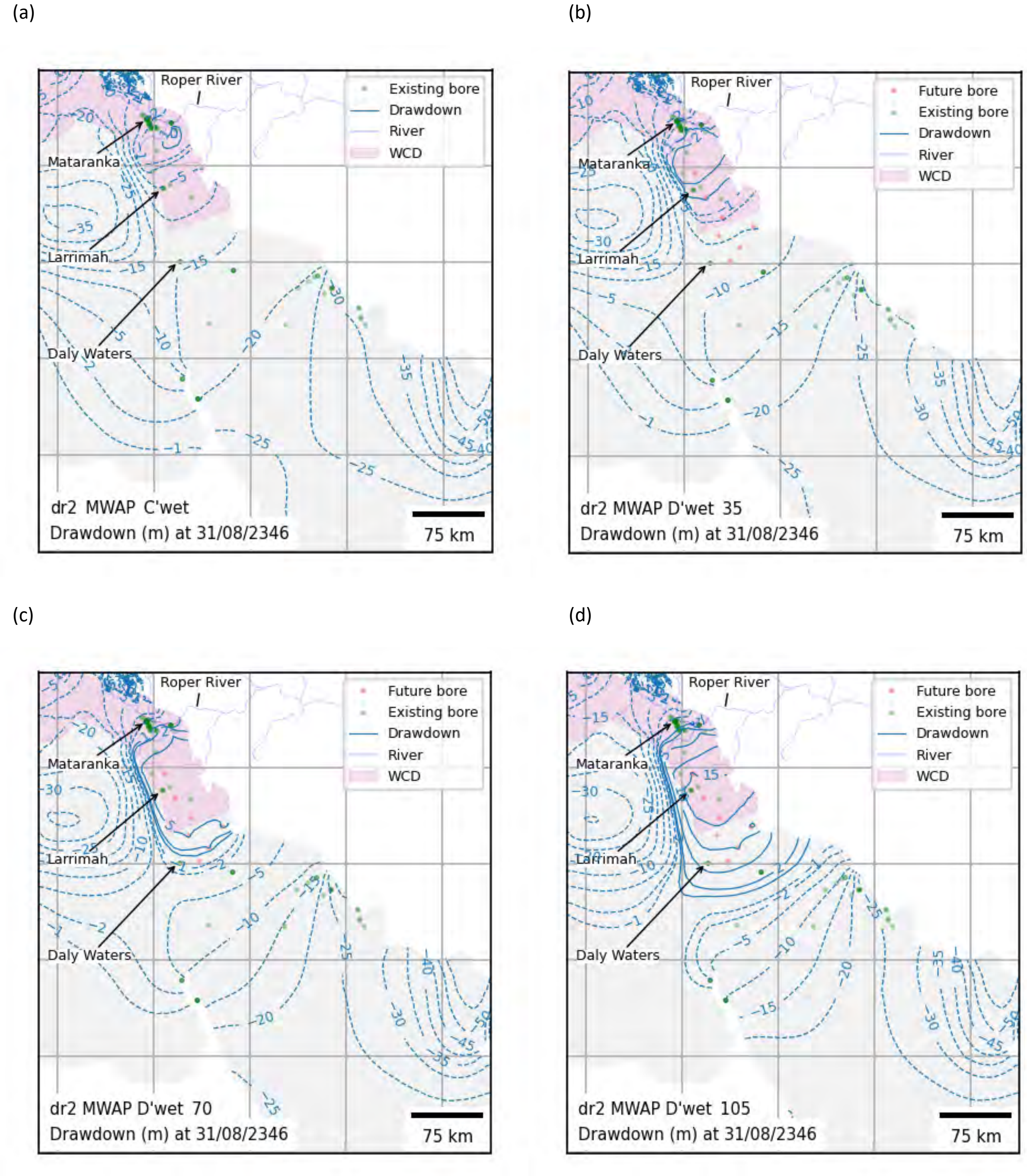


Figure 5-9 Drawdown contours relative to A′N at the end of the 436-year wet climate sequences under scenarios (a) C′wet (b) D′wet35, (c) D′wet70 and (d) D′wet105

Dashed lines indicate contours with negative values (i.e. groundwater-level rises relative to Scenario A′N).

5.2.4 Scenarios C′ and D′ – groundwater discharge

This section presents the simulated groundwater discharge at G9030013 (Roper River at Elsey Homestead) under scenarios C′ and D′. The locations of the groundwater discharge reporting sites are shown in Figure 4-5. The mean groundwater discharge for the last 109-year of the 436-year climate sequence under scenarios C′, D′dry, D′mid and D′wet is presented in Table 5-8. Hydrographs of groundwater discharge at G9030013 under scenarios C′, D′dry, D′mid, and D′wet are presented in Figure 5-10, Figure 5-11, Figure 5-12, and Figure 5-13, respectively.

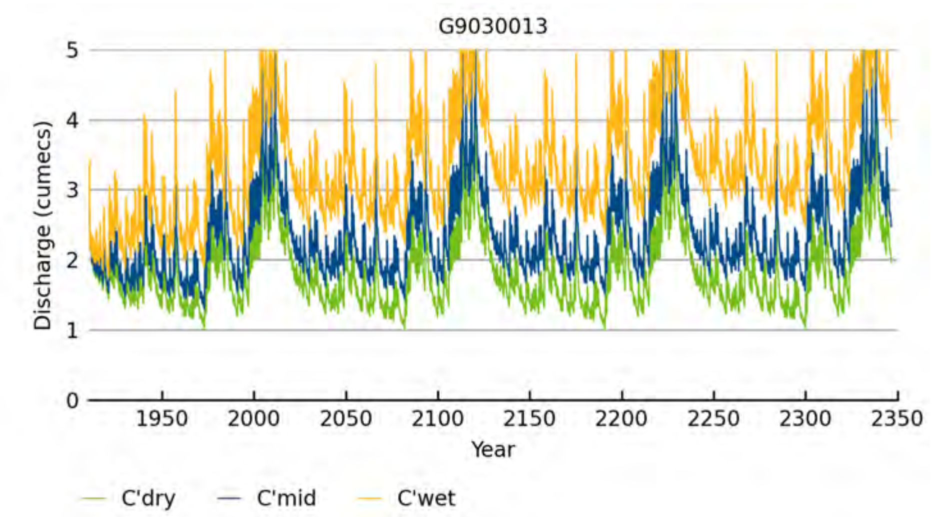
The C′dry and C′mid scenarios have less groundwater discharge than the A′N scenario due to the reduction in recharge. Conversely the C′wet Scenario has an increase in groundwater discharge to the Roper River. The D′ scenarios show a further reduction in discharge from the C′ scenarios with increasing future extraction.

Table 5-8 Mean groundwater discharge for the last 109-year climate sequence replicate (2237 to 2346) under scenarios C′ and D′ at G9030013 along the Roper River and the percentage change from Scenario A′N

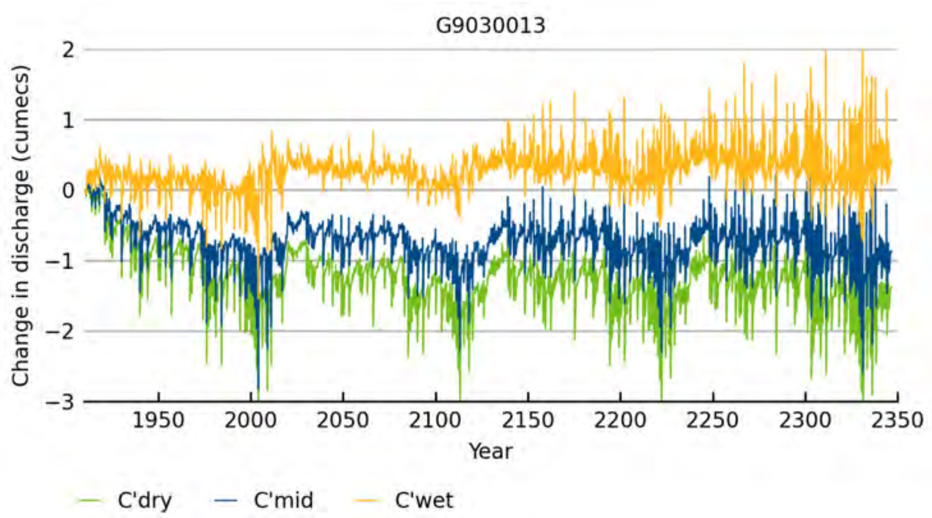
SCENARIO	GROUNDWATER DISCHARGE (m^3/s)	% CHANGE FROM A′N
A′N	3.3	na†
C′dry	1.8	−45
C′mid	2.5	−26
C′wet	3.6	10
D′dry35	1.6	−52
D′dry70	1.4	−59
D′dry105	1.1	−66
D′mid35	2.3	−31
D′mid70	2.1	−37
D′mid105	1.9	−44
D′wet35	3.5	7
D′wet70	3.5	4
D′wet105	3.4	2

A′N = Historical climate and no development; C′dry = Future dry climate sequence with current development; C′mid = Future mid climate sequence with current development; C′wet = Future wet climate sequence with current development; D′dry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; D′dry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; D′dry105 = Future climate sequences with current development and additional future development of 105 GL/year; D′mid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; D′mid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; D′mid105 = Future mid climate sequences with current development and additional future development of 105 GL/year; Dwet35 = Future wet climate sequences with current development and additional future development of 35 GL/year; Dwet70 = Future wet climate sequences with current development and additional future development of 70 GL/year; Dwet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.
†na = not applicable.

(a)



(b)



(c)

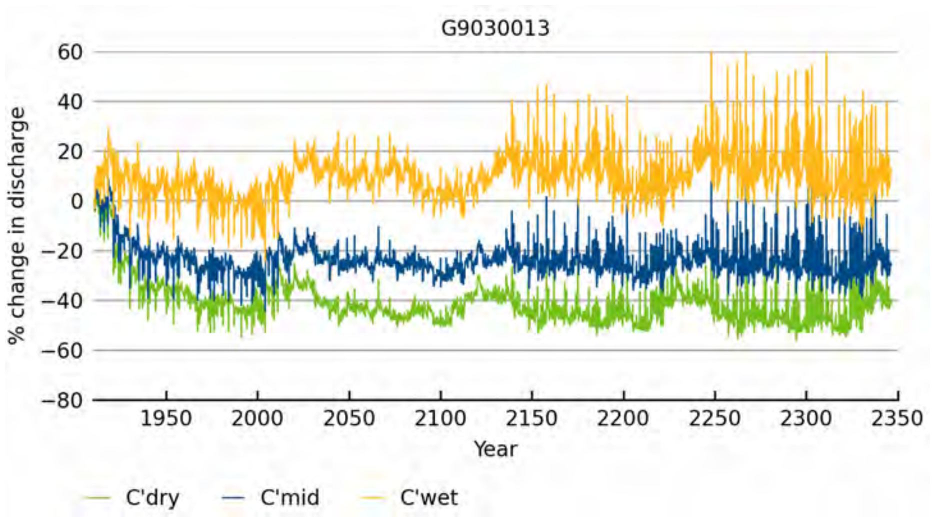
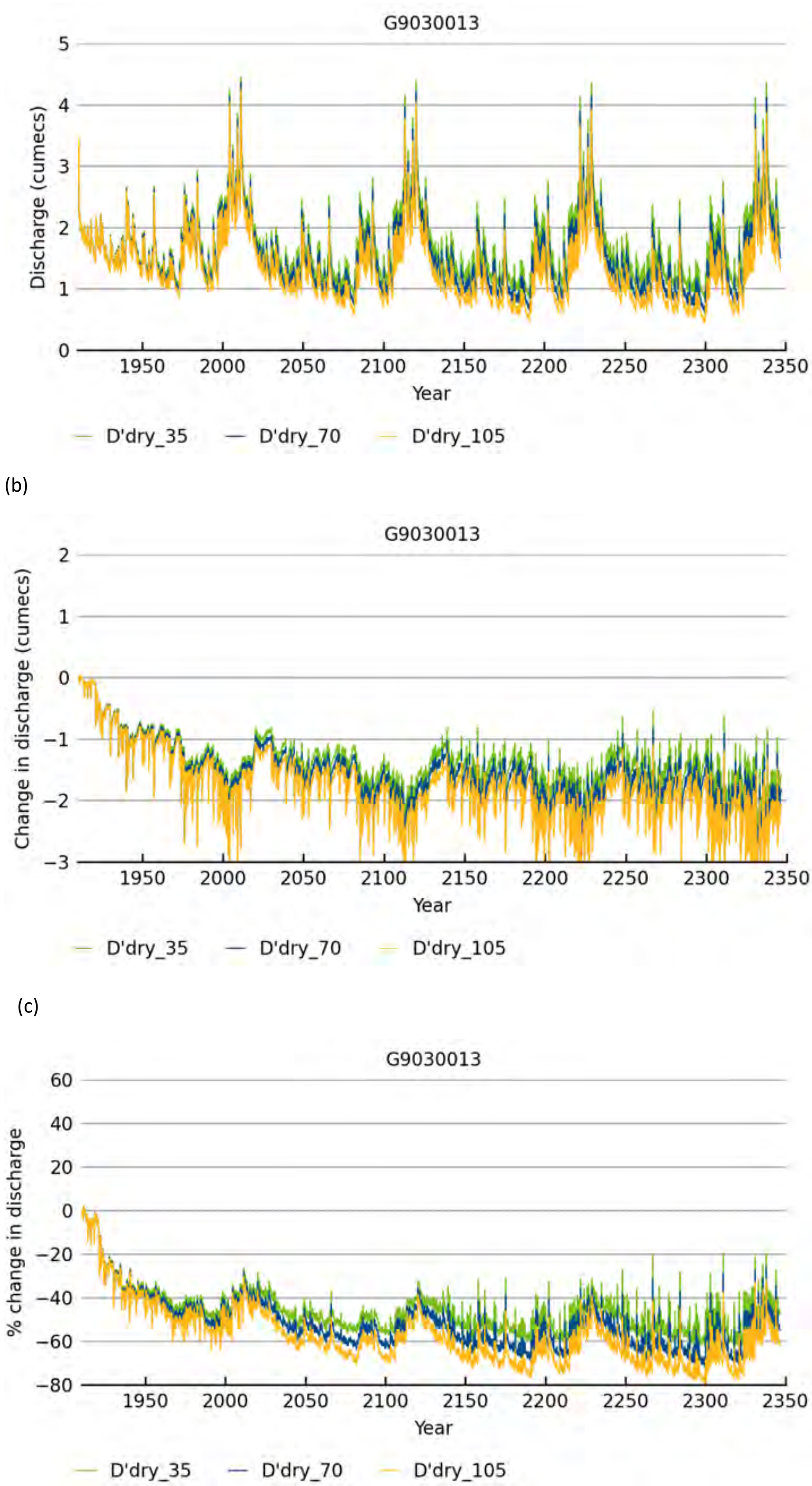


Figure 5-10 Hydrographs of groundwater discharge under Scenario C′ at gauging station G9030013 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A′N

(a)

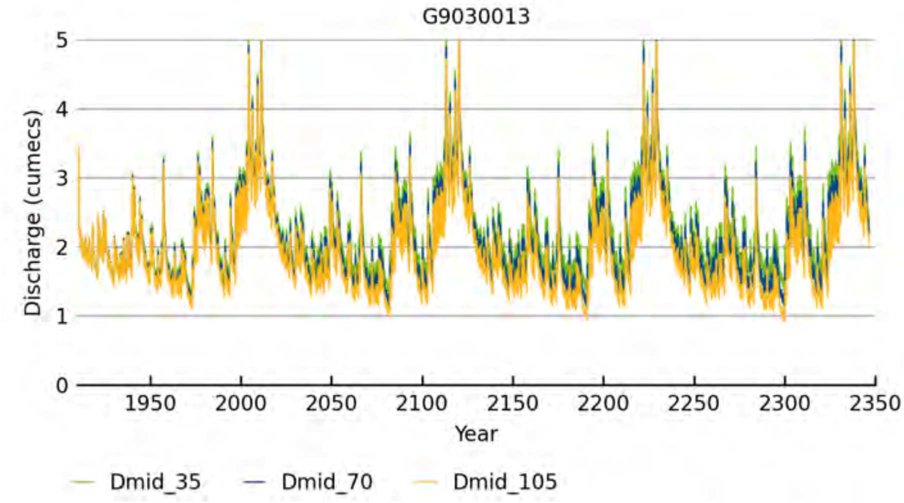


(b)

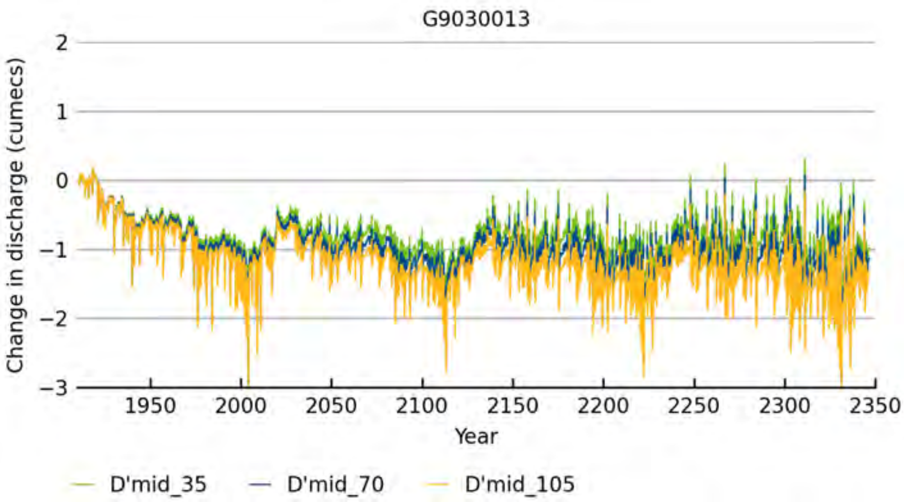
(c)

Figure 5-11 Hydrographs of groundwater discharge under Scenario D'dry at G9030013 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'N

(a)



(b)



(c)

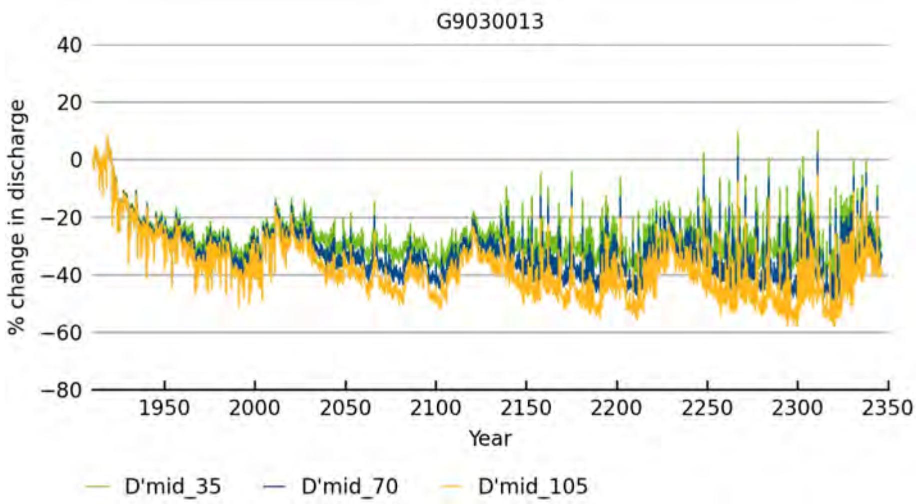
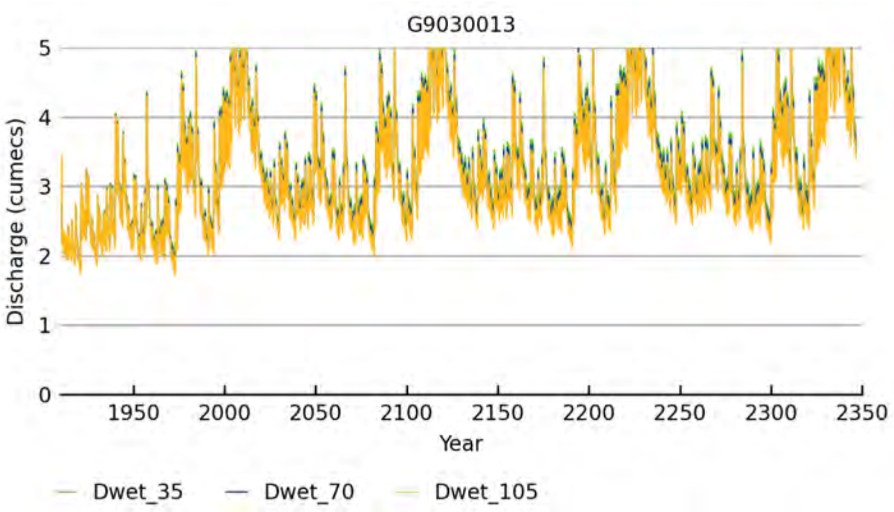
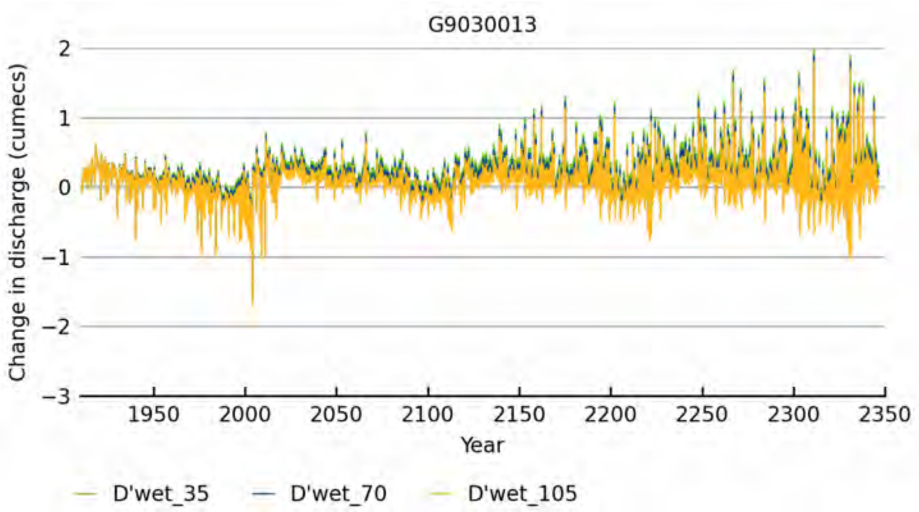


Figure 5-12 Hydrographs of groundwater discharge under Scenario D'mid at G9030013 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'N

(a)



(b)



(c)

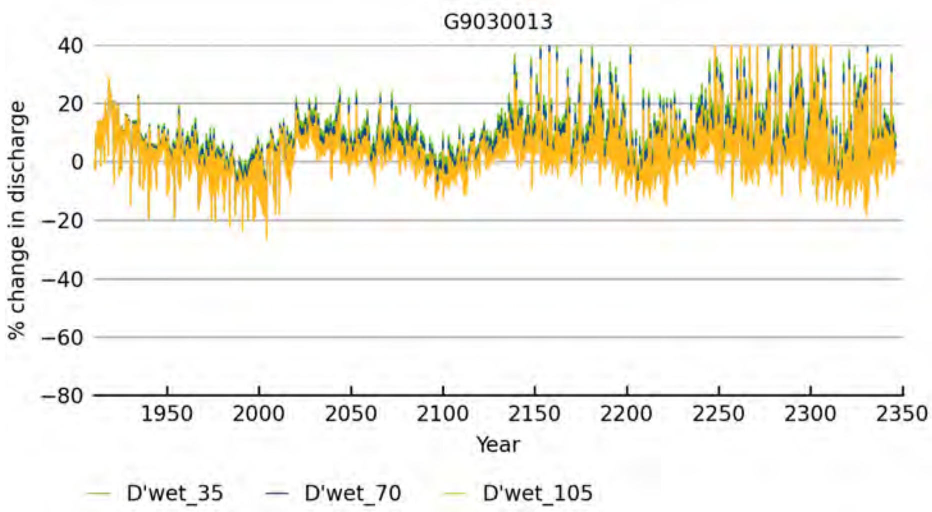


Figure 5-13 Hydrographs of groundwater discharge under Scenario D'wet at G9030013 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'N

6 Cambrian Limestone Aquifer 2059 to 2069 representative conditions results

6.1 Historical climate (scenarios A and B)

6.1.1 Scenarios A and B – water balances

The mean annual groundwater balance for the period 2059 to 2069 under scenarios AN, A, B35, B70 and B105 are presented for the MWMZ (Table 6-1) and the LWMZ (Table 6-2). The range in the water balance results is presented for the MWMZ and the LWMZ under Scenario A (Figure 6-1) and Scenario B (Figure 6-2).

None of the hypothetical groundwater development sites are in the MWMZ. Despite this, there is a decrease in groundwater discharging as ET (relative to Scenario AN, changes are A = −13%, B35 = −15%, B70 = −18% and B105 = −21%) and as discharge to the Roper River (relative to Scenario AN, changes are A = −9%, B35 = −10%, B70 = −10% and B105 = −11%).

The net inflow/outflow to the MWMZ also undergoes change, shifting from approximately +22 GL/year inflow under Scenario AN to a net inflow of +2 GL/year under Scenario B105. The reductions in ET, discharge to the rivers and groundwater inflows to the MWMZ are due to drawdown in the discharge areas of the model because of the increase in groundwater extraction associated with the hypothetical future groundwater developments in and to the south of the LWMZ.

The increase in groundwater extraction relative to Scenario AN in the LWMZ (Table 6-2) is balanced by inflows from the release of groundwater from storage and inflows to the LWMZ from outside the zone. The net flow to the LWMZ undergoes a change in direction, shifting from approximately -5 GL/year outflow under Scenario AN to +28 GL/year inflow under Scenario B105.

Table 6-1 Mean 10-year (2059 to 2069) annual water balances (GL/year) under scenarios A and B for the Mataranka Water Management Zone

	AN	A	B35	B70	B105
Inflow (gains)					
Recharge (diffuse)	204.0	205.5	205.8	206.1	206.3
Release from storage	189.7	189.2	190.8	192.7	194.4
From river	1.7	1.9	1.9	1.8	1.8
Sub-total	**395.5**	**396.6**	**398.5**	**400.6**	**402.6**
Outflow (losses)					
Evapotranspiration	101.1	88.4	85.5	82.8	80.1
Extraction	0	23.8	23.8	23.8	23.8
Capture into storage	195.6	195.0	194.3	193.8	193.3
To rivers	120.8	110.3	109.3	108.5	107.5

	AN	A	B35	B70	B105
Sub-total	**417.5**	**417.5**	**413.0**	**408.8**	**404.6**
Net flow In (+ve) / out (-ve)	**+22.0**	**+20.9**	**+14.5**	**+8.2**	**+2.0**

AN = Historical climate and no development; A = Historical climate and current development; B35 = Historical climate sequences with current development and additional future development of 35 GL/year; B70 = Historical climate sequences with current development and additional future development of 70 GL/year; B105 = Historical climate sequences with current development and additional future development of 105 GL/year.

Table 6-2 Mean 10-year (2059 to 2069) annual water balances (GL/year) under scenarios A and B for the Larrimah Water Management Zone

	AN	A	B35	B70	B105
Inflow (gains)					
Recharge (diffuse)	8.4	8.4	8.4	8.4	8.4
Release from storage	6.0	6.5	12.3	18.6	25.1
From river	na†	na†	na†	na†	na†
Sub-total	**14.4**	**14.8**	**20.7**	**27.0**	**33.5**
Outflow (losses)					
Evapotranspiration	na†	na†	na†	na†	na†
Extraction	na†	8.0	23.0	38.0	53.1
Capture into storage	9.1	9.0	8.5	8.2	7.9
To rivers	na†	na†	na†	na†	na†
Sub-total	**9.1**	**17.1**	**31.5**	**46.2**	**61.0**
Net flow In (+ve) / out (-ve)	**–5.3**	**+2.2**	**+10.8**	**+19.3**	**+27.5**

AN = Historical climate and no development; A = Historical climate and current development; B35 = Historical climate sequences with current development and additional future development of 35 GL/year; B70 = Historical climate sequences with current development and additional future development of 70 GL/year; B105 = Historical climate sequences with current development and additional future development of 105 GL/year.
†na = not applicable.

(a) (b)

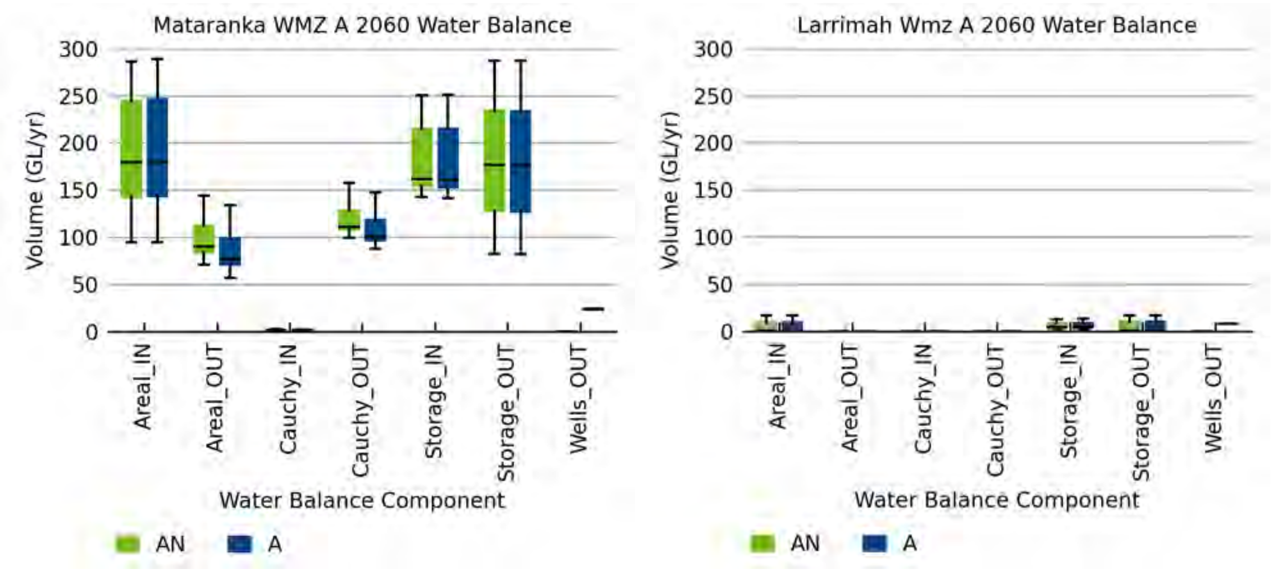


Figure 6-1 Annual water balances under Scenario A for the period 2059 to 2069 for (a) Mataranka Water Management Zone and (b) Larrimah Water Management Zone

Labels are different from Table 5-1: Areal_IN = recharge (diffuse); Areal_OUT = evapotranspiration; Cauchy_IN = from river; Cauchy_OUT = to river; Storage_IN = release from storage; Storage_OUT = capture into storage; and, Wells_OUT = extraction.

(a) (b)

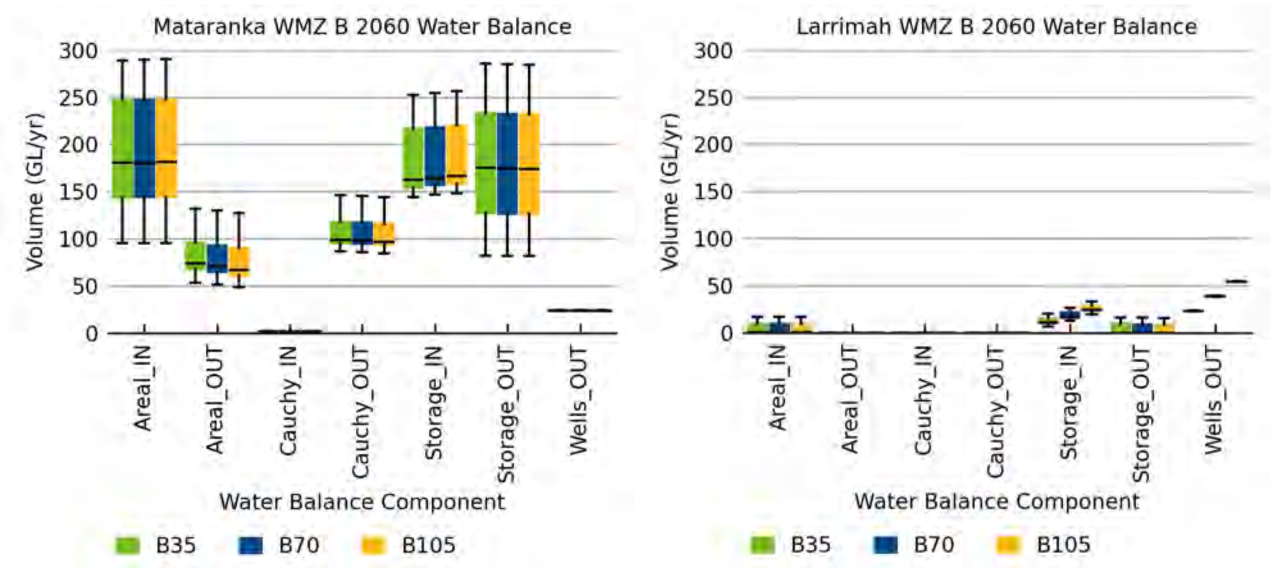


Figure 6-2 Annual water balances under Scenario B for the period 2059 to 2069 for (a) Mataranka Water Management Zone and (b) Larrimah Water Management Zone

Labels are different from Table 5-1: Areal_IN = recharge (diffuse); Areal_OUT = evapotranspiration; Cauchy_IN = from river; Cauchy_OUT = to river; Storage_IN = release from storage; Storage_OUT = capture into storage; and, Wells_OUT = extraction.

6.1.2 Scenarios A and B – groundwater levels

Groundwater levels at the six CLA reporting sites over the 50-year model run from 2019 to 2069 under scenarios A and B are presented in Figure 6-3 through Figure 6-8. The locations of the reporting sites are shown in Figure 4-5.

Each hydrograph reflects the different recharge conditions prevailing in the vicinity of that reporting site. RN028082 and RN029013 are both located in semi-arid areas and exhibit an episodic response. RN035796 is near the Roper River (refer to Figure 3-1), and the groundwater-level hydrograph reflects the connectivity of the surface water and the groundwater. The lower level of the hydrograph is controlled by the water level in the river during the dry season resulting in a relatively steady trend in the overall level.

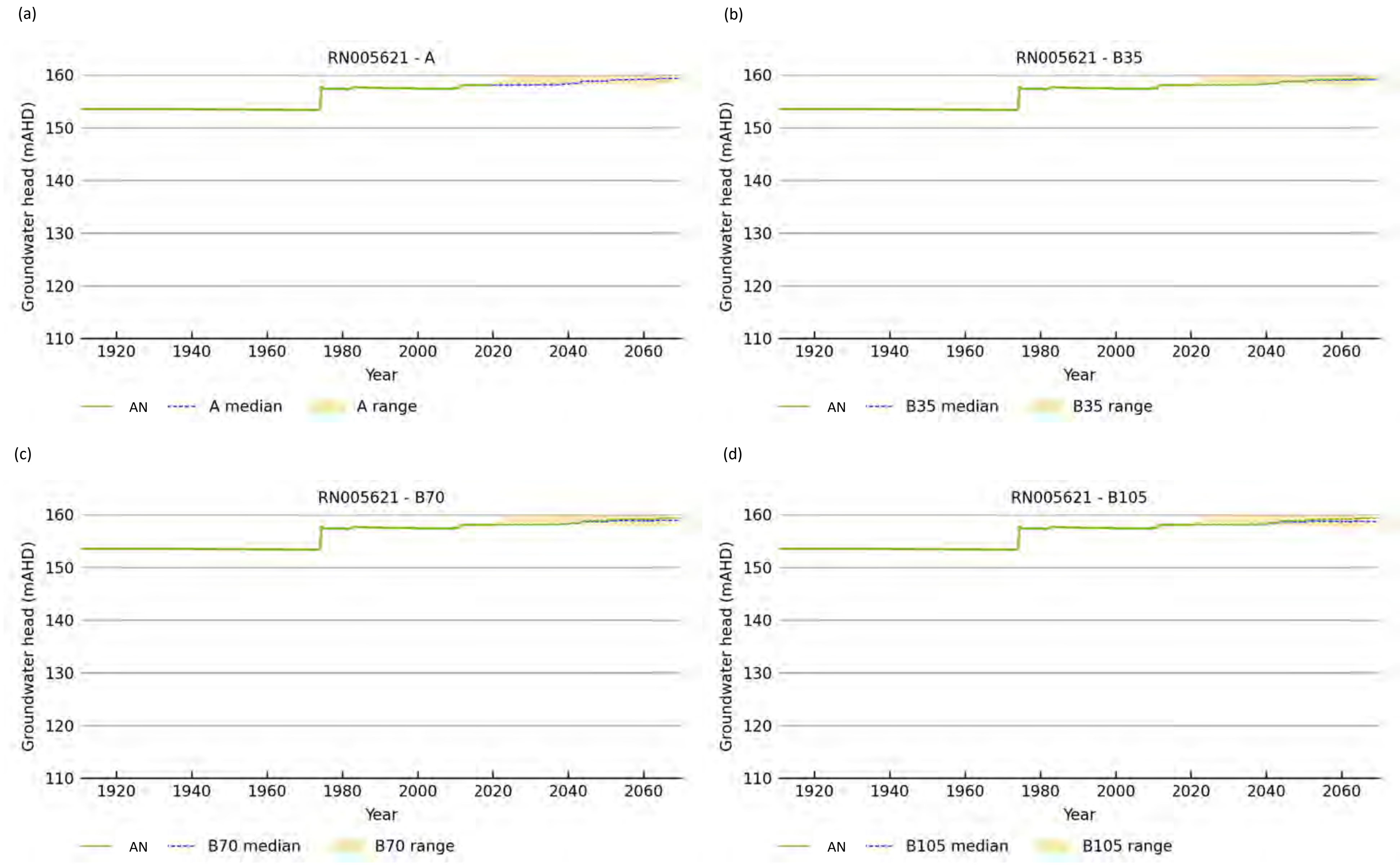


Figure 6-3 Hydrographs of groundwater levels (mAHD) at reporting site RN005621 under scenarios (a) A, (b) B35, (c) B70 and (d) B105

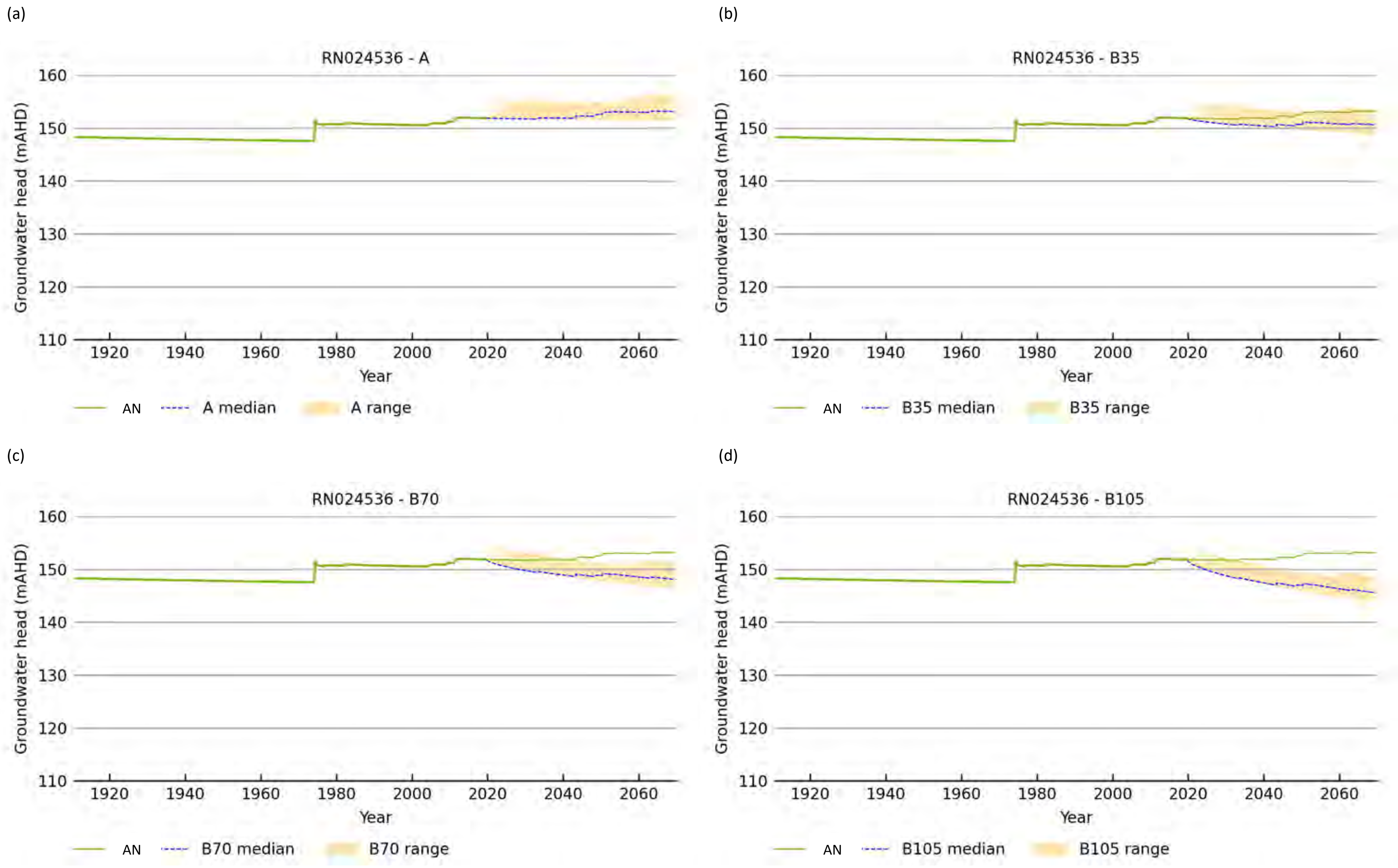


Figure 6-4 Hydrographs of groundwater levels (mAHD) at reporting site RN024536 under scenarios (a) A, (b) B35, (c) B70 and (d) B105

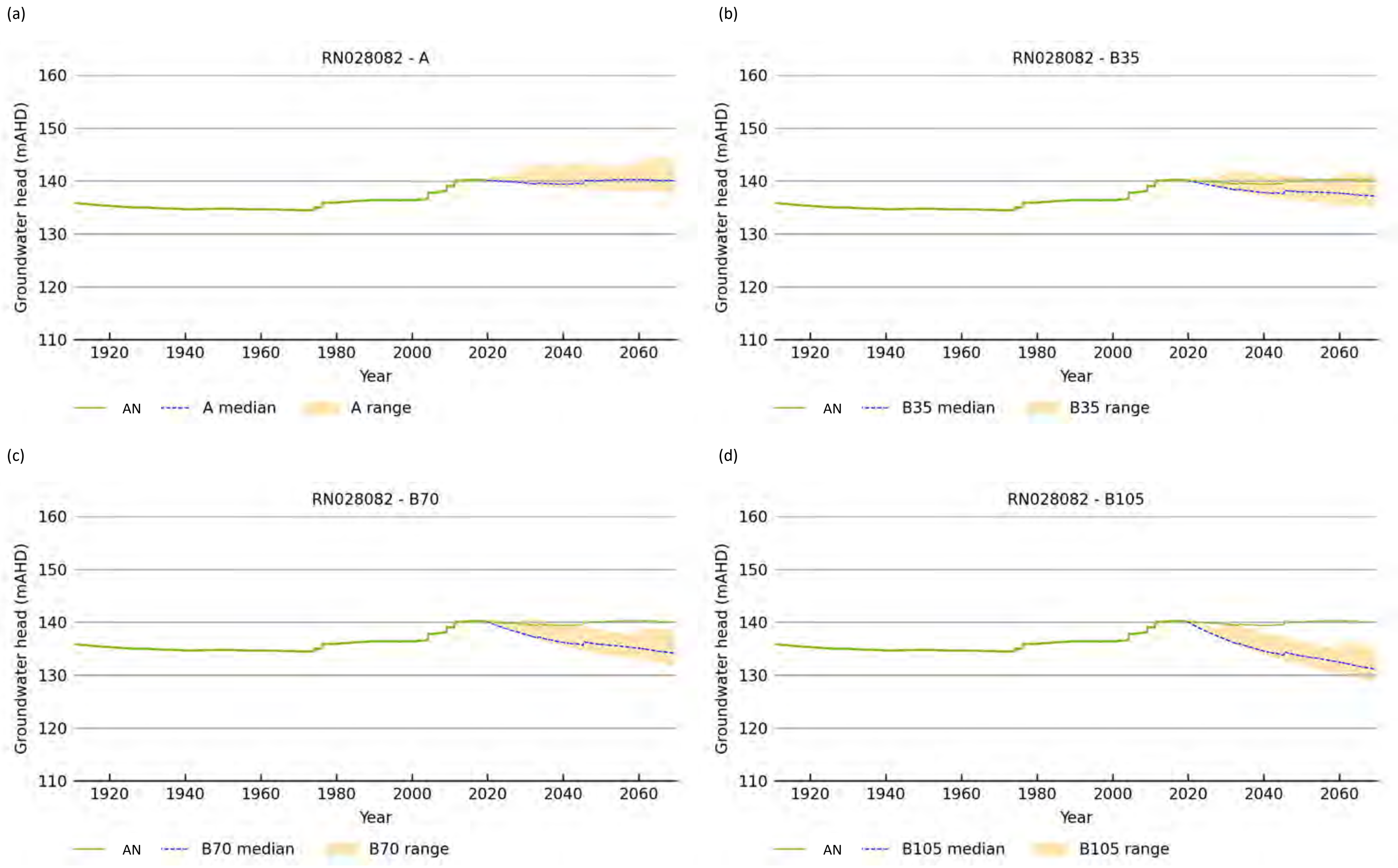


Figure 6-5 Hydrographs of groundwater levels (mAHD) at reporting site RN028082 under scenarios (a) A, (b) B35, (c) B70 and (d) B105

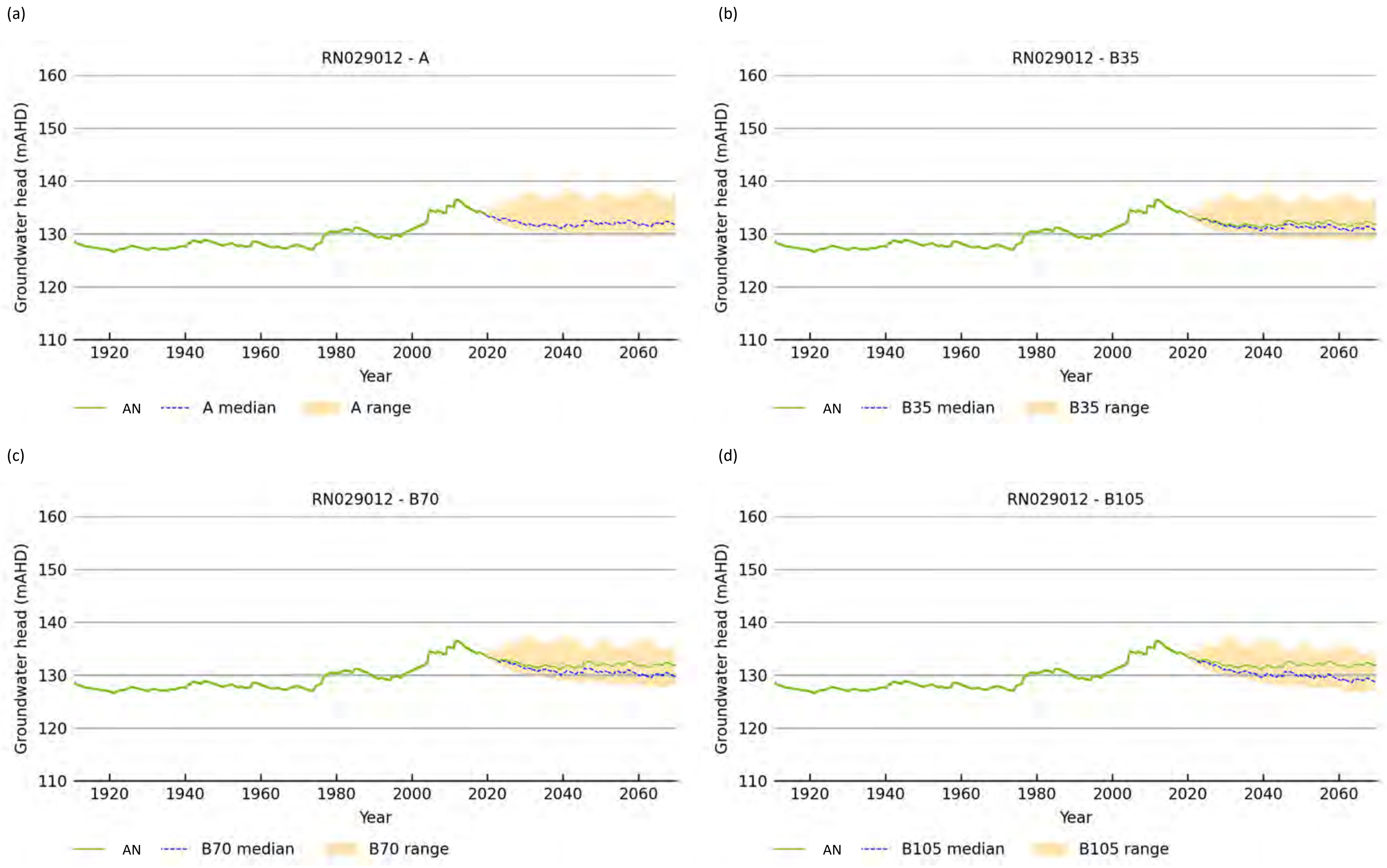


Figure 6-6 Hydrographs of groundwater levels (mAHD) at reporting site RN028082 under scenarios (a) A, (b) B35, (c) B70 and (d) B105

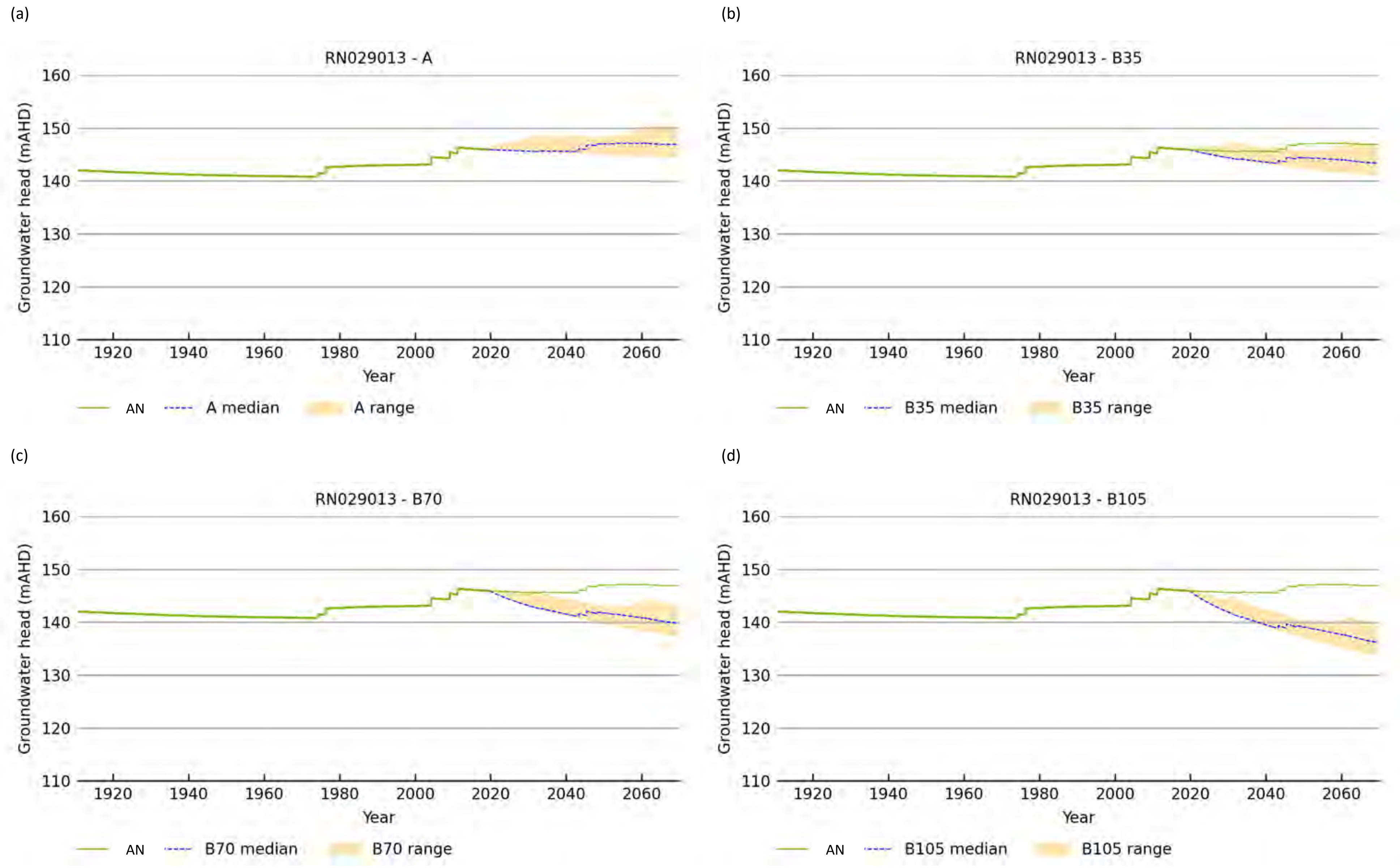


Figure 6-7 Hydrographs of groundwater levels (mAHD) at reporting site RN029013 under scenarios (a) A, (b) B35, (c) B70 and (d) B105

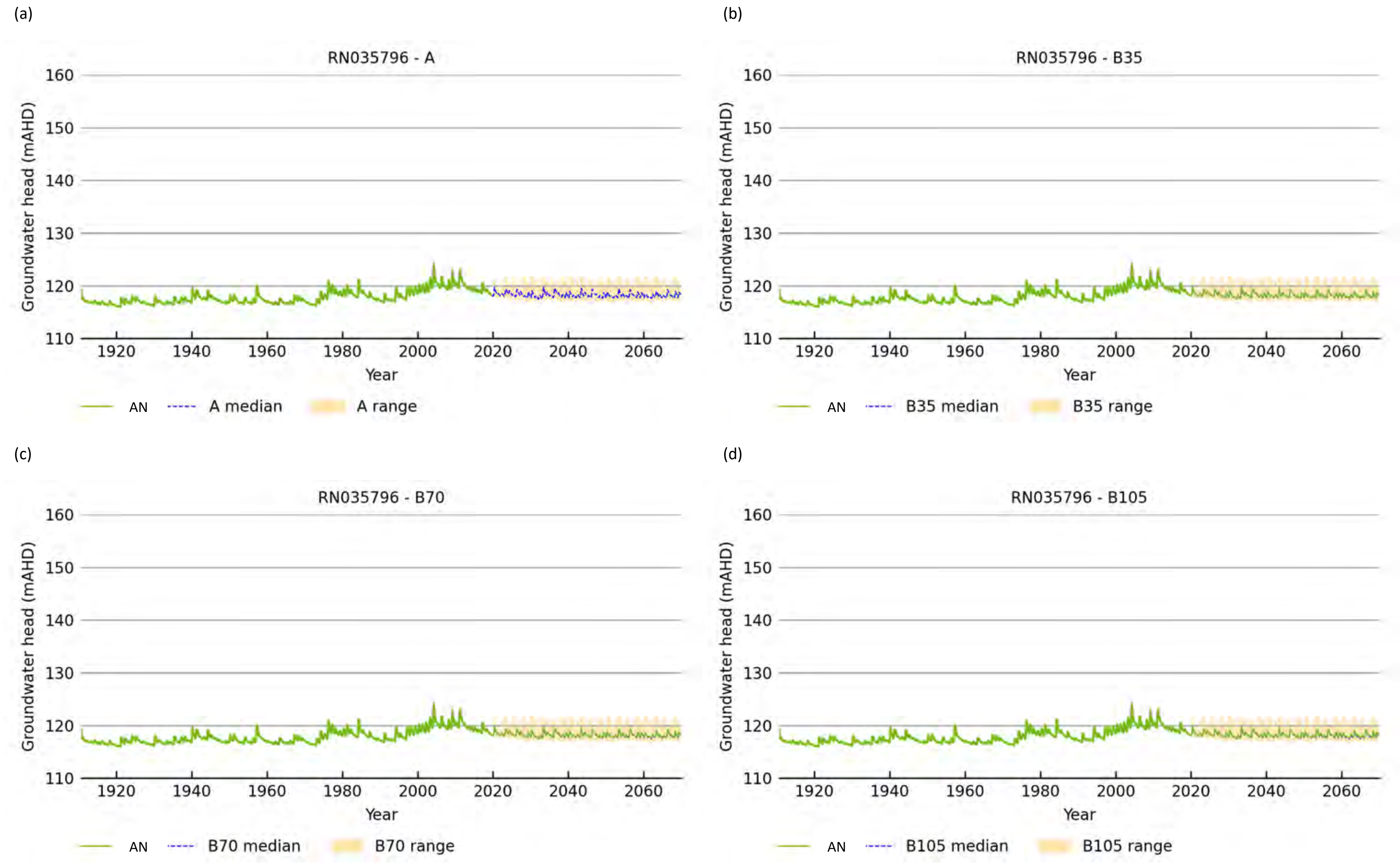


Figure 6-8 Hydrographs of groundwater levels (mAHD) at reporting site RN035796 under scenarios (a) A, (b) B35, (c) B70 and (d) B105

Mean groundwater levels over the last 10 years of the 11 climate sequences and at each site were determined to provide an indicator of the spatial and temporal changes to groundwater levels across different parts of the aquifer arising from changes in the water balance for each scenario Table 6-3. The difference in the mean groundwater levels between scenarios, therefore, also indicates the net accumulation or depletion of groundwater in storage.

Table 6-3 Mean groundwater levels (mAHD) at the six reporting sites under scenarios A and B for the last 10-year period (2059 to 2069) of the 11 × 50-year climate sequences

SCENARIO	RN005621	RN024536	RN028082	RN029012	RN029013	RN035796
AN	160.5	154.2	142.7	134.1	148.6	119.0
A	160.3	153.5	140.4	132.5	147.0	118.5
B35	160.1	151.1	137.6	131.6	143.6	118.4
B70	159.9	148.7	134.8	130.7	140.2	118.4
B105	159.7	146.4	132.0	129.7	136.8	118.4

AN = Historical climate and no development; A = Historical climate and current development; B35 = Historical climate sequences with current development and additional future development of 35 GL/year; B70 = Historical climate sequences with current development and additional future development of 70 GL/year; B105 = Historical climate sequences with current development and additional future development of 105 GL/year.

6.1.3 Scenarios A and B – 2069 groundwater drawdown contours

The p5, p50 and p95 drawdown contours at 31/8/2069 assuming current and future groundwater extraction are presented in Figure 6-9.

The drawdown contours at 31/8/2069 assuming Scenario A climate and current groundwater extraction are shown in Figure 6-9a. The maximum drawdown (>2 m) is centred roughly on the Larrimah WCD, and the drawdown of 1 m extends 140 to 150 km south-east of the Roper River.

The drawdown contours at 31/8/2069 under Scenario B35 are shown in Figure 6-9b. The maximum drawdown (>5 m) is centred roughly on the future hypothetical developments, and the drawdown of 1 m extends 210 to 220 km south-east of the Roper River.

The drawdown contours at 31/8/2069 under Scenario B70 are shown in Figure 6-9c. The maximum drawdown (>10 m) is centred roughly on the centroid of the future hypothetical developments, and the drawdown of 1 m extends 230 to 240 km south-east of the Roper River.

The drawdown contours at 31/8/2069 under Scenario B105 are shown in Figure 6-9d. The maximum drawdown (>10 m) is centred roughly on the centroid of the future hypothetical developments, and the drawdown of 1 m extends 240 to 250 km south-east of the Roper River.

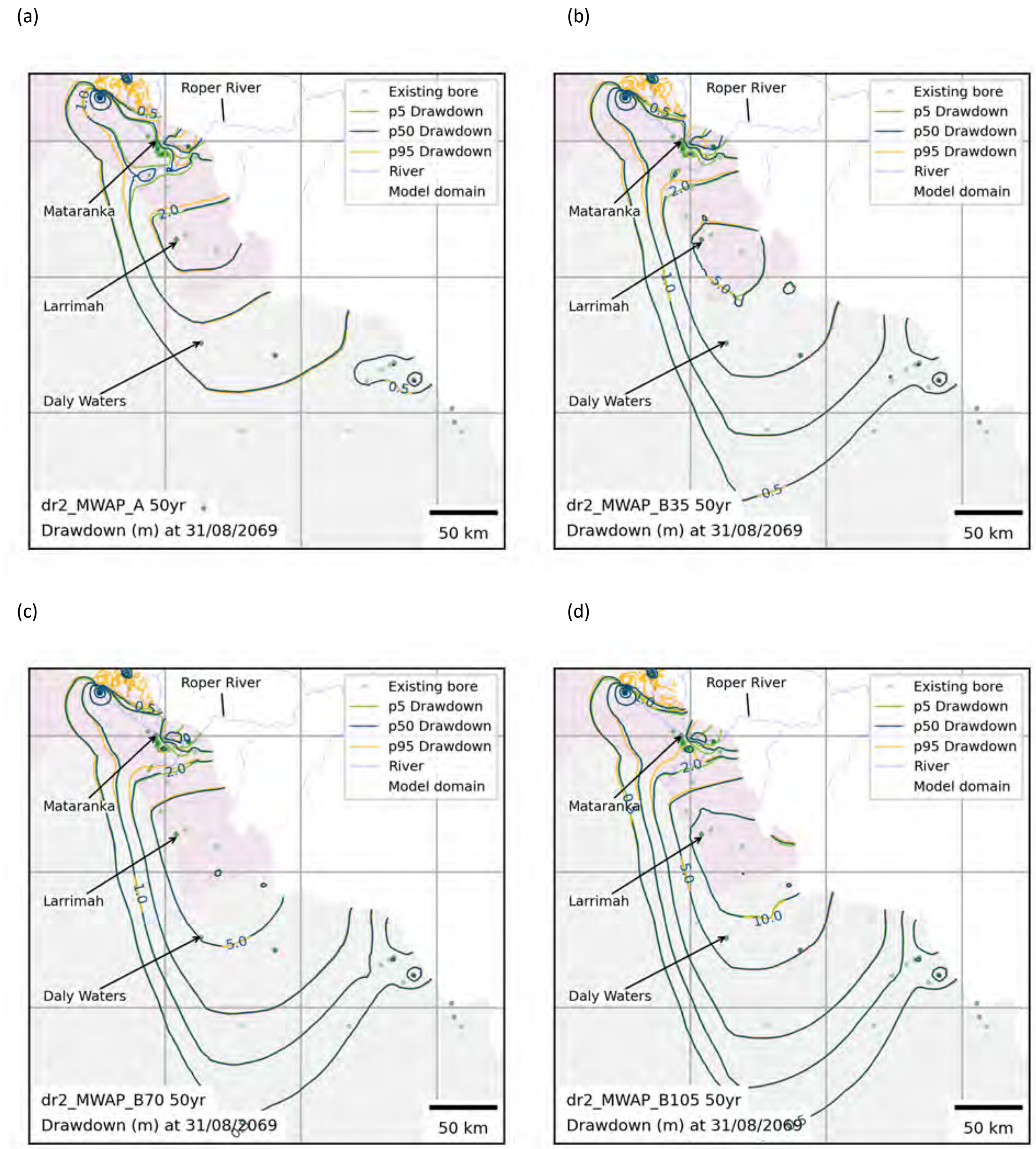


Figure 6-9 Drawdown contours at the end of the 11 × 50-year climate sequences under scenarios (a) A, (b) B35, (c) B70 and (d) B105

6.1.4 Scenarios A and B – 2059 to 2069 groundwater discharge

Mean groundwater discharges of the 11 climate sequences for the 10-year period (2059 to 2069) under scenarios A, B35, B70 and B105 at the Roper River (G9030013) are presented in Table 6-4.

Groundwater discharges under scenarios A, B35, B70 and B105 at the Roper River (G9030013) are presented in Figure 6-10. The range in groundwater discharge at each site has been clipped to accentuate the range where dry-season discharges dominate.

The percentage decreases in discharge under scenarios A, B35, B70 and B105 relative to Scenario AN at the Roper River (G9030013) are presented in Figure 6-11.

Table 6-4 Mean groundwater discharges at the gauging site on the Roper River (G9030013)

SCENARIO	GROUNDWATER DISCHARGE (m^3/s)	% CHANGE FROM AN
AN	3.3	Na
A	3	−9
B35	3	−10
B70	2.9	−10
B105	2.9	−11

AN = Historical climate and no development; A = Historical climate and current development; B35 = Historical climate sequences with current development and additional future development of 35 GL/year; B70 = Historical climate sequences with current development and additional future development of 70 GL/year; B105 = Historical climate sequences with current development and additional future development of 105 GL/year.
†na = not applicable.

(a)

(b)

(c)

(d)

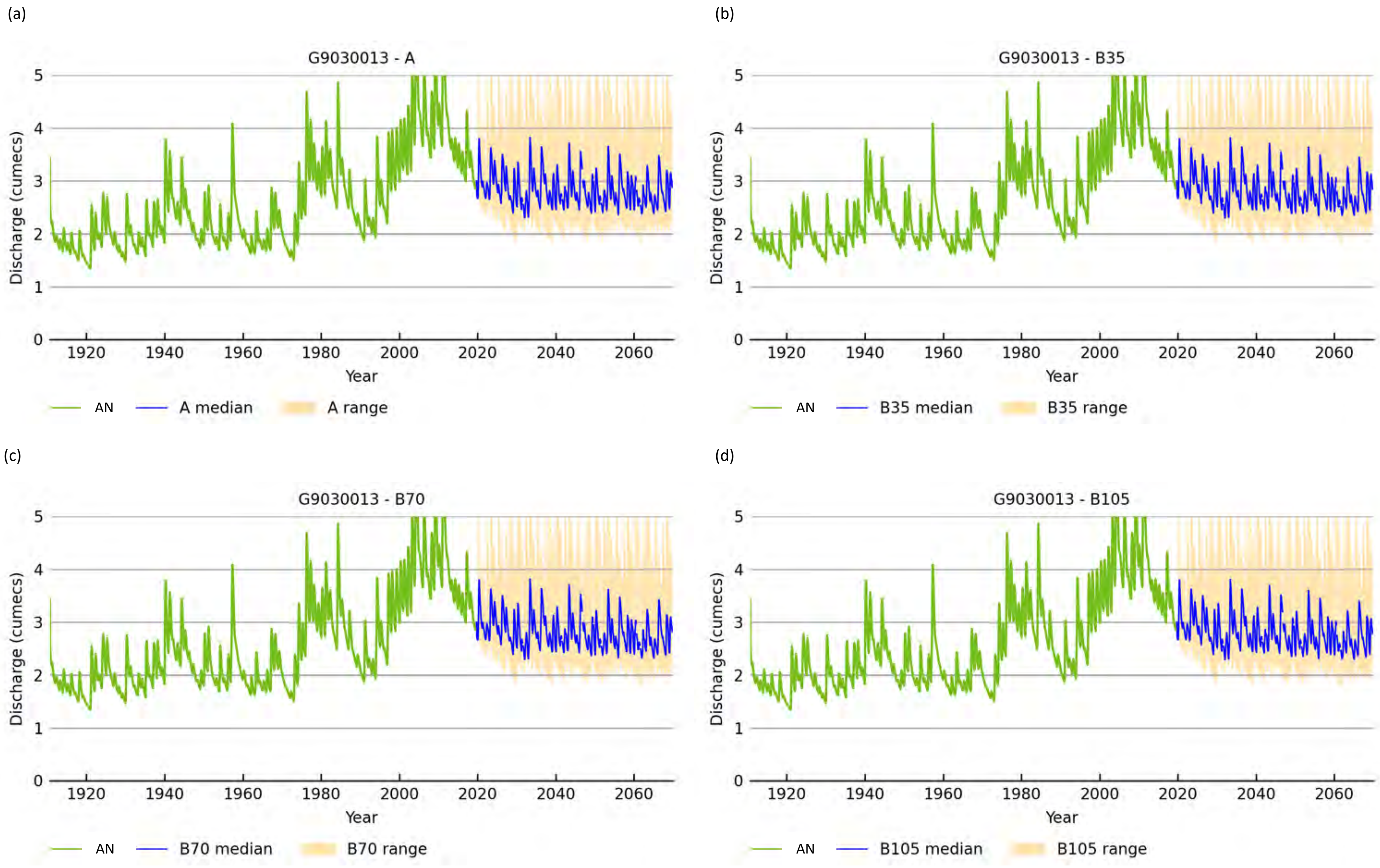


Figure 6-10 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030013 under scenarios (a) A, (b) B35, (c) B70 and (d) B105

The percentage changes in discharge at G9030013 (Roper River at Elsey Homestead) under scenarios A, B35, B70 and B105 are presented in Figure 6-11. The decrease in discharge at G9030013 from the CLA has been determined by comparing Scenario AN results to the A and B pumping scenarios.

