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Impact of climate change on groundwater in NSW

Assessment of the sensitivity of recharge and groundwater resources to a projected drying climate

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Contents

Figures

Tables

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This work used data derived from Regional Climate Model simulations performed as part of the NSW and ACT Regional Climate Modelling (NARCliM) project - see Evans JP, Ji F, Lee C, Smith P, Argueso D and Fita L (2014) "Design of a regional climate modelling projection ensemble experiment" Geosci. Model Dev., 7, 621-629. We thank Dr Fei Ji for his help providing and using this data.

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Executive summary

This project has used new climate and river flow simulations developed by the New South Wales (NSW) Department of Planning and Environment – Water Group (DPE-Water) to provide an overall picture of how climate change could impact groundwater resources in NSW. The project has quantified the potential impact of a projected drier climate on changes to recharge (via both diffuse and localised mechanisms) and identified renewable groundwater resources at risk across NSW. This new understanding can inform groundwater management going forward.

The simulated climate data used consists of two 10,000-year sequences of stochastically generated daily rainfall and potential evapotranspiration, representing historical and future (dry scenario) climate conditions respectively. Future rainfall projections have a wide range of uncertainty; hence a dry scenario was chosen to allow the assessment of what the most extreme risks could look like.

Changes to diffuse recharge have been estimated using the WAVES model that simulates the soil–vegetation–atmosphere system behaviour in terms of one–dimensional dynamic interactions, and fluxes, of energy, water, carbon, and solutes. The diffuse recharge estimates at point scale and upscaled to the groundwater source level are almost all indicating a decrease in diffuse recharge across NSW, with an average change in diffuse recharge of −14% and ranging from −52% to +6% across NSW's 125 groundwater sources.

As well as diffuse recharge, localised recharge through losing streams and overbank flooding can also be a significant source of recharge. Simulated changes in streamflow were used to estimate how stage height and thus in-stream recharge from losing streams may change. In line with a projected decrease in streamflow, the change in recharge from in-stream losses was found to vary from −3.4% to −55.4%. Changes in the recharge due to overbank flooding was also estimated from the simulated streamflow changes. These changes were more extreme than the other forms of recharge, with a projected range from −90.5% to +56.1% (only a single gauge, out of 42 investigated, produced an increase). Confidence in the magnitude of these projected localised recharge changes is limited given the dry scenario used does not account for the possibility of increased daily rainfall extremes. Increased extreme rainfall events could increase overbank flooding, meaning that our projected reductions are likely to be overly pessimistic and not suitable for use in planning without further assessment.

To determine how individual groundwater sources may be impacted by our projected recharge changes, we identified groundwater sources that are most vulnerable to the impacts of climate change relative to those that show more resilience to these direct impacts. This was achieved by combining an index of aquifer sensitivity with an index of stress to recharge changes, to produce a priority ranking of groundwater resources. This new priority ranking indicates which groundwater sources are likely to be most vulnerable to climate change over the next 40 years and therefore at greater relative risk in terms of available resources.

Recommendations are provided, on a groundwater source type basis, for where further investigations are warranted given the prioritisation results and identified knowledge gaps that limit our confidence in this preliminary assessment. For example, the inland alluvium priority groundwater sources that have a high proportion of recharge from localised sources all require more detailed investigations to ascertain the proportion of recharge due to flooding, losing streams, irrigation drainage and diffuse recharge. Methodological limitations impacting confidence in the estimated changes also require further investigation, such as the impact of changes in rainfall extremes on flooding and hence overbank flood recharge, the need for better methods to estimate recharge from flooding, and the assessment of the fit-for-purpose of the numerical groundwater models currently used in resource planning and management.

1 Introduction

1.1 Background

Groundwater is a significant strategic resource for New South Wales (NSW), supplying around one fifth of the state's total water needs. Groundwater sustains major agricultural and mining activities in rural areas, internationally protected natural environments, and more than 200 towns rely on groundwater for total or partial water supply. Groundwater availability thus underpins the long-term viability of regional communities and economic activities across NSW. With expected changes to current hydrological regimes arising from climate change, groundwater resources will play an increasingly important role in securing water supply.

This project uses the new climate and surface water data developed by the Department of Planning and Environment – Water Group (DPE-Water) to provide an overall picture of how climate change could impact groundwater resources in NSW. The project has focussed on the impact of changes to recharge (via both diffuse and localised mechanisms) on renewable groundwater resources across the whole state, drawing heavily on methods developed in the Barron et. al. (2011) continental-scale assessment of the potential impacts of climate change on Australian groundwater resources, to prioritise which groundwater sources are most at risk from climate change. The outputs of this project inform and support sustainable and adaptive groundwater management that considers climate change risks. Hence this project's outputs, determining which groundwater sources are most vulnerable to a dry future climate, identify prioritised groundwater risks and knowledge gaps, informing further activities and projects in the future.

1.2 Scope and objectives

This project quantitively assesses the potential impacts of future climate change on renewable groundwater resources across NSW. This report details a desktop investigation into modelled impacts of a drier future climate on diffuse and localised groundwater recharge across NSW, using newly available simulated climate (rainfall and potential evapotranspiration (PET)) and surface water data developed by DPE-Water. The point estimates of recharge change are upscaled to the groundwater source scale for all of NSW and used to provide a ranking of prioritised sources according to their combined stress and sensitivity to climate change. The research is reported under the following sections.

- Changes to diffuse recharge (Section 2)

  Objectives of this section include:

  a. Quantify the impact of climate change on diffuse recharge across NSW.

  b. Identify regional variability in diffuse recharge change and the underlying causes of such variations.

- Changes to localised recharge (Section 3)

Objectives of this section include:

a. Quantify the impact of climate change on localised recharge across NSW, for (i) in-stream recharge from losing streams and (ii) overbank (flood) recharge.

b. Compare magnitudes of localised and diffuse recharge changes and comment on whether groundwater is more/less resilient to climate change than surface water, and by how much.

- Groundwater source prioritisation (Section 4)

  Objectives of this section include:

  a. Identify potential future groundwater challenges in terms of which sources are resilient and which are the most vulnerable to climate change.

  b. Highlight regions or specific groundwater resources that require more detailed analysis for scoping future projects.

- Conclusions and recommendations (Section 5)

The impacts of climate change on demand for groundwater and how sea level rise could impact coastal aquifers are out of scope for this investigation.

1.3 Modelling climate risk

The development of NSW regional water strategies has involved production of new, state-of-the-art climate data that encompass an improved understanding of climate variability and change (DPIE, 2020). The simulated climate data consists of two 10,000-year sequences of stochastically generated daily rainfall and potential evapotranspiration (PET), representing historical and future (dry scenario) climate conditions respectively. Future rainfall projections have a wide range of uncertainty; hence a dry scenario was chosen to allow the assessment of what the most extreme risks could look like and to enable the stress-testing of system resilience.

Figure 1-1 summarises the four-step process used to produce the climate datasets (DPIE, 2020). Observed historical climate data, climate drivers and paleoclimate information are combined to produce a 500-year record accounting for a fuller range of climate variability than the 130-year historical record alone. This data informs a stochastic modelling approach to generate 10,000 years of data. The climate change projections used are from the NARCLiM (NSW and ACT Regional Climate Modelling) WRF (Weather and Regional Forecasting) regional climate model, downscaling GCMs forced by the IPCC A2 emissions scenario for a 2060-2079 future relative to a 1990-2009 baseline (Evans and McCabe, 2010, 2013; Evans et al., 2014). The downscaled changes are then used to perturb the 10,000-year historical sequence to provide a plausible sequence of future rainfall and PET.

DPE-Water selected a dry NARCLiM projection, the average of three WRF downscaling simulations from the CSIRO MK3.0 GCM, to provide monthly change factors to rescale the 10,000-year stochastically generated historical climate series. An inherent limitation of this approach is its inability to account for the possibility of increases in extreme daily rainfall events when the mean rainfall is projected to decrease. This limitation reduces our confidence in projected flood statistics as, for example, the overbank flood recharge decreases estimated herein are likely to be overly pessimistic.

The historical and future 10,000-year daily sequences are used as input to the diffuse recharge estimation (Section 2) and the river modelling undertaken by DPE-Water (as used in the localised recharge estimation in Section 3). Both the diffuse and localised recharge change estimates inform the groundwater source assessment presented in Section 4.

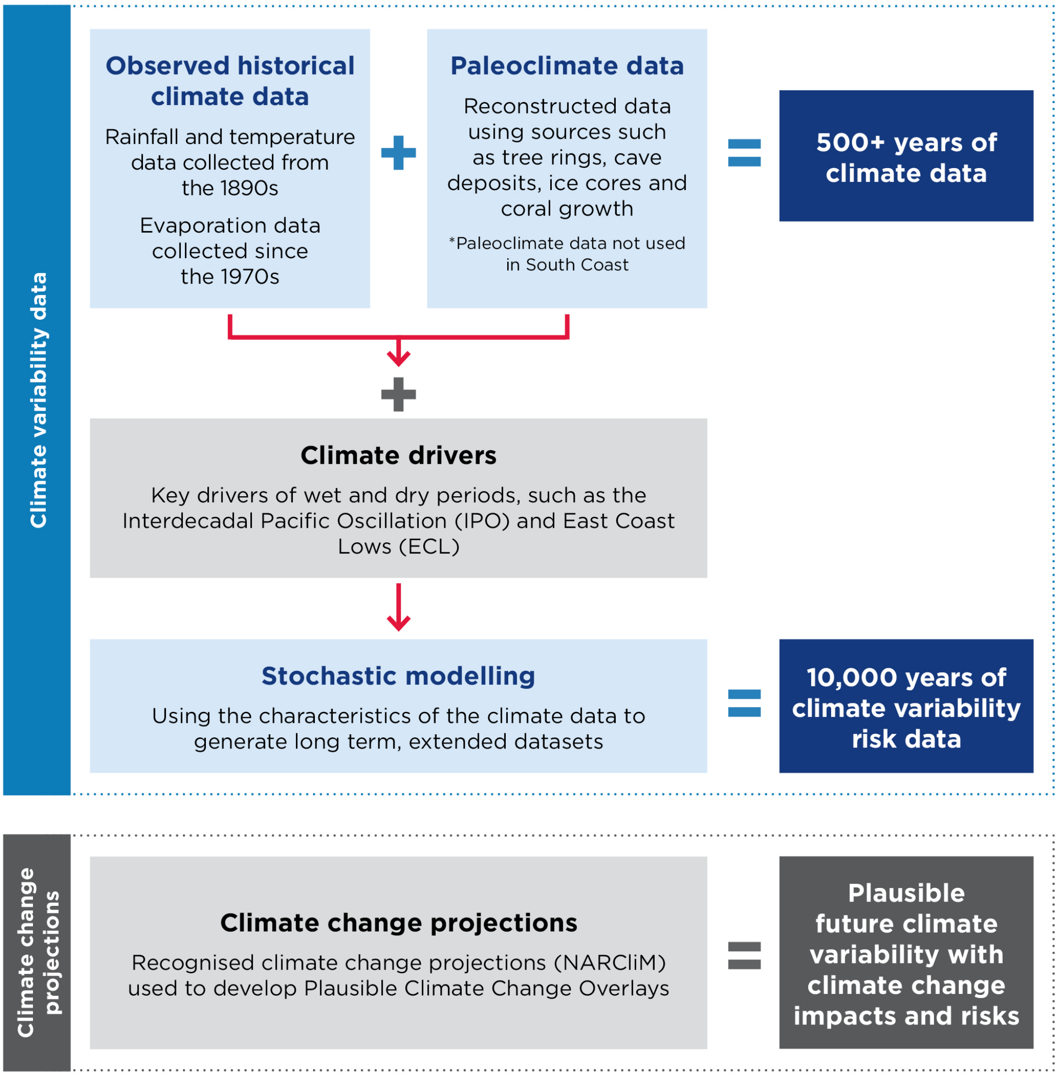


Figure 1-1 NSW DPE climate data and modelling approach (DPIE, 2020a)

2 Changes to diffuse recharge

2.1 Introduction

This section describes the data and methods used to generate historical, and future, diffuse recharge values in the project. The procedures for diffuse recharge estimation, and some data sources, are taken from the work of Crosbie et al. (2008; 2010; 2013), Ali et al. (2010) and Barron et al. (2011). The conceptualisation used is identical to previous work, using the WAVES model on idealised soil profiles and estimating recharge as unit drainage from the soil column. However, previous work modelled all sample climates on all soil profiles, where this work only uses climate series generated on the soil types they occupy. Objectives of this section include:

a. Quantify the impact of climate change on diffuse recharge across NSW
b. Identify regional variability in diffuse recharge change and the underlying causes of such variations

2.2 Scope and constraints

The project is a desktop study, not intended to make new measurements or generate new methods, but rather to use existing data sources and methods to complete the objectives. Due to the limited timeline of the project, its activities have been restricted to gathering existing data and processing it expeditiously. DPE-Water had requested that CSIRO consider the recommendations in Simmons et al. (2019), which suggested calibrating WAVES to locally available data (evaporation, soil moisture, vegetation, etc) rather than relying on generic parameters. This method is most useful for local estimation of water balance components but suffers the same problem when applied regionally. Any single combination of soil profile and characteristics, land cover and climate sequence, regardless of its source as locally measured or regionally averaged, must be extrapolated from a few points. Regionally averaged parameters from Crosbie et al. (2010) which were available for the soil and cover types of NSW were used *in lieu* of local measurements.

It is also important to note that while parameterisation is very important for calculating *absolute recharge locally* it is not as critical for calculating the *change in recharge regionally*. The errors introduced through incorrect parameterisation are minimised by reporting the change in recharge in percentage terms rather than the absolute recharge. The same parameter set is used in both the historical and future climate scenarios so to the degree possible the errors and bias in the parameters are consistent in terms of relative change. Where absolute values, small-scale or local recharge rates are important, then these general numbers and the direction of change may be indicative only.

2.3 Methodology

The simulation model used to estimate changes in diffuse recharge is WAVES (Dawes and Short, 1993; Dawes and Zhang, 2016). The WAVES model allows simulation of soil–vegetation–atmosphere system behaviour under alternative management and climatic variation, representing the interactions and feedbacks of the system with a consistent level of complexity, yet with adequate incorporation of the key processes. The model predicts one–dimensional dynamic interactions, and fluxes of energy, water, carbon, and solute within soil–vegetation–atmosphere systems. Running WAVES requires three primary data sources: daily climate series, soil profile and properties, and vegetation cover and behaviour, as discussed in subsequent sections.

2.3.1 Priority site selection

Climatic data analyses were available from DPE-Water at 899 locations across NSW. Given the timeline for modelling, analyses, review and reporting, it was not possible to perform diffuse recharge modelling at all of these locations. In line with the method of Crosbie et al. (2010; 2013), sites were chosen that included the main soil types according to ASRIS (Isbell et al., 1997; Johnston et al. ,2003), amalgamated Köppen-Geiger climate types (Crosbie et al., 2012), and coverage of the rainfall gradient across NSW. Care was taken to ensure one or more sites were present within each of the priority aquifer as assessed by Barron et al (2011), and in the largest soil groups, so that the regression relationships developed for upscaling were representative of the important groundwater resources. Of thirty priority-sites selected for diffuse recharge modelling, 28 had data provided in time for this analysis (Table 2-1; Figure 2-1), from which relationships between rainfall and recharge under historical and future climate conditions were derived.

For each site the following workflow was used:

1. Extract 1900-1999 daily climate records from SILO Datadrill (Jeffrey et al., 2001)
2. Generate file of SILO max and min temperature, vapour pressure deficit and shortwave radiation
3. Generate 10,000-year climate sequence combining the file of SILO data (for the above variables) and DPE-Water stochastic rainfall, re-using the SILO data every century
4. Generate an equivalent future 10,000-year climate sequence using monthly NARCliM scaling factors for all variables
5. Locate and generate soil files for a two-layered system (A and B horizon)
6. Generate WAVES input files using site location, estimated equilibrium tree LAI and soil type prefix
7. Run 6 WAVES simulations (2 climates, historical and future, X 3 land covers, bare, grass and tree)
8. Summarise WAVES output on annual basis; use EXCEL pivot tables to further summarise on century basis and generate linear regressions for use in interpolation/upscaling as presented in Section 2.4.2.

Table 2-1 Priority stations selected for diffuse recharge modelling

Station ID	Station Name	Rainfall (mm)[1]	Latitude	Longitude	Soil Group	K-G Climate[2]	Zone[3]
46037	TIBOOBURRA POST OFFICE	229	-29.4362	142.0097	Sodosol	BWh	2
47016	LAKE VICTORIA MET STATION	260	-34.0400	141.2700	Vertosol	BSk	2
48013	BOURKE POST OFFICE	348	-30.0917	145.9358	Vertosol	BSh	2
49002	BALRANALD (RSL)	325	-34.6398	143.5610	Vertosol	BSk	2
50020	WARROO (GEERON)	462	-33.2882	147.5364	Sodosol	BSk	2
51048	TRANGIE POST OFFICE	507	-32.0322	147.9826	Kandosol	BSk	2
53034	WEE WAA (PENDENNIS)	563	-30.1187	149.3232	Vertosol	Cfa	5
53048	MOREE COMPARISON	580	-29.4819	149.8383	Vertosol	Cfa	5
54135	BEEBO (MAURO)	607	-28.7200	150.9300	Dermosol	Cfa	5
55031	MANILLA POST OFFICE	650	-30.7477	150.7196	Dermosol	Cfa	5
58001	BALLINA (CROWLEY VILLAGE)	1805	-28.8528	153.5691	Hydrosol	Cfa	5
58037	LISMORE (CENTRE STREET)	1329	-28.8070	153.2628	Vertosol	Cfa	5
58059	ULMARRA (NEWSAGENCY)	1031	-29.6309	153.0287	Dermosol	Cfa	5
58080	WOOLI BEACH	1356	-29.8700	153.2653	Podosol	Cfa	5
58088	ETTRICK (CARARA)	1100	-28.6723	152.9083	Chromosol	Cfa	5
59040	COFFS HARBOUR MET OFFICE	1672	-30.3107	153.1187	Chromosol	Cfa	5
59047	CRESCENT HEAD	1458	-31.1802	152.9681	Hydrosol	Cfa	5
59120	THUMB CREEK (FIGTREE)	1465	-30.6800	152.6100	Tenosol	Cfa	5
60017	HANNAM VALE (HANNAM VALE ROAD)	1474	-31.7004	152.5833	Tenosol	Cfb	4
63036	OBERON (JENOLAN CAVES)	981	-33.8199	150.0227	Kandosol	Cfb	4
63066	ORANGE (MCLAUGHLIN ST)	863	-33.2741	149.1110	Kandosol	Cfb	4
65019	GOOLOOGONG POST OFFICE	612	-33.6146	148.4350	Chromosol	Cfa	5
69002	BEGA (NEWTOWN ROAD)	860	-36.6884	149.8380	Dermosol	Cfb	4
70072	QUEANBEYAN BOWLING CLUB	593	-35.3552	149.2292	Kandosol	Cfb	4
72022	HOLBROOK (RSL)	688	-35.7225	147.3178	Sodosol	Cfa	5
73015	GUNDAGAI	701	-35.0667	148.1000	Chromosol	Cfa	5
74008	GRONG GRONG (BEREMBED)	462	-34.8625	146.8184	Sodosol	BSk	2
75032	HILLSTON AIRPORT	393	-33.4915	145.5248	Sodosol	BSk	2

1 "Rainfall (mm)" is average annual value for 10,000-year stochastically generated rainfall sequence; data for 69002 Bega was truncated and used a 5,000-year sequence

2 "K-G climate" refers to Köppen-Geiger climate classification

3 "Zones" are amalgamated Köppen-Geiger climates; zone 2 are Arid climate types; zone 4 are Warm Temperate climates with equiseasonal rainfall; zone 5 are Hot Temperate climates with equiseasonal rainfall

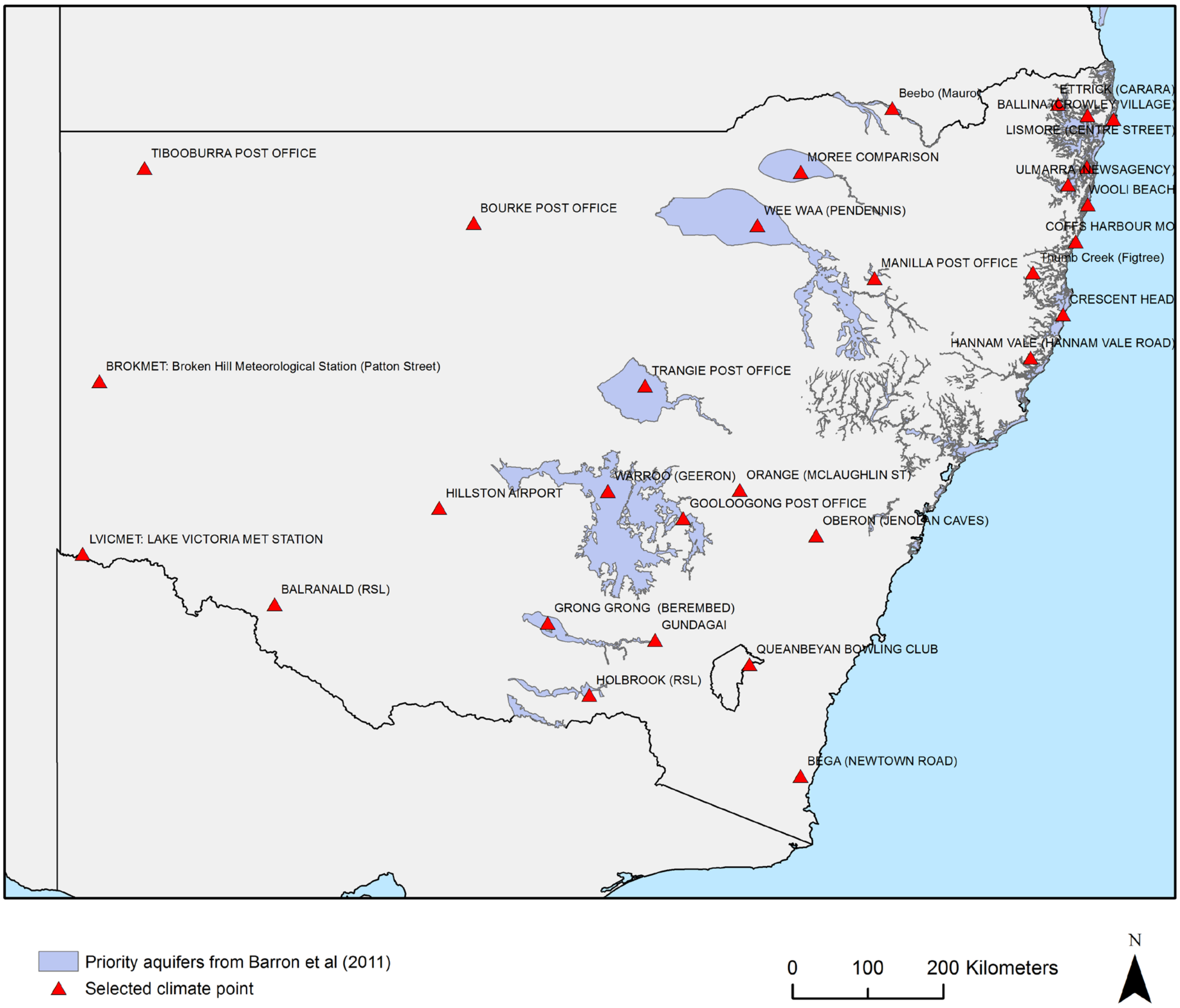


Figure 2-1 Selected sites (30) for WAVES modelling and diffuse recharge analysis; also shown are priority aquifers as assessed by Barron et al (2011)

2.3.2 Daily climate data

Using the 10,000-year daily rainfall series supplied by DPE-Water, two series are required at each model site: one generated stochastically from historical rainfall patterns, and one generated with the addition of monthly change factors based on NARCliM downscaled scenarios (as discussed in Section 1.3). To both expedite the transfer, and minimise the volume, of data transfer from DPE-Water, only the historical stochastically generated rainfall series were supplied for the 28 priority sites, along with monthly change parameters for each climate variable.

WAVES estimates soil evaporation and plant transpiration using the Penman–Monteith combination equation (Penman, 1948; Monteith, 1981). The surface energy balance solution requires daily values of maximum and minimum air temperature, vapour pressure deficit, rainfall and incoming solar radiation. Data on the historical climate at each location was downloaded from the SILO database (Jeffrey et al., 2001), and from this 100-years of daily temperature, vapour pressure deficit and solar radiation data were assembled. These data were combined directly with the stochastic rainfall series for the historical conditions simulation and were modified by NARCliM site-specific change parameters and combined with the NARCliM-perturbed rainfall for the future conditions. As indicated in Table 2-1 the data for 69002 Bega was truncated to a 5,000-year daily sequence.

2.3.3 Soil types and properties

Each soil was considered with two layers having an A-horizon fixed at 0.3 m thick, and a B-horizon extending down to 4 m. Each soil horizon in each soil+climate group was parameterised for the Broadbridge and White (1988) soil hydraulic model (Table 2-2). Parameters were taken from Crosbie et al. (2010) who used data from ASRIS (Johnston et al., 2003) on hydraulic conductivity and water holding capacity of major soil groups (Table 2-2). Other parameters were inferred based on soil texture descriptions (qv. Dawes and Zhang, 2016). Recharge was recorded as unit drainage at the lower boundary of the soil column.

2.3.4 Vegetation cover

The three land cover types modelled were: bare ground, perennial grass, and tree cover. The cover type and density were kept constant throughout each simulation as adding growth would complicate the modelling, require additional time for fitting and stability checks, and death of the vegetation during a simulation would invalidate the remainder of the run. It is not within the scope of the Project to consider vegetation survival or succession due to future climate change.

Neither cropping nor annuals of any type were considered. No irrigated or watered crops nor horticulture were considered. There are too many potential crop types and rotations, which require more detailed modelling and data. Where cropping is the dominant mapped vegetation cover, recharge will be assessed as the average of the bare ground and perennial grass values.

WAVES uses leaf area index (LAI) in surface water and energy balance modelling, and the equilibrium LAI of trees was estimated using the equation for eucalypts of Ellis et al. (1999); the LAI of perennial C3 grass cover was set to two-thirds of this value. Trees were allowed to extract water via roots down to 3 m while grass was limited to 0.3 m, equal to just the A-horizon. Cover maps from Barron et al. (2011) are shown in Figure 2-3.

Table 2-2 Soil types and unsaturated hydraulic properties for Broadbridge-White[1] soil model

Zone	Soil name	Layer	Ksat, m/d	θsat, v/v	θres, v/v	λ, m	C
2	Kandosol	1	4.497	0.3250	0.100	0.050	1.015
		2	0.926	0.3066	0.100	0.375	1.125
2	Sodosol	1	0.285	0.2975	0.100	0.375	1.300
		2	0.105	0.2262	0.100	0.375	1.300
2	Tenosol	1	4.872	0.3247	0.100	0.050	1.015
		2	3.599	0.3010	0.100	0.050	1.015
2	Vertosol	1	0.015	0.3059	0.100	0.375	1.400
		2	0.006	0.2553	0.100	1.250	1.750
4	Dermosol	1	4.083	0.3648	0.100	0.050	1.015
		2	1.086	0.2947	0.100	0.050	1.015
4	Kandosol	1	3.479	0.3470	0.100	0.050	1.015
		2	1.043	0.2935	0.100	0.050	1.015
4	Tenosol	1	3.427	0.3685	0.100	0.050	1.015
		2	1.612	0.3056	0.100	0.050	1.015
5	Chromosol	1	1.862	0.3166	0.100	0.050	1.015
		2	0.406	0.2279	0.100	0.375	1.300
5	Dermosol	1	1.743	0.3451	0.100	0.050	1.015
		2	0.437	0.2712	0.100	0.375	1.300
5	Hydrosol	1	0.411	0.3331	0.100	0.375	1.300
		2	0.042	0.2397	0.100	0.375	1.400
5	Podosol	1	5.393	0.3352	0.100	0.050	1.015
		2	1.350	0.2890	0.100	0.050	1.015
5	Sodosol	1	0.975	0.3127	0.100	0.375	1.125
		2	0.146	0.2090	0.100	0.375	1.300
5	Tenosol	1	1.761	0.3240	0.100	0.050	1.015
		2	0.703	0.2611	0.100	0.375	1.125
5	Vertosol	1	0.073	0.3161	0.100	0.375	1.400
		2	0.020	0.2604	0.100	0.375	1.400

1 The five parameters of the Broadbridge and White (1988) soil hydraulic model are: "Ksat" the saturated hydraulic conductivity (m/d); "θsat" the saturated (maximum) volumetric water content (vol/vol); "θres" the residual (minimum) volumetric water content; "λ" the capillary length scale (m); "C" the shape factor (value ranges between 1 and +∞).

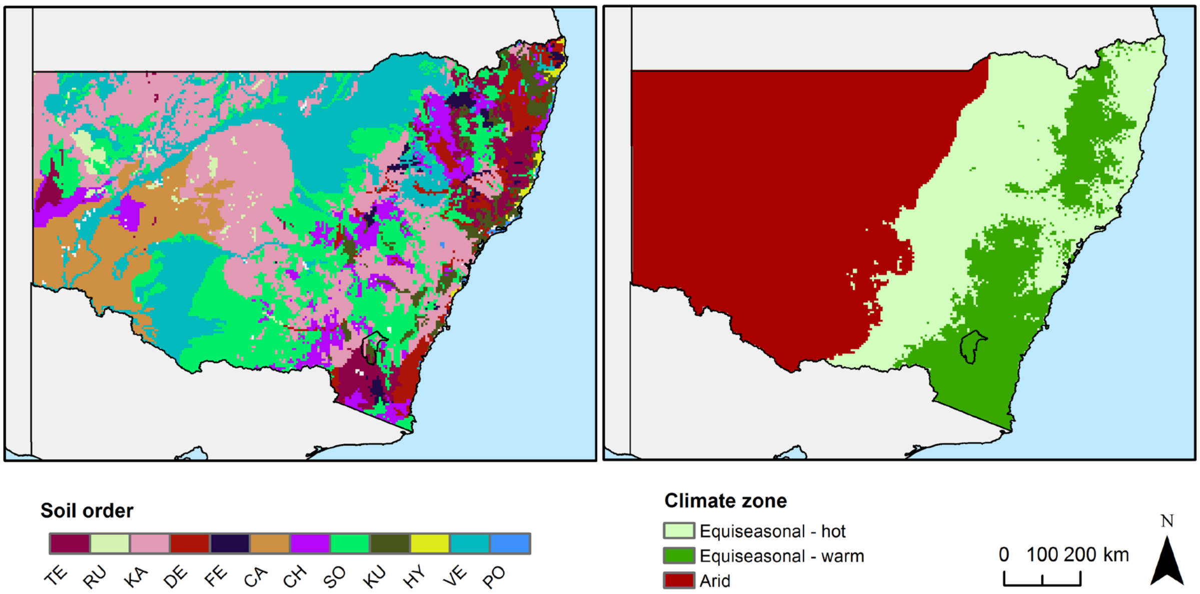


Figure 2-2 (a) Soil groups and (b) climate zones as used for diffuse recharge upscaling

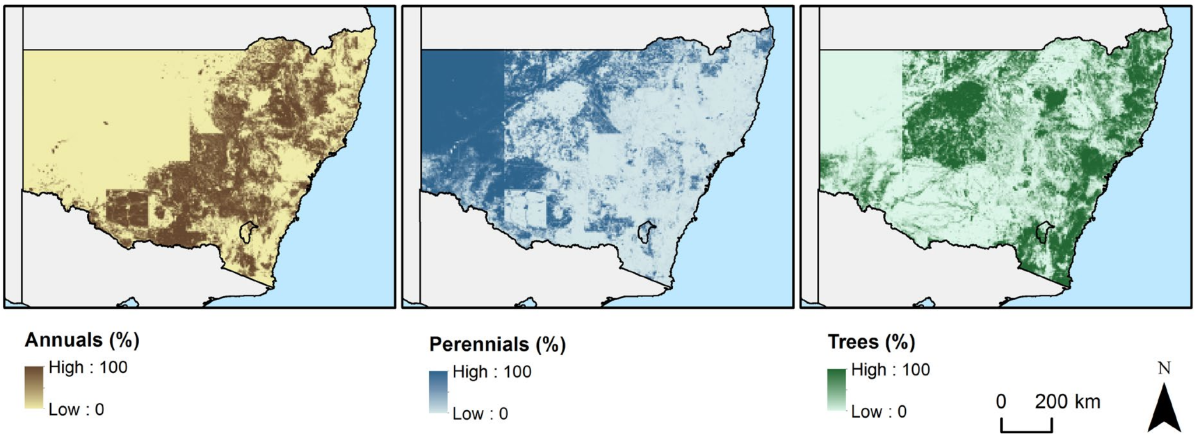


Figure 2-3 Land-cover types as used for diffuse recharge upscaling

2.3.5 Caveats

There are caveats on the WAVES modelling which start with the formulation of the Richards' equation solution used (Richards, 1931). The solution assumes a rigid, isothermal, non-hysteretic matrix through which liquid water moves in a single-phase. Clay soils that exhibit shrink-swell characteristics are not rigid, and if they crack then liquid water can move rapidly downward outside the soil matrix, i.e. macropore flow past the A-horizon. Further if the soil surface is prone to sealing due to intense rainfall then runoff may be generated thus reducing infiltration and potential recharge. The soil group most prone to these behaviours is Vertosols in Figure 2-2, which are most prominent in the lower reaches of the Lachlan and Murrumbidgee Rivers in the south, and black soils upstream of Bourke on the Macquarie, Namoi and Gwydir Rivers in northern NSW.

