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MURRAY–DARLING BASIN AUTHORITY

Water availability in the Murray–Darling Basin

An update of the CSIRO Murray–Darling Basin Sustainable Yields Assessment

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Contents

1. Introduction

In 2007–2008 CSIRO Murray-Darling Basin Sustainable Yields (MDBSY) project published a series of reports documenting water availability across the Murray-Darling Basin, including an assessment of the likely impacts of climate change to ~2030 on water availability (e.g. CSIRO 2008a). This assessment was the most comprehensive and integrated assessment of water availability ever undertaken for the Murray-Darling Basin. As a part of technical work supporting the development of the *Basin Plan* the Murray-Darling Basin Authority (MDBA) (with assistance from CSIRO and its consultants and state governments) has updated this assessment; the results of this work are presented in this report.

Generally, the same methods and models have been used in this updated assessment, and the results are presented for the regions defined in MDBSY. However, some methodological improvements have been made and some minor errors in MDBSY have been corrected. Both assessments have been undertaken using the Integrated River System Modelling Framework (IRSMF; Podger et al. 2010) that was developed as a part of the MDBSY project, and which has been further enhanced by CSIRO to support the preparation of the *Basin Plan*. In spite of considerable enhancements to the IRSMF to facilitate scenario modelling, output post-processing and data management, the underlying river system models are largely the same. These models are those developed and used by state governments, Snowy Hydro Limited and the MDBA to guide water resources planning and management. Nonetheless, the developers and owners of these models have made significant changes to these models subsequent to the MDBSY project and these changes have led to some differences in the water availability assessments. These differences are highlighted and explained in this report. In all cases, it is the view of the MDBA and the respective model developers that these model changes represent improvements over the prior versions and thus enable improved water resource assessments.

The MDBSY assessment was based on the climate period July 1895 to June 2006. In this updated assessment more recent data has been included to provide an assessment based on the period July 1895 to June 2009. Across most of the MDB, but particularly in the southern MDB, these recent years have been significantly drier than the long-term average; nonetheless, their inclusion does not greatly alter the long-term average water availability results.

The long-term average total surface water resource of the MDB (including current inter-basin transfers, notably via the Snowy Mountains Hydro-electric Scheme (SMHS)) under the historical climate has been assessed to 23,038 GL/yr – only 1.6% less than the MDBSY assessment. Of this decrease, 1.3% is attributed to the inclusion of three additional years of data (the relatively dry period of July 2006–June 2009), and 0.3% is attributed to refinements to the models and the methodology. Although this assessment is considered to be methodologically improved, the quantitative difference is not considered significant given the uncertainty associated with the modelling. The assessments for climate change scenarios suggest significant differences for the “dry extreme” and “wet extreme” 2030 climate scenarios, but similar results under the “median” 2030 scenario to the earlier assessment — a 10% reduction in Basin-wide water availability. The differences in the extreme scenarios reflect improvements in the scaling methods used and these changes and differences are described in this report. At the Basin scale (and for most regions) the dry and wet extremes are less extreme than in the previous assessment as a result of different projected global mean temperatures for these extremes by 2030.

Water availability assessments at a regional level (using the regions defined in the MDBSY project) for the historical climate are very similar except for the Murray, Barwon-Darling and the Gwydir regions. For the Murray region the 6% lower estimate of the resource currently available within this region is primarily a result of an improved methodology for accounting for the impact of development on the tributary inflows to the Murray. For the Barwon-Darling region the 10% higher estimate of the resource currently available within this region is the net result of changes to the without-development model for the Barwon-Darling (which has increased local inflows) and the improved methodology for accounting for the impact of development on the tributary inflows to the region (which has reduced tributary inflow) . For the Gwydir an improved approach to assessing the size of the water resource is used that has led to a 17% higher estimate of the resource in this region.

End of Basin flows (over the barrages) in the absence of dams and diversions are also reported herein – both with and without SMHS transfers. The modelled long-term average barrage flow in the absence of upstream development (and excluding SMHS transfers) for the period 1895-2009 is assessed to 12,503 GL/yr.

2. Definition of Water Availability

The MDBSY project defined annual average surface water availability for a region as the streamflow at the gauge on an upstream-downstream river transect where streamflow is greatest – the “point of maximum flow” under “without-development” conditions. For regions with comparatively small natural losses in flow upstream of this location (such as the Murray), this value is similar to the aggregate of river system inflows. However, it is typically a more reliable estimate as a significant fraction of river inflows are not measured directly and their estimation using models depends on downstream main-stem flow measurements. These “points of maximum flow” typically aggregate all inflows and are at a location in the system with a long and reliable historic record and thus a robust model calibration. In some cases however, to be sensible this assessment must include multiple parallel channels that join near the outflow from a region, or even include multiple distributary channels. These cases are described individually later in this report.

These assessments of water availability are made for “without-development” conditions, hence they depend upon clear definition of these conditions and a model that represents these conditions. In this and the prior assessment, without-development is taken to mean the absence of major water resource development but not an absence of catchment land use change or catchment development of farms dams or other intercepting activities. The “without-development” models are thus variants of the river system models developed to represent current water resource planning arrangements, in which diversions are set to zero and major infrastructure is removed.

Because river models are developed and calibrated to more recent observed flows (i.e. under developed conditions), the modified models that represent without-development conditions are likely to be less reliable. In particular, the modelling of river and floodplain losses is problematic, as these are inferred not measured, and are inferred from observation that represent developed (not without-development) conditions. Adjustments can be made, but these adjustments are often based on untestable assumptions. As well as river and floodplain losses, aspects of the river “configuration” have often changed in association with water resources development and it is difficult to accurately adjust models to reflect these changes. These changes include how flow is split amongst multiple distributary channels in anabranching systems (often associated with simple regulating structures which are poorly represented in river models) and changes in channel capacities due to direct river straightening, dredging or desnagging, or indirect channel enlargement as a result of prolonged bankfull flows associated with irrigation delivery. In addition, natural events have altered river configuration, such as Reddenville Break in the Macquarie Marshes. In spite of these uncertainties, this approach is still considered a more reliable approach than summing modelled inflows, large fractions of which are ungauged and sometimes poorly estimated by models.