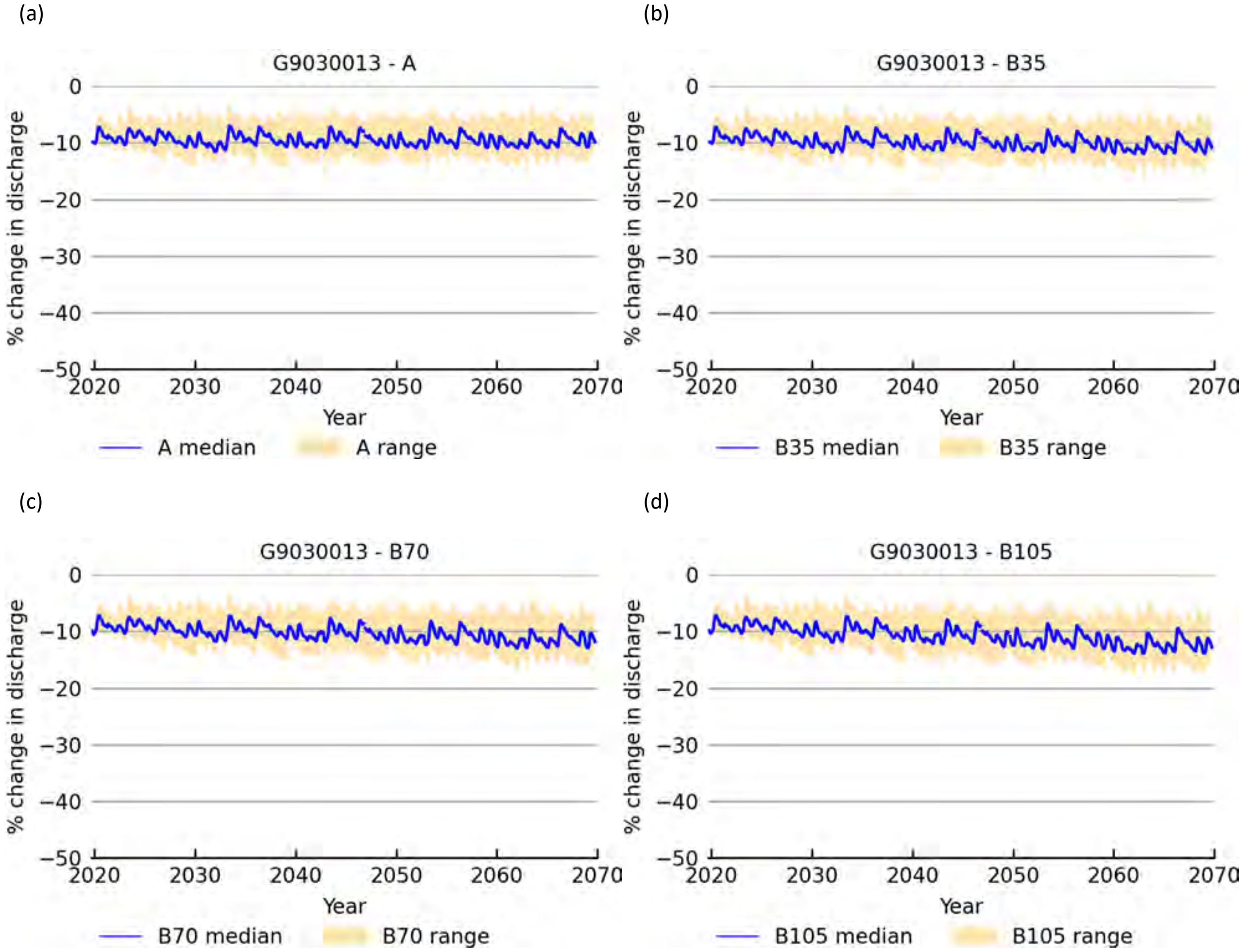


Figure 6-11 Percentage change in discharge relative to Scenario AN at G9030013 for the period 2019 to 2069 under scenarios (a) A, (b) B35, (c) B70 and (d) B105

6.2 Future climate (scenarios C and D)

Two groups of scenarios were used to examine the effects of current and hypothetical developments in conjunction with the three future climate sequences on the catchment water balance, groundwater levels and discharge to the river. The three input sequences (dry, mid and wet) represent changes in the mean annual rainfall of approximately –10, –2 and +10% and in PET of +10, +7.5 and +5%, respectively, from the historical climate sequence employed in Scenario A.

6.2.1 Scenarios C and D – water balances

The mean annual water balance of the 11 climate sequences for the last 10 years of scenarios C and D are presented for the MWMZ in Table 6-5 and for the LWMZ in Table 6-6. Each table row corresponds to a specific component of the water balance, and the columns represent each scenario considered.

The mean annual water balances of the last 10 years for each climate sequence under scenarios C and D for the MWMZ and LWMZ are also presented as boxplots to show the range in the various components. Scenarios Cdry, Cmid and Cwet water balance boxplots are presented in Figure 6-12. Scenarios Ddry, Dmid and Dwet water balance boxplots are presented in Figure 6-13, Figure 6-14 and Figure 6-15, respectively.

Because none of the hypothetical future development sites are in the MWMZ, scenarios D35, D70 and D105 have the same extraction as the A and C scenarios (i.e. 23.8 GL/year). Three of the hypothetical future groundwater development sites are in the LWMZ and four are in the southern portion of the Roper catchment.

The mean annual water balances under each future climate sequence (i.e. scenarios C and D, Table 6-5) indicate that, although the future rainfall for the mid climate sequences is similar to the historical rainfall (Section 4.1.1), the Cmid recharge value is less than the AN recharge because the Cmid climate sequence has a 7.5% higher PET rate, resulting in less deep drainage by the recharge models. The mean water balances indicate that recharge under Scenario Cwet is similar to that under Scenario AN climate sequences (Table 6-1).

Relative to Scenario AN, discharge of groundwater as ET decreases under Scenario Cdry and Cmid and increases under Scenario Cwet (relative to Scenario AN, changes are Cdry = −47%, Cmid = −35% and Cwet = +0.3%) and as discharge to the Roper River (relative to Scenario AN, changes are Cdry = −22%, Cmid = −13% and Cwet = +10%). Under the Ddry scenarios, ET decreases by up to about 60% and discharge to the river decreases between 32 and 35% relative to Scenario AN.

The net flow to the MWMZ decreases from 22 GL/year inflow under scenario AN to approximately 19 GL/year under Scenario Cdry and increases under Cmid to 22.5 GL/year and 35 GL/year under Cwet. Under Scenario Ddry, the net flow to the MWMZ reduces to an inflow of 12 GL/year under Scenario Ddry35 and to about 0.3 GL/year under Scenario Ddry105 due to the hypothetical future groundwater extraction inducing groundwater flow into the LWMZ to the south-east.

The reductions in ET, discharge to the rivers and groundwater inflows to the MWMZ are due to the increase in groundwater extraction associated with the hypothetical future groundwater developments in the LWMZ and to the south of the LWMZ.

In the LWMZ, scenarios D35, D70 and D105 represent a 15, 30 and 45 GL/year increase, respectively, in extraction over Scenario C. Note that there are no flows to or from rivers or to evapotranspiration in the Larrimah region because the depth of the water is greater than the depth at which these processes operate (Table 6-6).

Under natural conditions (i.e. Scenario AN), groundwater outflows from the LWMZ with a net flow of -5.3 GL/year. However, under all scenarios with either current or hypothetical future groundwater development (i.e. scenarios C and D), the regime changes where groundwater is induced into the LWMZ (Table 6-6). The net flow ranges from +1.2 GL/year inflow under Scenario Cdry up to +26.6 GL/year inflow under Scenario Dwet105.

Table 6-5 Mean 10-year (2059 to 2069) annual water balances (GL/year) under scenarios C and D in the Mataranka Water Management Zone

	CDRY	CMID	CWET	DDRY35	DDRY70	DDRY105	DMID35	DMID70	DMID105	DWET35	DWET70	DWET105
Inflow (gains)												
Recharge (diffuse)	116.4	141.0	202.2	117.4	117.5	117.6	142.4	142.5	142.7	203.8	204.2	204.3
Release from storage	98.2	114.5	159.6	101.7	104.4	107.4	116.6	119.0	121.4	160.9	162.6	164.5
From river	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3
Sub-total	**214.8**	**255.9**	**362.1**	**219.3**	**222.2**	**225.2**	**259.3**	**261.7**	**264.4**	**365.0**	**367.1**	**369.1**
Outflow (losses)												
Evapotranspiration	53.2	66.1	101.4	41.1	39.9	38.9	51.6	49.5	47.7	85.8	82.9	80.3
Extraction	0	0	0	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8
Capture into storage	86.1	106.5	162.8	84.9	84.4	83.9	105.5	105.0	104.5	161.6	161.0	160.6
To rivers	94.4	105.7	132.5	81.7	80.4	78.9	93.8	92.7	91.5	121.3	120.3	119.4
Sub-total	**233.7**	**278.3**	**396.8**	**231.5**	**228.4**	**225.5**	**274.6**	**270.9**	**267.5**	**392.5**	**388.0**	**384.0**
Net flow In (+ve) / out (-ve)	**+18.9**	**+22.5**	**+34.7**	**+12.2**	**+6.3**	**+0.3**	**+15.4**	**+9.2**	**+3.1**	**+27.5**	**+21.0**	**+14.9**

Cdry = Future dry climate sequence with current development; Cmid = Future mid climate sequence with current development; Cwet = Future wet climate sequence with current development; Ddry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; Ddry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; Ddry105 = Future dry climate sequences with current development and additional future development of 105 GL/year; Dmid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; Dmid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; Dmid105 = Future mid climate sequences with current development and additional future development of 105 GL/year; Dwet35 = Future wet climate sequences with current development and additional future development of 35 GL/year; Dwet70 = Future wet climate sequences with current development and additional future development of 70 GL/year; Dwet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.

Table 6-6 Mean 10-year (2059 to 2069) annual water balances (GL/year) under scenarios C and D in the Larrimah Water Management Zone

	CDRY	CMID	CWET	DDRY35	DDRY70	DDRY105	DMID35	DMID70	DMID105	DWET35	DWET70	DWET105
Inflow (gains)												
Recharge (diffuse)	1.5	4.3	11.5	1.5	1.5	1.5	4.3	4.3	4.3	11.5	11.5	11.5
Release from storage	6.7	6.8	6.8	13.1	19.8	26.8	13.1	19.7	26.5	12.7	19.0	25.5
From river	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†
Sub-total	**8.2**	**11.1**	**18.3**	**14.7**	**21.4**	**28.3**	**17.4**	**24.0**	**30.8**	**24.2**	**30.5**	**37.0**
Outflow (losses)												
Evapotranspiration	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†
Extraction	8.0	8.0	8.0	23.0	38.0	53.1	23.0	38.0	53.1	23.0	38.0	53.1
Capture into storage	1.4	4.2	11.5	1.3	1.1	1.1	3.9	3.8	3.7	11.1	10.8	10.6
To rivers	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†	na†
Sub-total	**9.5**	**12.2**	**19.5**	**24.3**	**39.2**	**54.1**	**27.0**	**41.8**	**56.7**	**34.1**	**48.9**	**63.7**
Net flow In (+ve) / out (-ve)	**+1.2**	**+1.1**	**+1.3**	**+9.6**	**+17.8**	**+25.8**	**+9.6**	**+17.9**	**+26.0**	**+9.9**	**+18.4**	**+26.6**

Cdry = Future dry climate sequence with current development; Cmid = Future mid climate sequence with current development; Cwet = Future wet climate sequence with current development; Ddry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; Ddry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; Ddry105 = Future dry climate sequences with current development and additional future development of 105 GL/year; Dmid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; Dmid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; Dmid105 = Future mid climate sequences with current development and additional future development of 105 GL/year; Dwet35 = Future wet climate sequences with current development and additional future development of 35 GL/year; Dwet70 = Future wet climate sequences with current development and additional future development of 70 GL/year; Dwet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.
†na = not applicable.

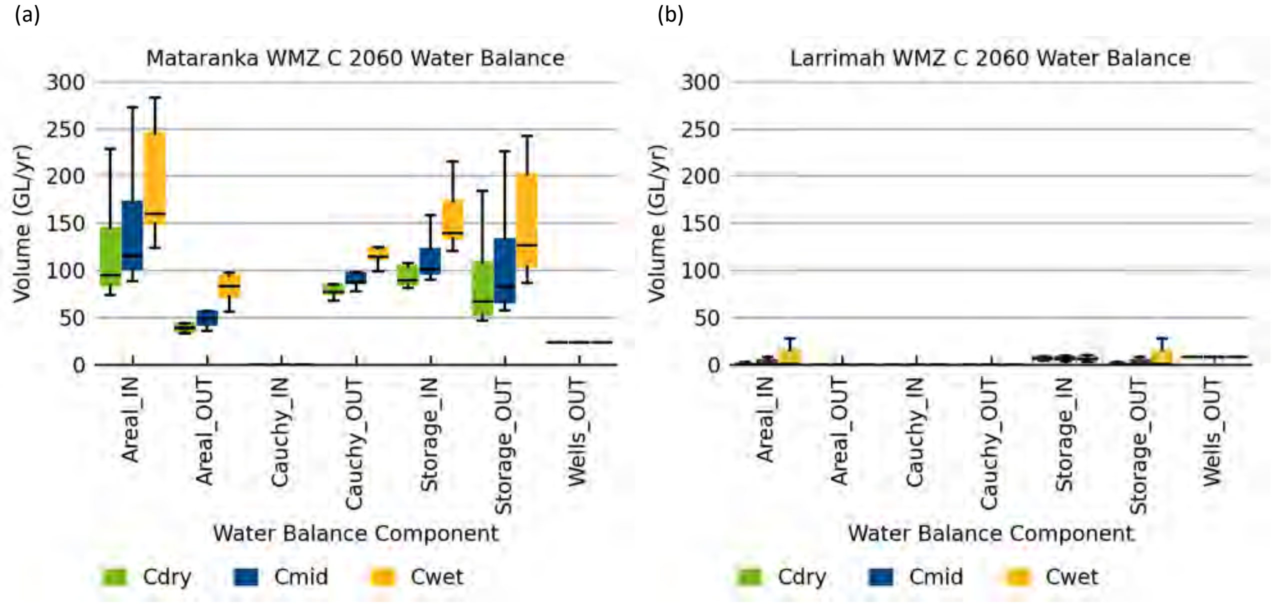


Figure 6-12 Boxplots of mean annual water balance components for the last 10-year period (2059 to 2069) under scenario C for (a) Mataranka Water Management Zone and (b) Larrimah Water Management Zone

Labels are different from Table 6-5: Areal_IN = recharge (diffuse); Areal_OUT = evapotranspiration; Cauchy_IN = from river; Cauchy_OUT = to river; Storage_IN = release from storage; Storage_OUT = capture into storage; and, Wells_OUT = extraction.

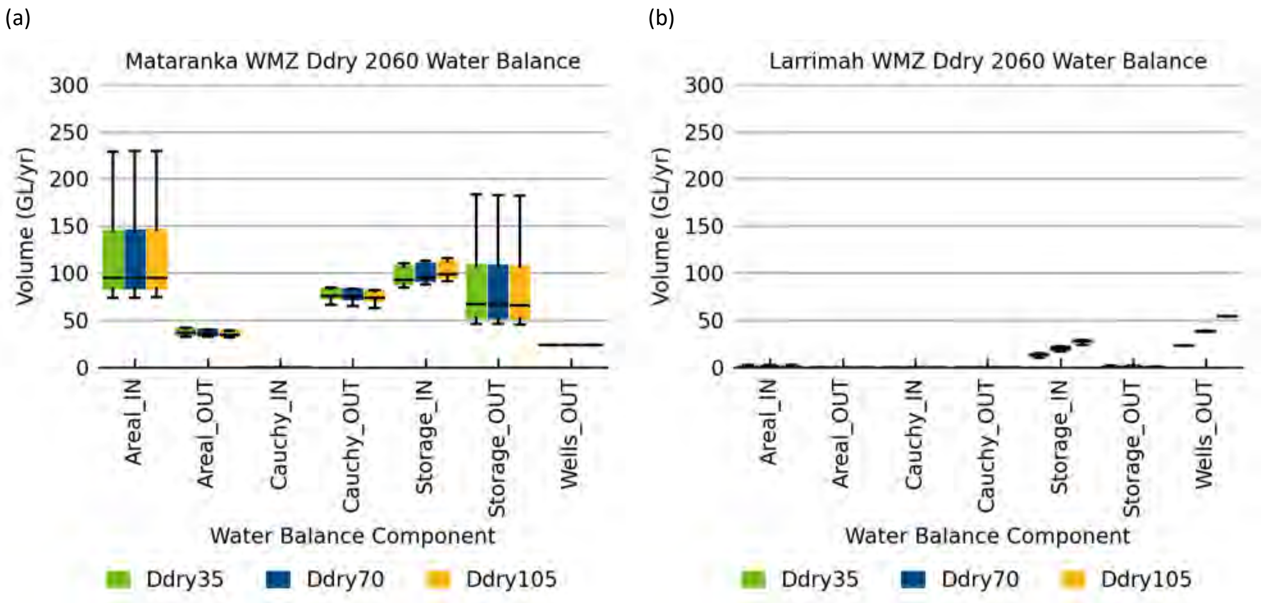


Figure 6-13 Boxplots of mean annual water balance components for the last 10-year period (2059 to 2069) under Scenario Ddry for (a) Mataranka Water Management Zone and (b) Larrimah Water Management Zone

Labels are different from Table 6-5: Areal_IN = recharge (diffuse); Areal_OUT = evapotranspiration; Cauchy_IN = from river; Cauchy_OUT = to river; Storage_IN = release from storage; Storage_OUT = capture into storage; and, Wells_OUT = extraction.

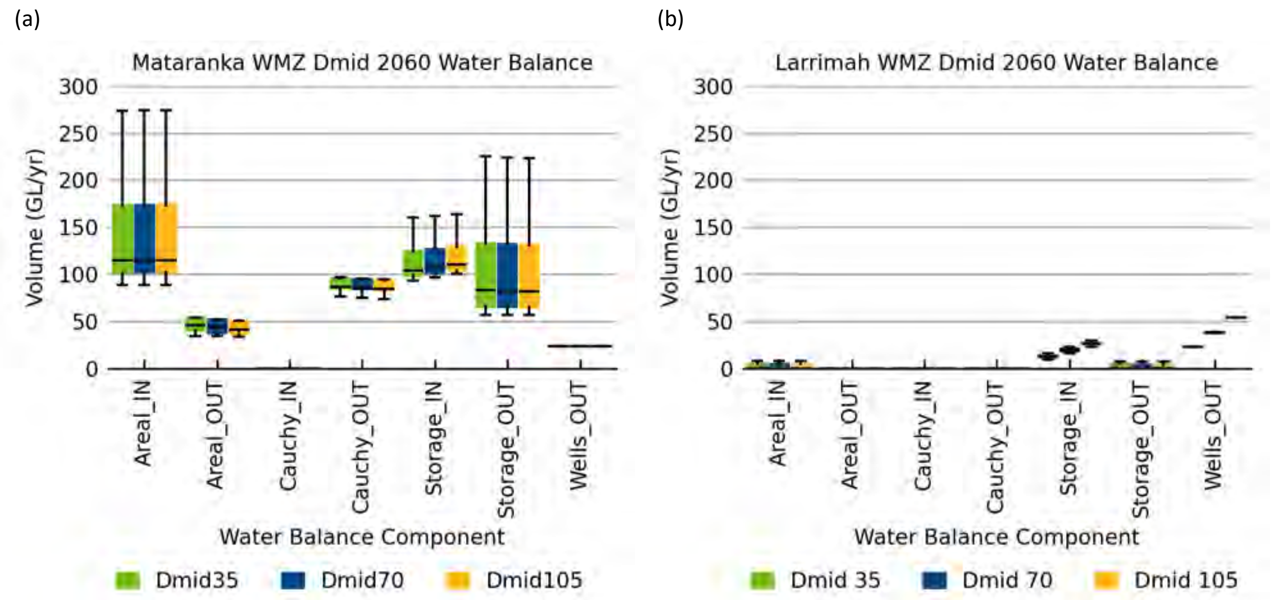


Figure 6-14 Boxplots of mean annual water balance components for the last 10-year period (2059 to 2069) under Scenario Dmid for (a) Mataranka Water Management Zone and (b) Larrimah Water Management Zone

Labels are different from Table 6-6: Areal_IN = recharge (diffuse); Areal_OUT = evapotranspiration; Cauchy_IN = from river; Cauchy_OUT = to river; Storage_IN = release from storage; Storage_OUT = capture into storage; and, Wells_OUT = extraction.

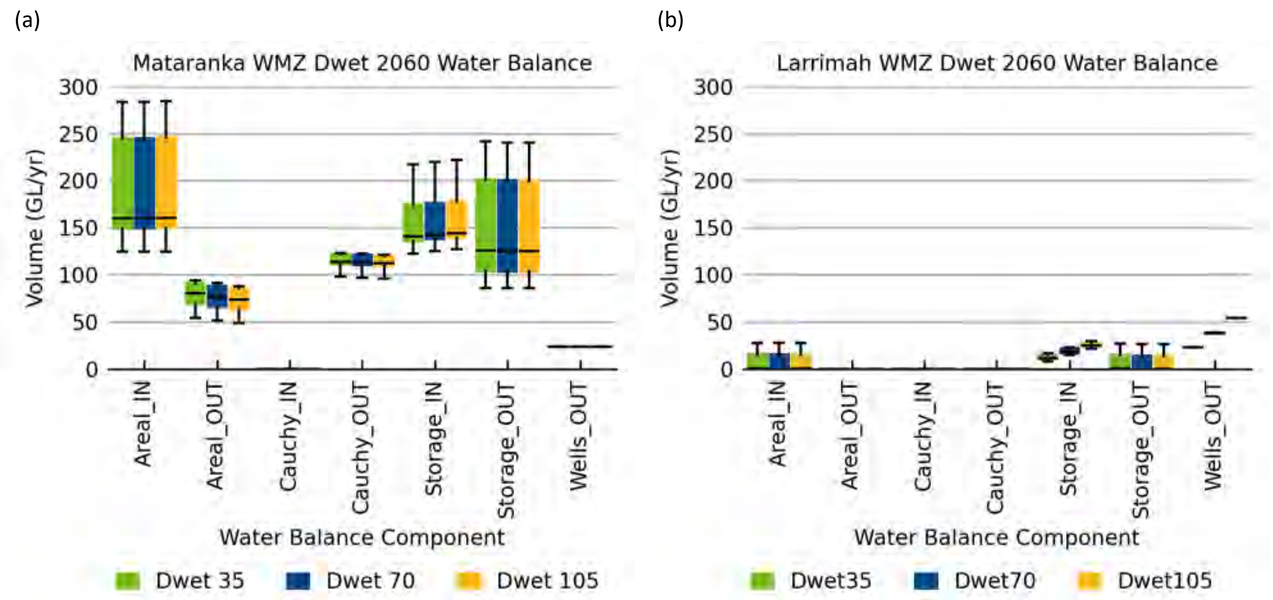


Figure 6-15 Boxplots of mean annual water balance components for the last 10-year period (2059 to 2069) under Scenario Dwet for (a) Mataranka Water Management Zone and (b) Larrimah Water Management Zone

Labels are different from Table 6-6: Areal_IN = recharge (diffuse); Areal_OUT = evapotranspiration; Cauchy_IN = from river; Cauchy_OUT = to river; Storage_IN = release from storage; Storage_OUT = capture into storage; and, Wells_OUT = extraction.

6.2.2 Scenarios C and D – groundwater levels

This section presents the simulated groundwater levels at six CLA reporting sites under scenarios C and D. The locations of the six groundwater-level reporting sites are shown in Figure 4-5.

Hydrographs of groundwater levels under scenarios C and D at the six reporting sites are presented in Figure 6-16 through Figure 6-27. The groundwater-level hydrographs show Scenario AN (green solid line) for reference, the median groundwater-level response determined from the 11 climate sequences (blue dashed line) and the range of groundwater levels from all 11 climate sequences (pale orange).

The groundwater-level hydrographs respond the expected manner for the three climate sequences. That is, the dry sequences show the lowest groundwater levels, the wet sequences show the highest groundwater levels and the mid sequences' groundwater levels sit somewhere in between the two extremes.

Table 6-7 presents the mean groundwater level at the six CLA reporting sites for the last 10-year period (2059 to 2069) of each climate ensemble under scenarios C and D. Each table row corresponds to a specific scenario, and the columns represent the mean groundwater level at each reporting site.

Scenario Cdry mean groundwater levels (Table 6-7) between are 1.7 to 6.2 m lower than Scenario AN. The difference in final groundwater level between Scenario Cdry and Scenario AN generally increases from south to north except at RN035796 (Figure 6-21a), which is affected by the proximity of the Roper River. The mean groundwater levels of the last 10-year period (Table 6-7) are lower at all reporting sites under Scenario Cdry than under Scenario AN.

Scenario Cmid mean groundwater levels (Table 6-7) are 0.9 to 5.2 m lower than Scenario AN.

Under Scenario Cwet, the mean groundwater levels at RN005621, RN024536 and RN035796 (Figure 6-16a, Figure 6-23a and Figure 6-33a, respectively) are 0.3 to 2.3 m higher than under Scenario AN. The mean groundwater levels at RN028082, RN029012 and RN029013 (Figure 6-30a, Figure 6-31a, Figure 6-32a, respectively) are 0.6 to 2.9 m lower than Scenario AN.

The mean groundwater levels under Scenario Ddry35 are 1.5 to 8 m lower than under Scenario AN. The mean groundwater levels under Scenario Ddry70 are 1.5 to 10.9 m lower than under Scenario AN. The mean groundwater levels under Scenario Ddry105 are 1.6 to 14 m lower than under Scenario AN.

The mean groundwater levels under Scenario Dmid35 are 0.9 to 6.8 m lower than under Scenario AN. The mean groundwater levels under Scenario Dmid70 are 1 to 10 m lower than under Scenario AN. The mean groundwater levels under Scenario Dmid105 are 1.0 to 13.2 m lower than under Scenario AN.

The mean groundwater levels under Scenario Dwet35 are between 2.1 m higher and 4.9 m lower than under Scenario AN. The mean groundwater levels under Scenario Dwet70 are between 1.9 m higher and 7.8 m lower than under Scenario AN. The mean groundwater levels under Scenario Dwet105 are between 1.7 m higher and 10.7 m lower than under Scenario AN.

Table 6-7 Mean groundwater levels (mAHD) at Cambrian Limestone Aquifer reporting sites for the last 10-years period (2059 to 2069) of the 11 climate sequences under scenarios C and D

SCENARIO	RN005621	RN024536	RN028082	RN029012	RN029013	RN035796
AN	160.5	154.2	142.7	134.1	148.6	119.0
Cdry	158.8	151.9	137.5	127.9	144.7	117.6
Cmid	159.6	152.7	138.3	128.9	145.6	118.1
Cwet	162.8	155.4	140.5	131.2	148.0	119.3
Ddry35	158.6	149.5	134.7	126.9	141.4	117.5
Ddry70	158.4	147.1	131.8	125.9	138.0	117.5
Ddry105	158.2	144.7	128.9	124.9	134.6	117.4
Dmid35	159.4	150.3	135.5	127.9	142.2	118.1
Dmid70	159.3	147.9	132.7	126.9	138.8	118.0
Dmid105	159.1	145.5	129.8	126.0	135.4	118.0
Dwet35	162.6	153.1	137.8	130.3	144.6	119.3
Dwet70	162.4	150.7	134.9	129.4	141.3	119.3
Dwet105	162.2	148.3	132.1	128.4	137.9	119.2

AN = Historical climate and no development; Cdry = Future dry climate sequences current development; Cmid = Future mid climate sequences current development; Cwet = Future wet climate sequences current development; Ddry35 = Future dry climate sequences current development and future development of 35 GL/year; Ddry70 = Future dry climate sequences current development and future development of 70 GL/year; Ddry105 = Future dry climate sequences current development and future development of 105 GL/year; Dmid35 = Future mid climate sequences current development and future development of 35 GL/year; Dmid70 = Future mid climate sequences current development and future development of 70 GL/year; Dmid105 = Future mid climate sequences current development and future development of 105 GL/year); Dwet35 = Future wet climate sequences current development and future development of 35 GL/year; Dwet70 = Future wet climate sequences current development and future development of 70 GL/year; Dwet105 = Future wet climate sequences current development and future development of 105 GL/year.

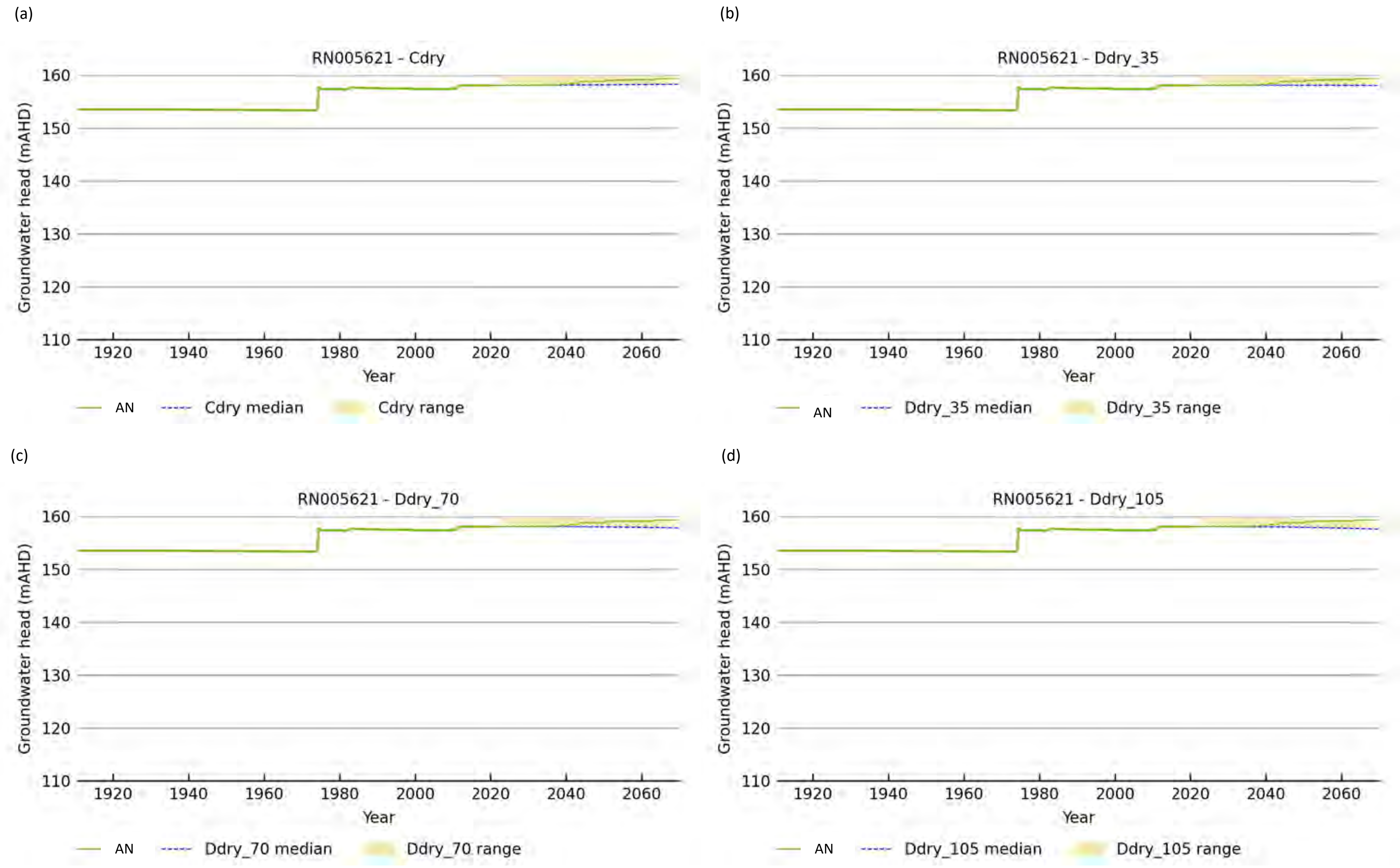


Figure 6-16 Hydrographs of groundwater level (mAHD) at reporting site RN005621 under scenarios (a) Cdry, (b) Ddry 35, (c) Ddry 70 and (d) Ddry 105

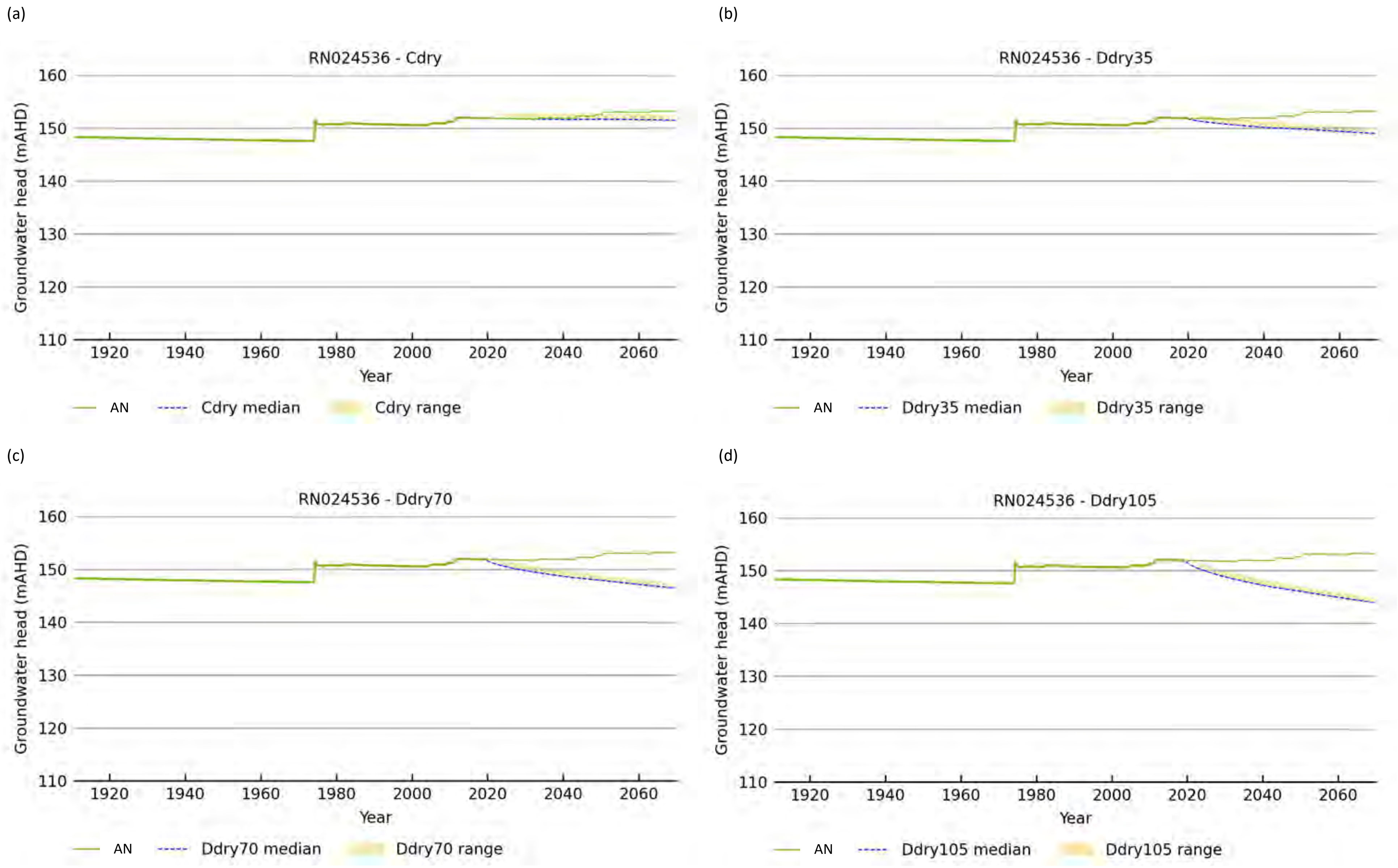


Figure 6-17 Hydrographs of groundwater level (mAHD) at reporting site RN024536 under scenarios (a) Cdry, (b) Ddry 35, (c) Ddry 70 and (d) Ddry 105

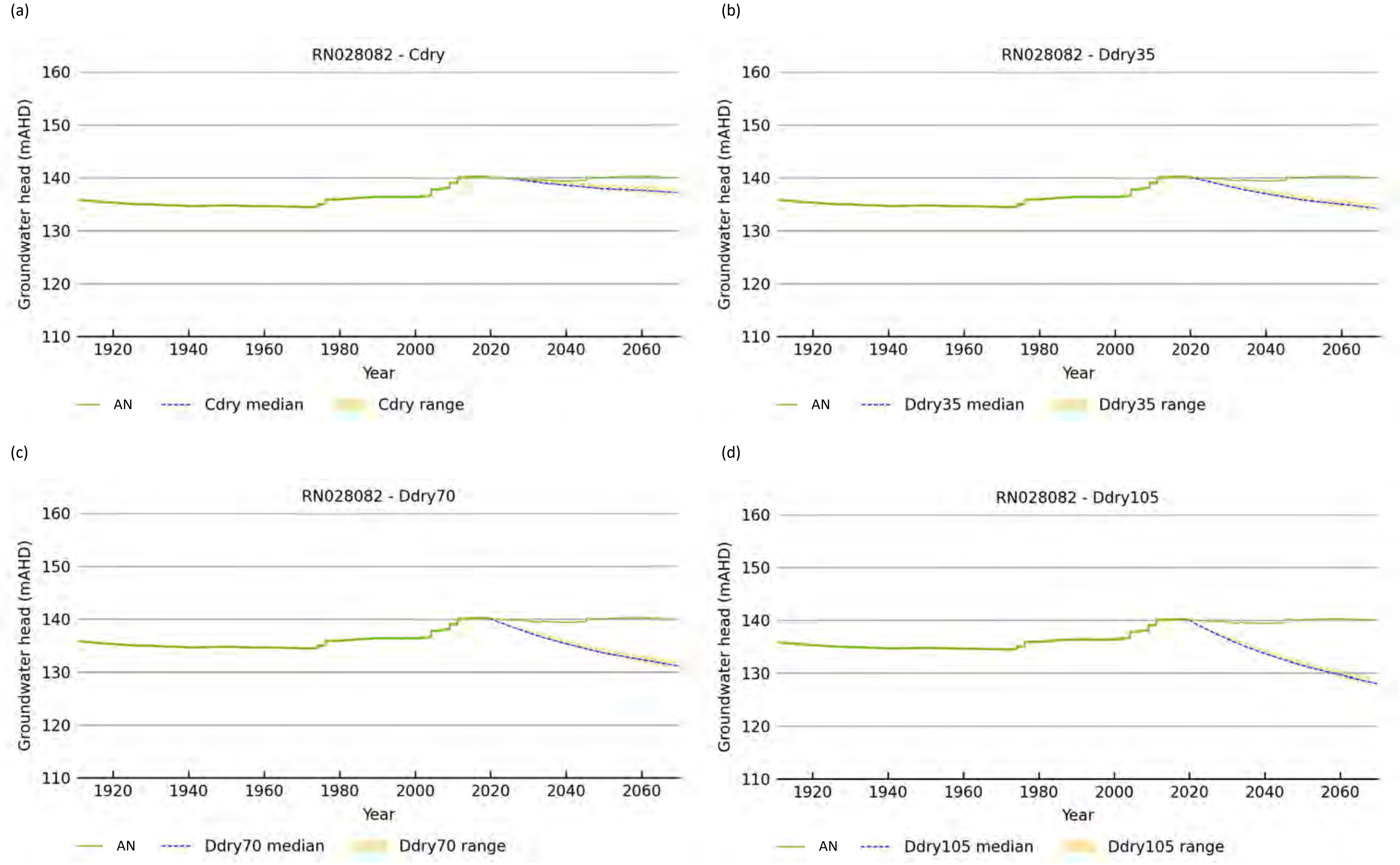


Figure 6-18 Hydrographs of groundwater level (mAHD) at reporting site RN028082 under scenarios (a) Cdry, (b) Ddry 35, (c) Ddry 70 and (d) Ddry 105

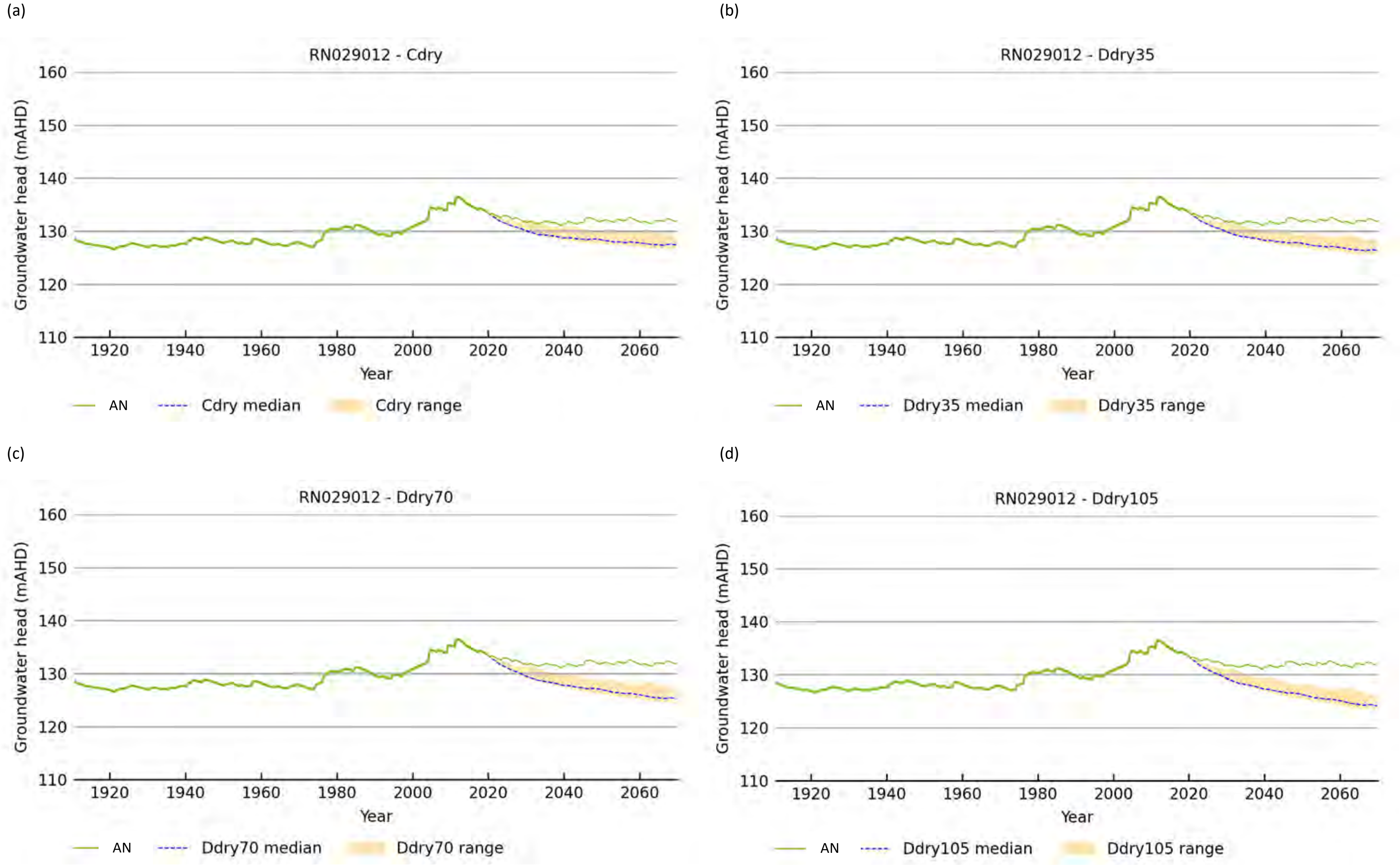


Figure 6-19 Hydrographs of groundwater level (mAHD) at reporting site RN029012 under scenarios (a) Cdry, (b) Ddry 35, (c) Ddry 70 and (d) Ddry 105

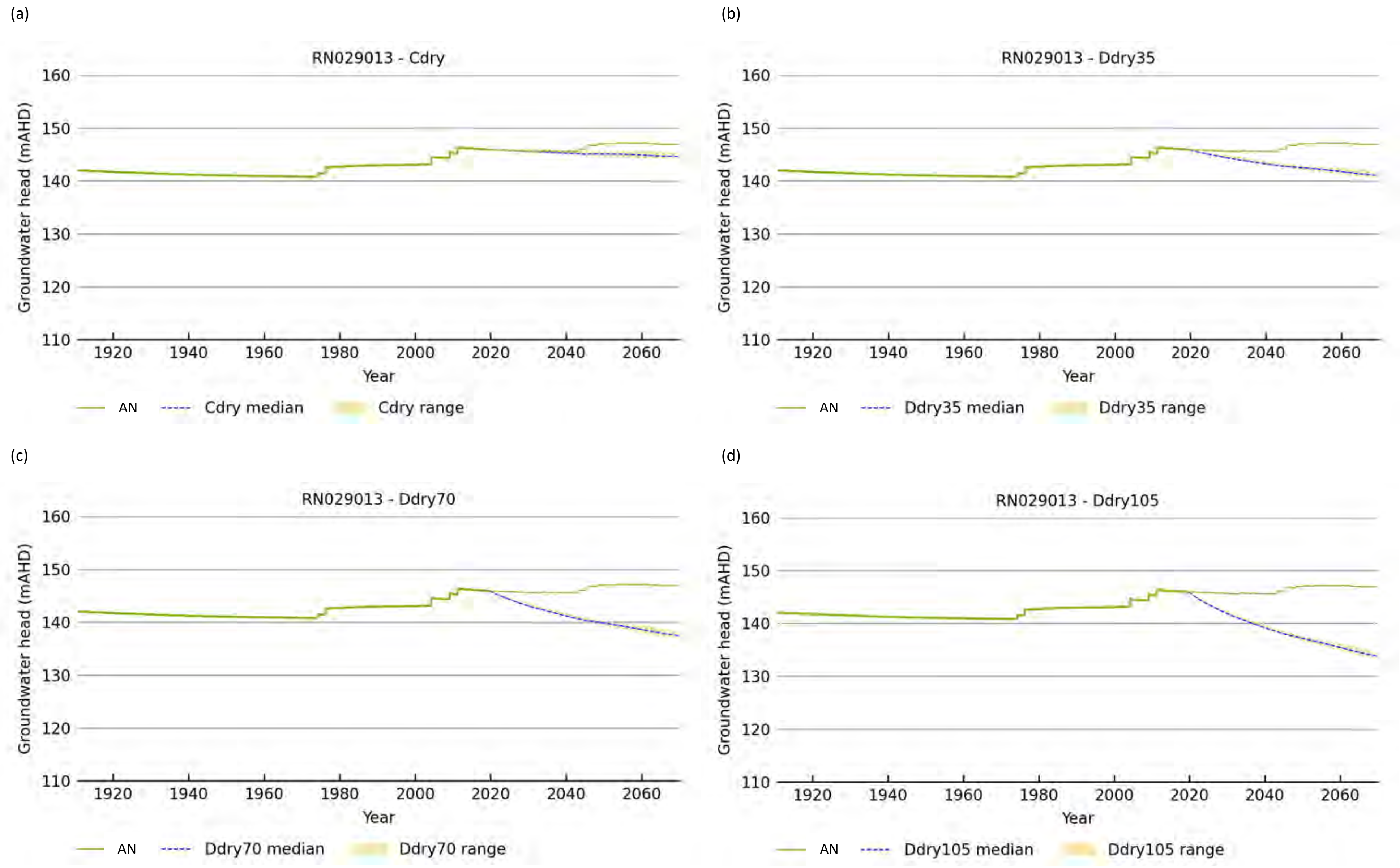


Figure 6-20 Hydrographs of groundwater level (mAHD) at reporting site RN029013 under scenarios (a) Cdry, (b) Ddry 35, (c) Ddry 70 and (d) Ddry 105

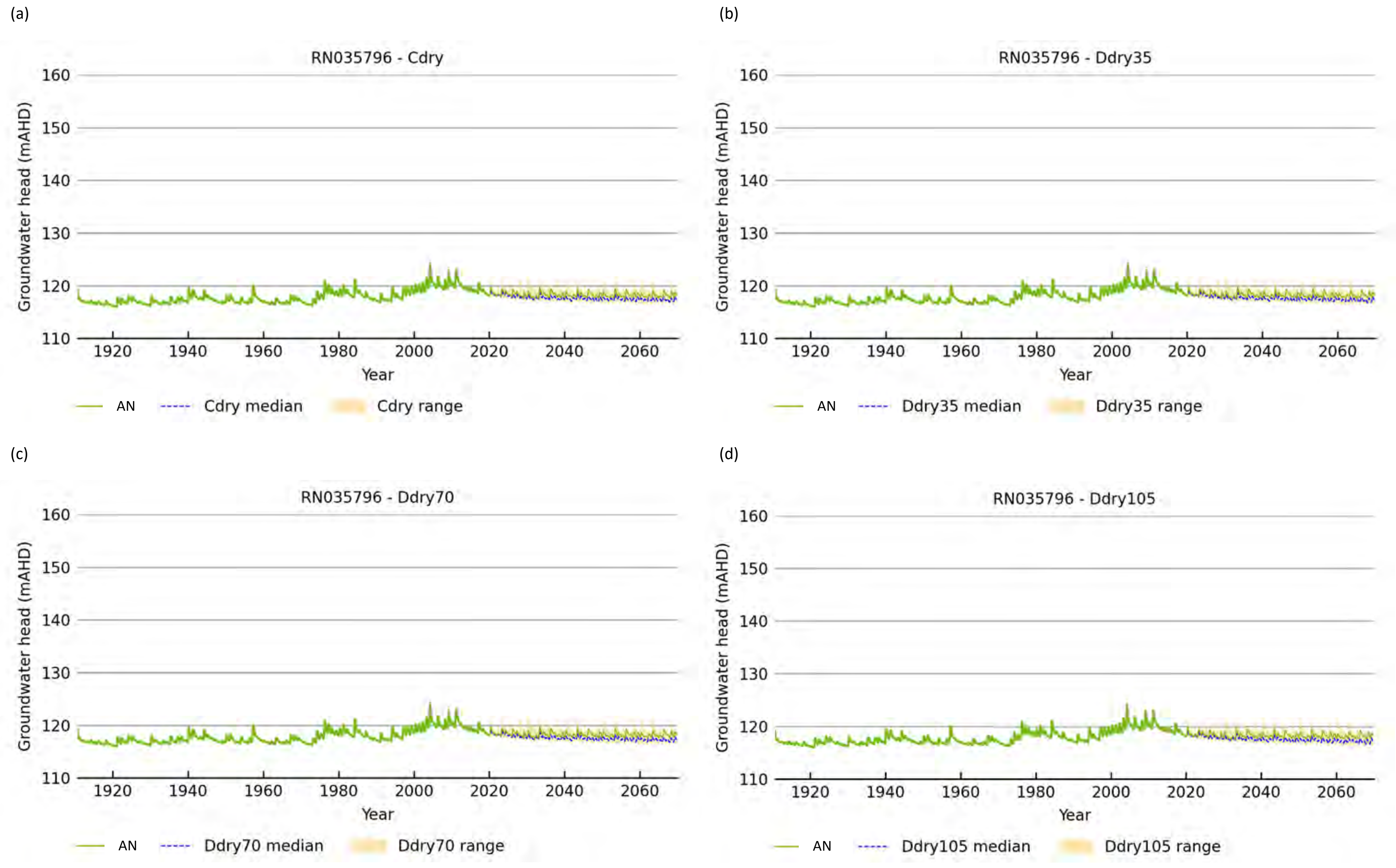


Figure 6-21 Hydrographs of groundwater level (mAHD) at reporting site RN035796 under scenarios (a) Cdry, (b) Ddry 35, (c) Ddry 70 and (d) Ddry 105

(a)

(b)

(c)

(d)

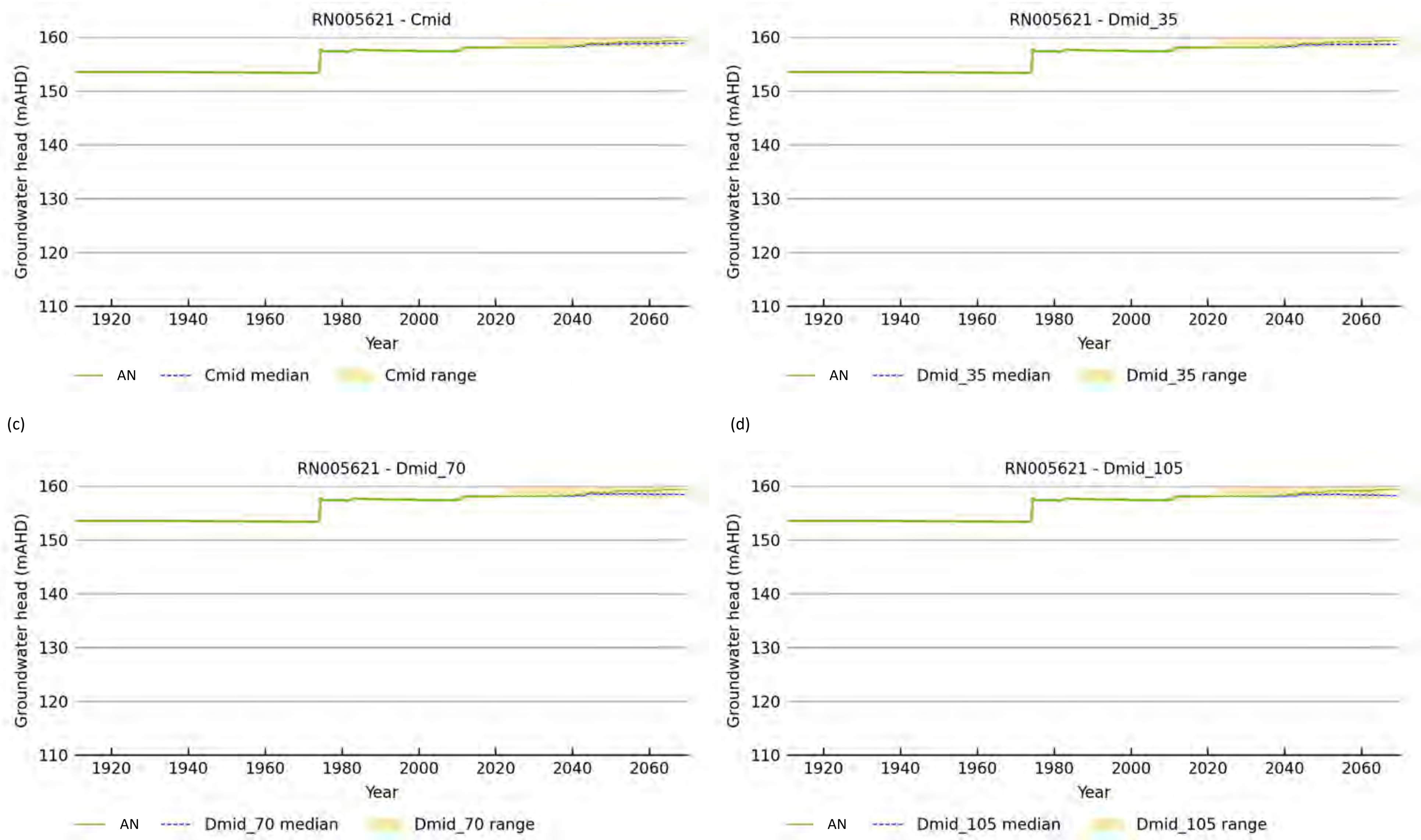


Figure 6-22 Hydrographs of groundwater level (mAHD) at reporting site RN005621 under scenarios (a) Cmid, (b) Dmid 35, (c) Dmid 70 and (d) Dmid 105

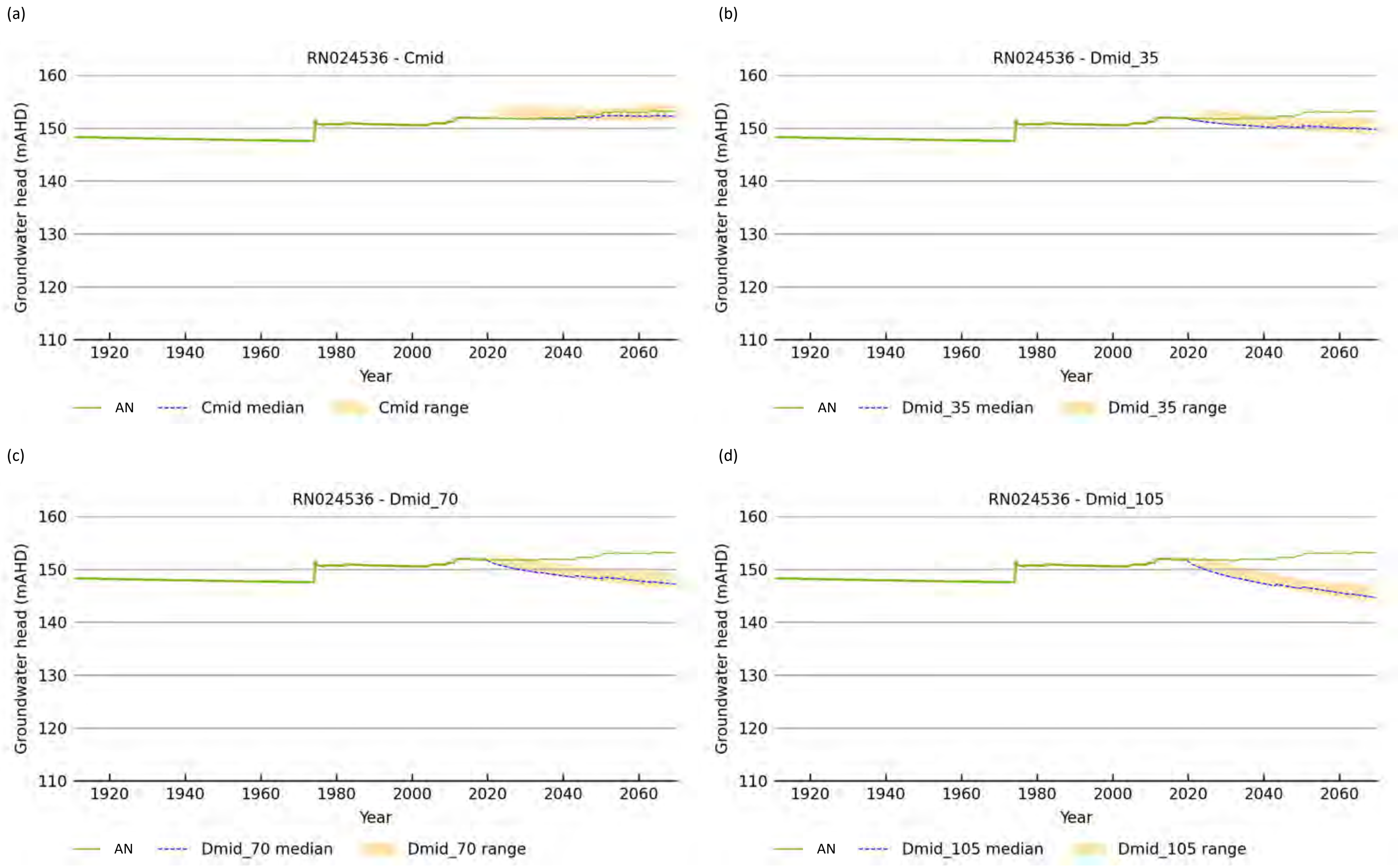


Figure 6-23 Hydrographs of groundwater level (mAHD) at reporting site RN024536 under scenarios (a) Cmid, (b) Dmid 35, (c) Dmid 70 and (d) Dmid 105

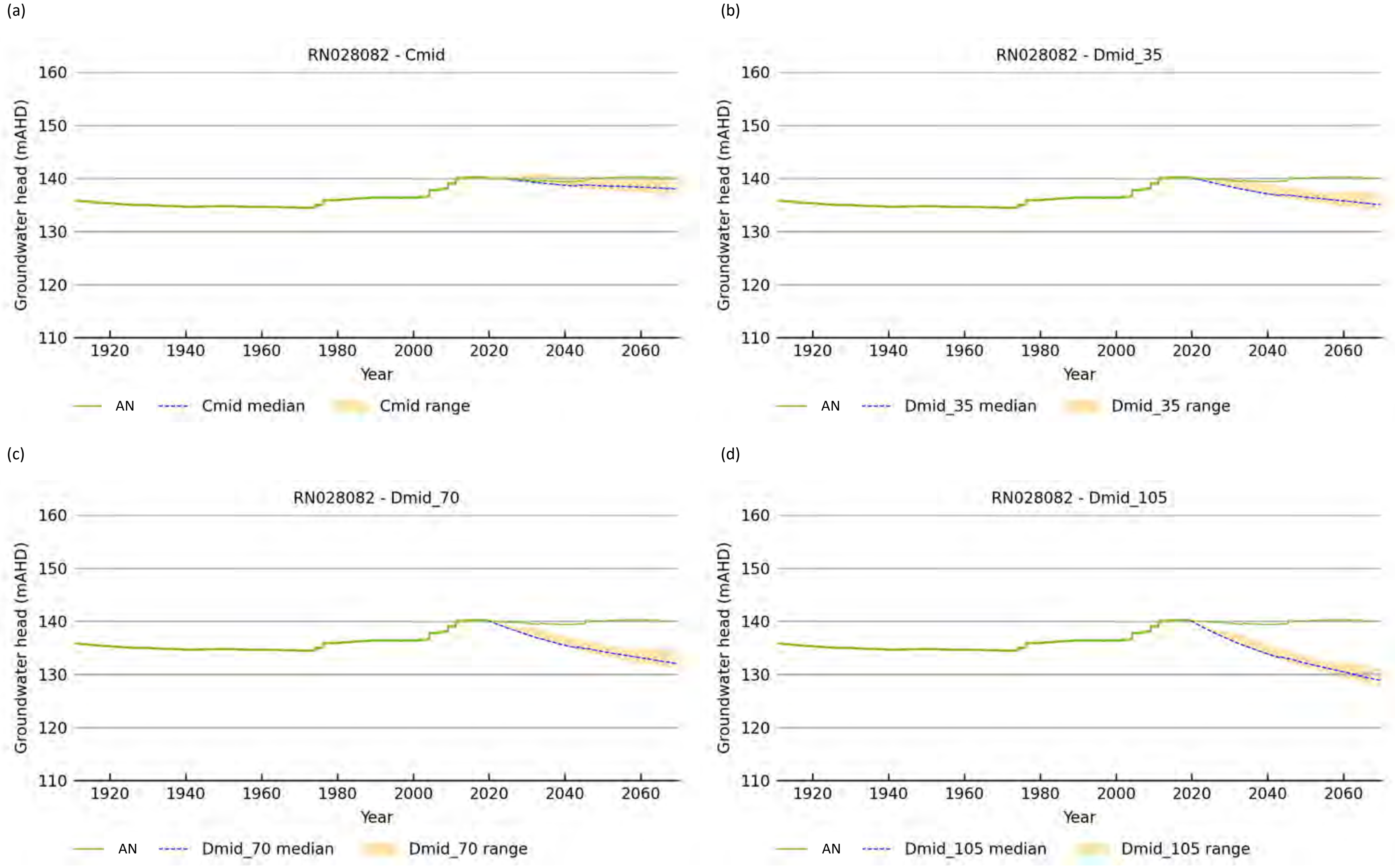


Figure 6-24 Hydrographs of groundwater level (mAHD) at reporting site RN028082 under scenarios (a) Cmid, (b) Dmid35, (c) Dmid70 and (d) Dmid105

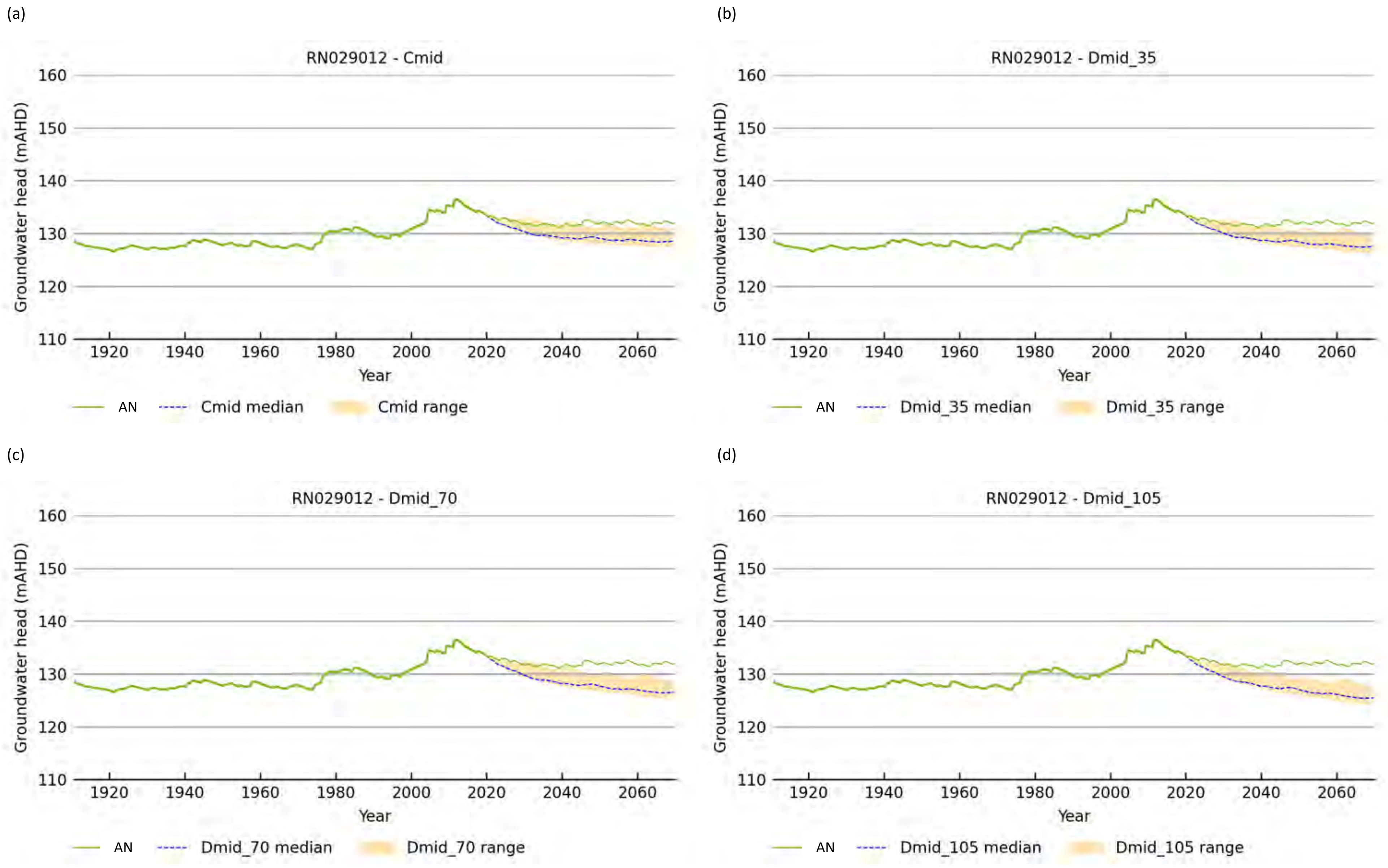


Figure 6-25 Hydrographs of groundwater level (mAHD) at reporting site RN029012 under scenarios (a) Cmid, (b) Dmid 35, (c) Dmid 70 and (d) Dmid 105