Any area that receives significant snow, or where the soil can freeze, may also be subject to surface and sub-surface processes not included in the solution. The snowfields of NSW are limited in area between the ACT and the NSW-Victoria border, in alpine areas with elevation greater than ~1500m. Diffuse groundwater recharge may not be meaningful in these areas.

Recharge has been calculated by WAVES assuming a unit hydraulic gradient at the lower boundary of the column, i.e. the soil is freely draining at 4 m depth. This will be incorrect when actual soils are shallower than this or skeletal in nature, or where there is exposed rock at the surface, mainly in elevated and mountainous terrain of the Great Dividing Range. Whether significant groundwater resources exist in these areas, or if diffuse recharge is significant here, is not considered in this work. The set-up is also not valid if there is a local shallow water table less than 4 m from the land surface, either permanently or seasonally. In this regard, areas with consumptive use issues of significant local groundwater interaction require localised consideration and modelling.

Interpolation of recharge across the domain is a source of uncertainty. In the Project we use the same method as Crosbie et al. (2010) where there is a single relationship between rainfall and recharge for each soil+climate group for each cover type. In the Project with many priority sites covering important groundwater source features, there is more than a single site in most soil+climate groups, which lead to the development of relationships using amalgamated data as shown in Table 2-4. This method is relatively straightforward to implement in a GIS environment, using the base soil and climate data. However, in cases where the different sites do not fall reasonably on the same regression line, alternate and more complex interpolation methods could have been employed. For example, the Chromosol in climate zone 5 has four modelled sites with annual rainfall between 600 and 1600 mm/year. An alternate interpolation method might be to use the regression coefficients of the nearest site in the soil+climate group, although that might create distinct break lines in the interpolated recharge if the coefficients are different enough between sites. Another alternative would be to estimate recharge from all site regressions and then use a weighted average to generate a final value. Such methods are more complex and may introduce errors or biases that are difficult to quantify.

2.4 Results

2.4.1 Site-based diffuse recharge

The water balance from WAVES has been summarised for 28 priority sites to an annual average showing rainfall and recharge in Table 2-3. Future NARCliM rainfall decreases compared to stochastic current rainfall in all cases except for 58001 Ballina, while for several high rainfall sites the reduction is very small, less than 10 mm per year on average.

Annual average recharge also decreases with reduced rainfall, except in the case of 58001 Ballina where it increases with rainfall. Some of the high rainfall sites with small reductions of annual rainfall have changes in rainfall seasonally that result in slightly increased recharge under both grass and tree cover, e.g. 58037 Lismore, 58080 Wooli, 58088 Ettrick and 59040 Coffs Harbour. These sites are all on the east coast of NSW outside the Murray-Darling Basin and have average rainfall greater than 1100 mm/year. There is no evidence to suggest these outcomes should be rejected, rather they point to the complexity of future climate seasonality as it interacts with vegetation cover.

Linear least-squares regressions were developed between rainfall and recharge at each priority site, based on 100 individual pairs representing each 100-year average in the 10,000-year sequence (Table 2-4). See examples in Appendix A . For interpolation purposes, all sites with matching soil group and climate zone were amalgamated and a common regression equation developed for their combined data.

Due to some soil+climate groups being small, or not associated with major groundwater sources targeted with site selection, not all actual groups were modelled. For this reason, a mapping was developed so that existing linear recharge model parameters could be used in these other groups, with the most similar soil hydraulic properties. The details of these mappings are presented in Table 2-5.

Table 2-3 Annual average modelled rainfall (mm) and recharge (mm) at priority sites for three land covers

Site ID	Name	Modelled Rainfall		Modelled Recharge					
				Bare		Grass		Tree	
		Historical	Future	Historical	Future	Historical	Future	Historical	Future
46037	Tibooburra	228.6	212.2	20.6	18.2	17.4	16.2	8.7	9.3
47016	Lake Victoria	260.3	237.9	26.5	19.6	6.4	4.1	0.1	0.1
48013	Bourke	347.6	303.7	30.4	21.7	7.1	4.3	0.1	0.1
49002	Balranald	324.7	294.2	41.1	31.3	10.8	7.2	0.1	0.1
50020	Warroo	462.2	411.6	89.6	59.8	45.9	33.6	12.3	9.3
51048	Trangie	507.4	449.4	309.4	259.5	217.3	177.2	45.5	37.0
53034	Wee Waa	563.2	489.9	59.2	29.8	24.1	12.7	0.4	0.1
53048	Moree	580.1	521.9	65.8	43.0	30.1	20.8	0.3	0.2
54135	Beebo	607.2	543.2	330.0	282.8	202.5	167.8	44.0	38.8
55031	Manilla	650.4	628.9	365.9	340.0	222.3	205.1	46.6	44.2
58001	Ballina	1804.5	1877.4	925.0	954.4	435.6	486.2	125.1	174.3
58037	Lismore	1329.4	1324.6	426.2	410.7	136.4	141.8	3.6	5.8
58059	Ulmarra	1030.8	980.4	701.1	651.3	458.0	425.0	162.1	151.7
58080	Wooli	1355.9	1347.1	829.4	815.0	498.9	504.3	167.8	185.7
58088	Ettrick	1099.9	1095.9	741.4	731.3	456.6	461.5	181.7	196.1
59040	Coffs Harbour	1671.8	1663.9	1296.1	1283.8	891.3	897.6	435.3	460.9
59047	Crescent Head	1457.7	1420.0	679.5	637.9	294.8	290.0	76.7	85.3
59120	Thumb Creek	1464.9	1406.4	1091.7	1033.4	706.5	674.1	302.5	303.0
60017	Hannam Vale	1473.5	1395.0	977.8	903.3	622.1	582.2	237.3	234.7
63036	Jenolan	980.9	883.1	577.9	483.5	258.7	207.8	60.1	42.6
63066	Orange	862.7	773.1	469.8	385.0	239.4	186.4	56.5	32.6
65019	Gooloogong	612.2	567.9	369.4	329.4	222.5	195.3	60.2	50.3
69002	Bega	860.4	807.7	475.4	430.1	322.6	291.3	120.9	107.0
70072	Queanbeyan	593.2	541.1	245.6	203.0	129.0	104.3	12.8	8.5
72022	Holbrook	688.3	632.2	267.9	215.9	114.3	87.3	57.6	39.4
73015	Gundagai	700.8	641.3	448.1	394.8	250.4	214.8	73.1	57.9
74008	Grong Grong	461.5	435.6	104.3	82.9	45.8	37.7	14.7	11.1
75032	Hillston	393.0	345.4	60.6	40.0	32.1	24.2	9.6	8.2

Table 2-4 Linear regression slope and intercept values for each soil group+climate zone, climate scenario and cover

Zone	Soil	Historical						Future						Stations
		Bare		Grass		Tree		Bare		Grass		Tree		
		Slope	Intc	Slope	Intc	Slope	Intc	Slope	Intc	Slope	Intc	Slope	Intc	
2	Kandosol	0.7538	-73.02	0.6469	-110.91	0.2259	-69.12	0.7406	-73.39	0.6425	-111.56	0.2447	-73.00	51048
2	Sodosol	0.3278	-57.87	0.1254	-13.15	0.0230	2.42	0.2648	-42.77	0.0988	-6.78	0.0092	6.26	46037, 50020, 74008, 75032
2	Tenosol													47007
2	Vertosol	0.1000	1.55	0.0294	-1.05	0.00005	0.005	0.1072	-5.68	0.0285	-2.75	0.00004	-0.003	47016, 48013, 49002
4	Dermosol	0.9077	-305.56	0.7914	-358.30	0.5268	-332.42	0.8970	-294.42	0.7792	-338.09	0.4933	-291.52	59002
4	Kandosol	0.8506	-259.82	0.3510	-76.10	0.1302	-62.58	0.8126	-238.04	0.3154	-64.82	0.1019	-46.73	63036, 63066, 70072
4	Tenosol	0.9159	-371.77	0.7343	-459.86	0.4870	-480.22	0.9046	-358.65	0.7259	-430.41	0.4898	-448.58	60017
5	Chromosol	0.8678	-172.47	0.6368	-195.04	0.3582	-178.22	0.8623	-170.80	0.6445	-197.21	0.3781	-183.85	58088, 59040, 65019, 73015
5	Dermosol	0.8768	-203.20	0.6127	-173.08	0.2910	-137.72	0.8545	-188.40	0.6018	-165.83	0.2748	-118.94	54135, 55031, 58027, 58059
5	Hydrosol	0.7031	-344.51	0.4105	-304.29	0.1503	-144.29	0.6890	-339.77	0.4305	-321.68	0.1997	-199.43	58001, 59047
5	Podosol	0.9070	-400.52	0.7000	-450.28	0.4230	-405.70	0.9014	-399.27	0.7081	-449.57	0.4606	-434.67	58080
5	Sodosol	0.6962	-211.30	0.4235	-177.19	0.2947	-145.29	0.6500	-195.00	0.3705	-146.99	0.2351	-109.27	72022
5	Tenosol	0.9064	-235.96	0.7758	-429.88	0.5332	-478.61	0.9037	-237.64	0.7765	-418.09	0.5497	-470.05	59120
5	Vertosol	0.4789	-211.06	0.1447	-55.72	0.0043	-2.09	0.4563	-194.18	0.1531	-60.79	0.0070	-3.43	53034, 53048, 58037

Table 2-5 Mapping of small and missing soil+climate groups to WAVES modelled combinations

Code	Climate Zone	Soil Group	Mapped Code	Mapped Climate	Mapped Soil
208	Arid	Chromosol	207	Arid	Sodosol
209	Arid	Calcarosol	212	Arid	Kandosol
213	Arid	Rudosol	212	Arid	Kandosol
214	Arid	Tenosol	212	Arid	Kandosol
403	Equiseasonal - warm	Podosol	503	Equiseasonal - hot	Podosol
404	Equiseasonal - warm	Vertosol	505	Equiseasonal - hot	Hydrosol
405	Equiseasonal - warm	Hydrosol	511	Equiseasonal - hot	Dermosol
406	Equiseasonal - warm	Kurosol	412	Equiseasonal - warm	Kandosol
407	Equiseasonal - warm	Sodosol	508	Equiseasonal - hot	Chromosol
408	Equiseasonal - warm	Chromosol	508	Equiseasonal - hot	Chromosol
410	Equiseasonal - warm	Ferrosol	411	Equiseasonal - warm	Dermosol
506	Equiseasonal - hot	Kurosol	508	Equiseasonal - hot	Chromosol
510	Equiseasonal - hot	Ferrosol	508	Equiseasonal - hot	Chromosol
512	Equiseasonal - hot	Kandosol	412	Equiseasonal - warm	Kandosol
513	Equiseasonal - hot	Rudosol	414	Equiseasonal - warm	Tenosol

2.4.2 Upscaled diffuse recharge

The relative change in recharge between the historical and future WAVES simulations for the selected sites and each vegetation class has been upscaled, using the regression relationships discussed above, to produce maps of projected recharge change across NSW. The annual vegetation class has been estimated as the mean recharge of the bare ground and perennial grass WAVES regression parameters. Figure 2-4 shows the mean annual rainfall change from historical to future (a dry scenario produced by averaging three WRF simulations downscaling the CSIRO Mk-3.0 GCM). Estimated annual recharge changes, from the upscaling regression relationships, are shown in Figure 2-5 and are presented on a groundwater source basis in Figure 2-6.

The relative recharge changes are greater than the rainfall changes, as expected given the non-linear residual processes involved. At the scale of the downscaled rainfall (5 km) some areas show rainfall and recharge increases, e.g. in the south-east of the State (Figure 2-5). When averaged on a groundwater source basis, such extreme changes are much reduced (Figure 2-6).

Table 2-6 lists rainfall and recharge changes at the groundwater source scale, with only 4 of the 125 sources showing an increase in recharge. There is an average −14% decrease in recharge, with the elasticity of recharge change to rainfall change averaging 2.4 (Figure 2-7).

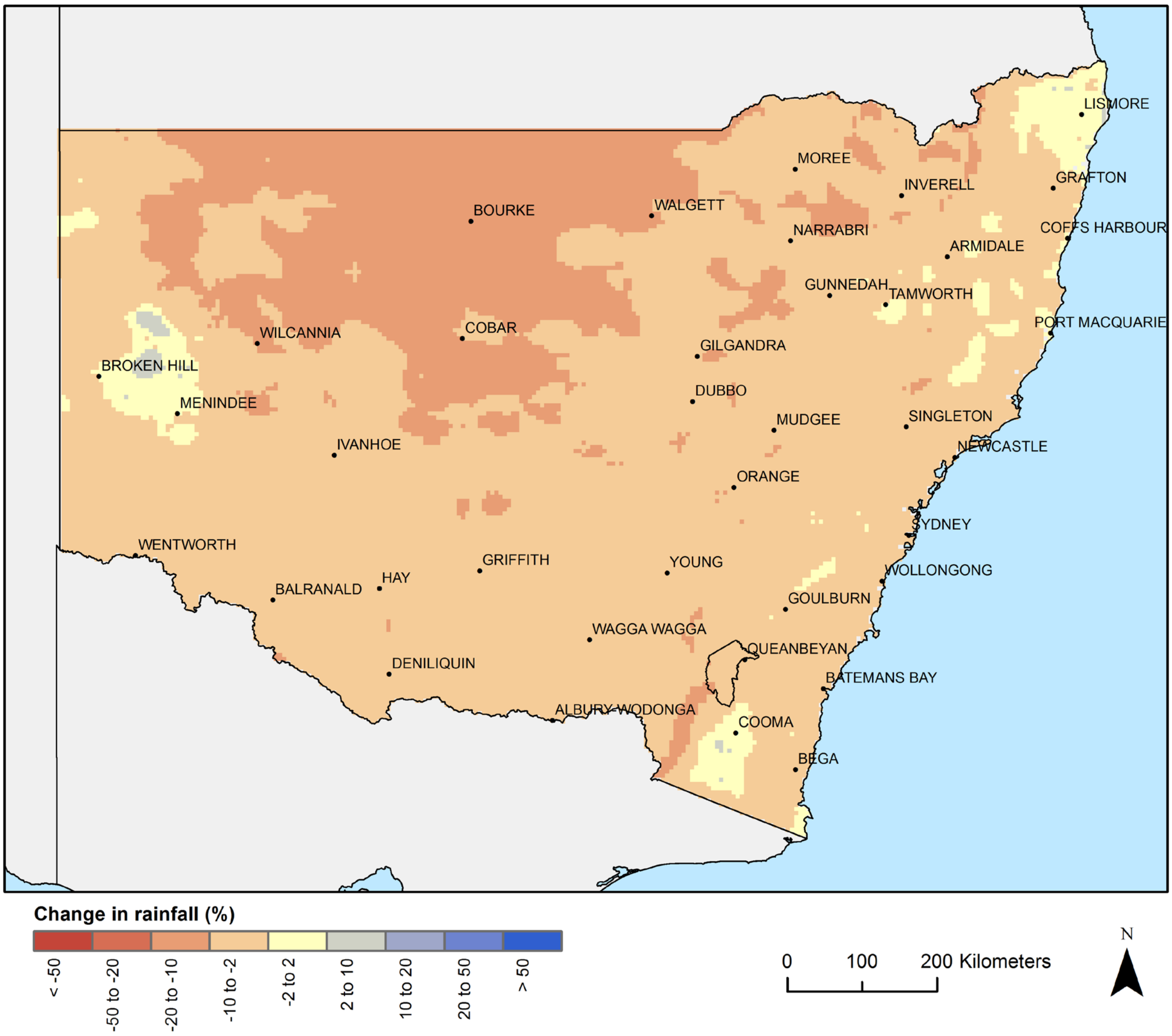


Figure 2-4 Future annual average rainfall change (%) for a 2060 to 2079 future relative to a 1990 to 2009 base (Evans et al. 2014)

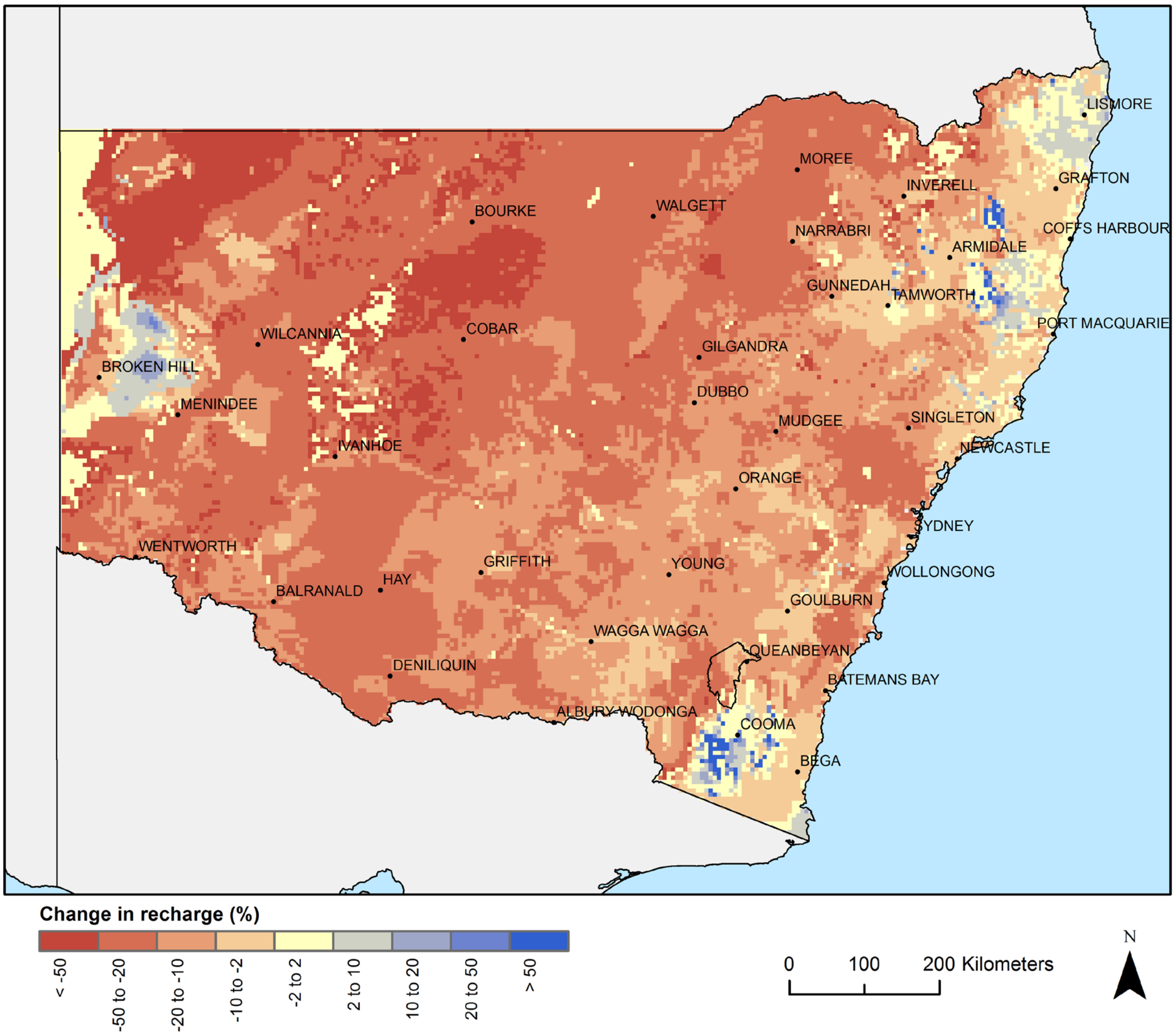


Figure 2-5 Future annual average recharge change (%)

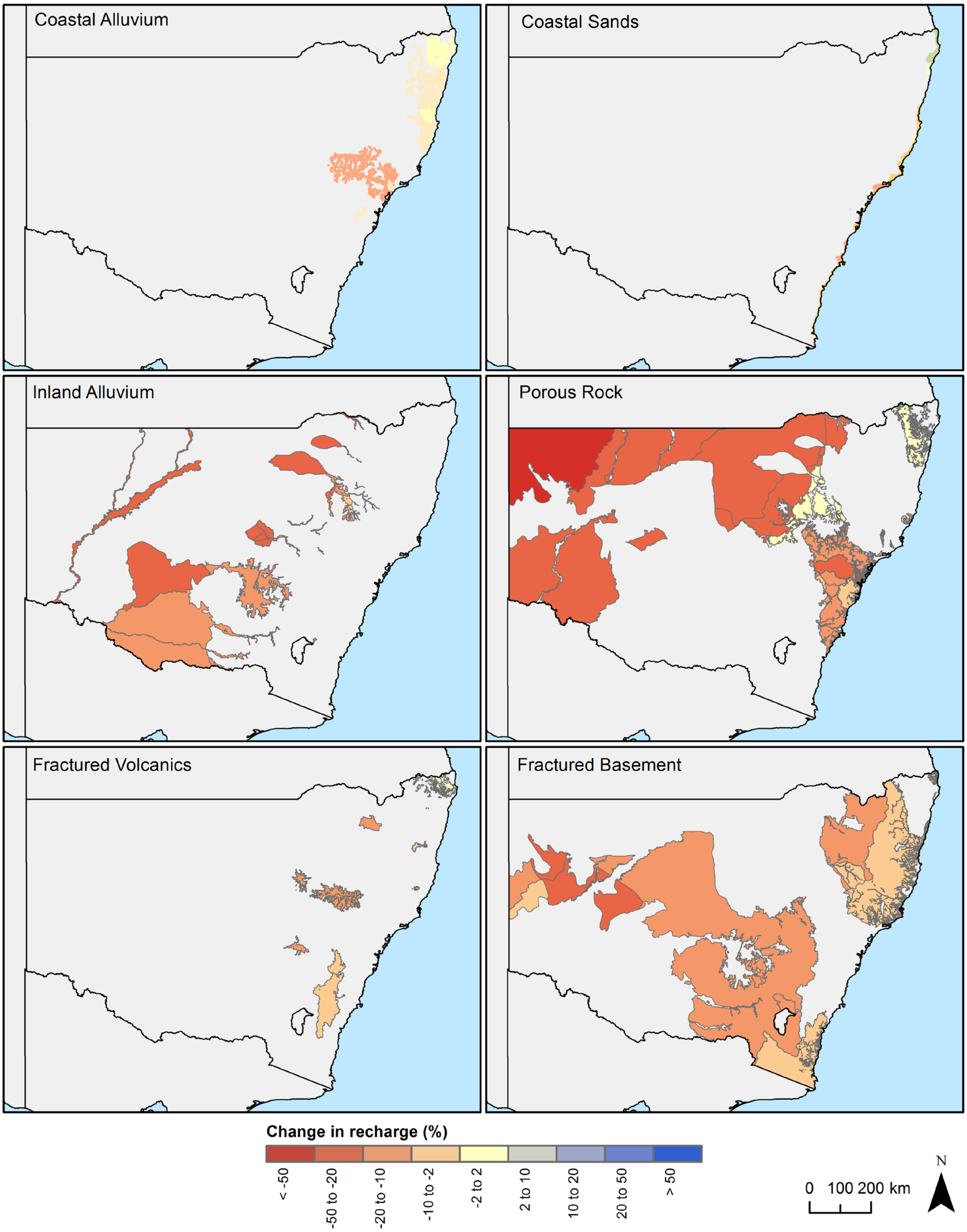


Figure 2-6 Future annual average recharge change on a groundwater source basis (%). [Note: the size of the coastal alluvium and coastal sands groundwater sources have been exaggerated to ensure they can be seen on the figure.]

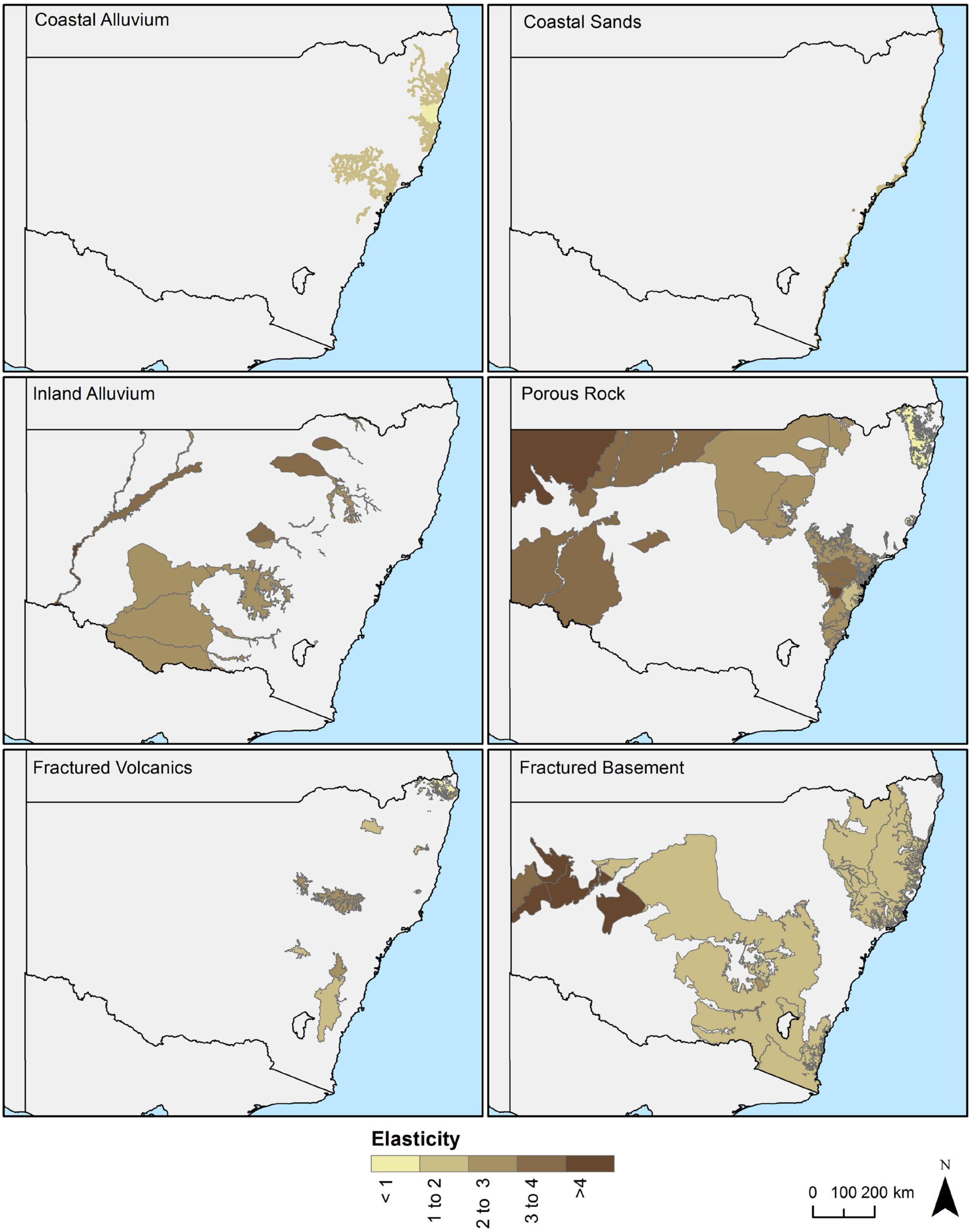


Figure 2-7 Recharge elasticity to rainfall change (% change in recharge for a 1% change in rainfall). [Note: the size of the coastal alluvium and coastal sands groundwater sources have been exaggerated to ensure they can be seen on the figure.]

Table 2-6 Upscaled changes to rainfall and recharge and the recharge elasticity to rainfall change (%)

Groundwater Source	Rainfall change (%)	Recharge change (%)	Elasticity
Adelaide Fold Belt MDB	-1.4	-6.2	4.4
Adelaide Fold Belt North Western	-4.7	-16.6	3.5
Alstonville Basalt Plateau	0.7	2.1	2.9
Bell Alluvial	-8.5	-14.6	1.7
Bellinger River Coastal Floodplain Alluvial	-3.3	-3.1	0.9
Bellinger-Nambucca Coastal Sands	-1.3	-3.9	2.9
Belubula Valley Alluvial	-5.5	-11.1	2.0
Billabong Alluvium	-6.3	-18.6	2.9
Botany Sands	-3.0	-5.9	1.9
Brunswick River Coastal Floodplain Alluvial	0.0	1.1	26.8
Bulahdelah Sandstone	-4.6	-5.3	1.2
Bungendore Alluvial	-7.9	-13.0	1.6
Castlereagh Alluvial	-7.8	-15.5	2.0
Clarence Coastal Sands	-0.1	0.3	-2.1
Clarence Morton Basin	-2.6	-1.8	0.7
Clarence River Coastal Floodplain Alluvial	-3.8	-4.7	1.2
Coastal Macleay Floodplain Alluvial	-2.7	-3.5	1.3
Coastal Nambucca Floodplain Alluvial	-2.4	-1.7	0.7
Coffs Harbour Coastal Sands	-1.6	-0.1	0.1
Comboyne Basalt	-4.2	-6.0	1.4
Coopers Creek Alluvial	0.0	0.1	-4.5
Coxs River Fractured Rock	-4.2	-9.5	2.3
Cudgegong Alluvial	-7.8	-19.9	2.6
Currabubula Alluvial	-4.0	-11.0	2.8
Dorrigo Basalt	-5.3	-8.0	1.5
Eastern Recharge	-9.2	-22.0	2.4
GAB Central Shallow (MDB)	-10.9	-38.4	3.5
GAB Central Shallow (North Western)	-8.7	-51.7	5.9
GAB Surat Shallow	-9.7	-25.5	2.6
GAB Warrego Shallow	-13.4	-40.4	3.0
Gloucester Basin	-3.7	-3.9	1.1
Goulburn Fractured Rock	-5.2	-9.7	1.9
Great Lakes Coastal Sands	-3.7	-4.9	1.3
Gundagai	-5.2	-10.1	2.0
Gunnedah - Oxley Basin MDB	-7.1	-14.9	2.1
Hastings Coastal Sands	-1.5	-1.1	0.8
Hastings River Coastal Floodplain Alluvial	-4.4	-7.1	1.6
Hawkesbury Alluvium	-4.4	-7.7	1.8
Hawkesbury to Hunter Coastal Sands	-6.6	-9.9	1.5
Hunter Regulated River Alluvial	-6.3	-11.4	1.8
Inverell Basalt MDB	-7.9	-12.4	1.6
Kanmantoo Fold Belt North Western	-7.4	-37.4	5.0

Groundwater Source	Rainfall change (%)	Recharge change (%)	Elasticity
Kanmantoo Fold Belt MDB	-6.4	-26.5	4.1
Kulnura Mangrove Mountain	-8.0	-22.8	2.8
Kyeamba Creek GW source	-5.0	-16.4	3.3
Lachlan Fold Belt Coast	-4.7	-6.2	1.3
Lachlan Fold Belt MDB	-7.9	-15.7	2.0
Liverpool ranges basalt coast	-6.1	-14.7	2.4
Liverpool ranges basalt MDB	-7.0	-16.8	2.4
Lorne Basin	-3.8	-3.6	1.0
Lower Darling Alluvial	-3.9	-25.0	6.5
Lower Gwydir	-7.9	-26.8	3.4
Lower Lachlan	-6.9	-20.7	3.0
Lower Macquarie Zone 1	-9.1	-23.0	2.5
Lower Macquarie Zone 2	-8.0	-23.8	3.0
Lower Macquarie Zone 3	-7.8	-25.2	3.2
Lower Macquarie Zone 4	-8.6	-28.7	3.3
Lower Macquarie Zone 5	-8.5	-26.0	3.1
Lower Macquarie Zone 6	-9.1	-20.0	2.2
Lower Murray Shallow	-6.9	-19.6	2.9
Lower Murrumbidgee Shallow	-6.8	-18.8	2.8
Lower Namoi	-8.9	-30.1	3.4
Macintyre Alluvial	-9.7	-26.1	2.7
Macleay Coastal Sands	-2.6	-3.6	1.4
Manilla Alluvial	-3.2	-4.6	1.5
Manning-Camden Haven Coastal Sands	-3.7	-6.8	1.8
Maroota Tertiary Sands	-7.7	-21.0	2.7
Metropolitan Coastal Sands	-6.4	-10.3	1.6
Mid Murrumbidgee Zone 3	-4.2	-11.9	2.8
New England Fold Belt Coast	-4.4	-6.5	1.5
New England Fold Belt MDB	-7.7	-13.4	1.7
North Coast Volcanics	-0.5	-0.4	0.8
NSW Border Rivers Downstream Keetah Bridge Alluvial	-9.6	-25.0	2.6
NSW Border Rivers Upstream Keetah Bridge Alluvial	-7.7	-15.9	2.0
Orange Basalt	-8.2	-14.7	1.8
Ottleys Creek Alluvial	-9.8	-26.3	2.7
Oxley Basin coast	-6.9	-16.7	2.4
Paroo Alluvial	-12.3	-49.7	4.0
Peel alluvium	-2.8	-4.1	1.5
Peel fractured rock	-4.3	-5.9	1.4
Quipolly alluvial	-4.9	-11.5	2.4
Quirindi Alluvial	-4.1	-8.6	2.1
Richmond Coastal Sands	0.8	5.9	7.0
Richmond Regulated Alluvial	-0.2	1.6	-6.8

Groundwater Source	Rainfall change (%)	Recharge change (%)	Elasticity
South East Coastal sands	-4.4	-9.0	2.1
Southern Recharge	-8.7	-23.7	2.7
Stockton	-6.2	-11.9	1.9
Stuarts Point	-2.4	-3.8	1.6
Sydney Basin Blue Mountains	-3.6	-16.1	4.4
Sydney Basin Central	-5.1	-9.8	1.9
Sydney Basin Coxs River	-5.3	-8.4	1.6
Sydney Basin MDB	-7.1	-14.2	2.0
Sydney Basin Nepean	-4.5	-10.2	2.3
Sydney Basin North	-6.5	-21.7	3.3
Sydney Basin North Coast	-6.8	-15.4	2.3
Sydney Basin Richmond	-5.3	-16.9	3.2
Sydney Basin South	-7.2	-15.3	2.1
Sydney Basin South Coast	-5.7	-14.7	2.6
Talbragar Alluvial	-5.7	-13.3	2.3
Tomago	-6.4	-12.1	1.9
Tomaree	-5.2	-8.2	1.6
Tweed-Brunswick Coastal Sands	1.3	3.5	2.7
Upper Darling Alluvial	-11.3	-37.5	3.3
Upper Gwydir Alluvial	-8.8	-14.7	1.7
Upper Lachlan Alluvial	-6.0	-16.6	2.8
Upper Macquarie Alluvial	-8.8	-18.2	2.1
Upper Murray	-5.9	-14.9	2.5
Upper Namoi Zone 1	-6.2	-14.7	2.4
Upper Namoi Zone 10	-6.8	-16.0	2.3
Upper Namoi Zone 11	-4.6	-14.0	3.0
Upper Namoi Zone 12	-4.8	-7.8	1.6
Upper Namoi Zone 2	-8.1	-23.5	2.9
Upper Namoi Zone 3	-3.0	-8.4	2.8
Upper Namoi Zone 4	-5.9	-17.2	2.9
Upper Namoi Zone 5	-7.0	-19.3	2.8
Upper Namoi Zone 6	-6.5	-16.4	2.5
Upper Namoi Zone 7	-6.0	-15.0	2.5
Upper Namoi Zone 8	-4.1	-10.0	2.5
Upper Namoi Zone 9	-6.9	-16.7	2.4
Wagga Wagga Alluvial	-4.4	-8.5	1.9
Warrego Alluvial	-12.7	-33.7	2.7
Warrumbungle Basalt	-9.3	-19.8	2.1
Western Murray Porous Rock	-5.7	-22.7	4.0
Yass Catchment	-7.6	-12.8	1.7
Young granite	-4.7	-11.4	2.4

Littleboy et al. (2015) produced estimates of recharge changes in NSW, also using NARCliM regional climate projections. In contrast to our study's use of only one GCM's downscaled projections (CSIRO MK3.0, average of three versions of WRF), they used all twelve NARCliM simulations (four GCMs downscaled by three versions of WRF). They coupled the PERFECT one-dimensional water balance model with the HYDRUS 2D model to account for lateral water movement and assumed the partitioned vertical component to be recharge.