An additional aspect of water resource development that is sometimes overlooked is the impact on streamflow of groundwater use. In several cases, the observed streamflow record used to calibrate a river model includes some impact from historical groundwater use. Because of the delays or lags inherent in large aquifers, the eventual full impact on streamflow of current or historical groundwater use is seldom present in observed streamflow records. In the MDB Sustainable Yields project, although adjustments to water availability assessments were not made to correct for the impacts of catchment interception activities, adjustments were made to correct for the impacts of groundwater use. These include both adjustments to the modelled inflows and post-modelling adjustments to correct for impacts implicit in river model calibrations. In the policy context of the *Basin Plan*, the water resources that support interception take and groundwater take are treated as largely separate from the water resource that supports take from modelled watercourses, and therefore corrections to the surface water availability assessment are not made for either the impacts of interception or groundwater take. These differences are described region by region.

3. Climate Scenarios

Any model based assessment of water availability is dependent on assumptions made about climate, as this determines runoff and thus river inflows. Assessments are presented in this report for four climate scenarios: (i) historical climate, (ii) a "median" 2030 climate change scenario, (iii) a "dry extreme" 2030 climate change scenario, and (iv) a "wet extreme" 2030 climate change scenario. The derivation of these scenarios is described below.

Model runs for Basin Plan modelling are identified by a unique three-digit code. This code links to results databases but also to a database which stores all inputs files, parameter files and model executables – thus fully describing the run. The model runs for these climate scenarios used in the water availability results reported here are listed in Table 1

Table 1. Model run numbers for each of the water availability scenarios.

Valley	Development	Climate	Model Run Number
MDB-wide	Without development Including SMHS transfers	Historical	522
		2030 Median	520
		2030 Dry	523
		2030 Wet	524
	Without development Excluding SMHS transfers	Historical	566
		2030 Median	568
		2030 Dry	567
		2030 Wet	569
Barwon-Darling	Without development Barwon-Darling with baseline tributaries	Historical	369
		2030 Median	371
		2030 Dry	370
		2030 Wet	372
Murray	Without development Murray (including SMHS) with baseline tributaries	Historical	532
		2030 Median	535
		2030 Dry	533

		2030 Wet	536

3.1. Historical Climate Scenario

For these assessments the historical climate scenario is defined as the period July 1985 to June 2009. This is based on best estimates of the actual climatic conditions across the Basin for this historical period. Key climate variables used to determine river inflows are rainfall (SILO; Jeffrey et al. 2001) and potential evapo-transpiration (PET; Morton 1983; Chiew and McMahon 1991). As comprehensive records of these variables do not exist across the entire Basin for this historical period, the actual data used are composite data sets that combine observations with modelled estimates of these variables. The modelled inflows for individual river models are estimated using rainfall-runoff models that typically used climate observations within the sub-catchment of interest or nearby climate stations. The suite of climate data used for developing and calibrating each river model is describing in separate documentation produced by the model developers (Chiew et al. 2009b, CSIRO 2008a). Both the rainfall-runoff and river models are calibrated to observed streamflow measurements. Again, streamflow records do not extend across the full historical climate scenario period in all cases; the models are thus used to estimate streamflow in ungauged sub-catchments and for ungauged periods by extrapolating climate-runoff relationships (derived based on available climate and flow observations) through space and time.

Importantly, rainfall-runoff models are typically calibrated to observed streamflow over the last three to four decades, and thus the relationship derived between climate and runoff (and thus streamflow) reflects the typical catchment conditions over this calibration period. Calibration sub-catchments for rainfall-runoff modelling are typically selected to ensure the observed streamflow records are “unimpaired”, which is usually taken to mean they are not affected by significant local water abstraction and reasonably stationary with respect to major changes in catchment land use including interception activities such as farm dams. Nonetheless, catchment conditions during these calibration periods typically reflect post-catchment clearing for agriculture across much of the Basin. The modelled runoff and thus river inflows are therefore not representative of pre-European settlement conditions (for which in any case there are no streamflow measurements).

3.2. Climate Change Scenarios

The climate change scenarios considered in these water availability assessments are those which were selected for use in the development of the *Basin Plan*. These were selected on the basis of advice provided to MDBA by CSIRO (Chiew et al., 2009a). The three future climate scenarios are analogous to the climate scenarios used in the MDBSY project. The derivation of these MDBSY scenarios is described in detail in CSIRO (2007). For *Basin Plan* work these scenarios have been updated and improved for MDBA by CSIRO. A short summary of the method is provided below followed by a description and explanation of the major differences and improvements relative to MDBSY.

3.2.1. Summary of the Derivation of Climate Change Scenarios

The future daily climate series were obtained using the daily scaling method that considers potential changes to the daily rainfall distribution and seasonal means. The method scales the historical daily rainfall (and monthly PET) sequence, informed by 15 global climate models (GCMs) and three global warming scenarios. The median and dry and wet extreme results presented here (see Section 4) are selected based on the future mean annual runoff modelled by the SIMHYD rainfall-runoff model averaged over each of the 18 MDBSY modelling regions.

The “median” scenario is the median of the 15 simulations (rainfall-runoff modelling informed by projections from the 15 GCMs) for the mid-range global warming (1.0^{o}C increase in global average surface air temperature by 2030 relative to 1990). The “dry extreme” result and the “wet extreme” are the second driest (in terms of mean annual runoff) simulation and second wettest simulation respectively of the 15 simulations (1.3^{o}C increase in global temperature; Podger et al 2010). In the method used here, the driest and wettest modelling results will both come from the high global warming scenario.