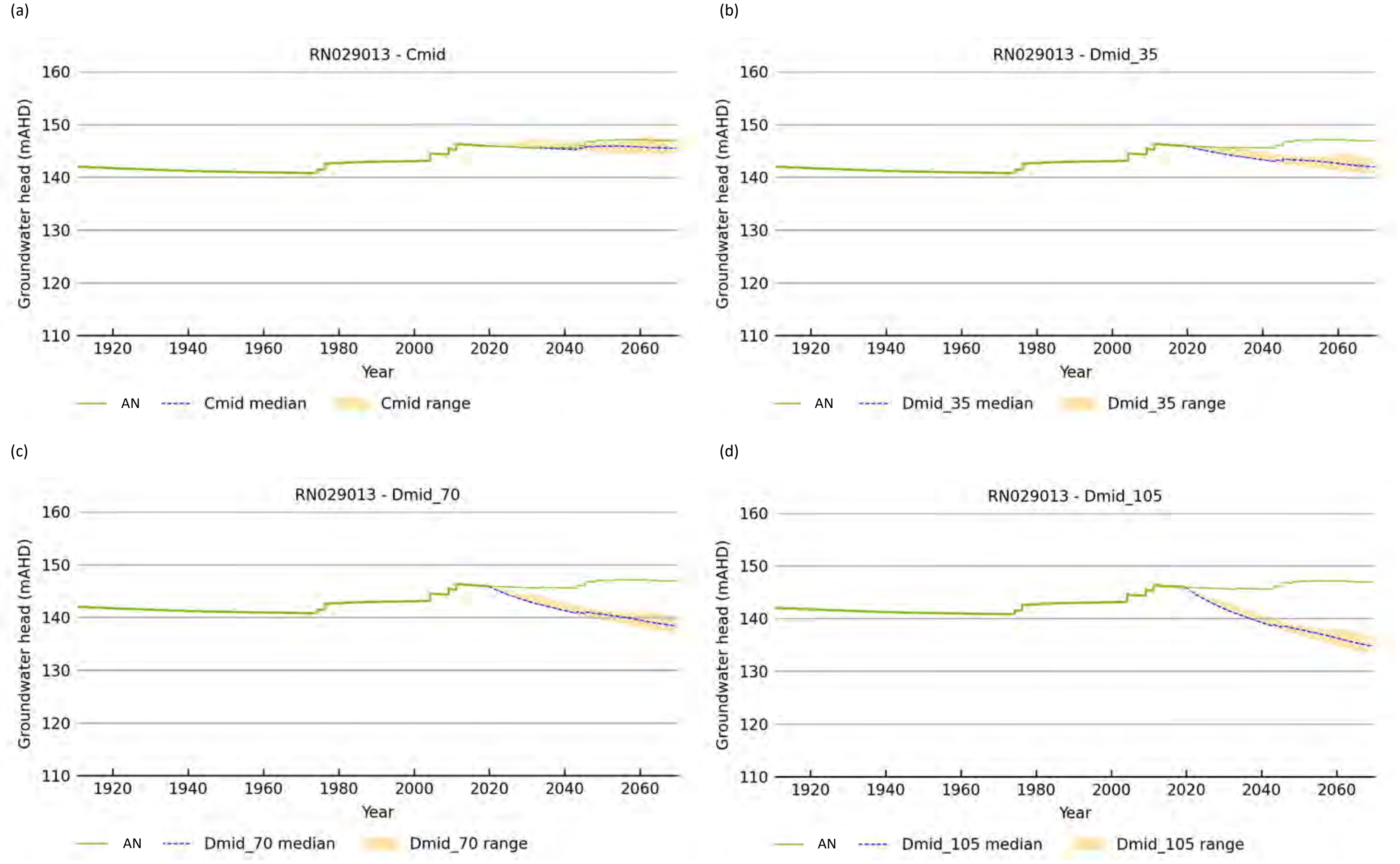


Figure 6-26 Hydrographs of groundwater level (mAHD) at reporting site RN029013 under scenarios (a) Cmid, (b) Dmid 35, (c) Dmid 70 and (d) Dmid 105

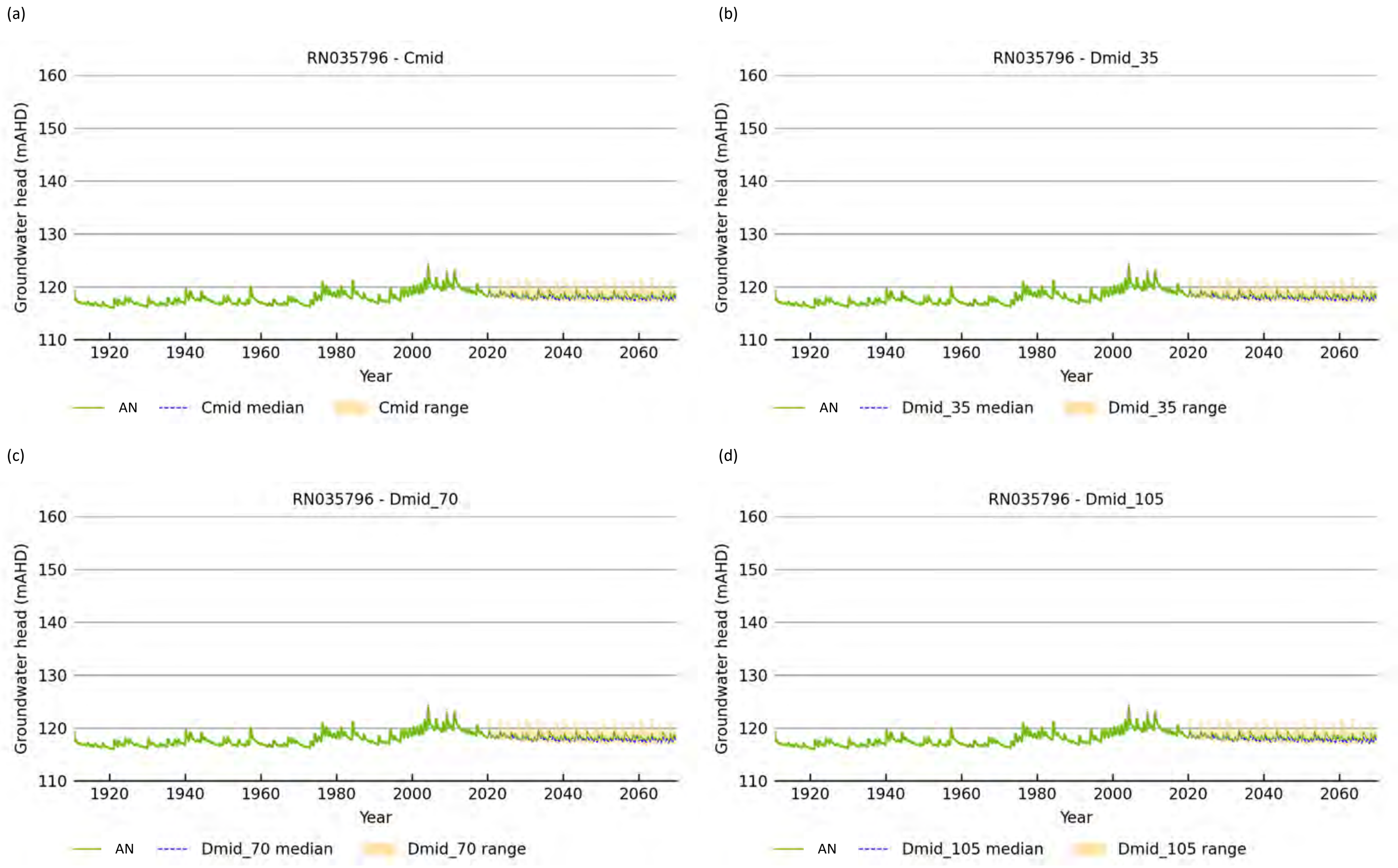


Figure 6-27 Hydrographs of groundwater level (mAHD) at reporting site RN035796 under scenarios (a) Cmid, (b) Dmid 35, (c) Dmid 70 and (d) Dmid 105

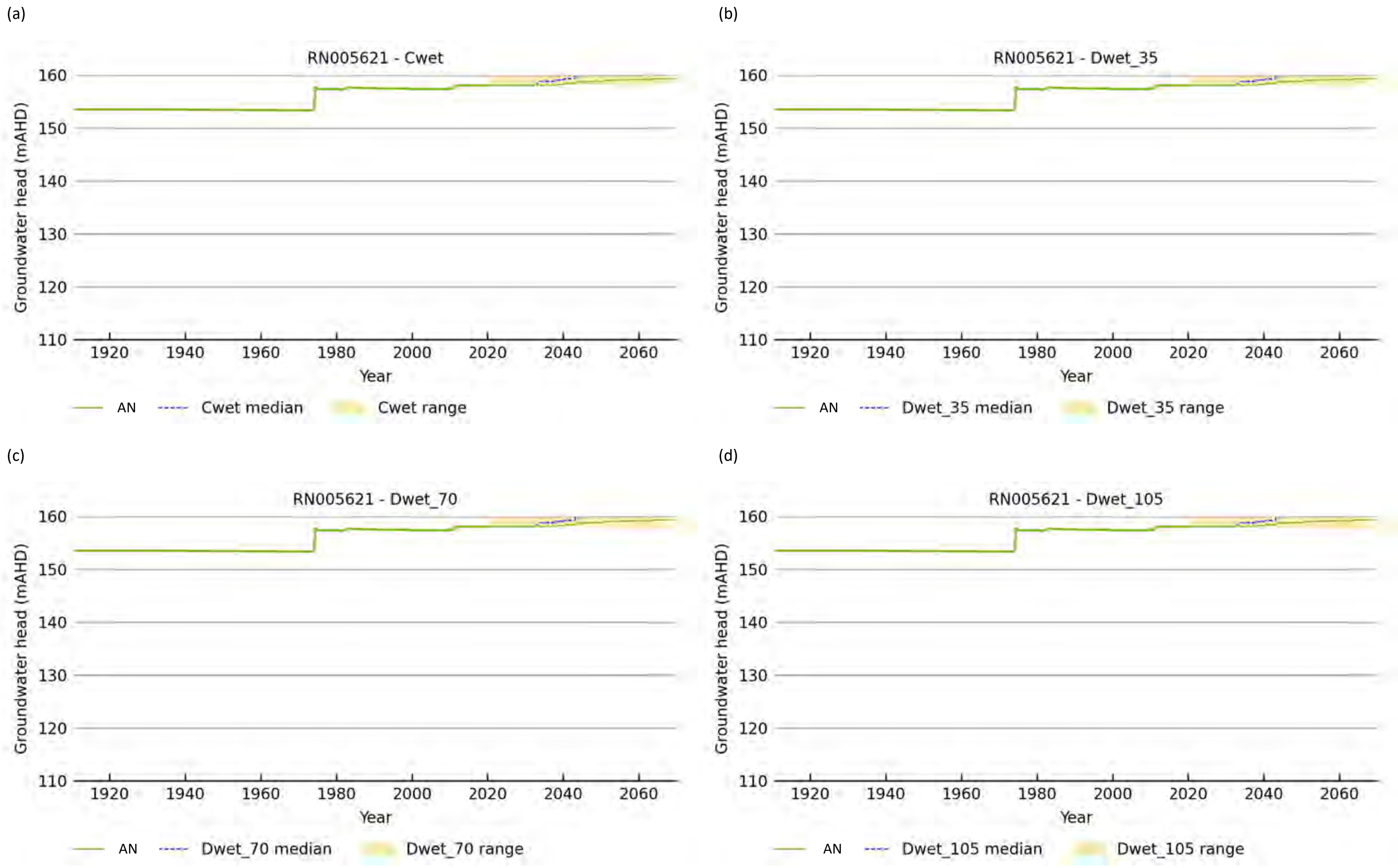


Figure 6-28 Hydrographs of groundwater level (mAHD) at reporting site RN005621 under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105

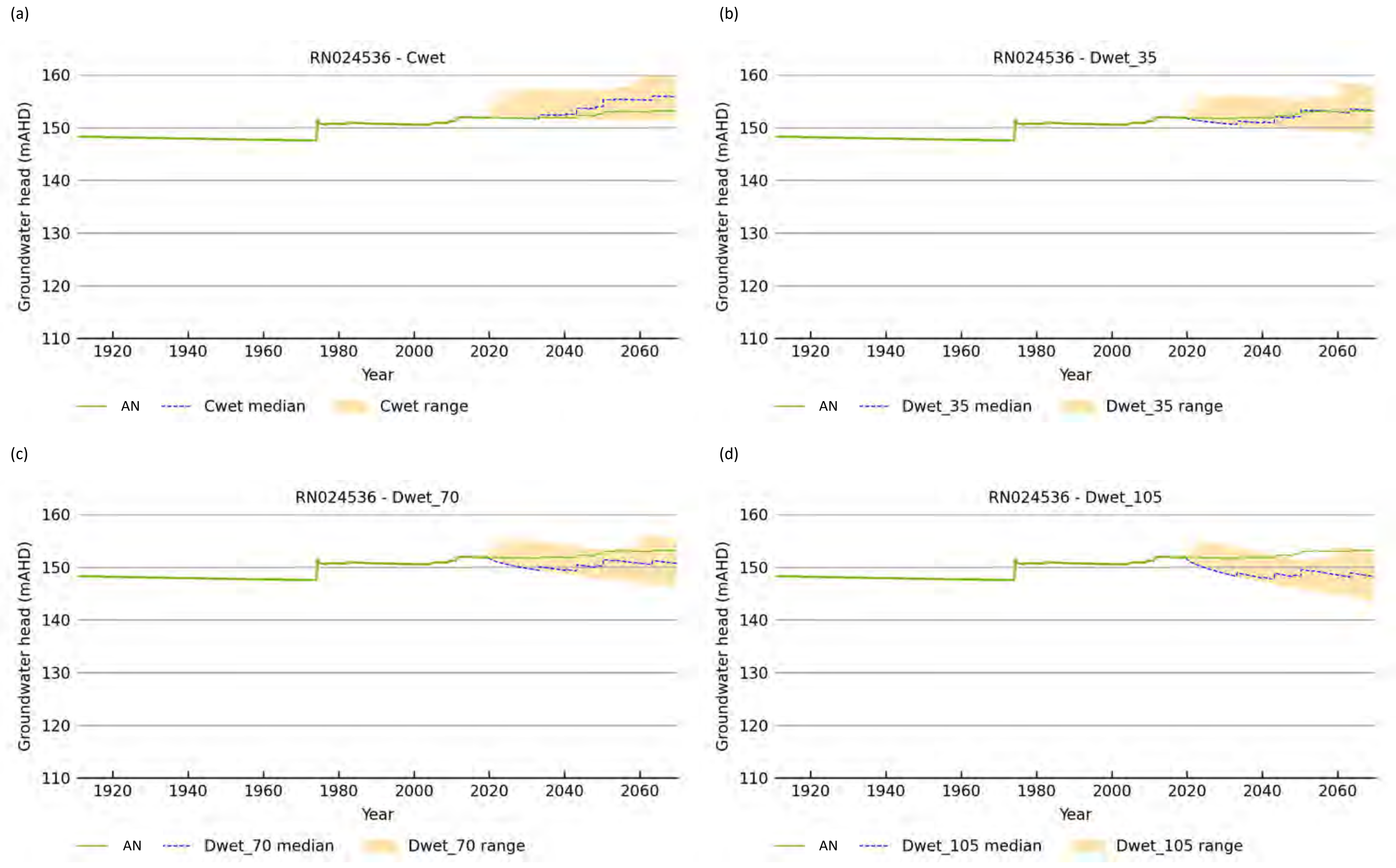


Figure 6-29 Hydrographs of groundwater level (mAHD) at reporting site RN024536 under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105

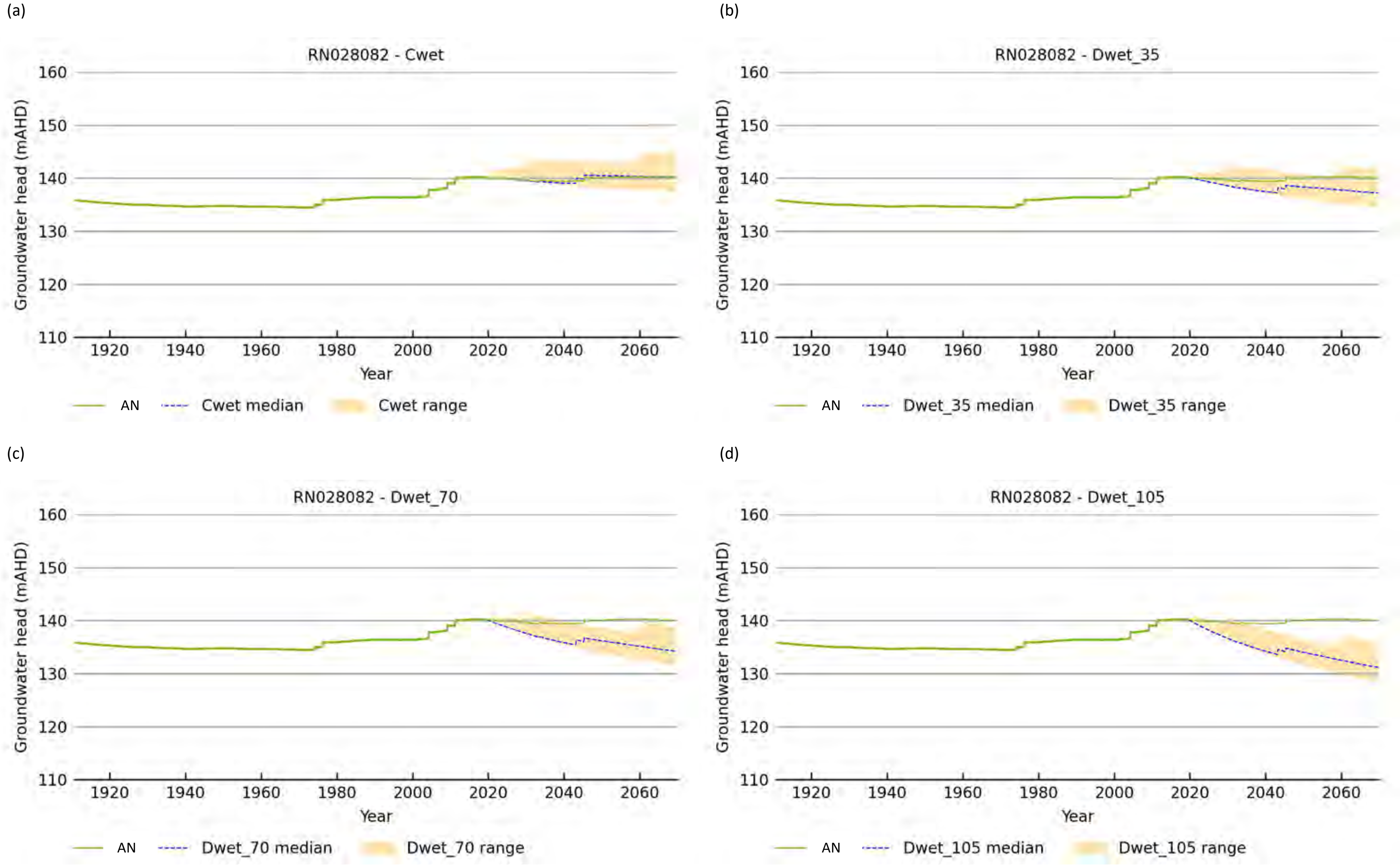


Figure 6-30 Hydrographs of groundwater level (mAHD) at reporting site RN028082 under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105

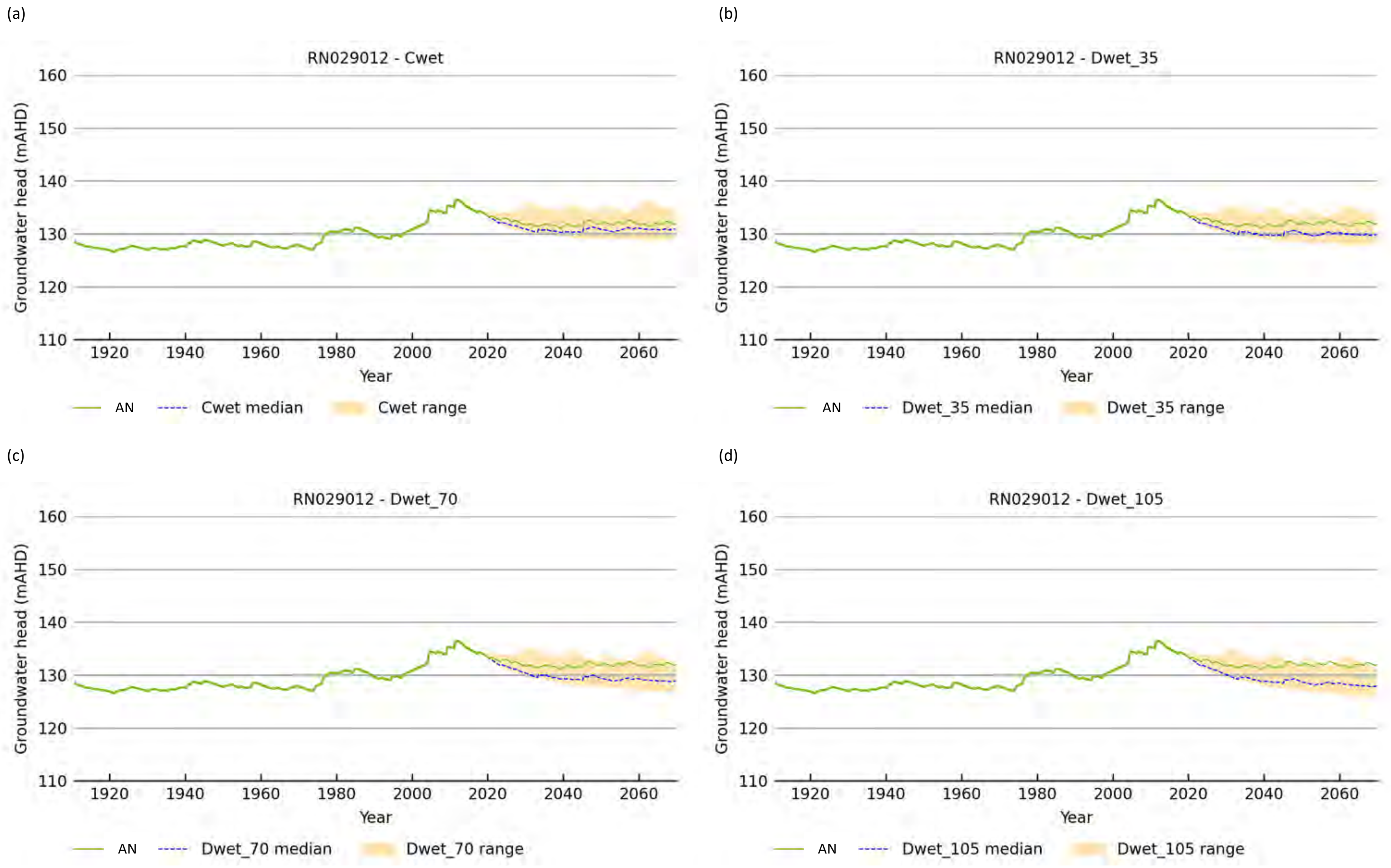


Figure 6-31 Hydrographs of groundwater level (mAHD) at reporting site RN029012 under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105

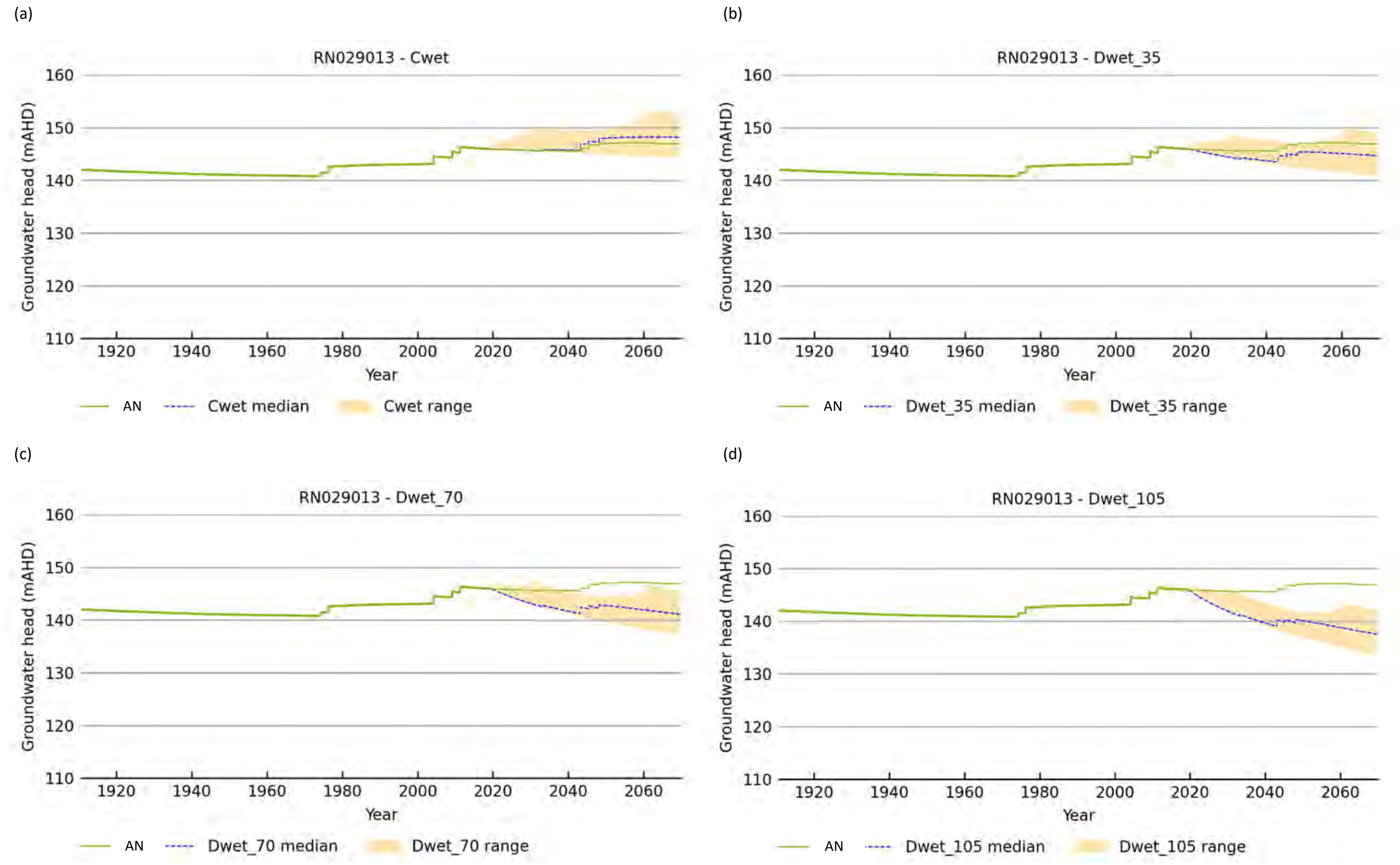


Figure 6-32 Hydrographs of groundwater level (mAHD) at reporting site RN029013 under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105

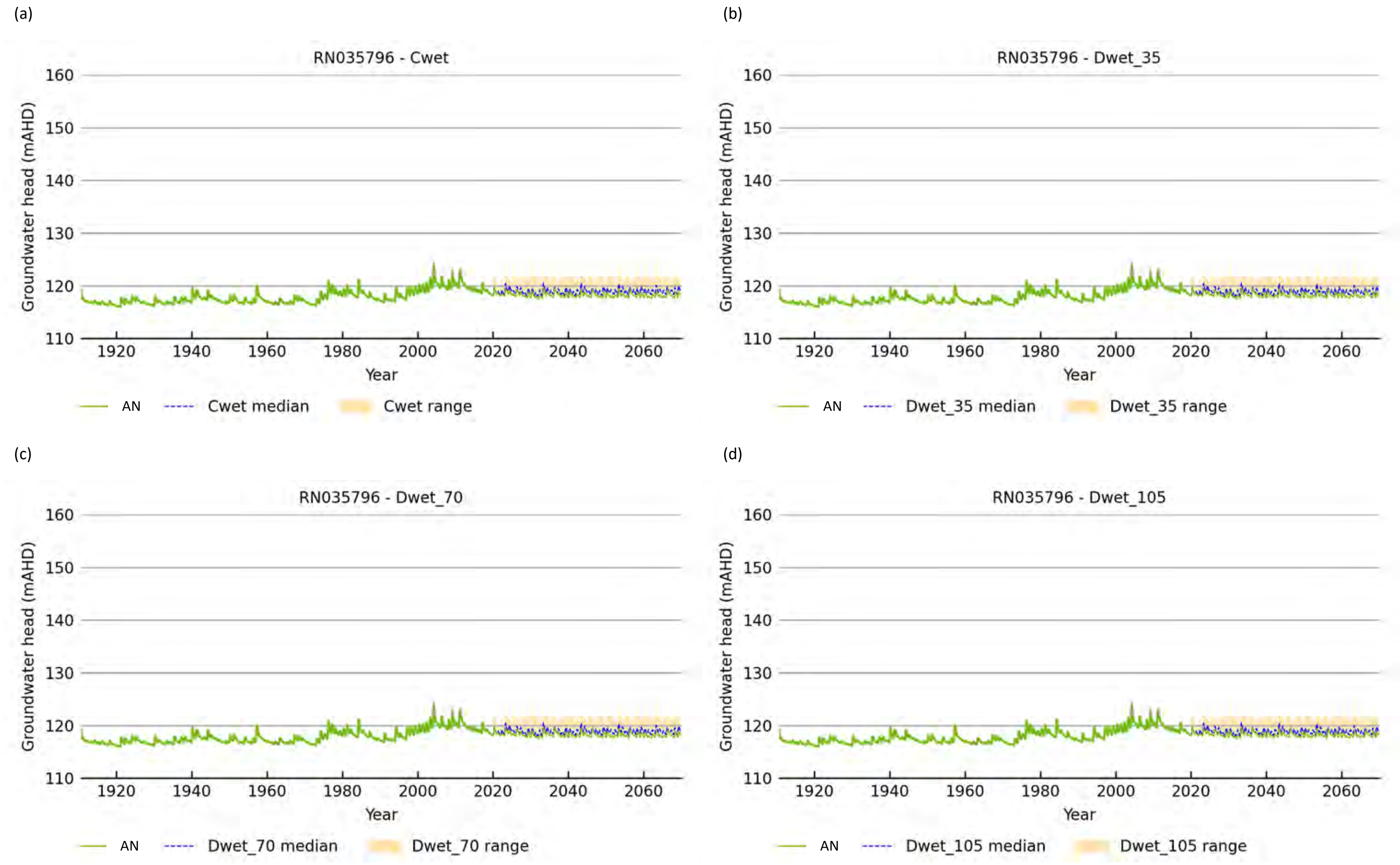


Figure 6-33 Hydrographs of groundwater level (mAHD) at reporting site RN035796 under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105

6.2.3 Scenarios Cdry and Ddry – 2069 groundwater drawdown contours

The drawdown contours at 31/8/2069 under Scenario Cdry relative to Scenario AN are shown in Figure 6-34a. The maximum drawdown (>5 m) is centred roughly on the Larrimah WCD, and the drawdown of 2 m extends further south than Daly Waters.

The drawdown contours at 31/8/2069 under Scenario Ddry35 relative to Scenario AN are shown in Figure 6-34b. The maximum drawdown (>5 m) is centred roughly on the future hypothetical developments, and the drawdown extends further south-east outside the Roper catchment.

The drawdown contours at 31/8/2069 under Scenario Ddry70 relative to Scenario AN are shown in Figure 6-34c. The maximum drawdown (>10 m) is centred roughly on the centroid of the future hypothetical developments, and the drawdown extends further south-east outside the Roper catchment.

The drawdown contours at 31/8/2069 under Scenario Ddry105 relative to Scenario AN are shown in Figure 6-34d. The maximum drawdown (>15 m) is centred roughly on the centroid of the future hypothetical developments, and the drawdown extends further south-east outside the Roper catchment.

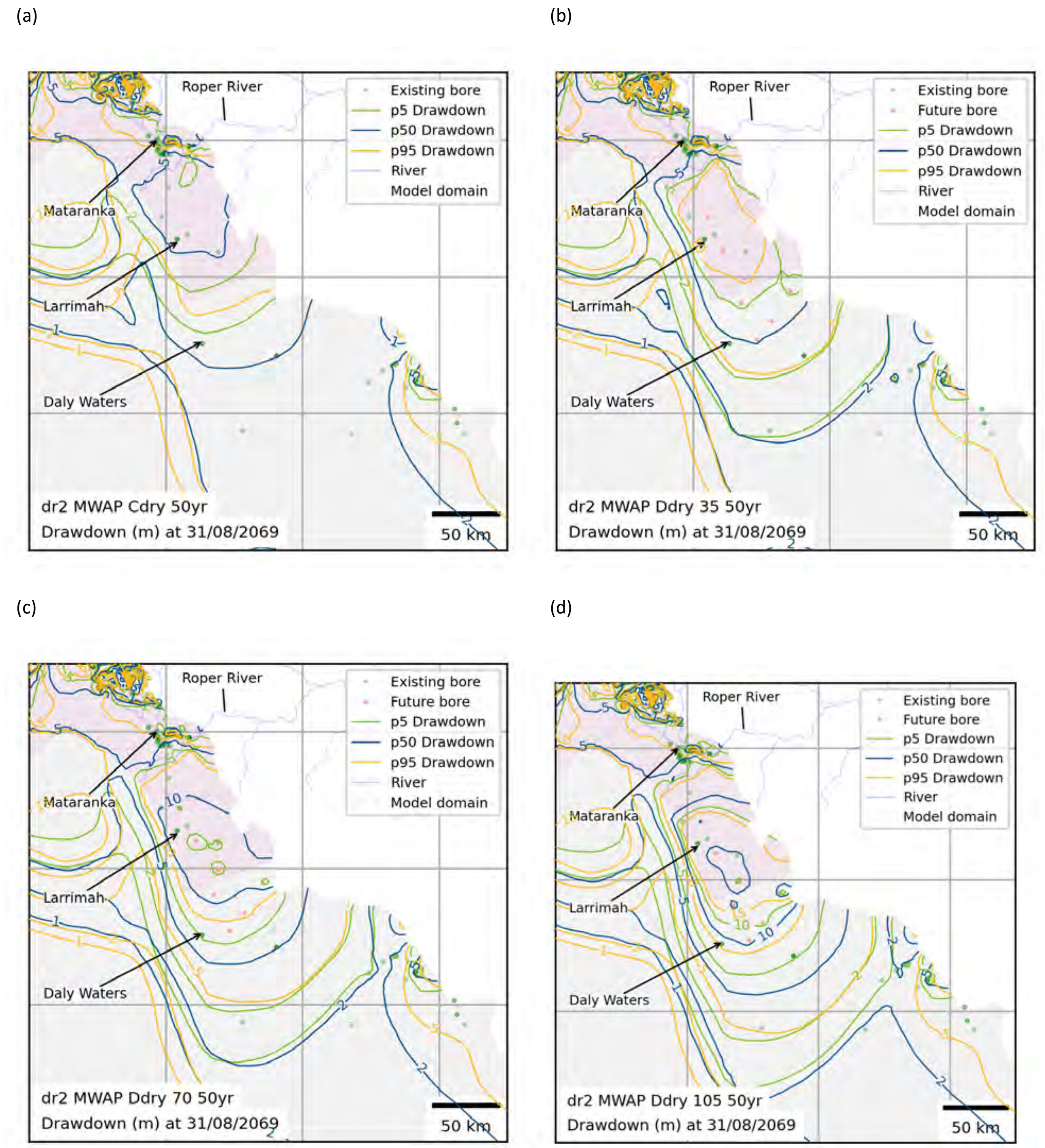


Figure 6-34 Drawdown contours relative to Scenario AN under scenarios (a) Cdry, (b) Ddry35, (c) Ddry70 and (d) Ddry105 at the end of the 11 × 50-year climate sequences

6.2.4 Scenarios Cmid and Dmid – 2069 groundwater drawdown contours

The drawdown contours at 31/8/2069 under Scenario Cmid relative to Scenario AN are shown in Figure 6-35a. The maximum drawdown (>5 m) is centred roughly on the Larrimah WCD, and the drawdown of 1 m extends beyond Daly Waters south-east of the Roper catchment.

The drawdown contours at 31/8/2069 under Scenario Dmid35 relative to Scenario AN are shown in Figure 6-35b. The maximum drawdown (>5 m) is centred roughly on the future hypothetical developments.

The drawdown contours at 31/8/2069 under Scenario Dmid70 relative to Scenario AN are shown in Figure 6-35c. The maximum drawdown (>10 m) is centred roughly on the centroid of the future hypothetical developments.

The drawdown contours at 31/8/2069 under Scenario Dmid105 relative to Scenario AN are shown in Figure 6-35d. The maximum drawdown (>15 m) is centred roughly on the centroid of the future hypothetical developments.

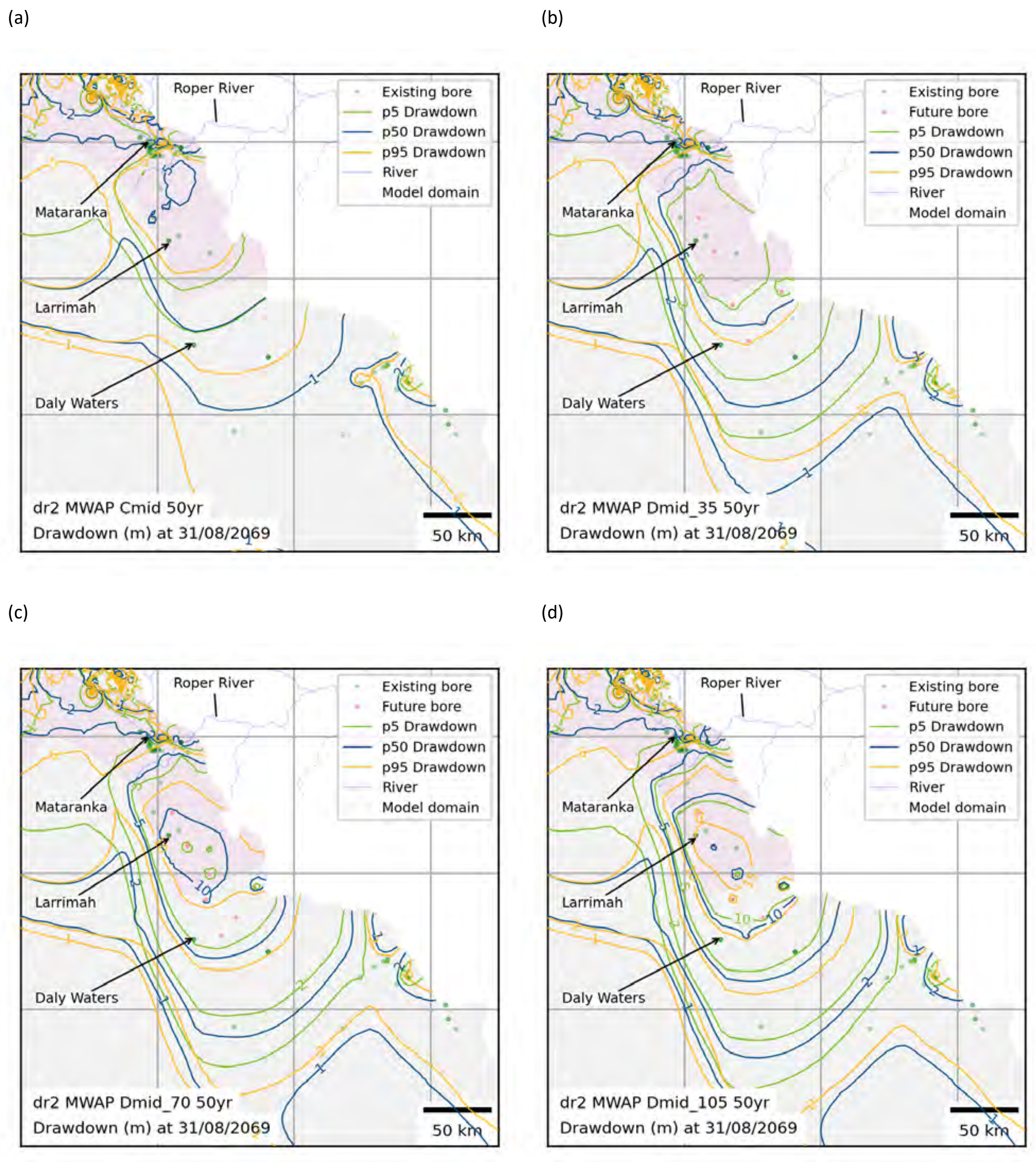


Figure 6-35 Drawdown contours relative to Scenario AN under scenarios (a) Cmid, (b) Dmid 35, (c) Dmid 70 and (d) Dmid 105 at the end of the 11 × 50-year climate sequences

6.2.5 Scenarios Cwet and Dwet – 2069 groundwater drawdown contours

The drawdown contours at 31/8/2069 under Scenario Cwet relative to Scenario AN are shown in Figure 6-36a. The maximum drawdown (>2 m) is centred roughly on the Larrimah WCD, but the drawdown contours are negative outside the MWMZ and LWMZ, indicating an increase in groundwater level relative to Scenario AN due to the wetter future climate.

The drawdown contours at 31/8/2069 under Scenario Dwet35 relative to Scenario AN are shown in Figure 6-36b. The maximum drawdown (>5 m) is centred roughly on the future hypothetical developments, and the drawdown of 1 m extends to Daly Waters. The majority of the model domain has a predicted increase in groundwater level relative to Scenario AN due to the wetter future climate.

The drawdown contours at 31/8/2069 under Scenario Dwet70 relative to Scenario AN are shown in Figure 6-36c. The maximum drawdown (5 to 10 m) is centred roughly on the centroid of the future hypothetical developments, and the drawdown of 1 m extends further south-east of the Roper catchment. However, the majority of the model domain has a predicted increase in groundwater level relative to Scenario AN due to the wetter future climate.

The drawdown contours at 31/8/2069 under Scenario Dwet105 relative to Scenario AN are shown in Figure 6-36d. The maximum drawdown (>10 m) is centred roughly on the centroid of the future hypothetical developments, and the drawdown of 1 m extends further south-east of the Roper catchment. However, the majority of the model domain has a predicted increase in groundwater level relative to Scenario AN due to the wetter future climate.

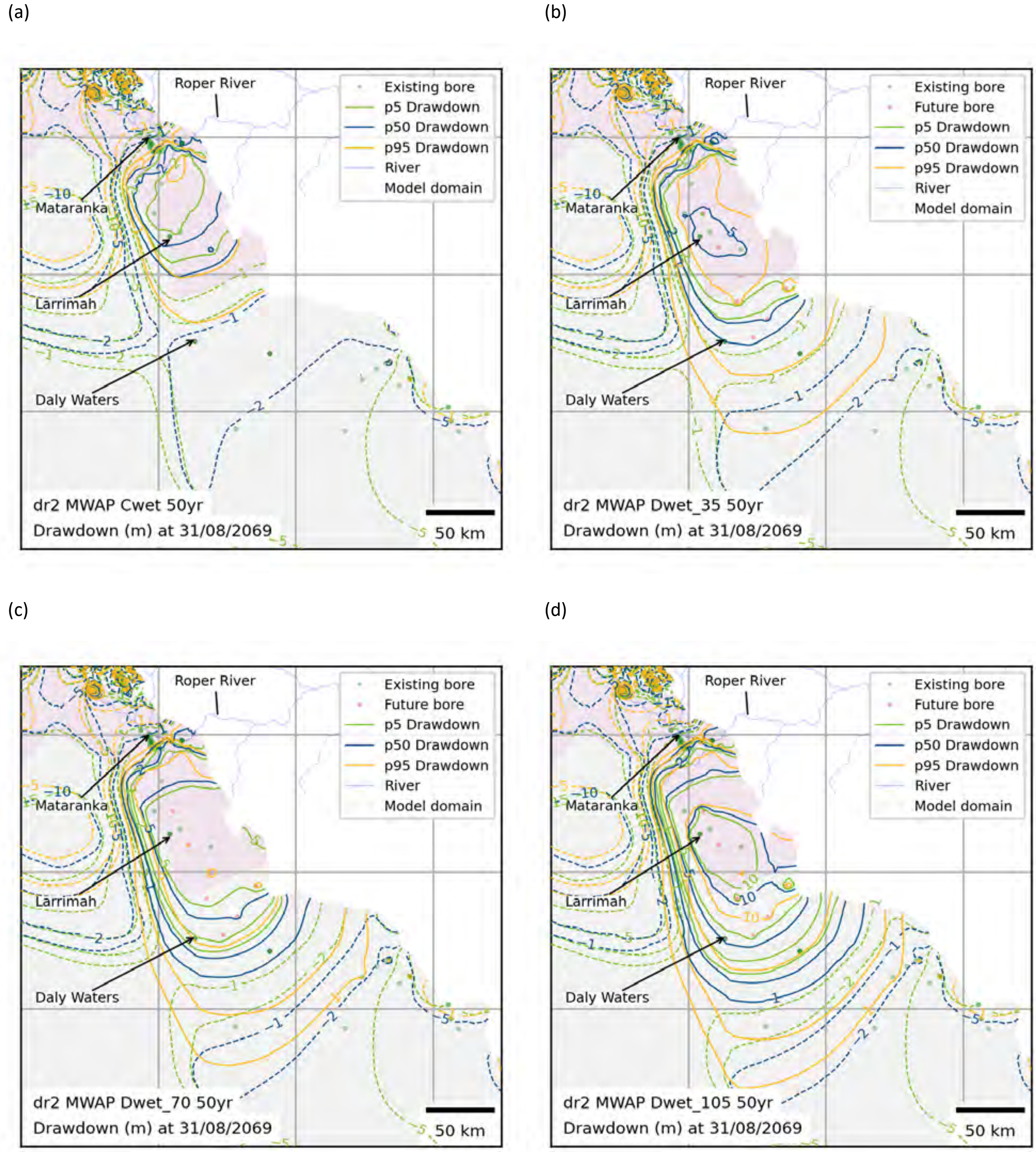


Figure 6-36 Drawdown contours relative to Scenario AN under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105 at the end of the 11 × 50-year climate sequences

Dashed lines indicate contours with negative values (i.e. groundwater-level rises relative to Scenario AN).

6.2.6 Scenarios C and D – groundwater discharge

This section presents the simulated groundwater discharge at G9030013 (Roper River at Elsey Homestead) under scenarios C and D. The locations of the groundwater discharge reporting sites are shown in Figure 4-5.

Table 6-8 presents the mean groundwater discharge at G9030013 for the last 10-year period (2059 to 2069) of each climate sequence under scenarios C and D. Each table row corresponds to a specific scenario, and the columns represent the mean groundwater discharge and the % change from Scenario AN.

The wet scenarios exhibit mean discharges at site G9030013 (Elsey Homestead) that are greater than those simulated in Scenario AN.

Table 6-8 Mean groundwater discharge at the Roper River (G9030013) under scenarios C and D

SCENARIO	GROUNDWATER DISCHARGE (m^3/s)	% CHANGE FROM AN
AN	3.3	na†
Cdry	2.3	−30
Cmid	2.6	−19
Cwet	3.4	+4
Ddry35	2.3	−31
Ddry70	2.2	−32
Ddry105	2.2	−33
Dmid35	2.6	−20
Dmid70	2.6	−21
Dmid105	2.6	−22
Dwet35	3.4	+3
Dwet70	3.4	+3
Dwet105	3.3	+2

AN = Historical climate and no development; Cdry = Future dry climate sequences current development; Cmid = Future mid climate sequences current development; Cwet = Future wet climate sequences current development; Ddry35 = Future dry climate sequences current development and future development of 35 GL/year; Ddry70 = Future dry climate sequences current development and future development of 70 GL/year; Ddry105 = Future dry climate sequences current development and future development of 105 GL/year; Dmid35 = Future mid climate sequences current development and future development of 35 GL/year; Dmid70 = Future mid climate sequences current development and future development of 70 GL/year; Dmid105 = Future mid climate sequences current development and future development of 105 GL/year); Dwet35 = Future wet climate sequences current development and future development of 35 GL/year; Dwet70 = Future wet climate sequences current development and future development of 70 GL/year; Dwet105 = Future wet climate sequences current development and future development of 105 GL/year.
†na = not applicable.

Hydrographs of groundwater discharge under scenarios C and D are presented in Figure 6-37 through Figure 6-39. The groundwater discharge hydrographs show Scenario AN (green solid line) for reference, the median groundwater discharge determined from the 11 climate sequences (blue dashed line) and the range of groundwater levels from all 11 climate sequences (pale orange).

The hydrographs highlight the effects of climate relative to the effects of increased extraction in Scenario D relative to Scenario C. This is also evident in the mean groundwater discharges at each site presented in Table 6-8.

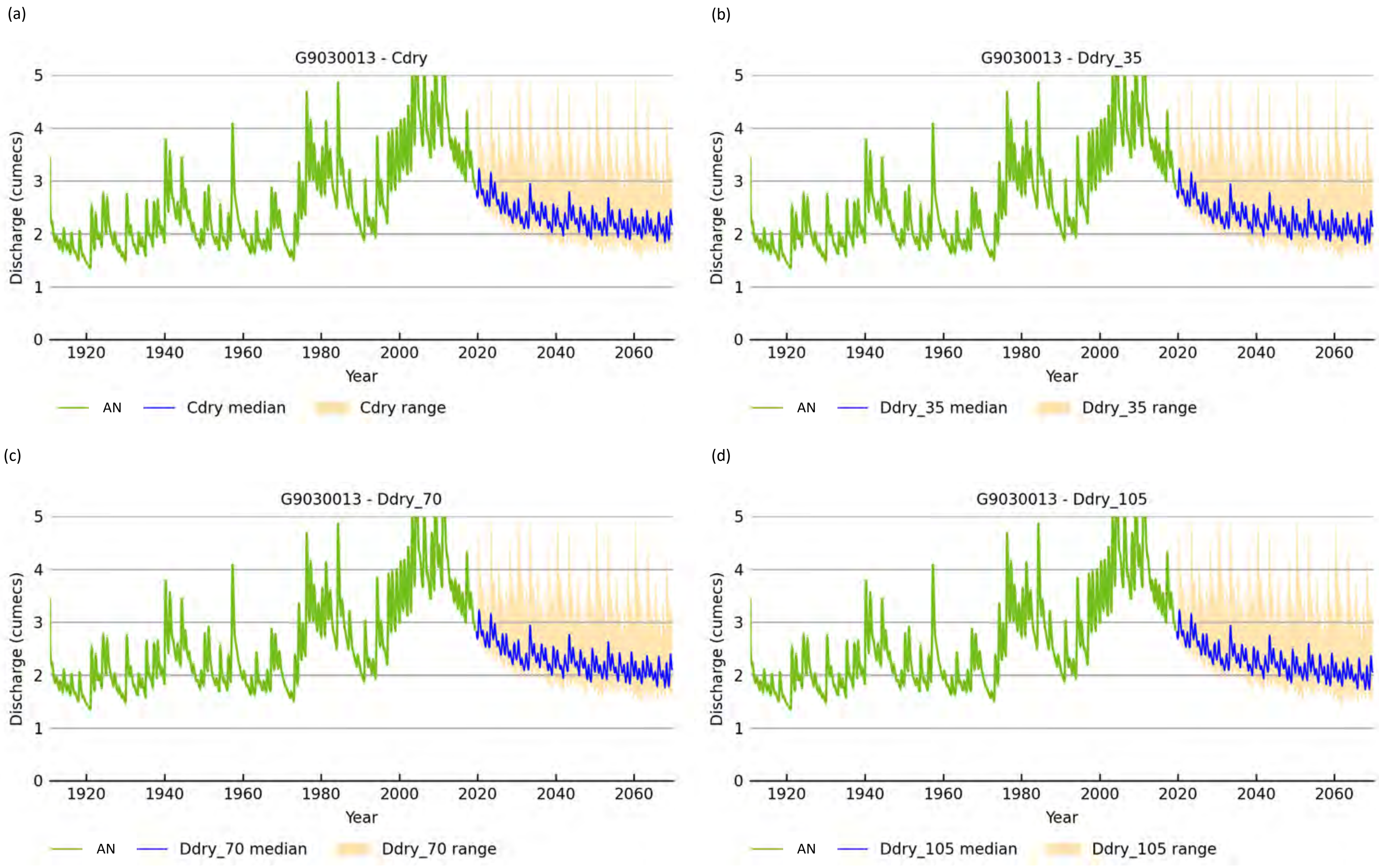


Figure 6-37 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030013 under scenarios (a) Cdry, (b) Ddry 35, (c) Ddry 70 and (d) Ddry 105

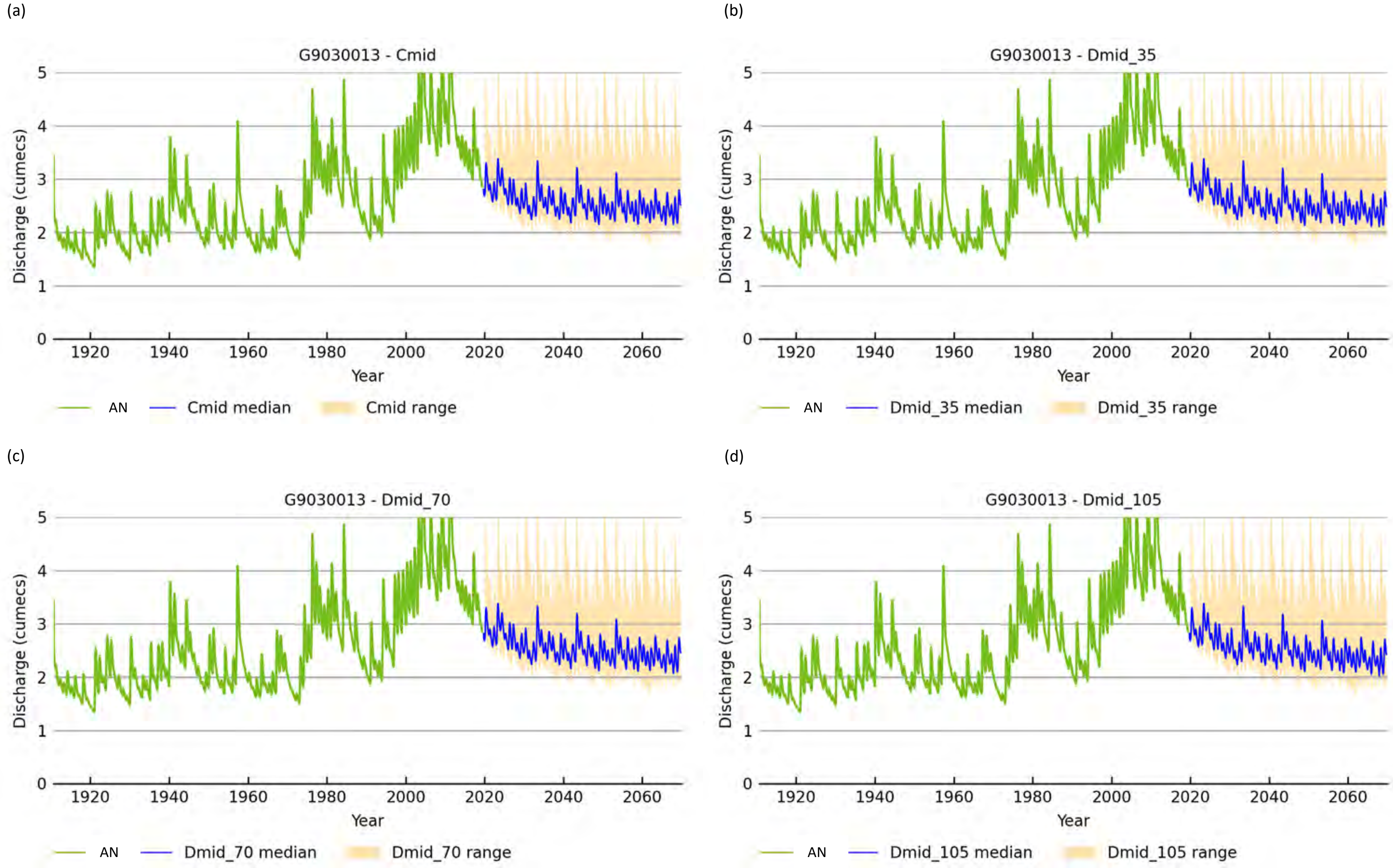


Figure 6-38 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030013 under scenarios (a) Cmid, (b) Dmid 35, (c) Dmid 70 and (d) Dmid 105

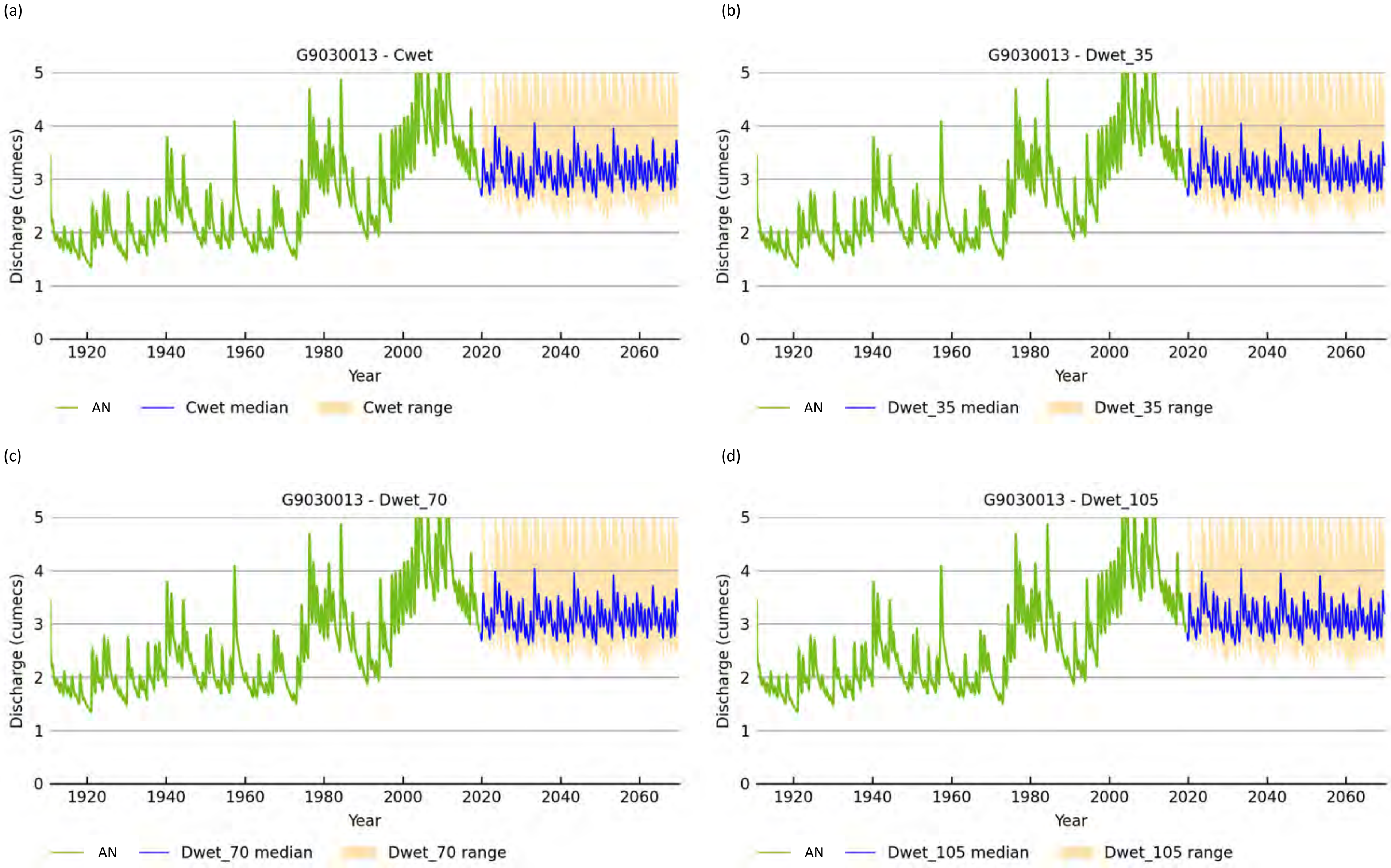


Figure 6-39 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030013 under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105

The percentage changes in discharge at G9030013 under future climate scenarios for dry, mid and wet are presented in Figure 6-40, Figure 6-41 and Figure 6-42, respectively. The change in discharge at G9030013 from the CLA has been determined by comparing the natural Scenario AN results to the C and D pumping scenarios.