Littleboy et al. (2015) present estimated recharge changes as absolute (mm) changes both spatially (e.g. Figure 19 in Littleboy et al. 2015) and averaged across NSW (e.g. Figure 21 in Littleboy et al. 2015). Thus, it is difficult to compare the magnitude of changes estimated by Littleboy et al. (2015) to those produced here without access to the modelling results. Littleboy et al. (2015) results for the CSIRO-Mk3.0 WRF runs used in this study produce less recharge, whereas results from the other nine runs produced more recharge.

The change in recharge results from the Barron et al (2011) can be compared to those made here however there are significant differences in the methodologies. The Barron et al (2011) used 16 CMIP3 A2 scenario GCM runs with downscaling using daily scaling for global warming of +1.0, +1.7 and +2.4°C corresponding to low, medium and high global warming for 2050 relative to 1990. The top two panels of Figure 2-8 both use the CSIRO Mk3.0 GCM but differ in their downscaling to come up with very different change in recharge results. The results from this study only have small areas of the north east and south east of the state with increased recharge whereas the Barron et al (2011) study has most of the eastern portion of the state with projections of increased recharge. An increase in recharge projected in the west of the state in this study is not replicated in the same location in the earlier study. The dry future climate from Barron et al (2011) has the entirety of the state with a decrease in recharge whereas the median future climate has most of the eastern half of the state with a projected increase in recharge. The results of the present study fall in between the median and dry futures of Barron et al (2011).

There is a great deal of uncertainty around the projection of recharge under a future climate, this uncertainty can be investigated through the use of multiple GCMs, downscaling methods and hydrological models as seen in the comparison of results from this study, Littleboy et al (2015) and Barron et al (2011).

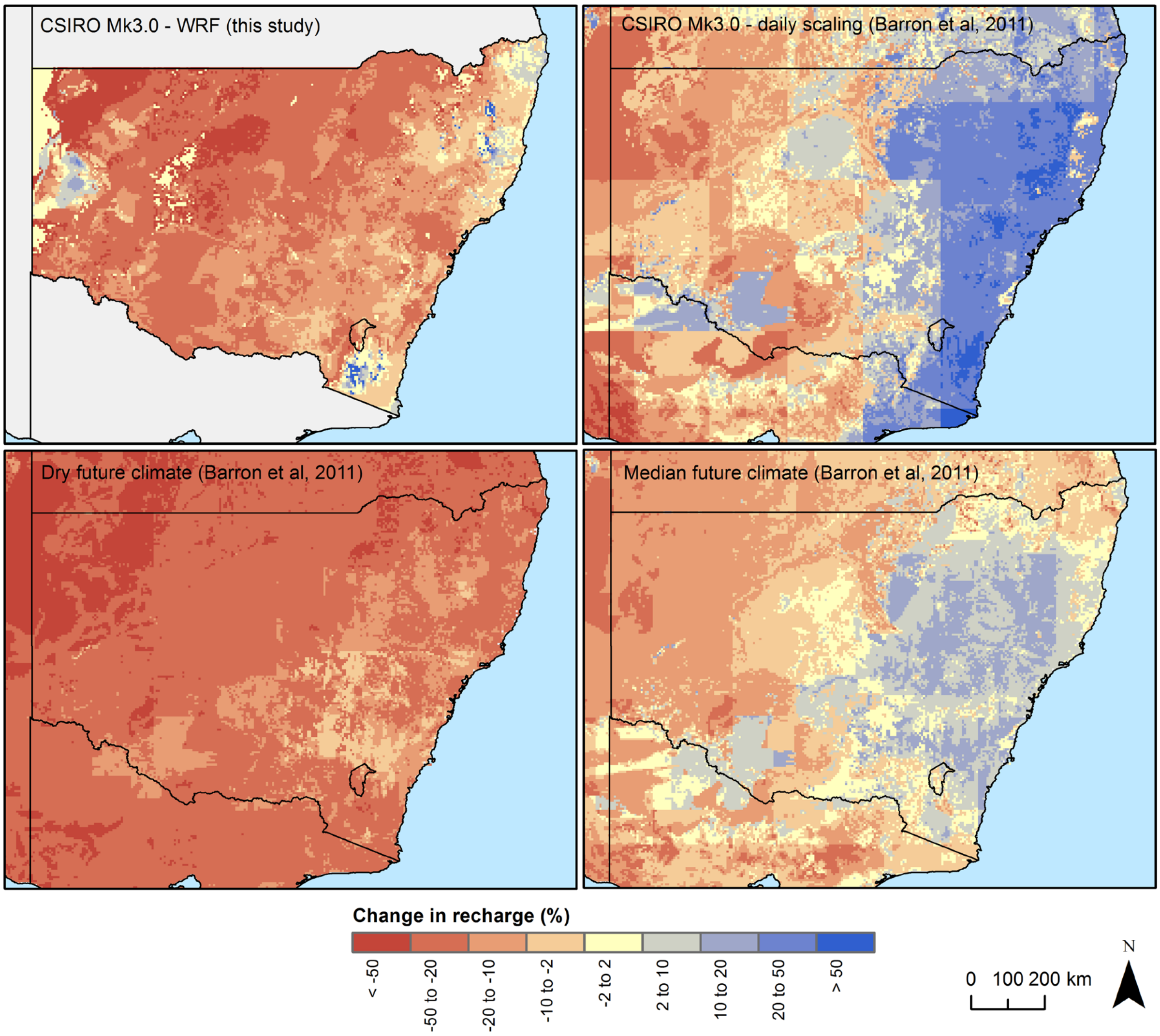


Figure 2-8 Comparison of change in recharge from this study to previous study by Barron et al (2011)

2.5 Conclusions

The assessment of estimated future changes to diffuse recharge has identified the following:

- Given the selection of a dry climate change scenario, the diffuse recharge estimates at point scale and upscaled to the groundwater source level are almost all indicating a decrease in diffuse recharge across NSW, with an average change in diffuse recharge of −14% and ranging from −52% to +6% across the 125 groundwater sources (Table 2-6).
- The spatial pattern in diffuse recharge change (Figure 2-5; Figure 2-6) follows the rainfall change pattern (Figure 2-4), with relatively larger declines in the west and north and smaller declines along the coast, with the least percentage decline in the north-east. The larger relative declines are in drier, often arid, areas (as seen in elasticity, Figure 2-7) so the absolute magnitude of recharge is low in these regions.
- Interannual and seasonal changes in rainfall distribution, particularly in higher rainfall areas, can result in increases in modelled annual recharge even with decreases in annual average rainfall.

3 Changes to localised recharge

3.1 Introduction

The connection between surface water and groundwater can be broadly split into gaining streams and losing streams. In gaining streams the groundwater is discharging into the stream, in losing streams the surface water is recharging the groundwater. Braaten and Gates (2003) described a generalised case for the Western flowing rivers in NSW whereby: the upland streams are gaining; the narrow alluvial valleys are connected and generally net losing; the wide alluvial plains are losing-disconnected; and, the end of valley confluences with the Murray/Barwon/Darling are generally gaining. The majority of groundwater use is within the narrow alluvial valleys and the wide alluvial plains which are generally losing systems. Within the losing streams, two sources of recharge are considered as localised recharge: in-stream recharge through the bed and banks of the stream; and overbank flooding where the recharge is over the more extensive areas of the floodplain. These recharge processes are especially significant for the big inland alluvial groundwater systems associated with rivers such as the Namoi and Lachlan.

Objectives of this section include:

a. Quantify the impact of climate change on localised recharge across NSW, for (i) in-stream recharge from losing streams and (ii) overbank (flood) recharge

b. Compare magnitudes of localised and diffuse recharge changes and comment on whether groundwater is more/less resilient to climate change than surface water, and by how much

3.2 Methodology

The estimation of the changes in localised recharge between the future and historical climate scenarios requires an assessment of which river reaches are losing reaches and therefore recharging the groundwater. This information was collated for the western flowing rivers in the Murray-Darling Basin by Parsons et al. (2008) but no similar collation has occurred for the eastern flowing coastal rivers. With incomplete information on which streams are losing or gaining, the change in localised recharge has been estimated for all alluvial water sources irrespective of their connection status (i.e. a 50 % reduction in localised recharge to a water source with zero localised recharge is still zero localised recharge).

For the losing reaches of the stream network, the simulated daily flow for the historical and future climate scenarios is required at the downstream gauge. DPE-Water Regional Water Strategies team has recently completed running the historical and future 10,000-year stochastic climate scenarios through the river models to generate this information. The flow duration curves of these simulations are shown in Appendix B for the gauges investigated.

The river models used to generate these daily flow simulations were developed by DPE (IQQM and eWater Source) for quantifying water availability, flows and diversions under varying climate conditions, to inform the development of water sharing arrangements. These river system models are designed to support contemporary water management decisions at basin scales. The models are built from components which are linked, through adding nodes and links, to represent the system to be modelled. Links connect, store and route water passing between nodes. There are many types of nodes to represent places where water can be added, diverted, stored, and recorded (for reporting) in a model, including:

- water sources (supply), such as inflows, storages
- water users (demand), such as crops, towns, industries, the environment
- reporting points, such as gauges and environmental assets.

The river models are made up of component models that are run together to simulate multiple processes within the system, including:

- rainfall–runoff models that converts rainfall into runoff across the landscape
- irrigated crop models that simulate the crop growth cycle, and thus water demand
- storage models that simulate the management of storage water.

Component model parameter estimation uses a combination of parameter values:

- assigned directly, based on measured data, such as where there is surveyed or LIDAR data of on-farm storages
- assigned based on published advice from industry or research
- calibrated by systematically adjusting to match recorded data at the site or of system behaviours, by iteratively checking how well model outputs match recorded data and parameters are adjusted to improve performance.

Model calibration with climate data as the primary inputs is conducted on a reach-by-reach basis using available recorded data such as gauged flows, metered diversions, infrastructure, and crop areas. These individual calibrations are then combined and validated at a whole of river system scale. Further model assembly, data and validation steps are described in detail in DPE reports on a river system basis, e.g. DPIE (2020b). Their use in the development of regional water strategies for NSW, when driven by the new climate scenarios, is described in DPIE (2020c).

For the estimation of in-stream recharge, details of the channel cross-section are required to estimate the wetted perimeter and the rating curve for estimating the stage heights from the modelled flow. These data are available for the gauges investigated from WaterNSW (https://realtimedata.waternsw.com.au/). See example calculation in Appendix C .

For the estimation of overbank flood recharge, the stage height at which the stream overtops the bank is required. An estimate of this is available for the BoM’s flood warning heights for minor, moderate and major flooding (Bureau of Meteorology, 2013).

The details of the method for the estimation of the change in recharge due to climate change for the in-stream and overbank flooding recharge are in the next two sub-sections.

3.2.1 In-stream recharge

Recharge through the stream bed is generally considered as two endmembers (although there is a transition between them): losing disconnected streams and losing connected streams. The losing disconnected stream is the simpler case of the two.

In a losing disconnected stream, the infiltration (I) from the river will only be limited by the conductance of the riverbed, the depth to the water table is too great to limit the infiltration (Brunner et al, 2009). In these circumstances the infiltration can be calculated based on Darcy's law (Crosbie et al., 2014):

$$I = K_c\, WP \left(\frac{0.5h + d_c + h_{mis}}{d_c} \right) t \qquad \textbf{Equation 1}$$

where K_c is the hydraulic conductivity of the clogging layer, WP is the wetted perimeter, h is the stage height, d_c is the depth of the clogging layer, h_{mis} is the soil suction at the base of the clogging layer and t is time. As we don't know the hydraulic conductivity of the clogging layer or its thickness on a whole of river reach basis, our ability to calculate the magnitude of the infiltration is limited. In this case we are interested in the proportional change in the infiltration between the future (F) and historical (H) scenarios:

$$\frac{I_F}{I_H} = \frac{K_c\, WP_F \left(\frac{0.5h_F + d_c + h_{mis}}{d_c} \right) t}{K_c\, WP_H \left(\frac{0.5h_H + d_c + h_{mis}}{d_c} \right) t} \qquad \textbf{Equation 2}$$

If we then make the assumption that K_c and d_c do not change between the two scenarios and that d_c and h_{mis} are very small, we are left with the ratio of future to historical infiltration equal to the ratio of the future to historical wetted perimeter multiplied by the stage height:

$$\frac{I_F}{I_H} = \frac{WP_F\, h_F}{WP_H\, h_H} \qquad \textbf{Equation 3}$$

If the infiltration through the riverbed is assumed to become recharge, then the change in in-stream recharge as a percentage becomes:

$$\Delta R_{IS}(\%) = 100 \left(\frac{(WP_F\, h_F) - (WP_H\, h_H)}{WP_H\, h_H} \right) \qquad \textbf{Equation 4}$$

This is illustrated in Figure 3-1 for a case where there is a reduction in flow in a future scenario and as a consequence there is a reduction in the stage height and the wetted perimeter. The calculation of WP x h (Equation 4) is conducted daily before being averaged annually to allow the calculation of an annual change in recharge. The annual changes are not reported here and are averaged over the 10,000 year time series.

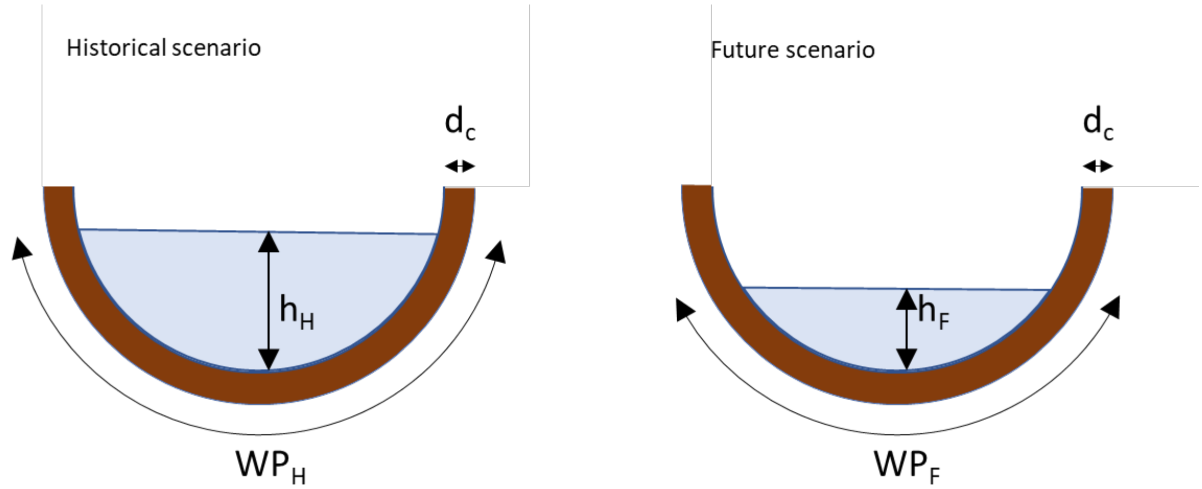


Figure 3-1 Schematic of a reduction in stage height and wetted perimeter for a future scenario with a reduction flow compared to a historical scenario

In a losing connected stream, the pressure at the base of the clogging layer (γ_p) is above atmospheric pressure and so Equation 1 becomes:

$$I = K_c \, WP \left(\frac{0.5h + d_c - \gamma_p}{d_c} \right) t \qquad \text{Equation 5}$$

If we make the same assumptions that were made for the losing disconnected case, with the additional assumption that the water table does not change position between scenarios from being very close to the base of the clogging layer (i.e. γ_p does not change and is very small) then the losing connected case collapses back to the same result as the losing disconnected case and the change in recharge between the historical and future scenarios can be calculated using Equation 4. This is a gross simplification that will lead to an error in the change in recharge if the water table depth beneath the river is reduced under a future climate, this is because for a given stage height the infiltration will change linearly with a change in water table position (Brunner et al., 2009). Our method for testing this assumption follows.

3.2.2 Sensitivity analysis of in-stream recharge to variable water table

Our original assumption was that Equation 5 collapses back to Equation 4 as we assumed that the groundwater level was at the bed of the stream and did not change (i.e., the case shown in Figure 3-1). In a losing connected stream, the groundwater level is generally above the bed of the stream but below the level of the stream stage (Figure 3-2) (by definition in the case of a losing stream there is a downward head gradient from the stream to the groundwater).

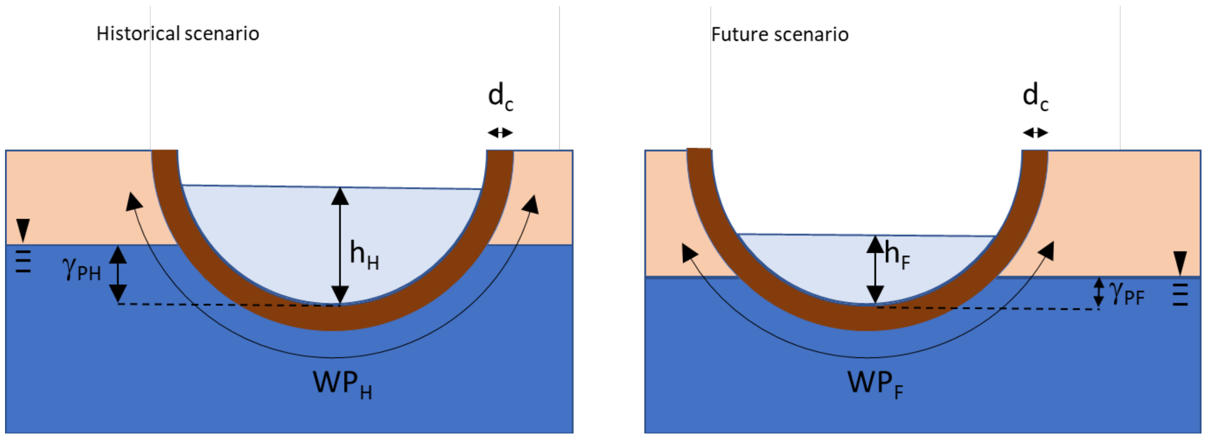


Figure 3-2 Conceptual cross-section of a losing connected stream for the historical and drier future climate scenarios

If this assumption about the groundwater level is relaxed, then the proportional change in the infiltration becomes:

$$\frac{I_F}{I_H} = \frac{K_c\, WP_F \left(\dfrac{h_F + d_c - \gamma_{pF}}{d_c}\right) t}{K_c\, WP_H \left(\dfrac{h_H + d_c - \gamma_{pH}}{d_c}\right) t} \qquad \text{Equation 6}$$

where K_C doesn't change between scenarios and d_c is assumed to be extremely small and also doesn't change between scenarios, this simplifies to:

$$\Delta R_{IS}(\%) = 100\left(\frac{\left(WP_F\,(h_F - \gamma_{pF})\right) - \left(WP_H(h_H - \gamma_{pH})\right)}{WP_H(\,h_H - \gamma_{pH})}\right) \qquad \text{Equation 7}$$

In a connected system the groundwater level will also generally rise and fall with the stream stage, this means that γ_p has some dependency on h. It is proposed to test the assumption of the groundwater level for three cases:

1. The groundwater level is equal between the historical and future scenarios but has a dependency on the stream stage. In this case $\gamma_{pH} = \gamma_{pF}$ and γ_{pH} is a linear function of h_H: $\gamma_{pH} = \alpha.\ h_H$, where α takes the value of 0.1, 0.2 and 0.5.
2. The groundwater level is different between the historical and future scenarios but dependent upon the stream stage. In this case $\gamma_{pH} = \alpha.h_H$ and $\gamma_{pF} = \alpha.H_F$, where α takes the value of 0.1, 0.2 and 0.5.
3. The groundwater level is different between the historical and future scenarios but there is also an additional regional groundwater level decline due to decreased diffuse recharge or additional extraction. In this case $\gamma_{pH} = \alpha.h_H$ and $\gamma_{pF} = \alpha.H_F\text{-}\beta$, where α takes the value of 0.1, 0.2 and 0.5 and β is a regional groundwater level decline of 0.1, 0.5 and 1.0 m.

This sensitivity analysis was conducted at two representative losing connected reaches at 419001 Namoi River at Gunnedah and 410001 Murrumbidgee River at Wagga Wagga.

3.2.3 Overbank recharge

Doble et al., (2012) showed that the recharge due to overbank flooding can be estimated as the minimum of the potential infiltration and the ability of the aquifer to store and transmit water away from the floodzone. At its simplest, recharge is at a maximum rate when the water table is deep and there is storage available and then the recharge rate decreases when the water table rises to the surface and becomes limited by the groundwater flow in the horizontal direction. Assuming that there is storage available in the aquifer, the overbank recharge can be estimated from Darcy's law in a similar manner to the in-stream recharge (Doble et al., 2012):

$$I = K_c\, x_w \left(\frac{h_w}{d_c} + 1\right) t_w \qquad \text{Equation 8}$$

where x_w is the width of the flooding, h_w is the depth of the flooding across the floodplain and t_w is the duration of the flooding in days. As with the instream recharge we do not know the hydraulic conductivity of the floodplain soils or the thickness of the clogging layer across the floodplain at the landscape scale so we cannot estimate the magnitude of the infiltration. There is the further complication that we do not know the width or depth of the flooding. While remote sensing can be used to generate the area of flooding (Mueller et al., 2016), and this has been used to estimate recharge from flooding (Doble et al, 2014), it can only be applied retrospectively to historical events. For predictive modelling using the stochastic scenarios a model is needed that relates river flow to flood extent and depth (e.g. Teng et al., 2019), with such work currently being undertaken across the MDB and likely to become available over the next few years. Until the results of such detailed modelling are available, we can also use the simulated volume of overbank flow as a method to derive change in the overbank recharge (ΔR_{OB}):

$$\Delta R_{OB}(\%) = 100\left(\frac{\left[x_{w_F}\left(\frac{h_{w_F}}{d_c}+1\right)\right] - \left[x_{w_H}\left(\frac{h_{w_H}}{d_c}+1\right)\right]}{\left[x_{w_H}\left(\frac{h_{w_H}}{d_c}+1\right)\right]}\right) \qquad \text{Equation 9}$$

If d_c is assumed to be very small compared to h_w then:

$$d_c \to 0, \frac{\left[x_{w_F}\left(\frac{h_{w_F}}{d_c}+1\right)\right] - \left[x_{w_H}\left(\frac{h_{w_H}}{d_c}+1\right)\right]}{\left[x_{w_H}\left(\frac{h_{w_H}}{d_c}+1\right)\right]} \to \frac{\left[x_{w_F}.h_{w_F}\right] - \left[x_{w_H}.h_{w_{FH}}\right]}{\left[x_{w_H}.h_{w_{FH}}\right]} \qquad \text{Equation 10}$$

then we are left with:

$$\Delta R_{OB}(\%) = 100\left(\frac{\left[x_{w_F}.h_{w_F}\right] - \left[x_{w_H}.h_{w_H}\right]}{\left[x_{w_H}.h_{w_H}\right]}\right) \qquad \text{Equation 11}$$

We still don't know the extent of the flooding (x_w) or the depth of flooding on the floodplain (h_w) but the product of these two unknowns is the volume of water on the floodplain (Q_{FP}).

$$Q_{FP} = x_w . h_w \qquad \text{Equation 12}$$

From the rating curve we know the flow at bankfull (Q_{BF}) so can assume that the volume of water on the floodplain is any flow under overbank conditions (Q_{OB}) in excess of the bankfull flow (Figure 3-3):

$$Q_{FP} = Q_{OB} - Q_{BF} \qquad \text{Equation 13}$$

This is subject to the constraint that $Q_{FP} = 0$ when $Q<Q_{BF}$. Equation 13 is assuming that the floodplain does not have any storage and that the daily flowrate above bankfull is equal to the volume of water on the floodplain for that day. If Equation 13 is substituted into Equation 12, and then Equation 11, we have

$$\Delta R_{OB}(\%) = 100\left(\frac{[Q_{OB_F} - Q_{BF}] - [Q_{OB_H} - Q_{BF}]}{[Q_{OB_H} - Q_{BF}]}\right) \qquad \text{Equation 14}$$

The change in recharge due to overbank flooding is calculated as a long term average over the 10,000 years of simulation therefore reporting only a single value for each gauging station.

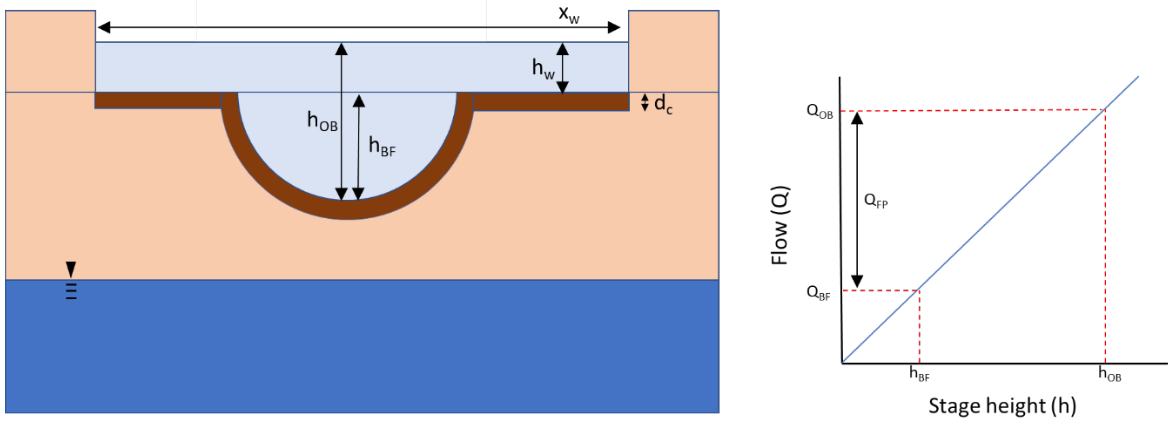


Figure 3-3 Not knowing x_w and h_w (Equation 11) becomes irrelevant as we can assume that their product is equal to Q_{FP} which can be estimated as the difference between Q_{OB} and Q_{BF}

3.2.4 Upscaling change in localised recharge from the gauge to the water source

The change in localised recharge due to in-stream and overbank flooding recharge is calculated at the scale of the gauging station, a point location on the stream network. The result that is needed to assess the change in resource is an areal change in recharge at the scale of the water source. Where available, we have assumed that the change in recharge at the gauge is applicable to the entire water source (or average of several gauges). Where we do not have modelled data for a water source this upscaling can be completed using a covariate that is known for each water source and gauging station that can be related to the change in localised recharge for each gauging station. The most suitable covariate that we have available is the change in the rainfall for the upstream contributing area. The source of the change in recharge estimates for each water source are shown in Appendix D .

3.3 Results

An assessment of BoM flood locations and DPE river simulation gauges resulted in the selection of 42 locations that had all necessary data (streamflow simulations, flood height thresholds, rating curves and cross sections) for the analysis of localised recharge changes (Table 3-1, Figure 3-4 and Figure 3-5).