The method therefore considers the range of local/regional future rainfall projections from the 15 GCMs for a low, mid and high global warming scenario (0.7^{o}C, 1.0^{o}C and 1.3^{o}C) by 2030 relative to 1990 (Podger et al. 2010). This range of global warming mainly reflects the sensitivity of global climate to anthropogenic greenhouse gas (GHG) concentrations. There is little difference in the projected global warming for different GHG emission scenarios by 2030, but beyond 2050 the amount of global warming is very dependent on the GHG emission scenarios. The GCMs and the global warming scenarios are from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (4AR) (IPCC, 2007).

The method used here is very similar to the methods used in MDBSY (Chiew et al., 2008a 2008b) and South Eastern Australian Climate Initiative (SEACI) (Post et al., 2008), and is described and assessed scientifically in Chiew et al. (2009a). The main differences between the method used for the updated water availability assessment here and used in the MDBSY are:

i. modelling for the updated assessment has been extended to June 2009 (the MDBSY modelling ends in December 2006) using data from SILO (Jeffrey et al. 2001);
ii. rainfall-runoff model calibration and regionalisation to predict runoff in gauged and ungauged areas across the Murray-Darling Basin (more than 40,000 ~5 km grid cells) has been improved in the updated assessment (in particular to reduce bias in long-term mean estimates) (Viney et al., 2009; Vaze et al., 2010); and
iii. the low, mid and high global warming used in the updated assessment are 0.7^{o}C, 1.0 ^{o}C and 1.3^{o}C respectively compared to 0.45^{o}C, 1.03 ^{o}C and 1.60^{o}C used in the MDBSY.

The differences in the future rainfall and runoff simulations relative to the historical rainfall and runoff in the updated assessment and in MDBSY caused by (i) and (ii) are marginal. The global warming range used in MDBSY takes into account carbon cycle feedbacks based on extrapolation to 2100 (CSIRO & BoM, 2007). For projections to 2030, the IPCC range of 0.7^{o}C to 1.3^{o}C is more realistic and has been used in subsequent Sustainable Yields projects (southwest Western Australia; CSIRO 2009a, and Tasmania; CSIRO 2009b). The more realistic global warming scenario used in the updated assessment (iii) also gives similar median result, but a less dry extreme dry result and a less wet extreme wet result compared to MDBSY (by about 10 to 20 percent).

4. Water Availability Assessment

4.1. Murray-Darling Basin

As in the MDBSY project two alternate assessments of the Basin-wide water available are provided. The first is the average annual without-development streamflow at Wentworth on the Murray River downstream of the Darling River junction. This is the integrated flow from across the connected river network of the Basin and is the point of maximum flow for the entire river system. Under the historical climate for the period 1895–2009 this is assessed to be 15,128 GL/yr. In spite of the addition of three drier than average years to the period used in the prior assessment, this assessment is 5% higher due to changes in the without-development models for the Barwon-Darling, Murrumbidgee and connected Goulburn-Broken/Campaspe/Loddon-Avoca regions. These changes are described in the sections below. This assessment (and those below) includes (as in the prior assessment) the water resources transferred into the Basin from neighbouring basins notably via the SMHS. This dominant inter-basin transfer represents 937 GL/yr (or 6%) of the water availability assessment at Wentworth. The coefficient of variation of the annual water availability at Wentworth is 0.50 and this temporal variability is shown in Figure 1.

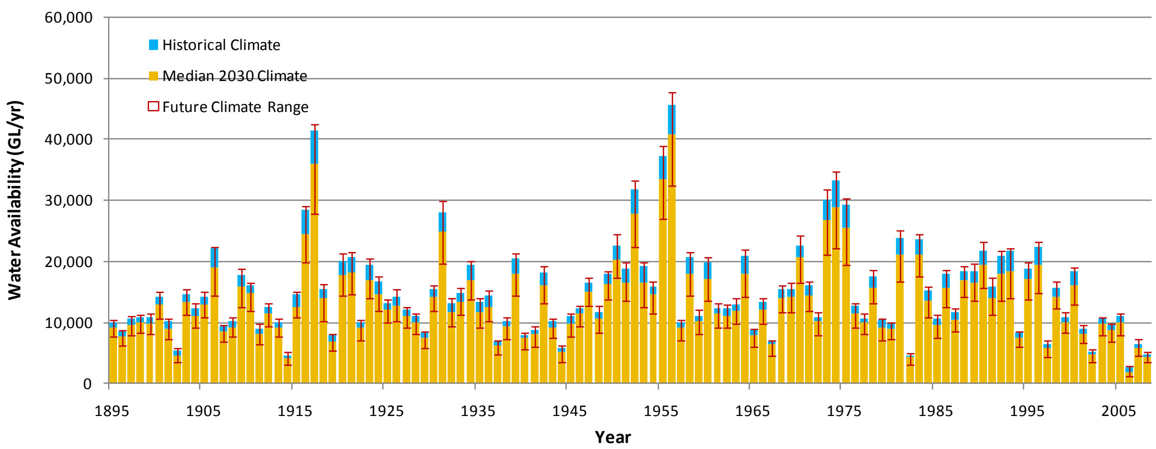

Figure 1. Time series of annual water availability (GL/yr) for the Basin assessed at Wentworth showing patterns of inter-annual variability and indicating the impacts of climate change on water availability. The red bars indicate the range between the water availability under the wet extreme 2030 scenario and the dry extreme 2030 scenario.

The results for the climate change scenarios represented in Figure 1 show an 11% reduction in water availability at Wentworth for the median 2030 climate scenario (yellow columns), a 28% reduction for the dry extreme 2030 scenario and a 5% increase for the wet extreme 2030 scenario (red bars). The dry extreme in particular is less severe than the MDBSY result, largely due to the improvements in temperature scaling described earlier. The annual pattern of these climate impacts are indicated on Figure 1.