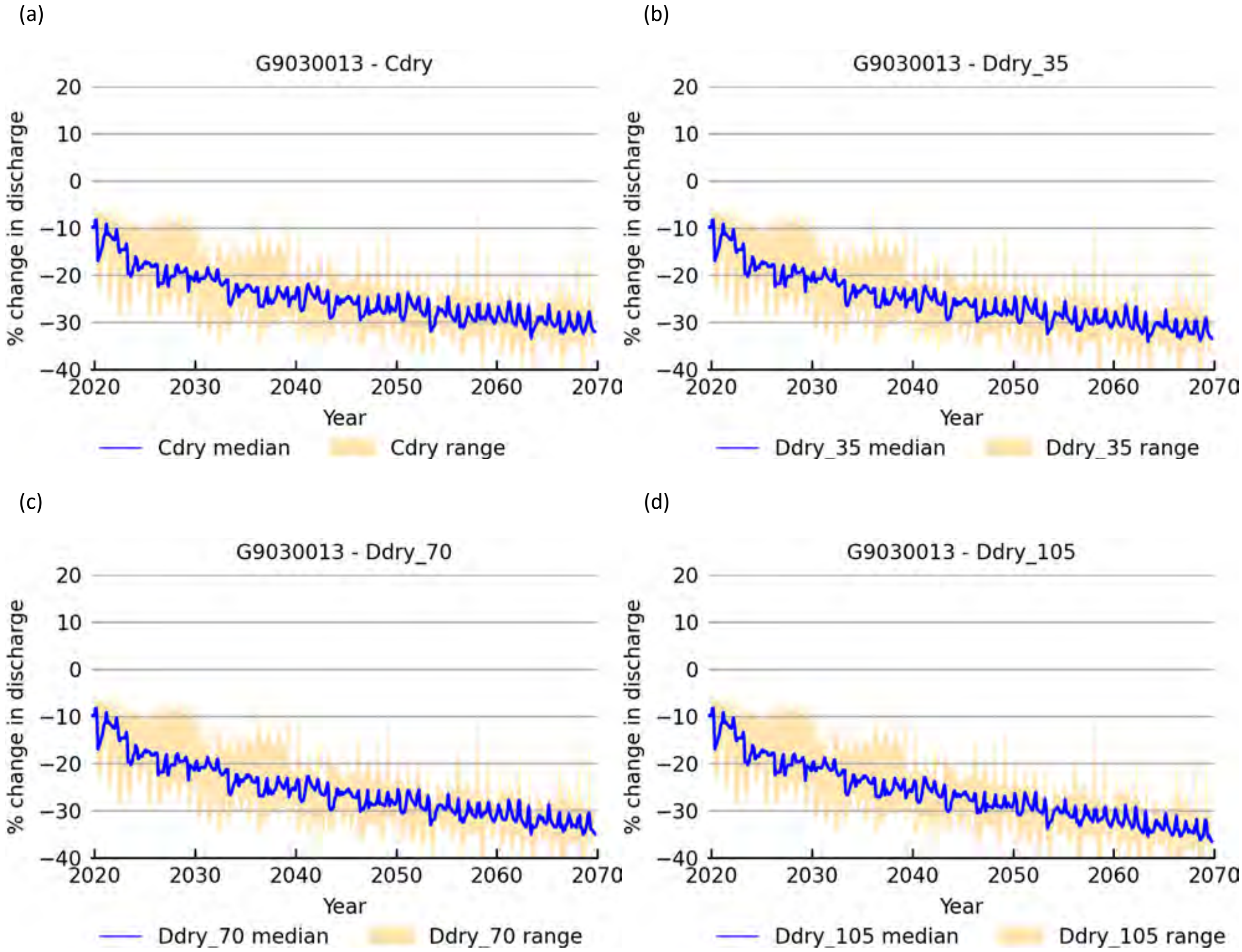


Figure 6-40 Change in discharge relative to Scenario AN at G9030013 under scenarios (a) Cdry, (b) Ddry 35, (c) Ddry 70 and (d) Ddry 105

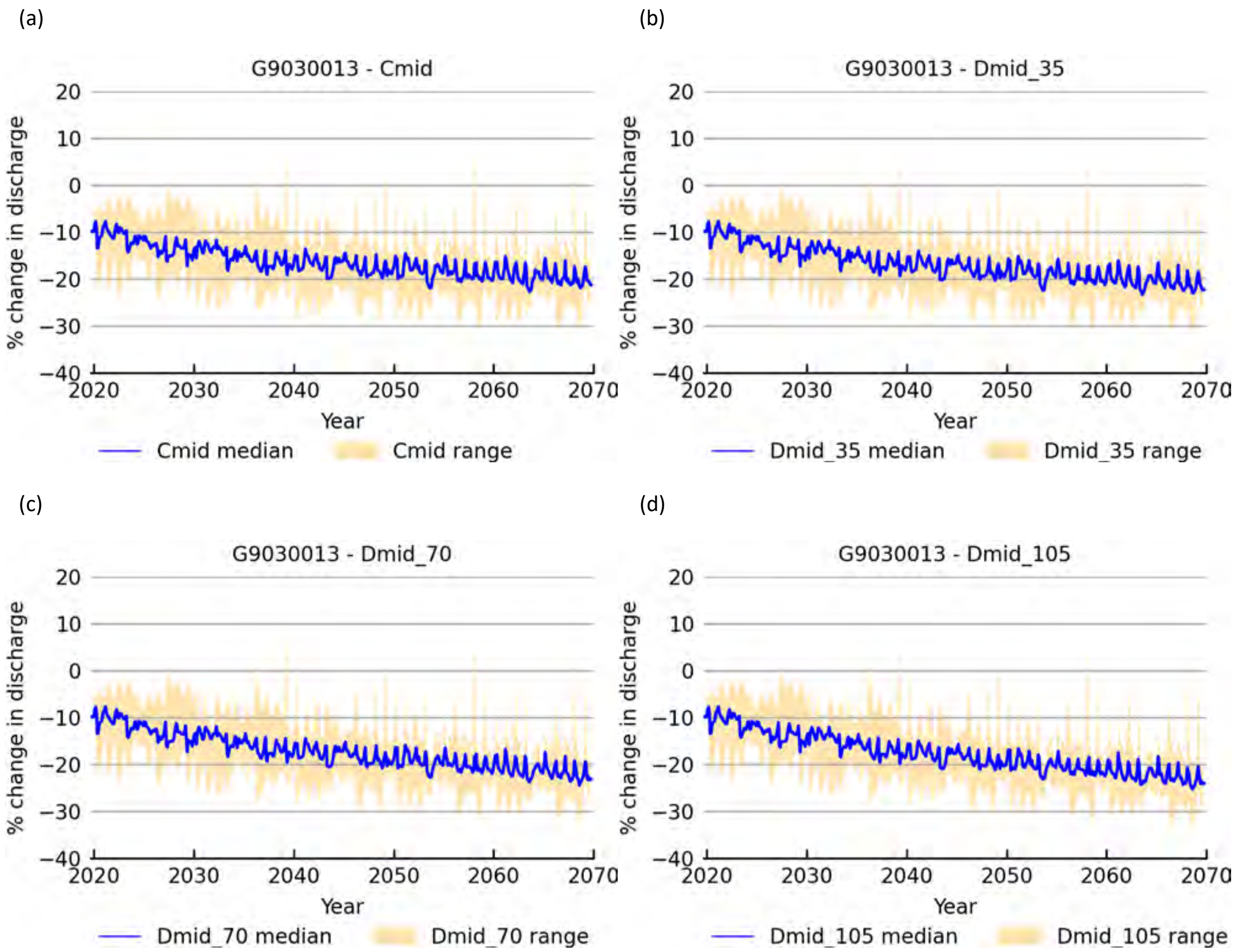


Figure 6-41 Change in discharge relative to Scenario AN at G9030013 under scenarios (a) Cmid, (b) Dmid 35, (c) Dmid 70 and (d) Dmid 105

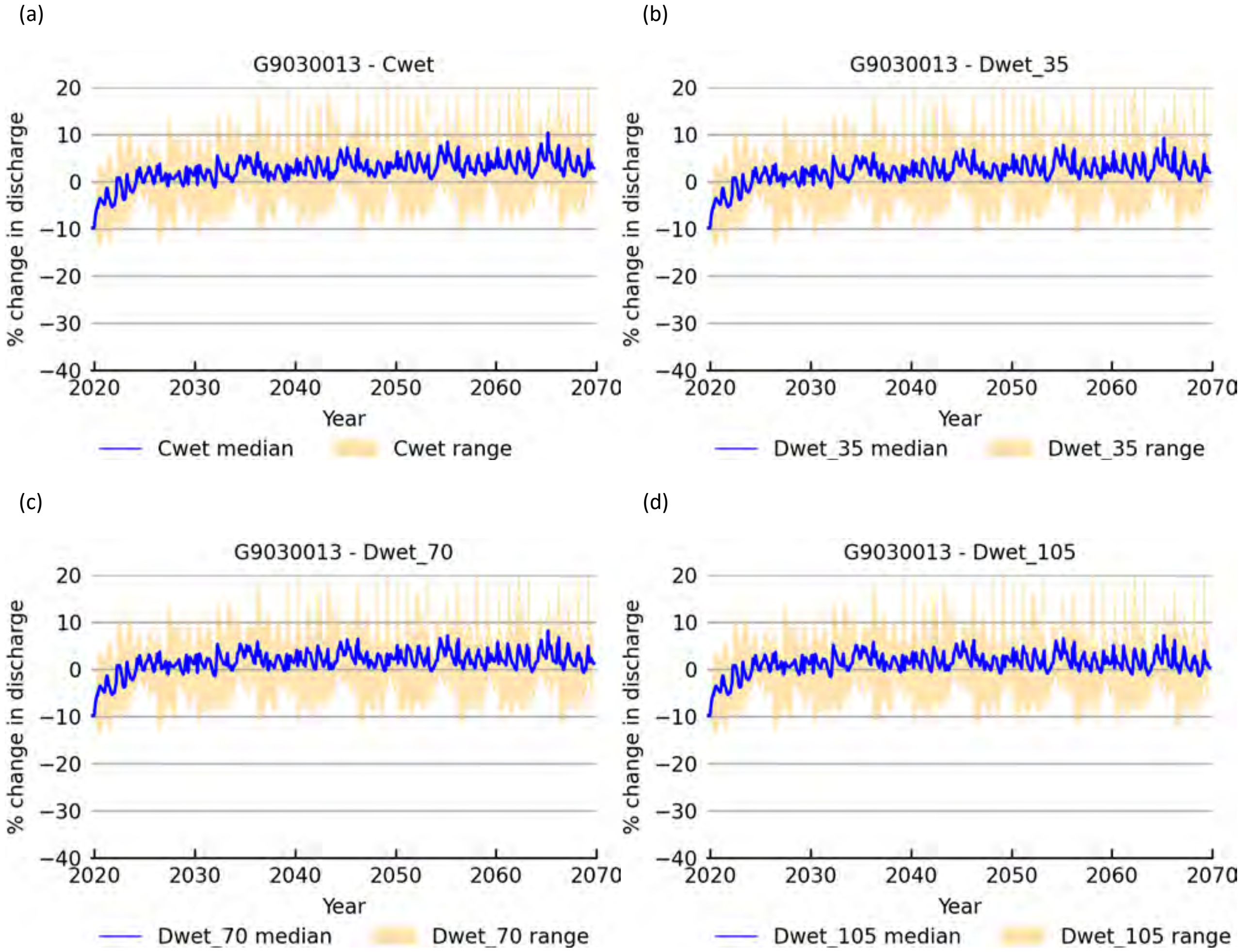


Figure 6-42 Change in discharge relative to Scenario AN at G9030013 under scenarios (a) Cwet, (b) Dwet 35, (c) Dwet 70 and (d) Dwet 105

7 Dook Creek Aquifer quasi-equilibrium results (436 years)

7.1 Historical climate (scenarios A′ and B′)

7.1.1 Scenarios A′ and B′ – water balances

Mean annual water balances for the portion of the DCA within the Roper catchment under scenarios A′ and B′ and under quasi-equilibrium conditions for the last 109 years of the 436-year climate sequence are presented in Table 7-1.

The data show that current extraction is very low, so the water balance components under Scenario A′ are almost the same as Scenario A′N. The hypothetical future extraction in Scenario B′ results in reductions in evapotranspiration (from −4% for B′6 to −12% for B′18), rivers (from −5% for B′6 to −16% for B′18) and springs (from −15% for B′6 to −38% for B′18).

Table 7-1 Quasi-equilibrium mean annual water balances (GL/year) for the last 109 years of the 436-year climate sequence under scenarios A′N, A′ and B′ for the Dook Creek Aquifer within the Roper catchment

	A′N	A′	B′6	B′12	B′18
Inflow (gains)					
Recharge (diffuse)	151.9	151.9	152.0	152.2	152.3
Release from storage	111.7	111.7	112.4	113.0	113.7
From river	0.1	0.1	0.1	0.1	0.1
Sub-total	**263.8**	**263.8**	**264.5**	**265.3**	**266.1**
Outflow (losses)					
Evapotranspiration	70.5	70.5	67.8	65.0	62.2
Extraction	0.0	0.1	6.1	12.1	18.1
Capture into storage	108.1	108.1	108.4	108.7	109.0
To rivers	20.8	20.8	19.7	18.6	17.4
To springs	7.4	7.4	6.3	5.4	4.6
Sub-total	**206.8**	**206.8**	**208.2**	**209.7**	**211.3**
Net flow in (+ve) / out (-ve)	**−57.0**	**−57.0**	**−56.3**	**−55.6**	**−54.8**

A′N = Historical climate and no development; A′ = Historical climate and current development; B′6 = Historical climate sequences with current development and additional future development of 6 GL/year; B′12 = Historical climate sequences with current development and additional future development of 12 GL/year; B′18 = Historical climate sequences with current development and additional future development of 18 GL/year.

7.1.2 Scenarios A′ and B′ – groundwater levels

The locations of the five DCA groundwater-level reporting sites are shown in Figure 4-5.

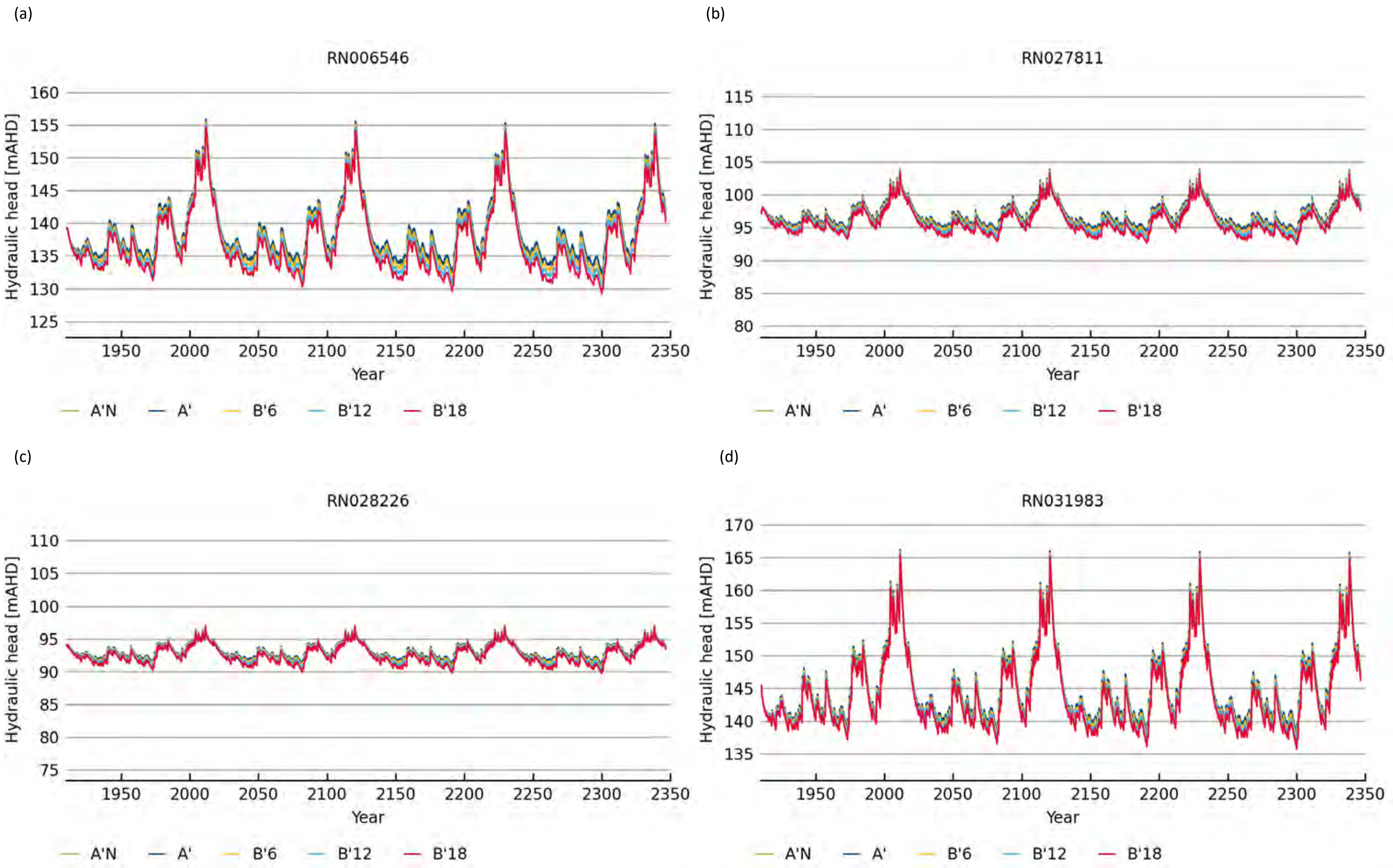
Table 7-2 presents the mean groundwater level at the five DCA reporting sites for the last 109-year climate sequence replicate under scenarios A′ and B′. Each table row corresponds to a specific scenario, and the columns represent the mean groundwater level at each reporting site. The low levels of extraction in Scenario A′ result in minimal change in the groundwater level at all five reporting sites. The increasing levels of hypothetical extraction under the B scenarios result in increasing reductions in groundwater levels. Changes range from −0.2 to −0.8 m under Scenario B′6 to −0.7 to −2.6 m under Scenario B′18.

Table 7-2 Quasi-equilibrium mean groundwater levels (mAHD) for the last 109 years of the 436-year climate sequence under scenarios A′N, A′ and B′ for the Dook Creek Aquifer groundwater reporting sites

SCENARIO	RN006546	RN027811	RN028226	RN031983	RN036302
A′N	138.7	96.9	93.1	145.2	133.1
A′	138.7	96.9	93.1	145.2	133.1
B′6	138	96.5	92.9	144.7	132.3
B′12	137.2	96.1	92.6	144.2	131.5
B′18	136.4	95.7	92.4	143.7	130.5

A′N = Historical climate and no development; A′ = Historical climate and current development; B′6 = Historical climate sequences with current development and additional future development of 6 GL/year; B′12 = Historical climate sequences with current development and additional future development of 12 GL/year; B′18 = Historical climate sequences with current development and additional future development of 18 GL/year.

Hydrographs of groundwater levels under scenarios A′ and B′ at the five reporting sites are presented in Figure 7-1. These show that the increasing extraction in Scenario B leads to a reduction in groundwater level relative to A′N during dry years, but in wet years the groundwater levels re-set such that the groundwater levels in Scenario A′N are very similar to the Scenario B groundwater levels. This is particularly evident in RN006546 and RN036302.


(a)
RN006546
Hydraulic head [mAHD]
Year
A'N
A'
B'6
B'12
B'18
(b)
RN027811
Hydraulic head [mAHD]
Year
A'N
A'
B'6
B'12
B'18
(c)
RN028226
Hydraulic head [mAHD]
Year
A'N
A'
B'6
B'12
B'18
(d)
RN031983
Hydraulic head [mAHD]
Year
A'N
A'
B'6
B'12
B'18

(e)

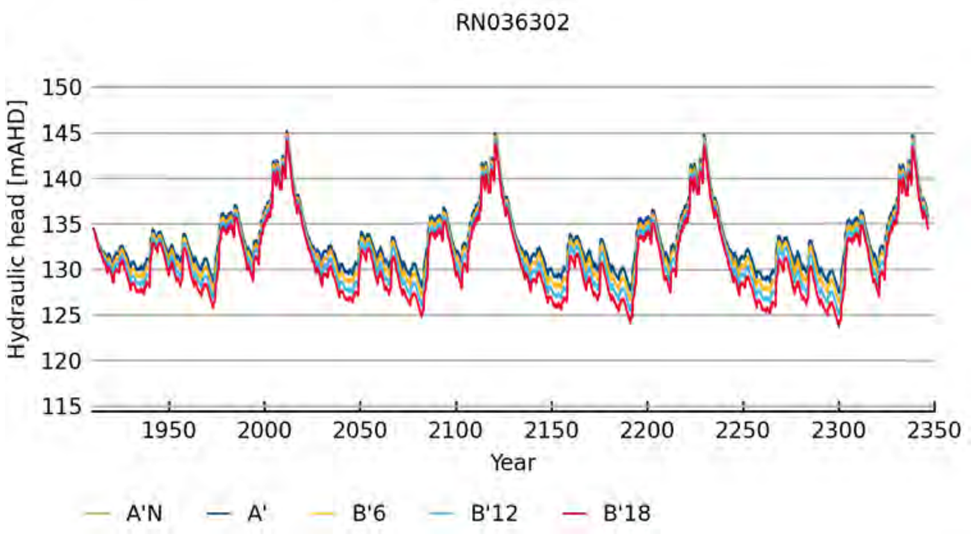


Figure 7-1 Hydrographs of groundwater level (mAHD) under quasi-equilibrium scenarios A′ and B′ at the five reporting sites: (a) RN006546, (b) RN027811, (c) RN028226, (d) RN031983, and (e) RN036302

7.1.3 Scenarios A′ and B′ – groundwater drawdown contours

Under Scenario A′, the drawdown after 436 years is minimal due to the small amount of extraction, so no contours can be seen on Figure 7-2a. Under Scenario B′6, the maximum drawdown is greater than 1 m in an area surrounding the hypothetical development (Figure 7-2b). Under Scenario B′12, the area surrounding the hypothetical developments has greater than 2 m drawdown (Figure 7-2c), and this area is expanded further under Scenario B′18 (Figure 7-2d).

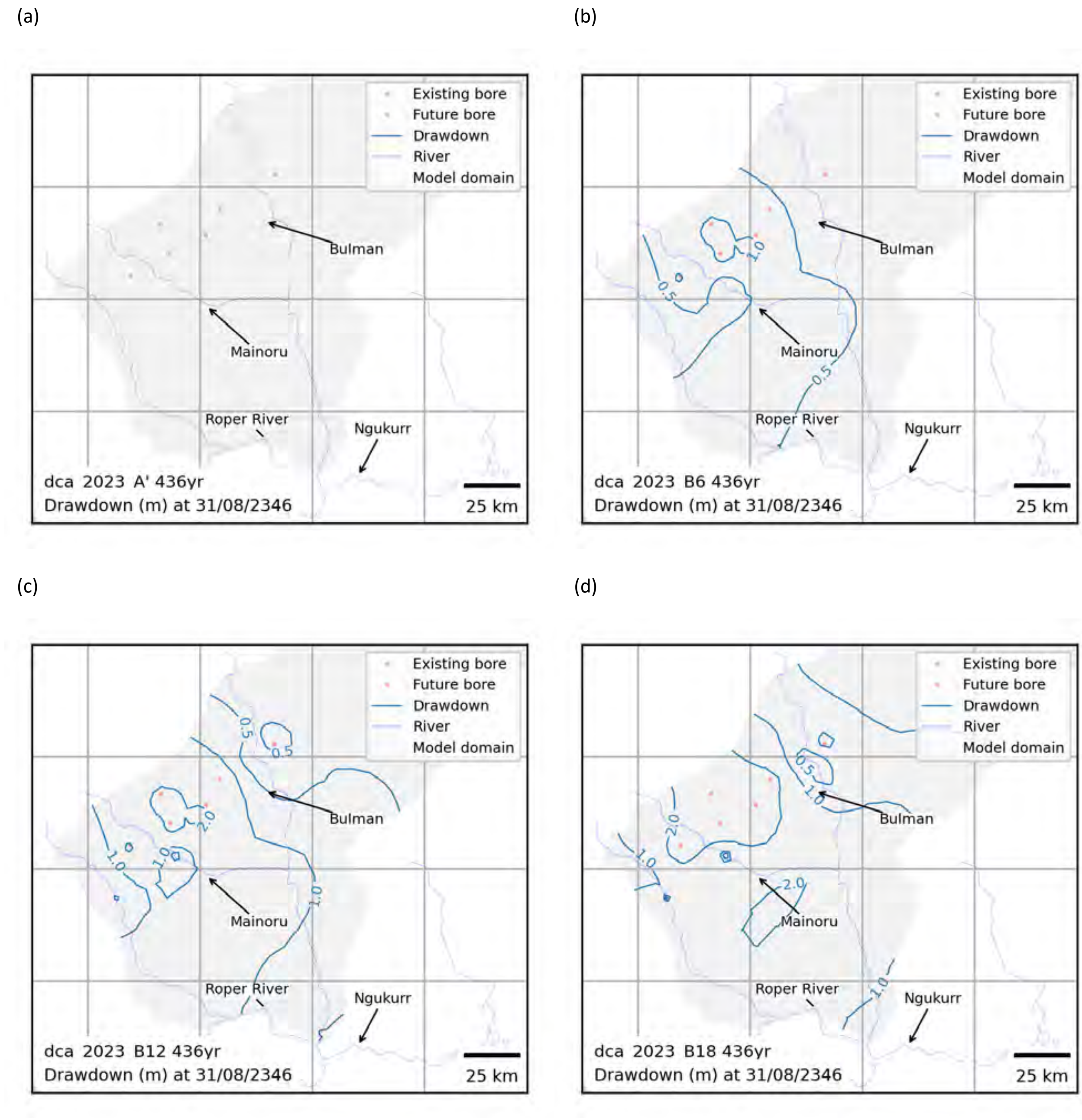


Figure 7-2 Drawdown contours under scenarios (a) A′, (b) B′6, (c) B′12 and (d) B′18 at the end of the 436-year quasi-equilibrium historical climate sequence

7.1.4 Scenarios A′ and B′ – groundwater discharge

The mean groundwater discharges at the Wilton River at G9030003 and Flying Fox Creek at G9030108 for the last 109 years of the 436-year climate sequence under scenarios A′ and B′ are presented in Table 7-3. The data show that the current minimal extraction has no measurable change in the flow at either gauge. The additional hypothetical extraction under Scenario B′ results in a change in discharge of −5%, −11% and −16% under scenarios B′6, B′12 and B′18, respectively.

Table 7-3 Quasi-equilibrium mean groundwater discharge for the last 109-year climate sequence replicate under scenarios A′ and B′ at groundwater discharge sites along the Wilton River (G9030003) and Flying Fox Creek (G9030108)

SCENARIO	G9030003 GROUNDWATER DISCHARGE (m^3/s)	G9030003 % CHANGE FROM A′N	G9030108 GROUNDWATER DISCHARGE (m^3/s)	G9030108 % CHANGE FROM A′N
A′N	0.10	na†	0.56	na†
A′	0.10	0	0.56	0
B′6	0.09	−5	0.53	−5
B′12	0.09	−11	0.50	−11
B′18	0.08	−16	0.47	−16

A′N = Historical climate and no development; A′ = Historical climate and current development; B′6 = Historical climate sequences with current development and additional future development of 6 GL/year; B′12 = Historical climate sequences with current development and additional future development of 12 GL/year; B′18 = Historical climate sequences with current development and additional future development of 18 GL/year.
†na = not applicable.

Groundwater discharges under scenarios A′ and B′ at the Wilton River at G9030003 and Flying Fox Creek at G9030108 are presented in Figure 7-3. The differences between results under Scenario A′N and under scenarios A′, B′6, B′12 and B′18 at sites G9030003 and G9030108 are presented in Figure 7-4a and Figure 7-4b, respectively. The differences as percentage change from Scenario A′N for scenarios A′, B′6, B′12 and B′18 at sites G9030003 and G9030108 are presented in Figure 7-5a and Figure 7-5b, respectively.

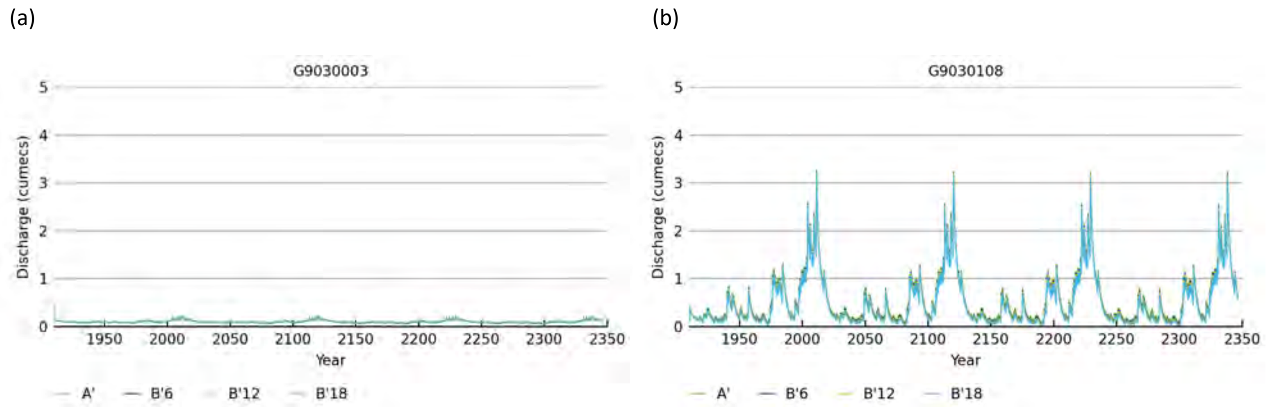


Figure 7-3 Groundwater discharge (m^3/second) under scenarios A′, B′6, B′12 and B′18 at (a) G9030003 and (b) G9030108

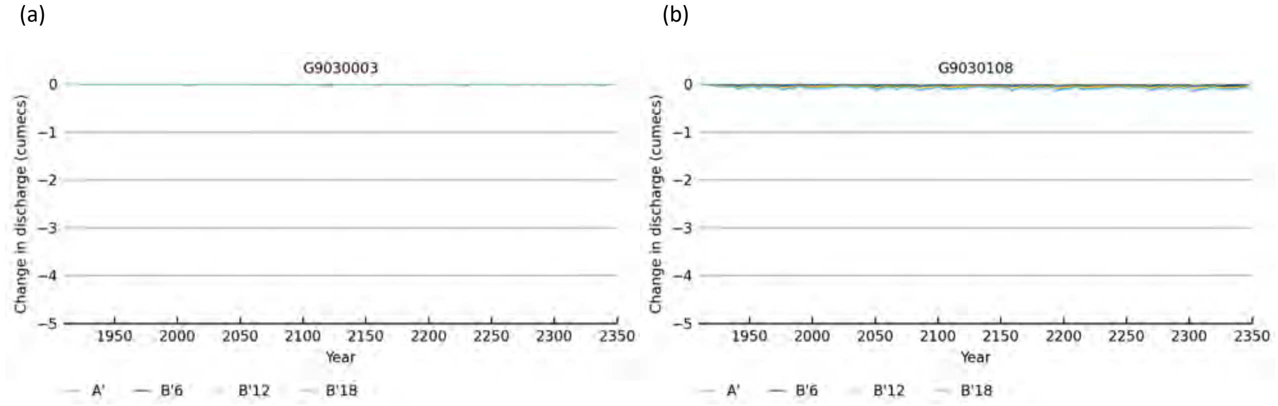


Figure 7-4 Difference in groundwater discharge (m^3/second) between Scenario A′N and scenarios A′, B′6, B′12 and B′18 at (a) G9030003 and (b) G9030108

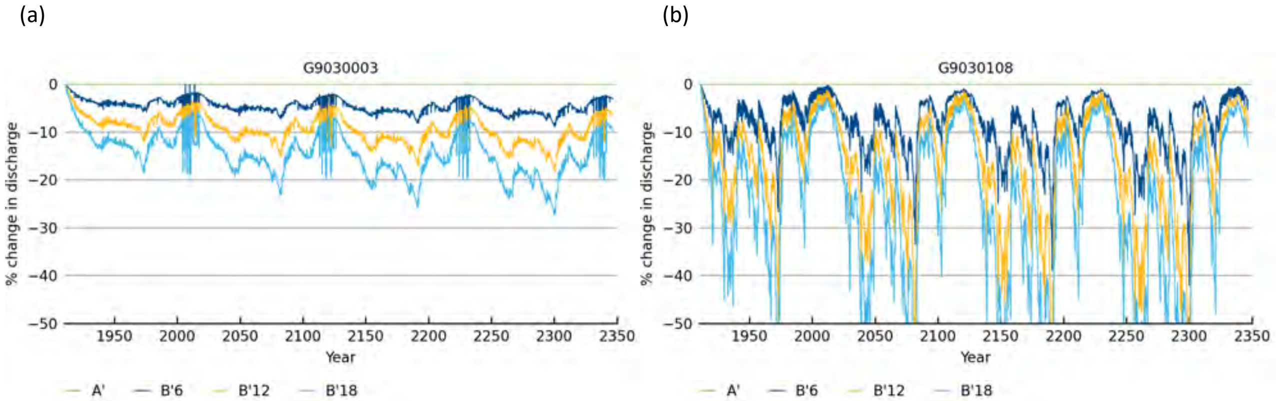


Figure 7-5 Percentage change between Scenario A′N and scenarios A′, B′6, B′12 and B′18 at (a) G9030003 and (b) G9030108

7.2 Future climate (scenarios C′ and D′)

7.2.1 Scenarios C′ and D′ – water balances

Mean annual water balances for the last 109 years of the quasi-equilibrium scenarios C′ and D′ are presented in Table 7-4, Table 7-5 and Table 7-6 for the dry, mid and wet climate sequences, respectively.

Under a future dry climate, a reduction in recharge relative to Scenario A′N is balanced by a reduction in discharge to evapotranspiration, rivers and springs in Scenario C′dry. These reductions in discharge are greater under Scenario D as the hypothetical extractions are much greater than under Scenario C′dry.

Under a future mid climate, a reduction in recharge relative to Scenario A′N is balanced by a reduction in discharge to evapotranspiration, rivers and springs in Scenario C′mid. These reductions in discharge are greater under Scenario D as the hypothetical extractions are much greater than under Scenario C′mid.

Under a wet future climate there is an increase in recharge relative to Scenario A′N due to the increase in rainfall, resulting in an increase in discharge via evapotranspiration, rivers and springs in Scenario C′wet. These increases in discharge decrease with the increase in extractions from Scenario B′6 through Scenario B′12 and to Scenario B′18.

Table 7-4 Mean annual water balances (GL/year) for the last 109 years of 436-year simulation for quasi-equilibrium future dry climate sequences under scenarios C′ and D′ within the Dook Creek Aquifer in the Roper catchment

	A′	C′DRY	D′DRY6	D′DRY12	D′DRY18
Inflow (gains)					
Recharge (diffuse)	151.9	114.0	114.1	114.2	114.2
Release from storage	111.7	89.7	90.5	91.4	92.3
From river	0.1	0.1	0.1	0.1	0.1
Sub-total	**263.8**	**203.7**	**204.7**	**205.6**	**206.6**
Outflow (losses)					
Evapotranspiration	70.5	52.7	49.7	46.7	43.8
Extraction	0.0	0.1	6.1	12.1	18.1
Capture into storage	108.1	83.7	84.0	84.2	84.5
To rivers	20.8	9.6	8.5	7.6	6.6
To springs	7.4	2.2	1.8	1.4	1.0
Sub-total	**206.8**	**148.2**	**150.0**	**152.0**	**154.0**
Net flow in (+ve) / out (-ve)	**−57.0**	**−55.6**	**−54.6**	**−53.6**	**−52.6**

A′ = Historical climate and current development; C′dry = Future dry climate and current development; D′dry6 = Future dry climate sequences with current development and additional future development of 6 GL/year; D′dry12 = Future dry climate sequences with current development and additional future development of 12 GL/year; D′dry18 = Future dry climate sequences with current development and additional future development of 18 GL/year.

Table 7-5 Mean annual water balances (GL/year) for the last 109 years of 436-year simulation for quasi-equilibrium future mid climate sequences under scenarios C′ and D′ in the Dook Creek Aquifer within the Roper catchment

	A′	C′MID	D′MID6	D′MID12	D′MID18
Inflow (gains)					
Recharge (diffuse)	151.9	142.2	142.3	142.4	142.5
Release from storage	111.7	105.8	106.5	107.2	107.9
From river	0.1	0.1	0.1	0.1	0.1
Sub-total	**263.8**	**248.1**	**248.9**	**249.7**	**250.5**
Outflow (losses)					
Evapotranspiration	70.5	66.0	63.3	60.5	57.6
Extraction	0.0	0.1	6.1	12.1	18.1
Capture into storage	108.1	101.7	102.0	102.3	102.6
To rivers	20.8	17.8	16.7	15.5	14.4
To springs	7.4	5.7	4.9	4.1	3.4
Sub-total	**206.8**	**191.3**	**192.8**	**194.4**	**196.1**
Net flow in (+ve) / out (-ve)	**−57.0**	**−56.8**	**−56.0**	**−55.3**	**−54.4**

A′ = Historical climate and current development; C′mid = Future mid climate and current development; D′mid6 = Future mid climate sequences with current development and additional future development of 6 GL/year; D′mid12 = Future mid climate sequences with current development and additional future development of 12 GL/year; D′mid18 = Future mid climate sequences with current development and additional future development of 18 GL/year.

Table 7-6 Mean annual water balances (GL/year) for the last 109 years of 436-year simulation for quasi-equilibrium future wet climate sequences under scenarios C′ and D′ in the Dook Creek Aquifer within the Roper catchment

	A′	C′WET	D′WET6	D′WET12	D′WET18
Inflow (gains)					
Recharge (diffuse)	151.9	196.3	196.4	196.5	196.7
Release from storage	111.7	141.7	142.0	142.3	142.6
From river	0.1	0.2	0.2	0.2	0.2
Sub-total	**263.8**	**338.2**	**338.6**	**339**	**339.5**
Outflow (losses)					
Evapotranspiration	70.5	89.4	87.0	84.5	82.0
Extraction	0.0	0.1	6.1	12.1	18.1
Capture into storage	108.1	139.4	139.5	139.6	139.7
To rivers	20.8	34.1	33.1	32.2	31.2
To springs	7.4	17.7	15.9	14.1	12.4
Sub-total	**206.8**	**280.6**	**281.5**	**282.4**	**283.4**
Net flow in (+ve) / out (-ve)	**−57.0**	**−57.6**	**−57.1**	**−56.6**	**−56.0**

A′ = Historical climate and current development; C′wet = Future wet climate and current development; D′wet6 = Future wet climate sequences with current development and additional future development of 6 GL/year; D′wet12 = Future wet climate sequences with current development and additional future development of 12 GL/year; D′wet18 = Future wet climate sequences with current development and additional future development of 18 GL/year.

7.2.2 Scenarios C′ and D′ – groundwater levels

The locations of the five DCA groundwater-level reporting sites are shown in Figure 4-5.

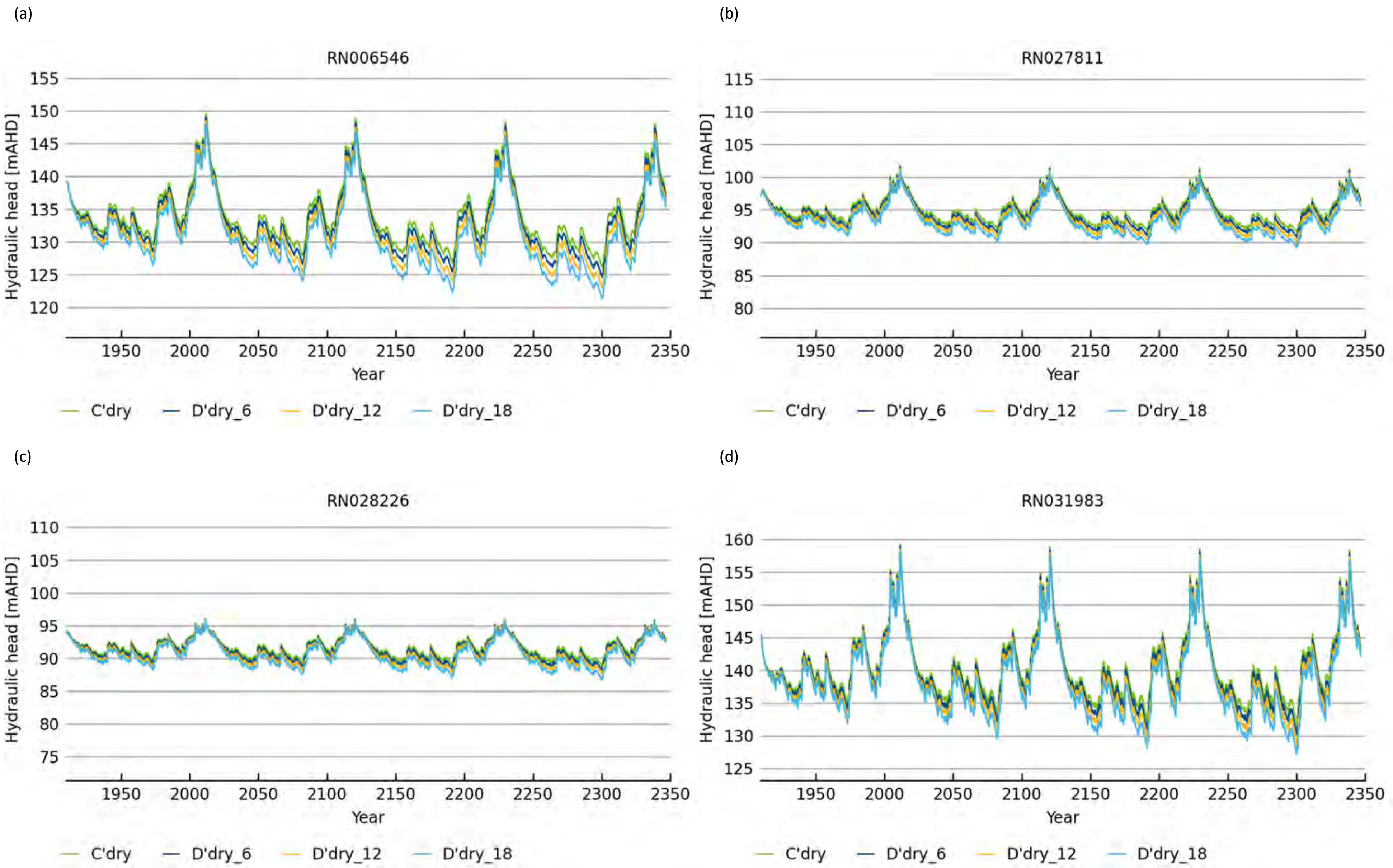
Table 7-7 presents the mean groundwater level at the five DCA reporting sites for the last 10-year period (2059 to 2069) of each climate sequence under scenarios C′ and D′. Each table row corresponds to a specific scenario, and the columns represent the mean groundwater level at each reporting site.

Hydrographs of groundwater level under scenarios C′ and D′ at the five reporting sites are presented for the dry, mid and wet climate sequences in Figure 7-6, Figure 7-7 and Figure 7-8, respectively.

Table 7-7 Mean groundwater levels (mAHD) for the last 109-year period (2237 to 2346) of quasi-equilibrium future climate scenarios C′ and D′

SCENARIO	RN006546	RN027811	RN028226	RN031983	RN036302
A’N	138.7	96.9	93.1	145.2	133.1
C’dry	132.9	94.6	91.5	139.9	127.7
C’mid	137.4	96.4	92.8	144	132.0
C’wet	143.2	98.6	94.1	149.5	136.5
D’dry6	131.7	94.0	91.1	139.0	126.4
D’dry12	130.5	93.4	90.6	138.0	125.0
D’dry18	129.2	92.8	90.2	136.9	123.6
D’mid6	136.7	96.0	92.5	143.5	131.1
D’mid12	135.8	95.5	92.2	143.0	130.1
D’mid18	135.0	95.1	91.9	142.4	129.1
D’wet6	142.7	98.4	93.9	149.2	136.1
D’wet12	142.3	98.1	93.8	148.9	135.7
D’wet18	141.8	97.8	93.7	148.6	135.3

A’N = Historical climate and no development; C’dry = Future dry climate sequences current development; C’mid = Future mid climate sequences current development; C’wet = Future wet climate sequences current development; D’dry6 = Future dry climate sequences current development and future development of 6 GL/year; D’dry12 = Future dry climate sequences current development and future development of 12 GL/year; D’dry18 = Future dry climate sequences current development and future development of 18 GL/year; D’mid6 = Future mid climate sequences current development and future development of 6 GL/year; D’mid12 = Future mid climate sequences current development and future development of 12 GL/year; D’mid18 = Future mid climate sequences current development and future development of 18 GL/year); D’wet6 = Future wet climate sequences current development and future development of 6 GL/year; D’wet12 = Future wet climate sequences current development and future development of 12 GL/year; D’wet18 = Future wet climate sequences current development and future development of 18 GL/year.


(a)
RN006546
Hydraulic head [mAHD]
Year
C'dry
D'dry_6
D'dry_12
D'dry_18
(b)
RN027811
Hydraulic head [mAHD]
Year
C'dry
D'dry_6
D'dry_12
D'dry_18
(c)
RN028226
Hydraulic head [mAHD]
Year
C'dry
D'dry_6
D'dry_12
D'dry_18
(d)
RN031983
Hydraulic head [mAHD]
Year
C'dry
D'dry_6
D'dry_12
D'dry_18

(e)

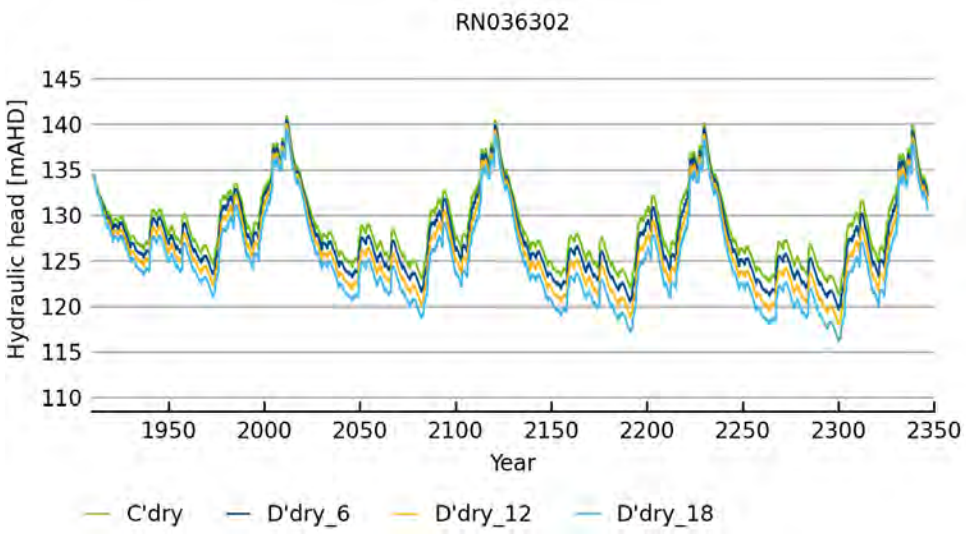
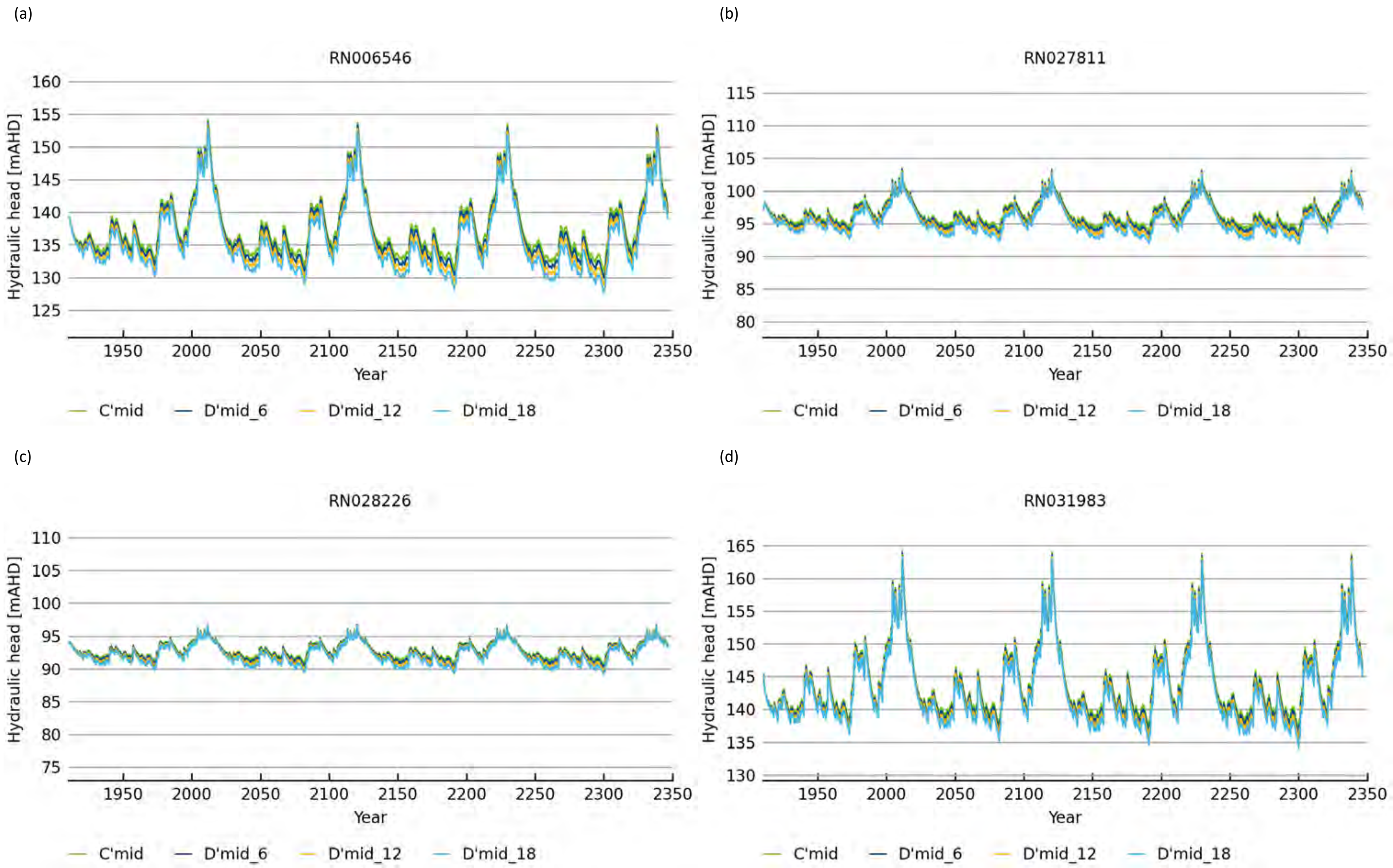


Figure 7-6 Hydrographs of groundwater level (mAHD) under the quasi-equilibrium scenarios C'dry and D'dry at the five reporting sites: (a) RN006546, (b) RN027811, (c) RN028226, (d) RN031983 and (e) RN036302


(a)
RN006546
Hydraulic head [mAHD]
Year
C'mid
D'mid_6
D'mid_12
D'mid_18
(b)
RN027811
Hydraulic head [mAHD]
Year
C'mid
D'mid_6
D'mid_12
D'mid_18
(c)
RN028226
Hydraulic head [mAHD]
Year
C'mid
D'mid_6
D'mid_12
D'mid_18
(d)
RN031983
Hydraulic head [mAHD]
Year
C'mid
D'mid_6
D'mid_12
D'mid_18

(e)

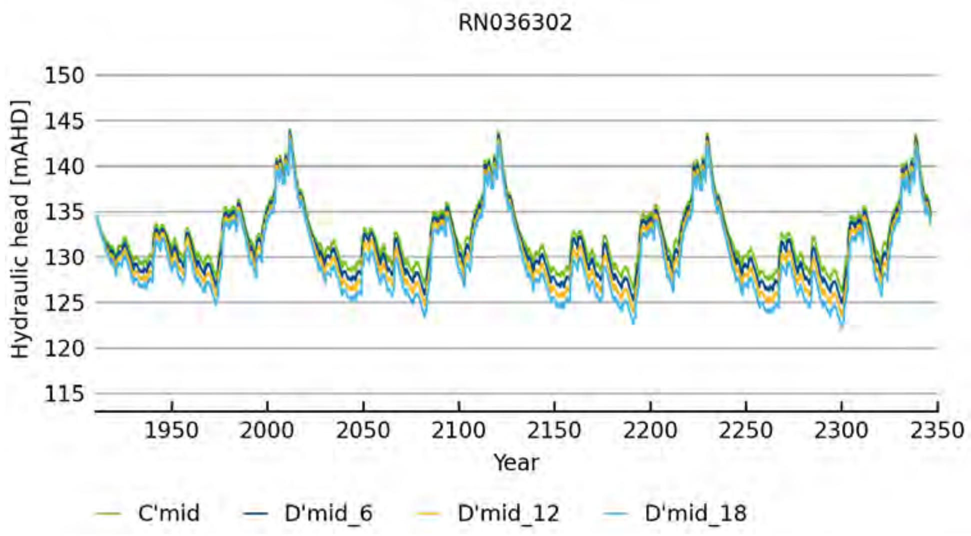
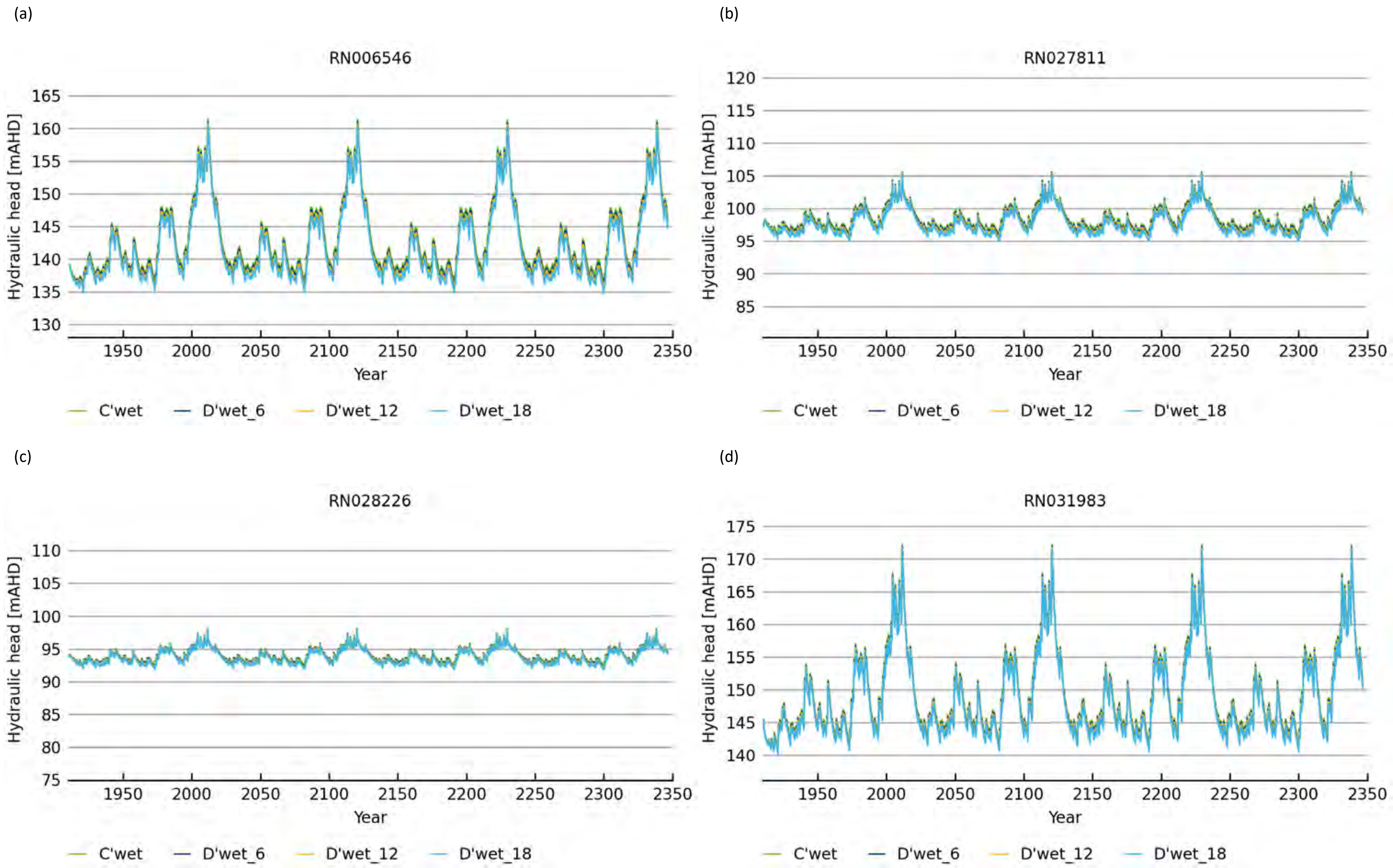


Figure 7-7 Hydrographs of groundwater level (mAHD) under the quasi-equilibrium scenarios C'mid and D'mid at the five reporting sites: (a) RN006546, (b) RN027811, (c) RN028226, (d) RN031983 and (e) RN036302


(a)
RN006546
Hydraulic head [mAHD]
Year
C'wet
D'wet_6
D'wet_12
D'wet_18
(b)
RN027811
Hydraulic head [mAHD]
Year
C'wet
D'wet_6
D'wet_12
D'wet_18
(c)
RN028226
Hydraulic head [mAHD]
Year
C'wet
D'wet_6
D'wet_12
D'wet_18
(d)
RN031983
Hydraulic head [mAHD]
Year
C'wet
D'wet_6
D'wet_12
D'wet_18

(e)

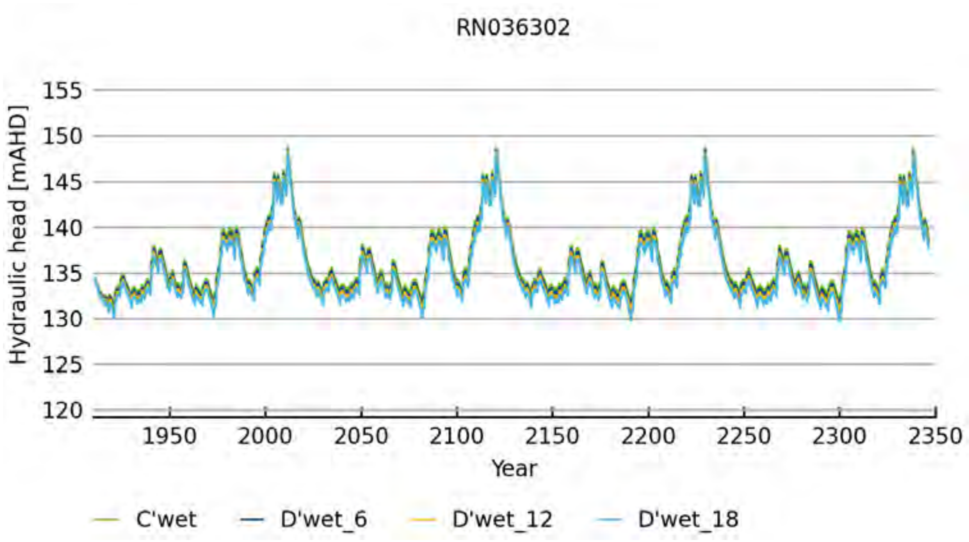


Figure 7-8 Hydrographs of groundwater level (mAHD) under the quasi-equilibrium scenarios C'wet and D'wet at the five reporting sites: (a) RN006546, (b) RN027811, (c) RN028226, (d) RN031983 and (e) RN036302

7.2.3 Scenarios C′ and D′ – groundwater drawdown contours

The drawdown contours at 31/8/2346 were determined by comparing Scenario A′N to scenarios C′ and D′ heads. The drawdown contours relative to Scenario A′N assuming dry climate sequence under scenarios C′ and D′ are shown in Figure 7-9. The drawdown contours relative to Scenario A′N assuming mid climate sequence under scenarios C′ and D′ are shown in Figure 7-10. The drawdown contours relative to Scenario A′N assuming wet climate sequence under scenarios C′ and D′ are shown in Figure 7-11.

With minimal extraction, the C scenarios show the impact of a future climate relative to Scenario A′N. Scenario C′dry shows drawdown of greater than 5 m, Scenario C′mid shows a small drawdown of less than 1 m for most of the model domain and Scenario C′wet shows the influence of increased recharge with an increase in groundwater level in excess of 5 m in the north-west of the model domain. The drawdown contours relative to Scenario A′N under scenarios D′dry6, D′dry12 and D′dry18 are shown in Figure 7-9b, Figure 7-9c and Figure 7-9d, respectively. The maximum drawdown is centred on the hypothetical future bores about 50 km to the north of Mainoru. The D′dry6 contours show a maximum drawdown of greater than 5 m. The D′dry12 contours show a maximum drawdown of 5 to 10 m. The D′dry18 contours show a final drawdown of greater than 10 m, with a large portion of the model domain with drawdown greater than 5 m.

The drawdown contours relative to Scenario A′N under scenarios Dmid6, Dmid12 and Dmid18 are shown in Figure 7-10b, Figure 7-10c and Figure 7-10d, respectively. The maximum drawdown is centred on the hypothetical future bores about 50 km to the north of Mainoru.

The drawdown contours relative to Scenario A′N under scenarios D′wet6, D′wet12 and D′wet18 are shown in Figure 7-11b, Figure 7-11c and Figure 7-11d, respectively. The wet climate sequences show the increase in groundwater level due to the increased recharge. The increase in groundwater level around the hypothetical developments decreases with increasing extraction from Scenario D′wet6 to Scenario D′wet18.

(a)

(b)

(c)

(d)

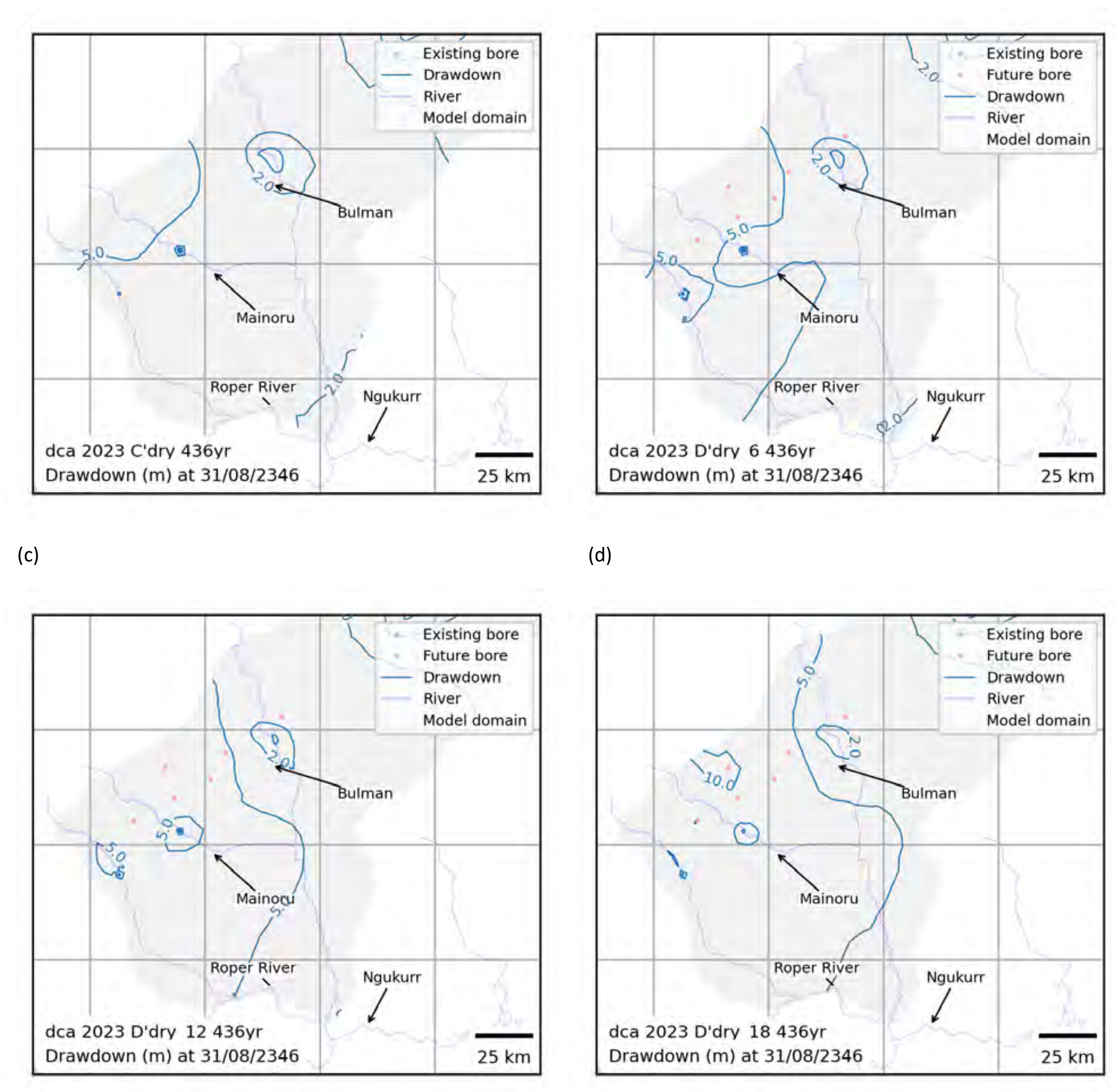


Figure 7-9 Drawdown contours relative to Scenario A'N under scenarios (a) C'dry, (b) D'dry6, (c) D'dry12 and (d) D'dry18 at the end of the 436-year quasi-equilibrium historical climate sequence

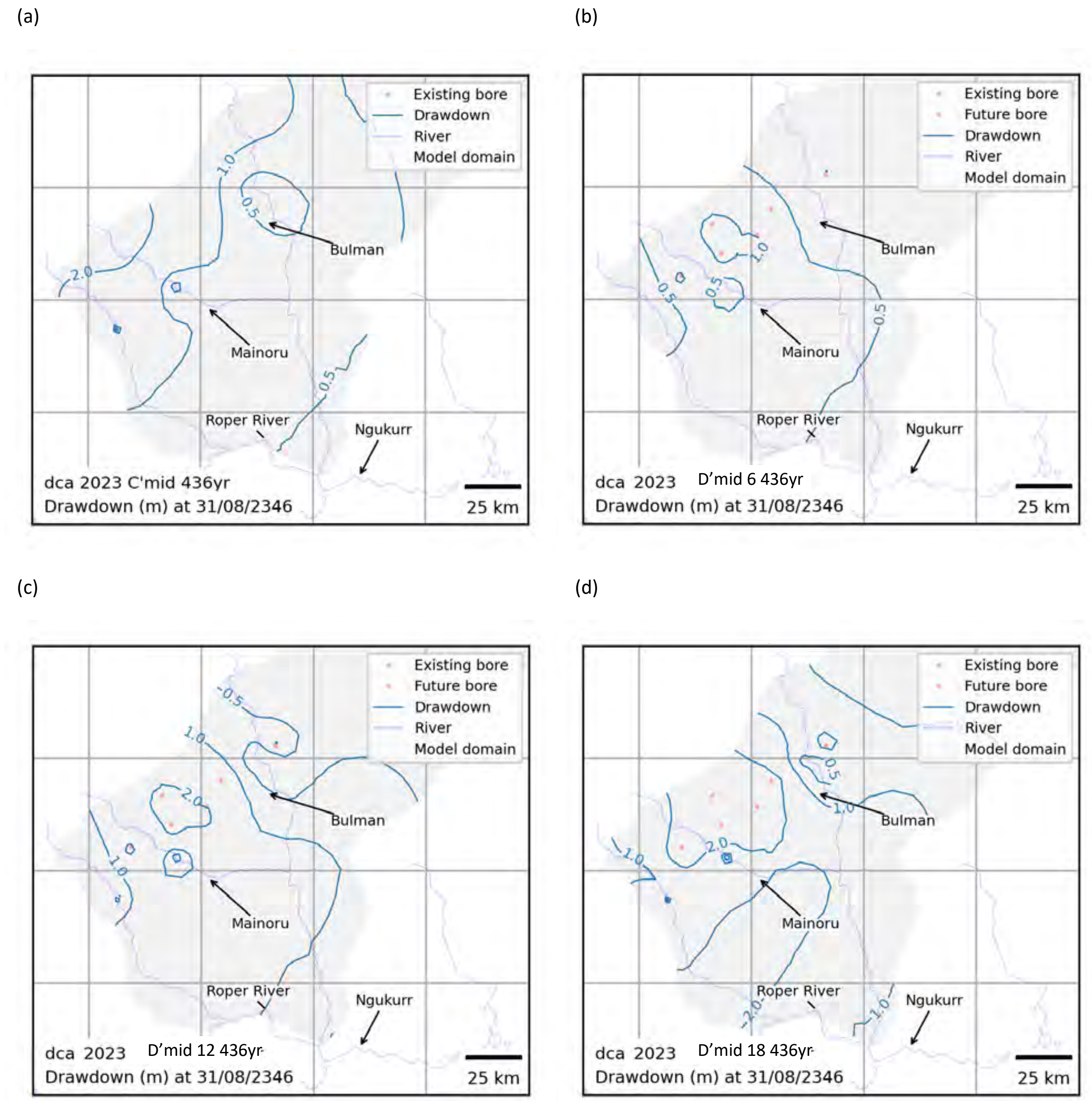


Figure 7-10 Drawdown contours relative to Scenario A'N under scenarios (a) C'mid, (b) D'mid6, (c) D'mid12 and (d) D'mid18 at the end of the 436-year quasi-equilibrium historical climate sequence

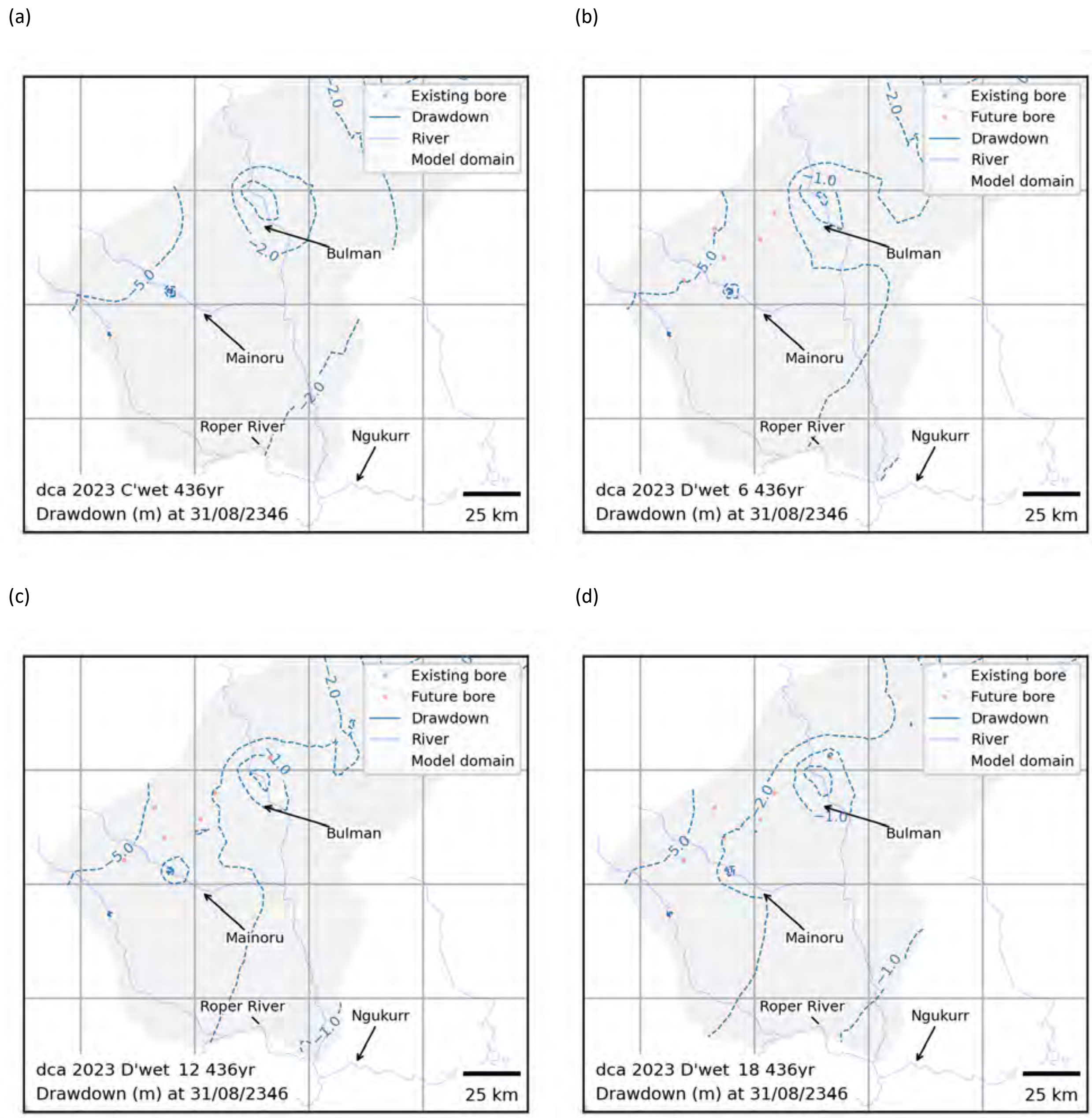


Figure 7-11 Drawdown contours relative to Scenario A'N under scenarios (a) C'wet, (b) D'wet6, (c) D'wet12 and (d) D'wet18 at the end of the 436-year quasi-equilibrium historical climate sequence

Dashed lines indicate contours with negative values (i.e. groundwater-level rises relative to Scenario A'N).