Table 3-1 Gauges selected for localised recharge change estimation

Gauge Number	Gauge Name	Latitude	Longitude
203005	RICHMOND RIVER AT WIANGAREE	-28.5049	152.9669
203900	RICHMOND RIVER AT KYOGLE	-28.6206	152.9962
409003	EDWARD RIVER AT DENILIQUIN	-35.5300	144.9657
409025	MURRAY RIVER DOWNSTREAM YARRAWONGA WEIR	-36.0114	145.9940
410001	MURRUMBIDGEE RIVER AT WAGGA WAGGA	-35.1006	147.3674
410004	MURRUMBIDGEE RIVER AT GUNDAGAI	-35.0750	148.1074
410005	MURRUMBIDGEE RIVER AT NARRANDERA	-34.7554	146.5489
410006	TUMUT RIVER AT TUMUT	-35.3027	148.2342
410021	MURRUMBIDGEE RIVER AT DARLINGTON POINT	-34.5664	146.0027
410081	COOMA CREEK AT COOMA NO.2 (THE GRANGE)	-36.2619	149.1352
410130	MURRUMBIDGEE RIVER AT D/S BALRANALD WEIR	-34.6650	143.4917
412002	LACHLAN RIVER AT COWRA	-33.8330	148.6839
412004	LACHLAN RIVER AT FORBES (COTTONS WEIR)	-33.4108	147.9914
412005	LACHLAN RIVER AT BOOLIGAL	-33.8695	144.8811
412036	LACHLAN RIVER D/S JEMALONG WEIR	-33.4001	147.7744
412039	LACHLAN RIVER AT HILLSTON WEIR	-33.4873	145.5040
412195	BELUBULA RIVER AT LYNDON (UPSTREAM CANOWINDRA)	-33.5769	148.6753
416001	BARWON RIVER AT MUNGINDI	-28.9762	148.9848
416006	SEVERN RIVER AT ASHFORD	-29.2939	151.1212
418002	MEHI RIVER AT MOREE	-29.4651	149.8511
418004	GWYDIR RIVER AT YARRAMAN BRIDGE	-29.4261	149.8471
418013	GWYDIR RIVER AT GRAVESEND ROAD BRIDGE	-29.5819	150.3666
419001	NAMOI RIVER AT GUNNEDAH	-30.9720	150.2556
419012	NAMOI RIVER AT BOGGABRI	-30.6682	150.0578
419021	NAMOI RIVER AT BUGILBONE (RIVERVIEW)	-30.2732	148.8207
419026	NAMOI RIVER AT GOANGRA	-30.1414	148.3875
421001	MACQUARIE RIVER AT DUBBO	-32.2712	148.6023
421023	BOGAN RIVER AT GONGOLGON	-30.3472	146.8978
422001	BARWON RIVER AT DANGAR BRIDGE (WALGETT)	-30.0154	148.0604
422002	BARWON RIVER AT BREWARRINA	-29.9470	146.8638
422003	BARWON RIVER AT COLLARENEBRI MAIN CHANNEL	-29.5469	148.5767
422004	BARWON RIVER AT MOGIL MOGIL	-29.3530	148.6885
422005	BOKHARA RIVER AT BOKHARA (GOODWINS)	-29.6243	147.0194
422006	CULGOA RIVER AT D/S COLLERINA (KENEBREE)	-29.7735	146.5179
424002	PAROO RIVER AT WILLARA CROSSING	-29.2417	144.4559
425003	DARLING RIVER AT BOURKE TOWN	-30.0861	145.9387
425004	DARLING RIVER AT LOUTH	-30.5347	145.1151
425005	DARLING RIVER AT POONCARIE	-33.3864	142.5678
425007	DARLING RIVER AT BURTUNDY	-33.7464	142.2683
425008	DARLING RIVER AT WILCANNIA MAIN CHANNEL	-31.5591	143.3791
425010	MURRAY RIVER AT LOCK NO. 10 (WENTWORTH)	-34.1100	141.9045
425900	DARLING RIVER AT TILPA	-30.9344	144.4188

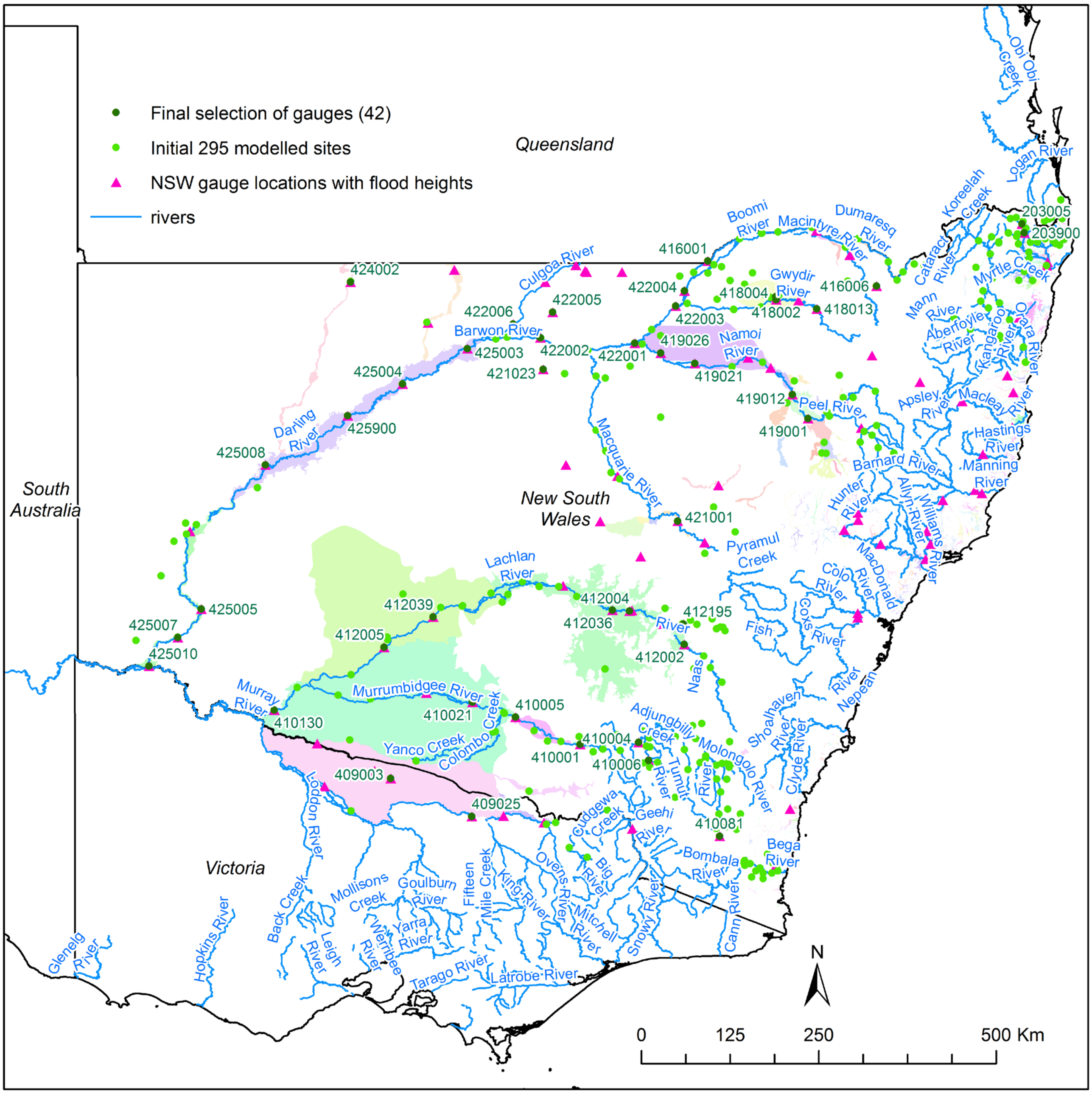


Figure 3-4 Location of gauges used in localised recharge change assessment

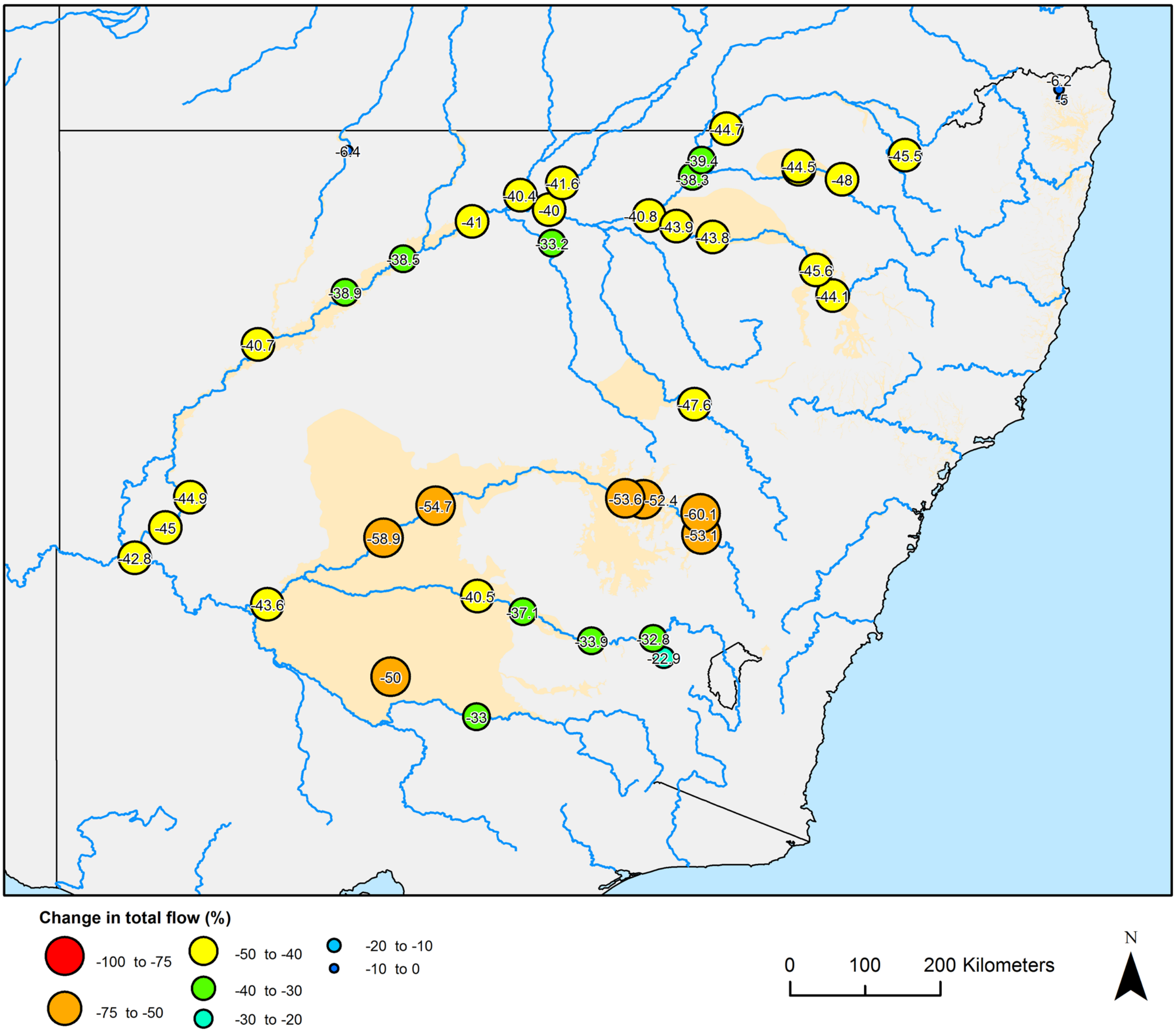


Figure 3-5 Change in total flow (%) for the 42 selected gauges

3.3.1 In-stream recharge

Results of our standard approach (based on Equation 4), that doesn't account for changes in groundwater level, are mapped in Figure 3-6. This shows that there is some geographical consistency in the results (as would be expected with downstream flow depending upon upstream flow). There are four points on the Lachlan River that range in change in in-stream recharge from −38.5% to −55.4% (the −19.4% is on the Belubula) and three points on the Gwydir that range from −19.3% to −21.1%. All of the gauges analysed have a predicted decrease in localised recharge due to in-stream losses but the magnitude is much greater in the western flowing rivers compared to the only gauges analysed flowing east (Richmond River, −3.4% and −4.4%).

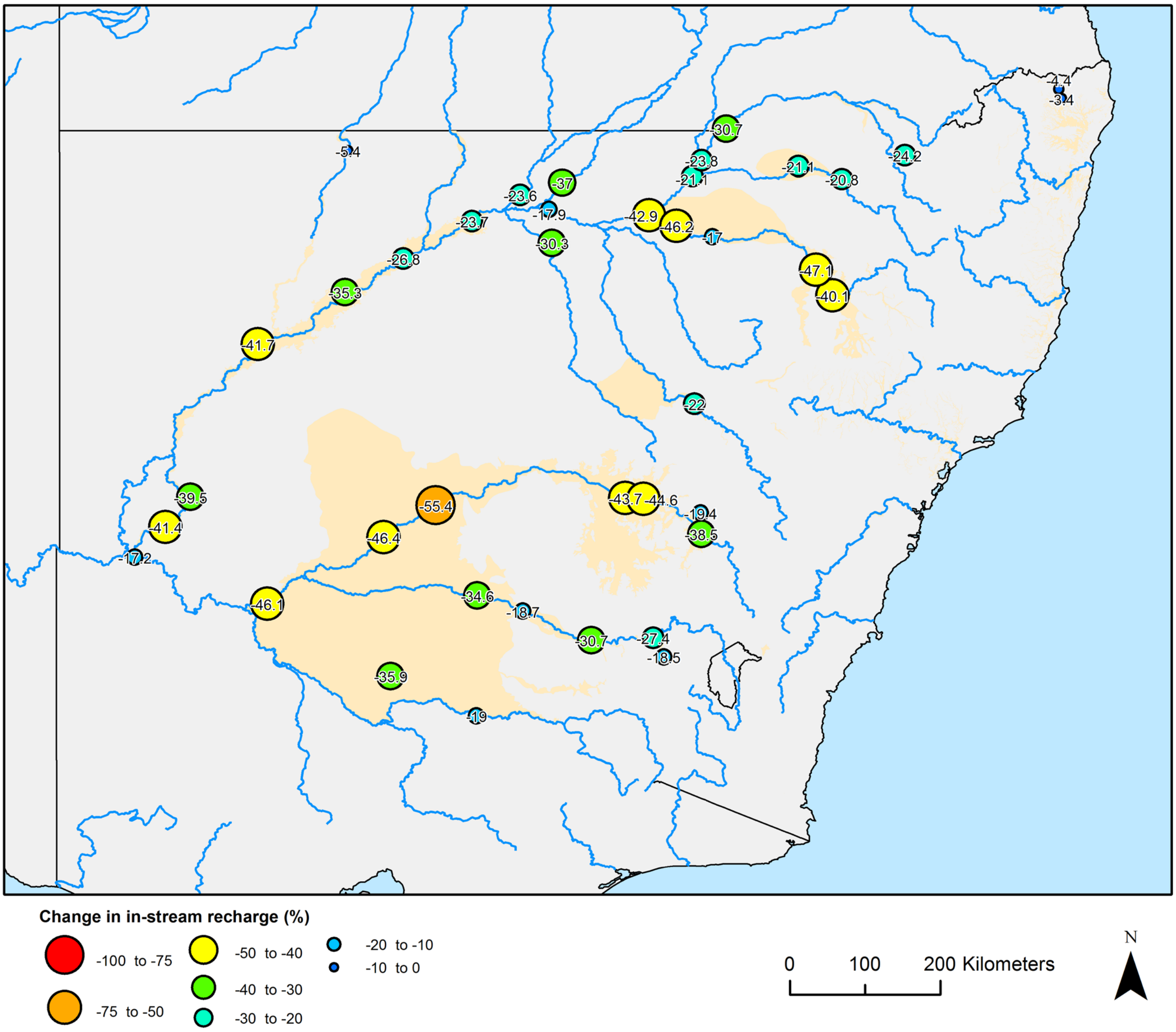


Figure 3-6 Estimated changes (%) of in-stream (losing stream) localised recharge

Results from the sensitivity analysis (section 3.2.2) to assess the assumption of groundwater level change are summarised, for the example station 419001 Namoi River at Gunnedah, in Figure 3-7 for case 1, Figure 3-9 for case 2 and in Figure 3-10 for case 3 and for station 410001 Murrumbidgee River at Wagga Wagga in Figure 3-8 for case 1, and in Figure 3-11 for case 3. The base case for the change in in-stream recharge is for an average of −40.1% for 419001 Namoi River at Gunnedah and −30.7% for 410001 Murrumbidgee River at Wagga.

Case 1 explored the assumption that the water table is static, for this case the assumption was made that the groundwater level was equal between the historical and future climate scenarios but had a dependency on the historical stream stage. It can be seen (Figure 3-7 and Figure 3-8) that the change in recharge became more negative with increasing values of alpha (−38%, −42% and −61% for α = 0.1, 0.2 and 0.5 respectively in the Namoi and −31%, −33% and −49% for α = 0.1, 0.2 and 0.5 respectively in the Murrumbidgee). This is because with increasing α the difference in water level between the surface water and groundwater becomes smaller under the historical scenario and therefore the relative difference between the water levels between the historical and future scenarios becomes larger.

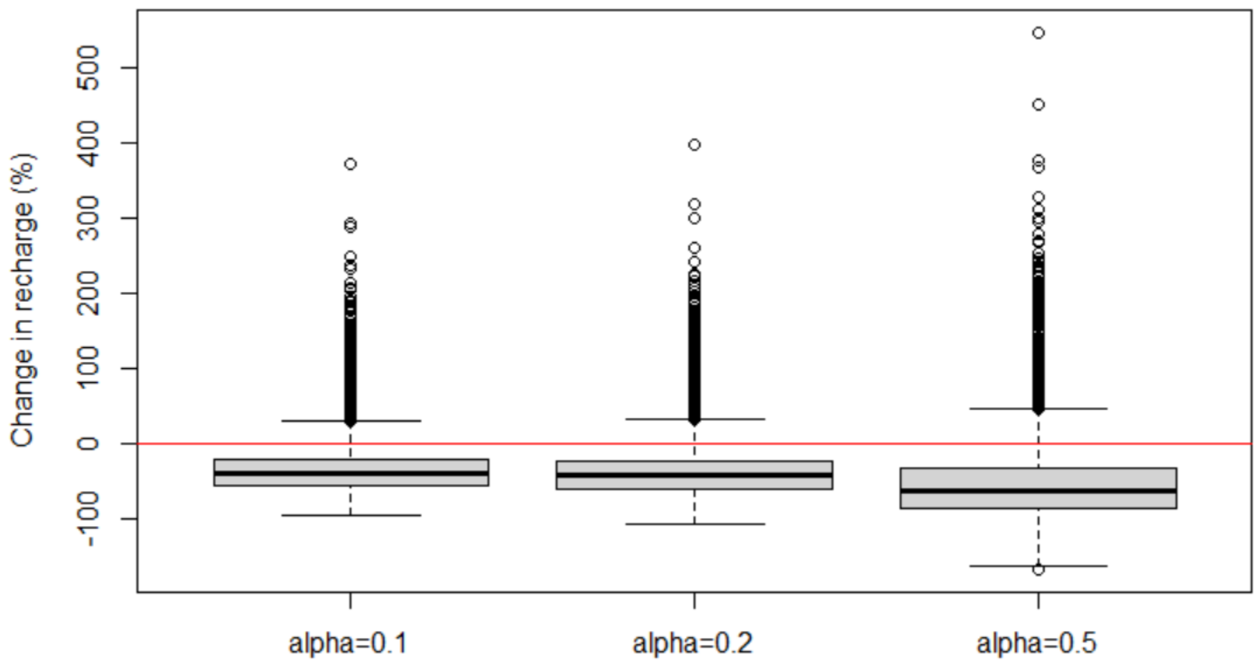


Figure 3-7 Estimated changes to annual in-stream localised recharge where the groundwater level is equal between the historical and future scenarios but has a dependency on the historical stream stage for 419001 Namoi River at Gunnedah. The value of α is the groundwater level as a proportion of the stage height relative to the stream bed.

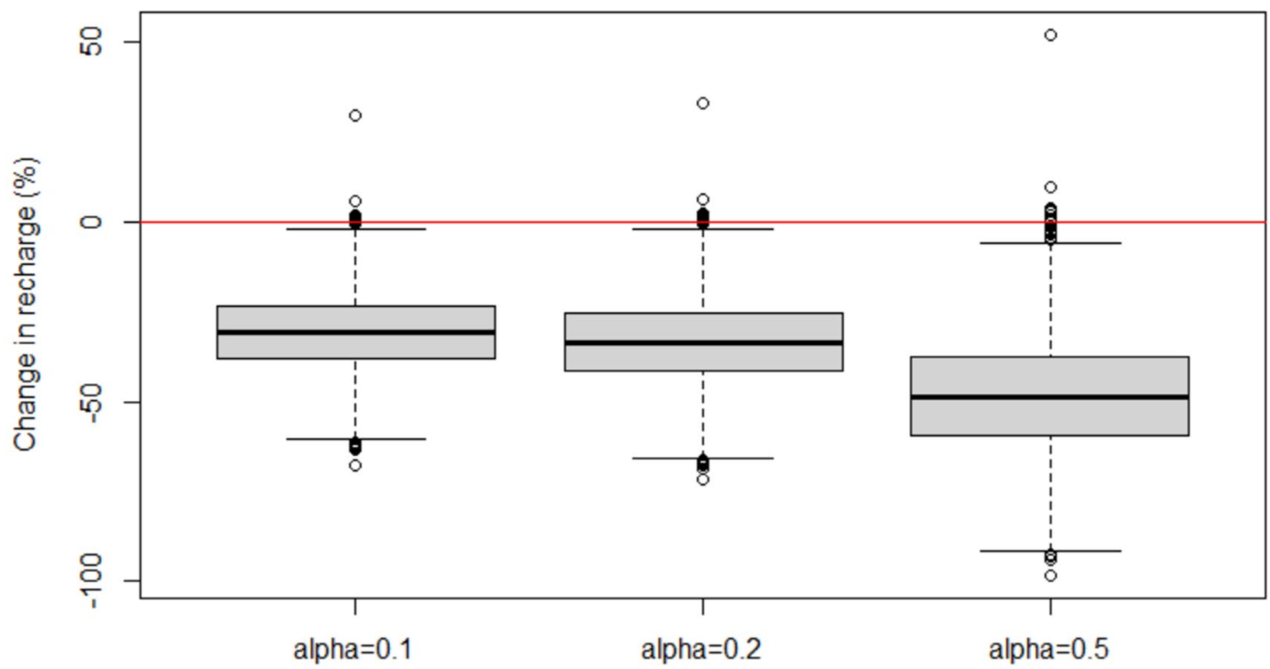


Figure 3-8 Estimated changes to annual in-stream localised recharge where the groundwater level is equal between the historical and future scenarios but has a dependency on the historical stream stage for 410001 Murrumbidgee River at Wagga Wagga. The value of α is the groundwater level as a proportion of the stage height relative to the stream bed.

For case 2 the assumption that the groundwater level was the same between the historical and future scenarios was relaxed from case 1. The results for case 2 (Figure 3-9) were identical irrespective of the value of α, each value showed a median of −35% change in in-stream recharge for 419001 Namoi River at Gunnedah (the Murrumbidgee example is not shown). In this case the relative difference between the surface water and groundwater levels are maintained and so the relative difference in recharge is the same (but the magnitude of the recharge would be different for different values of α).

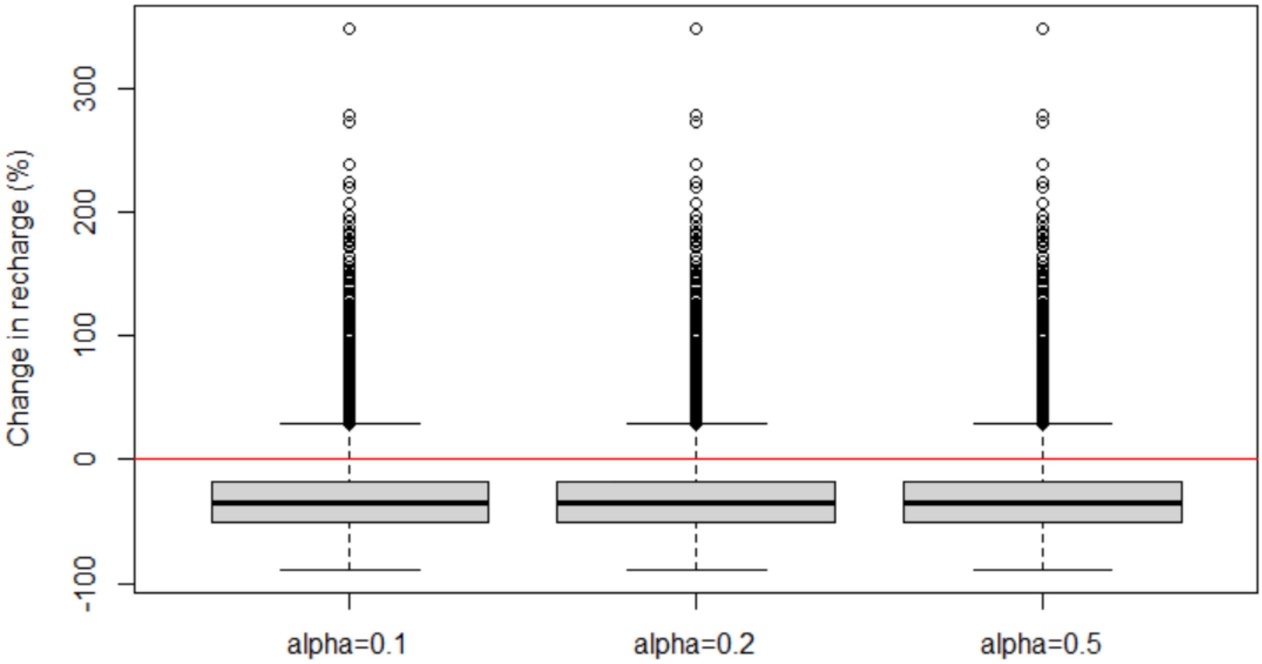


Figure 3-9 Estimated changes to annual in-stream localised recharge where the groundwater level is not equal between the historical and future scenarios but has a dependency on the stream stage for 419001 Namoi River at Gunnedah. The value of a is the groundwater level as a proportion of the stage height relative to the stream bed.

Case 3 (Figure 3-10 and Figure 3-11) is the same as case 2 but also includes a regional reduction in the groundwater level as could be expected under a future drier climate with increased demands placed on the groundwater system. For a minor reduction in regional groundwater level (β = 0.1 m) the change in recharge is still a reduction but the magnitude of the change is much reduced compared to the previous cases (−16%, −13% and −0.6% for α = 0.1, 0.2 and 0.5 respectively in the Namoi and −23%, −23% and −19% for α = 0.1, 0.2 and 0.5 respectively in the Murrumbidgee). The change in in-stream recharge for a 0.5 m reduction in the regional water table between the historical and future climate scenarios is positive for all values of α in the Namoi and for α equal to 0.2 or 0.5 in the Murrumbidgee. For a 1.0 m reduction in the regional water table the results become even greater with the change in recharge being +136%, +156% and +268% for α = 0.1, 0.2 and 0.5 respectively in the Namoi and +22%, +28% and +62% in the Murrumbidgee. The in-stream recharge under a future climate can increase even with a decrease in flow due if there is a reduction in the regional groundwater level, this is due to the increased hydraulic gradient between the surface water and groundwater with the falling water table.

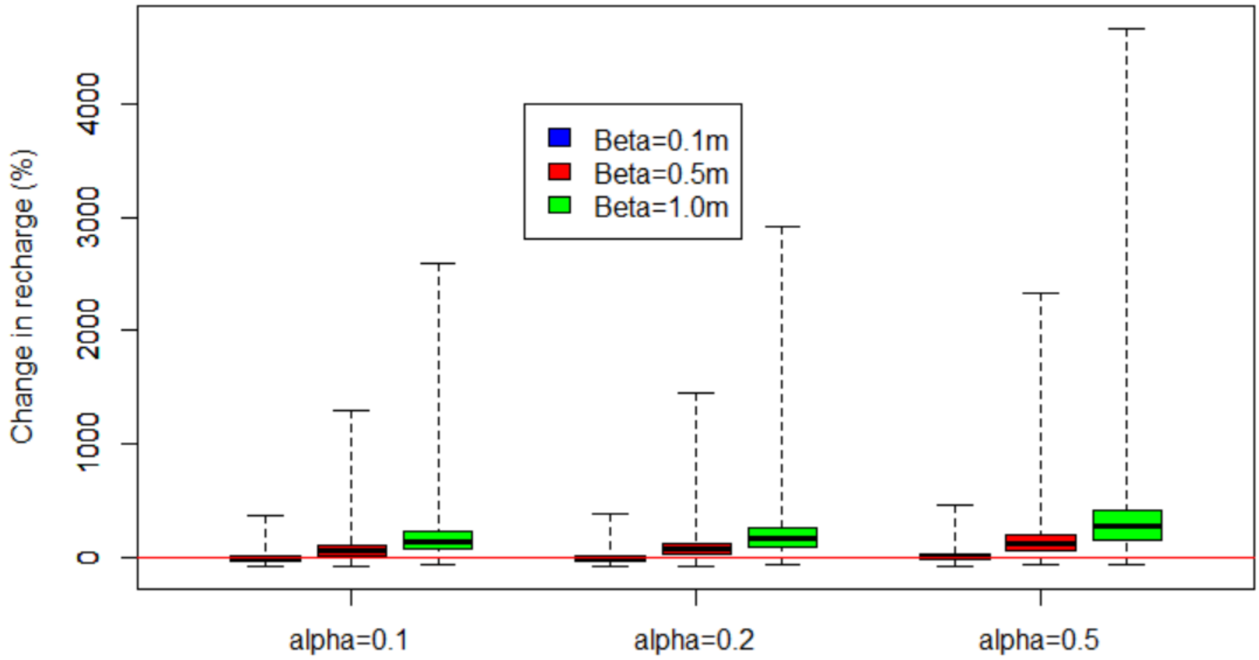


Figure 3-10 Estimated changes to annual in-stream localised recharge under different dependencies on stream stage height and additionally different levels of groundwater decline for 419001 Namoi River at Gunnedah

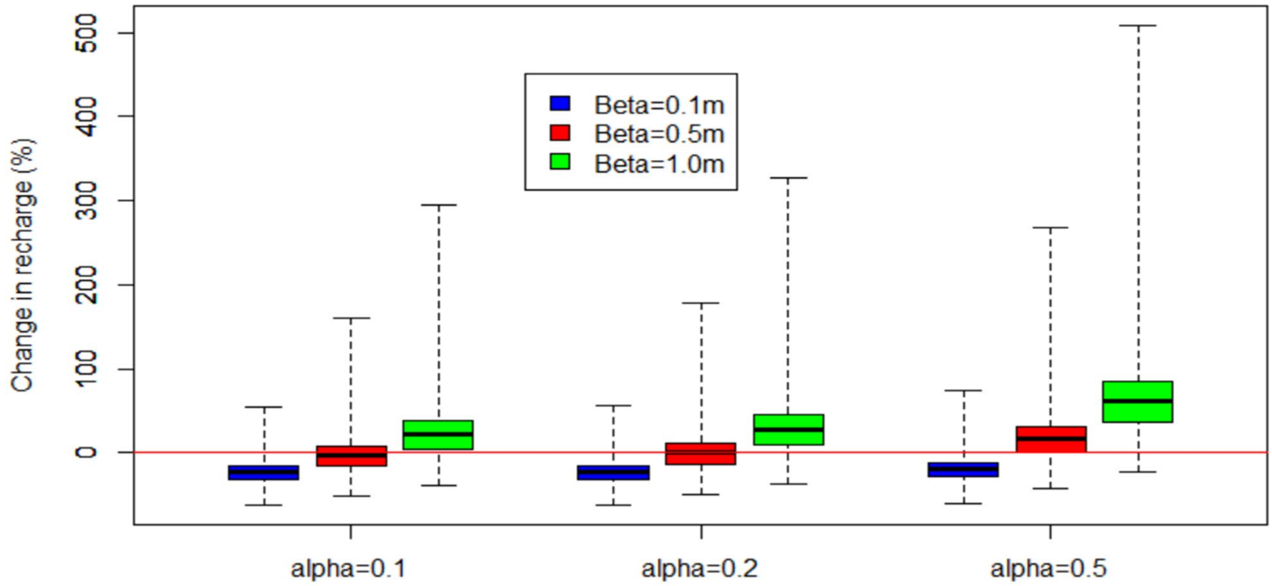


Figure 3-11 Estimated changes to annual in-stream localised recharge under different dependencies on stream stage height and additionally different levels of groundwater decline for 410001 Murrumbidgee River at Wagga Wagga

3.3.2 Overbank recharge

Using the simulated changes in the volume of overbank flow between the historical and future scenarios (Equation 14), the estimated mean changes in overbank recharge are mapped in Figure 3-12. Similarly with the change in in-stream recharge, there is some spatial consistency in the results. The results in southern MDB range from −51.9% to −90.5% and for the northern MDB from −17.5 to −64.6. The smallest changes were seen in the Richmond River where the change in recharge due to overbank flooding was between −8.1% and −13.3% and the Paroo at −4.7%.

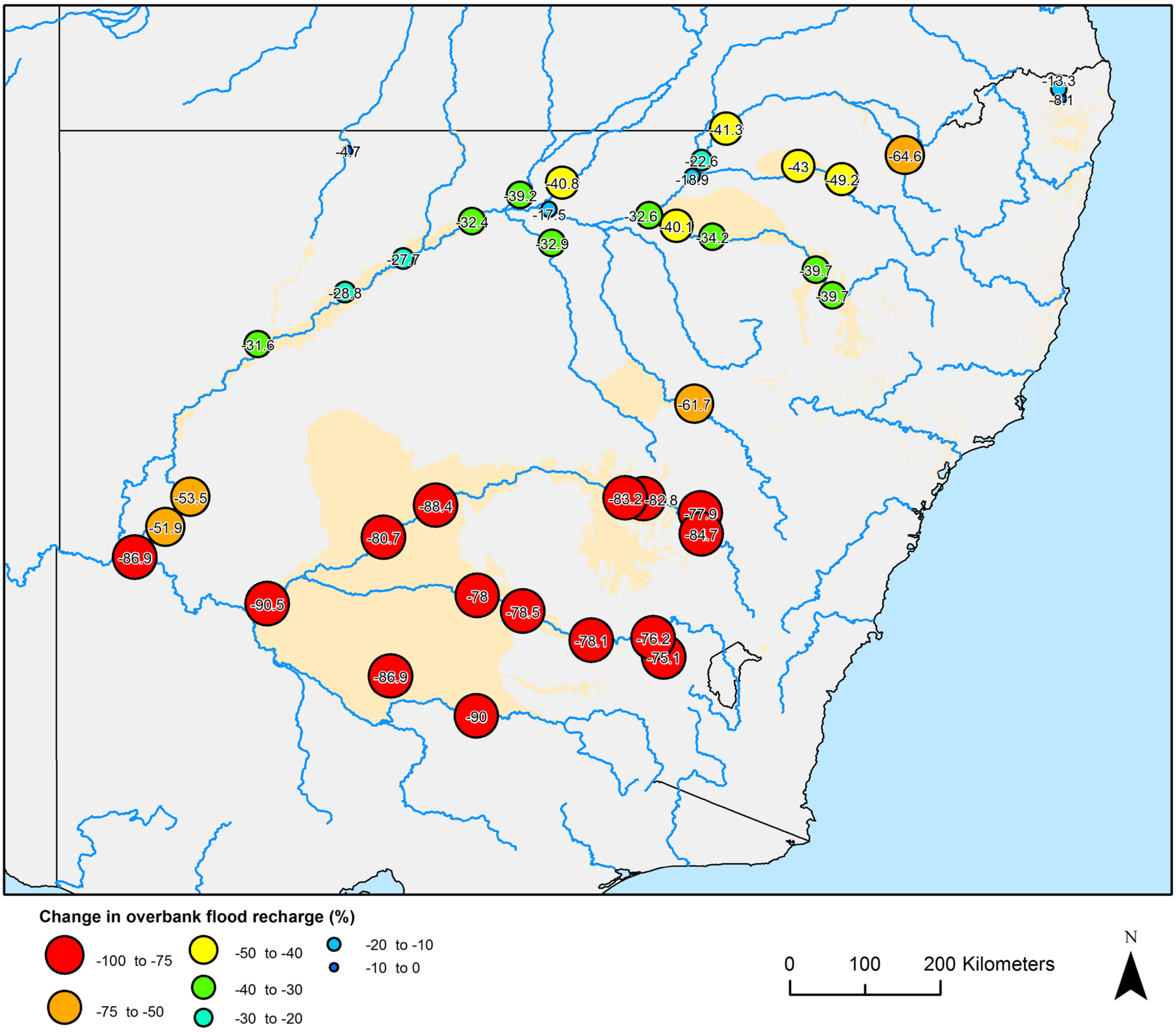


Figure 3-12 Estimated changes to overbank localised recharge

3.3.3 Comparison of localised recharge changes

At the point scale (i.e., gauges) the estimated changes in localised recharge, for both in-stream and overbank flood recharge, are shown in Table 3-2 alongside the simulated changes in long-term mean streamflow. Across the 42 gauges analysed the magnitude of the change in in-stream recharge is generally less than the magnitude of the change in streamflow, the opposite is true for the change in overbank recharge. For a 1% change in streamflow there is on average a 0.7% change in in-stream recharge and a 1.5% change in overbank recharge.