The second assessment is the sum of the assessments for the 18 separate regions, where for the Barwon-Darling and the Murray regions only the internally generated water availability (adjusted to the point of maximum flow using efficiency calculations) is considered to avoid double-counting. These regional assessments and summation are shown in Table 2; the Basin-wide total is 23,038 GL/yr – 1.6% lower than the prior assessment. The values of the coefficient of variation of annual water availability reflect the greater inter-annual variability of water availability in the northern parts of the basin; the variability between years of this Basin total is shown in Figure 2. Basin-wide water availability has decreased by 10% under a median climate scenario, 27% under a dry scenario, and increased by 9% under a wet scenario.

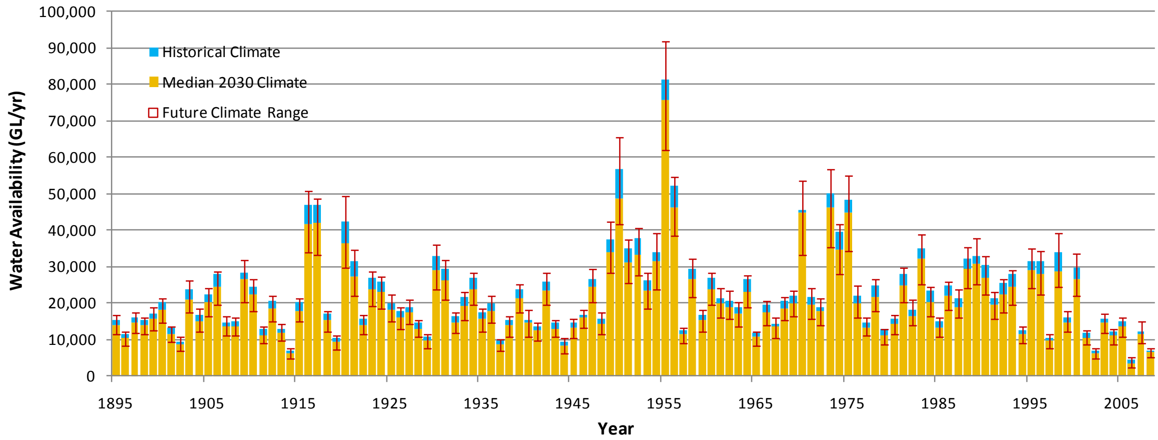

Figure 2. Time series of annual water availability (GL/yr) for the Basin totalled across the 18 modelling regions showing patterns of inter-annual variability and indicating the impacts of climate change on water availability. The red bars indicate the range between the water availability under the wet extreme 2030 scenario and the dry extreme 2030 scenario.

Table 2. Summary of average annual water availability results by region and for the Basin under all climate scenarios. Annual coefficients of variation (CV) are listed and the percentage differences from the historical climate are given for each of the climate change scenarios

	Historical Climate		2030 Climate								
			Median			Dry Extreme			Wet Extreme		
	Average (GL/yr)	CV	Average (GL/yr)	CV	% Change from Historical	Average (GL/yr)	CV	% Change from Historical	Average (GL/yr)	CV	% Change from Historical
Paroo	449	0.93	441	0.97	-2%	362	0.99	-19%	598	0.95	33%
Warrego	425	1.16	409	1.31	-4%	313	1.19	-27%	575	1.15	35%
Condamine-Balonne	1336	1.05	1218	1.05	-9%	1043	1.08	-22%	1525	1.05	14%
Moonie	98	1.37	85	1.39	-13%	72	1.46	-27%	117	1.36	20%
Border Rivers	1071	0.88	965	0.92	-10%	801	0.91	-25%	1219	0.89	14%
Gwydir	906	0.97	824	1.01	-9%	699	0.96	-23%	1121	0.97	24%
Namoi	879	1.28	830	1.24	-6%	691	1.26	-21%	1167	1.30	33%
Macquarie-Castlereagh	1536	0.95	1422	0.95	-7%	1241	0.96	-19%	1854	0.95	21%
Barwon-Darling	316	3.07	287	3.27	-9%	195	4.00	-38%	489	2.72	55%
Lachlan	1114	0.86	973	0.86	-13%	806	0.85	-28%	1172	0.86	5%
Murrumbidgee	4208	0.48	3867	0.47	-8%	3221	0.46	-23%	4629	0.47	10%
Murray	4680	0.42	4191	0.42	-10%	3,292	0.44	-30%	4765	0.43	2%
Ovens	1728	0.51	1509	0.50	-13%	1,177	0.51	-32%	1744	0.50	1%
Goulburn-Broken	3368	0.49	2940	0.49	-13%	2299	0.48	-32%	3284	0.49	-2%
Campaspe	281	0.73	236	0.72	-16%	173	0.71	-39%	271	0.73	-4%
Loddon-Avoca	304	0.73	258	0.72	-15%	167	0.71	-45%	275	0.73	-10%
Wimmera	218	0.68	188	0.68	-14%	119	0.70	-45%	208	0.68	-4%
Eastern Mt Lofty Ranges	120	-	99	-	-18%	58	-	-52%	117	-	-3%
MDB at Wentworth	15,128	0.50	13,519	0.48	-11%	10,850	0.48	-28%	15,885	0.49	5%
Total across regions	23,038	0.52	20,743	0.52	-10%	16,728	0.52	-27%	25,130	0.53	9%

A region-by-region summary of the 2030 climate results is shown in Figure 3. A clear trend is visible when moving from the northern end of the Basin to the south – generally the southern regions experience a larger proportional decrease in water availability under a median climate, and this is matched with a smaller range in future climate values. In contrast, the northern regions display a smaller decrease under a 2030 median climate, however the range of future climate values (in a sense, the uncertainty) is greater. In particular, the values in the Paroo, Warrego and Namoi regions range (approximately) from a decrease of 20% to an increase of 35%. The volume of water available in the Barwon-Darling region is almost completely dependent on its upstream tributaries, hence this value is highly uncertain.