7.2.4 Scenarios C' and D' – groundwater discharge

Mean groundwater discharges at Wilton River (G9030003) and Flying Fox Creek (G9030108) under scenarios C', D'dry, D'mid and D'wet are presented in Table 7-8.

These data show that the impact of a future climate without an increase in extraction is very large with changes in groundwater discharges ranging from −35 to +33% at the Wilton River and −57 to +66% at Flying Fox Creek under scenarios C'dry and C'wet, respectively. The increase in extraction under Scenario D results in a reduction in groundwater discharge relative to Scenario C; the extreme case is Scenario D'dry18 changing by −59 and −69% relative to Scenario A'N at the Wilton River and Flying Fox Creek, respectively. For all levels of hypothetical development, there is an increase in groundwater discharge under the D′wet scenarios in both waterways, but less than that simulated under Scenario C′wet (without the additional development).

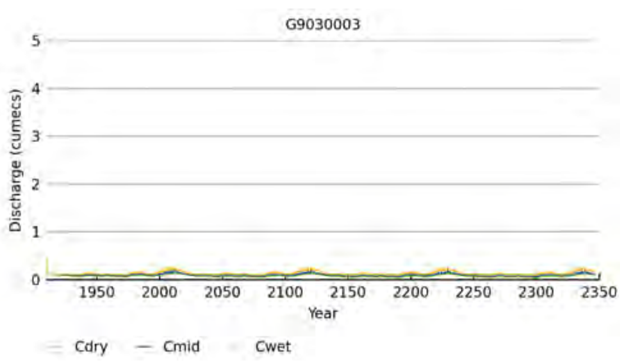
Table 7-8 Mean groundwater discharge under scenarios C′ and D′ at Wilton River (G9030003) and Flying Fox Creek (G9030108)

SCENARIO	G9030003 GROUNDWATER DISCHARGE (m^3/s)	G9030003 % CHANGE	G9030108 GROUNDWATER DISCHARGE (m^3/s)	G9030108 % CHANGE
A′N	0.10	na†	0.56	na
C′dry	0.06	−35	0.24	−57
C′mid	0.09	−8	0.47	−15
C′wet	0.13	+33	0.93	+66
D′dry6	0.06	−42	0.21	−62
D′dry12	0.05	−50	0.19	−66
D′dry18	0.04	−59	0.17	−69
D′mid6	0.08	−14	0.44	−20
D′mid12	0.08	−19	0.41	−26
D′mid18	0.07	−26	0.38	−31
D′wet6	0.13	+29	0.90	+62
D′wet12	0.12	+24	0.88	+58
D′wet18	0.12	+19	0.86	+54

A′N = Historical climate and current development; C′dry = Future dry climate sequences current development; C′mid = Future mid climate sequences current development; C′wet = Future wet climate sequences current development; D′dry6 = Future dry climate sequences current development and future development of 6 GL/year; D′dry12 = Future dry climate sequences current development and future development of 12 GL/year; D′dry18 = Future dry climate sequences current development and future development of 18 GL/year; D′mid6 = Future mid climate sequences current development and future development of 6 GL/year; D′mid12 = Future mid climate sequences current development and future development of 12 GL/year; D′mid18 = Future mid climate sequences current development and future development of 18 GL/year);
D′wet6 = Future wet climate sequences current development and future development of 6 GL/year; D′wet12 = Future wet climate sequences current development and future development of 12 GL/year; D′wet18 = Future wet climate sequences current development and future development of 18 GL/year.
†na = not applicable.

Groundwater discharges at gauging stations G903003 and G9030108 under scenarios C′dry, C′mid and C′wet are presented in Figure 7-12. The change in discharge relative to Scenario A′N is shown in Figure 7-13 and the relative change is shown in Figure 7-14.

(a)



(b)

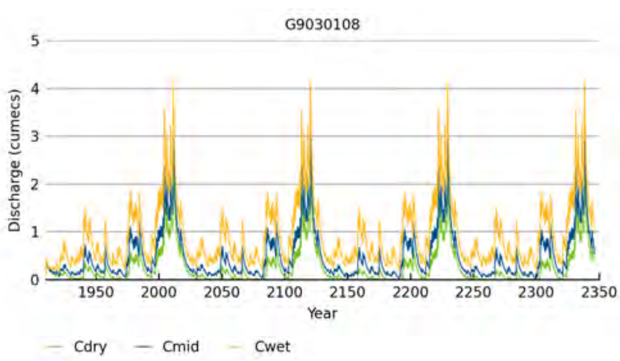


Figure 7-12 Hydrographs of groundwater discharge (m^3/second) under scenarios C′dry, C′mid and C′wet at (a) Wilton River (G9030003) and (b) Flying Fox Creek (G9030108)

(a) (b)

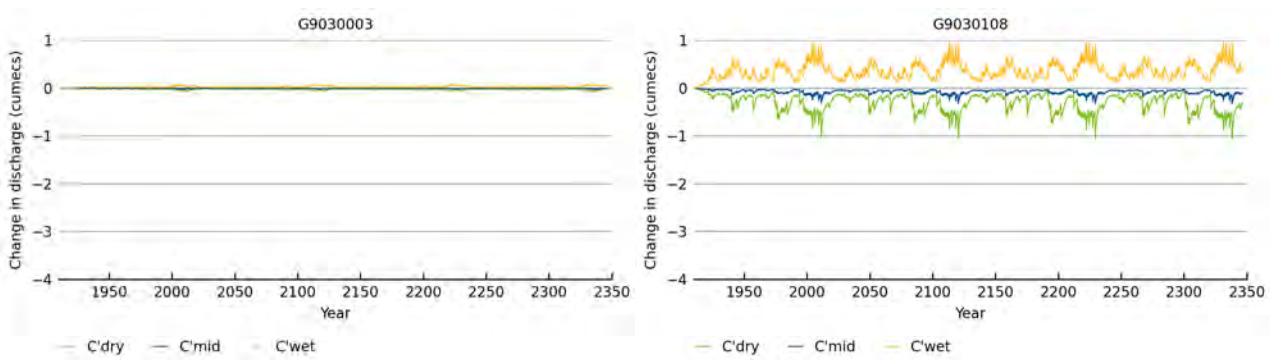


Figure 7-13 Difference in groundwater discharge (m^3/second) between Scenario A'N and scenarios C'dry, C'mid and C'wet at (a) Wilton River (G9030003) and (b) Flying Fox Creek (G9030108)

(a) (b)

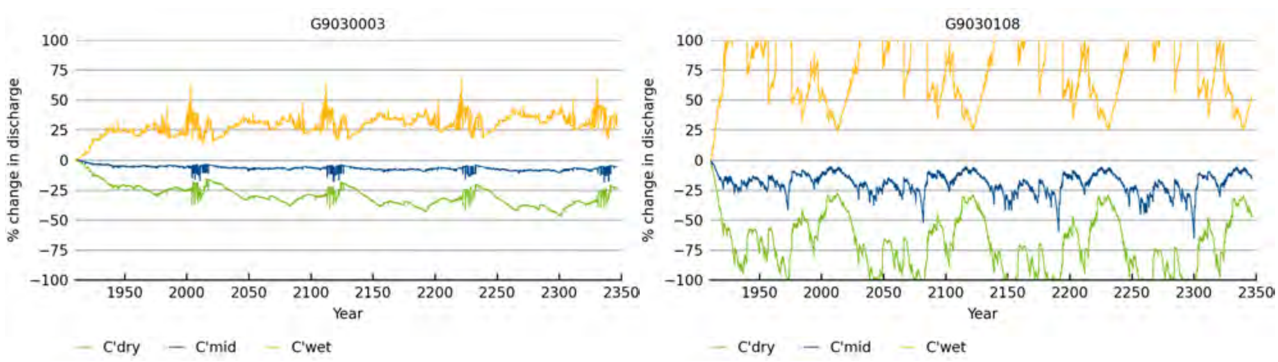


Figure 7-14 Percentage change in groundwater discharge between Scenario A'N and scenarios C'dry, C'mid and C'wet at (a) Wilton River (G9030003) and (b) Flying Fox Creek (G9030108)

Groundwater discharges at gauging station G903003 under scenarios D'dry, D'mid, and D'wet are presented in Figure 7-15, Figure 7-16, and Figure 7-17, respectively. Groundwater discharges at gauging station G9030108 under scenarios D'dry, D'mid, and D'wet are presented in Figure 7-18, Figure 7-19, and Figure 7-20, respectively.

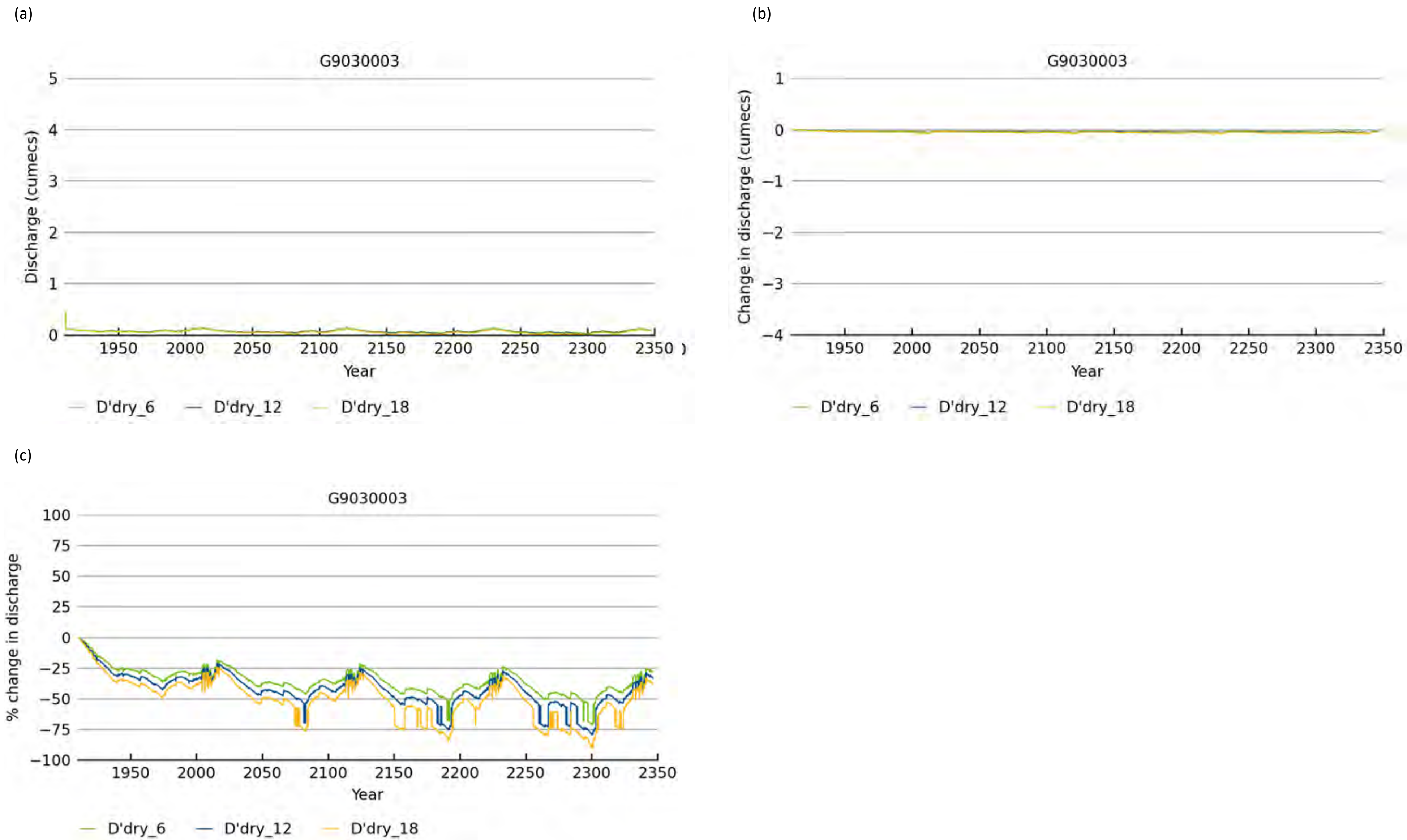


Figure 7-15 Hydrographs of groundwater discharge under Scenario D'dry at gauging station G9030003 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'N

(a)

(b)

(c)

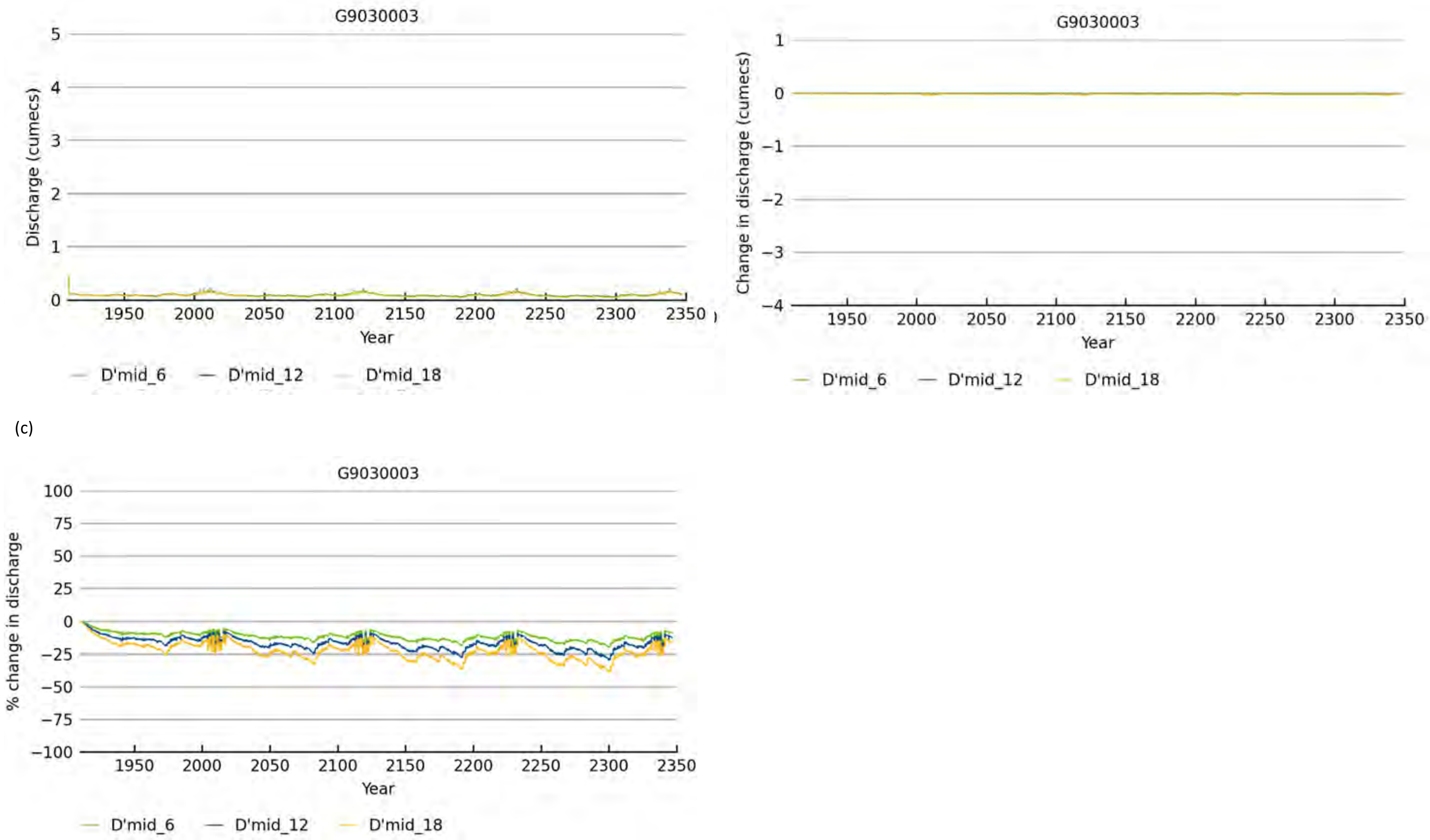
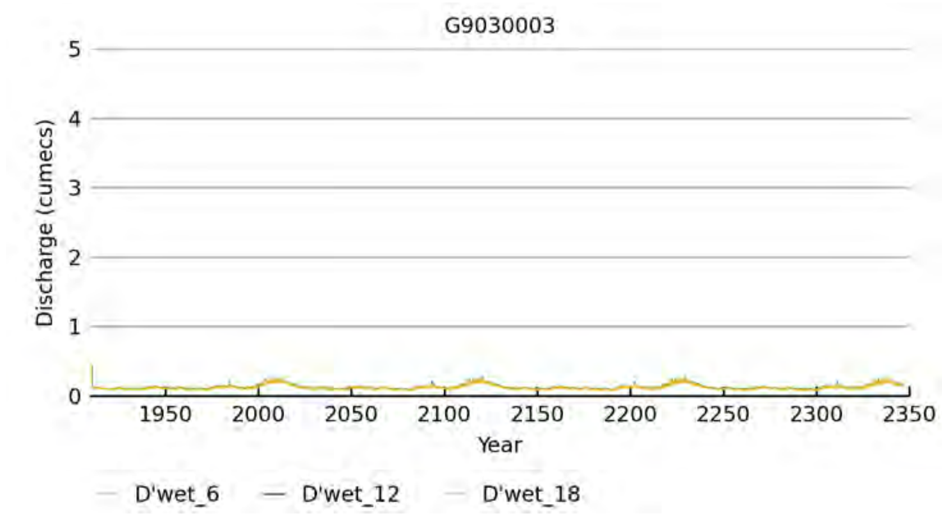
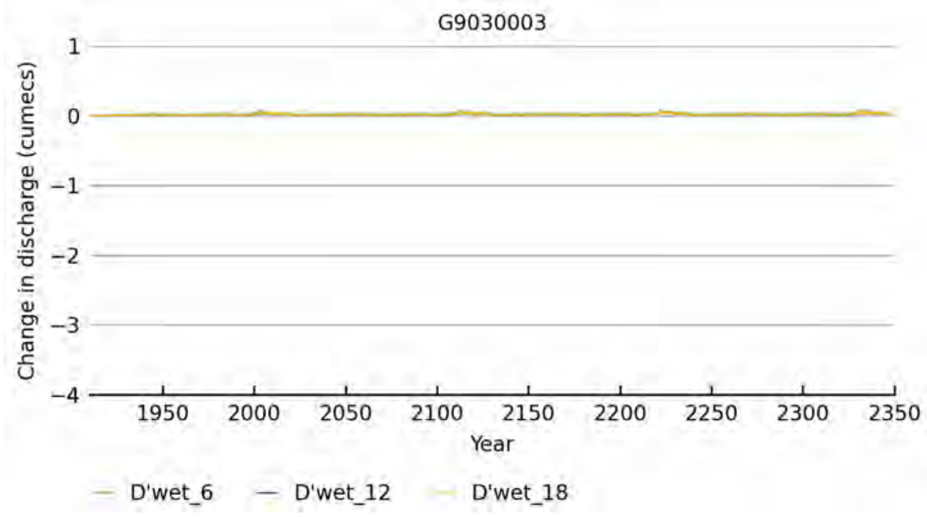


Figure 7-16 Hydrographs of groundwater discharge under Scenario D'mid at gauging station G9030003 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'N

(a)



(b)



(c)

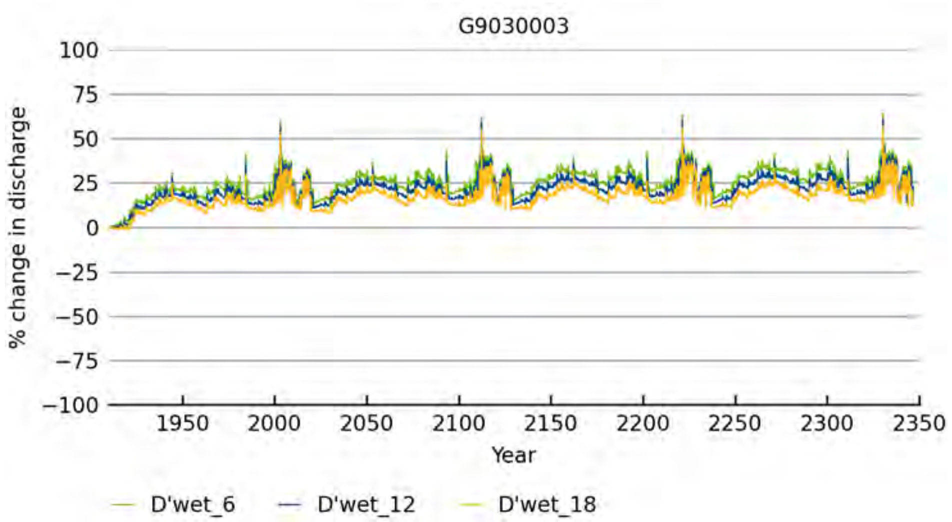


Figure 7-17 Hydrographs of groundwater discharge under Scenario D'wet at gauging station G9030003 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'N

(a)

(b)

(c)

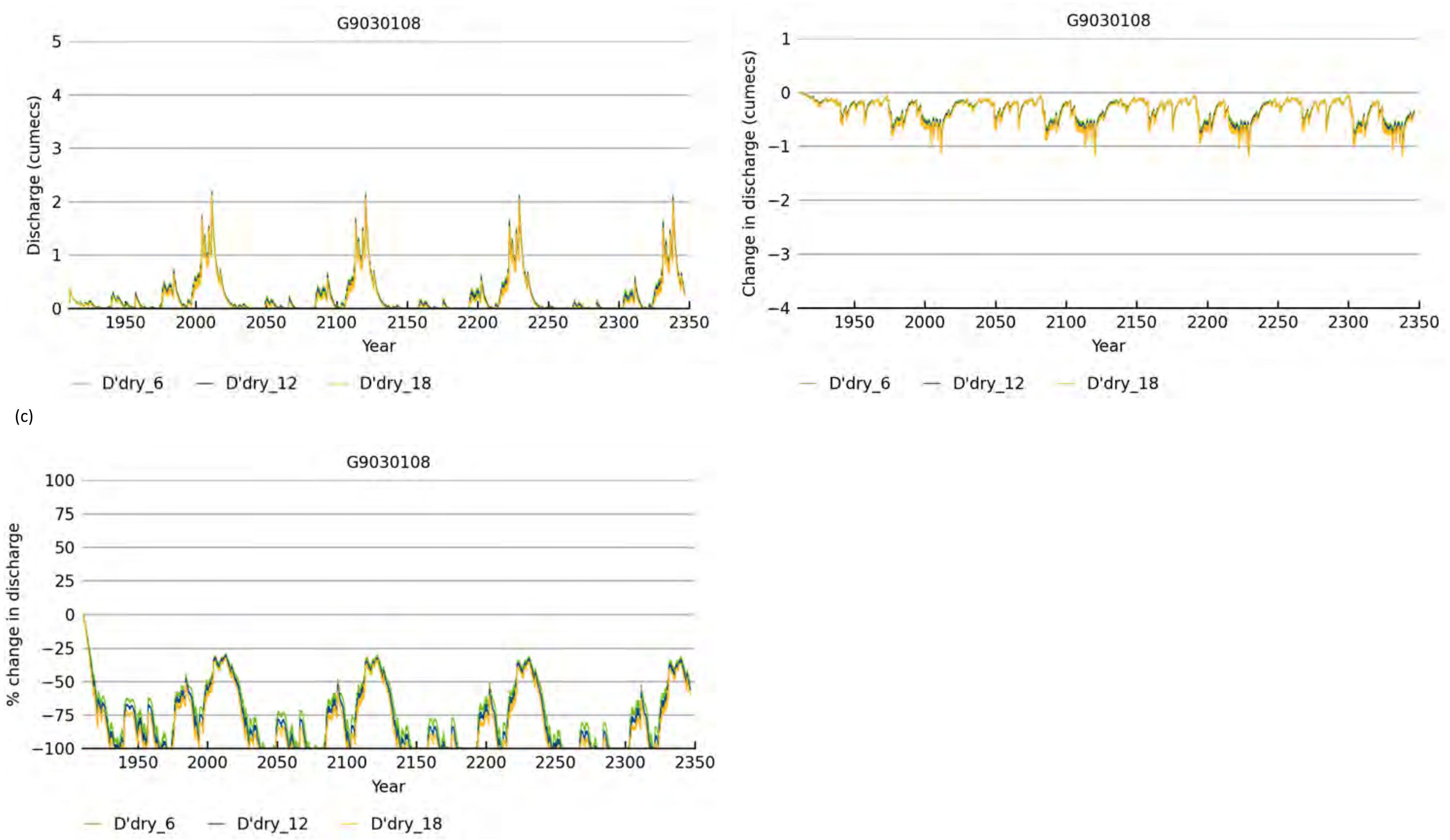


Figure 7-18 Hydrographs of groundwater discharge under Scenario D'dry at gauging station G9030108 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'N

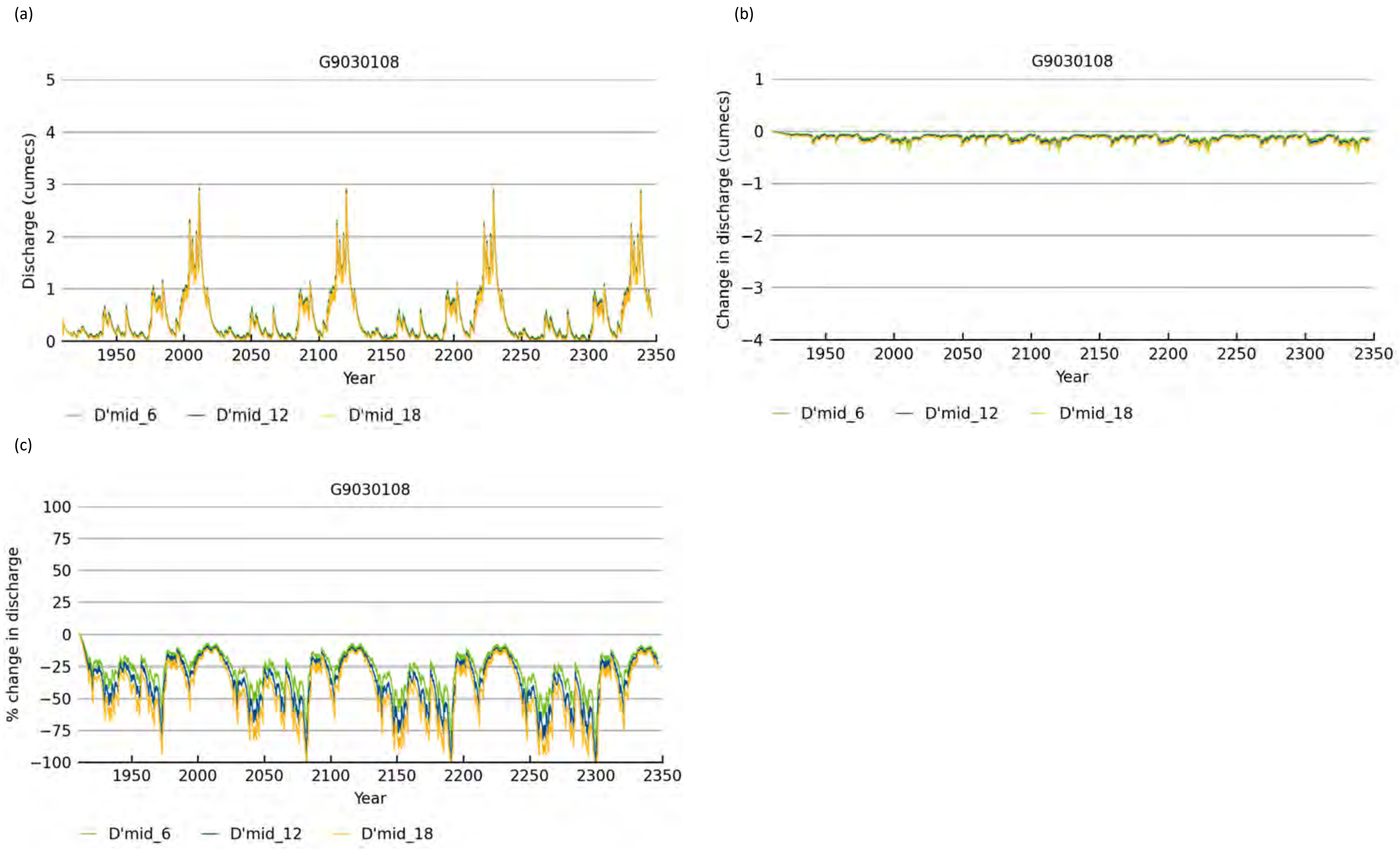


Figure 7-19 Hydrographs of groundwater discharge under Scenario D'mid at gauging station G9030108 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'N

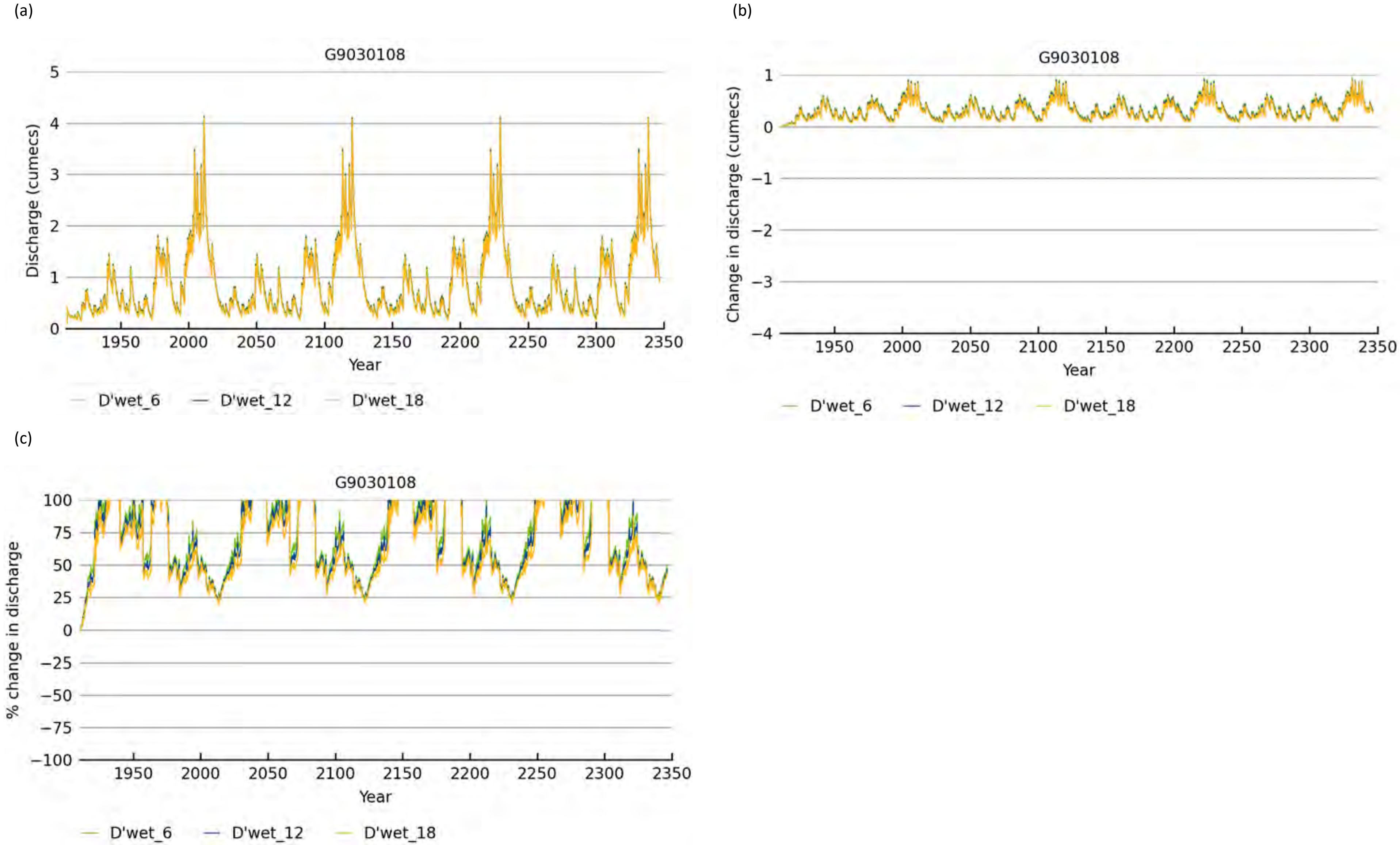


Figure 7-20 Hydrographs of groundwater discharge under Scenario D'wet at gauging station G9030108 showing (a) discharge (m^3/second) and (b) change (m^3/second) and (c) percentage change in discharge relative to Scenario A'NDook Creek Aquifer 2059 to 2069 representative conditions results

7.3 Historical climate (scenarios A and B)

7.3.1 Scenarios A and B – water balances

The ranges in mean annual water balances for the final 10-year period of each set of 50-year climate sequences under scenarios A and B are presented as boxplots in Figure 7-21. The corresponding mean annual water balances are presented in Table 7-9. This shows that there is little change in the water balance of Scenario A from Scenario AN due to the very small levels of current extraction. The B scenarios show that an increase in extraction results in a reduction in discharge to evapotranspiration, rivers and springs.

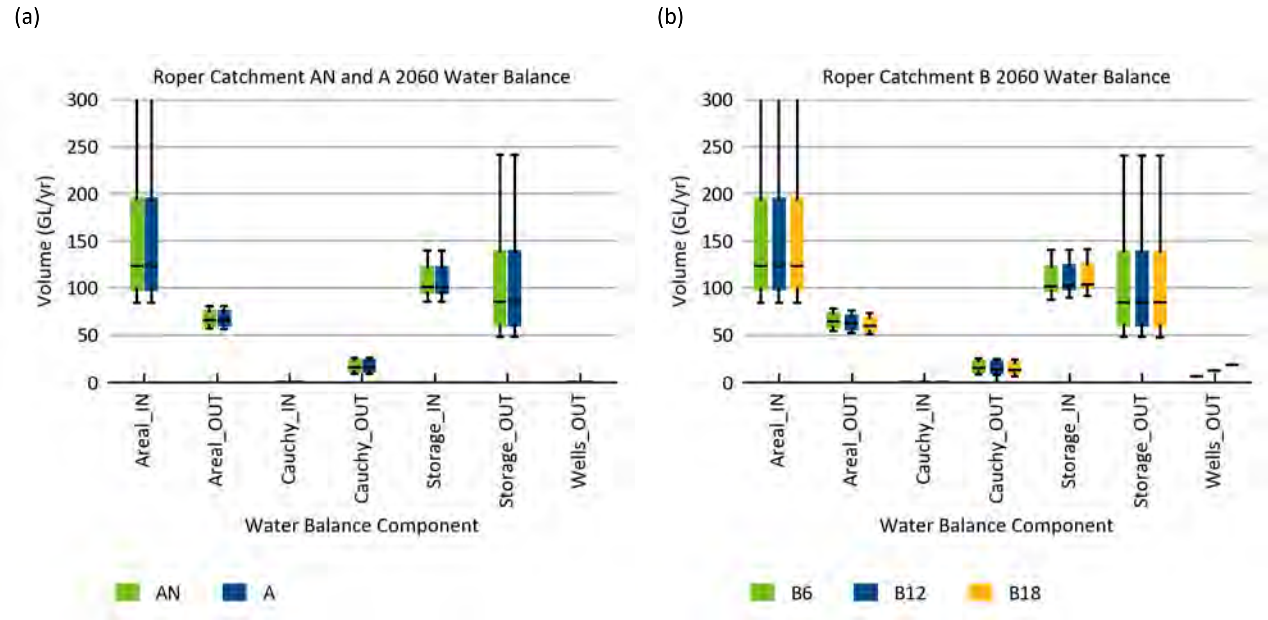


Figure 7-21 Dook Creek Aquifer water balances within the Roper catchment under scenarios (a) A and (b) B

Labels are different from Table 7-9: Areal_IN = recharge (diffuse); Areal_OUT = evapotranspiration; Cauchy_IN = from river; Cauchy_OUT = to river; Storage_IN = release from storage; Storage_OUT = capture into storage; and Wells_OUT = extraction.

Table 7-9 Mean annual water balances (GL/year) under scenarios A and B in the Dook Creek Aquifer Roper catchment area

	AN	A	B6	B12	B18
Inflow (gains)					
Recharge (diffuse)	151.8	151.8	151.9	152.0	152.1
Release from storage	116.3	116.3	117.5	118.8	120.2
From river	0.1	0.1	0.1	0.1	0.1
Sub-total	**268.2**	**268.2**	**269.5**	**270.9**	**272.4**
Outflow (losses)					
Evapotranspiration	73.4	73.4	71.2	68.9	66.7
Extraction	-	0.1	6.1	12.1	18.2
Capture into storage	106.0	106.0	106.0	105.9	105.8
To rivers	22.2	22.2	21.3	20.5	19.6
To springs	8.7	8.7	7.7	6.8	6.0
Sub-total	**210.3**	**210.4**	**212.3**	**214.2**	**216.3**
Net flow in (+ve) / out (-ve)	**−57.9**	**−57.8**	**−57.2**	**−56.7**	**−56.1**

AN = Historical climate and no development; A = Historical climate and current development; B6 = Historical climate sequences with current development and additional future development of 6 GL/year; B12 = Historical climate sequences with current development and additional future development of 12 GL/year; B18 = Historical climate sequences with current development and additional future development of 18 GL/year.

7.3.2 Scenarios A and B – groundwater levels

The locations of the five DCA groundwater-level reporting sites are shown in Figure 4-5.

Table 7-10 presents the mean groundwater level at the five DCA reporting sites for the last 10-year period (2059 to 2069) of each climate sequence under scenarios A and B. Each table row corresponds to a specific scenario, and the columns represent the mean groundwater level at each reporting site; this is to provide a simple indicator of the effects observed at the reported groundwater sites.

The groundwater levels at the five reported sites over the 50-year model run from 2019 to 2069 under scenarios A and B are presented in Figure 7-22 through Figure 7-26. The groundwater-level hydrographs show Scenario AN (green solid line) for reference, the median groundwater-level response determined from the 11 climate sequences (blue dashed line) and the range of groundwater levels from all 11 climate sequences (pale orange).

Each hydrograph reflects the different recharge conditions prevailing in the vicinity of that reporting site. RN006546 and RN031983 are located on Mountain Valley Station, RN006546 near Mountain Valley homestead and RN031983 at the downstream extent of groundwater discharge to Flying Fox Creek. RN036302 is located on Mainoru Station about 5.5 km from the downstream extent of groundwater discharge to Mainoru River.

The results show that there is minimal difference between the groundwater levels under Scenario A relative to Scenario AN due to the minimal extraction. At each location under Scenario B, the groundwater level decreases as extraction increases from Scenario B6 to Scenario B18.

Table 7-10 Mean groundwater levels (mAHD) under scenarios A and B for the period 2059 to 2069

SCENARIO	RN006546	RN027811	RN028226	RN031983	RN036302
AN	139.8	97.3	93.3	146.1	134.0
A	139.8	97.3	93.3	146.1	134.0
B6	139.4	97.0	93.1	145.8	133.5
B12	138.9	96.7	92.9	145.4	132.9
B18	138.4	96.4	92.7	145.1	132.3

AN = Historical climate and no development; A = Historical climate and current development; B6 = Historical climate sequences with current development and additional future development of 6 GL/year; B12 = Historical climate sequences with current development and additional future development of 12 GL/year; B18 = Historical climate sequences with current development and additional future development of 18 GL/year.

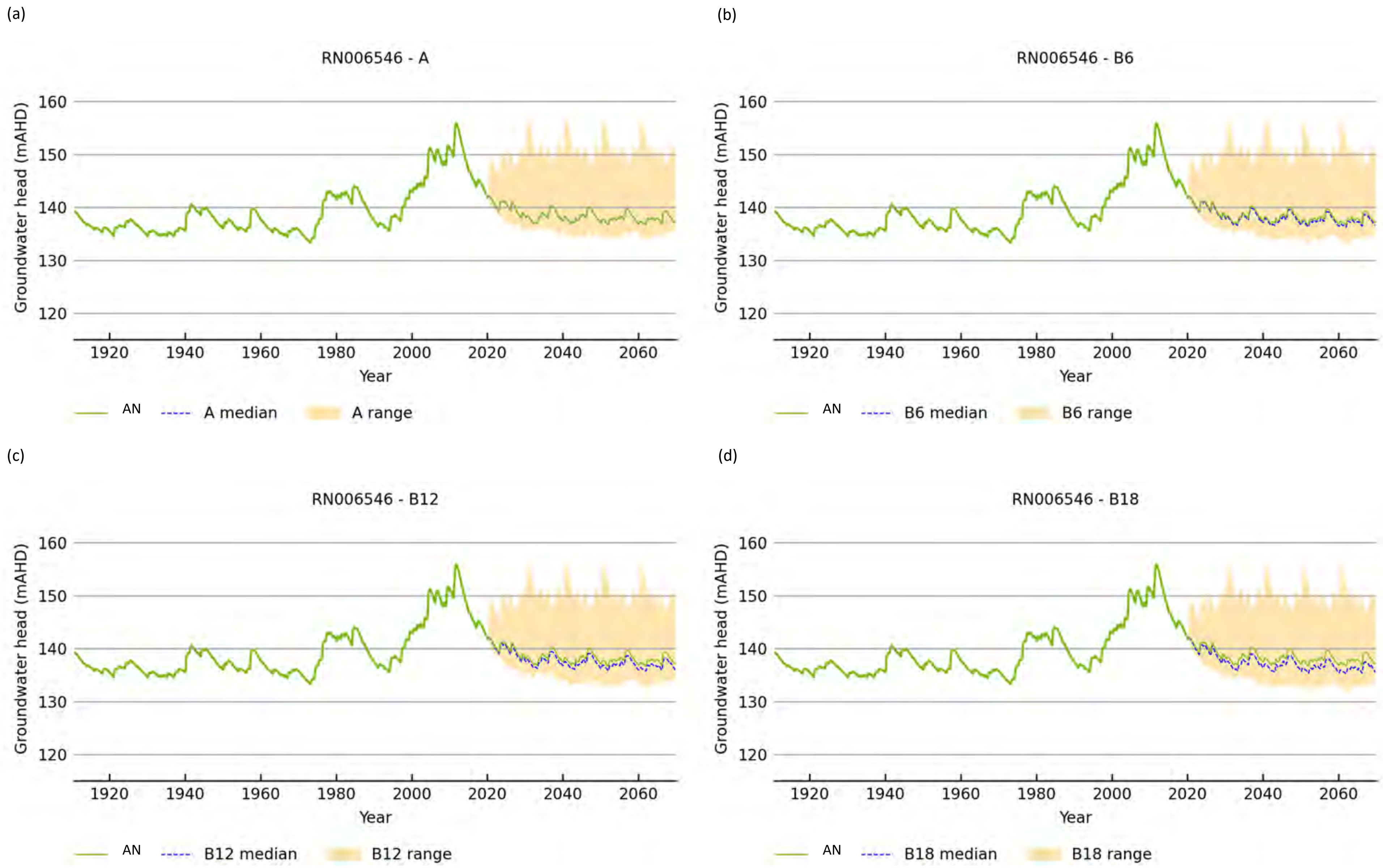


Figure 7-22 Hydrographs of groundwater level at reporting site RN006546 (Mountain Valley Station) under scenarios (a) A, (b) B6, (c) B12 and (d) B18

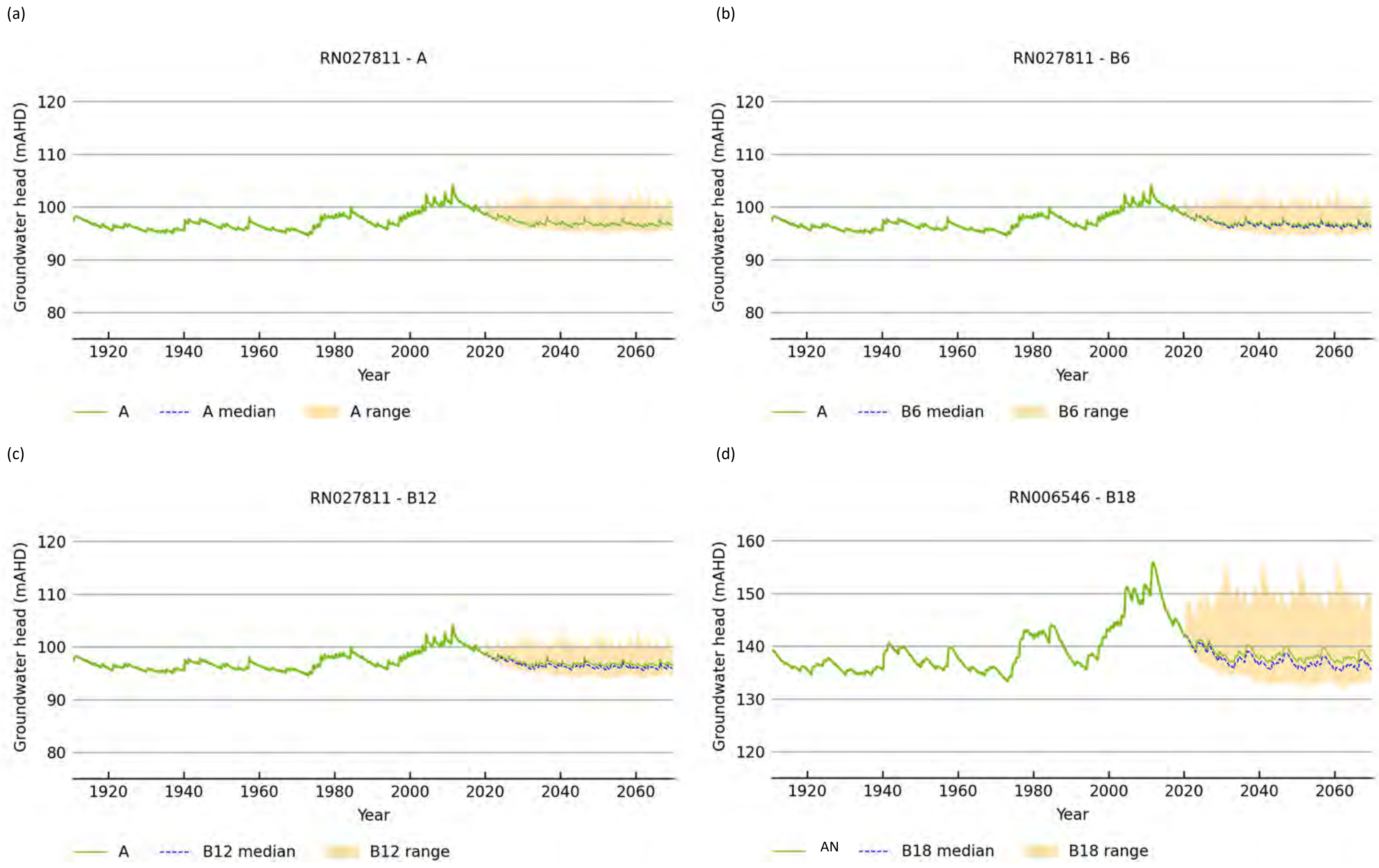


Figure 7-23 Hydrographs of groundwater level at reporting site RN027811 under scenarios (a) A, (b) B6, (c) B12 and (d) B18

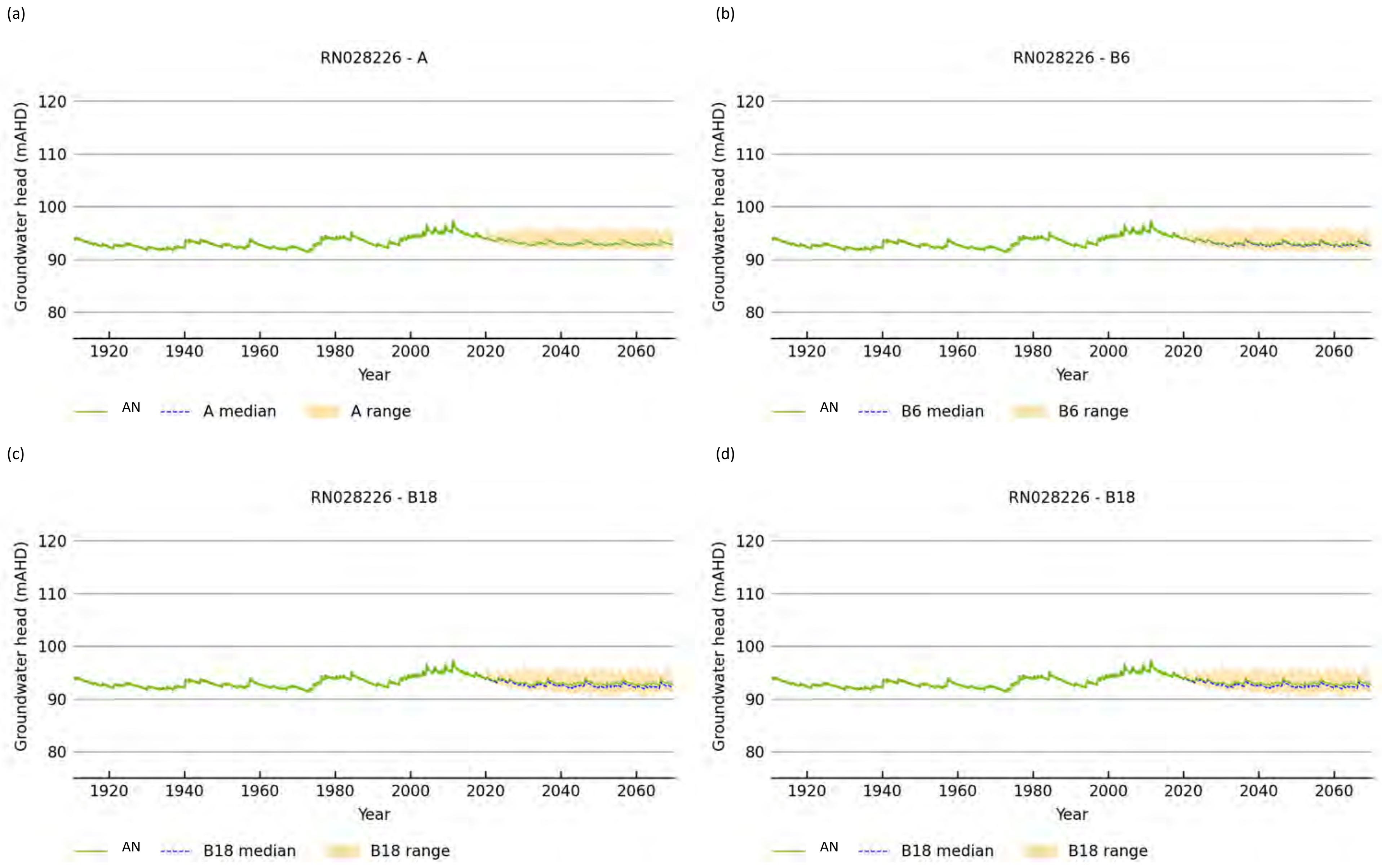


Figure 7-24 Hydrographs of groundwater level at reporting site RN028226 under scenarios (a) A, (b) B6, (c) B12 and (d) B18

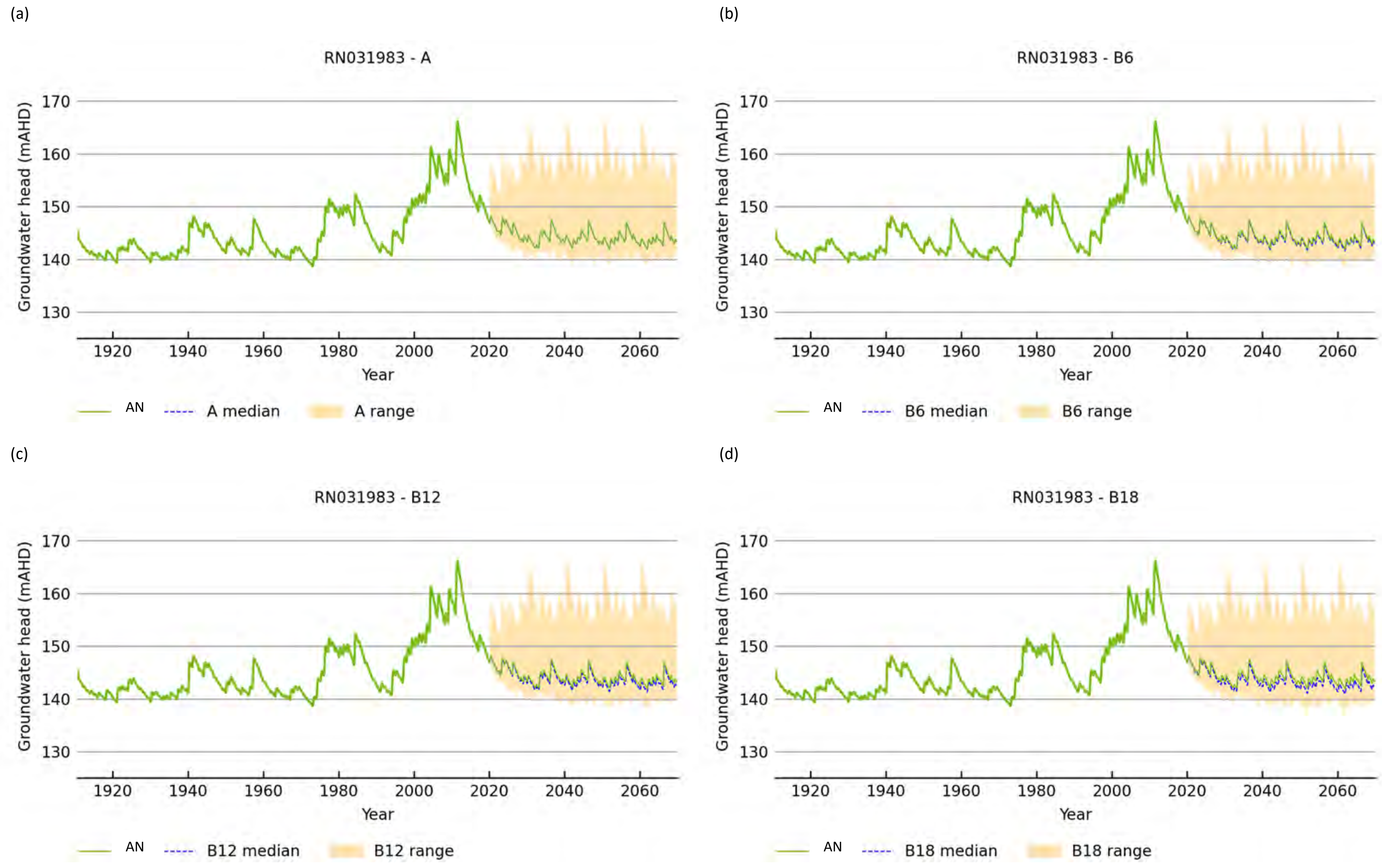


Figure 7-25 Hydrographs of groundwater level at reporting site RN031983 under scenarios (a) A, (b) B6 (c) B12 and (d) B18

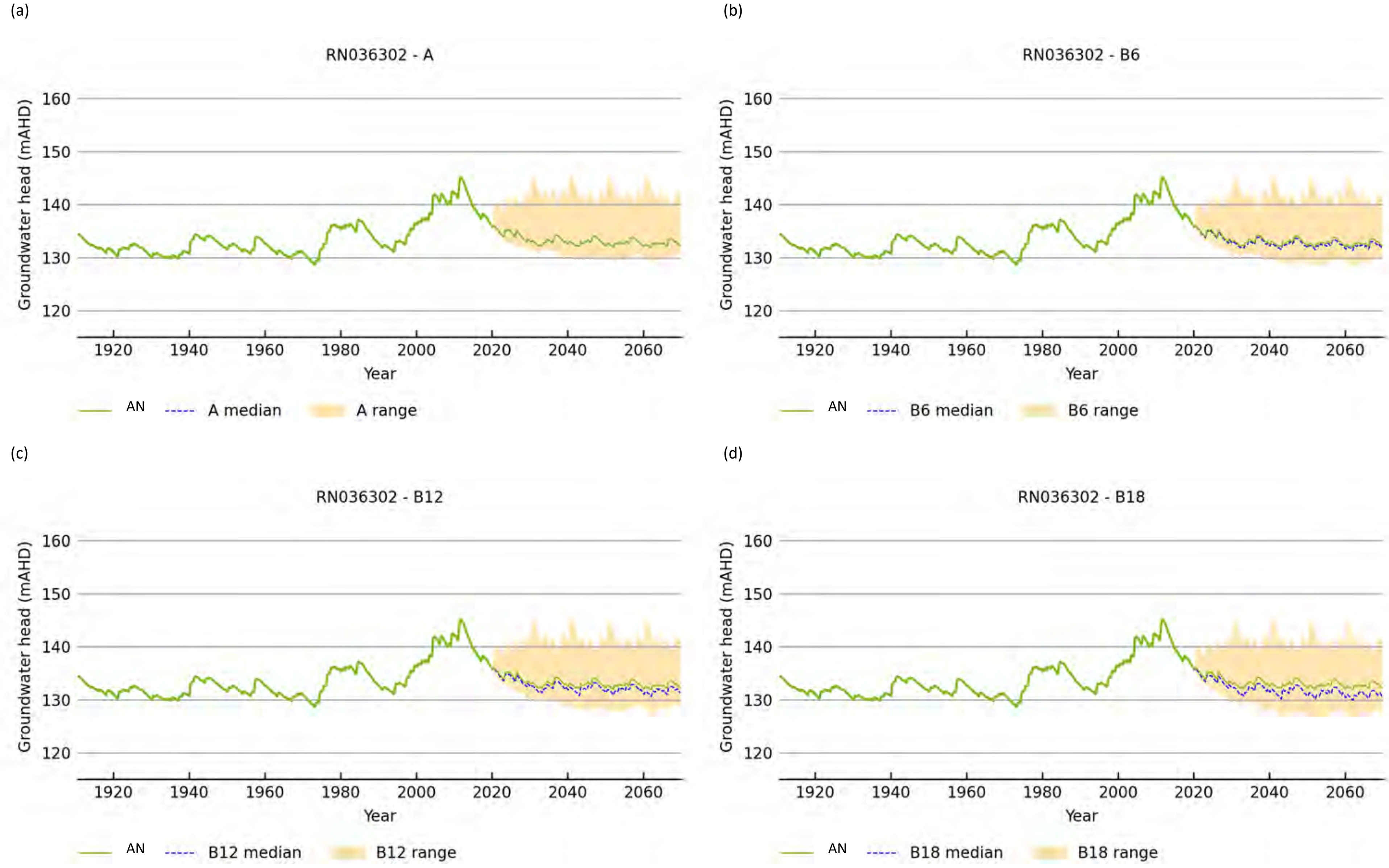


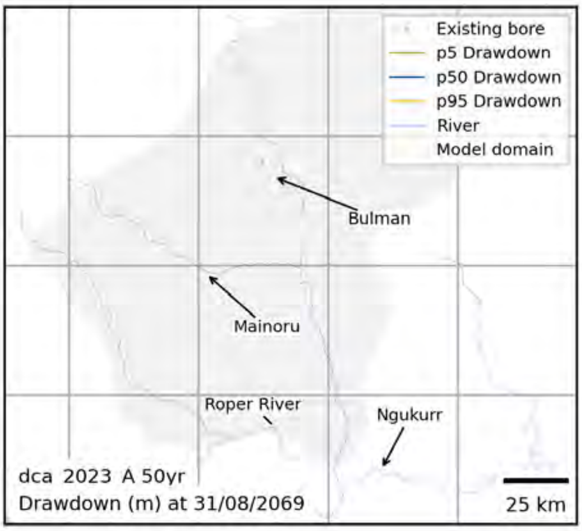
Figure 7-26 Hydrographs of groundwater level at reporting site RN036302 under scenarios (a) A, (b) B6, (c) B12 and (d) B18

7.3.3 Scenarios A and B – 2069 groundwater drawdown contours

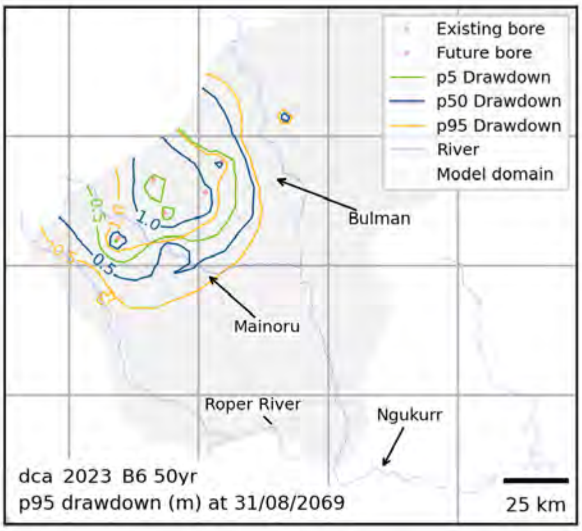
The drawdown contours at 31/8/2069 determined by comparing the heads under Scenario AN to the heads under scenarios A and B are shown in Figure 7-27. No drawdowns are apparent under the climate sequences under Scenario A due to the very low level of groundwater pumping.

The drawdown contours under scenarios B6, B12 and B18 are shown in Figure 7-27b, Figure 7-27c, and Figure 7-27d, respectively. The maximum drawdown is centred on the hypothetical future bores about 50 km to the north of Mainoru. The B6 contours show a maximum drawdown of 1 to 2 m. The B12 contours show a maximum drawdown of 2 to 5 m. The B18 contours show a final drawdown of greater than 5 m, with drawdown confined to the north-west unconfined portion of the model domain.

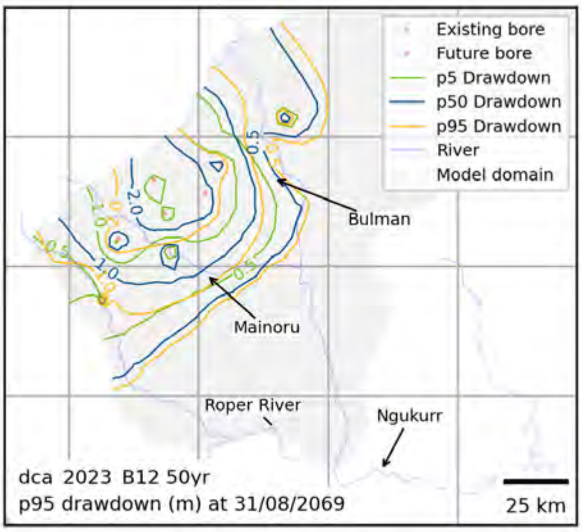
(a)



(b)



(c)



(d)

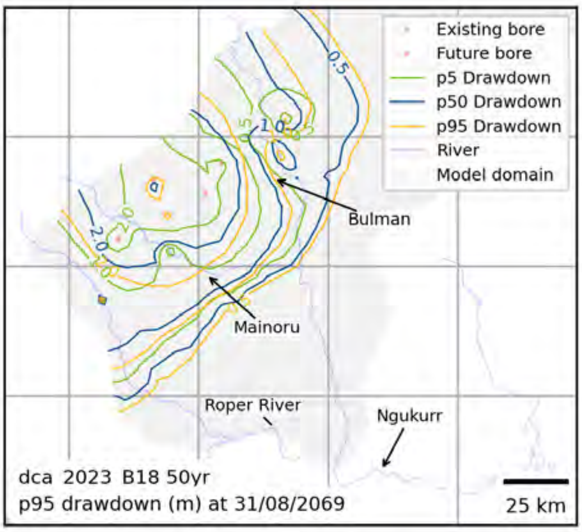


Figure 7-27 Drawdown contours under scenarios (a) A, (b) B6, (c) B12 and (d) B18 at the end of the 11 × 50-year climate sequences

7.3.4 Scenarios A and B – groundwater discharge

Mean groundwater discharges of the 11 climate sequences for the 10-year period (2059 to 2069) under scenarios A, B6, B12 and B18 at the Wilton River (G9030003) and Flying Fox Creek (G9030108) are presented in Table 7-11.

Groundwater discharges under scenarios A, B6, B12 and B18 at the Wilton River (G9030003) are presented in Figure 7-28 and at Flying Fox Creek (G9030108) in Figure 7-29.

Table 7-11 Mean groundwater discharge under scenarios A and B at Wilton River (G9030003) and Flying Fox Creek (G9030108)

SCENARIO	G9030003 GROUNDWATER DISCHARGE (m^3/s)	G9030003 % CHANGE FROM AN	G9030108 GROUNDWATER DISCHARGE (m^3/s)	G9030108 % CHANGE FROM AN
AN	0.11	na†	0.63	na
A	0.11	0	0.63	0
B6	0.10	−3	0.61	−3
B12	0.10	−7	0.59	−7
B18	0.10	−11	0.57	−11

AN = Historical climate and no development; A = Historical climate and current development; B6 = Historical climate sequences with current development and additional future development of 6 GL/year; B12 = Historical climate sequences with current development and additional future development of 12 GL/year; B18 = Historical climate sequences with current development and additional future development of 18 GL/year.
†na = not applicable.