Table 3-2 Flow and localised recharge changes

			Change in recharge (%)	
Gauge Number	Gauge Name	Flow change (%)	In-stream	Overbank
203005	RICHMOND RIVER AT WIANGAREE	-6.2	-4.4	-13.3
203900	RICHMOND RIVER AT KYOGLE	-5.0	-3.4	-8.1
409003	EDWARD RIVER AT DENILIQUIN	-50.0	-35.9	-86.9
409025	MURRAY RIVER DOWNSTREAM YARRAWONGA WEIR	-33.0	-19.0	-90.0
410001	MURRUMBIDGEE RIVER AT WAGGA WAGGA	-33.9	-30.7	-78.1
410004	MURRUMBIDGEE RIVER AT GUNDAGAI	-32.8	-27.4	-76.2
410005	MURRUMBIDGEE RIVER AT NARRANDERA	-37.1	-18.7	-78.5
410006	TUMUT RIVER AT TUMUT	-22.9	-18.5	-75.1
410021	MURRUMBIDGEE RIVER AT DARLINGTON POINT	-40.5	-34.6	-78.0
410081	COOMA CREEK AT COOMA NO.2 (THE GRANGE)	-46.9		
410130	MURRUMBIDGEE RIVER AT D/S BALRANALD WEIR	-43.6	-46.1	-90.5
412002	LACHLAN RIVER AT COWRA	-53.1	-38.5	-84.7
412004	LACHLAN RIVER AT FORBES (COTTONS WEIR)	-52.4	-44.6	-82.8
412005	LACHLAN RIVER AT BOOLIGAL	-58.9	-46.4	-80.7
412036	LACHLAN RIVER D/S JEMALONG WEIR	-53.6	-43.7	-83.2
412039	LACHLAN RIVER AT HILLSTON WEIR	-54.7	-55.4	-88.4
412195	BELUBULA RIVER AT LYNDON (UPSTREAM CANOWINDRA)	-60.1	-19.4	-77.9
416001	BARWON RIVER AT MUNGINDI	-44.7	-30.7	-41.3
416006	SEVERN RIVER AT ASHFORD	-45.5	-24.2	-64.6
418002	MEHI RIVER AT MOREE	-43.1	-19.3	56.1
418004	GWYDIR RIVER AT YARRAMAN BRIDGE	-44.5	-21.1	-43.0
418013	GWYDIR RIVER AT GRAVESEND ROAD BRIDGE	-48.0	-20.8	-49.2
419001	NAMOI RIVER AT GUNNEDAH	-44.1	-40.1	-39.7
419012	NAMOI RIVER AT BOGGABRI	-45.6	-47.1	-39.7
419021	NAMOI RIVER AT BUGILBONE (RIVERVIEW)	-43.8	-17.0	-34.2
419026	NAMOI RIVER AT GOANGRA	-43.9	-46.2	-40.1
421001	MACQUARIE RIVER AT DUBBO	-47.6	-22.0	-61.7
421023	BOGAN RIVER AT GONGOLGON	-33.2	-30.3	-32.9
422001	BARWON RIVER AT DANGAR BRIDGE (WALGETT)	-40.8	-42.9	-32.6
422002	BARWON RIVER AT BREWARRINA	-40.0	-17.9	-17.5
422003	BARWON RIVER AT COLLARENEBRI MAIN CHANNEL	-38.3	-21.1	-18.9
422004	BARWON RIVER AT MOGIL MOGIL	-39.4	-23.8	-22.6
422005	BOKHARA RIVER AT BOKHARA (GOODWINS)	-41.6	-37.0	-40.8
422006	CULGOA RIVER AT D/S COLLERINA (KENEBREE)	-40.4	-23.6	-39.2
424002	PAROO RIVER AT WILLARA CROSSING	-6.4	-5.4	-4.7
425003	DARLING RIVER AT BOURKE TOWN	-41.0	-23.7	-32.4
425004	DARLING RIVER AT LOUTH	-38.5	-26.8	-27.7
425005	DARLING RIVER AT POONCARIE	-44.9	-39.5	-53.5
425007	DARLING RIVER AT BURTUNDY	-45.0	-41.4	-51.9
425008	DARLING RIVER AT WILCANNIA MAIN CHANNEL	-40.7	-41.7	-31.6
425010	MURRAY RIVER AT LOCK NO. 10 (WENTWORTH)	-42.8	-17.2	-86.9
425900	DARLING RIVER AT TILPA	-38.9	-35.3	-28.8

3.3.4 Upscaling change in localised recharge to the water sources

The changes in localised recharge due to in-stream losses (section 3.3.1) and overbank flooding (section 3.3.2) can be related to the change in rainfall in the upstream contributing area (Figure 3-13). These relationships show a greater sensitivity to a change in rainfall in the change in recharge due to overbank flooding, this can be seen in the slope of regression lines (3.3 for the change in in-stream losses and 5.7 for overbank flooding).

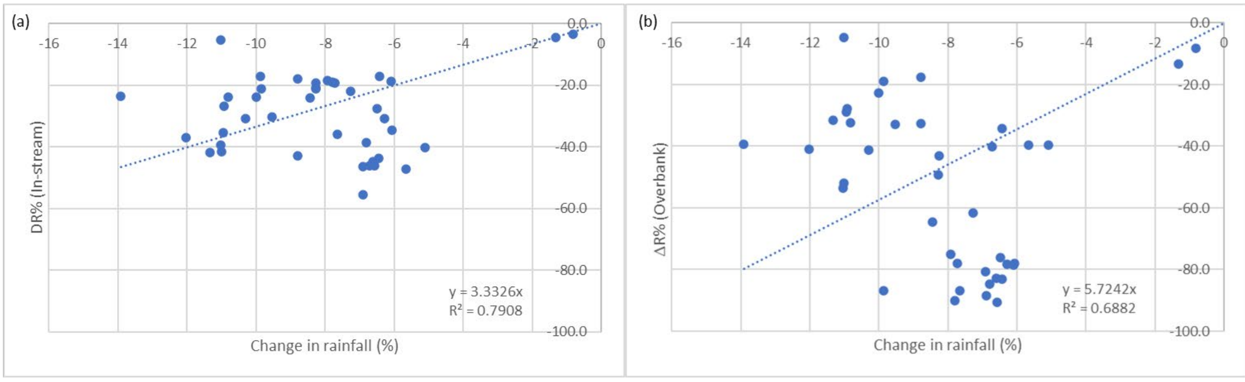


Figure 3-13 Upscaling relationships between the change in rainfall for the upstream contributing area of the gauge and change in recharge due to (a) in-stream leakage and (b) overbank flooding

The regression lines in Figure 3-13 can be used to upscale the change in localised recharge due to in-stream losses and overbank flooding to the alluvial water sources across NSW that do not have estimates from the gauge data for. At the water source scale (Figure 3-14, Table 3-3), the change in localised recharge ranges from practically no change (e.g. Brunswick River Coastal Floodplain Alluvial Groundwater Source) to a very severe decrease in recharge (e.g. Macintyre Alluvial Groundwater Source).

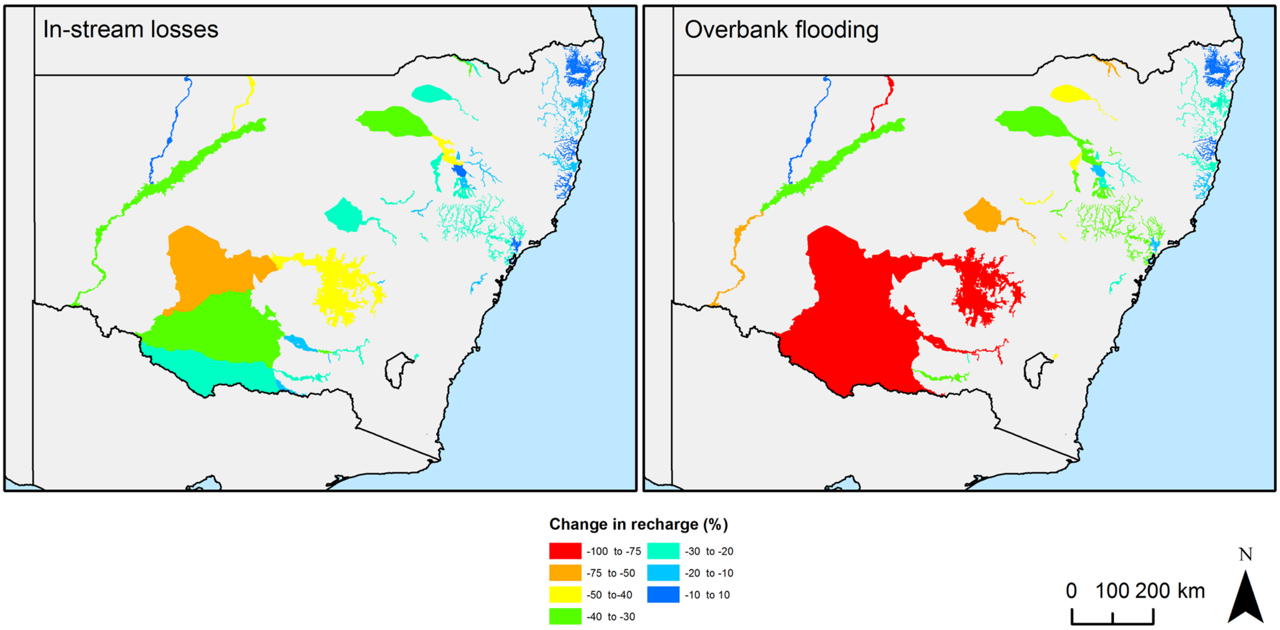


Figure 3-14 The change in localised recharge at the scale of the water source for recharge due to in-stream losses and overbank flooding

Table 3-3 The change in localised recharge for each alluvial water source in NSW

Groundwater Source	Change in Rainfall (%)	Change in Recharge (In-stream) %	Change in Recharge (Overbank) %
Bell Alluvial Groundwater Source	-7.6	-25.4	-43.7
Bellinger River Coastal Floodplain Alluvial Groundwater Water Source	-1.3	-4.4	-7.6
Belubula Valley Alluvial Groundwater Source	NA	-19.4	-77.9
Billabong Alluvium	-6.4	-21.2	-36.4
Brunswick River Coastal Floodplain Alluvial Groundwater Source	0.6	2.1	3.7
Bungendore/Lake George Alluvial	-7.9	-26.4	-45.4
Castlereagh Alluvial	-7.8	-26.0	-44.6
Clarence River Coastal Floodplain Alluvial Groundwater Source	-4.6	-15.3	-26.3
Coastal Macleay Floodplain Alluvial Groundwater Source	-3.8	-12.7	-21.9
Coastal Nambucca Floodplain Alluvial Groundwater Source	-1.6	-5.3	-9.1
Coopers Creek Alluvial Groundwater Source	0.0	-0.1	-0.2
Cudgegong Alluvial Groundwater Source	-7.9	-26.4	-45.4
Currabubula Alluvial Groundwater Source	-3.9	-13.1	-22.5

Groundwater Source	Change in Rainfall (%)	Change in Recharge (In-stream) %	Change in Recharge (Overbank) %
Gundagai	NA	-25.6	-76.5
Hastings River Coastal Floodplain Alluvial Groundwater Source	-2.7	-9.1	-15.7
Hawkesbury Alluvium	-5.2	-17.2	-29.6
Hunter Regulated River Alluvial Water Source	-6.8	-22.6	-38.8
Kyeamba Creek GW source	-5.0	-16.7	-28.7
Lower Darling Alluvial Groundwater Source	NA	-32.7	-64.1
Lower Gwydir Groundwater Source	NA	-20.2	-43.0
Lower Lachlan Groundwater Source	NA	-50.9	-84.5
Lower Macquarie Zone 1	NA	-22.0	-61.7
Lower Macquarie Zone 2	NA	-22.0	-61.7
Lower Macquarie Zone 3	NA	-22.0	-61.7
Lower Macquarie Zone 4	NA	-22.0	-61.7
Lower Macquarie Zone 5	NA	-22.0	-61.7
Lower Macquarie Zone 6	NA	-22.0	-61.7
Lower Murray Shallow Groundwater Source	NA	-27.4	-88.5
Lower Murrumbidgee Shallow Groundwater	NA	-36.5	-81.9
Lower Namoi Groundwater Source	NA	-35.4	-35.6
Macintyre Alluvial Groundwater Source	-8.9	-29.8	-51.1
Manilla Alluvial	-5.5	-18.3	-31.5
Mid Murrumbidgee Zone 3	NA	-18.7	-78.5
NSW Border Rivers Downstream Keetah Bridge Alluvial Groundwater Source	-9.1	-30.2	-51.8
NSW Border Rivers Upstream Keetah Bridge Alluvial Groundwater Source	-9.0	-29.9	-51.3
Ottleys Creek Alluvial Groundwater Source	-9.8	-32.6	-55.9
Paroo Alluvial Groundwater Source	NA	-5.4	-4.7
Peel alluvium	-4.3	-14.2	-24.4
Quipolly alluvial	-4.9	-16.4	-28.1

Groundwater Source	Change in Rainfall (%)	Change in Recharge (In-stream) %	Change in Recharge (Overbank) %
Quirindi Alluvial	-4.1	-13.8	-23.7
Richmond Regulated Alluvial Water Source	-0.1	-0.4	-0.7
Talbragar Alluvial	-5.7	-19.1	-32.9
Upper Darling Alluvial Groundwater Source	NA	-31.9	-30.1
Upper Gwydir Alluvial Groundwater Source	NA	-20.8	-49.2
Upper Lachlan Alluvial	NA	-42.3	-83.6
Upper Macquarie Alluvial	NA	-22.0	-61.7
Upper Murray Groundwater Source	NA	-19.0	-90.0
Upper Namoi Zone 1	-6.2	-20.6	-35.4
Upper Namoi Zone 10	-6.8	-22.7	-39.0
Upper Namoi Zone 11	NA	-47.1	-39.7
Upper Namoi Zone 12	-4.8	-15.9	-27.3
Upper Namoi Zone 2	-8.2	-27.2	-46.7
Upper Namoi Zone 3	-3.0	-9.9	-17.0
Upper Namoi Zone 4	NA	-43.6	-39.7
Upper Namoi Zone 5	NA	-47.1	-39.7
Upper Namoi Zone 6	-6.5	-21.7	-37.4
Upper Namoi Zone 7	-6.1	-20.2	-34.8
Upper Namoi Zone 8	-4.1	-13.6	-23.3
Upper Namoi Zone 9	-6.9	-23.0	-39.5
Wagga Wagga Alluvial	NA	-30.7	-78.1
Warrego Alluvial Groundwater Source	-14.8	-49.2	-84.5

3.4 Conclusions

The assessment of estimated future changes to localised recharge has identified the following:

- There is a clear signal of reduced streamflow leading to large percentage reductions in estimated localised recharge, the magnitude of the relative reduction in localised recharge is greater from overbank flooding than for in-stream losses (Table 3-3).
- The assumptions made in the change in in-stream recharge for the losing-connected case may underestimate the change in recharge due to the assumption that the water table does not change between the historical and future climate scenarios. If the water table were to fall in the future climate relative to the historical climate then the change in in-stream localised recharge will be overestimated and may even be in wrong direction. This may require a detailed coupled surface-water groundwater model to properly account for these feed-back processes rather than the simple analytical calculations produced here.
- Large declines in flood volume result in large declines in overbank flood recharge. These declines are likely to be overly pessimistic given that the method used to produce the future rainfall series does not account for potential increases in daily rainfall extremes, which could underestimate the potential for increased flooding.
- The differences in the magnitudes for the predicted reductions in recharge due to diffuse recharge, losing streams and overbank flooding necessitates a greater process understanding of recharge in each groundwater source. It would appear that any alluvial groundwater source with a high proportion of localised recharge will see greater reductions in recharge than groundwater sources that have a greater proportion of diffuse recharge for a given change in rainfall.
- As the change in recharge from different processes can be so different, these processes need to be more accurately represented in the groundwater models if they are to be used for projections of the future state of the groundwater resource. In particular, we do not currently have adequate tools to estimate and predict recharge due to overbank flooding.

4 Groundwater source prioritisation

4.1 Introduction

The intention of this section was to follow the methods proposed in Currie et al., (2010) and Barron et al., (2011) for prioritising groundwater sources for further investigation, however after applying these methods it became apparent that they were not suitable for the current application. The previous ‘importance’ metric is biased towards groundwater sources with a large spatial extent, relies on extraction data that is not available in all groundwater sources and includes information on GDE’s (Groundwater-Dependent Ecosystems) that are already accounted for in the LTAAEL (Long-term average annual extraction limit).

Therefore, a new method for prioritisation has been developed that reworks the ‘sensitivity’ metric in terms of climate change and is only based on aquifer parameters (and is therefore independent of management actions) and introduces a new ‘stress’ metric that includes the management actions.

Objectives of this section include:

a. Identify potential future groundwater challenges in terms of which sources are resilient and which are the most vulnerable to climate change

b. Highlight regions or specific groundwater resources that require more detailed analysis for scoping future projects

This section therefore contributes to identifying potential groundwater challenges and groundwater sources vulnerable to the impacts of climate change as well as those groundwater sources that show more resilience to these direct impacts.

As the climate change impacts assessed here are due to changes in recharge, the groundwater sources that are completely buried and are not being recharged directly have been excluded from this analysis. The shallow and deep Murray and Murrumbidgee groundwater sources have been considered vertically connected and combined for this analysis.

4.2 Methods

4.2.1 Sensitivity metric

A groundwater source is deemed to be sensitive to climate change if it has a small storage relative to the recharge rate; this is particularly important where a small storage is combined with a reduction in recharge. The small storage means that any impacts from reduced recharge will be seen quickly, in water storages with large storage the impacts of climate change can be buffered for some time. The sensitivity metric is calculated as:

$$Sensitivity = \frac{R}{S} \times RSF^{-1}$$ **Equation 15**

where R is the recharge (ML/yr), S is the storage (ML) and RSF is the recharge scaling factor calculated as $\frac{R_{future}}{R_{historical}}$.

The $\frac{R}{S}$ component is a measure of the buffering capacity of a groundwater source. A high $\frac{R}{S}$ would indicate very little storage and little resilience to change. Low $\frac{R}{S}$ would be the big porous rock aquifers or inland alluvium that can potentially hold 1000s of years of water. The recharge is assumed to be the diffuse recharge calculated in section 2 of this report multiplied by the outcropping area of the groundwater source. Ideally, this should be the volume of recharge from all sources, in addition to the diffuse recharge, so should include irrigation drainage, stream losses and recharge due to overbank flooding. As we do not have the total recharge available for all groundwater sources the diffuse recharge is used as a surrogate. The storage of the groundwater source is derived from:

$$S = b \times A \times S_y \qquad \text{Equation 16}$$

where b is the average thickness of the groundwater source, A is the area of the outcropping portion of the groundwater source and S_y is the specific yield. The thickness is taken from the depth of regolith (Wilford et al, 2016) for the coastal sands, coastal alluvium and inland alluvium aquifer types (and the GAB Shallow Surat). There is better information on the depth of the aquifer available in the areas that have had groundwater models built, but using the depth of regolith mapping provides a consistent approach across all water sources in the state. The porous and fractured rock have an assumed thickness of 100 m. The specific yield for the coastal sands is assumed to be 0.2, for the inland and coastal alluvium it is assumed to be 0.1 and for the porous and fractured rock 0.05.

The RSF is as calculated in section 2 of this report for the diffuse recharge for the coastal sands, porous rock, fractured volcanics and fractured basement water sources, as is shown as a percentage change in recharge in Figure 2-6. For the coastal and inland alluvium water sources, the RSF should be calculated based on the total change in recharge from all sources combined. Since we do not know the relative proportions of recharge from diffuse, in-stream and overbank sources, the most conservative approach is taken where the RSF is calculated from the minimum future recharge from the three sources (Table 2-6; Table 3-3).

4.2.2 Stress metric

A groundwater source is deemed to be stressed if the LTAAEL is a high proportion of the recharge and the commitments are a high proportion of LTAAEL. This stress can be exacerbated by a reduction in recharge under a future climate. The stress metric is calculated as:

$$Stress = \frac{LTAAEL}{R} \times min\left(\frac{Committed}{LTAAEL}, 1\right) \times \mathrm{RSF}^{-1} \qquad \text{Equation 17}$$

where LTAAEL is the long-term average annual extraction limit (ML/yr) and Committed (ML/yr) is the sum of Basic Landholder Right (BLR) and Total Share Component. [Looking at the equation, LTAAEL is irrelevant to the outcome but it is necessary for the story].

The $\frac{LTAAEL}{R}$ part of the metric is assessing how conservative the entitlements are, a low value would be where LTAAEL is deliberately kept low, e.g. to protect baseflow. Note that the recharge used here is from that calculated in Section 2, it is not the same recharge rate that is used to set the LTAAEL.

The $\frac{Committed}{LTAAEL}$ part of the metric is assessing how much extraction could take place versus what has been assessed as sustainable. It doesn't use actual extraction values because current sleeper licences could be activated at any time increasing extraction without management intervention. In groundwater sources that currently have commitments greater than LTAAEL this is forced to be 1 as management interventions prevent the actual extractions being greater than LTAAEL.

The RSF is as calculated in section 2 of this report for the diffuse recharge for the coastal sands, porous rock, fractured volcanics and fractured basement water sources, as is shown as a percentage change in recharge in Figure 2-6. For the coastal and inland alluvium water sources, the RSF should be calculated based on the total change in recharge from all sources combined. Since we do not know the relative proportions of recharge from diffuse, in-stream and overbank sources, the most conservative approach is taken where the RSF is calculated from the minimum future recharge from the three sources (Table 2-6; Table 3-3).

4.2.3 Prioritisation scheme

The two metrics are on different scales and have different units. The previous prioritisation of Barron et al (2011) solved this process through a normalisation process. It is much simpler and easier to communicate if the two metrics are combined through their ranks rather than magnitude.

The two metrics are used to create a priority list of groundwater sources for future detailed work. A groundwater source is a priority if it is both *sensitive* ***and*** *stressed*:

$$P = \left({Z_{se}}^2 + {Z_{st}}^2\right)^{0.5} \qquad \text{Equation 18}$$

where P is the prioritisation score, Z_{se} is the rank of the sensitivity index and Z_{st} is the rank of the stress index. P as calculated is equivalent to the distance from the origin if the sensitivity and stress metric ranks are plotted on an x-y plot.

4.3 Results

4.3.1 Sensitivity metric

The results of the sensitivity metric highlight those groundwater sources that have a small amount of storage relative to their recharge rate (Equation 15). The top 30 most sensitive groundwater sources (Table 4-1) are dominated by the alluvials (15 inland, 10 coastal) and coastal sands (3) with two fractured volcanics groundwater sources. These are generally in the high rainfall – high recharge areas of the state (Figure 4-1).

The least sensitive groundwater sources are those that have a large amount of storage and small volumes of recharge. These are predominantly the large inland alluvials, porous rock and fractured basement groundwater sources (Figure 4-1).

Table 4-1 The 30 groundwater sources with the highest sensitivity to climate change. The letter in brackets after the water source name is the source of recharge that contributes to the RSF value used in Equation 15, D = Diffuse, I = Instream and O = Overbank.

Rank	Groundwater source	Rank	Groundwater source
1	Bellinger River Coastal Floodplain Alluvial Groundwater Water Source (O)	16	Coastal Macleay Floodplain Alluvial Groundwater Source (O)
2	Coopers Creek Alluvial Groundwater Source (O)	17	Cudgegong Alluvial Groundwater Source (O)
3	Belubula Valley Alluvial Groundwater Source (O)	18	Richmond Regulated Alluvial Water Source (O)
4	Coastal Nambucca Floodplain Alluvial Groundwater Source (O)	19	Hawkesbury Alluvium (O)
5	Gundagai (O)	20	Bungendore/Lake George Alluvial (O)
6	Upper Gwydir Alluvial Groundwater Source (O)	21	Hawkesbury to Hunter Coastal Sands (D)
7	Brunswick River Coastal Floodplain Alluvial Groundwater Source (I)	22	Upper Macquarie Alluvial (O)
8	Hastings River Coastal Floodplain Alluvial Groundwater Source (O)	23	Metropolitan Coastal Sands (D)
9	Clarence River Coastal Floodplain Alluvial Groundwater Source (O)	24	Botany Sands (D)
10	Bell Alluvial Groundwater Source (O)	25	Comboyne Basalt (D)
11	Manilla Alluvial (O)	26	NSW Border Rivers Upstream Keetah Bridge Alluvial Groundwater Source (O)
12	Wagga Wagga Alluvial (O)	27	Upper Namoi Zone 12 (O)
13	Hunter Regulated River Alluvial Water Source (O)	28	Lower Macquarie Zone 6 (O)
14	Upper Murray Groundwater Source (O)	29	Upper Namoi Zone 11 (O)
15	Peel alluvium (O)	30	Alstonville Basalt Plateau groundwater source (D)

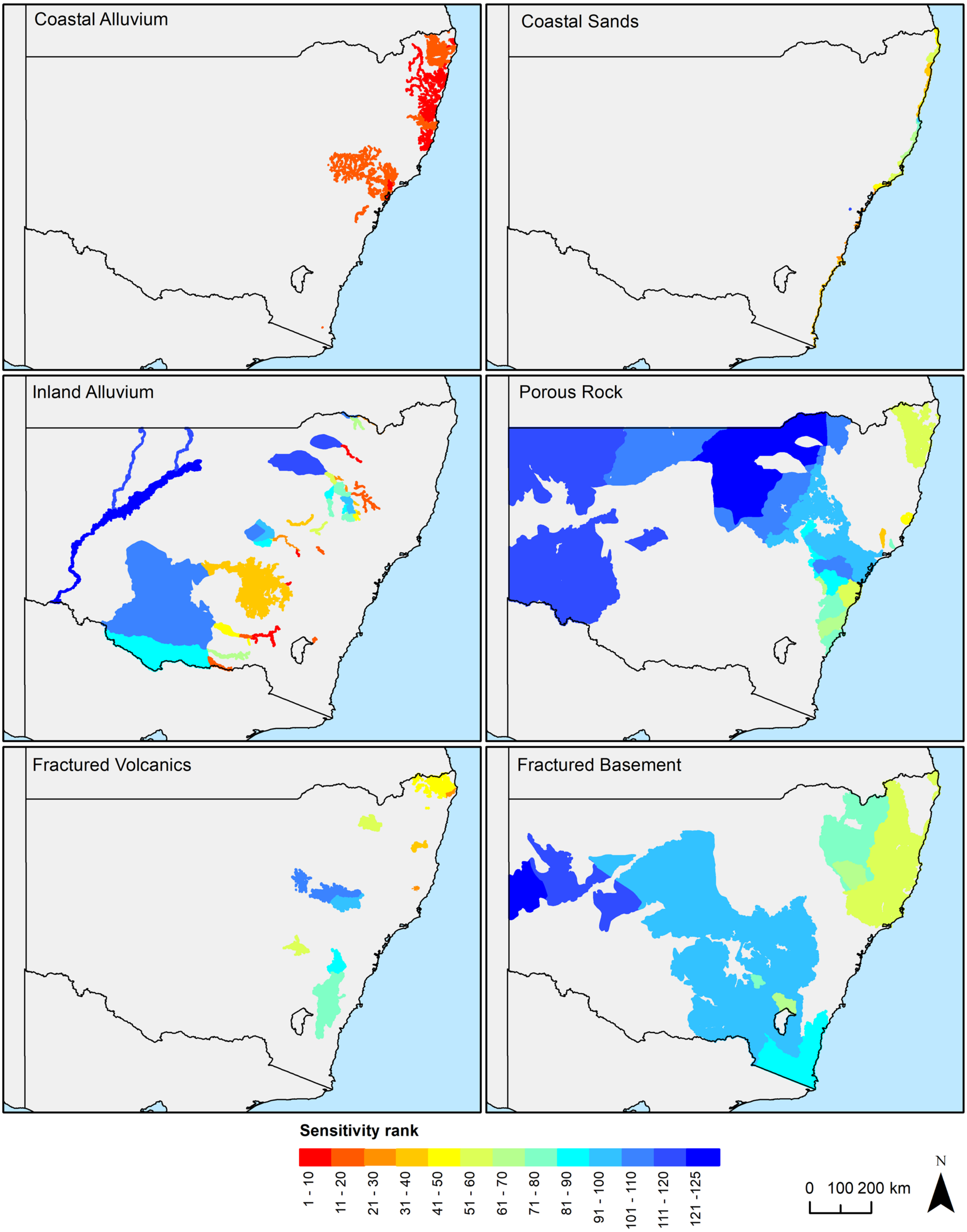


Figure 4-1 Sensitivity rank of groundwater sources

4.3.2 Stress metric

The results of the stress metric highlight those groundwater sources that have a high proportion of commitments relative to LTAAEL and where the LTAAEL is a high proportion of the recharge (Equation 17). The top 30 groundwater sources ranked by the stress metric (Table 4-2) are dominated by the inland alluvials (28) with some coastal sands (2). Almost half of the inland alluvial groundwater sources in the top 30 are within the Namoi catchment (Figure 4-2).

The least stressed groundwater sources are those that have low levels of commitments or a small proportion of the recharge available for allocation. These are predominantly the coastal alluvials, porous rock and fractured basement groundwater sources (Figure 4-2).

Table 4-2 The 30 groundwater sources with the highest stress ranking. The letter in brackets after the water source name is the source of recharge that contributes to the RSF value used in Equation 17, D = Diffuse, I = Instream and O = Overbank.

Rank	Groundwater source	Rank	Groundwater source
1	Wagga Wagga Alluvial (O)	16	Upper Namoi Zone 1 (O)
2	Lower Macquarie Zone 1 (O)	17	Lower Macquarie Zone 2 (O)
3	Stuarts Point (D)	18	Upper Namoi Zone 9 (O)
4	Upper Murray Groundwater Source (O)	19	Upper Namoi Zone 4 (I)
5	Lower Murray Groundwater Source (O)	20	Quirindi Alluvial (O)
6	Belubula Valley Alluvial Groundwater Source (O)	21	Cudgegong Alluvial Groundwater Source (O)
7	Mid Murrumbidgee Zone 3 (O)	22	Lower Namoi Groundwater Source (O)
8	Lower Macquarie Zone 6 (O)	23	Upper Namoi Zone 7 (O)
9	Quipolly alluvial (O)	24	Lower Gwydir Groundwater Source (O)
10	Bell Alluvial Groundwater Source (O)	25	Upper Namoi Zone 10 (O)
11	Lower Murrumbidgee Groundwater (O)	26	Upper Namoi Zone 6 (O)
12	Upper Namoi Zone 8 (O)	27	Upper Namoi Zone 3 (O)
13	Upper Namoi Zone 5 (I)	28	Tomago (D)
14	Lower Lachlan Groundwater Source (O)	29	Upper Lachlan Alluvial (O)
15	Upper Macquarie Alluvial (O)	30	Kyeamba Creek GW source (O)

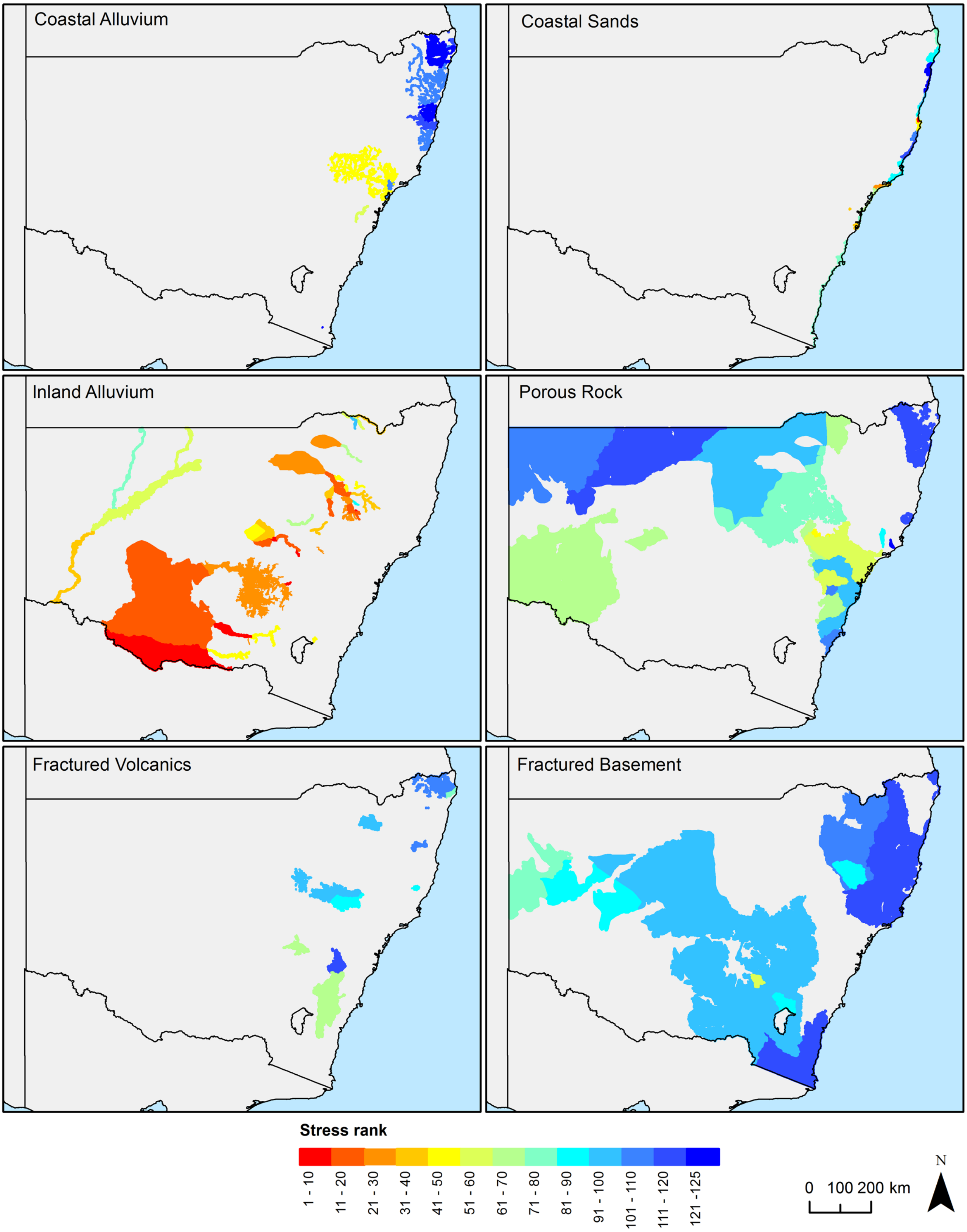


Figure 4-2 Stress rank of groundwater sources

4.3.3 Prioritisation scheme

The prioritisation scheme was developed to identify those groundwater sources that are both sensitive to climate change and under stress that could be exacerbated by climate change. This is displayed graphically in Figure 4-3. There are 18 of the highest 30 ranked groundwater sources for sensitivity (green box in Figure 4-3) included within the top 30 priority groundwater sources (red dots in Figure 4-3) and 17 of the highest ranked groundwater sources for stress (yellow box in Figure 4-3) included in the top 30 priority groundwater sources. There 7 groundwater sources that are in the 30 highest ranked groundwater sources for both sensitivity and stress and only 1 groundwater source that is not ranked in the top 30 of either sensitivity or stress but are included in the 30 highest priority groundwater sources (Figure 4-3).