The Murray, Murrumbidgee, Goulburn-Broken and Ovens systems represent the bulk of available water in the MDB – they comprise 61% of the total Basin value. These four regions display roughly equivalent proportional decreases in water availability under a median climate scenario (around 10%) and they all show the same relatively narrow range in 2030 climate water availabilities: a decrease of approximately 25% under the dry extreme to a small change from historical under the wet extreme. These systems largely determine the volume of end of basin flows, which would be expected to decrease by 12% under a 2030 median climate scenario and without development conditions.

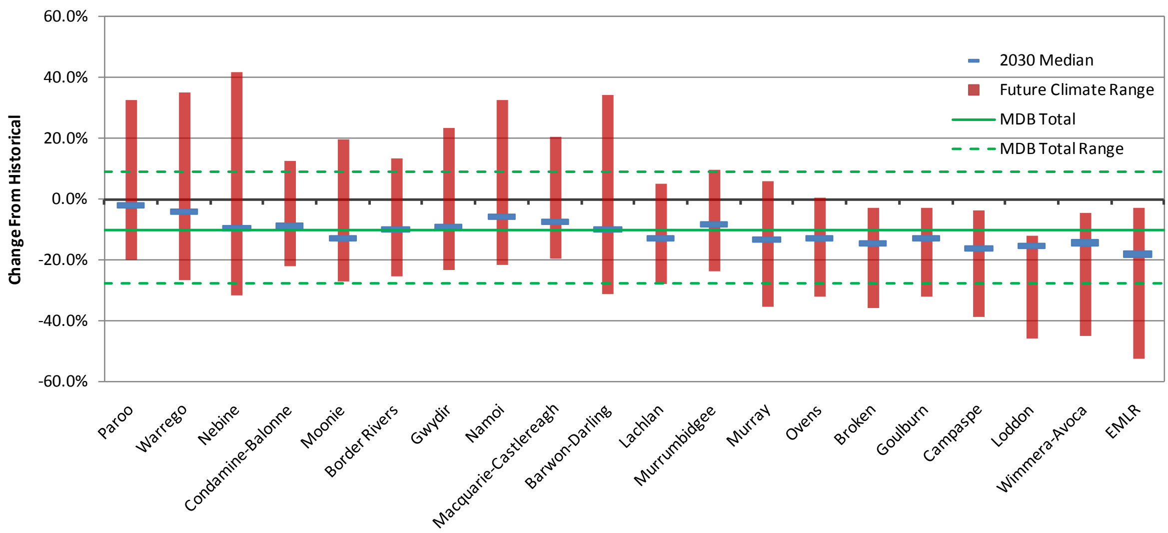

Figure 3. Change in water availability under future climate scenarios for all 18 regions (blue bars) and the total MDB (green line). The red bars indicate the water availability range for each region defined by the 2030 wet and dry scenarios. The 2030 climate range of the total MDB is represented by the dashed lines. The values for the Murray and Barwon-Darling regions are calculated from the 'baseline tributaries' scenario described below.

4.2. Paroo

The water availability assessment for the Paroo under the historical climate is very similar to the MDBSY result. The without-development model is unchanged, the assessment approach is unchanged and there are no groundwater issues to consider. The water availability assessment is made at the Caiwarro gauge (424201, Figure 4) and the average annual value over the modelling period is 449 GL/yr – approximately 1% higher than the MDBSY assessment due to the inclusion of three addition years of data. This increase is mainly due to the relatively wet period in the second half of 2007.

The assessment for the median climate change is similar to MDBSY and represents a 2% reduction from the historical value. The wet extreme assessment (a 33% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (19% reduction) is slightly more severe than the MDBSY assessment in spite of the revised temperatures scaling; this is because of an error in the analysis of the GISS GCM results in MDBSY for the Paroo, Condamine-Balonne and Barwon-Darling regions.

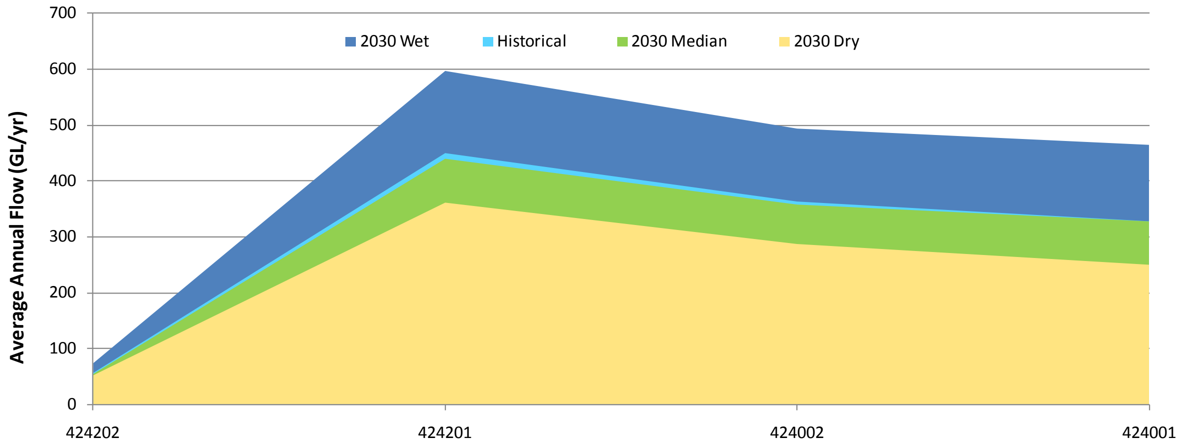

Figure 4. Transect of mean annual flow down the Paroo River indicating point of maximum flow at the Caiwarro gauge.