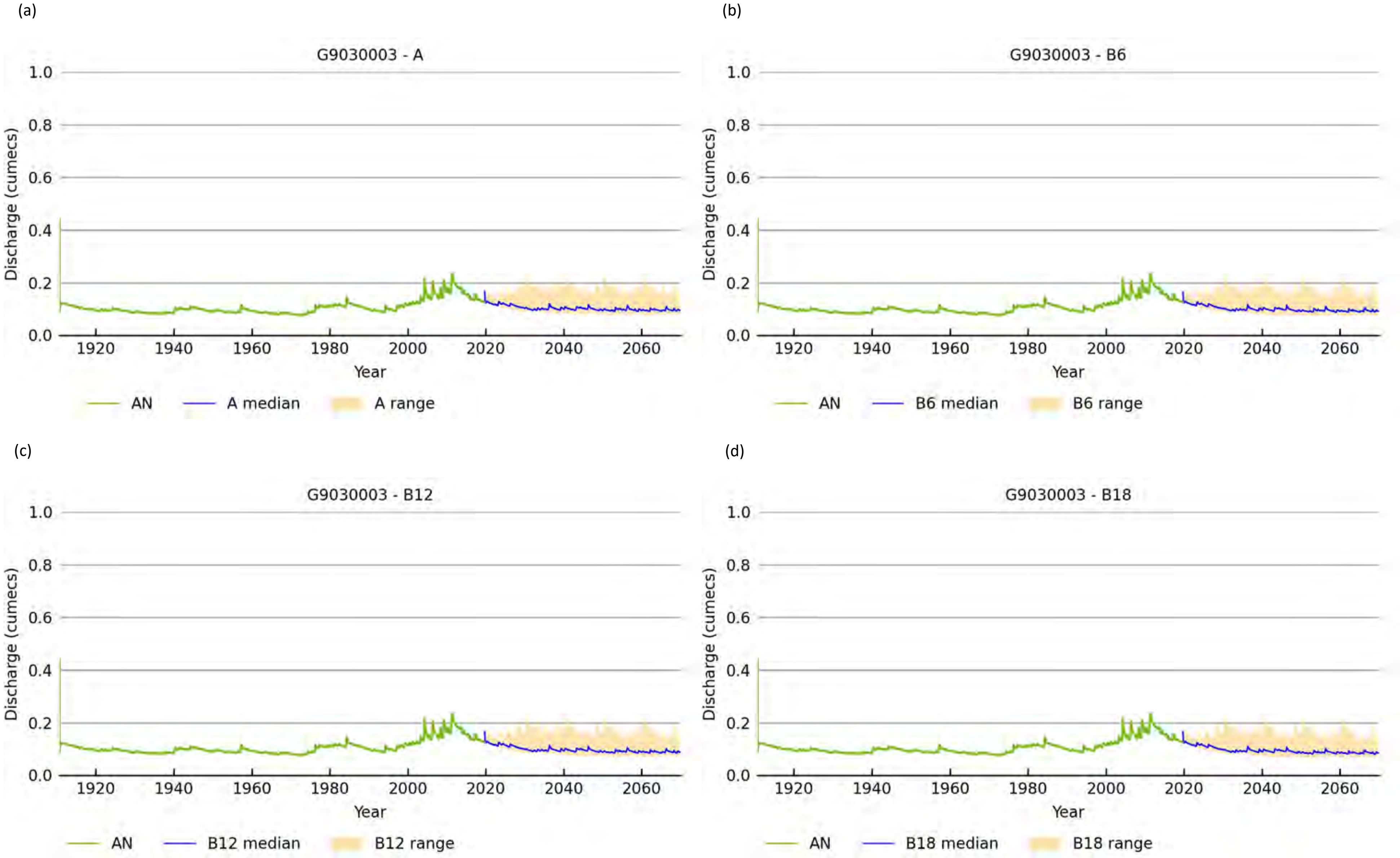
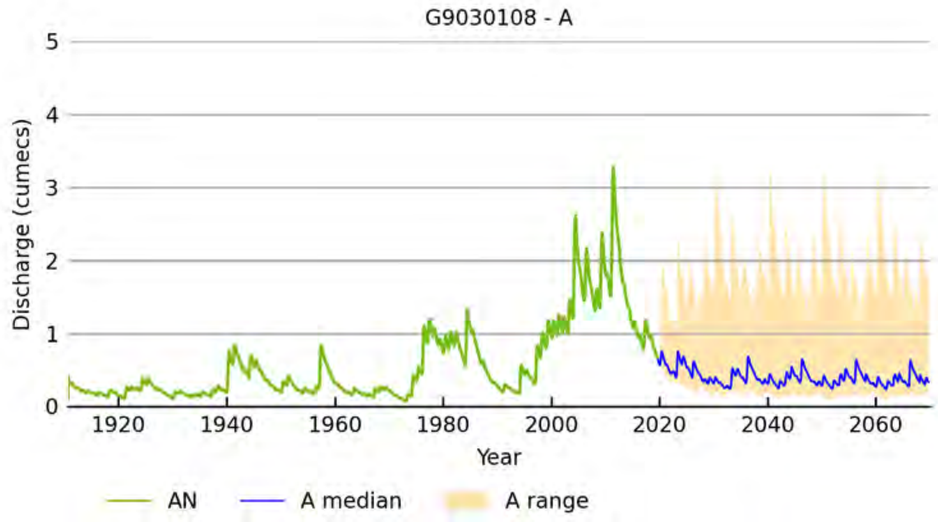
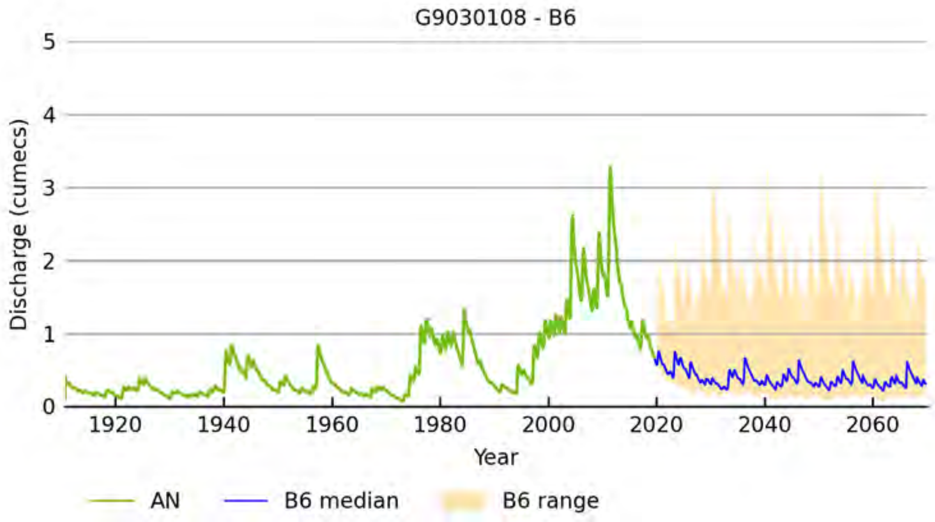


Figure 7-28 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030003 on the Wilton River under scenarios (a) A, (b) B6, (c) B12 and (d) B18

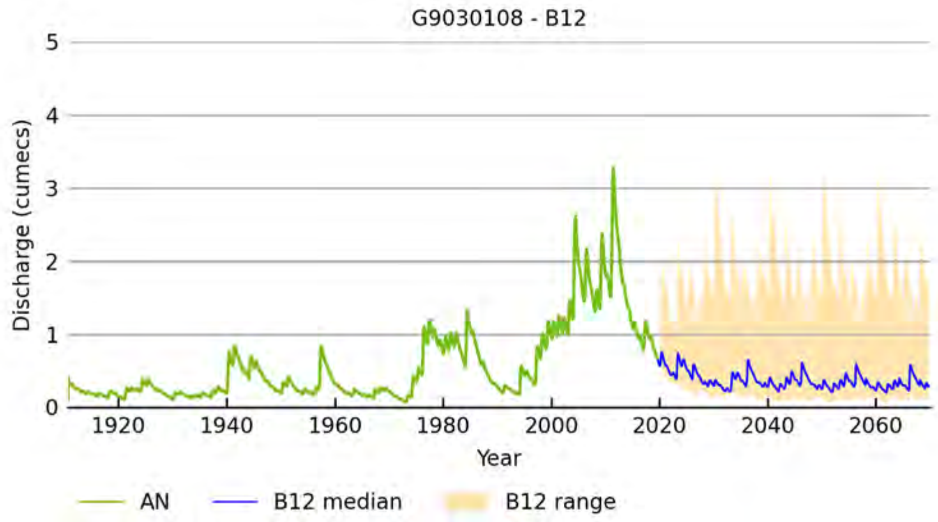
(a)



(b)



(c)



(d)

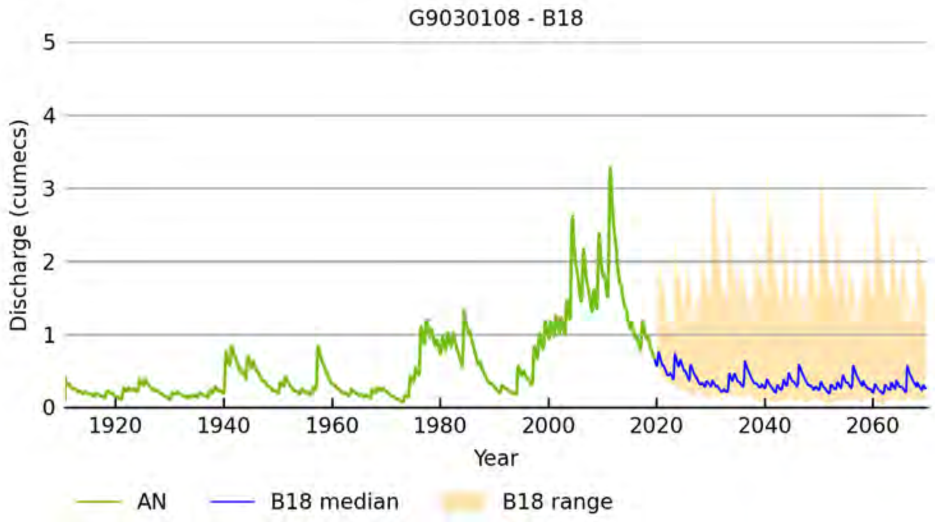


Figure 7-29 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030108 on Flying Fox Creek under scenarios (a) A, (b) B6, (c) B12, and (d) B18

The percentage decreases in discharge under scenarios A, B35, B70 and B105 relative to Scenario AN at the Roper River at G9030003 are presented in Figure 7-30 and at Flying Fox Creek at G9030108 in Figure 7-31.

The decrease in discharge at the two sites has been determined by comparing the natural AN and B pumped scenarios. Scenario B18 shows the greatest decrease in the median groundwater discharge. Under scenario B18, G9030003 shows a change in discharge of −18% to −8% with a median of about −12% and G9030108 shows a change from −5% to greater than −50% with a median of about −23%.

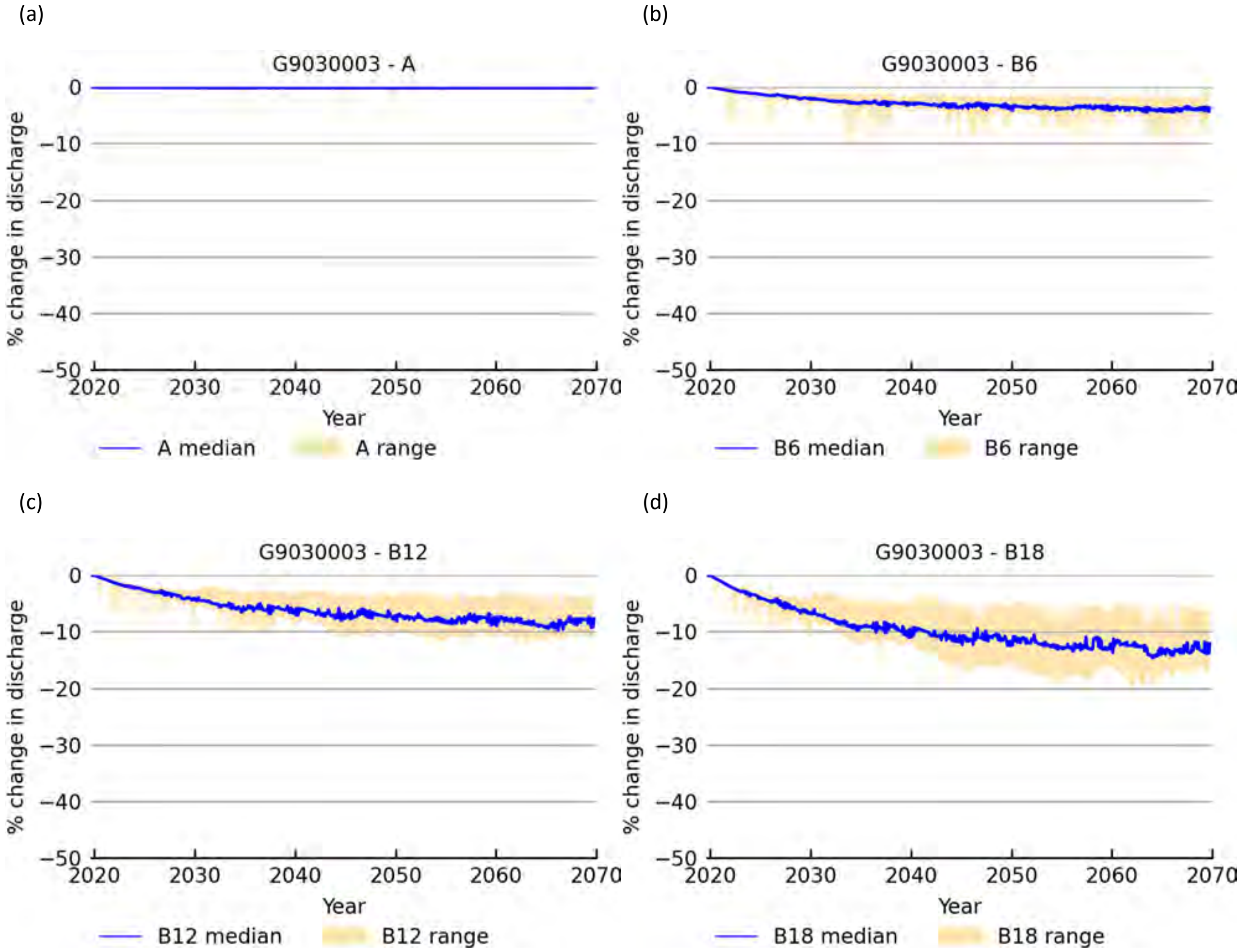


Figure 7-30 Percentage change in discharge relative to Scenario AN at G9030003 under scenarios (a) A, (b) B6, (c) B12 and (d) B18

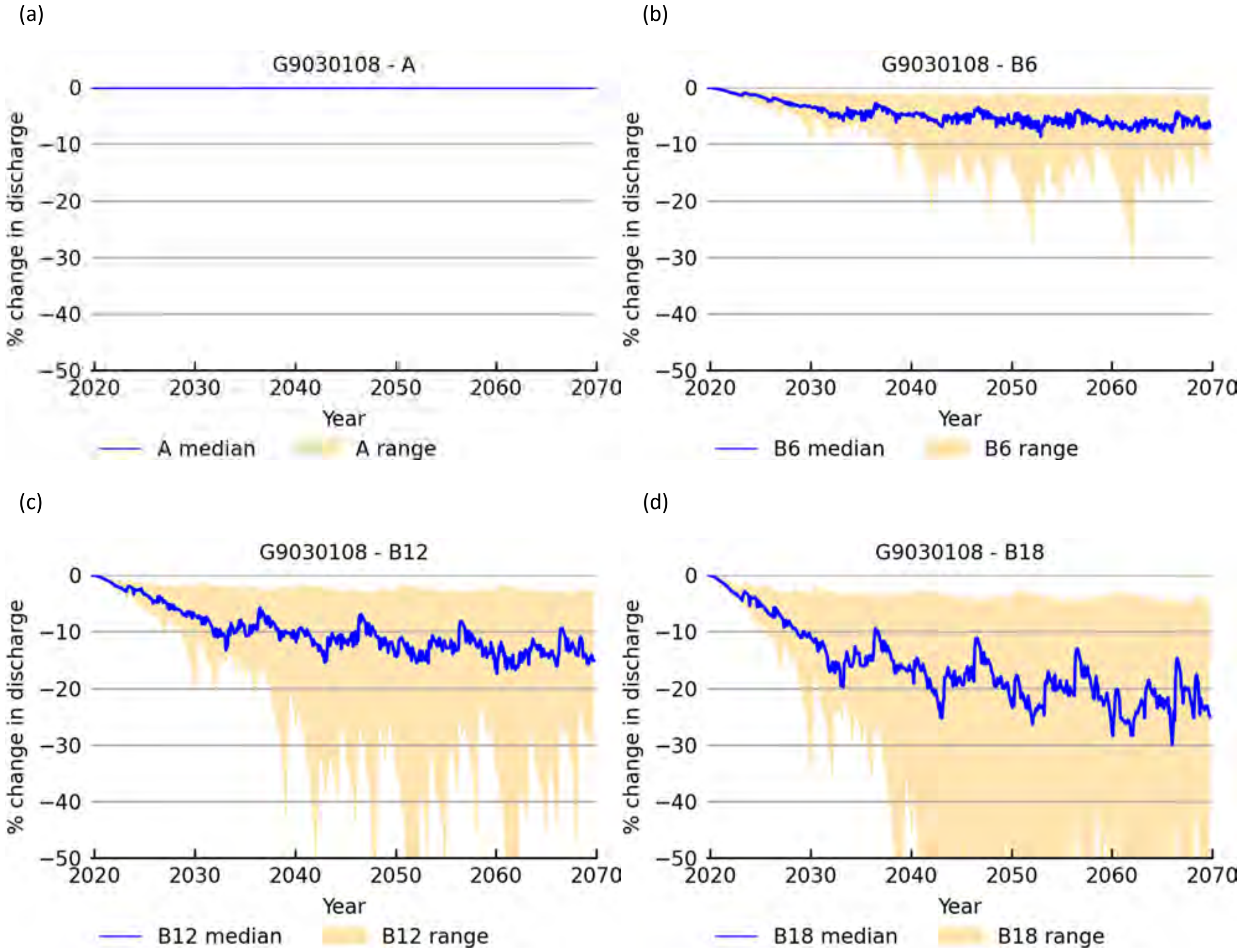


Figure 7-31 Percentage change in discharge relative to Scenario AN at G9030108 under scenarios (a) A, (b) B6, (c) B12 and (d) B18

7.4 Future climate (scenarios C and D)

Scenarios C and D were used to examine the effects of current and hypothetical future developments in conjunction with the three future climate sequences on catchment water balance, groundwater levels and discharge to the rivers.

7.4.1 Scenarios C and D – water balances

The ranges in mean annual water balances for the final 10-year period of each set of the 50-year climate sequences under scenarios C and D are presented as boxplots in Figure 7-32. The corresponding mean annual water balances for the dry, mid, and wet climate sequences are presented in Table 7-12, Table 7-13, and Table 7-14, respectively.

(a)

(b)

(c)

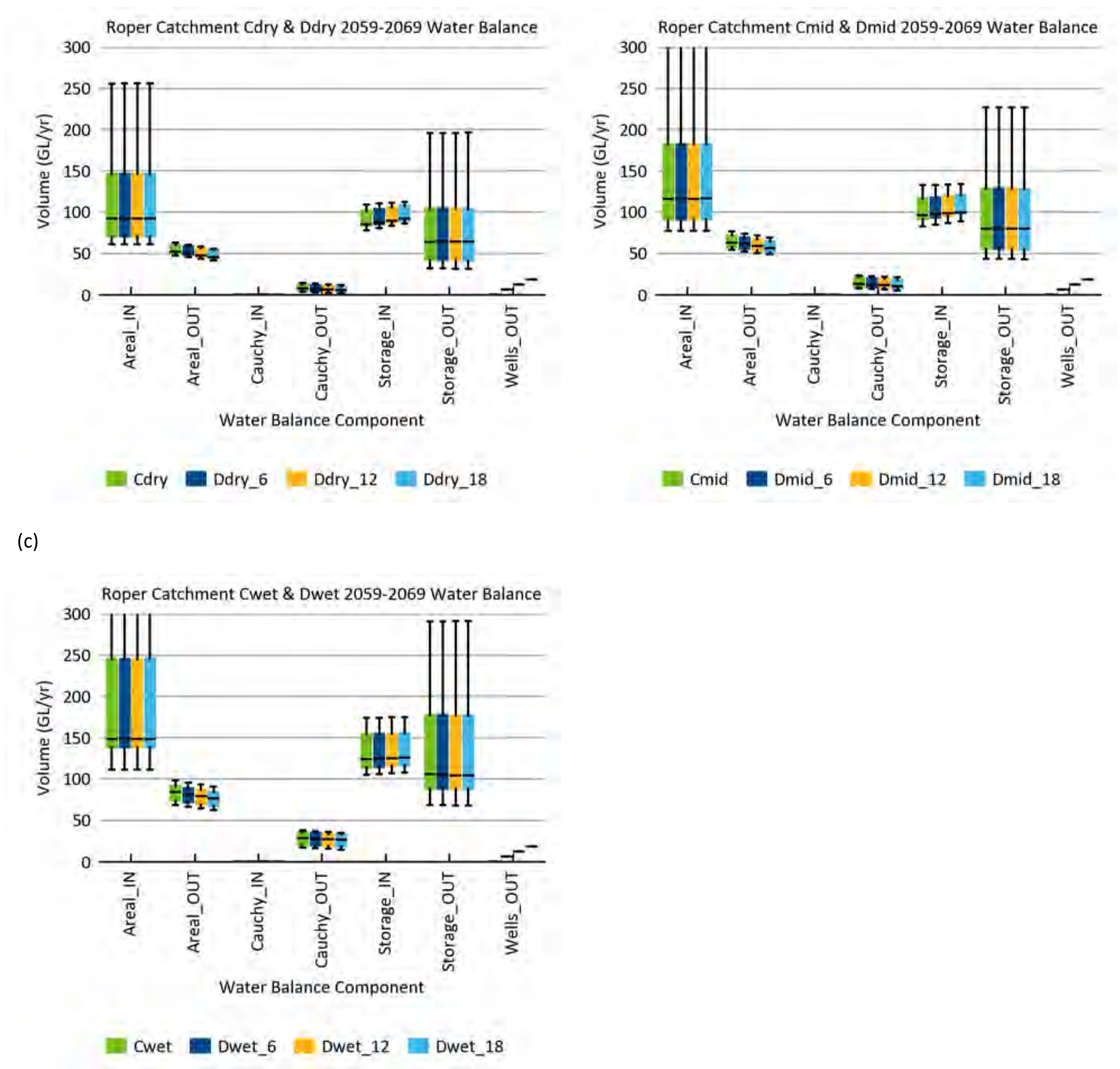


Figure 7-32 Dook Creek Aquifer water balances within the Roper catchment under scenarios (a) Cdry and Ddry, (b) Cmid and Dmid and (c) Cwet and Dwet

Labels are different from Table 7-12, Table 7-13 and Table 7-14: Areal_IN = recharge (diffuse); Areal_OUT = evapotranspiration; Cauchy_IN = from river; Cauchy_OUT = to river; Storage_IN = release from storage; Storage_OUT = capture into storage; and, Wells_OUT = extraction.

Table 7-12 Mean water balances (GL/year) for dry climate sequences under scenarios C and D in the Dook Creek Aquifer Roper catchment area

	A	CDRY	DDRY6	DDRY12	DDRY18
Inflow (gains)					
Recharge (diffuse)	151.8	113.9	114.0	114.0	114.1
Release from storage	116.3	98.2	99.9	101.8	103.6
From river	0.1	0.1	0.1	0.1	0.1
Sub-total	**268.2**	**212.2**	**214.0**	**215.8**	**217.8**
Outflow (losses)					
Evapotranspiration	73.4	59.3	57.2	55.0	52.9
Extraction	0.1	0.1	6.1	12.1	18.2
Capture into storage	106.0	79.7	79.7	79.5	79.4
To rivers	22.2	12.4	11.6	10.8	10.1
To springs	8.7	3.7	3.2	2.8	2.4
Sub-total	**210.4**	**155.2**	**157.8**	**160.2**	**163**
Net flow in (+ve) / out (-ve)	**−57.8**	**−57**	**−56.2**	**−55.7**	**−54.8**

A = Historical climate and current development; Cdry = Future dry climate and current development; Ddry6 = Future dry climate sequences with current development and additional future development of 6 GL/year; Ddry12 = Future dry climate sequences with current development and additional future development of 12 GL/year; Ddry18 = Future dry climate sequences with current development and additional future development of 18 GL/year.

Table 7-13 Mean water balances (GL/year) for mid climate sequences under scenarios C and D in the Dook Creek Aquifer Roper catchment area

	A	CMID	DMID6	DMID12	DMID18
Inflow (gains)					
Recharge (diffuse)	151.8	141.9	142.1	142.2	142.3
Release from storage	116.3	111.1	112.5	113.9	115.5
From river	0.1	0.1	0.1	0.1	0.1
Sub-total	**268.2**	**253.2**	**254.7**	**256.2**	**257.8**
Outflow (losses)					
Evapotranspiration	73.4	69.7	67.5	65.3	63.1
Extraction	0.1	0.0	6.1	12.1	18.2
Capture into storage	106.0	99.0	99.0	98.9	98.8
To rivers	22.2	19.6	18.7	17.9	17.0
To springs	8.7	7.1	6.3	5.6	5.0
Sub-total	**210.4**	**195.4**	**197.6**	**199.8**	**202.1**
Net flow in (+ve) / out (-ve)	**−57.8**	**−57.8**	**−57.1**	**−56.4**	**−55.7**

A = Historical climate and current development; Cmid = Future mid climate and current development; Dmid6 = Future mid climate sequences with current development and additional future development of 6 GL/year; Dmid12 = Future mid climate sequences with current development and additional future development of 12 GL/year; Dmid18 = Future mid climate sequences with current development and additional future development of 18 GL/year.

Table 7-14 Mean water balances (GL/year) for wet climate sequences under scenarios C and D in the Dook Creek Aquifer Roper catchment area

	A	CWET	DWET6	DWET12	DWET18
Inflow (gains)					
Recharge (diffuse)	151.8	196.0	196.1	196.2	196.3
Release from storage	116.3	143.2	143.9	144.6	145.4
From river	0.1	0.2	0.2	0.2	0.2
Sub-total	**268.2**	**339.4**	**340.2**	**341.0**	**341.9**
Outflow (losses)					
Evapotranspiration	73.4	90.1	87.8	85.6	83.4
Extraction	0.1	0.1	6.1	12.1	18.2
Capture into storage	106.0	139.0	138.8	138.7	138.5
To rivers	22.2	34.2	33.4	32.7	31.9
To springs	8.7	17.9	16.3	14.7	13.1
Sub-total	**210.4**	**281.3**	**282.4**	**283.8**	**285.1**
Net flow in (+ve) / out (-ve)	**−57.8**	**−58.1**	**−57.8**	**−57.2**	**−56.8**

A = Historical climate and current development; Cwet = Future wet climate and current development; Dwet6 = Future wet climate sequences with current development and additional future development of 6 GL/year; Dwet12 = Future wet climate sequences with current development and additional future development of 12 GL/year; Dwet18 = Future wet climate sequences with current development and additional future development of 18 GL/year.

7.4.2 Scenarios C and D – groundwater levels

Mean groundwater levels at the five reported sites over the last 10 years of the 11 × 50-year model runs under scenarios C and D are presented in Table 7-15. Change in mean groundwater level is a simple indicator of the effects due to climate change and the hypothetical future developments. Hydrographs of groundwater level for the dry, mid, and wet climate sequences under scenarios C and D at the five reporting sites are presented in Figure 7-33 through Figure 7-47.

These show that the Cdry and Cmid future climates result in a decrease in mean groundwater level relative to Scenario AN, and the groundwater level falls further with increased extraction under Ddry and Dmid. Under a Cwet future climate, the groundwater level increases, even under the Dwet scenarios with an increase in extraction.

Table 7-15 Mean groundwater levels (mAHD) for the 10-year period 2059 to 2069 under scenarios C and D

SCENARIO	RN006546	RN027811	RN028226	RN031983	RN036302
AN	139.8	97.3	93.3	146.1	134.0
Cdry	135.9	95.6	92.1	142.1	130.5
Cmid	138.9	96.9	93.0	145.1	133.3
Cwet	143.5	98.7	94.1	149.9	136.8
Ddry6	135.3	95.2	91.8	141.6	129.7
Ddry12	134.6	94.8	91.5	141.1	128.9
Ddry18	133.9	94.4	91.2	140.6	128.0
Dmid6	138.4	96.6	92.8	144.8	132.7
Dmid12	137.9	96.3	92.6	144.4	132.0
Dmid18	137.3	95.9	92.4	144.0	131.3
Dwet6	143.2	98.5	94.0	149.7	136.4
Dwet12	142.8	98.2	93.9	149.4	136.1
Dwet18	142.5	98.0	93.8	149.2	135.7

AN = Historical climate and no development; Cdry = Future dry climate sequences current development; Cmid = Future mid climate sequences current development; Cwet = Future wet climate sequences current development; Ddry6 = Future dry climate sequences current development and future development of 6 GL/year; Ddry12 = Future dry climate sequences current development and future development of 12 GL/year; Ddry18 = Future dry climate sequences current development and future development of 18 GL/year; Dmid6 = Future mid climate sequences current development and future development of 6 GL/year; Dmid12 = Future mid climate sequences current development and future development of 12 GL/year; Dmid18 = Future mid climate sequences current development and future development of 18 GL/year); Dwet6 = Future wet climate sequences current development and future development of 6 GL/year; Dwet12 = Future wet climate sequences current development and future development of 12 GL/year; Dwet18 = Future wet climate sequences current development and future development of 18 GL/year.

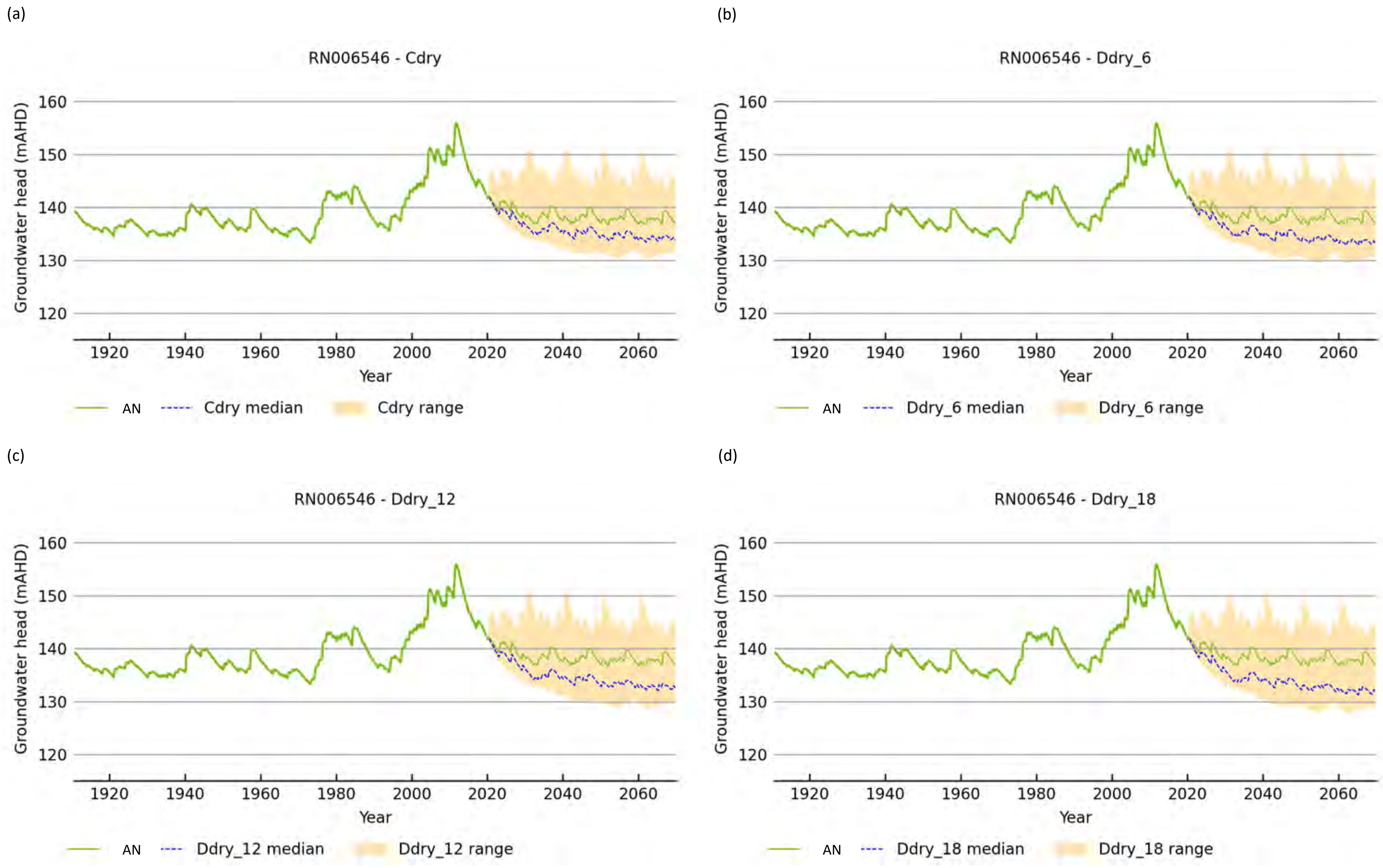


Figure 7-33 Hydrographs of groundwater level at reporting site RN006546 (Mountain Valley Station) under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18

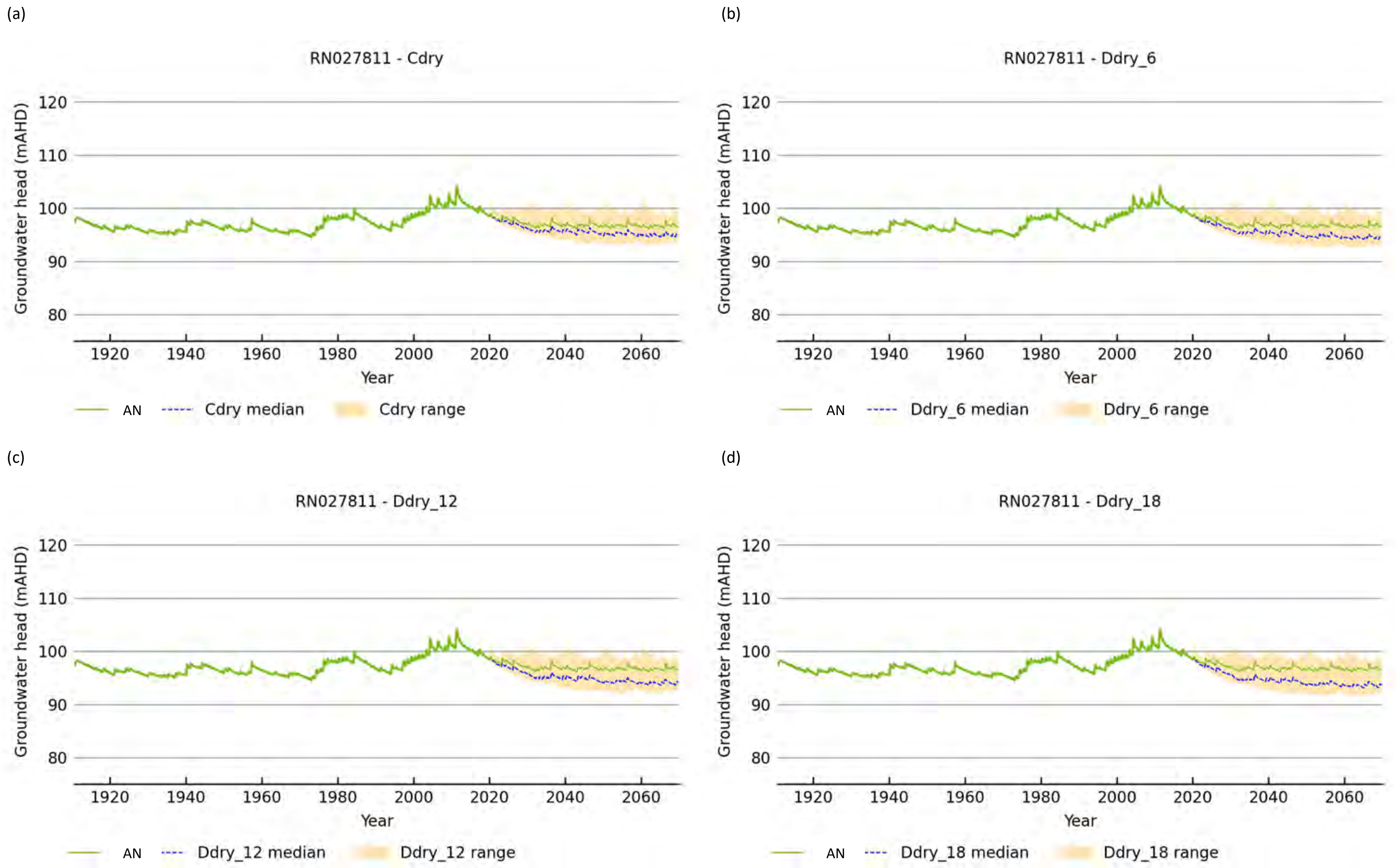


Figure 7-34 Hydrographs of groundwater level at reporting site RN027811 (Bulman and Weemol) under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18

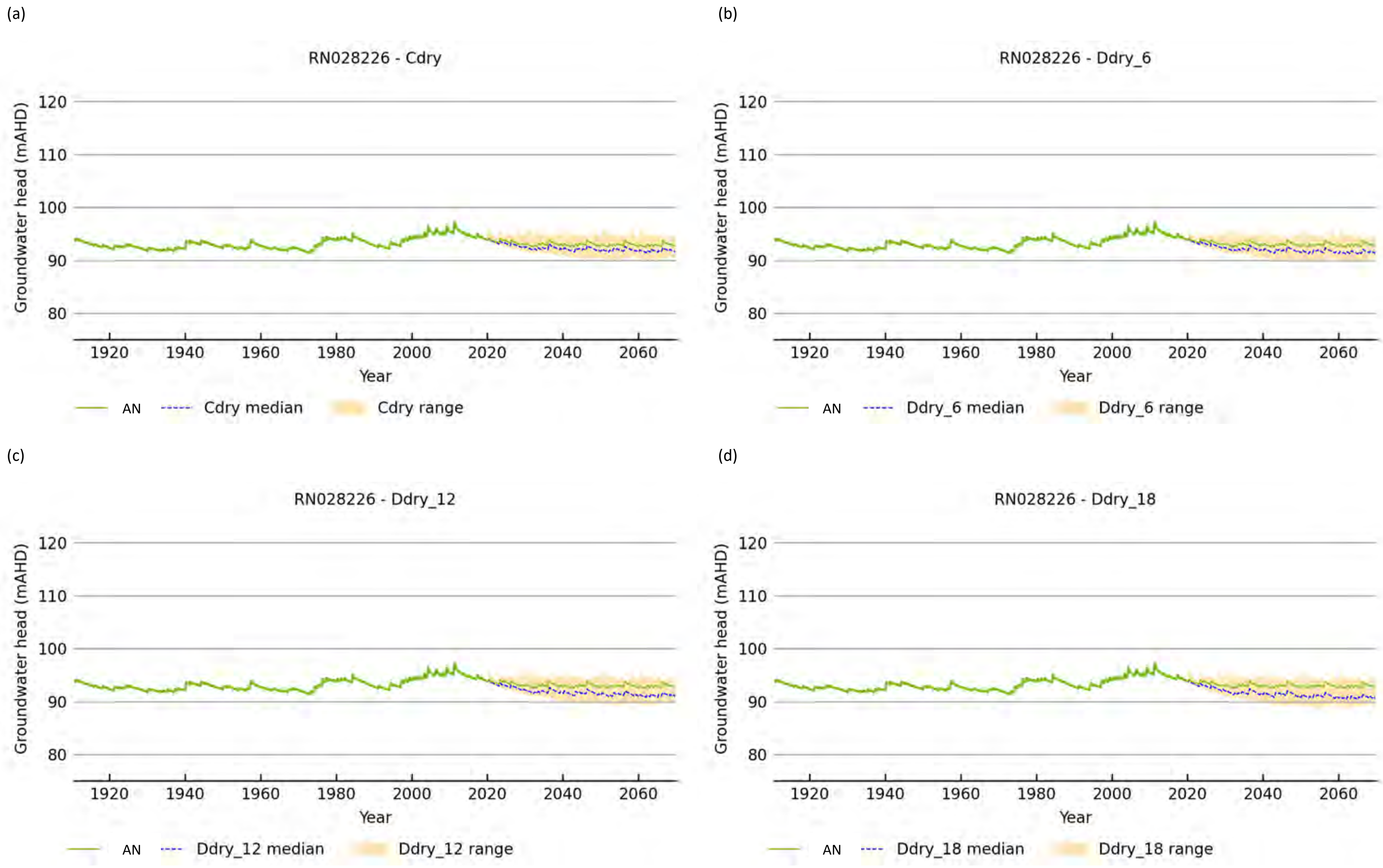


Figure 7-35 Hydrographs of groundwater level at reporting site RN028226 (Wilton River) under scenarios (a) Cdry, (b) Dmid6, (c) Dmid12 and (d) Dmid18

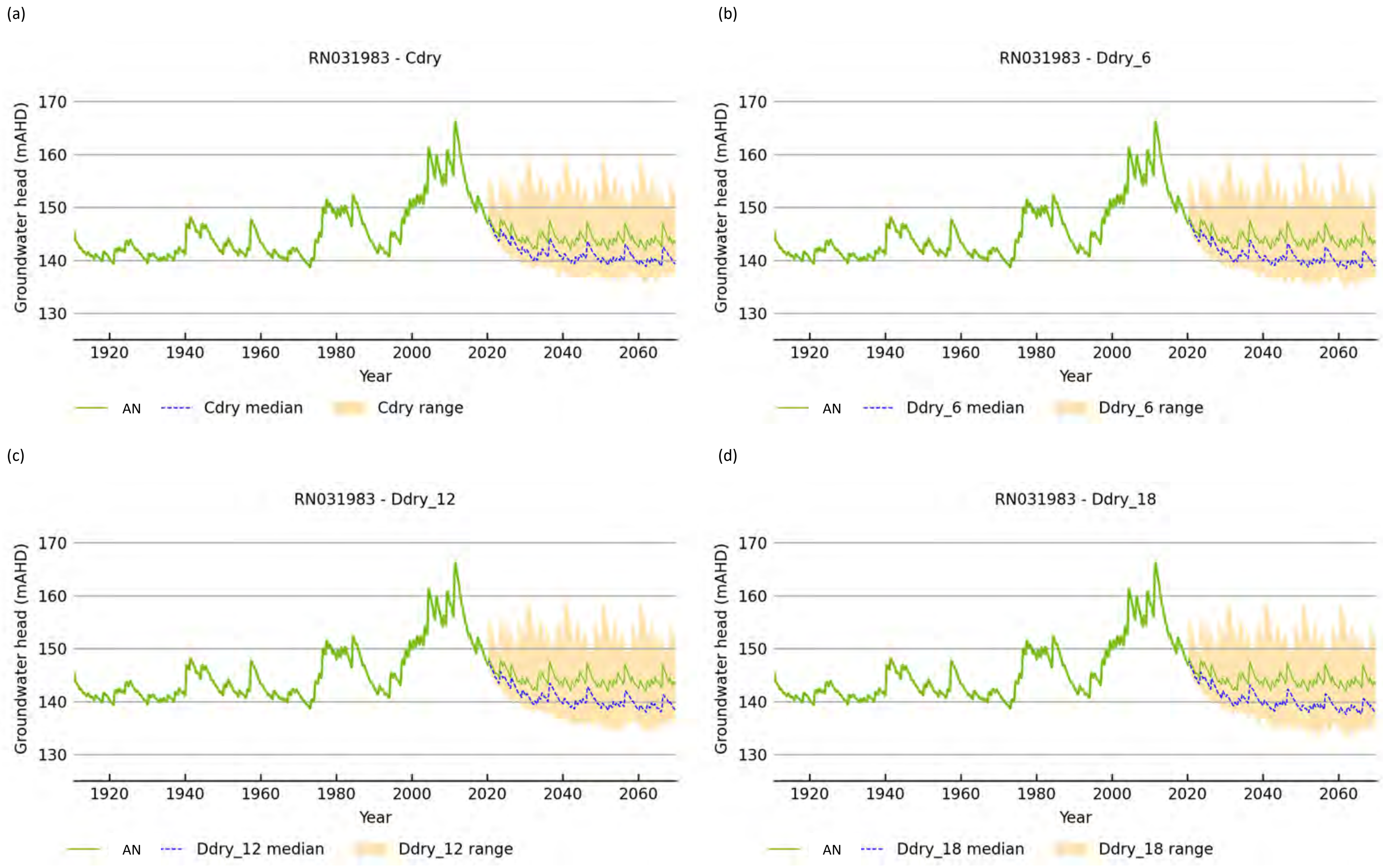


Figure 7-36 Hydrographs of groundwater level at reporting site RN031983 (Flying Fox Creek) under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18

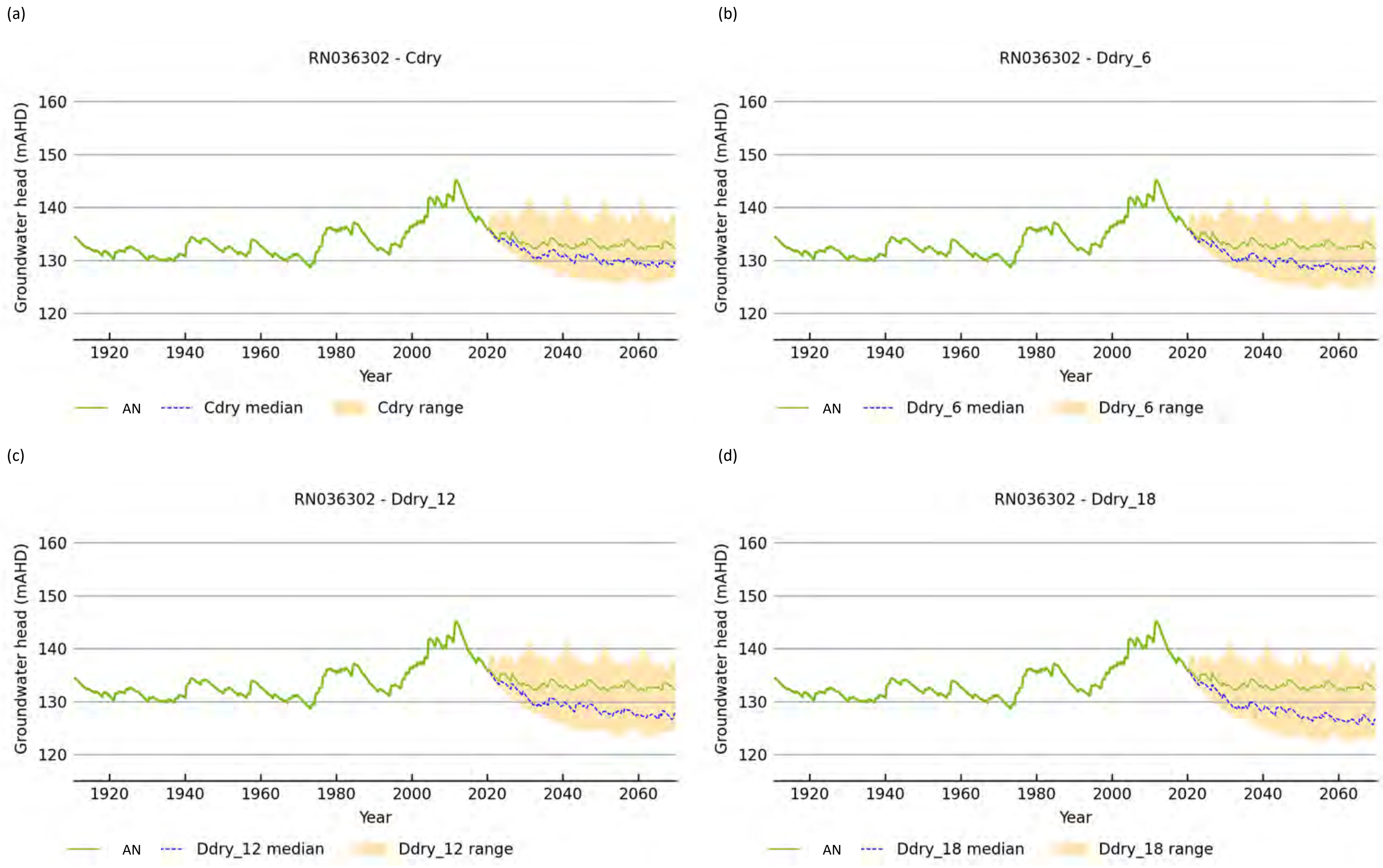


Figure 7-37 Hydrographs of groundwater level at reporting site RN036302 under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18

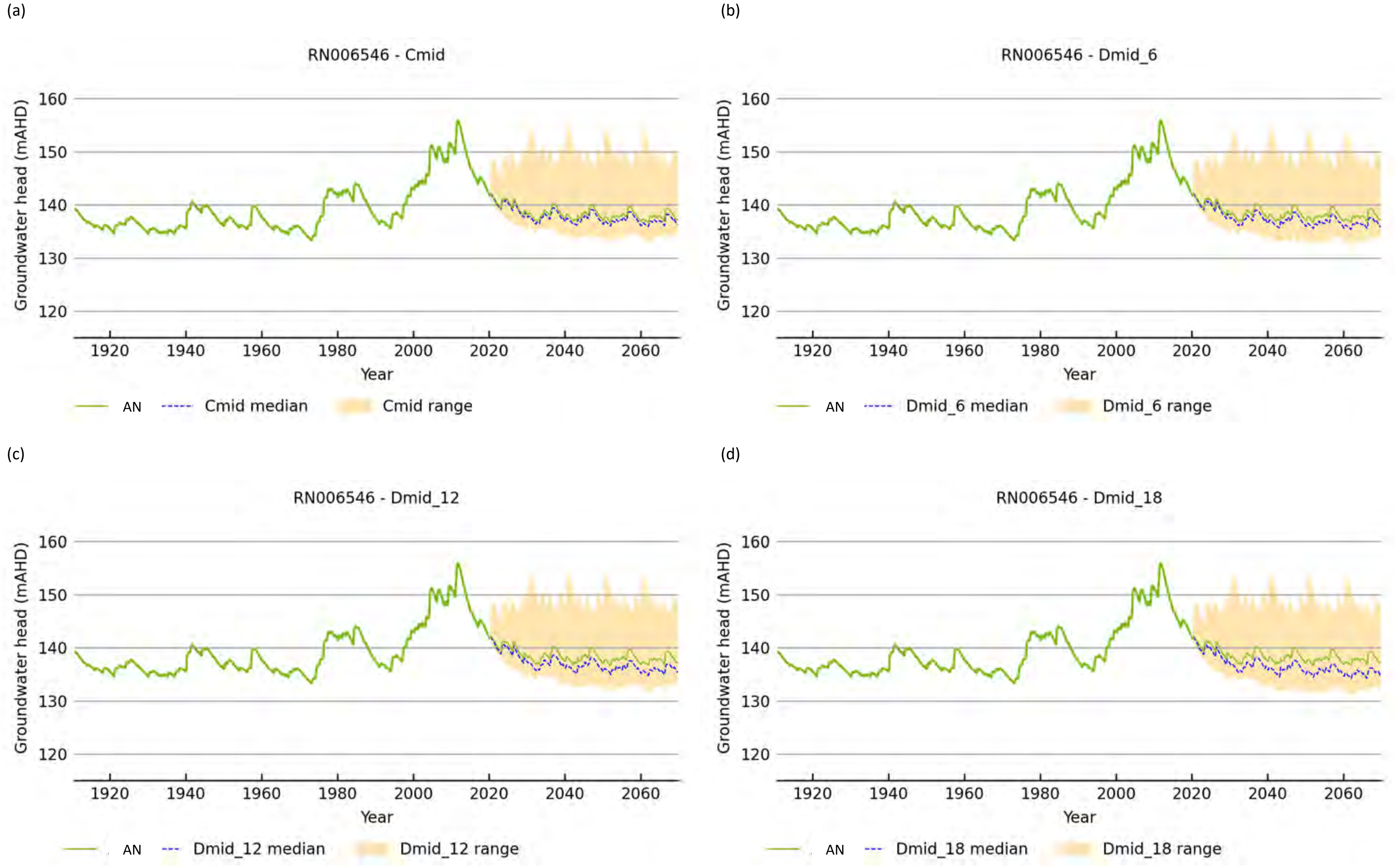
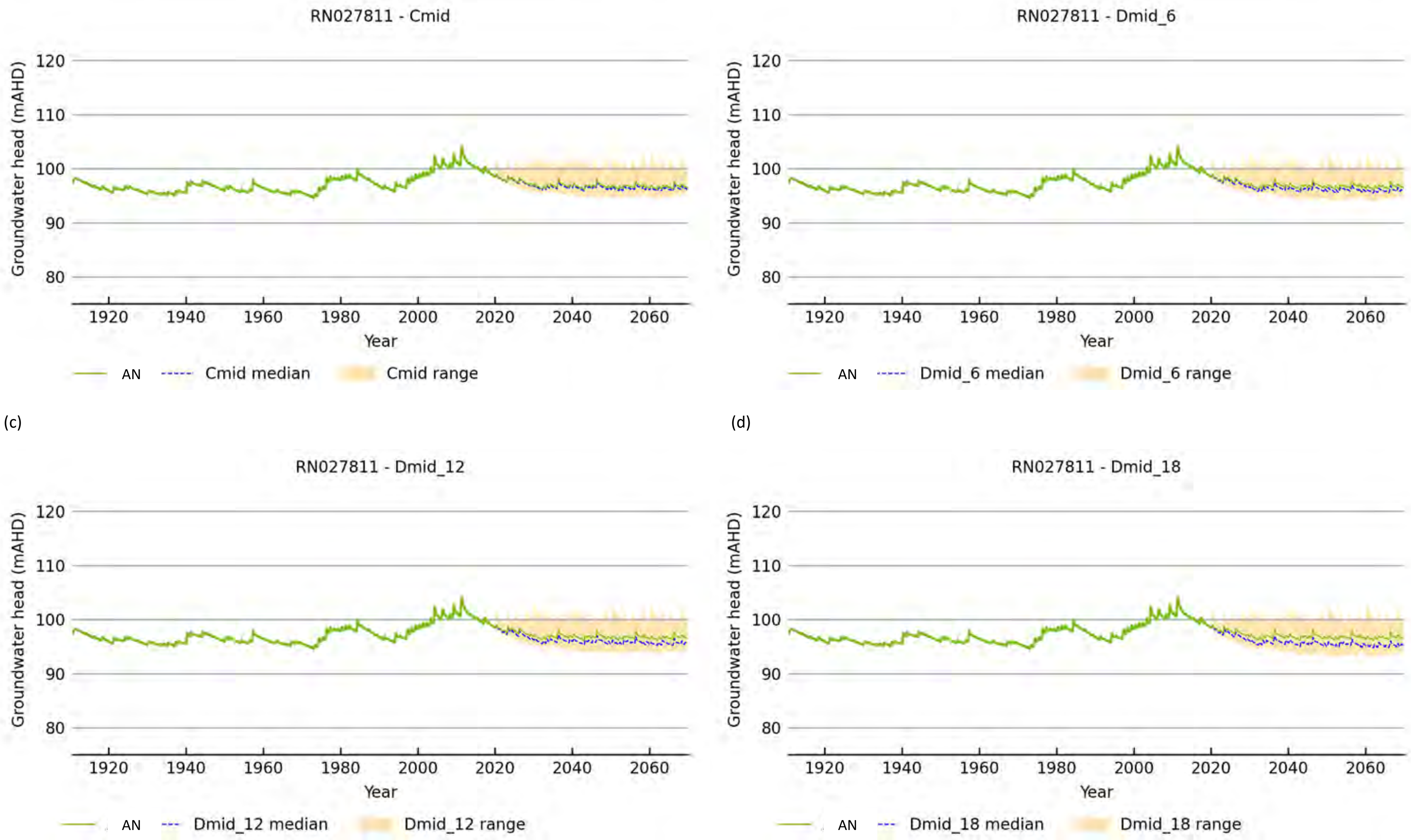


Figure 7-38 Hydrographs of groundwater level at reporting site RN006546 (Mountain Valley Station) under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

(a)

(b)



(c)

(d)

Figure 7-39 Hydrographs of groundwater level at reporting site RN027811 (Bulman and Weemol) under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

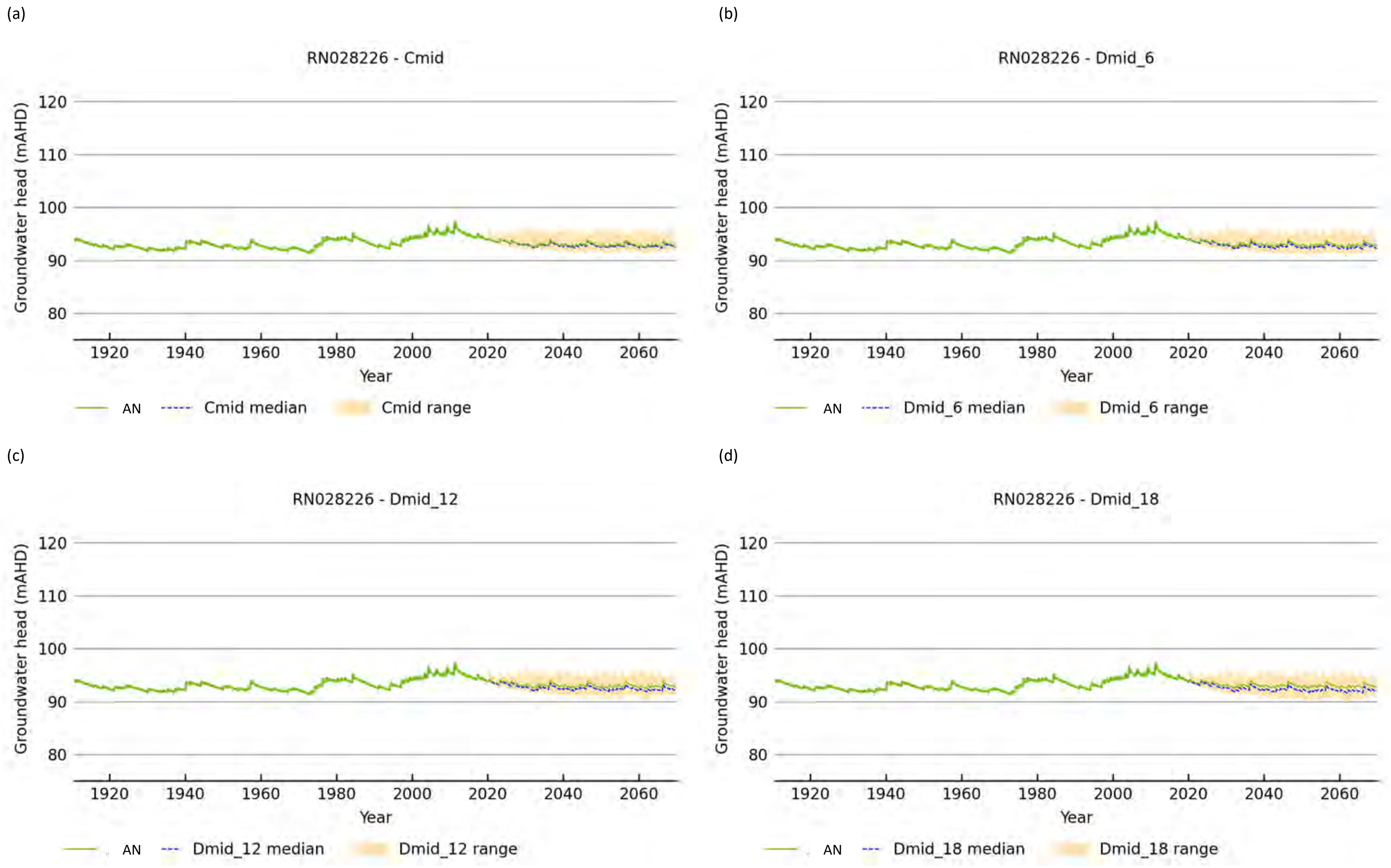


Figure 7-40 Hydrographs of groundwater level at reporting site RN028226 (Wilton River) under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

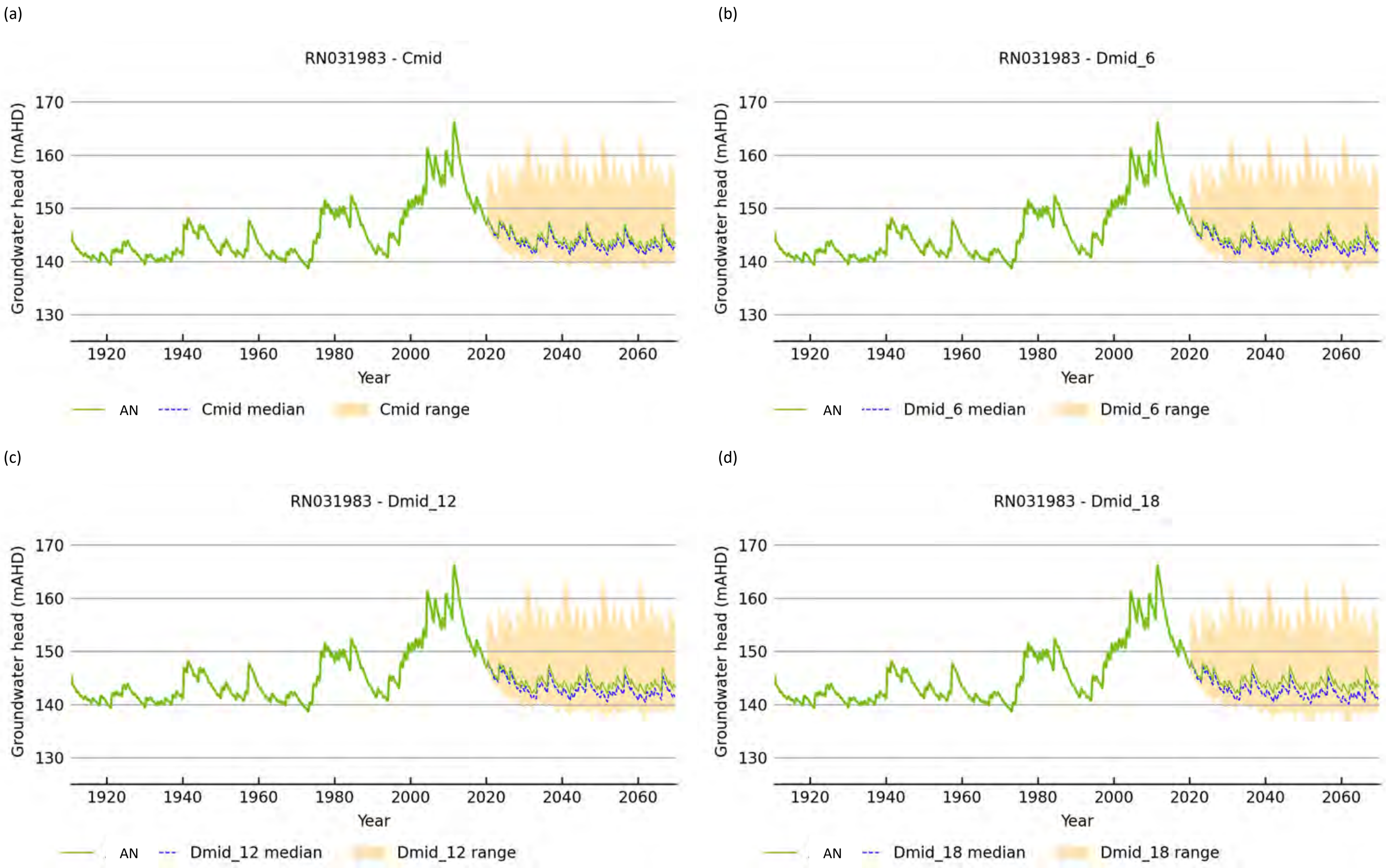


Figure 7-41 Hydrographs of groundwater level at reporting site RN031983 (Flying Fox Creek) under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

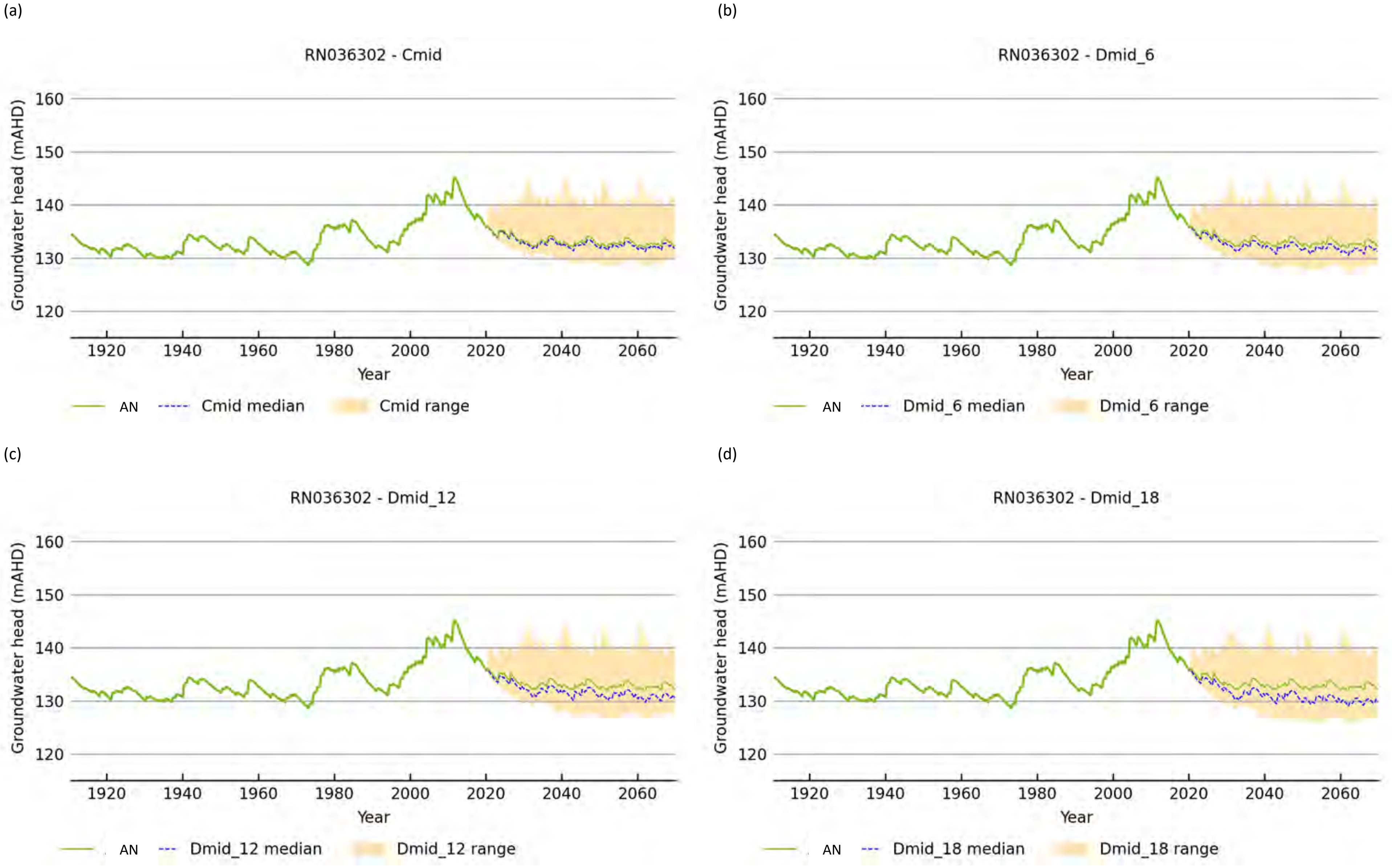


Figure 7-42 Hydrographs of groundwater level at reporting site RN036302 under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