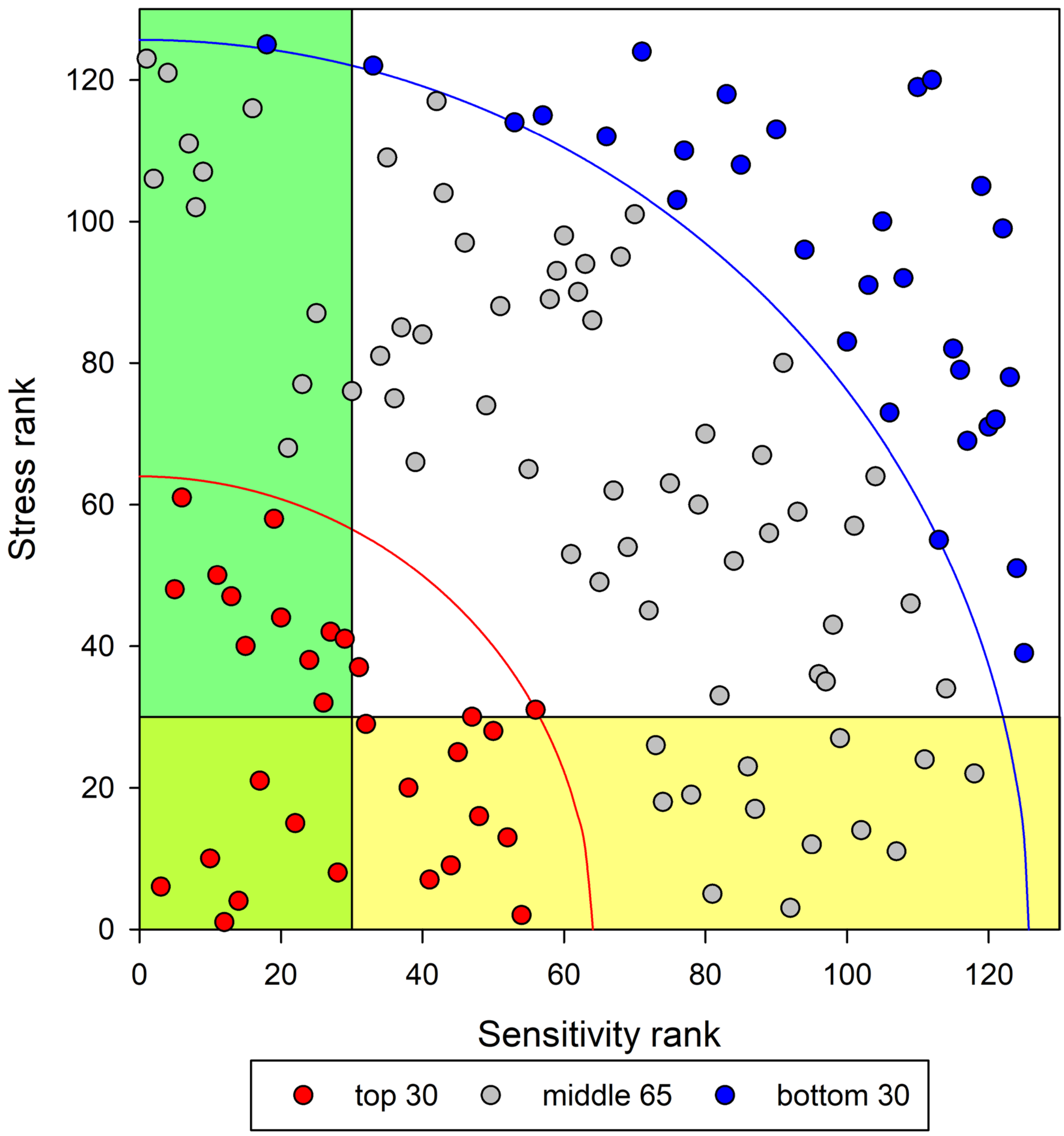


Figure 4-3 The stress and sensitivity rank of the 125 groundwater sources evaluated. The yellow box shows the highest ranked 30 groundwater sources on the stress metric and the green box shows the highest ranked 30 groundwater sources on the sensitivity metric. Inside the red arc are the 30 highest priority groundwater sources and outside the blue arc are the lowest 30 priority groundwater sources.

The majority of the 30 highest ranked priority groundwater sources are alluviums (25 inland, 2 coastal) with the rest being coastal sands (3), these are listed in Table 4-3 and shown on Figure 4-4. These 30 groundwater sources are administered under 10 water sharing plans. Six of these water sharing plans have multiple groundwater sources included: the Namoi Alluvial Groundwater Sources 2020 has 9 high priority groundwater sources; the Macquarie-Castlereagh Groundwater Sources 2020 has 6; the Murrumbidgee Alluvial Groundwater Sources Order 2020 has 5; the Greater Metropolitan Region Groundwater Sources 2011 has 2; the North Coast Coastal Sands Groundwater Sources 2016 has 2; and, the Lachlan Alluvial Groundwater has 2 groundwater sources included in the 30 priority groundwater sources.

The lowest priority groundwater sources are those that are not particularly sensitive to climate change and not particularly stressed. These are dominated by the large fractured basement and porous rock groundwater sources (Figure 4-4). [Note: the buried water sources have been excluded from this analysis and so have not been considered.]

Table 4-3 The 30 highest ranked priority groundwater sources based on level of stress and sensitivity to climate change

Rank	Groundwater source	Rank	Groundwater source
1	Belubula Valley Alluvial Groundwater Source	16	Tomaree
2	Wagga Wagga Alluvial	17	Bungendore/Lake George Alluvial
3	Bell Alluvial Groundwater Source	18	Hunter Regulated River Alluvial Water Source
4	Upper Murray Groundwater Source	19	Upper Namoi Zone 12
5	Upper Macquarie Alluvial	20	Upper Namoi Zone 11
6	Cudgegong Alluvial Groundwater Source	21	Upper Namoi Zone 1
7	Lower Macquarie Zone 6	22	Manilla Alluvial
8	NSW Border Rivers Upstream Keetah Bridge Alluvial Groundwater Source	23	Upper Namoi Zone 10
9	Mid Murrumbidgee Zone 3	24	Upper Namoi Zone 5
10	Peel alluvium	25	Lower Macquarie Zone 1
11	Quirindi Alluvial	26	Kyeamba Creek GW source
12	Upper Lachlan Alluvial	27	Tomago
13	Quipolly alluvial	28	Hawkesbury Alluvium
14	Botany Sands	29	Upper Gwydir Alluvial Groundwater Source
15	Gundagai	30	Talbragar Alluvial

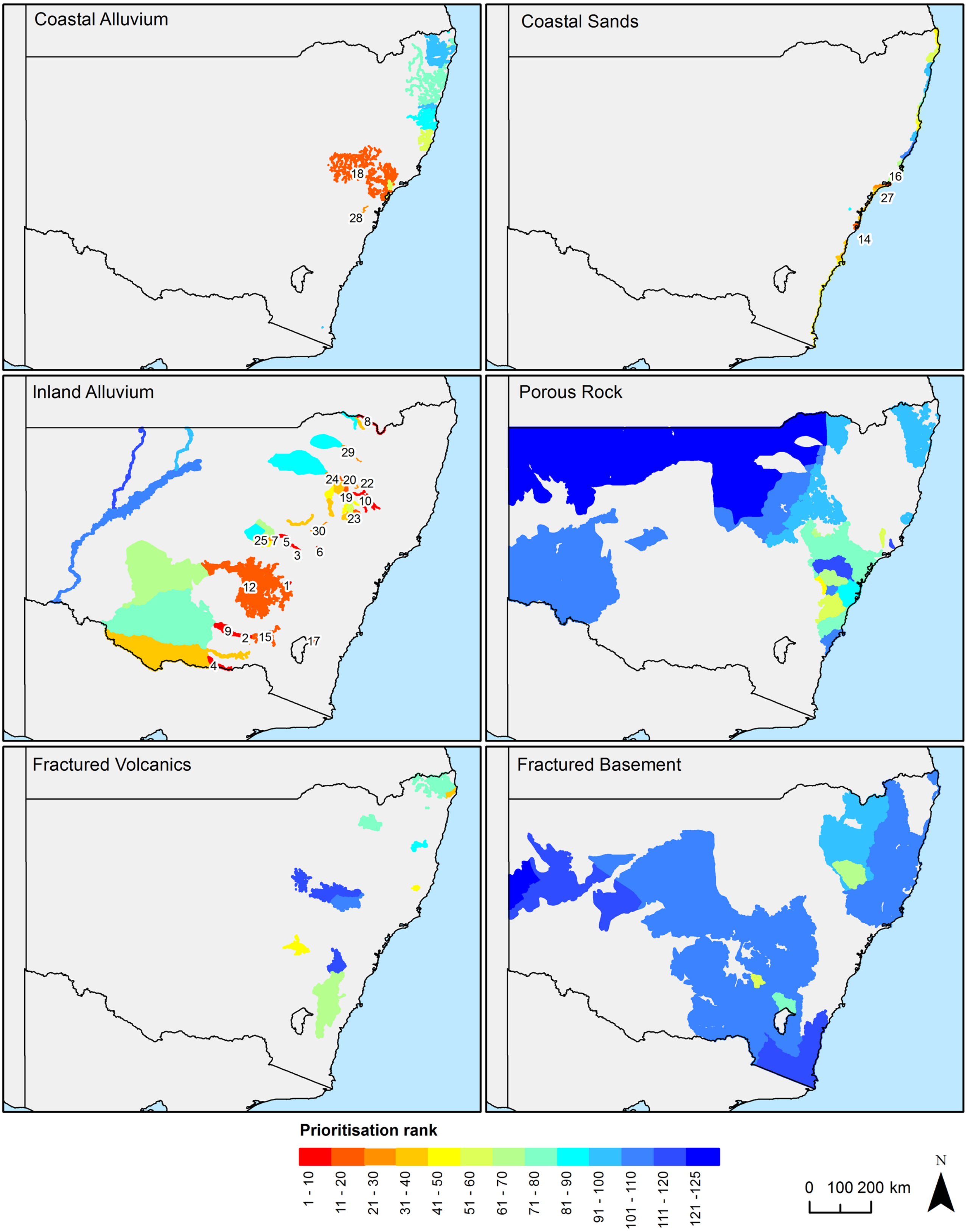


Figure 4-4 Prioritisation rank of groundwater sources

4.4 Conclusions

A revised prioritisation scheme has been developed to assess which groundwater sources need further detailed investigations due to climate change. This prioritisation is based around two metrics: the sensitivity of a groundwater source to climate change; and the stress that the groundwater source is currently under. Through this process, the 30 most sensitive and the 30 most stressed groundwater sources have been identified. In combining these metrics, the 30 highest priority groundwater sources for further investigation have been identified.

5 Conclusions and recommendations

The findings in the sections above contribute to a more informed understanding of how a drying climate over the next several decades could impact on groundwater recharge across NSW. This is a first attempt at assessing impacts of the new DPE-Water climate and surface water simulations on diffuse and localised recharge change. These recharge change estimates are complemented by a new prioritisation of groundwater sources accounting for their sensitivity to climate change and current level of stress, knowledge that can begin to inform risk assessment and guidance for groundwater management plan development across the state. The top 30 highest priority groundwater sources have been identified for further investigation and this section further splits these into high and medium priority within the top 30.

We provide recommendations for further research for the priority groundwater sources (Table 4-3) grouped by aquifer type:

- 25 priority groundwater sources are Inland Alluvium aquifer type
- 3 priority groundwater sources are Coastal Sands aquifer type
- 2 priority groundwater sources are Coastal Alluvium aquifer type
- No priority groundwater sources are Fractured Volcanics aquifer type
- No priority groundwater sources are Porous Rock aquifer type
- No priority groundwater sources are Fractured Basement aquifer type

5.1 Inland Alluvium

There were nine priority groundwater sources identified in the Namoi catchment. The Peel Alluvium, Upper Namoi Zones 11 & 12 and Manilla Alluvium groundwater sources were classified as high sensitivity but not particularly high stress; and, the Quirindi Alluvial, Quipolly Alluvial and Upper Namoi Zones 1, 5 & 10 groundwater sources were classified as high stress but not particularly high sensitivity. Seven of the nine are fully committed (except Upper Namoi Zones 1 & 10) and some can have high levels of extractions (particularly Peel Alluvium and Upper Namoi Zones 1 & 5, see Appendix E for details of extractions). The projection for diffuse recharge under the future climate assessed here is for between 4 and 19% reduction, 9 to 47% reduction in in-stream recharge and 16 to 40% reduction in overbank flood recharge. Seven of the nine groundwater sources in the Namoi (except Upper Namoi Zones 1 & 10) are a high priority for future detailed investigations to assess how the reduction in recharge (diffuse and localised) will impact upon the water resource, existing users and environmental assets.

There were six priority groundwater sources identified in the Macquarie catchment. The Bell Alluvial Groundwater Source, Upper Macquarie Alluvial, Cudgegong Alluvial Groundwater Source and Lower Macquarie Zone 6 were classified as high sensitivity and high stress; the Lower Macquarie Zone 1 was classified as high stress but not particularly high sensitivity; and the

Talbragar Alluvial was classified as not particularly high sensitivity or stress. Five of the six are fully committed (except Lower Macquarie Zone 6) and four of the six can have high levels of extractions (particularly Upper Macquarie Alluvial). The projection for diffuse recharge under the future climate assessed here is for between 13 and 23% reduction, 19 to 28% reduction in in-stream recharge and 33 to 62% reduction in overbank flood recharge. Five of the six of these groundwater sources in the Macquarie (except Lower Macquarie Zone 6) are a high priority for future detailed investigations to assess how the reduction in recharge (diffuse and localised) will impact upon the water resource, existing users and environmental assets.

There were five priority groundwater sources identified in the Murrumbidgee. The Wagga Wagga Alluvial was classified as both high sensitivity and high stress; Mid Murrumbidgee Zone 3 and Kyeamba Creek were classified as high stress but not particularly high sensitivity; and Gundagai and Bungendore/Lake George Alluvial were classified as high sensitivity but not particularly high stress. They are all fully committed and can have high levels of extractions. The projection for diffuse recharge under the future climate assessed here is for between 9 and 16% reduction, 17 to 31% reduction in in-stream recharge and 29 to 79% reduction in overbank flood recharge. All of these groundwater sources in the Murrumbidgee are a high priority for future detailed investigations to assess how the reduction in recharge (diffuse and localised) will impact upon the water resource, existing users and environmental assets.

There were two priority groundwater sources identified in the Lachlan catchment. The Belubula Valley Alluvial Groundwater Source was classified as high stress and high sensitivity; and the Upper Lachlan Alluvial was classified as high stress but not particularly high sensitivity. They are currently fully committed and can have high levels of extraction. The projection for diffuse recharge under the future climate assessed here is for a 11% reduction, 19% reduction in in-stream recharge and 78% reduction in overbank flood recharge in the Belubula and 17%, 42% and 84% reductions in the Upper Lachlan for the diffuse, in-stream and overbank flood recharge respectively. Both the Belubula Valley Alluvial Groundwater Source and Upper Lachlan Alluvial are a high priority for future detailed investigations to assess how the reduction in recharge (diffuse and localised) will impact upon the water resource, existing users and environmental assets.

There was one priority groundwater source identified in the Border Rivers, the NSW Border Rivers Upstream Keetah Bridge Alluvial Groundwater Source. It was classified as high sensitivity but not particularly high stress. It is currently fully committed and can have high levels of extraction. The projection for diffuse recharge under the future climate assessed here is for a 16% reduction, 26% reduction in in-stream recharge and 44% reduction in overbank flood recharge. The NSW Border Rivers Upstream Keetah Bridge Alluvial Groundwater Source is a high priority for future detailed investigations to assess how the reduction in recharge (diffuse and localised) will impact upon the water resource, existing users and environmental assets.

There was one priority groundwater source identified in the Gwydir, the Upper Gwydir Alluvial Groundwater Source. It was classified as high sensitivity but not particularly stressed. It is currently fully committed but there is not much extraction data available as few bores are metered in this groundwater source. The projection for diffuse recharge under the future climate assessed here is for a 15% reduction, 21% reduction in in-stream recharge and 49% reduction in overbank flood recharge. The Upper Gwydir Alluvial Groundwater Source is a high priority for future detailed investigations to assess how the reduction in recharge will impact upon the water resource, existing users and environmental assets.

There was one priority groundwater source identified in the Murray catchment, the Upper Murray Groundwater Source. It was classified as high stress and high sensitivity. It is currently fully committed and can have high levels of extraction. The projection for diffuse recharge under the future climate assessed here is for a 15% reduction, 19% reduction in in-stream recharge and 90% reduction in overbank flood recharge. The Upper Murray Groundwater Source is a high priority for future detailed investigations to assess how the reduction in recharge will impact upon the water resource, existing users and environmental assets.

All groundwater sources that have a high proportion of recharge from localised sources will need more detailed investigations as the reduction in recharge could be very substantial. This will require several areas of investigation:

- The proportion of recharge due to flooding, losing streams, irrigation drainage and diffuse recharge from rainfall needs to be understood for each groundwater source. The higher the proportion of flood recharge in the total recharge, the higher the potential reductions in recharge will be under a future climate. It is likely that the Inland Alluvium Aquifer Type will have the highest proportion of flood and losing stream recharge of all the aquifer types.
- The method used here to generate the future climate time series needs to be assessed as to its suitability for use in making projections of future recharge due to flooding. The method used relies on scaling the historical stochastic climate time series – the presence of an event will not change, only the magnitude. If the drivers of flooding change under a future dry climate, then the method used may not be appropriate. For example, if cyclones can track further south, or the frequency of east coast lows increases, then there could be more frequent higher magnitude floods alongside an overall reduction in rainfall that would not be projected under the current method of generating the future climate time series.
- We do not currently have a suitable method for estimating recharge from flooding, especially in a predictive sense for future flooding. Any new method will need to be dependent on flows generated from river modelling, flood extents estimated from stage heights and spatially explicit estimates of recharge.
- Most of these inland alluvial groundwater sources have numerical groundwater models, these need to be assessed as to their suitability to simulate under a future climate. In particular the recharge input to the model needs to be broken down into recharge due to flooding, losing streams, irrigation and diffuse recharge from rainfall. The river boundary condition also needs to be very flexible: it needs to change conductance with changing wetted perimeter (via relationships with flow via stage height); be capable of simulating the transition from perennial stream to intermittent stream without creating water; and be capable of simulating the transition from gaining stream to losing connected to losing disconnected as the water table falls.

5.2 Coastal Sands

The scope of this work was to investigate the climate change effects on water sources based on a change in recharge. The coastal sands aquifer type is also potentially impacted by sea level rise and coastal inundation but these impacts are out of scope for this report.

The majority of bores are not metered in the water sources of the coastal sands aquifer type, therefore we can't comment on the level of extractions relative to commitments.

The Botany Sands were classified as high sensitivity but not particularly high stress. They are currently under-committed and projected to have a 6% decrease in recharge under the future climate assessed here. The Botany Sands are a medium priority for further detailed investigation.

Tomaree was classified as not particularly high sensitivity or stress. It is currently under-committed and projected to have an 8% decrease in recharge under the future climate assessed here. Tomaree is a medium priority for further detailed investigation.

Tomago was classified as high stress but not particularly high sensitivity. Tomago is currently fully committed and can have high extraction rates; it is projected to have a 12% reduction in diffuse recharge for the future climate scenario assessed here. Tomago is a high priority for future detailed investigations to assess how the reduction in recharge will impact upon the water resource, existing users and environmental assets. The existing groundwater model will need to be assessed to evaluate if it is suitable for making projections under a future climate.

5.3 Coastal Alluvium

The majority of bores are not metered in the water sources of the coastal alluvium aquifer type; therefore, we can't comment on the level of extractions relative to commitments.

The Hunter Regulated River Alluvial groundwater source was classified as high sensitivity but not particularly high stress. It is currently fully committed and projected to have a 11% reduction in diffuse recharge, 21% reduction in in-stream recharge and 36% reduction in overbank flood recharge. The calculated LTAAEL/R ratio is low so the projected reduction in recharge will not see the LTAAEL exceed recharge. It is a medium priority for further detailed investigation.

The Hawkesbury Alluvium groundwater source was classified as high sensitivity but not particularly high stress. It is currently under-committed and projected to have an 8% decrease in diffuse recharge, 15% reduction in in-stream recharge and 25% reduction in overbank flooding recharge under the future climate scenario assessed here. It is a medium priority for further detailed investigation.

5.4 Fractured Volcanics

There are no fractured volcanic groundwater sources that are a high priority for further detailed investigations into the impact of climate change on groundwater in NSW.

5.5 Porous Rock

There are no porous rock groundwater sources that are a high priority for further detailed investigations into the impact of climate change on groundwater in NSW.

5.6 Fractured Basement

There are no fractured basement groundwater sources that are a high priority for further detailed investigations into the impact of climate change on groundwater in NSW.

Appendix A Diffuse recharge example

Site 49002 Balranald

The following graphs show the WAVES results for the site at Balranald for bare soil.

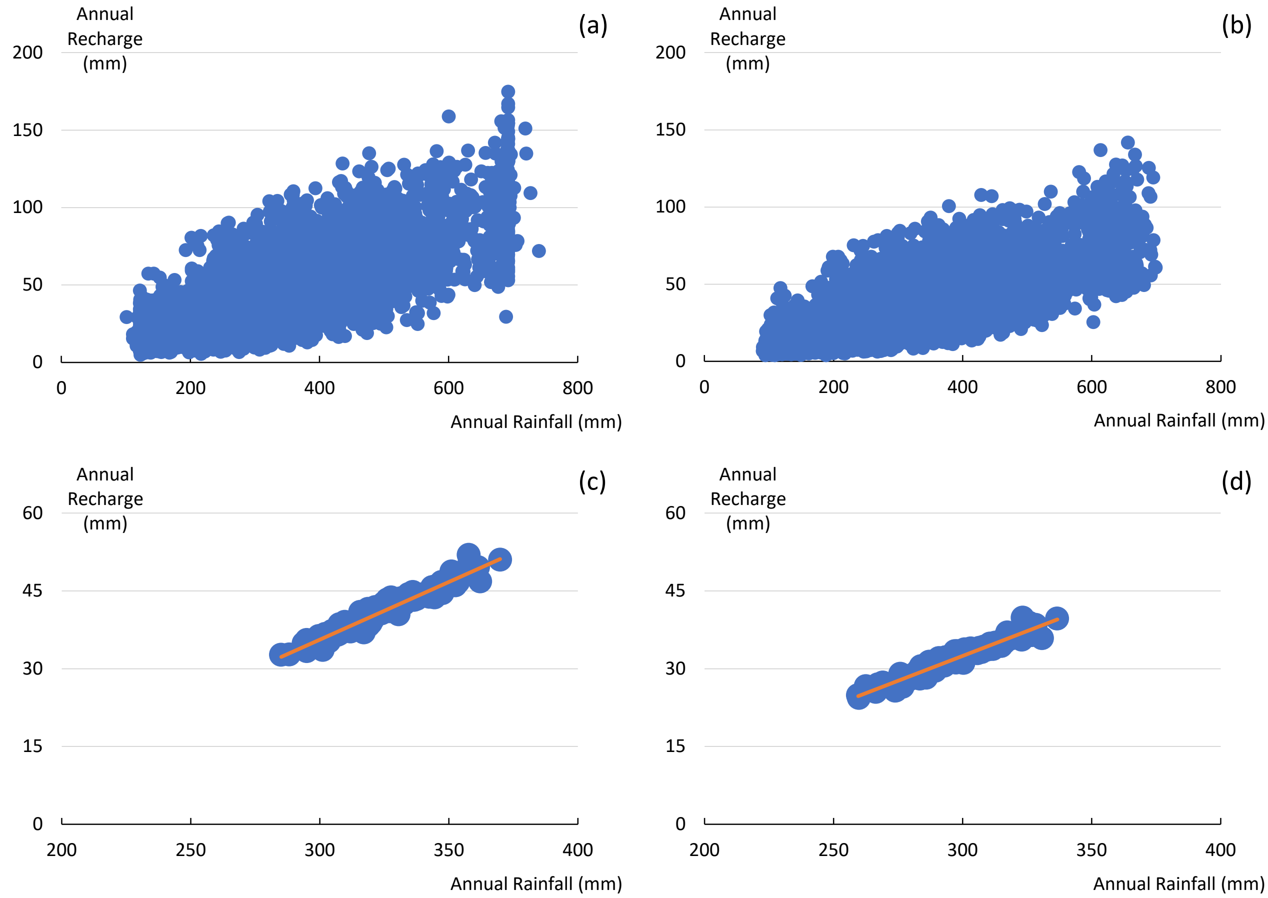


Figure A.1 Annual rainfall versus recharge based on 10,000 individual points for (a) stochastic historic and (b) NARCliM future climate, and summarised to 100 century averages for (c) stochastic historic and (d) NARCliM future climate, on bare ground land cover at 49002 Balranald

As is typical of all the results, on an annual basis the 10,000 points provide a general spread but are extremely variable. The range of rainfall for example is between 100 and 700mm annually, while the average over the entire period is 325 and 294mm, for stochastic and NARCLiM respectively. The average value is much clearer in the century summary.

The graphs for grass cover and tree cover are shown below, with the expected reduction in recharge with increasing LAI cover and rooting depth. The overall recharge difference with no cover is 41 to 31mm, a change of −24% from stochastic to NARCLiM climate, with grass cover is 10.8 to 7.2mm (−33%) and for tree cover is 0.036 to 0.013mm (−63%).

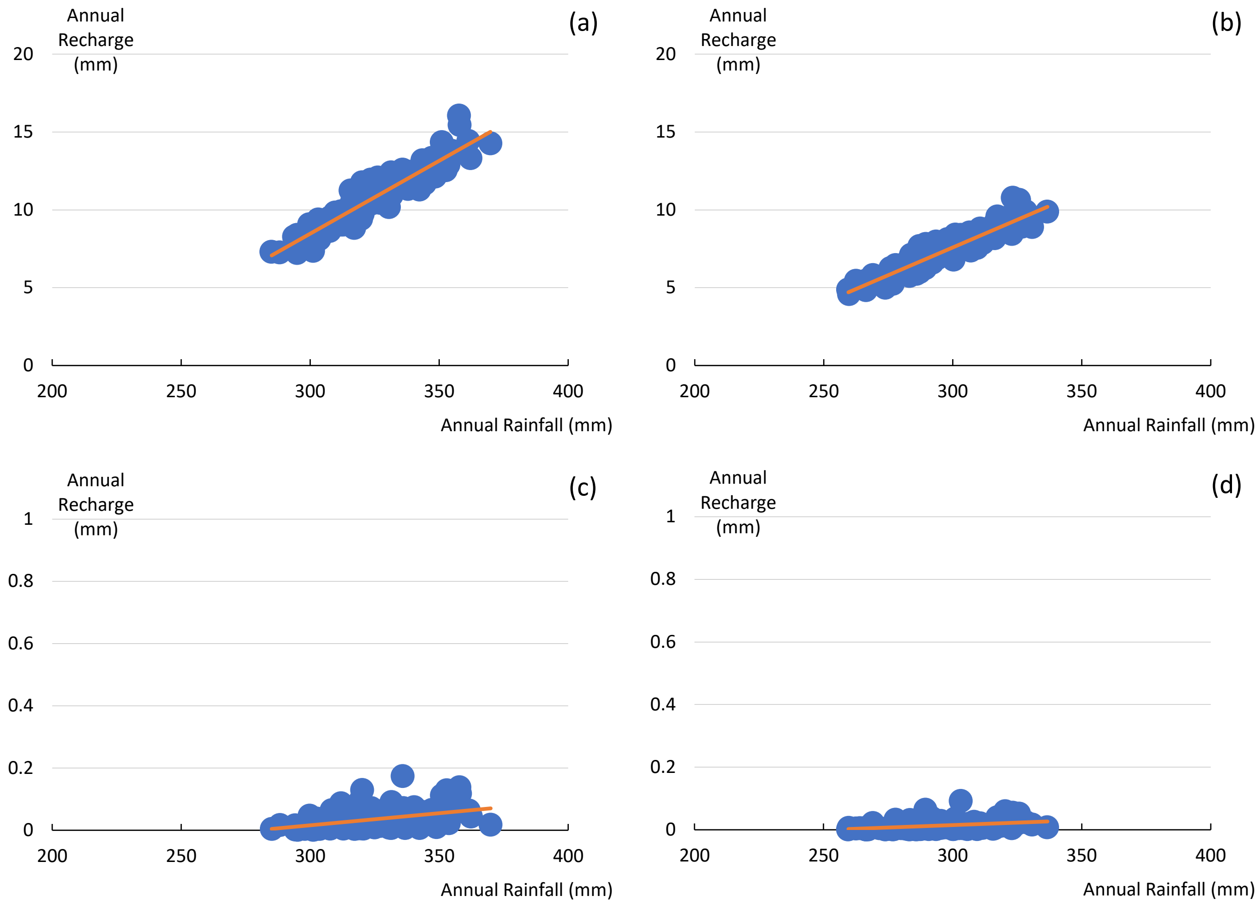


Figure A.2 Century average rainfall versus recharge at 49002 Balranald for grass under (a) stochastic historical and (b) NARCliM future climate, and tree cover under (c) stochastic historical and (d) NARCliM future climate

Site 51048 Trangie

The site for 51048 Trangie has greater soil hydraulic conductivity than at Balranald, along with more rainfall (507 and 449mm) and greater LAI cover (tree LAI=1.0; grass LAI=0.67). The century average graphs are shown for the two climate sequences and three land covers below. Another common feature of the results is that as cover increases so does the scatter in recharge, with a subsequent reduction in linear correlation coefficient between rainfall and recharge.

The simulated change in recharge from stochastic to NARCLiM future climate was −16% with no cover (309 to 259mm), −18% with grass cover (217 to 177mm) and −19% with trees (45 to 37mm).

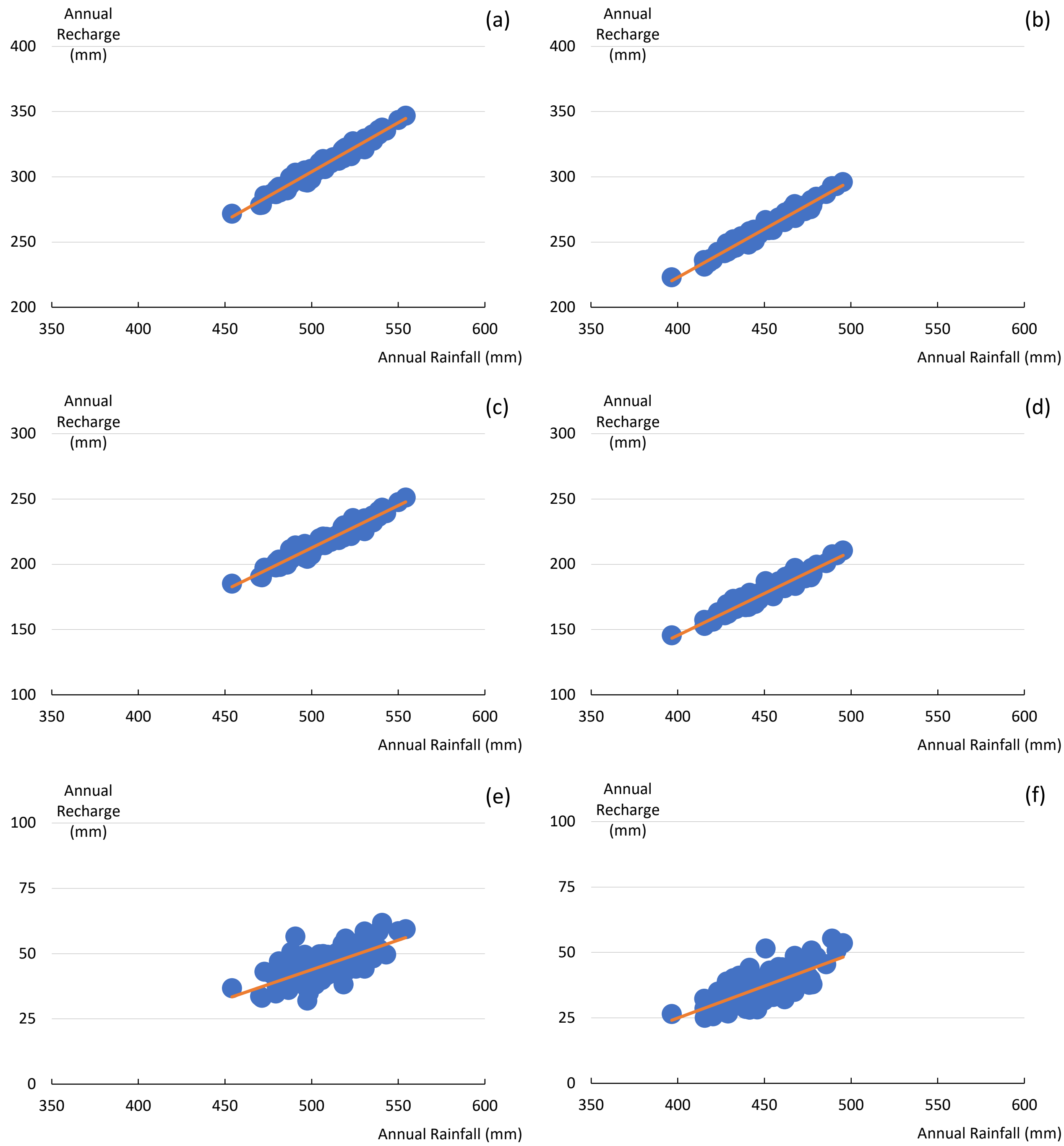


Figure A.3 Century average rainfall versus recharge at 51048 Trangie for bare ground under (a) stochastic historical and (b) NARCliM future climate, grass cover under (c) stochastic historical and (d) NARCliM future climate, and tree cover under (e) stochastic historical and (f) NARCliM future climate

Site 58037 Lismore

At Lismore there is much more rainfall than the previous sites, but in the NARCLiM future climate series the overall average rainfall only declines by 5mm/year from 1329 to 1325mm (tree LAI=3.0). Under these conditions there is little difference in recharge with the bare and grass covers between climate sequences, but with obvious changes in average recharge. Due to the monthly change factors however, while average recharge with no cover declines from 426 to 411mm, it increases under grass cover from 136 to 142mm and under tree cover from 3.6 to 5.8mm. This result is a consequence of altering daily rainfall totals unevenly across the year, and the overall rainfall distribution throughout the year.