4.3. Warrego

The water availability assessment for the Warrego under the historical climate is very similar to the MDBSY result. The without-development model is unchanged, the assessment approach is unchanged and there are no groundwater issues to consider. The water availability assessment is made at the Wyandra gauge (423203, Figure 5) and the average annual value over the modelling period is 425 GL/yr – about 1% higher than the MDBSY assessment due to the inclusion of three addition years of data.

The assessment for the median climate change is similar to MDBSY and represents a 4% reduction from the historical value. The wet extreme assessment (a 35% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (27% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

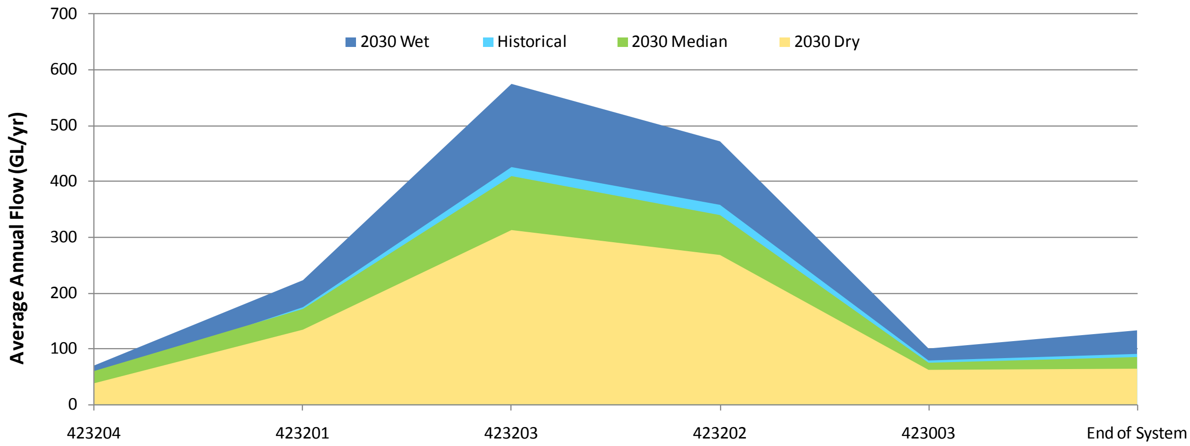

Figure 5. Transect of mean annual flow down the Warrego River indicating point of maximum flow at the Wyandra gauge.

4.4. Condamine-Balonne

The water availability assessment for the Condamine-Balonne under the historical climate is similar to the MDBSY result. The without-development models are unchanged and the assessment approach is unchanged, however MDBSY made a small adjustment for groundwater modelling impacts implicit in river model calibration; this adjustment is excluded in the current study. The water availability assessment is the total of the without-development streamflow assessments made at the St George gauge (422201, Figure 6) and at the end-of-system location for the Nebine model. The end-of-system location for the Nebine model is not a gauge station location and hence the estimated flows at this point are uncalibrated. The flows at this point combine flow from the Nebine itself with some outflows from the Warrego catchment (4 GL/yr). These flows are indirectly assessed using measurements from the gauge downstream on the Culgoa River (422006, downstream of Collerina). The average annual value over the modelling period is 1336 GL/yr (1281 GL/yr at St George and 55 GL/yr at the Nebine end-of-system) – about 2% lower than the MDBSY assessment. Approximately three-quarters of this 2% reduction is due to the inclusion of three additional years of data, and the remainder is due to the exclusion of the small groundwater impact adjustment.

The assessment for the median climate change is similar to MDBSY and represents a 9% reduction from the historical value. The wet extreme assessment (a 14% increase) is less extreme than the MDBSY result due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (22% reduction) is slightly more severe than the MDBSY assessment in spite of the revised temperatures scaling; this is because of an error in the analysis of the GISS GCM results in MDBSY for the Paroo, Condamine-Balonne and Barwon-Darling regions.

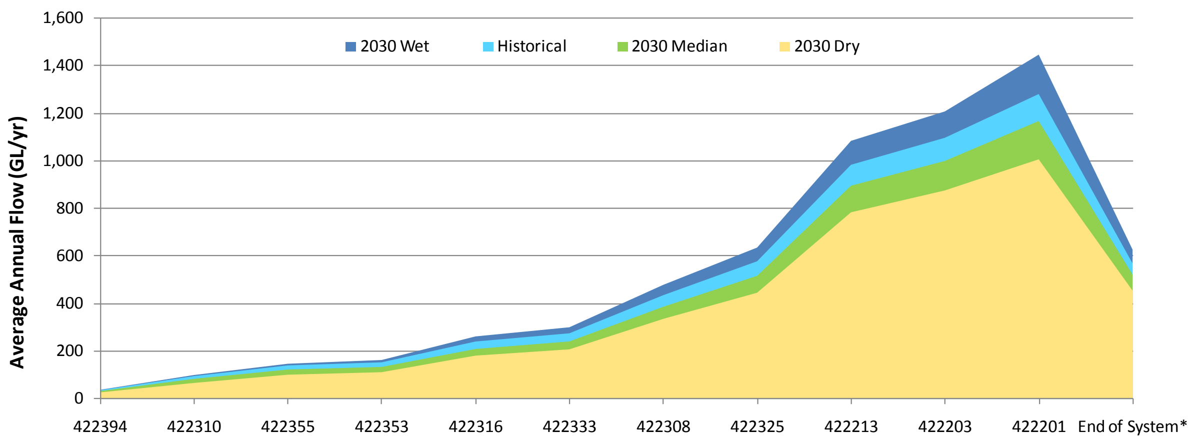

Figure 6. Transect of mean annual flow down the Condamine-Balonne River indicating point of maximum flow at the St George gauge. The end-of-system is the total of the end-of-system flows for the Narran (gauge 422019), Bokhara (gauge 422005) and Culgoa (gauge 422006) rivers. The water availability for the region includes the end-of-system flow for the Nebine River.