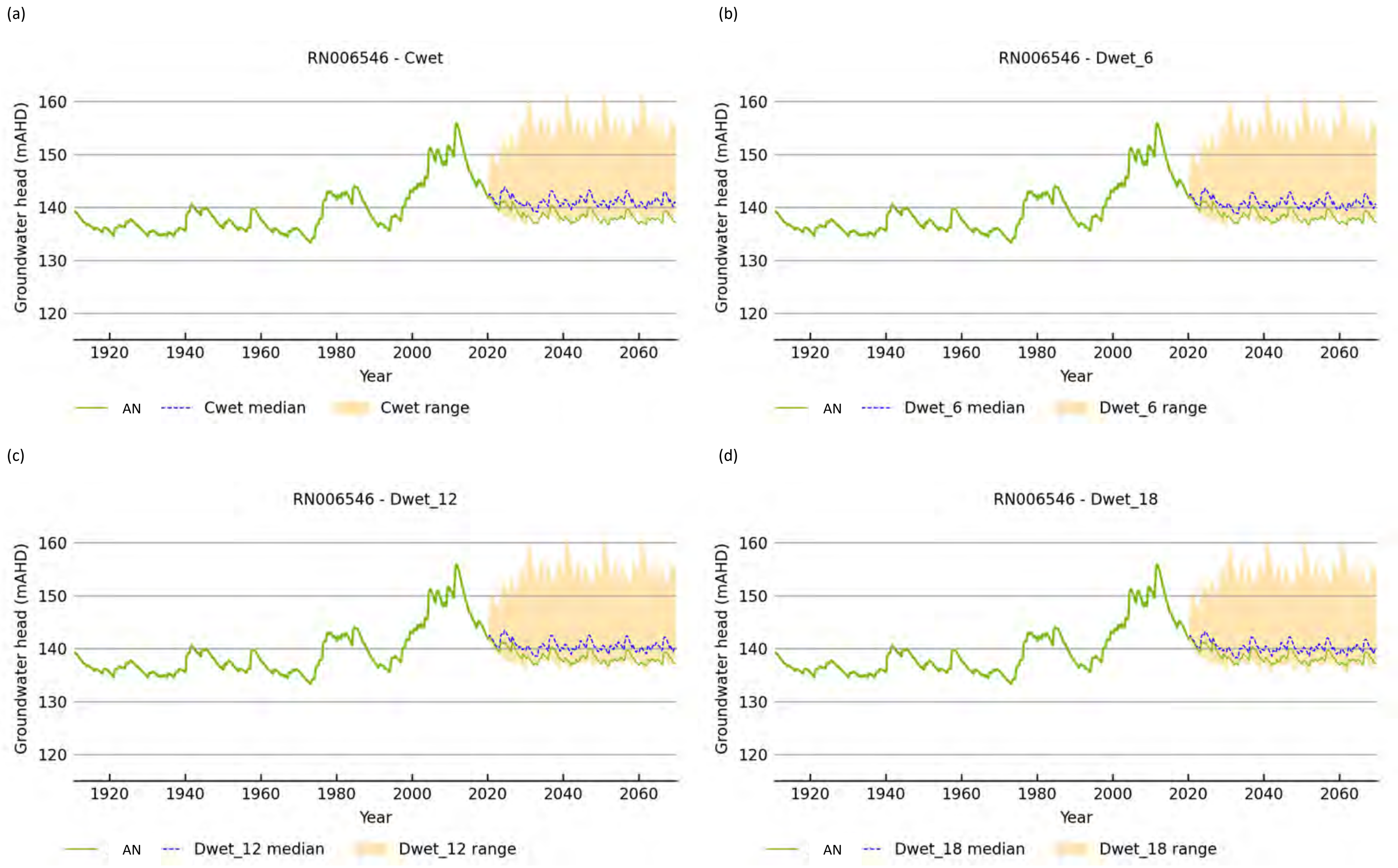


Figure 7-43 Hydrographs of groundwater level at reporting site RN006546 (Mountain Valley Station) under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18

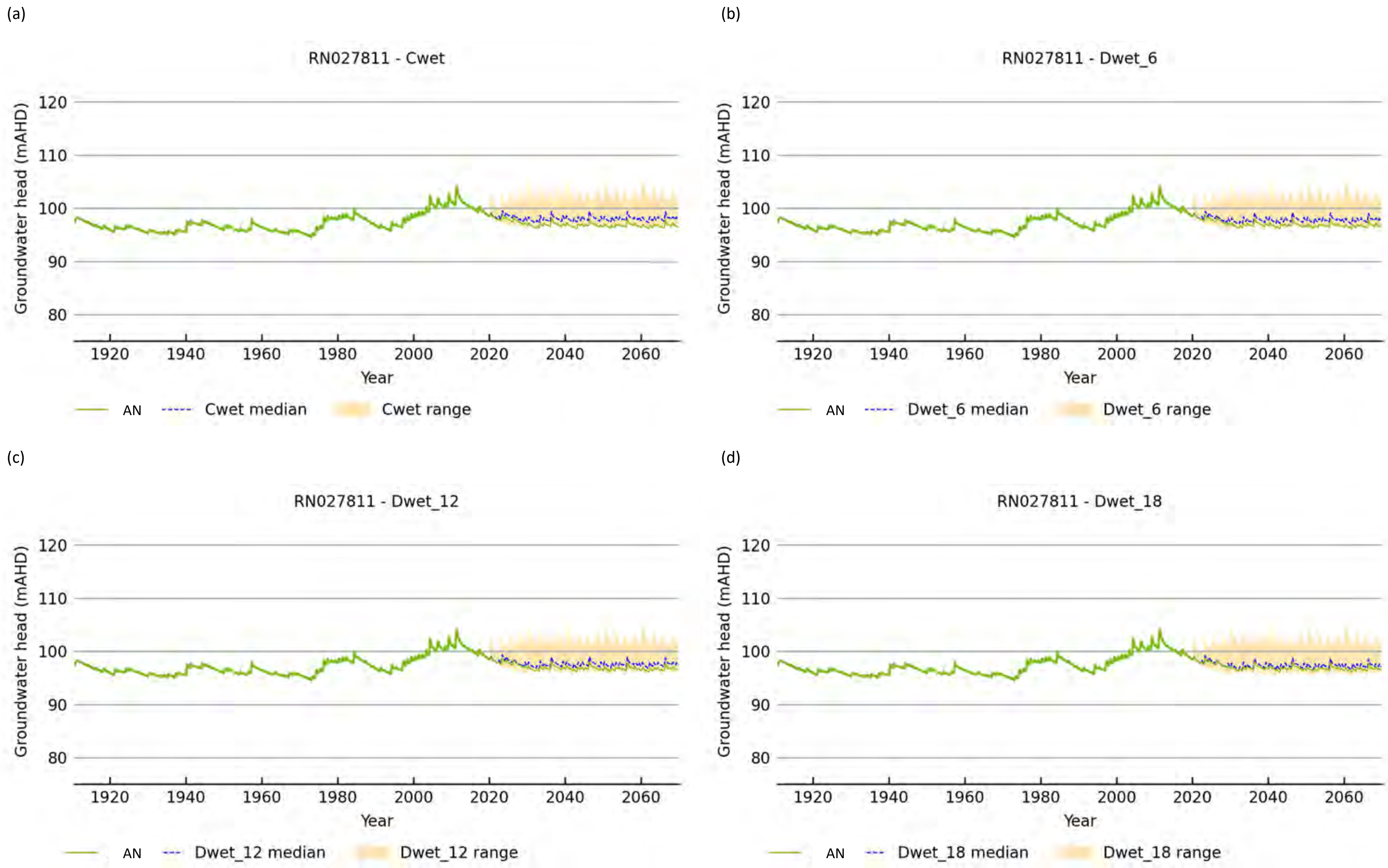


Figure 7-44 Hydrographs of groundwater level at reporting site RN027811 (Bulman and Weemol) under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18

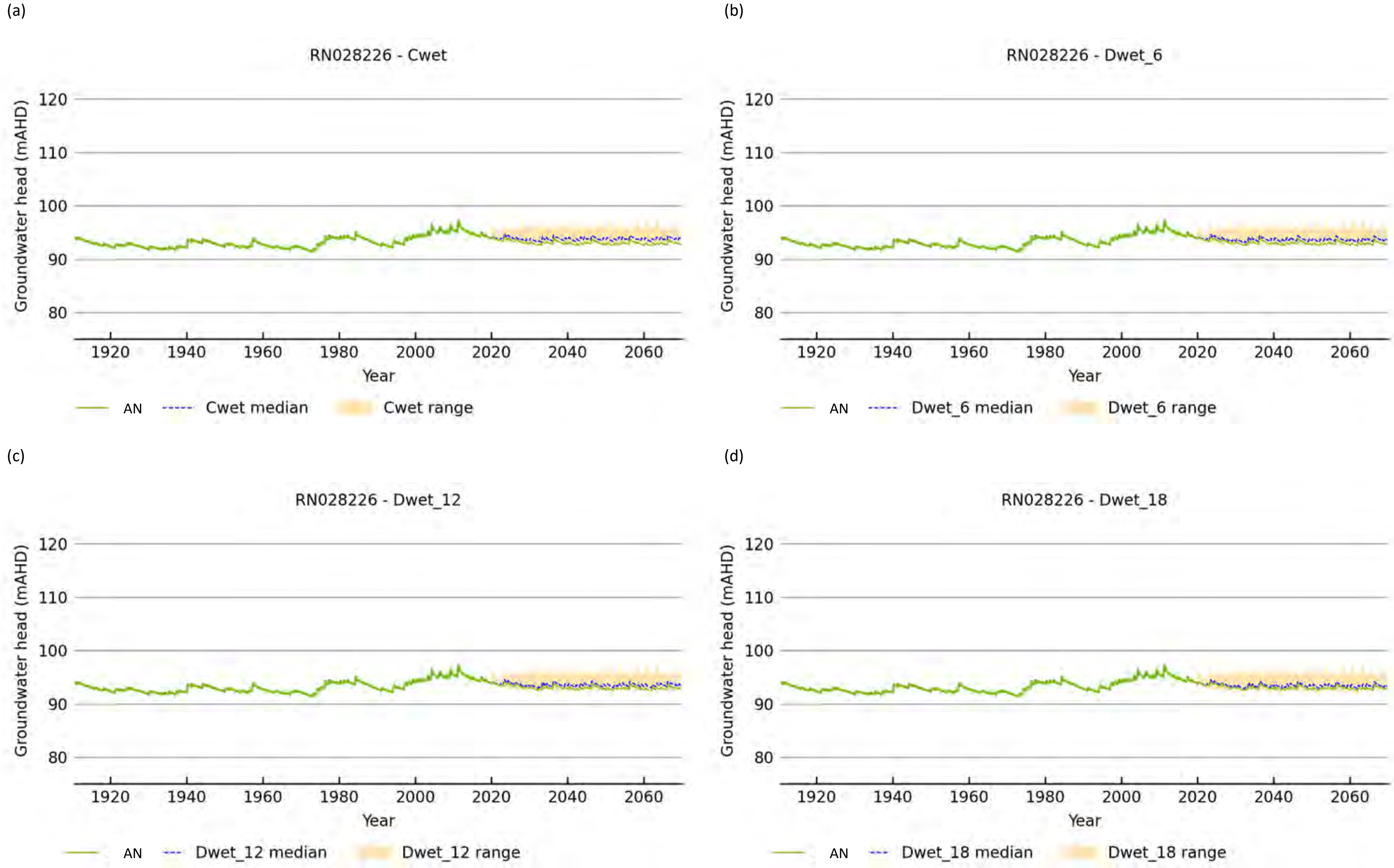


Figure 7-45 Hydrographs of groundwater level at reporting site RN028226 (Wilton River) under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18

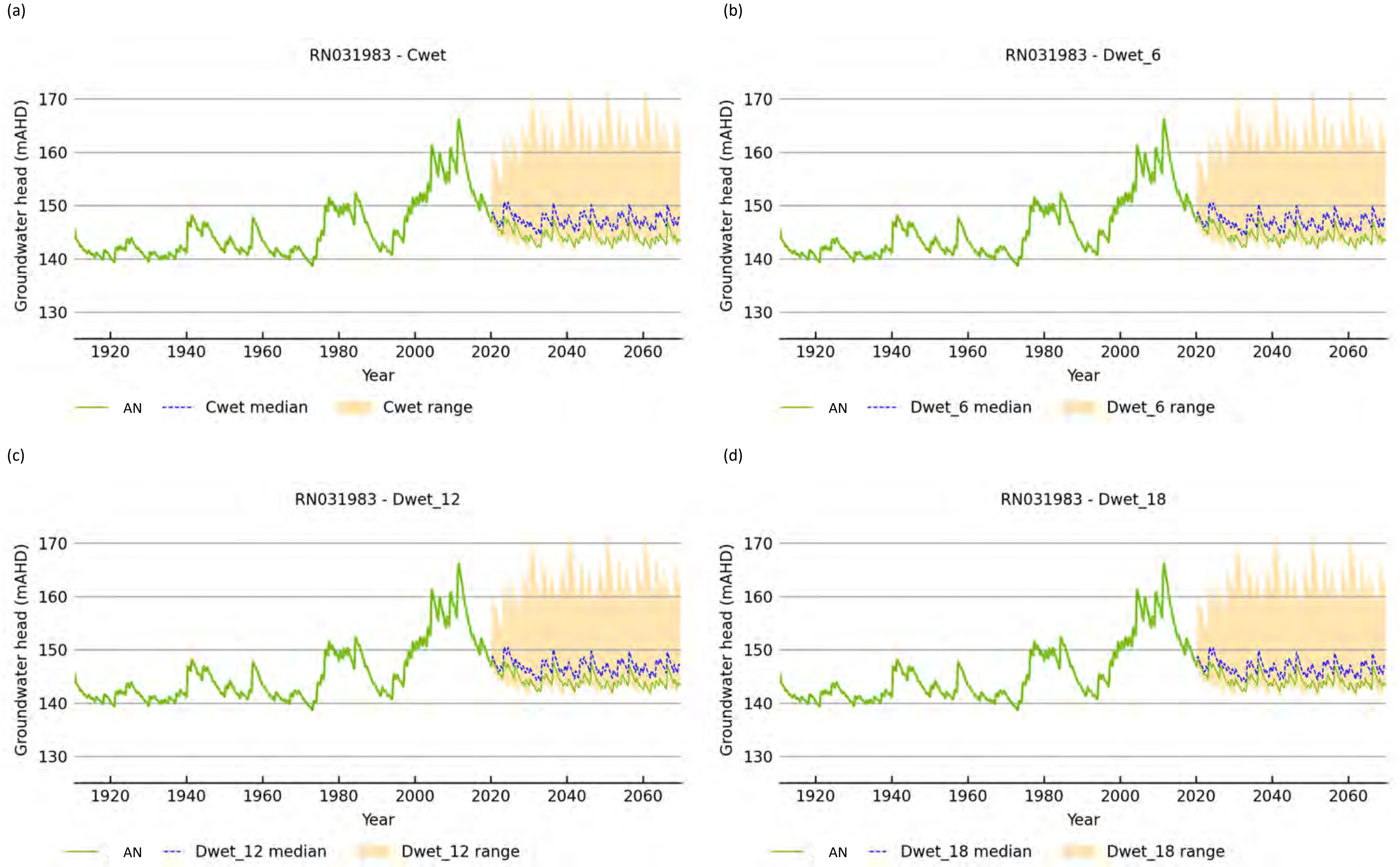


Figure 7-46 Hydrographs of groundwater level at reporting site RN031983 (Flying Fox Creek) under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18

(a)

(b)

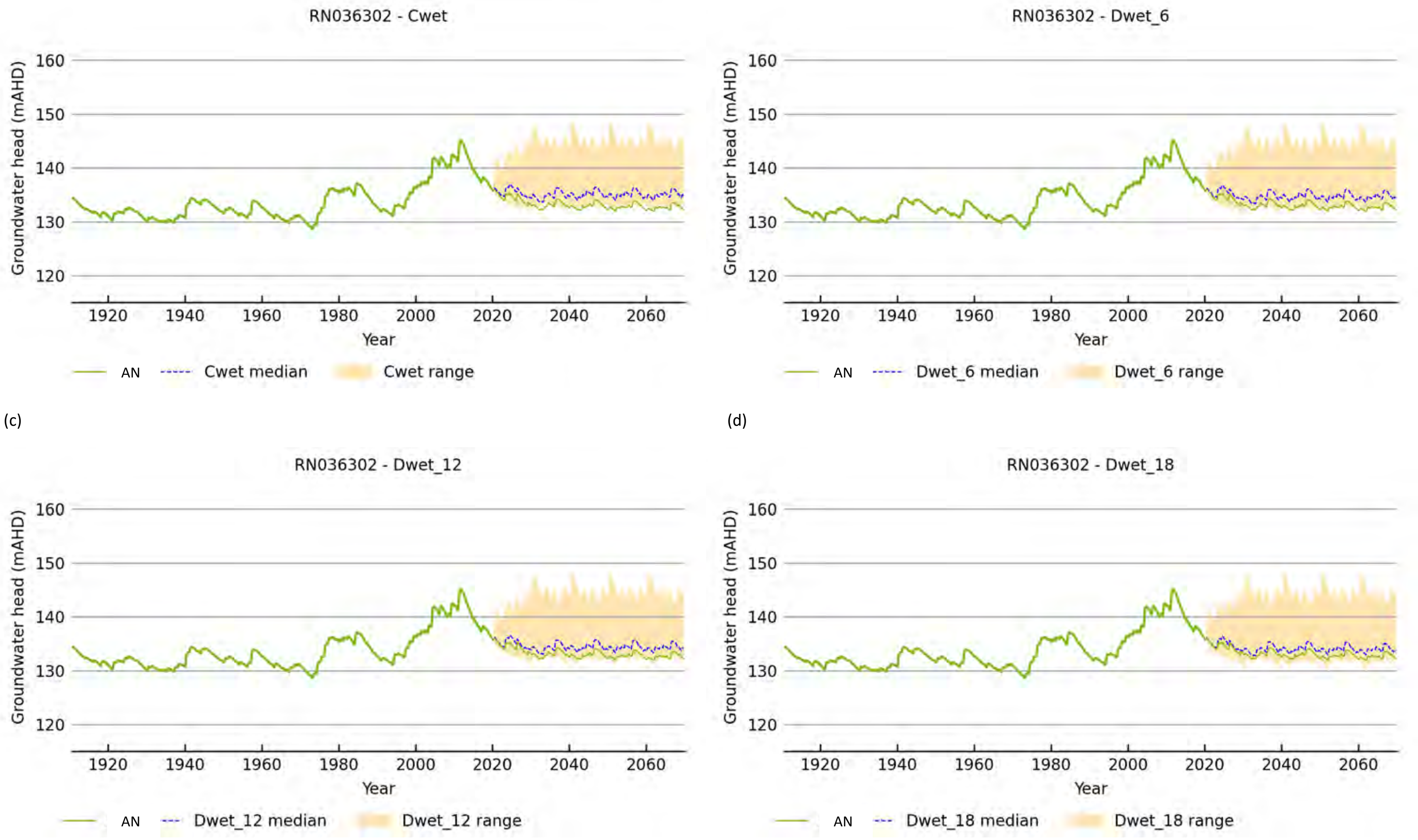


Figure 7-47 Hydrographs of groundwater level at reporting site RN036302 under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18

7.4.3 Scenarios C and D – 2069 groundwater drawdown contours

The drawdown contours at 31/8/2069 relative to Scenario AN assuming dry climate sequence under scenarios C and D are shown in Figure 7-48. The drawdown contours at 31/8/2069 relative to Scenario AN assuming mid climate sequences under scenarios C and D are shown in Figure 7-49. The drawdown contours at 31/8/2069 relative to Scenario AN assuming wet climate sequences under scenarios C and D are shown in Figure 7-50.

The drawdown contours under scenarios Cdry, Ddry6, Ddry12 and Ddry18 relative to Scenario AN are shown in Figure 7-48a, Figure 7-48b, Figure 7-48c, and Figure 7-48d, respectively. Under Scenario Cdry, the maximum drawdown is in the north-east of the model domain as a result of a reduction in recharge under the dry future climate relative to the historical climate of Scenario AN. The Ddry6 contours show a median drawdown of greater than 5 m in response to the additional extraction in the north of the model domain. The Ddry12 contours show a maximum drawdown of greater than 10 m, and the Ddry18 Scenario shows a much larger area with drawdown exceeding 10 m.

The drawdown contours under Scenarios Cmid, Dmid6, Dmid12 and Dmid18 relative to Scenario AN are shown in Figure 7-49a , Figure 7-49b, Figure 7-49c, and Figure 7-49d, respectively. The maximum drawdown under Scenario Cmid is less than under Cdry with a maximum drawdown of greater than 2 m in the north-east of the model domain. The Dmid6 contours show greater drawdown than the Cmid due to the extra extraction occurring; Dmid has a larger area showing a maximum drawdown greater than 2 m. The Dmid12 contours show a maximum drawdown of greater than 5 m in the across the aquifer around the hypothetical extraction bores, and the Dmid18 contours show a larger area with drawdown greater than 5 m.

The drawdown contours under Scenarios Cwet, Dwet6, Dwet12 and Dwet18 relative to Scenario AN are shown in Figure 7-50a, Figure 7-50b, Figure 7-50c, and Figure 7-50d, respectively. The wet climate sequences show an increase in groundwater level with a maximum of greater than 5 m in each wet climate scenario.

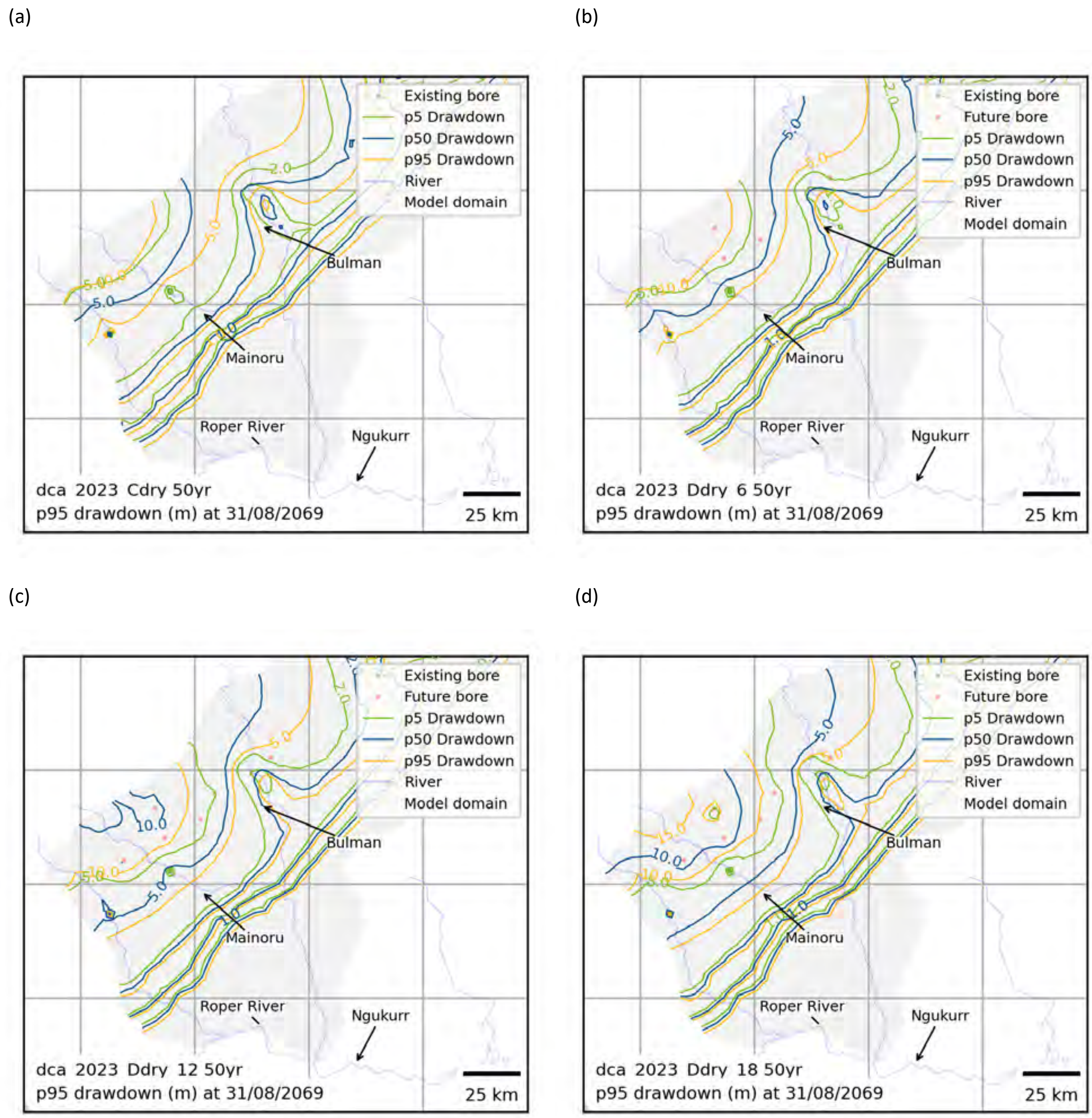


Figure 7-48 Drawdown contours relative to Scenario AN under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18 at the end of the 11 × 50-year climate sequences

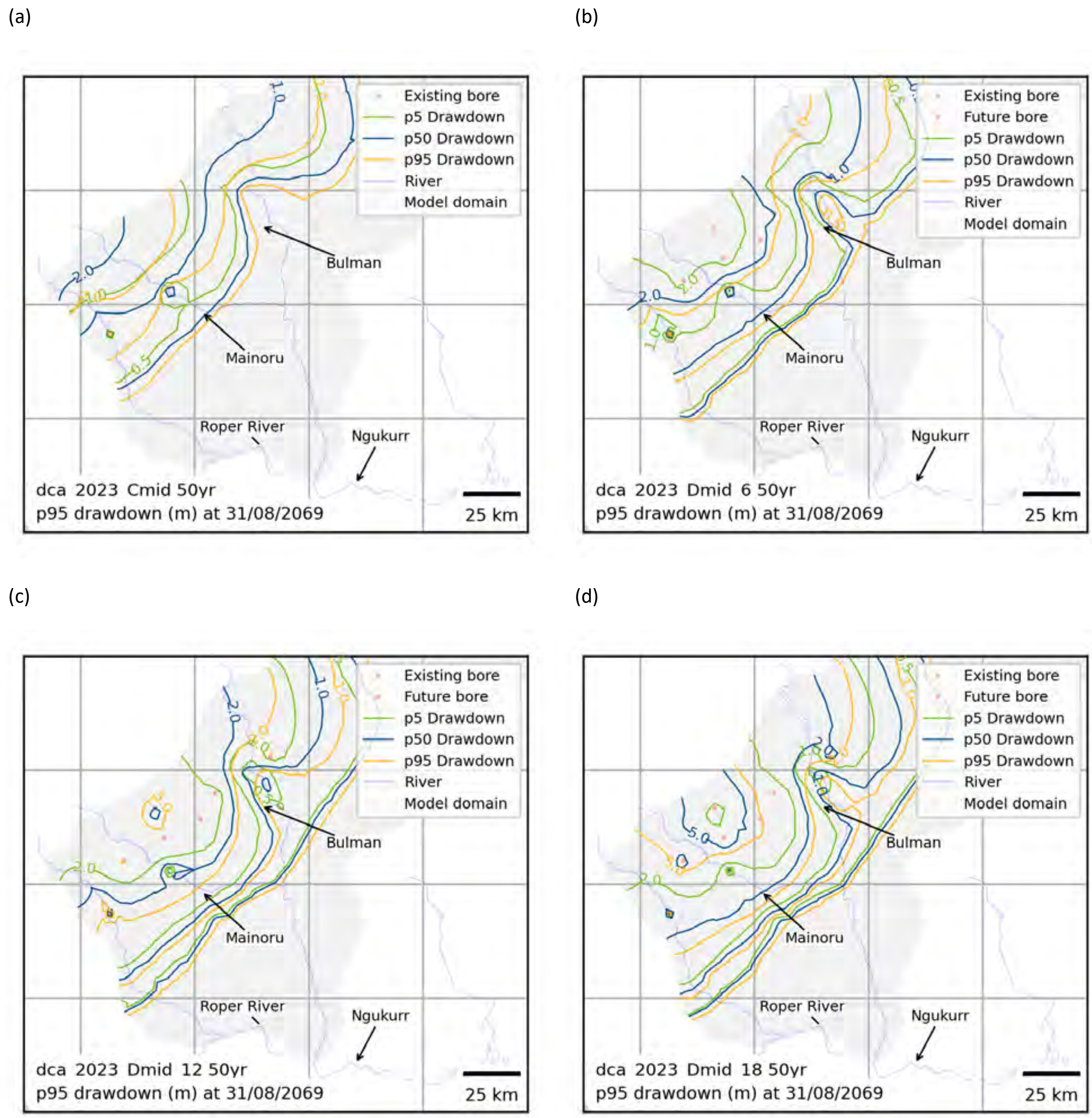


Figure 7-49 Drawdown contours relative to Scenario AN under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18 at the end of the 11 × 50-year climate sequences

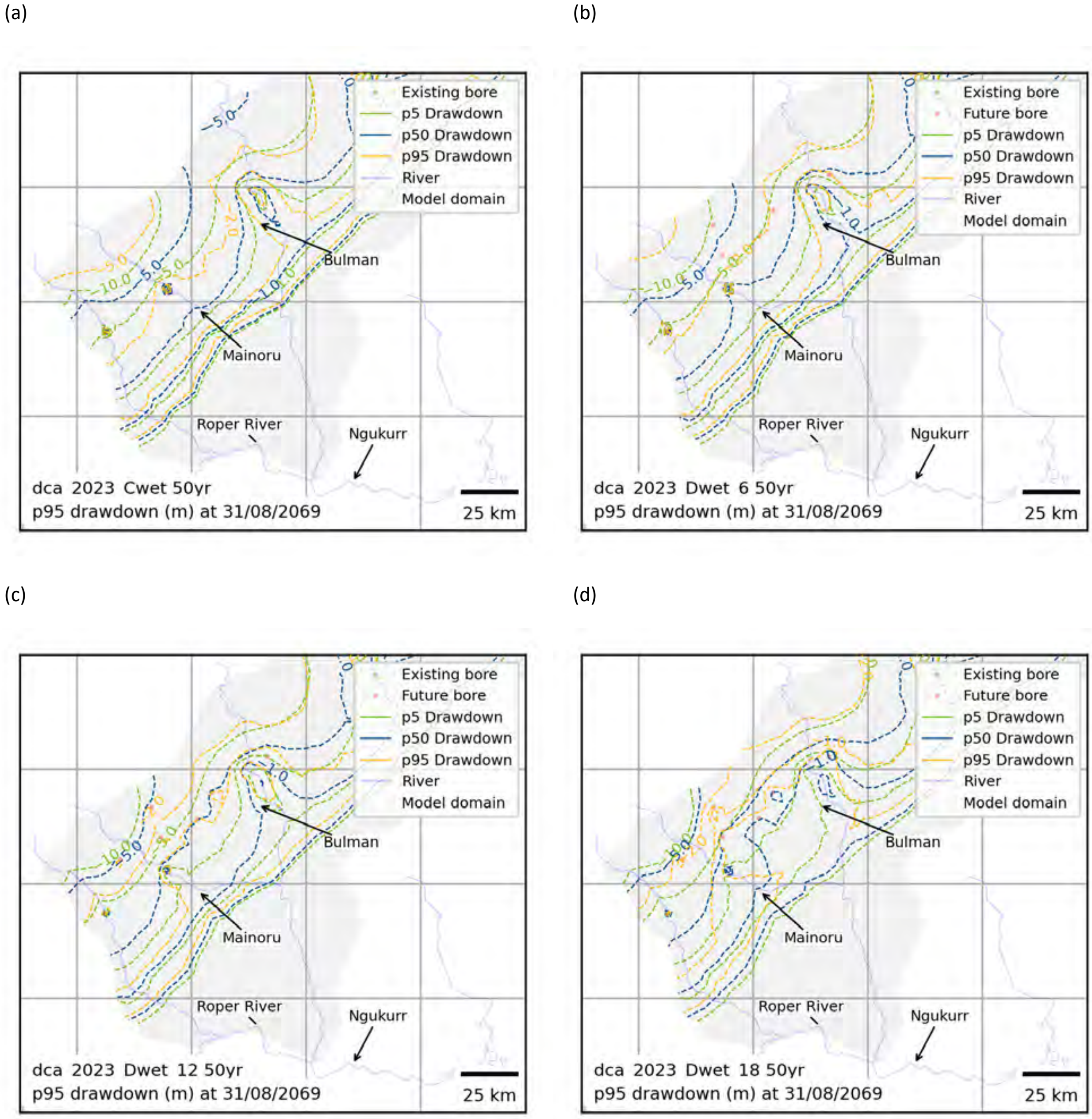


Figure 7-50 Drawdown contours relative to Scenario AN under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18 at the end of the 11 × 50-year climate sequences

Dashed lines indicate contours with negative values (i.e. groundwater-level rises relative to Scenario AN).

7.4.4 Scenarios C and D – groundwater discharge

The mean groundwater discharge for the last 10-year period (2059 to 2069) of each 50-year climate sequence at Wilton River (G9030003) and Flying Fox Creek (G9030108) are presented in Table 7-16. For the C scenarios this shows that there is a wide range of responses to the future climates. Relative to Scenario AN, Scenario Cdry shows changes of −22 and −45% at the Wilton River and Flying Fox Creek, respectively. At the other extreme, Scenario Cwet shows changes of +22 and +54%, respectively. The D scenarios all show a less discharge than their corresponding C scenario, but Scenario Dwet still shows an increase in discharge relative to Scenario AN.

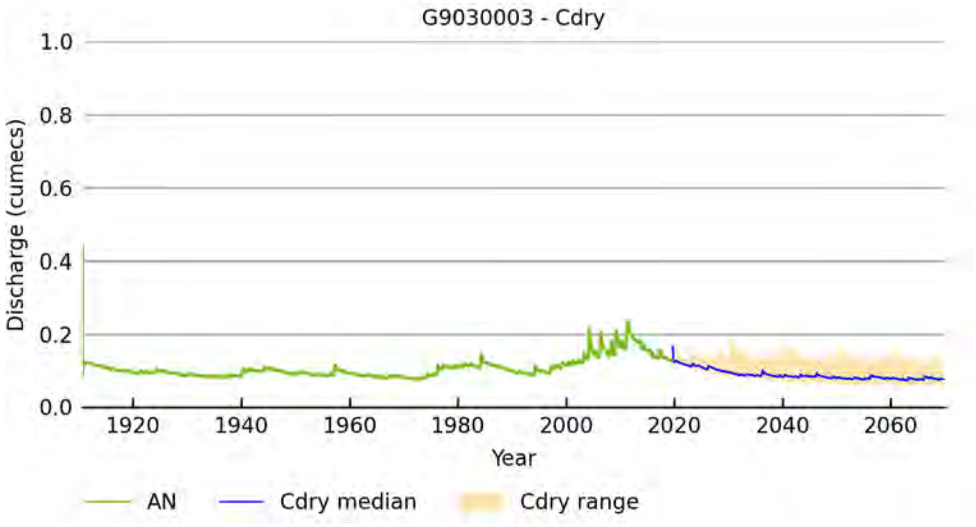
Table 7-16 Mean groundwater discharge for the last 10-year period (2059 to 2069) under scenarios C and D at Wilton River (G9030003) and Flying Fox Creek (G9030108)

SCENARIO	G9030003 GROUNDWATER DISCHARGE (m^3/s)	G9030003 % CHANGE FROM AN	G9030108 GROUNDWATER DISCHARGE (m^3/s)	G9030108 % CHANGE FROM AN
AN	0.11	na†	0.63	na
Cdry	0.08	−22	0.35	−45
Cmid	0.10	−6	0.56	−12
Cwet	0.13	+22	0.98	+54
Ddry6	0.08	−26	0.33	−48
Ddry12	0.08	−30	0.31	−51
Ddry18	0.07	−34	0.29	−54
Dmid6	0.10	−9	0.53	−16
Dmid12	0.09	−13	0.51	−19
Dmid18	0.09	−17	0.49	−23
Dwet6	0.13	+19	0.96	+51
Dwet12	0.13	+16	0.94	+48
Dwet18	0.12	+13	0.92	+45

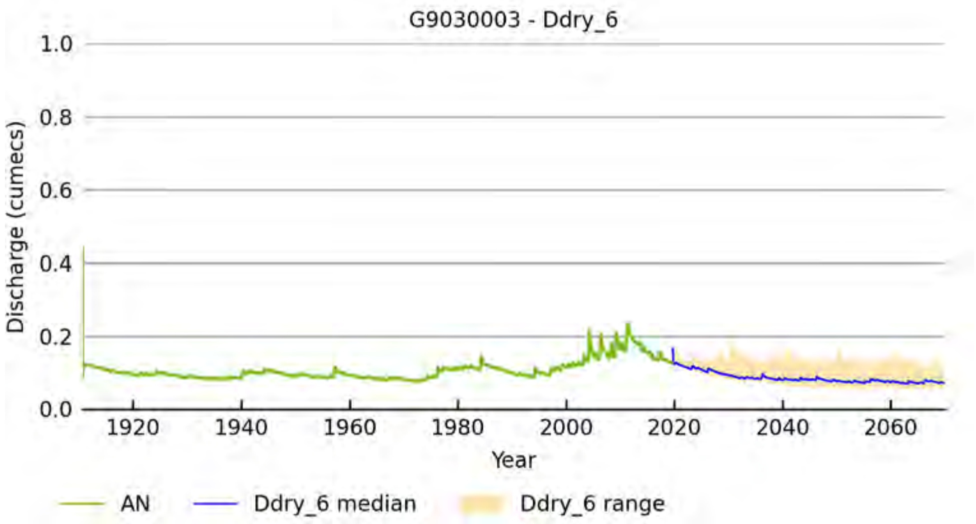
AN = Historical climate and no development; Cdry = Future dry climate sequences current development; Cmid = Future mid climate sequences current development; Cwet = Future wet climate sequences current development; Ddry6 = Future dry climate sequences current development and future development of 6 GL/year; Ddry12 = Future dry climate sequences current development and future development of 12 GL/year; Ddry18 = Future dry climate sequences current development and future development of 18 GL/year; Dmid6 = Future mid climate sequences current development and future development of 6 GL/year; Dmid12 = Future mid climate sequences current development and future development of 12 GL/year; Dmid18 = Future mid climate sequences current development and future development of 18 GL/year); Dwet6 = Future wet climate sequences current development and future development of 6 GL/year; Dwet12 = Future wet climate sequences current development and future development of 12 GL/year; Dwet18 = Future wet climate sequences current development and future development of 18 GL/year.
†na = not applicable.

The groundwater discharge hydrographs for the dry, mid and wet climate sequences at Wilton River (G9030003) are presented in Figure 7-51, Figure 7-52, and Figure 7-53, respectively, and at Flying Fox Creek (G9030108) in Figure 7-54, Figure 7-55, and Figure 7-56, respectively.

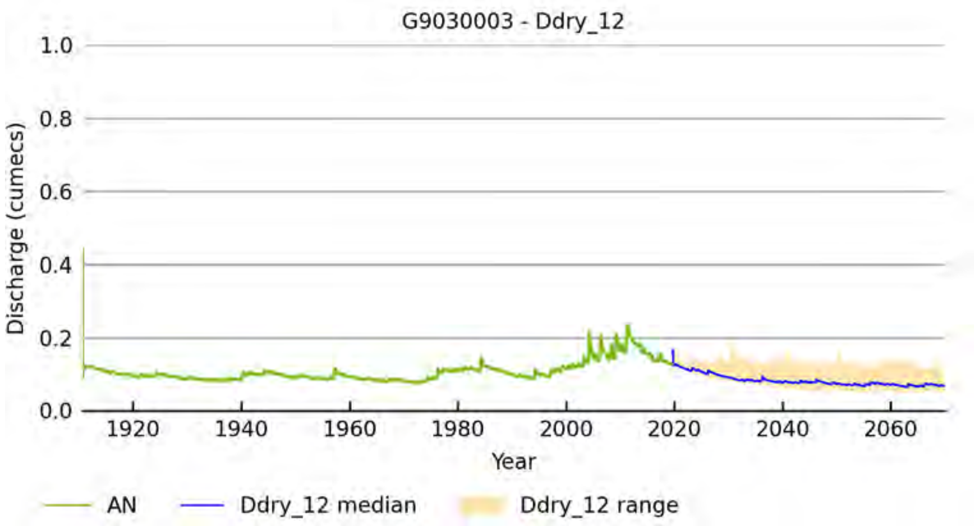
(a)


G9030003 - Cdry
Discharge (cumecs)
1.0
0.8
0.6
0.4
0.2
0.0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Cdry median
Cdry range

(b)


G9030003 - Ddry_6
Discharge (cumecs)
1.0
0.8
0.6
0.4
0.2
0.0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Ddry_6 median
Ddry_6 range

(c)


G9030003 - Ddry_12
Discharge (cumecs)
1.0
0.8
0.6
0.4
0.2
0.0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Ddry_12 median
Ddry_12 range

(d)

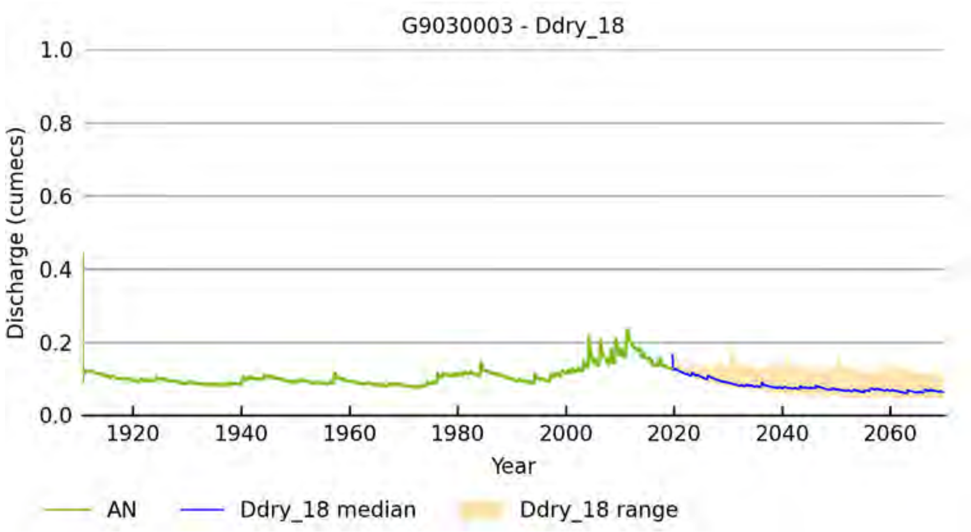
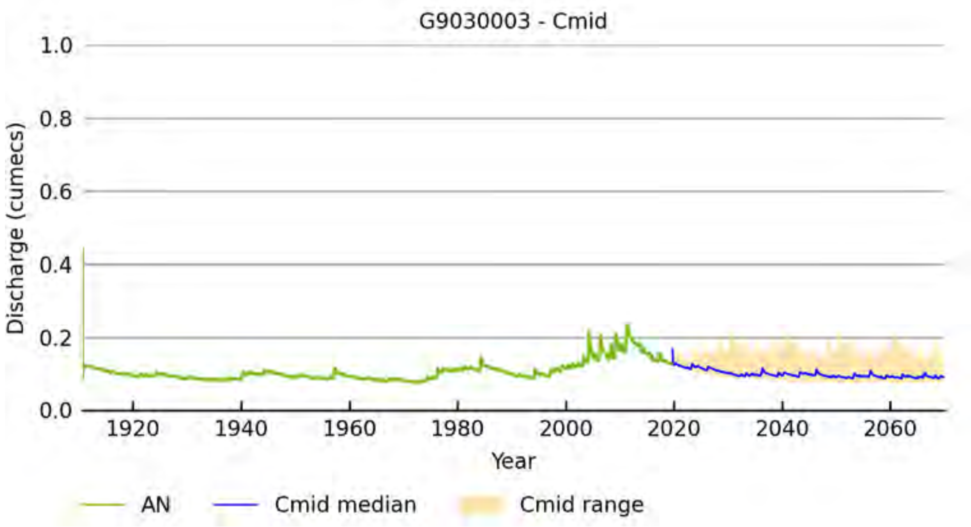
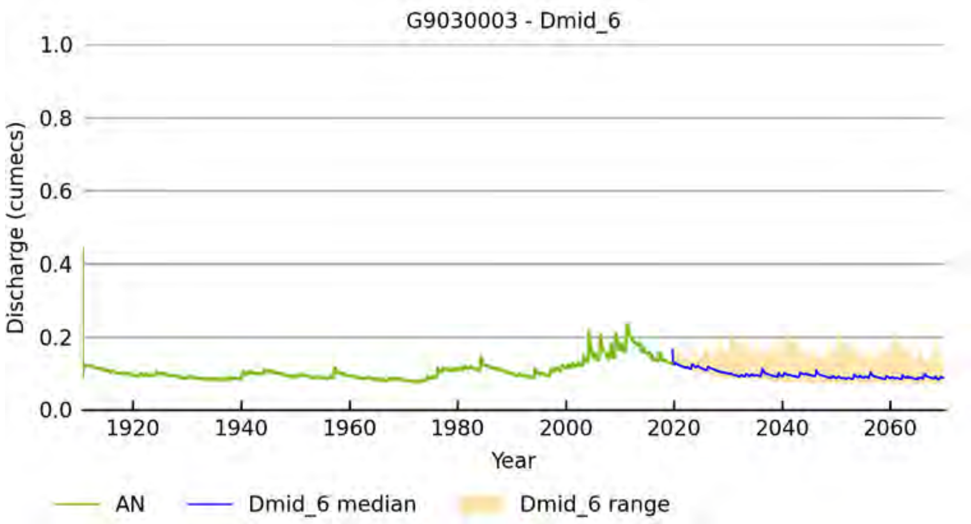


Figure 7-51 Hydrographs of groundwater discharge (m³/second) at gauging station G9030003 under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18

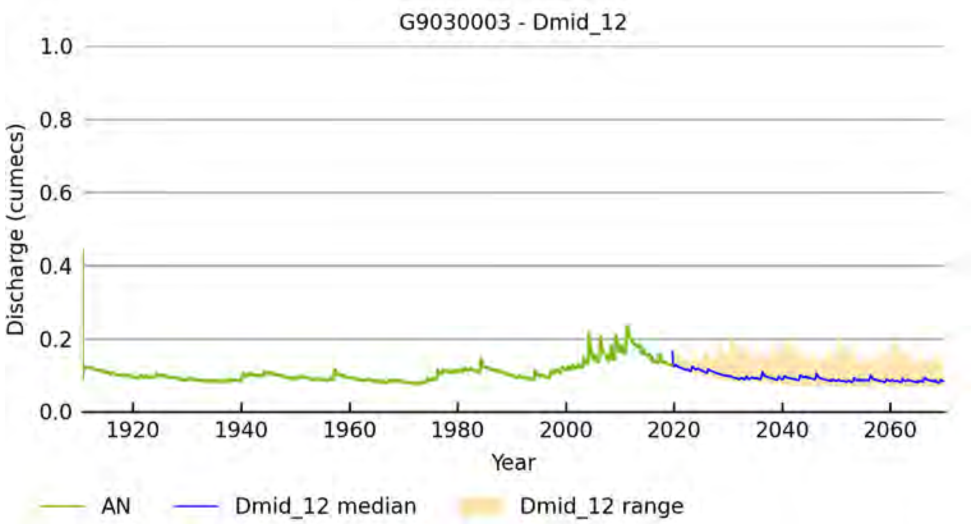
(a)


G9030003 - Cmid
Discharge (cumecs)
1.0
0.8
0.6
0.4
0.2
0.0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Cmid median
Cmid range

(b)


G9030003 - Dmid_6
Discharge (cumecs)
1.0
0.8
0.6
0.4
0.2
0.0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Dmid_6 median
Dmid_6 range

(c)


G9030003 - Dmid_12
Discharge (cumecs)
1.0
0.8
0.6
0.4
0.2
0.0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Dmid_12 median
Dmid_12 range

(d)

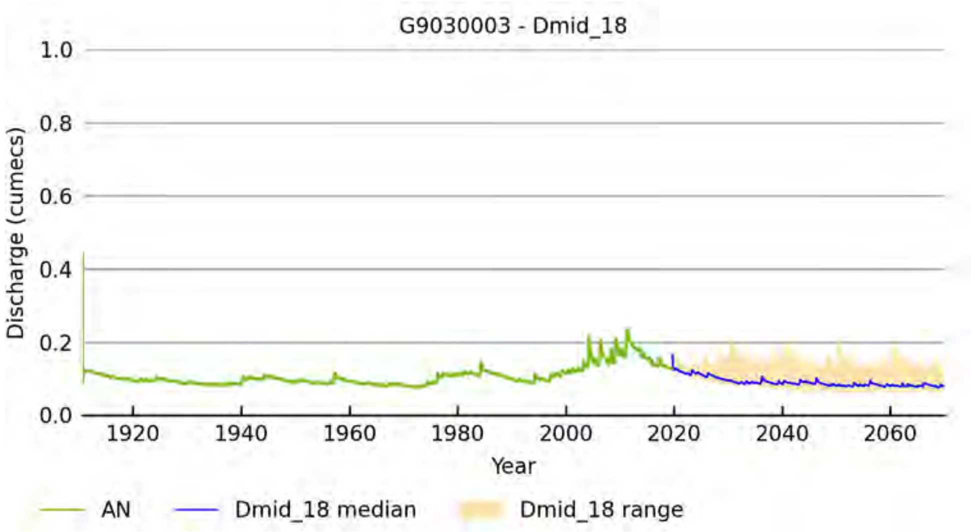
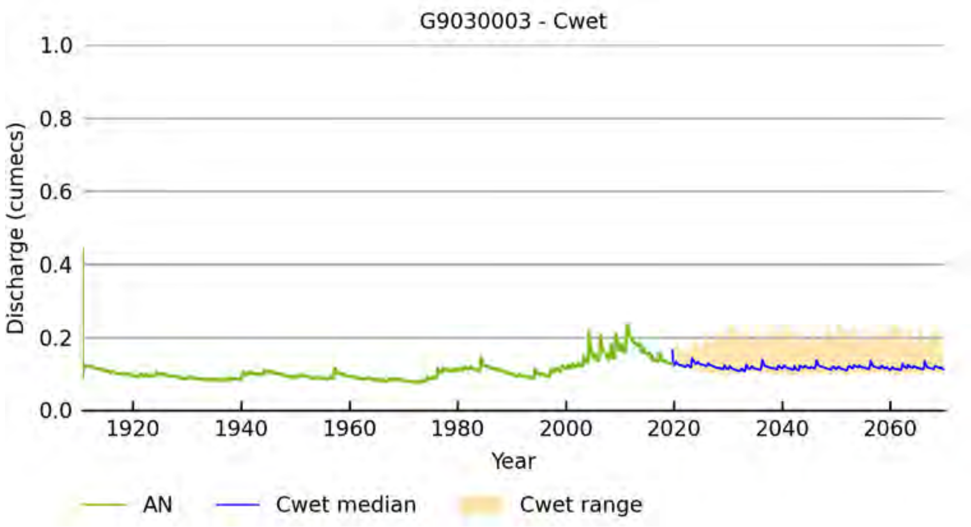
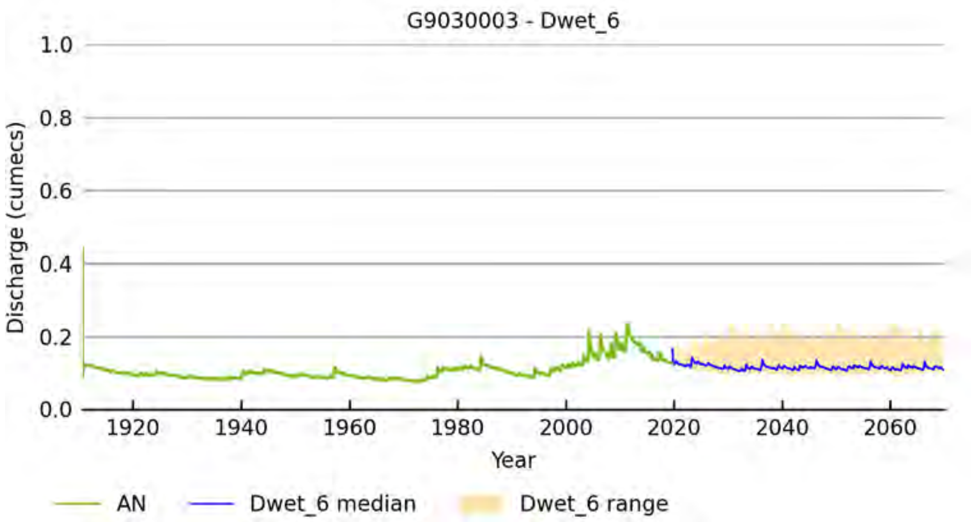


Figure 7-52 Hydrographs of groundwater discharge (m³/second) at gauging station G9030003 under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

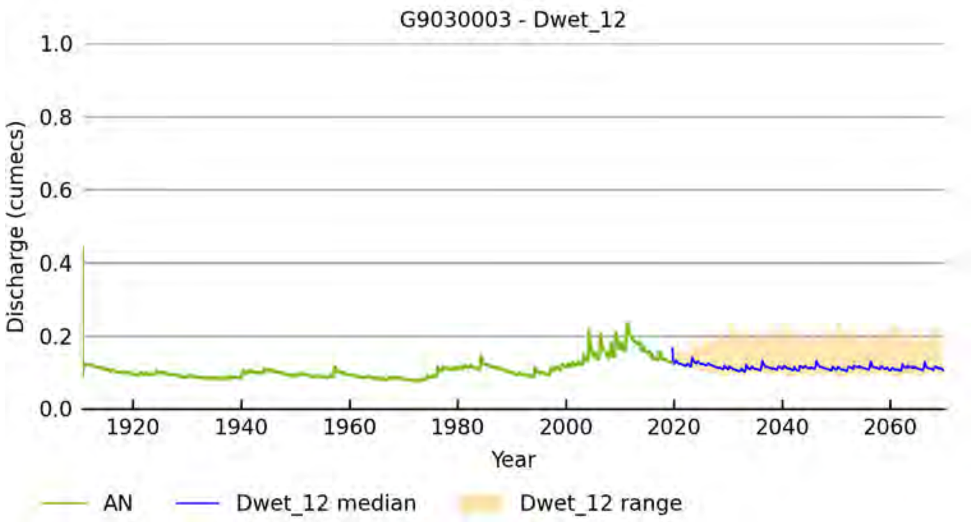
(a)


G9030003 - Cwet
1.0
0.8
0.6
0.4
0.2
0.0
Discharge (cumecs)
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Cwet median
Cwet range

(b)


G9030003 - Dwet_6
1.0
0.8
0.6
0.4
0.2
0.0
Discharge (cumecs)
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Dwet_6 median
Dwet_6 range

(c)


G9030003 - Dwet_12
1.0
0.8
0.6
0.4
0.2
0.0
Discharge (cumecs)
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Dwet_12 median
Dwet_12 range

(d)

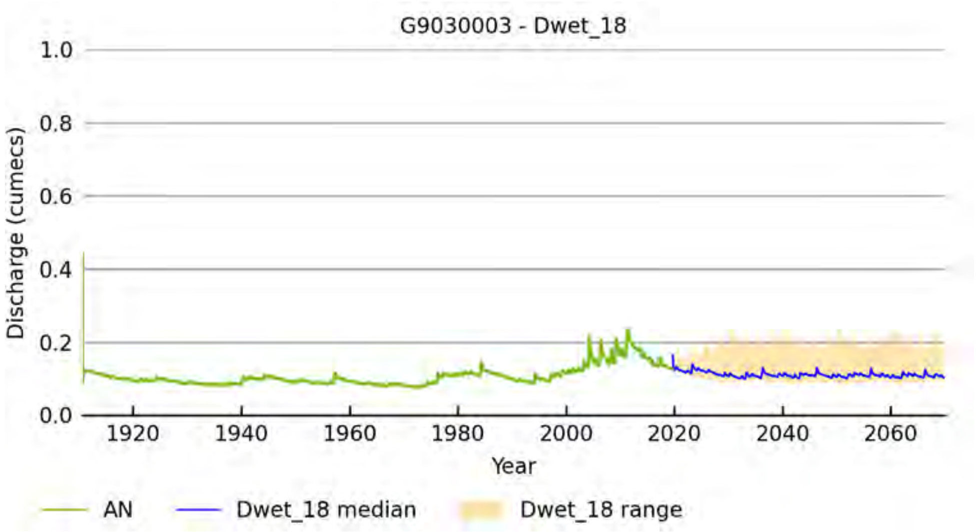
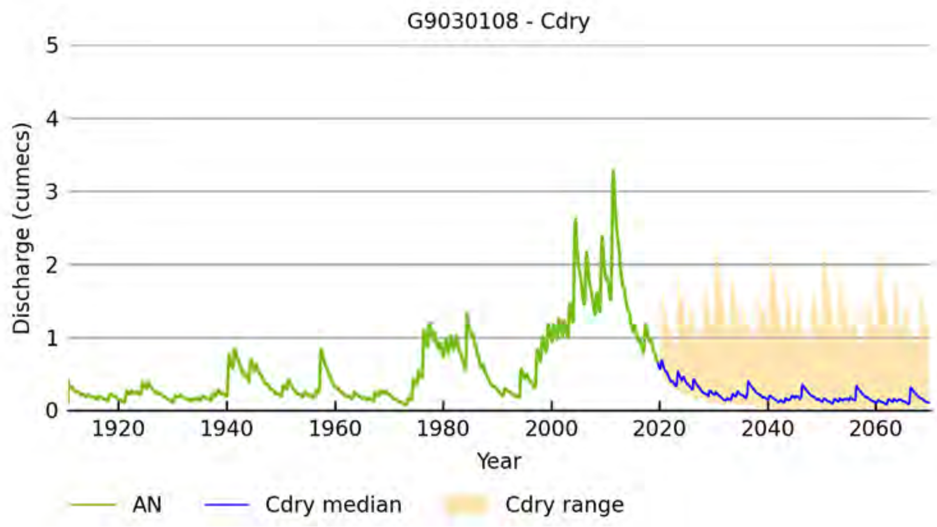


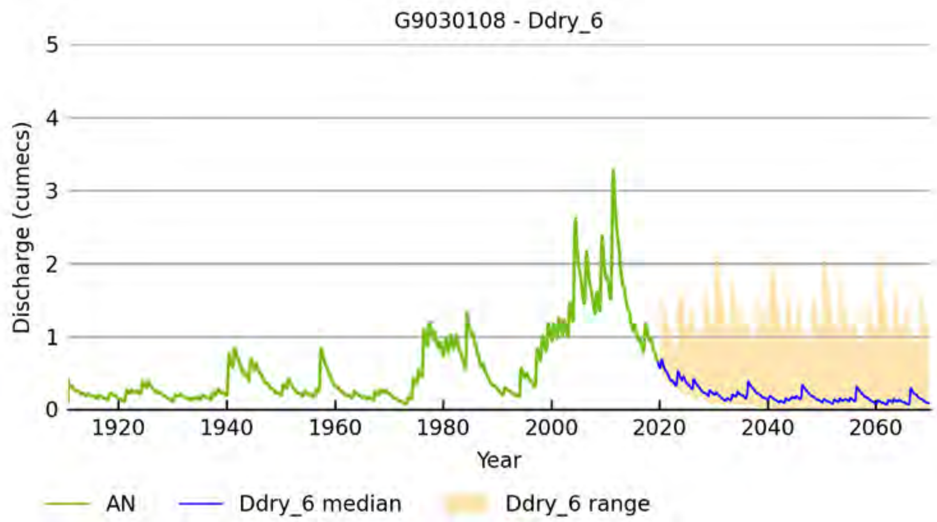
Figure 7-53 Hydrographs of groundwater discharge (m³/second) at gauging station G9030003 under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18

(a)



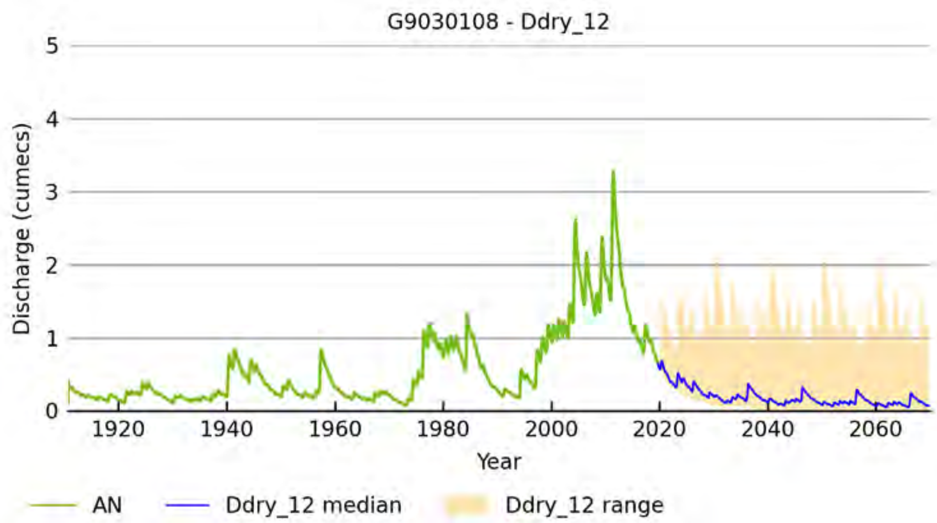
G9030108 - Cdry
Discharge (cumecs)
5
4
3
2
1
0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Cdry median
Cdry range

(b)



G9030108 - Ddry_6
Discharge (cumecs)
5
4
3
2
1
0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Ddry_6 median
Ddry_6 range

(c)



G9030108 - Ddry_12
Discharge (cumecs)
5
4
3
2
1
0
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Ddry_12 median
Ddry_12 range

(d)

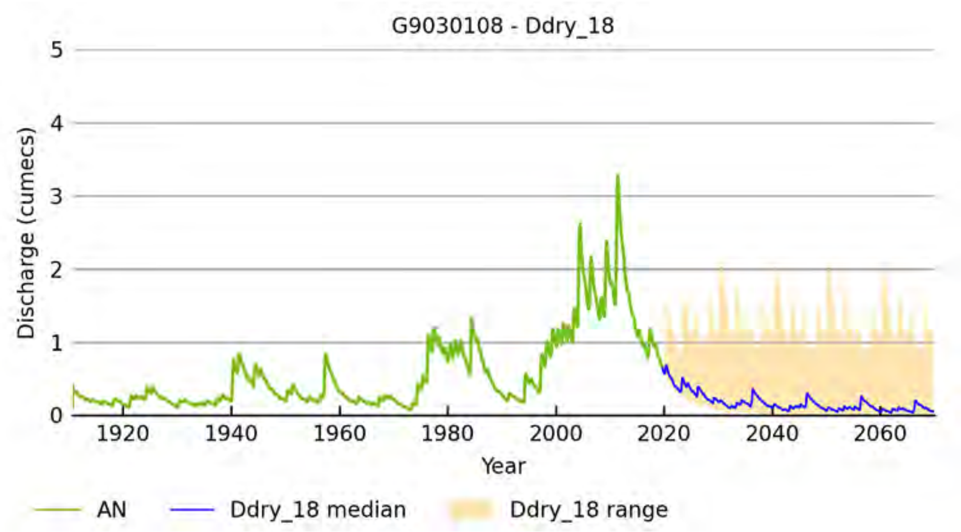
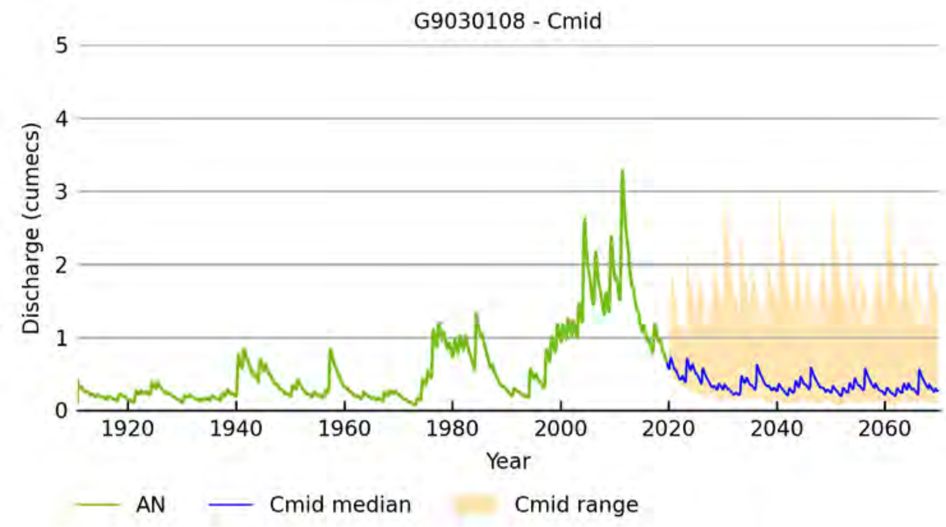


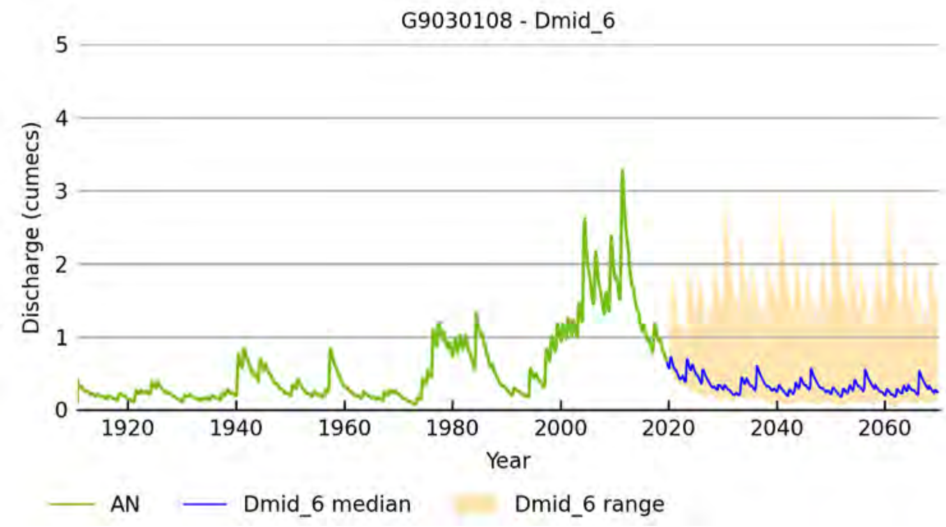
Figure 7-54 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030003 under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18

(a)



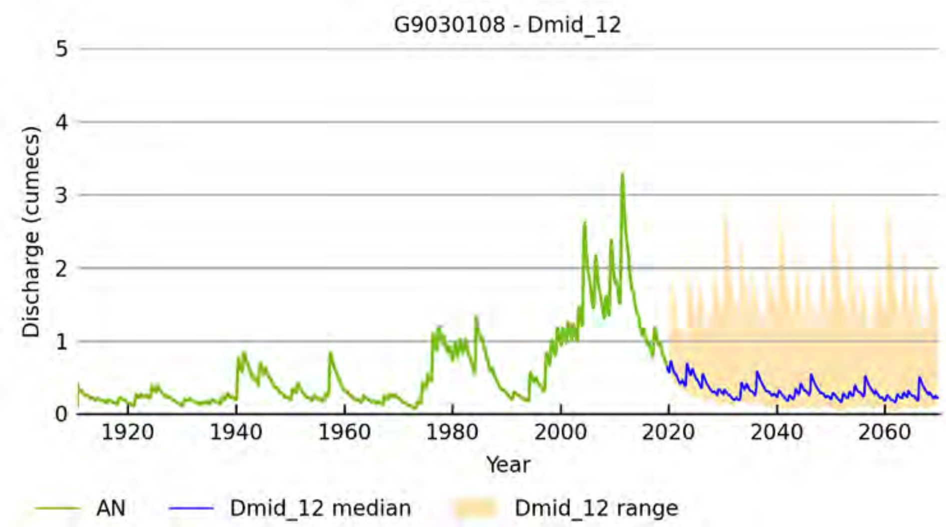
G9030108 - Cmid
5
4
3
2
1
0
Discharge (cumecs)
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Cmid median
Cmid range

(b)



G9030108 - Dmid_6
5
4
3
2
1
0
Discharge (cumecs)
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Dmid_6 median
Dmid_6 range

(c)



G9030108 - Dmid_12
5
4
3
2
1
0
Discharge (cumecs)
1920
1940
1960
1980
2000
2020
2040
2060
Year
AN
Dmid_12 median
Dmid_12 range

(d)

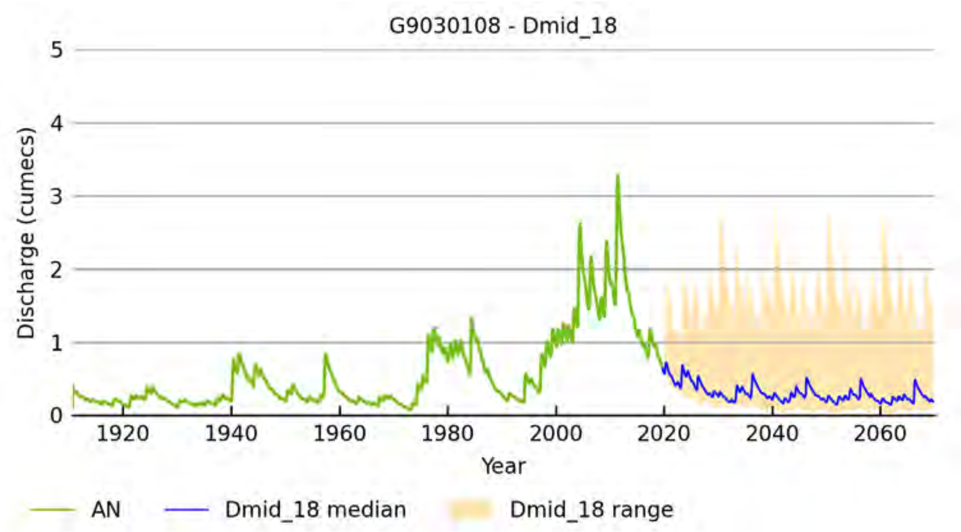
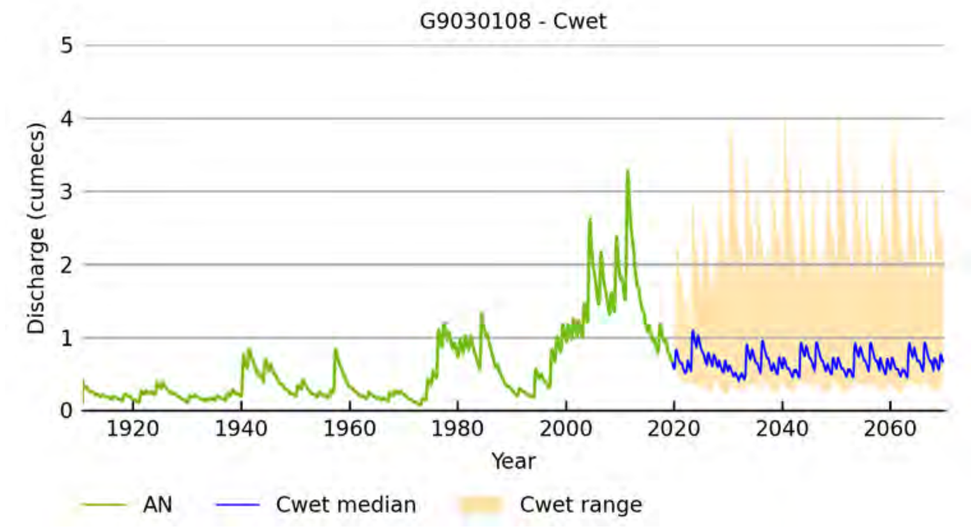
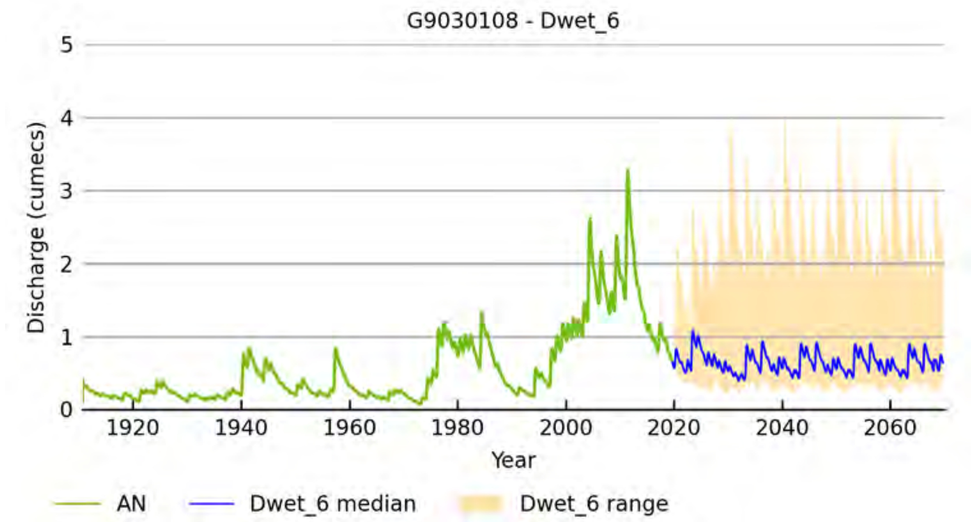


Figure 7-55 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030003 under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

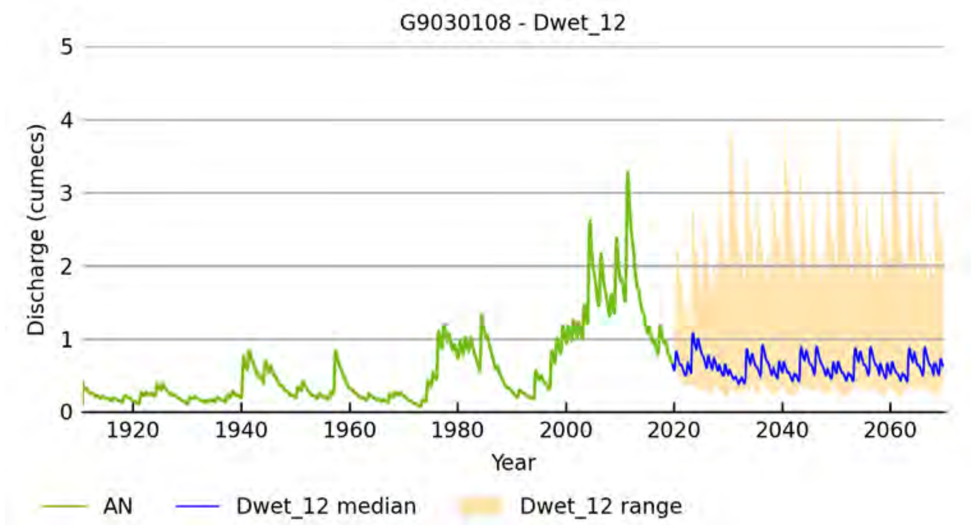
(a)


G9030108 - Cwet
Discharge (cumecs)
Year
AN
Cwet median
Cwet range

(b)


G9030108 - Dwet_6
Discharge (cumecs)
Year
AN
Dwet_6 median
Dwet_6 range

(c)


G9030108 - Dwet_12
Discharge (cumecs)
Year
AN
Dwet_12 median
Dwet_12 range

(d)

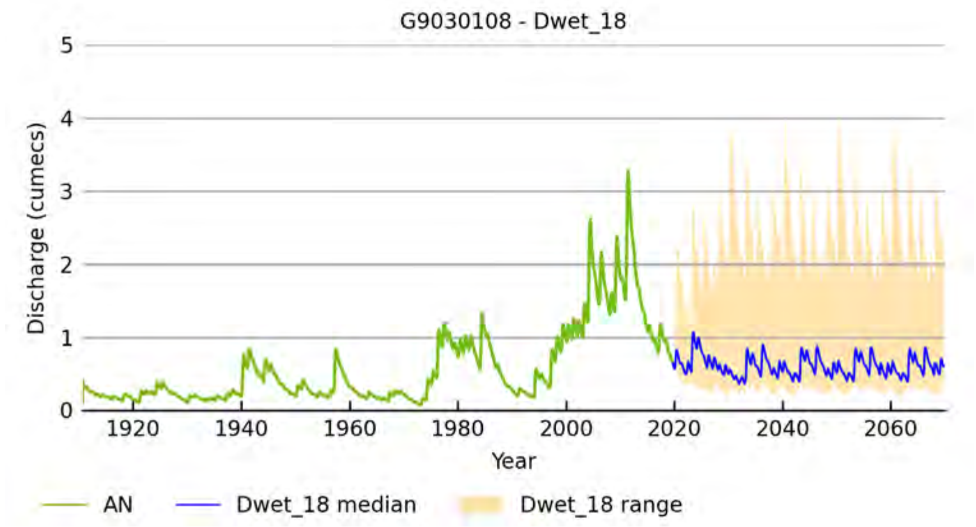


Figure 7-56 Hydrographs of groundwater discharge (m^3/second) at gauging station G9030108 under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18

The percentage decrease in discharge using the dry, mid, and wet climate sequences under scenarios C and D at Wilton River (G9030003) are presented in Figure 7-57, Figure 7-58, and Figure 7-52, respectively, and at Flying Fox Creek (G9030108) in Figure 7-60, Figure 7-61, and Figure 7-62, respectively.