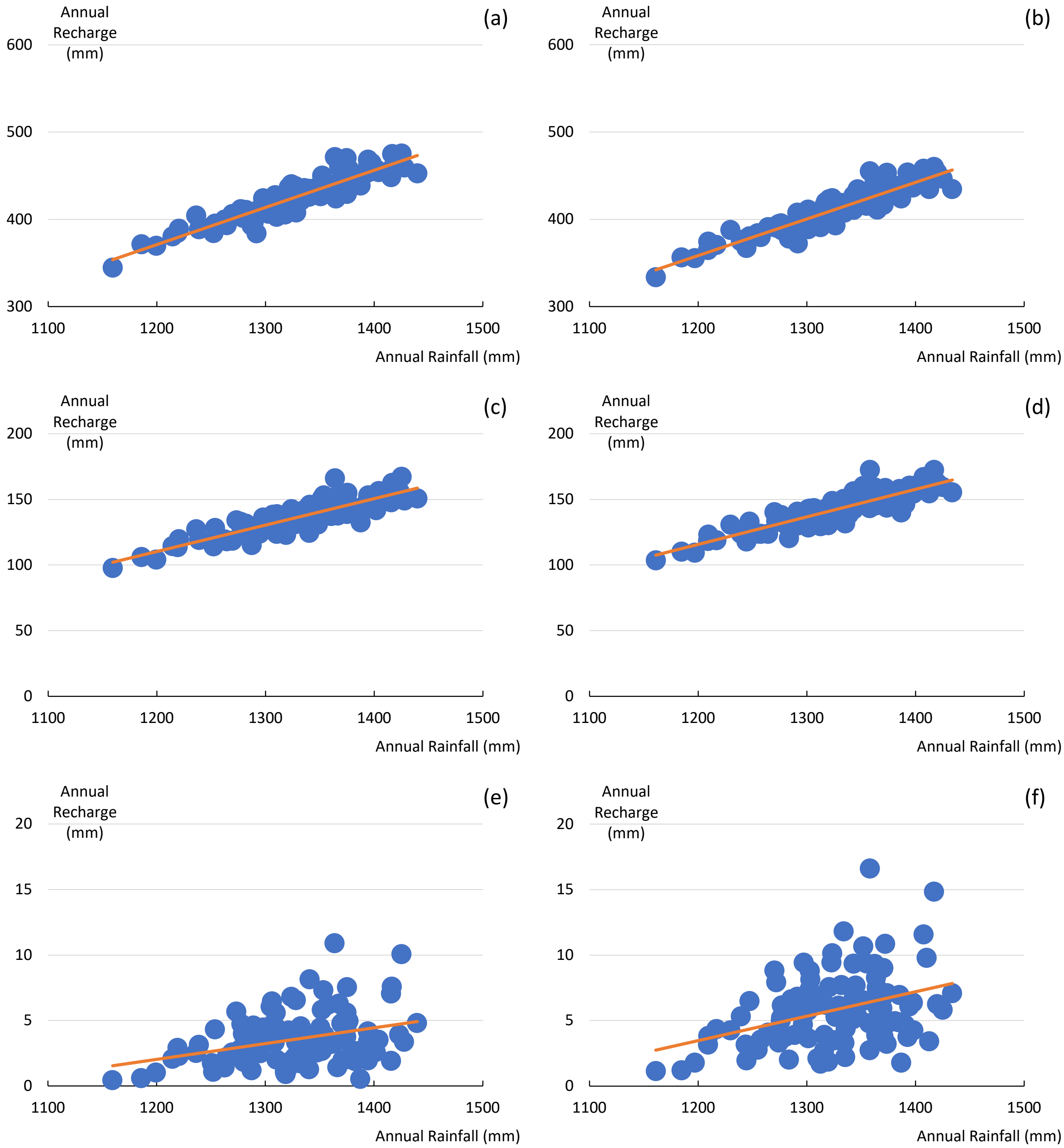


Figure A.4 Century average rainfall versus recharge at 58037 Lismore for bare ground under (a) stochastic historical and (b) NARCliM future climate, grass cover under (c) stochastic historical and (d) NARCliM future climate, and tree cover under (e) stochastic historical and (f) NARCliM future climate

Zone 5 Chromosol – sites 58088, 59040, 65019, 73015

Where multiple model sites share the same soil+climate zone, results were amalgamated to a single linear relationship between average annual rainfall and recharge. Results are shown here for climate zone 5 Equiseasonal Hot with Chromosol soil group.

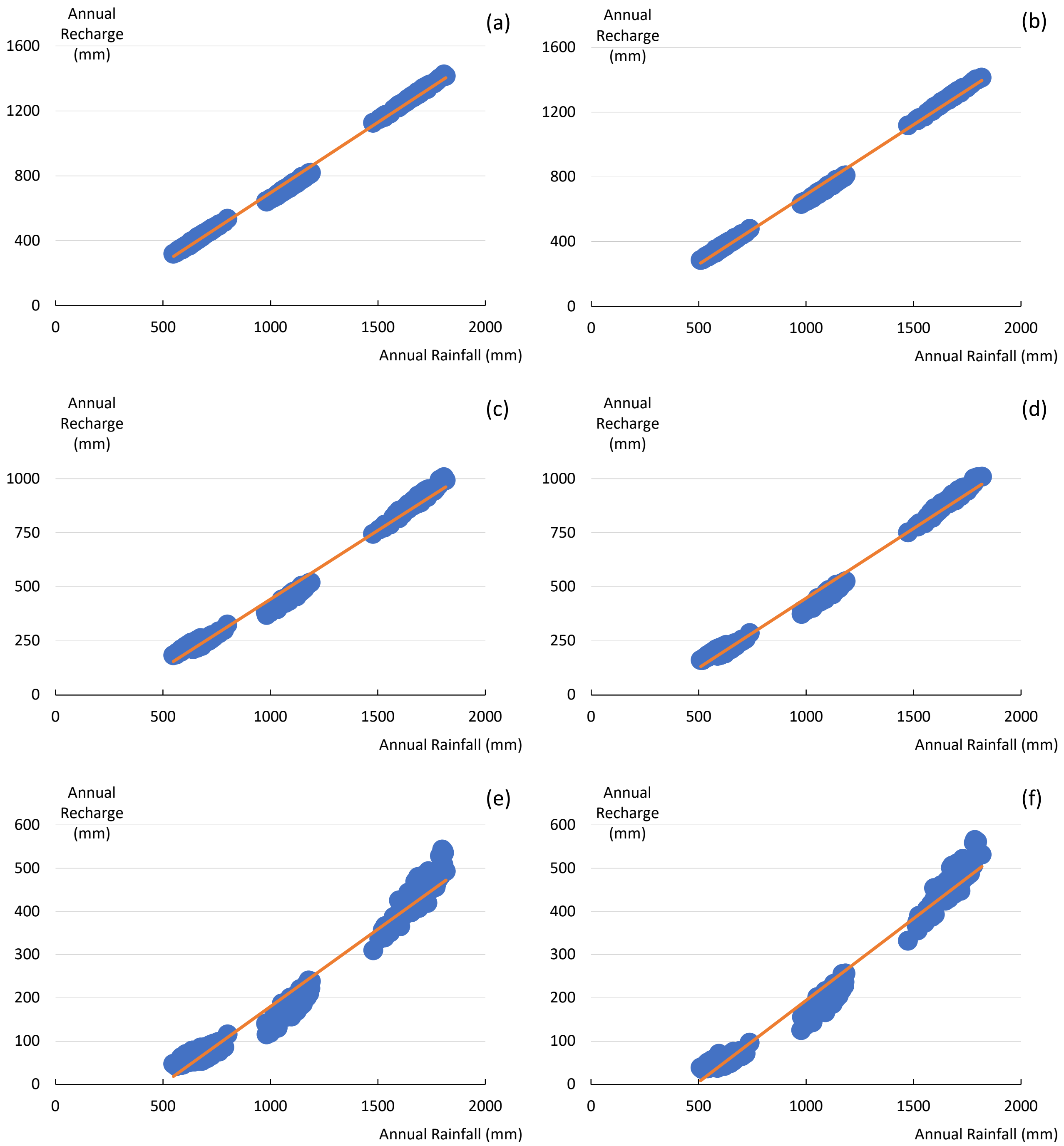
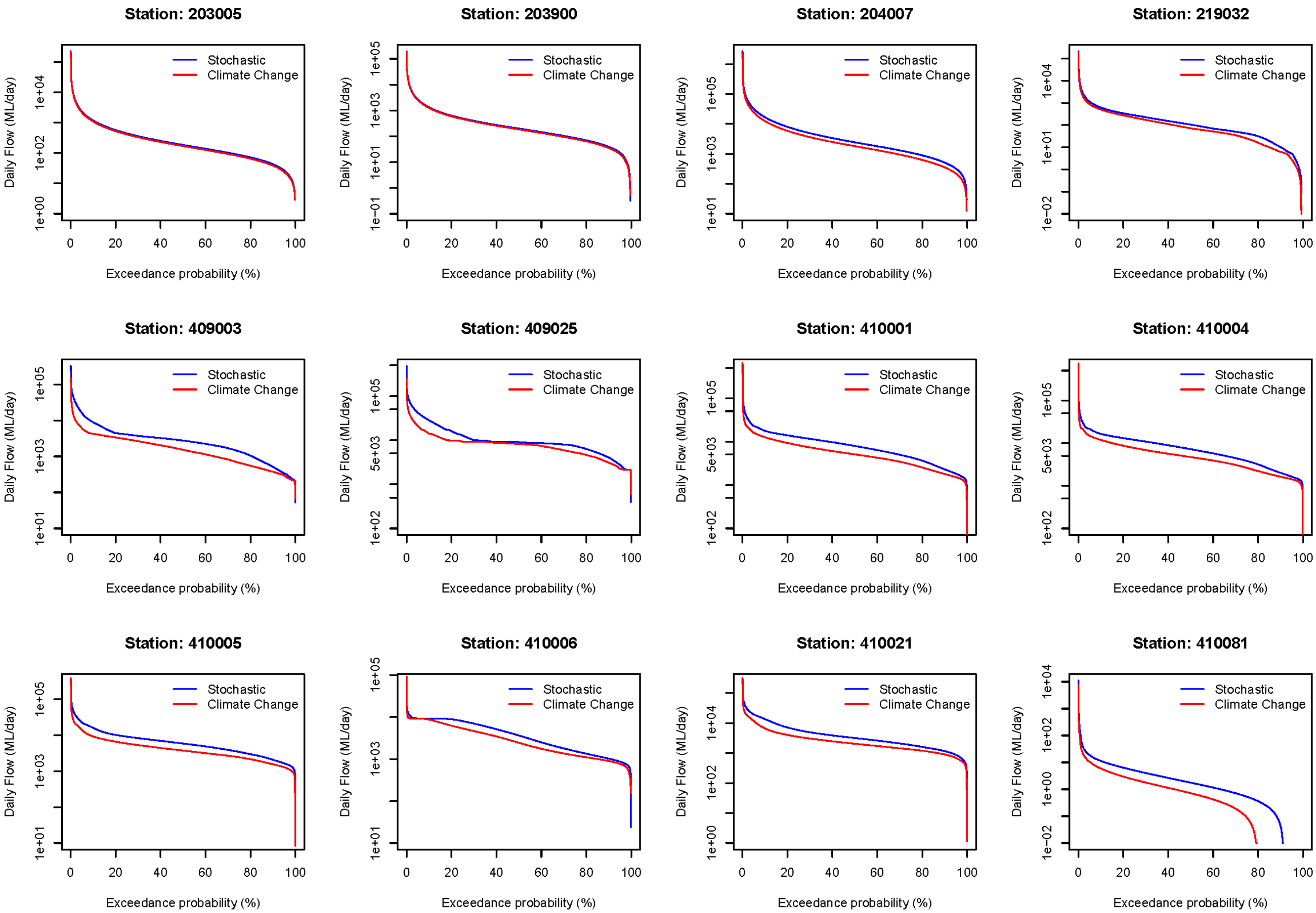
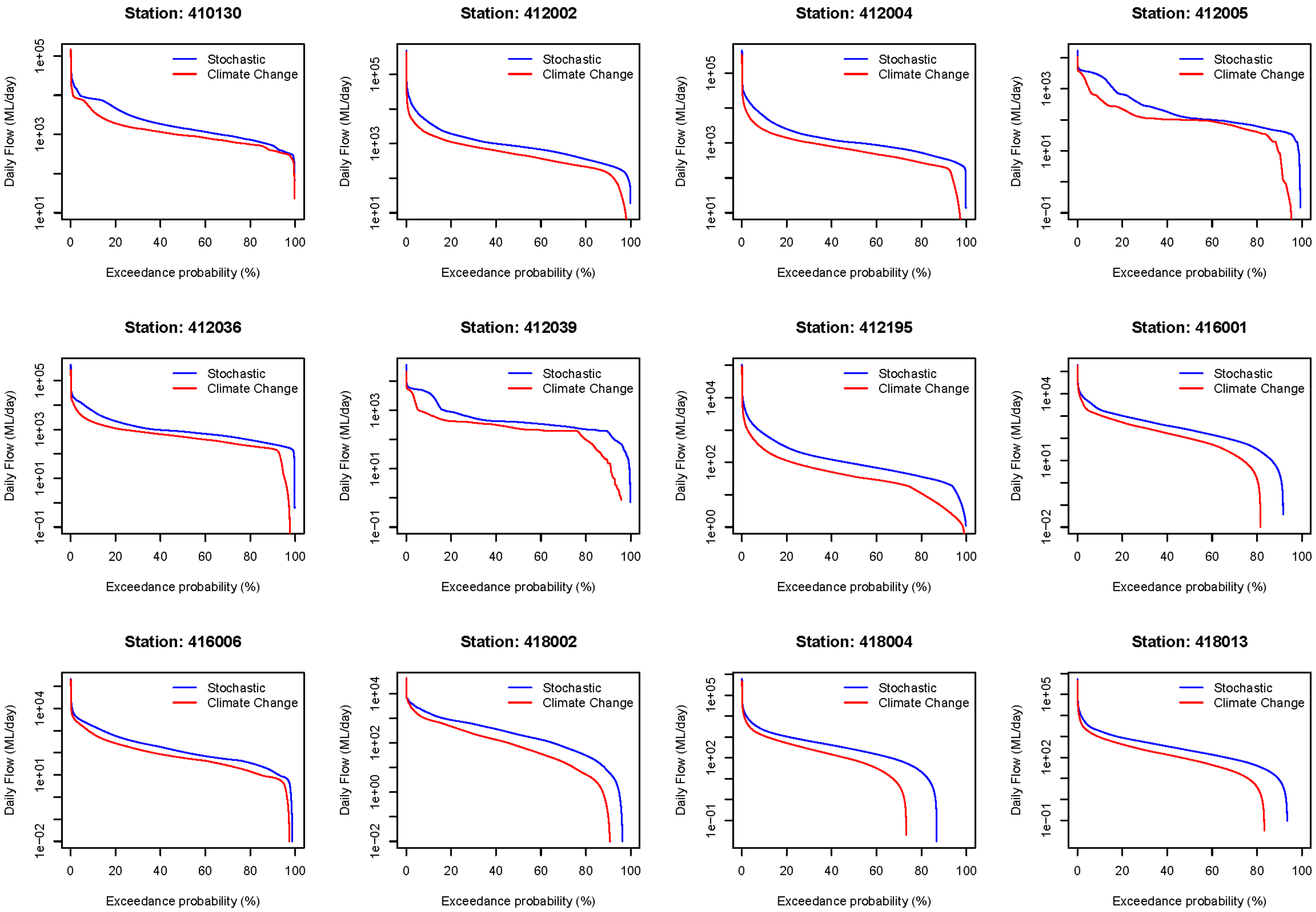
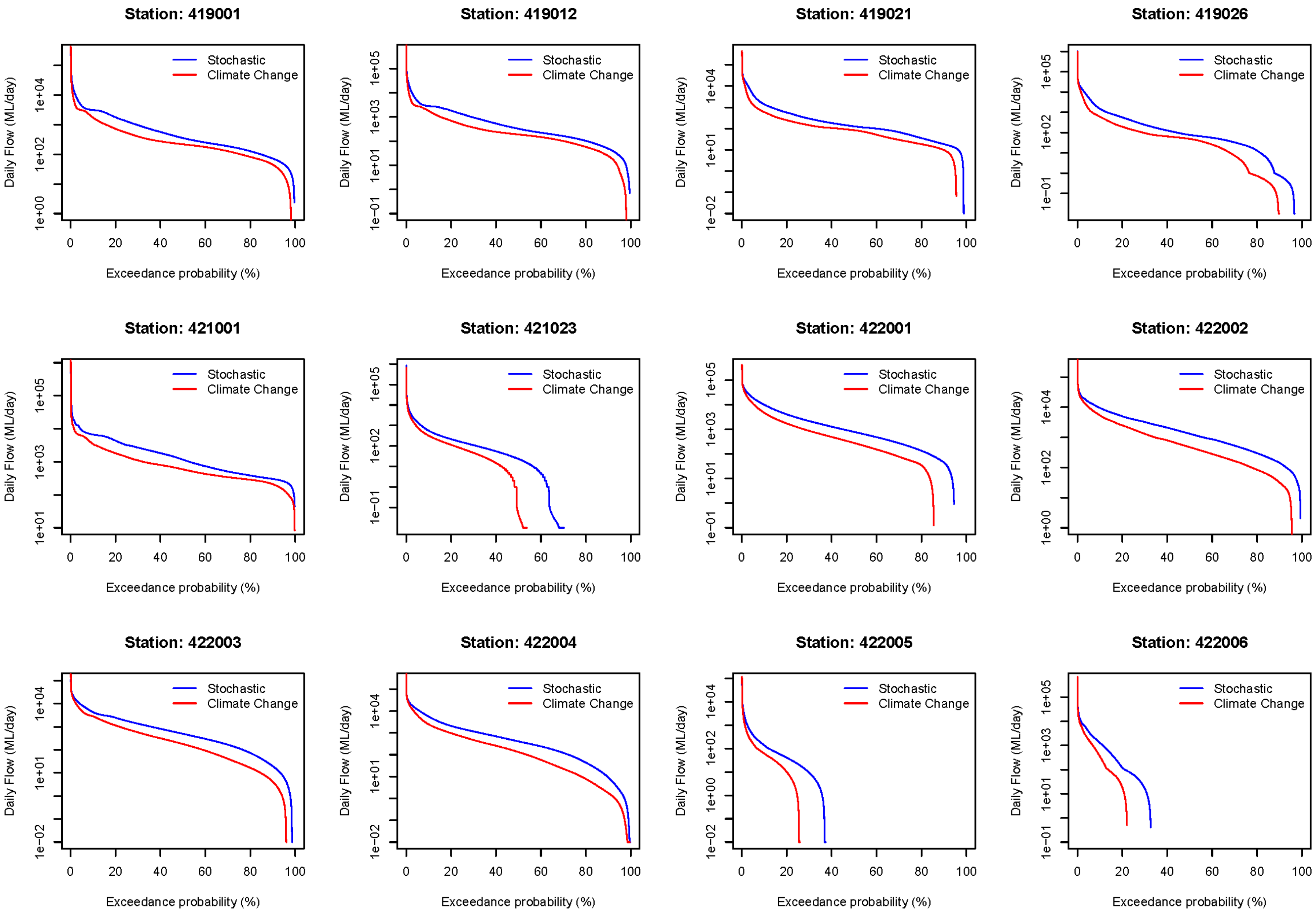


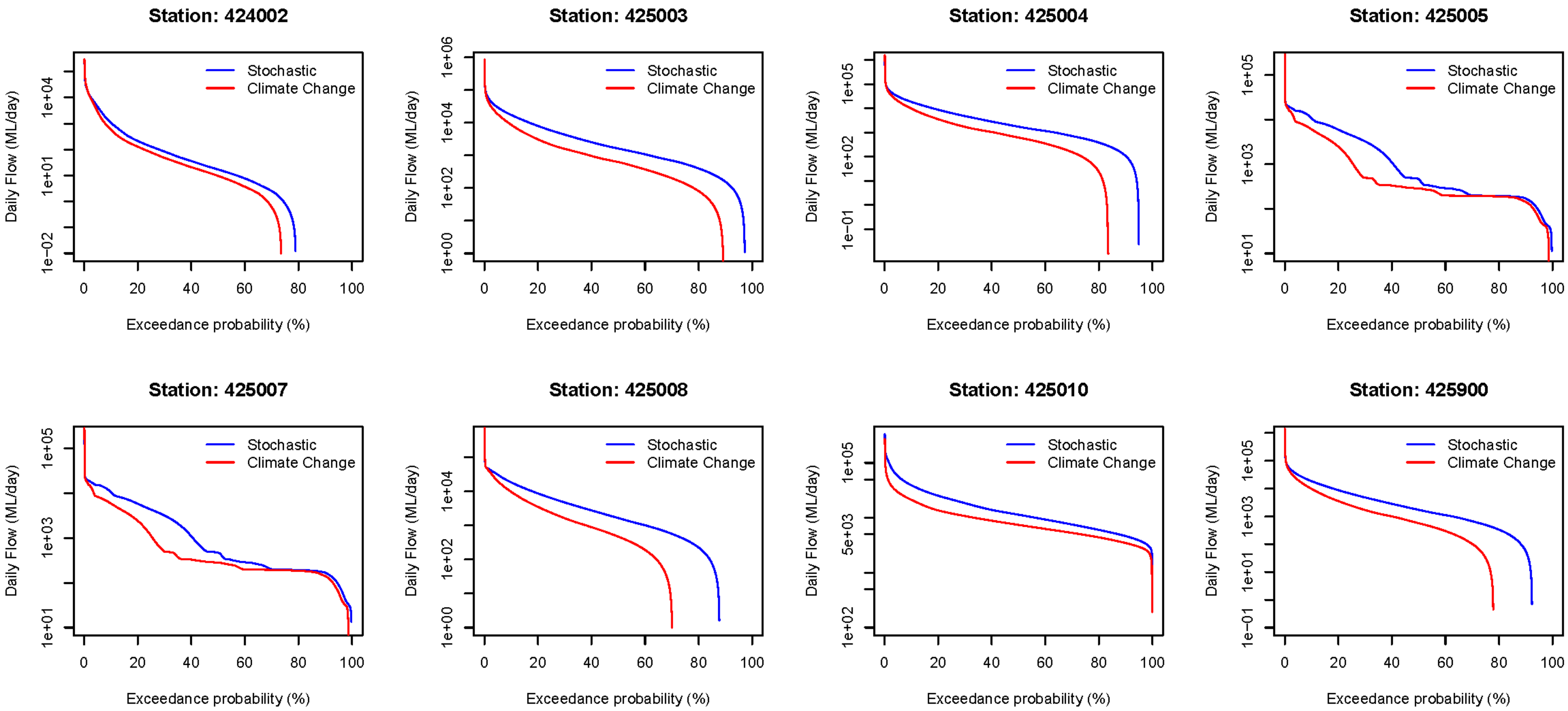
Figure A.5 Century-averaged rainfall and recharge data amalgamated for stations in Arid zone Chromosol soil for (a) stochastic historical climate bare cover, (b) NARCliM climate bare cover, (c) stochastic historical climate grass cover, (d) NARCliM climate grass cover, (e) stochastic historical climate tree cover, and (f) NARCliM climate tree cover

Appendix B Flow duration curves


Station: 203005
Station: 203900
Station: 204007
Station: 219032
Station: 409003
Station: 409025
Station: 410001
Station: 410004
Station: 410005
Station: 410006
Station: 410021
Station: 410081
Stochastic
Climate Change
Daily Flow (ML/day)
Exceedance probability (%)
0
20
40
60
80
100


Station: 410130
Station: 412002
Station: 412004
Station: 412005
Station: 412036
Station: 412039
Station: 412195
Station: 416001
Station: 416006
Station: 418002
Station: 418004
Station: 418013
Stochastic
Climate Change
Daily Flow (ML/day)
Exceedance probability (%)


Station: 419001
Station: 419012
Station: 419021
Station: 419026
Station: 421001
Station: 421023
Station: 422001
Station: 422002
Station: 422003
Station: 422004
Station: 422005
Station: 422006
Stochastic
Climate Change
Daily Flow (ML/day)
Exceedance probability (%)

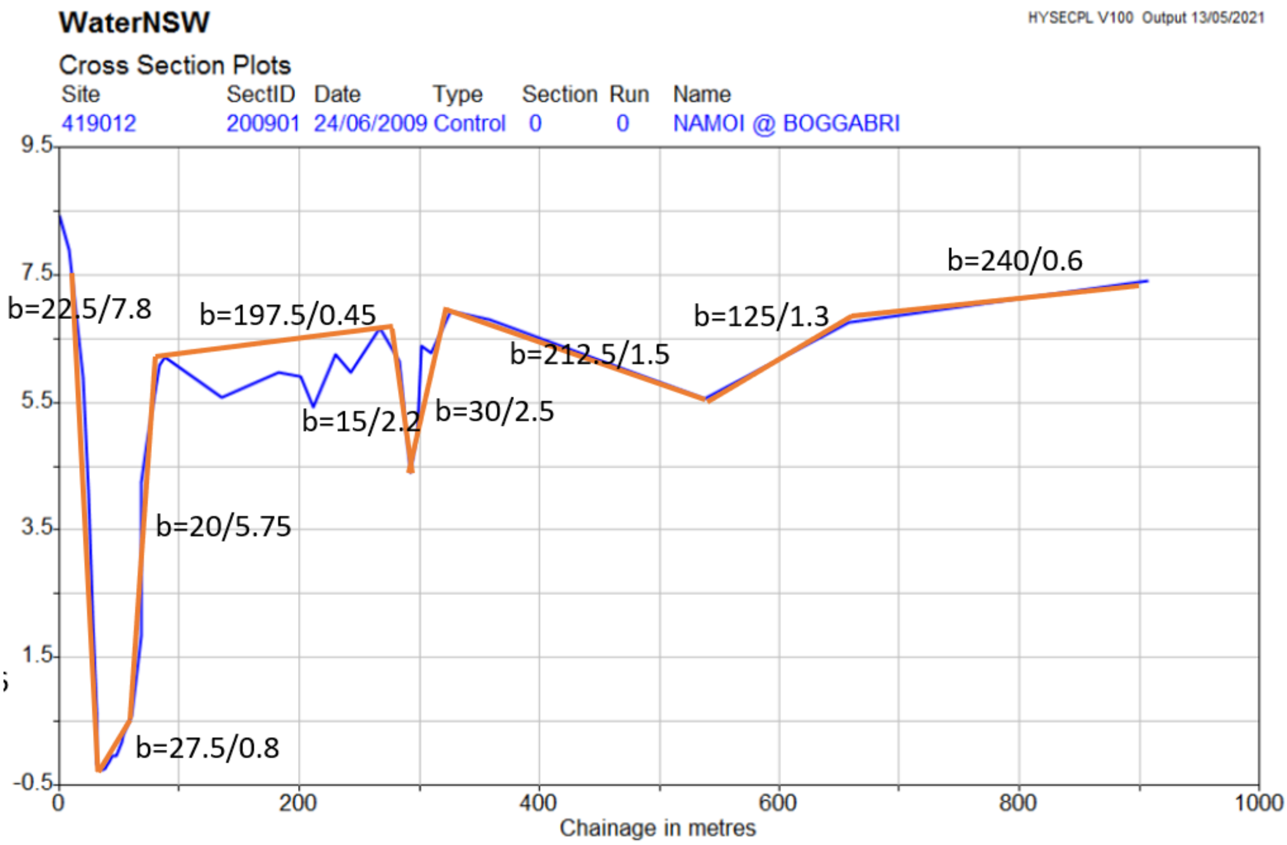


Station: 424002
Station: 425003
Station: 425004
Station: 425005
Station: 425007
Station: 425008
Station: 425010
Station: 425900
Stochastic
Climate Change
Daily Flow (ML/day)
Exceedance probability (%)

Appendix C Localised recharge example

Example calculations for gauge 419012 (Namoi River at Boggabri)

- Step 1: Create a look-up table between stage heights and flow
- Step 2: Estimate total wetted perimeter for a given height using cross-section



- Step 3: Use flow simulations to calculate, daily, stage height and then wetted perimeter
- Step 4: Leakage proportional to stage height * wetted parameter, since we're only using the proportional change between the historical and future series, and so provide an estimate of percentage change. We cannot quantify absolute leakage change.