4.5. Moonie

The water availability assessment for the Moonie under the historical climate is less than 1 GL/yr different from the MDBSY result. The without-development model is unchanged, the assessment approach is unchanged and there are no groundwater issues to consider. The water availability assessment is made at the Fenton gauge (417204, Figure 7) and the average annual value over the modelling period is 98 GL/yr.

The assessment for the median climate change is similar to MDBSY and represents a 13% reduction from the historical value. The wet extreme assessment (a 20% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (27% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

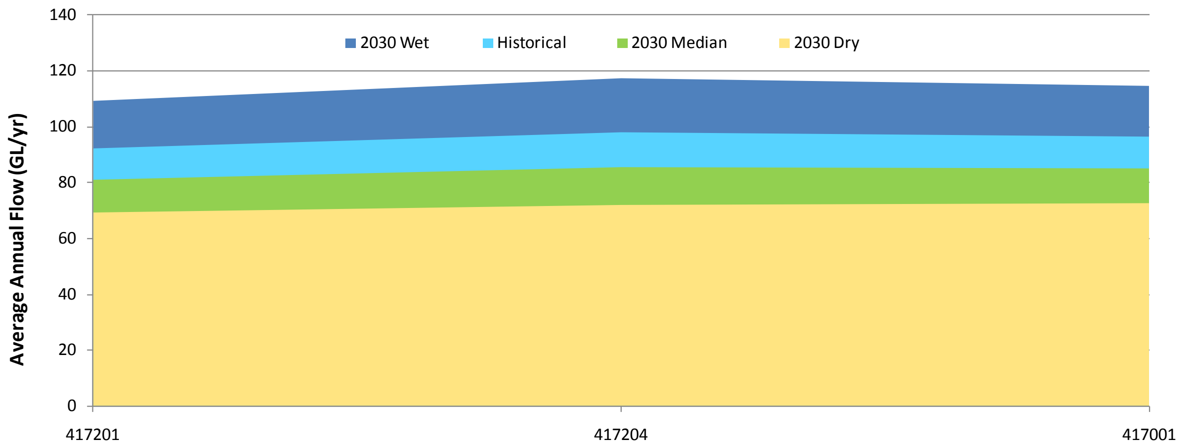

Figure 7. Transect of mean annual flow down the Moonie River indicating point of maximum flow at the Fenton gauge.

4.6. Border Rivers

The water availability assessment for the Border Rivers under the historical climate is less than 2% different from the MDBSY result. The without-development model is unchanged, the assessment approach is unchanged and there are no groundwater issues to consider. It is important to note however, that the originally published MDBSY results for the Border Rivers (1208 GL/yr) was found to be in error and a corrected value (1090 GL/yr) was published as an erratum to the original report. The water availability assessment is the sum of three individual assessments: the Dumaresq-Macintyre system (at the Bogabilla gauge 416002, Figure 8), the Weir River (the sum of flows at the Tallwood gauge 416202 and for the Yarrilwanna anabranch) and Whalan Creek (the sum of Macintyre breakouts and Mobbindry, Tackinbri and Croppa creek inflows). This total under the historical climate is 1071 GL/yr (Table 3).

Table 3. Water availability components for the Border Rivers region under different climate scenarios.

Component	Water Availability (GL/yr)			
	Historical	Dry 2030	Median 2030	Wet 2030
Dumaresq-Macintyre	888	657	797	1010
Weir River	123	105	113	134
Whalan Creek	60	39	55	75
Total	1071	801	965	1219

The assessment for the median climate change is similar to MDBSY and represents a 10% reduction from the historical value. The wet extreme assessment (a 14% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin*

Plan work. The dry extreme assessment (25% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

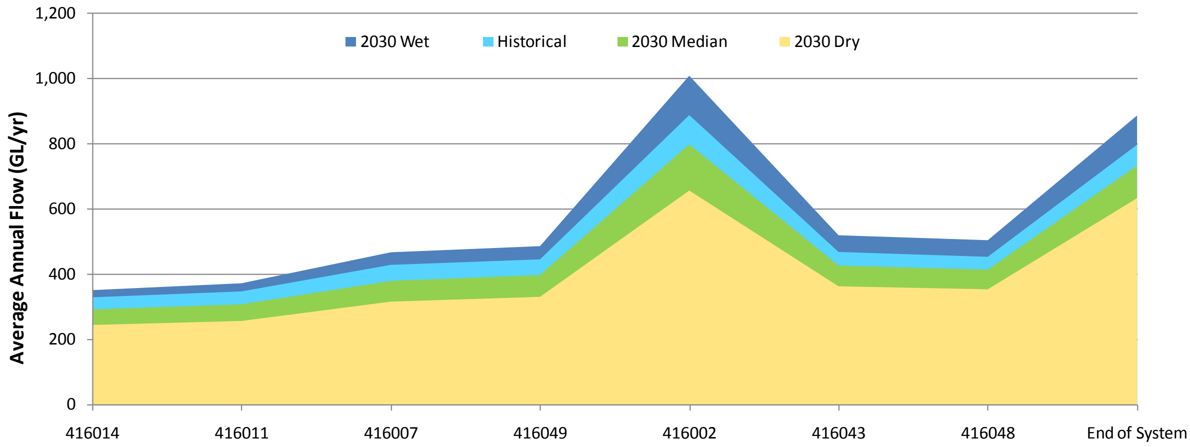

Figure 8. Transect of mean annual flow down the Dumaresq-Macintyre River indicating the point of maximum flow at the Bogabilla gauge. The end-of-system is the total of the end-of-system flows for the Barwon River at Mungindi (gauge 416001), the Boomi River at Neeworra (gauge 416028) and the Little Weir River (which diverts some flow around Mungindi).