The decrease in discharge relative to Scenario AN at the two sites has been determined by comparing the results to the C and D pumped scenarios. Scenario Ddry18 shows the greatest decrease in the median groundwater discharge. At G9030003, the decrease in discharge has a median of −34%. At G9030108, the decrease has a median of −54%.

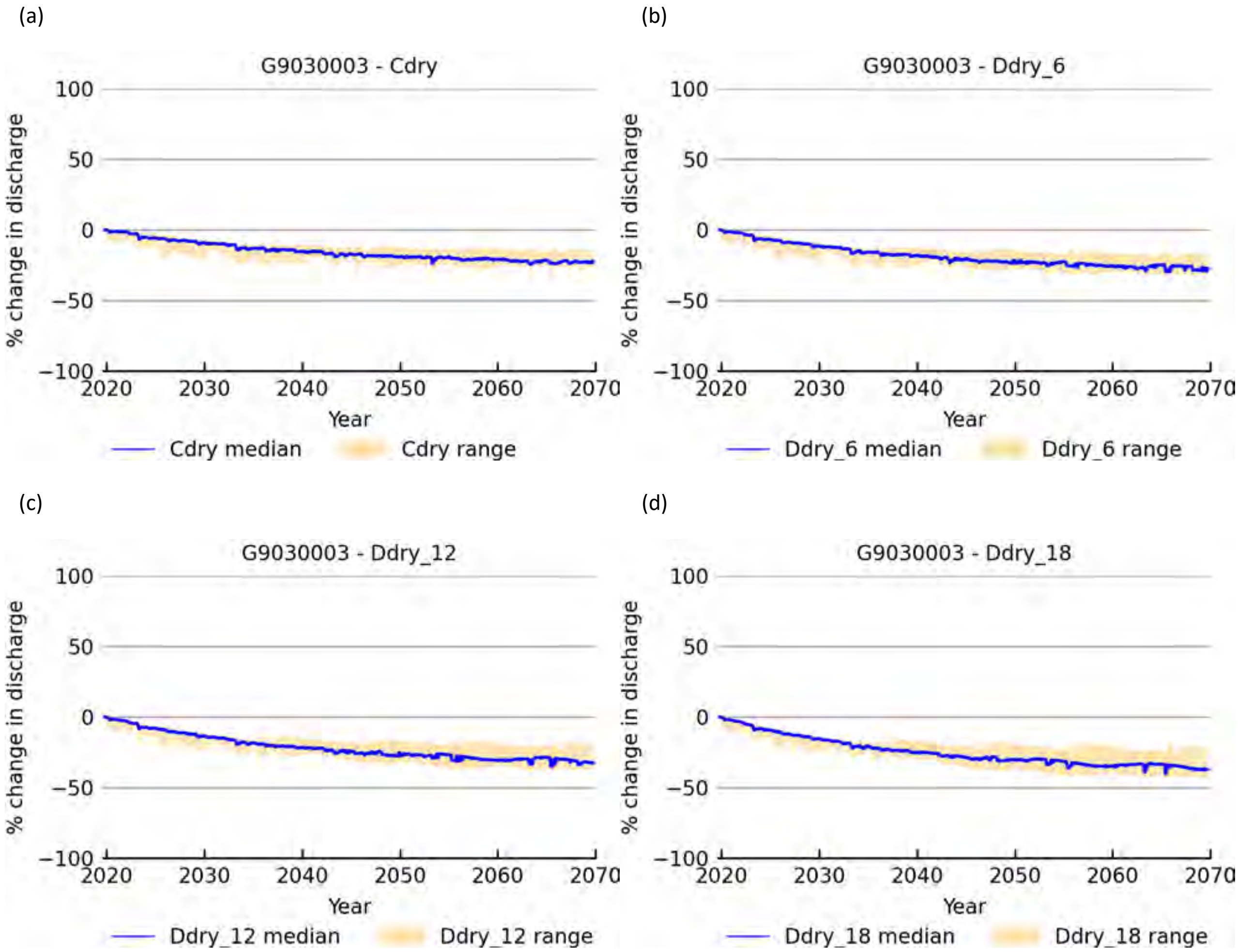


Figure 7-57 Percentage change in groundwater discharge relative to Scenario AN at G9030003 under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18

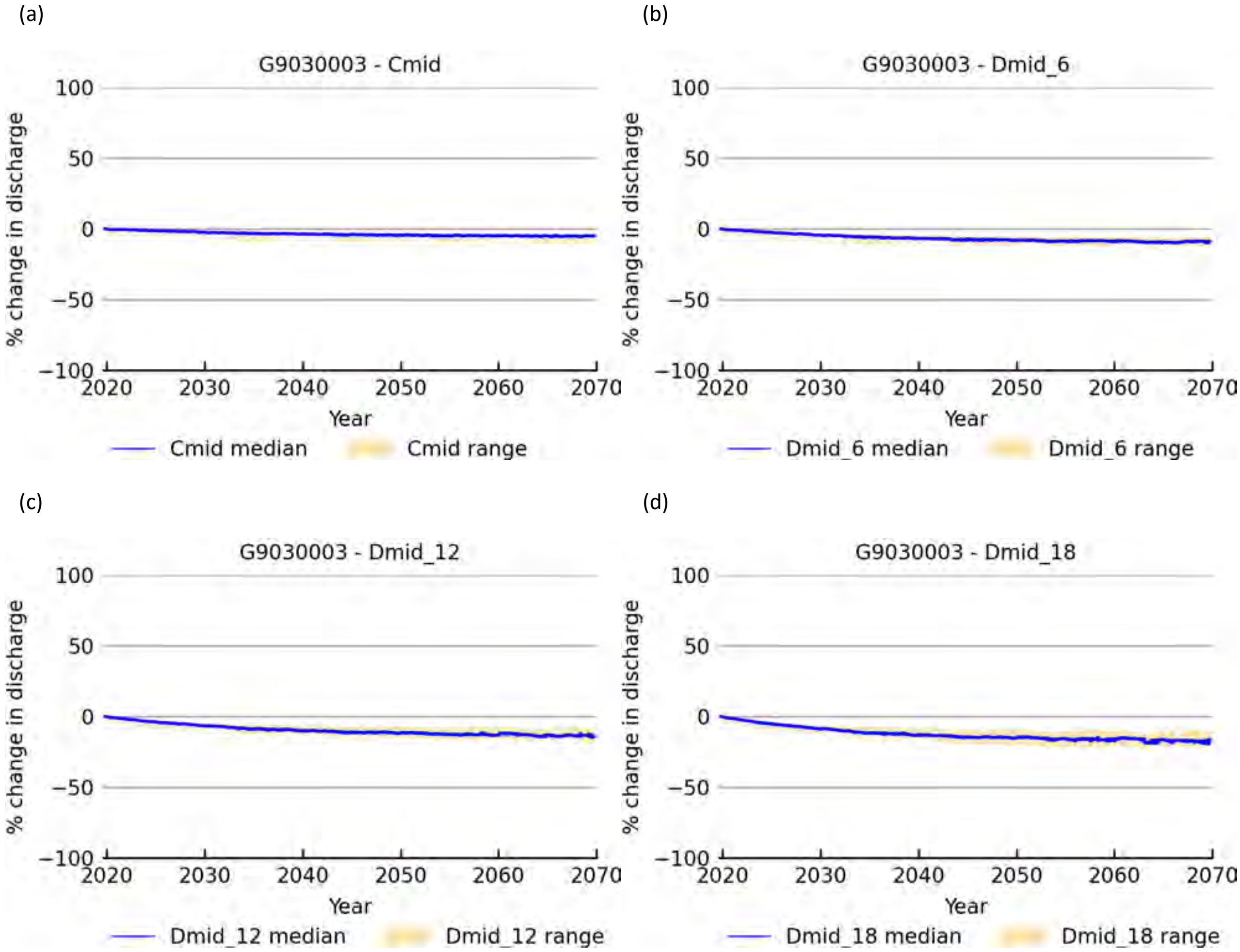


Figure 7-58 Percentage change in groundwater discharge relative to Scenario AN at G9030003 under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

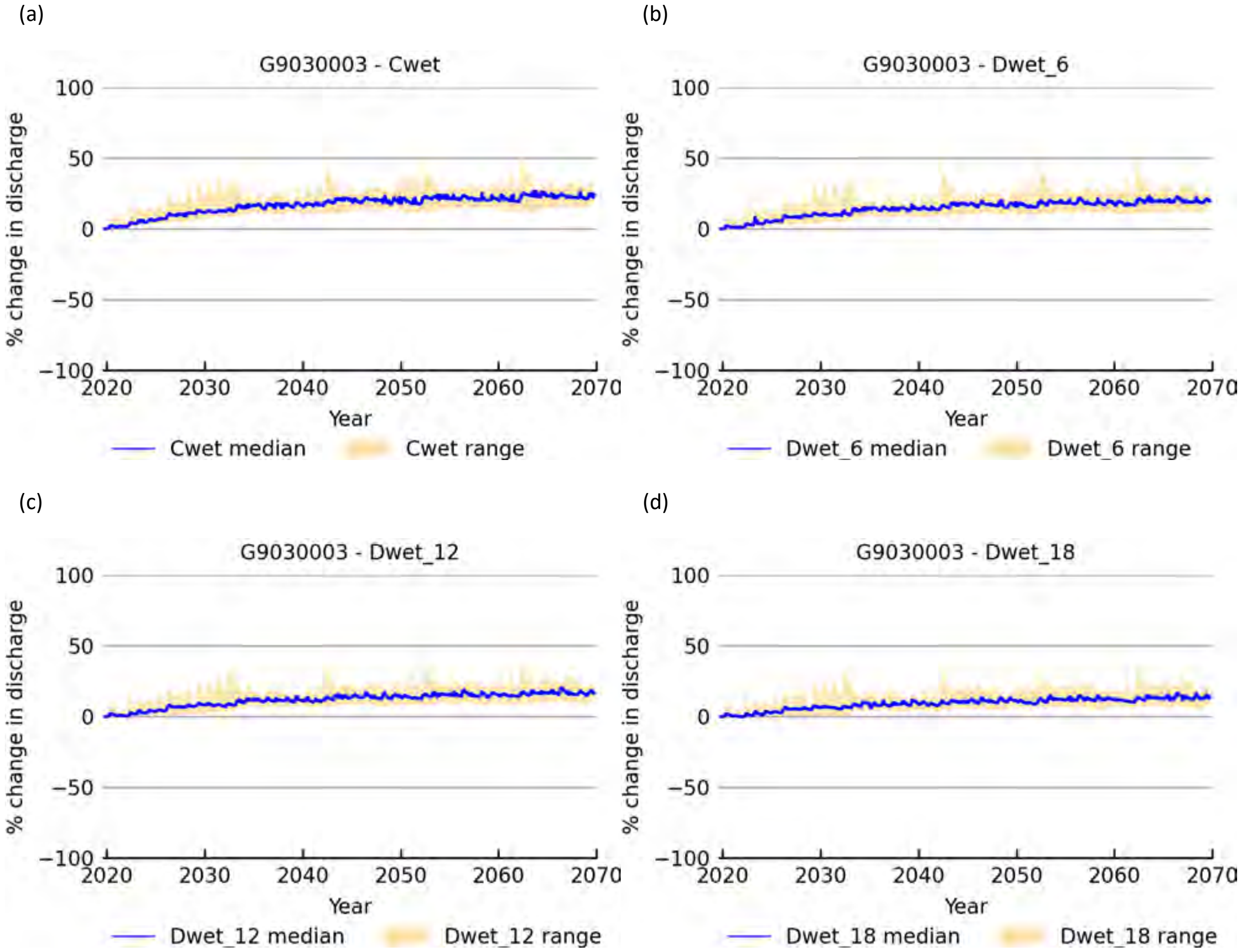


Figure 7-59 Percentage change in groundwater discharge relative to Scenario AN at G9030108 under scenarios (a) Cwet, (b) Dwet 6, (c) Dwet 12 and (d) Dwet 18

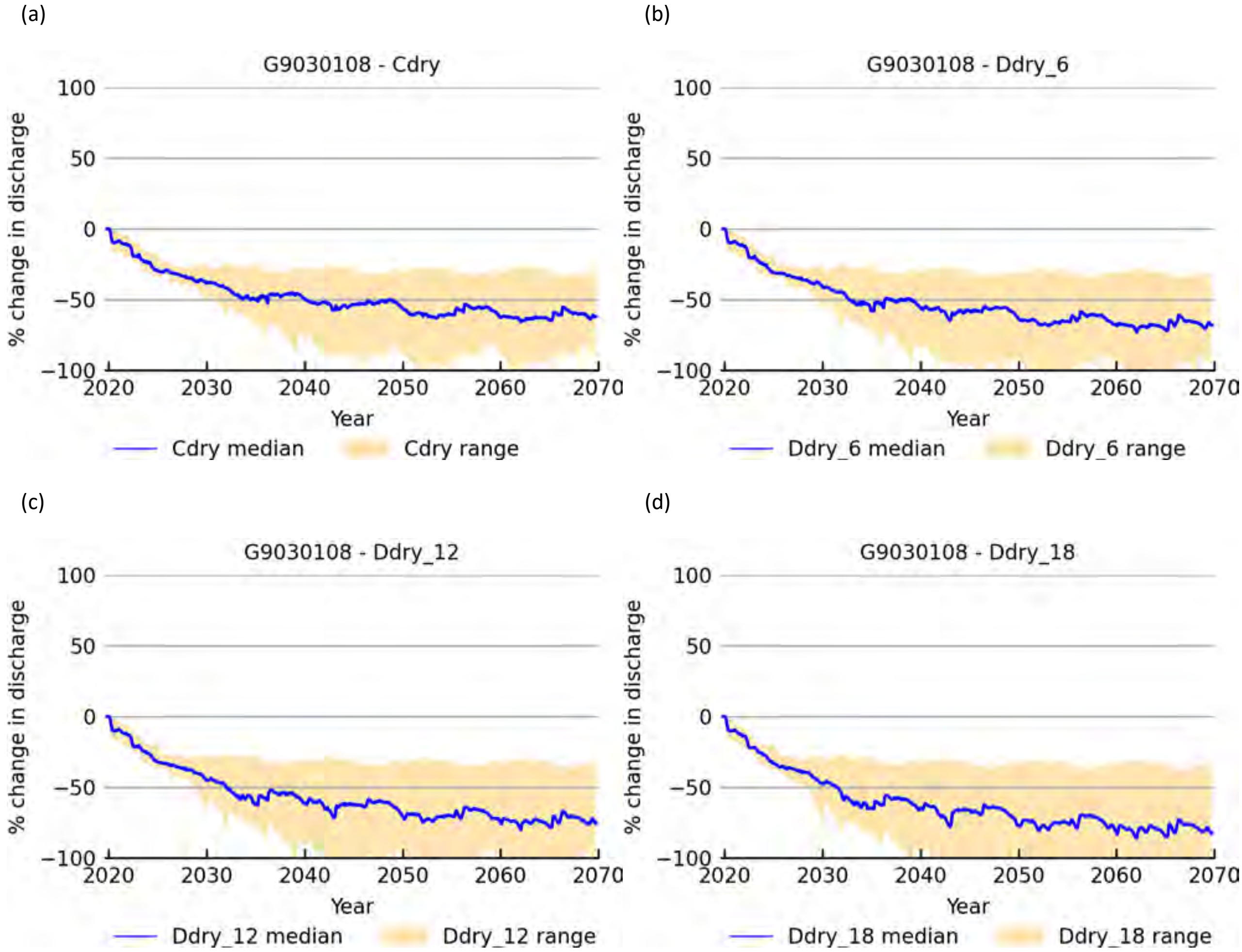


Figure 7-60 Percentage change in groundwater discharge relative to Scenario AN at G9030108 under scenarios (a) Cdry, (b) Ddry6, (c) Ddry12 and (d) Ddry18

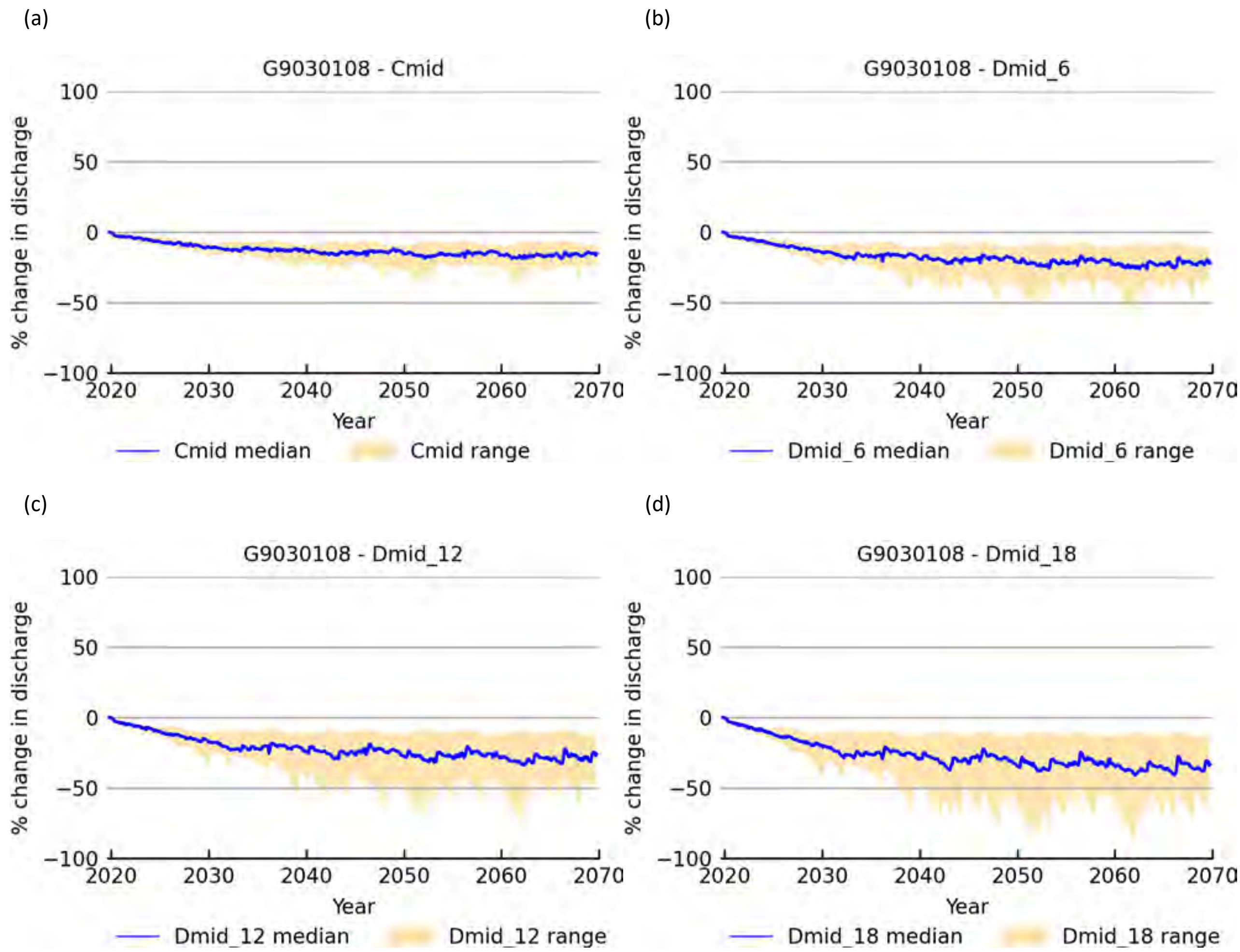


Figure 7-61 Percentage change in groundwater discharge relative to Scenario AN at G9030003 under scenarios (a) Cmid, (b) Dmid6, (c) Dmid12 and (d) Dmid18

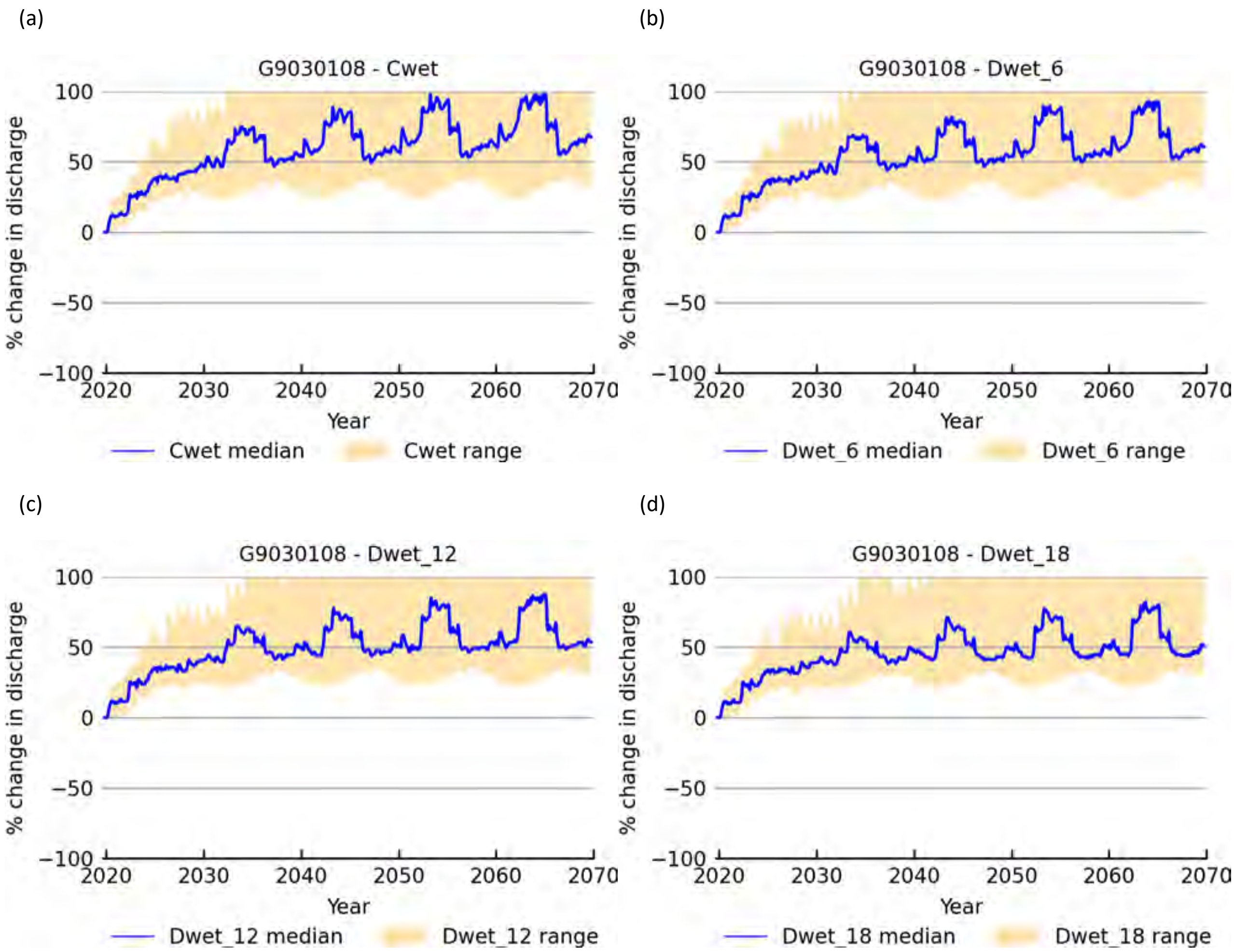


Figure 7-62 Percentage change in groundwater discharge relative to Scenario AN at G9030108 under scenarios (a) Cwet, (b) Dwet6, (c) Dwet12 and (d) Dwet18

8 Discussion

8.1 Comparison between quasi-equilibrium and projected 2059 to 2069 scenarios for the Cambrian Limestone Aquifer

The effects on the availability of groundwater for the CLA under the quasi-equilibrium results are generally much greater than under the projected 2059 to 2069 scenarios. For example, annual discharge volumes to the Roper River under quasi-equilibrium conditions are consistently lower than under the projected 2059 to 2069 conditions (Table 8-2), except under Scenario Cwet. This outcome reflects the lags associated with the regional nature of the CLA groundwater system, where changes in factors such as precipitation patterns or human-induced groundwater abstraction take time to propagate through the groundwater system and affect the groundwater levels and discharge rates.

The results under scenarios A′ and A, which show a similar level of reduction in groundwater discharge between the two timescales, reflect the same historical climate and recharge regimes and the location of the groundwater extraction relative to the Roper River.

In contrast, under scenarios B′ and D′dry, the centroid of the groundwater extraction sites moves to the southern half of LWMZ about 75 km to the south-east, and the difference between the quasi-equilibrium and projected 2059 to 2069 mean annual discharge is greater. This indicates that altering the location of the major pumping centres takes longer than the 50-year time frame of the projected 2059 to 2069 scenarios to propagate through the system to the river.

The differences between results under scenarios C′ and C also indicate that altering the climate inputs take longer than the 50-year time frame of the projected 2059 to 2069 scenarios to propagate through the system. Indeed the groundwater levels (Section 1.1.1) suggest that the system is still responding to the climate sequences even after 436 years.

8.2 Cambrian Limestone Aquifer water balances

8.2.1 Scenarios A and B quasi-equilibrium vs representative (2070) conditions

Although they show the same trends, there are some obvious differences between the water balance components under the quasi-equilibrium conditions and the representative future (2070) conditions. Under scenarios A′ and A, there is a similar amount of change in the MWMZ water balance components representing the ET and discharge to the river relative to scenarios A′N and AN. However, under scenarios B′ and B, the changes in these water balance components show more divergence, with greater reduction in ET and discharge to the river associated with the increasing groundwater extraction. The greater decrease in the annual ET volume suggests that some of the reduced groundwater availability caused by additional pumping is offset by reduced ET rather than reduced discharge to the river.

The changes in MWMZ groundwater ET discharge relative to Scenario A′N/AN are:

- A′ = −12%, B′35 = −21%, B′70 = −29%, B′105 = −37%
- A = −13%, B35 = −15%, B70 = −18%, B105 = −21%.

The changes in MWMZ river discharge relative to Scenario A′N/AN are:

- A′ = −9%, B′35 = −12%, B′70 = −15%, B′105 = −18%
- A = −9%, B35 = −10%, B70 = −10%, B105 = −11%.

Scenarios A′/A and B′/B show a lower increase in the annual rate of groundwater released from storage in the LWMZ under the quasi-equilibrium conditions than the representative (2070) conditions. The increase in net inflow to the LWMZ is also greater under the quasi-equilibrium conditions than under the representative (2070) conditions. These results indicate that the quasi-equilibrium conditions are closer to achieving a state of equilibrium than that of the representative (2070) conditions.

The changes in groundwater release from storage in the LWMZ relative to Scenario A′N/AN are:

- A′ = +2%, B′35 = +14%, B′70 = +26%, B′105 = +41%
- A = +8%, B35 = +105%, B70 = +210%, B105 = +318%.

The changes in groundwater inflow to LWMZ relative to Scenario A′N/AN are:

- A′ = +168%, B′35 = +474%, B′70 = +779%, B′105 = +1081%
- A = +142%, B35 = +304%, B70 = +464%, B105 = +619%.

8.2.2 Scenarios C and D quasi-equilibrium vs representative (2070) conditions

The influence of climate compared to additional groundwater extraction can be observed by comparing the water balance components under scenarios C′/C and D′/D.

Scenarios C′dry/Cdry and D′dry/Ddry show similar changes in the ET component relative to Scenario A′N/AN regardless of the increase in the future hypothetical pumping volume (e.g. relative to Scenario A′N, changes are C′dry = −67%, D′dry35 = −70%, D′dry70 = −71%, D′dry105 = −73%). The reduction in ET under the dry quasi-equilibrium conditions is about 9 to 11% greater than the reduction observed in the dry representative future (2070) conditions.

However, changes to the ET discharge component under scenarios C′dry/Cdry, C′mid/Cmid and C′wet/Cwet relative to Scenario A′N/AN show a much greater range of differences (e.g. relative to Scenario A′N, changes are C′dry = −67%, C′mid = −55%, C′wet = +3%) than with the additional groundwater extraction.

The changes in MWMZ groundwater ET discharge relative to Scenario A′N/AN are:

- C′dry = −67%, C′mid = −55%, C′wet = +3%, D′dry35 = −70%, D′dry70 = −71%, D′dry105 = −73%
- Cdry = −58%, Cmid = −47%, Cwet = −12%, Ddry35 = −59%, Ddry70 = −61%, Ddry105 = −62%.

Scenarios C′dry/Cdry and D′dry/Ddry show increasing changes in the river discharge component relative to Scenario A′N in response to the increasing future hypothetical pumping volume. The reduction in discharge to the river is between 14 to 31% greater under the dry quasi-equilibrium conditions than under the dry representative future (2070) conditions.

However, the changes to the river discharge component under scenarios C′dry/Cdry, C′mid/Cmid and C′wet/Cwet relative to Scenario A′N/AN show a much greater range of differences (e.g. relative to Scenario A′N, changes are C′dry = −45%, C′mid = −27%, C′wet = +8%) than with the additional groundwater extraction.

The changes in MWMZ discharge to the river relative to Scenario A′N/AN are:

- C′dry = −45%, C′mid = −27%, C′wet = +8%, D′dry35 = −52%, D′dry70 = −59%, D′dry105 = −66%
- Cdry = −31%, Cmid = −21%, Cwet = +1%, Ddry35 = −32%, Ddry70 = −33%, Ddry105 = −35%.

Scenarios C′/C and D′/D show a lower increase in the annual rate of groundwater released from storage in the LWMZ under the quasi-equilibrium conditions than the representative future (2070) conditions. The volume being pumped is being met by groundwater inflows to the areas being pumped. These inflows are greater in the quasi-equilibrium conditions than the representative future (2070) conditions. This indicates that the quasi-equilibrium conditions are closer to achieving a new state of equilibrium than are the representative future (2070) conditions.

The changes in groundwater release from storage in the LWMZ relative to Scenario A′N/AN are:

- C′dry = −77%, C′mid = −53%, C′wet = −17%, D′dry35 = −57%, D′dry70 = −37%, D′dry105 = −26%
- Cdry = +10%, Cmid = +13%, Cwet = +12%, Ddry35 = +117%, Ddry70 = +228%, Ddry105 = +343%.

The changes in groundwater inflow to the LWMZ relative to Scenario A′N/AN are:

- C′dry = +253%, C′mid = +225%, C′wet = +180%, D′dry35 = +553%, D′dry70 = +848%, D′dry105 = +1155%
- Cdry = +123%, Cmid = +121%, Cwet = +124%, Ddry35 = +283%, Ddry70 = +438%, Ddry105 = +590%.

Under the quasi-equilibrium conditions, a large proportion of the additional hypothetical groundwater extraction is ‘buffered’ by reductions in discharge to ET, inducing a greater volume of groundwater flow from the south-east of LWMZ and capture of groundwater throughflow that would otherwise flow downgradient from the MWMZ and LWMZ. Under the future representative (2070) conditions, a large proportion of the additional future groundwater extraction is buffered by release from storage in the LWMZ, as well as reductions in discharge to ET, inducing a greater volume of groundwater flow from the south-east of LWMZ and capture of groundwater throughflow that would otherwise flow downgradient from the MWMZ and LWMZ.

8.3 Cambrian Limestone Aquifer groundwater levels

Groundwater levels at the reporting sites show trends associated with climate, pumped volumes and location relative to pumping centres.

The quasi-equilibrium drawdown contours under future hypothetical developments extend about the same distance to the south-east. Similarly, the representative future (2070) conditions show consistent patterns related to the pumped volume. However, the two timescales considered differ noticeably: the extent and maximum drawdown for the quasi-equilibrium conditions are about twice the magnitude of the future representative conditions.

The patterns observed in the drawdown contours are reflected in the groundwater levels for each scenario, but the effects of climate are also evident. Reporting sites closer to the pumping developments show the greatest reduction in groundwater levels. RN019012 and RN028082 are closest to the pumping bores under the current pumping set-up in Scenario A, whereas RN028082 and RN029013 are centred on the future hypothetical pumping developments in Scenario B.

The differences or ‘drawdowns’ between the mean groundwater level under scenarios A′/A and B′/B relative to the scenarios A′N or AN are presented in Table 8-1. Generally, drawdowns under scenarios A′ and A are similar, but drawdowns under Scenario B′ are about two to three times greater than under Scenario B. RN005621 shows the greatest drawdown between the quasi-equilibrium and the future representative conditions with drawdown being about four times under Scenario A′/A and about ten times greater under Scenario B′/B.

Groundwater levels under the dry and mid future climate scenarios show a greater drawdown relative to the historical climate scenarios. However, the future wet scenario sees increases in groundwater level under current development and also in some places under future hypothetical levels of development. Groundwater levels under the quasi-equilibrium conditions show greater drawdown than under the future representative (2070) conditions.

Under Scenario C′dry, groundwater drawdown is about 10 to 12 m greater than under Scenario A′, drawdown under Scenario C′mid is about 5 to 7 m greater than under Scenario A′, and drawdown under Scenario C′wet is 1 to 17 m less than under Scenario A′ (i.e. Scenario C′wet groundwater levels are higher than under Scenario A′N).

The effect of a dryer climate and an increase in extractions can be examined by comparing drawdowns under Scenario B′/B and Scenario D′dry/Ddry conditions. Under quasi-equilibrium conditions, Scenario D′dry drawdowns at all sites except RN035796 are 10 to 14 m greater than the B′ drawdowns. In contrast, under future representative (2070) conditions, all sites except RN035796 under Scenario Ddry show drawdowns of about 2 to 4 m greater than the B′ drawdowns.

The quasi-equilibrium results (scenarios C′dry and D′dry) at the sites closest to the future hypothetical developments (RN028082, RN029012 and RN029013) are about two to three times greater than the drawdown under the representative future (2070) climate conditions (scenarios Cdry and Ddry).

The effect of a wetter climate and an increase in extraction can be examined by comparing drawdowns under Scenario B′/B and Scenario D′wet/Dwet conditions. This shows that the increased groundwater levels seen under Scenario Cwet are maintained in areas remote from future development (i.e. RN005621 and RN035796) under Scenario Dwet despite the extra extraction. However, in areas nearer the hypothetical developments, the drawdown is less under a future wet climate than under the historical climate.

Table 8-1 Differences in mean groundwater levels relative to A'N/AN (m) for Cambrian Limestone Aquifer reporting sites under historical and future climates with current and hypothetical future levels of development

SCENARIO	RN005621	RN024536	RN028082	RN029012	RN029013	RN035796
A'	−0.8	−1.3	−2.7	−1.7	−2.1	−0.5
A	−0.2	−0.7	−2.3	−1.6	−1.6	−0.5
B'35	−4.0	−8.4	−9.6	−4.2	−10.5	−0.6
B35	−0.4	−3.1	−5.1	−2.5	−5.0	−0.6
B'70	−7.2	−15.6	−16.8	−6.8	−19.2	−0.8
B70	−0.6	−5.5	−7.9	−3.4	−8.4	−0.6
B'105	−10.4	−22.9	−24.5	−9.5	−28.5	−1.0
B105	−0.8	−7.8	−10.7	−4.4	−11.8	−0.6
C'dry	−12.3	−12.4	−14.0	−11.2	−13.8	−2.2
Cdry	−1.7	−2.3	−5.2	−6.2	−3.9	−1.4
C'mid	−6.2	−7.0	−9.2	−7.5	−8.5	−1.2
Cmid	−0.9	−1.5	−4.4	−5.2	−3.0	−0.9
C'wet	+15.8	+11.9	+4.5	+0.1	+8.2	+0.7
Cwet	+2.3	+1.2	−2.2	−2.9	−0.6	+0.3
D'dry35	−15.5	−19.7	−21.9	−14.7	−22.8	−2.6
Ddry35	−1.9	−4.7	−8.0	−7.2	−7.2	−1.5
D'dry70	−18.7	−27.2	−30.4	−18.5	−32.6	−3.1
Ddry70	−2.1	−7.1	−10.9	−8.2	−10.6	−1.5
D'dry105	−21.5	−33.7	−38.3	−22	−41.6	−3.6
Ddry105	−2.3	−9.5	−13.8	−9.2	−14	−1.6
D'mid35	−8.7	−12.8	−13.9	−8.9	−15.1	−0.9
Dmid35	−1.1	−3.9	−7.2	−6.2	−6.4	−0.9
D'mid70	−11.9	−20.2	−21.9	−12.4	−24.4	−1.3
Dmid70	−1.2	−6.3	−10	−7.2	−9.8	−1
D'mid105	−15	−27.5	−30.4	−15.9	−34.3	−1.7
Dmid105	−1.4	−8.7	−12.9	−8.1	−13.2	−1
D'wet35	+13.3	+6.1	+0.6	−0.7	+2.3	+1.1
Dwet35	+2.1	−1.1	−4.9	−3.8	−4	+0.3
D'wet70	+10.1	−0.9	−6.3	−3.2	−6	+0.9
Dwet70	+1.9	−3.5	−7.8	−4.7	−7.3	+0.3
D'wet105	+6.9	−8	−13.6	−5.8	−14.6	+0.8
Dwet105	+1.7	−5.9	−10.6	−5.7	−10.7	+0.2

A'N/AN = Historical climate and no development; A/A' = Historical climate and current development; B35/B'35 = Historical climate and future development of 35 GL/year; B70/B'70 = Historical climate and future development of 70 GL/year; B105/B'105 = Historical climate and future development of 105 GL/year; C'dry/Cdry = Future dry climate sequence with current development; C'mid/Cmid = Future mid climate sequence with current development; C'wet/Cwet = Future wet climate sequence with current development; D'dry35/Ddry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; D'dry70/Ddry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; D'dry105/Ddry105 = Future climate sequences with current development and additional future development of 105 GL/year; D'mid35/Dmid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; D'mid70/Dmid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; D'mid105/Dmid105 = Future mid climate sequences with current development and additional future development of 105 GL/year;

D’wet35/Dwet35 = Future wet climate sequences with current development and additional future development of 35 GL/year;
D’wet70/Dwet70 = Future wet climate sequences with current development and additional future development of 70 GL/year;
D’wet105/Dwet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.

8.4 Cambrian Limestone Aquifer groundwater discharge to the Roper River

Groundwater discharge to the Roper River shows greater decline under the quasi-equilibrium conditions than under the representative (2070) conditions, and the greatest differences are evident when including different climate regimes (Table 8-2).

Comparing changes to mean discharge under scenarios A and B for the quasi-equilibrium and the representative (2070) conditions indicates that there is a difference in the estimated discharge. The quasi-equilibrium conditions indicate a 10 to 20% decrease in discharge to the Roper River associated with the additional groundwater developments; however, the representative (2070) conditions show about a 10% decrease in discharge to the Roper River under all scenarios. As identified in the previous sections, this is related to the distance of the future hypothetical developments from the river and the 50-year time frame of the representative future (2070) conditions not showing the full hydraulic impacts at the river which occur over a period of several hundreds of years.

Comparing changes to mean discharge under scenarios Cdry and Ddry for the quasi-equilibrium and the representative (2070) conditions indicates that there is a difference of an order of magnitude decrease in estimated discharge. The quasi-equilibrium conditions indicate a 45 to 66% decrease in discharge to the Roper River associated with the additional groundwater developments, while the representative (2070) conditions show about a 30% decrease in discharge to the Roper River under all Ddry scenarios. As identified in the previous sections, this is related to the distance of the future hypothetical developments from the river and the 50-year time frame of the representative future (2070) conditions showing limited influence from the future hypothetical developments and the effects of reduced recharge to the system.

Table 8-2 Mean annual discharge to the Roper River and percentage change in discharge under historical and future climates with current and hypothetical future levels of development

SCENARIO	DISCHARGE (m^3/s)	% CHANGE FROM A’N	SCENARIO	DISCHARGE (m^3/s)	% CHANGE FROM AN
A’N	3.3	na†	**AN**	3.3	Na
A’	3	−9	**A**	3	−9
B’35	2.9	−12	**B35**	3	−10
B’70	2.8	−15	**B70**	2.9	−10
B’105	2.7	−18	**B105**	2.9	−11
C’dry	1.8	−45	**Cdry**	2.3	−30
C’mid	2.5	−26	**Cmid**	2.6	−19
C’wet	3.6	+10	**Cwet**	3.4	+4
D’dry35	1.6	−52	**Ddry35**	2.3	−31
D’dry70	1.4	−59	**Ddry70**	2.2	−32

SCENARIO	DISCHARGE (m^3/s)	% CHANGE FROM A'N	SCENARIO	DISCHARGE (m^3/s)	% CHANGE FROM AN
D'dry105	1.1	−66	**Ddry105**	2.2	−33
D'mid35	2.3	−31	**Dmid35**	2.6	−20
D'mid70	2.1	−37	**Dmid70**	2.6	−21
D'mid105	1.9	−44	**Dmid105**	2.6	−22
D'wet35	3.5	+7	**Dwet35**	3.4	+3
D'wet70	3.5	+4	**Dwet70**	3.4	+3
D'wet105	3.4	+2	**Dwet105**	3.3	+2

A'N/AN = Historical climate and no development; A/A' = Historical climate and current development; B35/B'35 = Historical climate and future development of 35 GL/year; B70/B'70 = Historical climate and future development of 70 GL/year; B105/B'105 = Historical climate and future development of 105 GL/year; C'dry/Cdry = Future dry climate sequence with current development; C'mid/Cmid = Future mid climate sequence with current development; C'wet/Cwet = Future wet climate sequence with current development; D'dry35/Ddry35 = Future dry climate sequences with current development and additional future development of 35 GL/year; D'dry70/Ddry70 = Future dry climate sequences with current development and additional future development of 70 GL/year; D'dry105/Ddry105 = Future climate sequences with current development and additional future development of 105 GL/year; D'mid35/Dmid35 = Future mid climate sequences with current development and additional future development of 35 GL/year; D'mid70/Dmid70 = Future mid climate sequences with current development and additional future development of 70 GL/year; D'mid105/Dmid105 = Future mid climate sequences with current development and additional future development of 105 GL/year; D'wet35/Dwet35 = Future wet climate sequences with current development and additional future development of 35 GL/year; D'wet70/Dwet70 = Future wet climate sequences with current development and additional future development of 70 GL/year; D'wet105/Dwet105 = Future wet climate sequences with current development and additional future development of 105 GL/year.

†na = not applicable.

8.5 Dook Creek Aquifer water balances

Although the quasi-equilibrium conditions show greater decreases in water budget components than the representative (2070) conditions, the differences are not as pronounced for the DCA model as for the CLA.

8.5.1 Scenarios A and B quasi-equilibrium vs representative (2070) conditions

Under scenarios A and B relative to Scenario A'N/AN, the percentage difference in the release from storage is about the same, and the ET is about 1 to 3% less under quasi-equilibrium conditions than under representative (2070) conditions.

The changes in DCA groundwater ET discharge relative to Scenario A'N/AN are:

- A' = 0%, B'6 = −4%, B'12 = −8%, B'18 = −12%
- A = 0%, B6 = −3%, B12 = −7%, B18 = −10%.

Under scenarios A and B, the discharge to rivers relative to Scenario A'N/AN is about 2 to 7% less under quasi-equilibrium than under representative (2070) conditions.

The changes in DCA river discharge relative to Scenario A'N/AN are:

- A' = 0%, B'6 = −6%, B'12 = −12%, B'18 = −20%
- A = 0%, B6 = −4%, B12 = −8%, B18 = −13%.

The discharge to springs is about 4 to 15% less under quasi-equilibrium than under representative (2070) conditions.

The changes in DCA spring discharge relative to Scenario A′N/AN are:

- A′ = 0%, B′6 = −17%, B′12 = −37%, B′18 = −61%
- A = 0%, B6 = −13%, B12 = −28%, B18 = −45%.

These results indicate that, as with the CLA, the effects from the future hypothetical developments are close but not fully established during the 50-year time frame of the future representative (2070) condition. The fluxes to the springs, which are sourced from the confined portion of the DCA, show the greatest difference, which is interpreted to be related to the time it takes for the groundwater system to go from confined to unconfined conditions.

8.5.2 Scenarios C and D quasi-equilibrium vs representative (2070) conditions

Release from storage is about 1 to 9% and ET is about 1 to 13% less under quasi-equilibrium than under representative (2070) conditions. The greater differences are associated with the dry climate sequence, while the wet climate sequence produces similar annual volumes.

The changes in DCA groundwater recharge relative to Scenario A′N/AN are:

- C′dry = −25%, C′mid = −6%, C′wet = +29%, D′dry6 = −25%, D′dry12 = −25%, D′dry18 = −25%
- Cdry = −25%, Cmid = −7%, Cwet = +29%, Ddry6 = −25%, Ddry12 = −25%, Ddry18 = −25%.

The changes in DCA groundwater ET discharge relative to Scenario A′N/AN are:

- C′dry = −25%, C′mid = −6%, C′wet = +27%, D′dry6 = −30%, D′dry12 = −34%, D′dry18 = −38%.
- Cdry = −19%, Cmid = −5%, Cwet = +23%, Ddry6 = −25%, Ddry12 = −25%, Ddry18 = −25%.

Discharge to rivers is about 10 to 13% less under the dry quasi-equilibrium than under dry representative (2070) conditions. The Cmid difference is about 2% less under the quasi-equilibrium than under representative (2070) conditions, and the Cwet results are reversed with discharge to rivers about 10% greater under dry quasi-equilibrium than under dry representative (2070) conditions.

The changes in DCA river discharge relative to Scenario A′N/AN are:

- C′dry = −54%, C′mid = −14%, C′wet = +64%, D′dry6 = −59%, D′dry12 = −63%, D′dry18 = −68%
- Cdry = −44%, Cmid = −12%, Cwet = +54%, Ddry6 = −48%, Ddry12 = −51%, Ddry18 = −55%.

Discharge to springs is about 13% less under the Cdry quasi-equilibrium than under dry representative (2070) conditions. The Cmid difference is about 13% less under the dry quasi-equilibrium than under dry representative (2070) conditions, and the Cwet results are reversed with discharge to springs about 33% greater under dry quasi-equilibrium than under dry representative (2070) conditions. The Ddry scenarios are about 13 to 14% less under the dry quasi-equilibrium than under dry representative (2070) conditions.

The changes in DCA spring discharge relative to Scenario A′N/AN are:

- C′dry = −70%, C′mid = −23%, C′wet = +139%, D′dry6 = −76%, D′dry12 = −81%, D′dry18 = −86%
- Cdry = −57%, Cmid = −18%, Cwet = +106%, Ddry6 = −63%, Ddry12 = −68%, Ddry18 = −72%.

These results indicate that, as with the CLA, the effects from the future hypothetical developments are not fully established during the 50-year time frame of the future representative (2070) condition.

8.6 Dook Creek Aquifer groundwater levels

A comparison of the drawdown contour plots under scenarios B′ and B shows one main difference: groundwater drawdowns due to the future hypothetical developments propagate across the entire model domain under Scenario B′ quasi-equilibrium conditions, but the drawdown contours are restricted to the unconfined north-west portion of the domain under Scenario B. Similar observations are made in comparing drawdowns under scenarios C′/C and D′/D.

Differences between the mean groundwater level under the various A, B, C and D scenarios relative to Scenario A′N/AN are presented in Table 8-3. The differences in drawdown between the quasi-equilibrium vs representative (2070) conditions are generally less than 1 m with the greatest differences at sites RN006546 and RN036302 (maximum of 3.5 m). Groundwater levels under the dry and mid future climate scenarios show a greater drawdown relative to the historical climate scenarios than the wet future climate scenarios. Groundwater levels under a wet future climate show increases under Scenario Cwet with current levels of development and all Dwet scenarios with up to an extra 18 GL/year of hypothetical developments.

Table 8-3 Difference in mean groundwater levels relative to A′N/AN (m) for Dook Creek Aquifer reporting sites under historical and future climates with current and hypothetical future levels of development

SCENARIO	RN006546	RN027811	RN028226	RN031983	RN036302
A′	0	0	0	0	0
A	0	0	0	0	0
B′6	−0.7	−0.4	−0.2	−0.5	−0.8
B6	−0.4	−0.3	−0.2	−0.3	−0.5
B′12	−1.5	−0.8	−0.5	−1	−1.6
B12	−0.9	−0.6	−0.4	−0.7	−1.1
B′18	−2.3	−1.2	−0.7	−1.5	−2.6
B18	−1.4	−0.9	−0.6	−1	−1.7
C′dry	−5.8	−2.3	−1.6	−5.3	−5.4
Cdry	−3.9	−1.7	−1.2	−4.0	−3.5
C′mid	−1.3	−0.5	−0.3	−1.2	−1.1
Cmid	−0.9	−0.4	−0.3	−1.0	−0.7
C′wet	+4.5	+1.7	+1.0	+4.3	+3.4
Cwet	+3.7	+1.4	+0.8	+3.8	+2.8
D′dry6	−7.0	−2.9	−2	−6.2	−6.7
Ddry6	−4.5	−2.1	−1.5	−4.5	−4.3
D′dry12	−8.2	−3.5	−2.5	−7.2	−8.1
Ddry12	−5.2	−2.5	−1.8	−5	−5.1
D′dry18	−9.5	−4.1	−2.9	−8.3	−9.5

SCENARIO	RN006546	RN027811	RN028226	RN031983	RN036302
Ddry18	−5.9	−2.9	−2.1	−5.5	−6
D’mid6	−2	−0.9	−0.6	−1.7	−2
Dmid6	−1.4	−0.7	−0.5	−1.3	−1.3
D’mid12	−2.9	−1.4	−0.9	−2.2	−3
Dmid12	−1.9	−1	−0.7	−1.7	−2
D’mid18	−3.7	−1.8	−1.2	−2.8	−4
Dmid18	−2.5	−1.4	−0.9	−2.1	−2.7
D’wet6	+4	+1.5	+0.8	+4	+3
Dwet6	+3.4	+1.2	+0.7	+3.6	+2.4
D’wet12	+3.6	+1.2	+0.7	+3.7	+2.6
Dwet12	+3	+0.9	+0.6	+3.3	+2.1
D’wet18	+3.1	+0.9	+0.6	+3.4	+2.2
Dwet18	+2.7	+0.7	+0.5	+3.1	+1.7

A/A’ = Historical climate and current development B6/B’6 = Historical climate and future development of 6 GL/year; B12/B’12 = Historical climate and future development of 12 GL/year; B18/B’18 = Historical climate and future development of 18 GL/year; Cdry/C’dry = Future dry climate sequences current development; Cmid/C’mid = Future mid climate sequences current development; Cwet/C’wet = Future wet climate sequences current development; Ddry6/D’dry6 = Future dry climate sequences current development and future development of 6 GL/year; Ddry12/D’dry12 = Future dry climate sequences current development and future development of 12 GL/year; Ddry18/D’dry18 = Future dry climate sequences current development and future development of 18 GL/year; Dmid6/D’mid6 = Future mid climate sequences current development and future development of 6 GL/year; Dmid12/D’mid12 = Future mid climate sequences current development and future development of 12 GL/year; Dmid18/D’mid18 = Future mid climate sequences current development and future development of 18 GL/year; Dwet6/D’wet6 = Future wet climate sequences current development and future development of 6 GL/year; Dwet12/D’wet12 = Future wet climate sequences current development and future development of 12 GL/year; Dwet18/D’wet18 = Future wet climate sequences current development and future development of 18 GL/year.
†na = not applicable.

8.7 Dook Creek Aquifer groundwater discharge

Groundwater discharges calculated at Wilton River (G9030003) and Flying Fox Creek (9030108) are shown in Table 8-4 and Table 8-5, respectively.

Under Scenario B, the quasi-equilibrium results show a greater reduction in discharge than the simulations representative of 2070. This difference is due to the extent of the drawdown propagation at these times and demonstrates that the impacts of extraction are not fully realised within 50 years. (There is no discernible difference in the Scenario A discharge due to the minimal current extraction.)

The impacts of a future climate under Scenario C are also not fully realised within 50 years. The extreme cases at Wilton River are Scenario Cdry , which shows a change in discharge of −22% after 50 years and −35% at quasi-equilibrium, and Scenario Cwet, which shows a change in discharge of +22% after 50 years and +33% at quasi-equilibrium. Results at Flying Fox Creek are even more extreme with Cdry showing a change in discharge of −45% after 50 years and −57% at quasi-equilibrium and Cwet showing a change in discharge of +54% after 50 years and +66% at quasi-equilibrium.

Scenario D shows the same patterns as Scenario C with the discharge reduced due to the increased extraction. The greatest change in discharge is seen in Scenario Ddry18 at quasi-equilibrium.

Table 8-4 Mean annual discharge to the Wilton River (G9030003) and percentage change in discharge under historical and future climates with current and hypothetical future levels of development

SCENARIO	DISCHARGE (m3/s)	% CHANGE FROM A'N	SCENARIO	DISCHARGE (m3/s)	% CHANGE FROM AN
A'N	0.1	na†	**AN**	0.11	na
A'	0.1	0	**A**	0.11	0
B'6	0.09	−5	**B6**	0.1	−3
B'12	0.09	−11	**B12**	0.1	−7
B'18	0.08	−16	**B18**	0.1	−11
C'dry	0.06	−35	**Cdry**	0.08	−22
C'mid	0.09	−8	**Cmid**	0.1	−6
C'wet	0.13	+33	**Cwet**	0.13	+22
D'dry6	0.06	−42	**Ddry6**	0.08	−26
D'dry12	0.05	−50	**Ddry12**	0.08	−30
D'dry18	0.04	−59	**Ddry18**	0.07	−34
D'mid6	0.08	−14	**Dmid6**	0.1	−9
D'mid12	0.08	−19	**Dmid12**	0.09	−13
D'mid18	0.07	−26	**Dmid18**	0.09	−17
D'wet6	0.13	+29	**Dwet6**	0.13	+19
D'wet12	0.12	+24	**Dwet12**	0.13	+16
D'wet18	0.12	+19	**Dwet18**	0.12	+13

A/A' = Historical climate and current development B6/B'6 = Historical climate and future development of 6 GL/year; B12/B'12 = Historical climate and future development of 12 GL/year; B18/B'18 = Historical climate and future development of 18 GL/year; Cdry/C'dry = Future dry climate sequences current development; Cmid/C'mid = Future mid climate sequences current development; Cwet/C'wet = Future wet climate sequences current development; Ddry6/D'dry6 = Future dry climate sequences current development and future development of 6 GL/year; Ddry12/D'dry12 = Future dry climate sequences current development and future development of 12 GL/year; Ddry18/D'dry18 = Future dry climate sequences current development and future development of 18 GL/year; Dmid6/D'mid6 = Future mid climate sequences current development and future development of 6 GL/year; Dmid12/D'mid12 = Future mid climate sequences current development and future development of 12 GL/year; Dmid18/D'mid18 = Future mid climate sequences current development and future development of 18 GL/year; Dwet6/D'wet6 = Future wet climate sequences current development and future development of 6 GL/year; Dwet12/D'wet12 = Future wet climate sequences current development and future development of 12 GL/year; Dwet18/D'wet18 = Future wet climate sequences current development and future development of 18 GL/year.
†na = not applicable.

Table 8-5 Mean annual discharge to the Flying Fox Creek (G9030108) and percentage change in discharge under historical and future climates with current and hypothetical future levels of development

SCENARIO	DISCHARGE (m3/s)	% CHANGE FROM A'N	SCENARIO	DISCHARGE (m3/s)	% CHANGE FROM AN
A'N	0.56	na†	**AN**	0.63	na
A'	0.56	0	**A**	0.63	0
B'6	0.53	−5	**B6**	0.61	−3
B'12	0.5	−11	**B12**	0.59	−7
B'18	0.47	−16	**B18**	0.57	−11
C'dry	0.24	−57	**Cdry**	0.35	−45
C'mid	0.47	−15	**Cmid**	0.56	−12
C'wet	0.93	+66	**Cwet**	0.98	+54
D'dry6	0.21	−62	**Ddry6**	0.33	−48
D'dry12	0.19	−66	**Ddry12**	0.31	−51

SCENARIO	DISCHARGE (m3/s)	% CHANGE FROM A’N	SCENARIO	DISCHARGE (m3/s)	% CHANGE FROM AN
D’dry18	0.17	−69	**Ddry18**	0.29	−54
D’mid6	0.44	−20	**Dmid6**	0.53	−16
D’mid12	0.41	−26	**Dmid12**	0.51	−19
D’mid18	0.38	−31	**Dmid18**	0.49	−23
D’wet6	0.9	+62	**Dwet6**	0.96	+51
D’wet12	0.88	+58	**Dwet12**	0.94	+48
D’wet18	0.86	+54	**Dwet18**	0.92	+45

A/A’ = Historical climate and current development; B6/B’6 = Historical climate and future development of 6 GL/year; B12/B’12 = Historical climate and future development of 12 GL/year; B18/B’18 = Historical climate and future development of 18 GL/year; Cdry/C’dry = Future dry climate sequences current development; Cmid/C’mid = Future mid climate sequences current development; Cwet/C’wet = Future wet climate sequences current development; Ddry6/D’dry6 = Future dry climate sequences current development and future development of 6 GL/year; Ddry12/D’dry12 = Future dry climate sequences current development and future development of 12 GL/year; Ddry18/D’dry18 = Future dry climate sequences current development and future development of 18 GL/year; Dmid6/D’mid6 = Future mid climate sequences current development and future development of 6 GL/year; Dmid12/D’mid12 = Future mid climate sequences current development and future development of 12 GL/year; Dmid18/D’mid18 = Future mid climate sequences current development and future development of 18 GL/year; Dwet6/D’wet6 = Future wet climate sequences current development and future development of 6 GL/year; Dwet12/D’wet12 = Future wet climate sequences current development and future development of 12 GL/year; Dwet18/D’wet18 = Future wet climate sequences current development and future development of 18 GL/year.
†na = not applicable.

9 Conclusions

Two groundwater flow models were used to examine the effects of scenarios encompassing climate change and groundwater development on the water resources of the Roper River. From this analysis, the following key findings have emerged:

- Recent climate conditions have led to significantly higher recharge than the long-term mean.
- Using the historical climate to simulate the future climate to approximately 2070, the mean annual water balances and mean discharge to the Roper River in the Mataranka Water Management Zone (MWMZ) suggest that extractions under the current allocations will result in a reduction in discharge to the Roper River of 9% relative to no extractions. Current extractions in the Dook Creek Aquifer (DCA) are minimal and so have a negligible impact on streamflow.
- Hypothetical future groundwater developments under the historical climate will result in further reductions in discharge from the Cambrian Limestone Aquifer (CLA) to the Roper River and will reduce discharge from the DCA to Wilton River and Flying Fox Creek.
- The extensive spatial coverage, thickness and variable hydraulic properties of the two karstic groundwater systems significantly influence the time lags for hydrological impacts of both climate variability and groundwater extraction to propagate through each system. The full impacts of changes in stresses from extraction or climate on the aquifer systems are not evident in the 50-year future scenarios. The systems will require hundreds of years to come to a state of quasi-equilibrium.
- Increased groundwater extraction does not linearly correspond to a proportional decrease in groundwater discharge to rivers, especially in the case of the CLA. In the case of the CLA this is because a large proportion of groundwater extraction is ‘buffered’ by reductions in discharge to evapotranspiration, capture of groundwater to the south-east of Larrimah Water Management Zone (LWMZ) and capture of groundwater throughflow that would otherwise flow downgradient from the MWMZ and LWMZ.
- Because of its influence on the spatial and temporal variability in groundwater recharge, climate variability has a more significant potential impact on water resources in the Roper catchment than does current groundwater extraction.
- Future climate projections range from an increase in recharge under a wetter future climate to a reduction in recharge under the median and dry future climates.
- Under the dry and median future climates, any hypothetical development will lead to further reductions in discharge to Roper River, Wilton River and Flying Fox Creek. Under a wet future climate, with future groundwater developments, a small increase in discharge to the Roper River is projected and a much greater increase in discharge to Wilton River and Flying Fox Creek.

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