Appendix D Localised recharge by water source

Table D.1 Method used for estimating the change in localised recharge for each alluvial water source

Groundwater source	Rock_type	Localised R calc	Area for DP for regression	ΔP %	Flood ΔR %	Instream ΔR %
Bell Alluvial Groundwater Source	IA	regression	area u/s of gauge 421018	-7.6	-43.7	-25.4
Bellinger River Coastal Floodplain Alluvial Groundwater Water Source	CA	regression	area of alluvium	-1.3	-7.6	-4.4
Belubula Valley Alluvial Groundwater Source	IA	gauge 412195	NA	NA	-77.9	-19.4
Billabong Alluvium	IA	regression	area of alluvium	-6.4	-36.4	-21.2
Brunswick River Coastal Floodplain Alluvial Groundwater Source	CA	regression	area of alluvium	0.6	3.7	2.1
Bungendore/Lake George Alluvial	IA	regression	area of alluvium	-7.9	-45.4	-26.4
Castlereagh Alluvial	IA	regression	area of alluvium	-7.8	-44.6	-26.0
Clarence River Coastal Floodplain Alluvial Groundwater Source	CA	regression	whole of Clarence catchment	-4.6	-26.3	-15.3
Coastal Macleay Floodplain Alluvial Groundwater Source	CA	regression	whole of Macleay catchment	-3.8	-21.9	-12.7
Coastal Nambucca Floodplain Alluvial Groundwater Source	CA	regression	area of alluvium	-1.6	-9.1	-5.3
Coopers Creek Alluvial Groundwater Source	CA	regression	area of alluvium	0.0	-0.2	-0.1
Cudgegong Alluvial Groundwater Source	IA	regression	area u/s of gauge 421150	-7.9	-45.4	-26.4
Currabubula Alluvial Groundwater Source	IA	regression	area of alluvium	-3.9	-22.5	-13.1
Gundagai	IA	Av gauges 410004, 410006, 410001	NA	NA	-76.5	-25.6
Hastings River Coastal Floodplain Alluvial Groundwater Source	CA	regression	whole of Hastings catchment	-2.7	-15.7	-9.1
Hawkesbury Alluvium	CA	regression	whole of Hawkesbury catchment	-5.2	-29.6	-17.2
Hunter Regulated River Alluvial Water Source	CA	regression	area of alluvium	-6.8	-38.8	-22.6
Kyeamba Creek GW source	IA	regression	area of alluvium	-5.0	-28.7	-16.7
Lower Darling Alluvial Groundwater Source	IA	Av of gauges 425010, 425007, 425005	NA	NA	-64.1	-32.7
Lower Gwydir Groundwater Source	IA	Av of gauges 418002, 418004	NA	NA	-43.0	-20.2
Lower Lachlan Groundwater Source	IA	Av of gauges 412039, 412005	NA	NA	-84.5	-50.9
Lower Macquarie Zone 1	IA	gauge 421001	NA	NA	-61.7	-22.0
Lower Macquarie Zone 2	IA	gauge 421001	NA	NA	-61.7	-22.0
Lower Macquarie Zone 3	IA	gauge 421001	NA	NA	-61.7	-22.0
Lower Macquarie Zone 4	IA	gauge 421001	NA	NA	-61.7	-22.0
Lower Macquarie Zone 5	IA	gauge 421001	NA	NA	-61.7	-22.0
Lower Macquarie Zone 6	IA	gauge 421001	NA	NA	-61.7	-22.0

Lower Murray Groundwater Source	IA	Av of gauges 409025, 409003	NA	NA	-88.5	-27.4
Lower Murrumbidgee Groundwater	IA	Av of gauges 410005, 410021, 410130, 412005	NA	NA	-81.9	-36.5
Lower Namoi Groundwater Source	IA	Av of gauges 419021, 419026, 422001	NA	NA	-35.6	-35.4
Macintyre Alluvial Groundwater Source	IA	regression	area u/s of gauge 416012	-8.9	-51.1	-29.8
Manilla Alluvial	IA	regression	area u/s of gauge 419007	-5.5	-31.5	-18.3
Mid Murrumbidgee Zone 3	IA	gauge 410005	NA	NA	-78.5	-18.7
NSW Border Rivers Downstream Keetah Bridge Alluvial Groundwater Source	IA	regression	area u/s of gauge 416002	-9.1	-51.8	-30.2
NSW Border Rivers Upstream Keetah Bridge Alluvial Groundwater Source	IA	regression	area u/s of gauge 416040	-9.0	-51.3	-29.9
Ottleys Creek Alluvial Groundwater Source	IA	regression	area of alluvium	-9.8	-55.9	-32.6
Paroo Alluvial Groundwater Source	IA	gauge 424002	NA	NA	-4.7	-5.4
Peel alluvium	IA	regression	area u/s of gauge 419006	-4.3	-24.4	-14.2
Quipolly alluvial	IA	regression	area of alluvium	-4.9	-28.1	-16.4
Quirindi Alluvial	IA	regression	area of alluvium	-4.1	-23.7	-13.8
Richmond Regulated Alluvial Water Source	CA	regression (or av 203005, 203900)	whole of Richmond catchment	-0.1	-0.7	-0.4
Talbragar Alluvial	IA	regression	area of alluvium	-5.7	-32.9	-19.1
Upper Darling Alluvial Groundwater Source	IA	Av of gauges 425003, 425004, 425900, 425008	NA	NA	-30.1	-31.9
Upper Gwydir Alluvial Groundwater Source	IA	gauge 418013	NA	NA	-49.2	-20.8
Upper Lachlan Alluvial	IA	Av of gauges 412002, 412004, 412036	NA	NA	-83.6	-42.3
Upper Macquarie Alluvial	IA	gauge 421001	NA	NA	-61.7	-22.0
Upper Murray Groundwater Source	IA	gauge 409025	NA	NA	-90.0	-19.0
Upper Namoi Zone 1	IA	regression	area of alluvium	-6.2	-35.4	-20.6
Upper Namoi Zone 10	IA	regression	area of alluvium	-6.8	-39.0	-22.7
Upper Namoi Zone 11	IA	gauge 419012	NA	NA	-39.7	-47.1
Upper Namoi Zone 12	IA	regression	area of alluvium	-4.8	-27.3	-15.9
Upper Namoi Zone 2	IA	regression	area of alluvium	-8.2	-46.7	-27.2
Upper Namoi Zone 3	IA	regression	area of alluvium	-3.0	-17.0	-9.9
Upper Namoi Zone 4	IA	Av of gauges 419001, 419012	NA	NA	-39.7	-43.6
Upper Namoi Zone 5	IA	gauge 419012	NA	NA	-39.7	-47.1
Upper Namoi Zone 6	IA	regression	area of alluvium	-6.5	-37.4	-21.7
Upper Namoi Zone 7	IA	regression	area of alluvium	-6.1	-34.8	-20.2
Upper Namoi Zone 8	IA	regression	area of alluvium	-4.1	-23.3	-13.6
Upper Namoi Zone 9	IA	regression	area of alluvium	-6.9	-39.5	-23.0
Wagga Wagga Alluvial	IA	gauge 410001	NA	NA	-78.1	-30.7
Warrego Alluvial Groundwater Source	IA	regression	whole of Warrego catchment	-14.8	-84.5	-49.2

Appendix E Prioritisation

Table E.1 Table of inputs and calculations used in the prioritisation scheme

Groundwater source	hist_R	fut_R	Diffuse DR	Instream DR	Overbank DR	RSF	Long term average annual extraction limit (ML)	Basic landholder rights estimate	Extraction Av (ML/year)	Extraction MAX (ML/year)	Thickness of aquifer	Sy	Area_km2	Rock_type	Storage (ML)	Hist R:S	Commit/LTAAEL	LTAAEL/R	Sensitivity	Sensitivity Rank	Stress	Stress Rank	Prioritisation	Prioritisation rank
Belubula Valley Alluvial Groundwater Source	216	193	-11.1	-19.4	-77.9	0.22	2883	36	1274.6125	2711.4	14	0.1	36	IA	50699	0.15	1.00	0.37	0.69	3	1.68	6	6.71	1
Wagga Wagga Alluvial	152	139	-8.5	-30.7	-78.1	0.22	20648	135	17811.575	20609.8	21	0.1	124	IA	259837	0.07	1.00	1.09	0.33	12	4.99	1	12.04	2
Bell Alluvial Groundwater Source	238	203	-14.6	-28.4	-48.8	0.51	3299	6	1196.4	1738.4	12	0.1	21	IA	25622	0.19	1.00	0.67	0.37	10	1.31	10	14.14	3
Upper Murray Groundwater Source	135	115	-14.9	-19.0	-90.0	0.10	14109	403	12296.575	17401.6	41	0.1	482	IA	1994944	0.03	1.00	0.22	0.33	14	2.17	4	14.56	4
Upper Macquarie Alluvial	167	137	-18.2	-22.0	-61.7	0.38	17935	304	17143.1125	22745.5	23	0.1	285	IA	647498	0.07	1.00	0.38	0.19	22	0.98	15	26.63	5
Cudgegong Alluvial Groundwater Source	165	132	-19.9	-25.8	-44.4	0.56	2533	27	2027.1625	2825	12	0.1	38	IA	46914	0.13	1.00	0.40	0.24	17	0.72	21	27.02	6
Lower Macquarie Zone 6	145	116	-20.0	-22.0	-61.7	0.38	8202	42	1738.935714	2696.7	26	0.1	84	IA	218398	0.06	0.89	0.67	0.15	28	1.55	8	29.12	7
"NSW Border Rivers Upstream Keetah Bridge Alluvial Groundwater Source"	164	138	-15.9	-25.8	-44.3	0.56	8085	177	5334.45	8738	18	0.1	199	IA	366660	0.09	1.00	0.25	0.16	26	0.44	32	41.23	8
Mid Murrumbidgee Zone 3	87	77	-11.9	-18.7	-78.5	0.22	30176	496	17852.23333	33236.2	44	0.1	1024	IA	4524103	0.02	1.00	0.34	0.09	41	1.57	7	41.59	9
Peel alluvium	275	263	-4.1	-9.3	-16.0	0.84	9344	240	5940.71	8415.8	12	0.1	186	IA	217454	0.23	1.00	0.18	0.28	15	0.22	40	42.72	10
Quirindi Alluvial	89	81	-8.6	-13.8	-23.6	0.76	1231	14	150.4125	283.9	11	0.1	25	IA	26368	0.08	1.00	0.55	0.11	38	0.72	20	42.94	11
Upper Lachlan Alluvial	89	75	-16.6	-42.3	-83.6	0.16	94168	6280	55619.675	86966.3	41	0.1	13341	IA	54271197	0.02	1.00	0.08	0.13	32	0.48	29	43.19	12
Quipolly alluvial	66	58	-11.5	-16.3	-28.0	0.72	476	4	55.875	125.4	10	0.1	7	IA	7802	0.06	1.00	0.97	0.09	44	1.35	9	44.91	13
Botany Sands	387	365	-5.9			0.94	14684	1849	626.1333333	2813.3	11	0.2	94	CS	216164	0.17	0.68	0.40	0.18	24	0.29	38	44.94	14
Gundagai	200	180	-10.1	-25.6	-76.5	0.24	1926	156	941.45	1597.2	15	0.1	319	IA	483074	0.13	1.00	0.03	0.56	5	0.13	48	48.26	15

Groundwater source	hist_R	fut_R	Diffuse DR	Instream DR	Overbank DR	RSF	Long term average annual extraction limit (ML)	Basic landholder rights estimate	Extraction Av (ML/year)	Extraction MAX (ML/year)	Thickness of aquifer	Sy	Area_km2	Rock_type	Storage (ML)	Hist R:S	Commit/LTAAEL	LTAAEL/R	Sensitivity	Sensitivity Rank	Stress	Stress Rank	Prioritisation	Prioritisation rank
Tomaree	267	245	-8.2			0.92	6000	433	607.425	2136.8	10	0.2	62	CS	130071	0.13	0.84	0.36	0.14	31	0.33	37	48.27	16
Bungendore/Lake George Alluvial	243	212	-13.0	-26.5	-45.5	0.55	1268	25	545.1875	1027	21	0.1	60	IA	126992	0.11	1.00	0.09	0.21	20	0.16	44	48.33	17
Hunter Regulated River Alluvial Water Source	215	191	-11.4	-20.9	-35.8	0.64	25103.5	985.5	744.9909091	4495.9	10	0.1	1357	CA	1388779	0.21	1.00	0.09	0.33	13	0.13	47	48.76	18
Upper Namoi Zone 12	173	160	-7.8	-15.9	-27.3	0.73	2042	42	766.3928571	1266	16	0.1	95	IA	149505	0.11	1.00	0.12	0.15	27	0.17	42	49.93	19
Upper Namoi Zone 11	144	124	-14.0	-47.1	-39.7	0.53	2269	69	384.7214286	988	19	0.1	174	IA	323885	0.08	1.00	0.09	0.15	29	0.17	41	50.22	20
Upper Namoi Zone 1	70	59	-14.7	-20.7	-35.6	0.64	2127	27	1143.457143	2238.2	14	0.1	38	IA	52311	0.05	0.76	0.81	0.08	48	0.96	16	50.60	21
Manilla Alluvial	246	234	-4.6	-10.6	-18.2	0.82	1229	25	193.55	243.6	8	0.1	52	IA	42458	0.30	1.00	0.10	0.37	11	0.12	50	51.20	22
Upper Namoi Zone 10	109	91	-16.0	-22.7	-39.0	0.61	4518	18	132.3928571	620.9	21	0.1	54	IA	112998	0.05	0.43	0.77	0.08	45	0.54	25	51.48	23
Upper Namoi Zone 5	95	77	-19.3	-47.1	-39.7	0.53	16128	128	16331.59286	20781.1	25	0.1	289	IA	724639	0.04	1.00	0.59	0.07	52	1.11	13	53.60	24
Lower Macquarie Zone 1	112	87	-23.0	-22.0	-61.7	0.38	21807	132	14342.02143	22829.7	43	0.1	123	IA	533850	0.03	1.00	1.58	0.07	54	4.12	2	54.04	25
Kyeamba Creek GW source	92	77	-16.4	-16.7	-28.8	0.71	723	12	500.425	899.2	16	0.1	24	IA	37959	0.06	1.00	0.33	0.08	47	0.46	30	55.76	26
Tomago	308	271	-12.1			0.88	25000	421	2375.15625	22525	23	0.2	184	CS	853656	0.07	1.00	0.44	0.08	50	0.50	28	57.31	27
Hawkesbury Alluvium	258	238	-7.7	-14.6	-25.1	0.75	2456	305	0.277777778	2.1	15	0.1	127	CA	187658	0.17	0.60	0.08	0.23	19	0.06	58	61.03	28
Upper Gwydir Alluvial Groundwater Source	236	201	-14.7	-20.8	-49.2	0.51	721	73	6	48	9	0.1	104	IA	95635	0.26	1.00	0.03	0.51	6	0.06	61	61.29	29
Talbragar Alluvial	75	65	-13.3	-19.1	-32.9	0.67	3473	69	2416.8875	3669.7	18	0.1	152	IA	269227	0.04	1.00	0.31	0.06	56	0.45	31	64.01	30
Hawkesbury to Hunter Coastal Sands	451	406	-9.9			0.90	20445	25	19.125	36.1	13	0.2	139	CS	358778	0.17	0.11	0.33	0.19	21	0.04	68	71.17	31
Upper Namoi Zone 9	74	62	-16.7	-22.9	-39.4	0.61	11441	41	3013.157143	5289.3	27	0.1	326	IA	868302	0.03	0.99	0.47	0.05	74	0.77	18	76.16	32
Castlereagh Alluvial	126	106	-15.5	-26.0	-44.7	0.55	621	84			21	0.1	212	IA	445338	0.06	1.00	0.02	0.11	39	0.04	66	76.66	33
Upper Namoi Zone 6	72	60	-16.4	-21.8	-37.4	0.63	14096	96	1391.142857	2331	24	0.1	463	IA	1109324	0.03	0.78	0.42	0.05	73	0.53	26	77.49	34
Upper Namoi Zone 4	73	60	-17.2	-43.6	-39.7	0.56	26121	421	21601.52143	30654.3	29	0.1	850	IA	2501308	0.02	1.00	0.42	0.04	78	0.75	19	80.28	35
Metropolitan Coastal Sands	487	437	-10.3			0.90	27206	298	96.14444444	328.6	14	0.2	166	CS	473989	0.17	0.07	0.34	0.19	23	0.03	77	80.36	36

Groundwater source	hist_R	fut_R	Diffuse DR	Instream DR	Overbank DR	RSF	Long term average annual extraction limit (ML)	Basic landholder rights estimate	Extraction Av (ML/year)	Extraction MAX (ML/year)	Thickness of aquifer	Sy	Area_km2	Rock_type	Storage (ML)	Hist R:S	Commit/LTAAEL	LTAAEL/R	Sensitivity	Sensitivity Rank	Stress	Stress Rank	Prioritisation	Prioritisation rank
Macintyre Alluvial Groundwater Source	60	44	-26.1	-32.4	-55.6	0.44	373	104	29.4	33.8	22	0.1	153	IA	339803	0.03	1.00	0.04	0.06	61	0.09	53	80.81	37
Lower Murray Groundwater Source	44	36	-19.6	-27.4	-88.5	0.12	170793	6216	77539.38214	120313.6	95	0.1	17882	IA	169402444	0.00	0.99	0.22	0.04	81	1.85	5	81.15	38
Billabong Alluvium	131	106	-18.6	-21.1	-36.3	0.64	7500	635	2081.975	3507.5	37	0.1	713	IA	2633833	0.04	1.00	0.08	0.06	65	0.13	49	81.40	39
Alstonville Basalt Plateau groundwater source	713	728	2.1			1.02	8895	2014	31.2375	281.5	100	0.05	387	FR Vol	1932825	0.14	1.00	0.03	0.14	30	0.03	76	81.71	40
South East Coastal sands	182	166	-9.0			0.91	5600	407	39.85	66.4	8	0.2	148	CS	249234	0.11	0.14	0.21	0.12	36	0.03	75	83.19	41
Macleay Coastal Sands	184	177	-3.6			0.96	11300	28	184.25	737	20	0.2	181	CS	708892	0.05	0.40	0.34	0.05	72	0.14	45	84.91	42
Orange Basalt	273	233	-14.7			0.85	10700	1158	539.3375	698	100	0.05	983	FR Vol	4917135	0.05	1.00	0.04	0.06	55	0.05	65	85.15	43
Sydney Basin Coxs River	244	223	-8.4			0.92	17108	454	852.9666667	3764.2	100	0.05	547	PR	2734375	0.05	0.61	0.13	0.05	69	0.09	54	87.62	44
Currabubula Alluvial Groundwater Source	129	115	-11.0	-13.2	-22.7	0.77	60	18	0.8625	2.6	13	0.1	27	IA	33842	0.10	1.00	0.02	0.13	34	0.02	81	87.85	45
Upper Namoi Zone 2	69	53	-23.5	-27.2	-46.7	0.53	7327	127	8007.442857	12218	33	0.1	482	IA	1594497	0.02	1.00	0.22	0.04	82	0.41	33	88.39	46
Lower Macquarie Zone 2	79	60	-23.8	-22.0	-61.7	0.38	22761	151	13197.78571	21327.9	59	0.1	805	IA	4722162	0.01	1.00	0.36	0.04	87	0.93	17	88.65	47
Tweed-Brunswick Coastal Sands	187	194	3.5			1.03	19000	168	4.9	19.6	12	0.2	188	CS	443499	0.08	0.07	0.54	0.08	49	0.04	74	88.75	48
Upper Namoi Zone 7	64	55	-15.0	-20.2	-34.6	0.65	3721	21	1762.628571	2879	27	0.1	141	IA	380693	0.02	1.00	0.41	0.04	86	0.63	23	89.02	49
Comboyne Basalt	756	710	-6.0			0.94	2600	61	5.25	21	100	0.05	100	FR Vol	499424	0.15	0.37	0.03	0.16	25	0.01	87	90.52	50
Stockton	241	212	-11.9			0.88	14000	254	21.55625	130.6	26	0.2	113	CS	578913	0.05	0.09	0.51	0.05	67	0.05	62	91.29	51
Stuarts Point	101	97	-3.8			0.96	4180	20	96.5875	847	17	0.2	15	CS	51866	0.03	0.90	2.74	0.03	92	2.56	3	92.05	52
Bellinger-Nambucca Coastal Sands	252	242	-3.9			0.96	1175	19			12	0.2	53	CS	123030	0.11	0.17	0.09	0.11	37	0.02	85	92.70	53
Gloucester Basin	466	448	-3.9			0.96	2030	106			100	0.05	283	PR	1412655	0.09	1.00	0.02	0.10	40	0.02	84	93.04	54
Upper Namoi Zone 8	60	54	-10.0	-13.5	-23.2	0.77	16114	114	14269.25714	20361.2	28	0.1	315	IA	894000	0.02	1.00	0.86	0.03	95	1.12	12	95.75	55
Sydney Basin Nepean	202	182	-10.2			0.90	99568	5971	686.4444444	2969.3	100	0.05	3949	PR	19746750	0.04	0.37	0.12	0.05	75	0.05	63	97.95	56
Kulnura Mangrove Mountain groundwater source	148	114	-22.8			0.77	5700	1950	7.59375	52	100	0.05	488	PR	2439350	0.03	0.95	0.08	0.04	84	0.10	52	98.79	57
Young granite	192	170	-11.4			0.89	7110	759	1315.85	1840.1	100	0.05	715	FR FB	3575140	0.04	1.00	0.05	0.04	79	0.06	60	99.20	58

Groundwater source	hist_R	fut_R	Diffuse DR	Instream DR	Overbank DR	RSF	Long term average annual extraction limit (ML)	Basic landholder rights estimate	Extraction Av (ML/year)	Extraction MAX (ML/year)	Thickness of aquifer	Sy	Area_km2	Rock_type	Storage (ML)	Hist R:S	Commit/LTAAEL	LTAAEL/R	Sensitivity	Sensitivity Rank	Stress	Stress Rank	Prioritisation	Prioritisation rank
Richmond Coastal Sands	272	288	5.9			1.06	19000	120	10.95	23.2	17	0.2	488	CS	1686970	0.08	0.10	0.14	0.07	51	0.01	88	101.71	59
Hastings River Coastal Floodplain Alluvial Groundwater Source	446	414	-7.1	-14.8	-25.4	0.75	1727	21	10	10	12	0.1	503	CA	599796	0.37	0.55	0.01	0.50	8	0.01	102	102.31	60
Lower Macquarie Zone 3	55	41	-25.2	-22.0	-61.7	0.38	9752	402	4475.542857	7444.3	53	0.1	1182	IA	6263889	0.01	0.92	0.15	0.03	96	0.36	36	102.53	61
Upper Namoi Zone 3	75	69	-8.4	-9.9	-17.0	0.83	17499	199	16695.65714	28068	36	0.1	555	IA	1994220	0.02	1.00	0.42	0.03	99	0.51	27	102.62	62
Lower Lachlan Groundwater Source	26	21	-20.7	-50.9	-84.5	0.15	117000	9000	97758.46667	127770.6	83	0.1	26120	IA	217338274	0.00	1.00	0.17	0.02	102	1.11	14	102.96	63
Lower Macquarie Zone 4	64	45	-28.7	-22.0	-61.7	0.38	5326	226	3784.464286	5335.1	62	0.1	564	IA	3512008	0.01	1.00	0.15	0.03	97	0.39	35	103.12	64
Sydney Basin Richmond	139	116	-16.9			0.83	21103	1623	5231.488889	13802	100	0.05	2041	PR	10204100	0.03	0.87	0.07	0.03	89	0.08	56	105.15	65
Coopers Creek Alluvial Groundwater Source	653	654	0.1	-0.1	-0.2	1.00	36.5	36.5	4.9	19.6	9	0.1	16	CA	14071	0.73	1.00	0.00	0.73	2	0.00	106	106.02	66
Great Lakes Coastal Sands	179	170	-4.9			0.95	16000	41	463.925	624	15	0.2	419	CS	1263106	0.06	0.06	0.21	0.06	58	0.01	89	106.23	67
Goulburn Fractured Rock	191	173	-9.7			0.90	53074	3114	38.88888889	172.3	100	0.05	8302	FR Vol	41511299	0.04	1.00	0.03	0.04	80	0.04	70	106.30	68
Oxley Basin coast	105	88	-16.7			0.83	9600	155	287.775	327.7	100	0.05	554	PR	2772135	0.02	0.84	0.16	0.03	98	0.17	43	107.02	69
Peel fractured rock	267	252	-5.9			0.94	15874	4052	1074.89	1543.2	100	0.05	4480	FR FB	22397500	0.05	0.98	0.01	0.06	64	0.01	86	107.20	70
Coffs Harbour Coastal Sands	176	176	-0.1			1.00	3110	13			10	0.2	38	CS	78198	0.08	0.02	0.47	0.08	46	0.01	97	107.35	71
Clarence River Coastal Floodplain Alluvial Groundwater Source	398	380	-4.7	-12.6	-21.6	0.78	5457	150	0.125	0.5	11	0.1	1054	CA	1107789	0.38	0.21	0.01	0.48	9	0.00	107	107.38	72
Lower Murrumbidgee Groundwater	39	32	-18.8	-36.5	-81.9	0.18	300500	14500	259193.8643	381872.2	129	0.1	32990	IA	425191025	0.00	0.98	0.23	0.02	107	1.27	11	107.56	73
Yass Catchment groundwater	253	220	-12.8			0.87	5212	1153	425.7625	647.4	100	0.05	1951	FR FB	9752700	0.05	0.93	0.01	0.06	62	0.01	90	109.29	74
Inverell Basalt MDB	268	235	-12.4			0.88	4150	1073	231.4125	542.8	100	0.05	1752	FR Vol	8761200	0.05	1.00	0.01	0.06	59	0.01	93	110.14	75
Sydney Basin North Coast groundwater source	128	108	-15.4			0.85	90000	5087	4500	7427.2	100	0.05	11544	PR	57720000	0.03	0.82	0.06	0.03	93	0.06	59	110.14	76
Sydney Basin MDB Groundwater Source	149	128	-14.2			0.86	19100	465	534.1333333	698	100	0.05	2125	PR	10624100	0.03	0.58	0.06	0.03	88	0.04	67	110.60	77
Brunswick River Coastal Floodplain Alluvial Groundwater Source	534	539	1.1	0.1	0.2	1.00	763	45	4.9	19.6	11	0.1	46	CA	48034	0.51	0.09	0.03	0.51	7	0.00	111	111.22	78
North Coast Volcanics	439	437	-0.4			1.00	13000	3402	5.425	11.9	100	0.05	2905	FR Vol	14523900	0.09	0.52	0.01	0.09	43	0.01	104	112.54	79

Groundwater source	hist_R	fut_R	Diffuse DR	Instream DR	Overbank DR	RSF	Long term average annual extraction limit (ML)	Basic landholder rights estimate	Extraction Av (ML/year)	Extraction MAX (ML/year)	Thickness of aquifer	Sy	Area_km2	Rock_type	Storage (ML)	Hist R:S	Commit/LTAAEL	LTAAEL/R	Sensitivity	Sensitivity Rank	Stress	Stress Rank	Prioritisation	Prioritisation rank
Sydney Basin South	244	207	-15.3			0.85	69892	2098	24.63333333	130.9	100	0.05	3082	PR	15408550	0.05	0.09	0.09	0.06	63	0.01	94	113.16	80
Lower Gwydir Groundwater Source	39	29	-26.8	-20.2	-43.0	0.57	33000	700	35525.95	47472.2	63	0.1	2517	IA	15939374	0.01	1.00	0.34	0.01	111	0.59	24	113.56	81
Dorrigo Basalt	597	549	-8.0			0.92	5000	490			100	0.05	473	FR Vol	2363005	0.12	0.17	0.02	0.13	35	0.00	109	114.48	82
Sydney Basin Central	276	249	-9.8			0.90	45915	2601	3.188888889	18.8	100	0.05	3865	PR	19326000	0.06	0.14	0.04	0.06	60	0.01	98	114.91	83
"NSW Border Rivers Downstream Keetah Bridge Alluvial Groundwater Source"	52	39	-25.0	-31.9	-54.7	0.45	316	64	1.8875	2.3	49	0.1	195	IA	963947	0.01	1.00	0.03	0.02	101	0.07	57	115.97	84
Ottleys Creek Alluvial Groundwater Source	66	48	-26.3	-32.6	-56.0	0.44	30	30			28	0.1	116	IA	323535	0.02	1.00	0.00	0.05	68	0.01	95	116.83	85
"Coastal Macleay Floodplain Alluvial Groundwater Source"	341	329	-3.5	-9.0	-15.5	0.85	1599	74			16	0.1	427	CA	665873	0.22	0.13	0.01	0.26	16	0.00	116	117.10	86
Lower Macquarie Zone 5	39	29	-26.0	-22.0	-61.7	0.38	2871	473	407.0714286	866.7	72	0.1	1386	IA	9915416	0.01	1.00	0.05	0.01	109	0.14	46	118.31	87
Maroota Tertiary Sands	137	109	-21.0			0.79	645	17	2.911111111	26	100	0.2	5	CS	90298	0.01	0.30	1.04	0.01	114	0.40	34	118.96	88
Lower Namoi Groundwater Source	26	18	-30.1	-35.4	-35.6	0.64	88255	2255	81731.9	124108.2	68	0.1	7607	IA	51436885	0.00	1.00	0.45	0.01	118	0.70	22	120.03	89
Coastal Nambucca Floodplain Alluvial Groundwater Source	445	437	-1.7	-8.1	-13.9	0.86	857	36			9	0.1	135	CA	117711	0.51	0.06	0.01	0.59	4	0.00	121	121.07	90
Gunnedah–Oxley Basin MDB Groundwater Source	136	116	-14.9			0.85	127500	5778	5954.463636	8617.2	100	0.05	11596	PR	57980000	0.03	0.23	0.08	0.03	91	0.02	80	121.17	91
Eastern Recharge Groundwater Source	77	60	-22.0			0.78	16200	3200			100	0.05	5566	PR	27829500	0.02	1.00	0.04	0.02	104	0.05	64	122.11	92
Hastings Coastal Sands	193	191	-1.1			0.99	7100	26			19	0.2	256	CS	953894	0.05	0.04	0.14	0.05	70	0.01	101	122.89	93
"Bellinger River Coastal Floodplain Alluvial Groundwater Water Source"	587	569	-3.1	-11.1	-19.1	0.81	350	13			9	0.1	77	CA	67457	0.67	0.04	0.01	0.83	1	0.00	123	123.00	94
Lorne Basin	430	414	-3.6			0.96	9500	255			100	0.05	538	PR	2687540	0.09	0.04	0.04	0.09	42	0.00	117	124.31	95
Warrego Alluvial Groundwater Source	16	10	-33.7	-42.4	-72.8	0.27	289	239			58	0.1	694	IA	4044713	0.00	0.83	0.03	0.01	113	0.08	55	125.67	96
Clarence Morton Basin	332	326	-1.8			0.98	300000	2341	1	3.9	100	0.05	8880	PR	44400552	0.07	0.02	0.10	0.07	53	0.00	114	125.72	97
Richmond Regulated Alluvial Water Source	278	283	1.6	-0.8	-1.4	0.99	83	73	4.9	19.6	12	0.1	1433	CA	1669512	0.24	1.00	0.00	0.24	18	0.00	125	126.29	98

Groundwater source	hist_R	fut_R	Diffuse DR	Instream DR	Overbank DR	RSF	Long term average annual extraction limit (ML)	Basic landholder rights estimate	Extraction Av (ML/year)	Extraction MAX (ML/year)	Thickness of aquifer	Sy	Area_km2	Rock_type	Storage (ML)	Hist R:S	Commit/LTAAEL	LTAAEL/R	Sensitivity	Sensitivity Rank	Stress	Stress Rank	Prioritisation	Prioritisation rank
Clarence Coastal Sands	362	363	0.3			1.00	4200	74			14	0.2	476	CS	1289242	0.13	0.02	0.02	0.13	33	0.00	122	126.38	99
New England Fold Belt MDB	194	168	-13.4			0.87	39253	14520	90.3625	150.2	100	0.05	27987	FR FB	139935000	0.04	0.65	0.01	0.04	76	0.01	103	128.00	100
New England Fold Belt Coast	293	274	-6.5			0.93	60000	9605	118.25	280.7	100	0.05	48133	FR FB	240666504	0.06	0.39	0.00	0.06	57	0.00	115	128.35	101
Southern Recharge Groundwater Source	66	50	-23.7			0.76	38700	13500	3023.385714	5781	100	0.05	21523	PR	107613496	0.01	1.00	0.03	0.02	106	0.04	73	128.71	102
Liverpool ranges basalt coast	101	86	-14.7			0.85	12000	1238	261.2	1038.1	100	0.05	2738	FR Vol	13692200	0.02	0.33	0.04	0.02	100	0.02	83	129.96	103
Manning-Camden Haven Coastal Sands	173	161	-6.8			0.93	3300	45			17	0.2	238	CS	817394	0.05	0.03	0.08	0.05	66	0.00	112	130.00	104
Lower Darling Alluvial Groundwater Source	12	9	-25.0	-32.7	-64.1	0.36	2230	739	64.1	334.6	114	0.1	1648	IA	18844553	0.00	0.75	0.11	0.00	125	0.24	39	130.94	105
Upper Darling Alluvial Groundwater Source	12	8	-37.5	-31.9	-30.1	0.63	6009	2281	759.3	1477	58	0.1	7454	IA	43478431	0.00	0.97	0.07	0.00	124	0.10	51	134.08	106
Sydney Basin South Coast	191	163	-14.7			0.85	21500	416	0	0	100	0.05	1395	PR	6974800	0.04	0.03	0.08	0.04	77	0.00	110	134.27	107
Lachlan Fold Belt MDB	117	99	-15.7			0.84	253788	74311	5396.9875	7909	100	0.05	179389	FR FB	896945000	0.02	0.58	0.01	0.03	94	0.01	96	134.36	108
Western Murray Porous Rock	28	21	-22.7			0.77	226000	26747	534.1333333	698	100	0.05	73815	PR	369076016	0.01	0.28	0.11	0.01	117	0.04	69	135.83	109
Sydney Basin Blue Mountains	157	132	-16.1			0.84	7039	421	0	0	100	0.05	1173	PR	5866850	0.03	0.08	0.04	0.04	85	0.00	108	137.44	110
Liverpool ranges basalt MDB	84	70	-16.8			0.83	2160	1828	7.125	18	100	0.05	2858	FR Vol	14287700	0.02	1.00	0.01	0.02	103	0.01	91	137.44	111
Paroo Alluvial Groundwater Source	14	7	-49.7	-5.4	-4.7	0.50	292	242			54	0.1	925	IA	5012385	0.00	0.83	0.02	0.01	120	0.04	71	139.43	112
Kanmantoo Fild Belt North Western	23	14	-37.4			0.63	27930	2182			100	0.05	6068	FR FB	30341350	0.00	0.08	0.20	0.01	116	0.03	79	140.35	113
Adelaide Fold Belt MDB	22	20	-6.2			0.94	6900	2143			100	0.05	5921	FR FB	29602549	0.00	0.62	0.05	0.00	121	0.04	72	140.80	114
Kanmantoo Fold Belt MDB	27	20	-26.5			0.74	18700	8154	62.5	500	100	0.05	21066	FR FB	105329004	0.01	0.48	0.03	0.01	115	0.02	82	141.24	115
Warrumbungle Basalt	59	48	-19.8			0.80	550	540			100	0.05	1103	FR Vol	5515950	0.01	1.00	0.01	0.01	108	0.01	92	141.87	116
Bulahdelah Sandstone	235	222	-5.3			0.95	130	3			100	0.05	46	PR	228875	0.05	0.02	0.01	0.05	71	0.00	124	142.89	117
Coxs River Fractured Rock	173	157	-9.5			0.90	7005	190			100	0.05	1751	FR Vol	8755200	0.03	0.06	0.02	0.04	83	0.00	118	144.27	118
Lachlan Fold Belt Coast groundwater source	156	146	-6.2			0.94	20000	2697	4500	7427.2	100	0.05	20030	FR FB	100150498	0.03	0.29	0.01	0.03	90	0.00	113	144.46	119

Groundwater source	hist_R	fut_R	Diffuse DR	Instream DR	Overbank DR	RSF	Long term average annual extraction limit (ML)	Basic landholder rights estimate	Extraction Av (ML/year)	Extraction MAX (ML/year)	Thickness of aquifer	Sy	Area_km2	Rock_type	Storage (ML)	Hist R:S	Commit/LTAAEL	LTAAEL/R	Sensitivity	Sensitivity Rank	Stress	Stress Rank	Prioritisation	Prioritisation rank
Sydney Basin North	68	53	-21.7			0.78	19682	722	4.055555556	18.7	100	0.05	5414	PR	27069651	0.01	0.09	0.05	0.02	105	0.01	100	145.00	120
Adelaide Fold Belt North Western	17	14	-16.6			0.83	30381	2396			100	0.05	6589	FR FB	32943049	0.00	0.08	0.27	0.00	123	0.03	78	145.65	121

* The Lower Murray and Murrumbidgee have had their deep and shallow groundwater sources combined for this prioritisation

Shortened forms

CSIRO	Commonwealth Scientific and Industrial Research Organisation
GCM	Global Climate Model
GDE	Groundwater-Dependent Ecosystem
IPCC	Intergovernmental Panel on Climate Change
LTAAEL	Long-term average annual extraction limit
MDB	Murray–Darling Basin
NARCliM	NSW and ACT Regional Climate Modelling
RCM	Regional Climate Model
WRF	Weather Research and Forecasting (RCM)

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