4.7. Gwydir

The water availability assessment for the Gwydir region is significantly different to the published MDBSY result. In MDBSY the reported water available under the historical climate was 782 GL/yr – the mean annual flow at the Gravesend gauge (418013). The MDBSY report (CSIRO 2008b) noted difficulties when creating a transect of flow due to the complexity of the anabranching channels in the lower Gwydir. Here, we present an improved transect for the Gwydir region (Figure 9) which combines up to six separate flow assessments. The water availability assessment for the region is the maximum of this improved transect and is the sum of four locations: the Gwydir River downstream of Boolooroo Weir (gauge 418036), Gil Gil Creek at Weemelah (gauge 418027), the Mehi River downstream of Combadello Weir (gauge 418037) and the Moomin Creek inflows at Glendello (gauge 418060). This total under the historical climate is 906 GL/yr – 16% higher than the MDBSY assessment (Table 4).

Table 4. Water availability components for the Gwydir region under different climate scenarios.

Component	**Water Availability (GL/yr)**			
	Historical	Dry 2030	Median 2030	Wet 2030
Gwydir River	341	265	307	423
Gil Gil Creek	73	48	69	89
Mehi River	280	216	254	347
Moomin Creek	212	170	194	262
Total	**906**	**699**	**824**	**1121**

The assessment for the median climate change is similar to MDBSY and represents a 9% reduction from the revised historical value. The wet extreme assessment (a 24% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (23% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

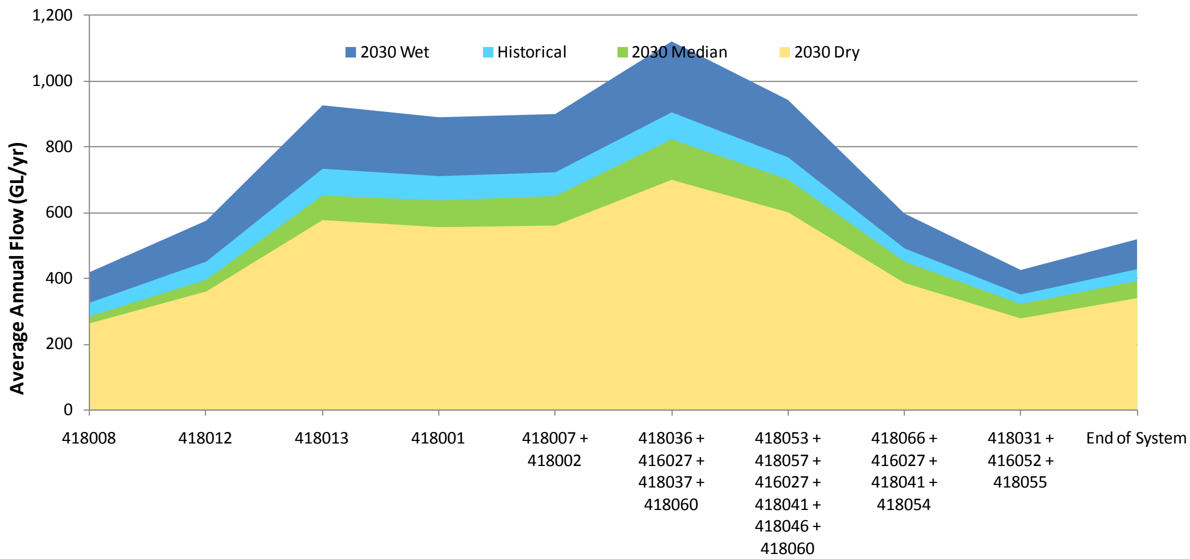

Figure 9. Transect of mean annual flow down the Gwydir indicating the point of maximum flow for the region transect summing flows across four locations. The end-of-system is the total of the end-of-system flows for the Gwydir River at Collymongle (gauge 418031), Gil Gil Creek at Galloway (gauge 416052), the Mehi River at Collaranebri (gauge 418055) and the Gingham watercourse return flow.

4.8. Namoi

The water availability assessment for the Namoi region is significantly different to the published MDBSY result. In MDBSY the reported water available under the historical climate was 965 GL/yr and included two groundwater adjustments to increase the available surface water. The first adjustment was to account for the reductions in river inflows that have occurred due to current groundwater abstraction (this adjustment was made by increasing the Mooki River and Cox's Creek inflows), and the second adjustment was to account for the leakage of streamflow due to current groundwater abstraction over the period of calibration of the river model. For *Basin Plan* purposes the groundwater impacts are excluded, as it was deemed that the water available for surface water use is the streamflow volume estimate that includes these impacts. The point of maximum flow for the Namoi for MDBSY work was the combination of the flow at the Bugilbone gauge (419021) on the Namoi River, the flow at Waminda on the Pian Creek anabranch (gauge 419049) and the gauged Baradine Creek inflows (419072; Figure 10). The total for these three locations from *Basin Plan* modelling for the historical period is 879 GL/yr (Table 5), around 1% lower than the MDBSY water availability assessment ignoring the groundwater-related adjustments described above.

Table 5. Water availability components for the Namoi region under different climate scenarios.

Component	**Water Availability (GL/yr)**			
	Historical	Dry 2030	Median 2030	Wet 2030
Namoi River	860	677	812	1142
Pian Creek	8	6	7	10
Baradine Creek	11	8	10	15
Total	**879**	**691**	**830**	**1167**

The assessment for the median climate change is similar to MDBSY (ignoring the groundwater-related adjustments) and represents a 6% reduction from the historical value. The wet extreme assessment (a 33% increase) is less extreme than the MDBSY results (ignoring the groundwater-related adjustments) due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (21% reduction) is also less severe than the MDBSY assessment (ignoring the groundwater-related adjustments) due to these improvements in temperature scaling.

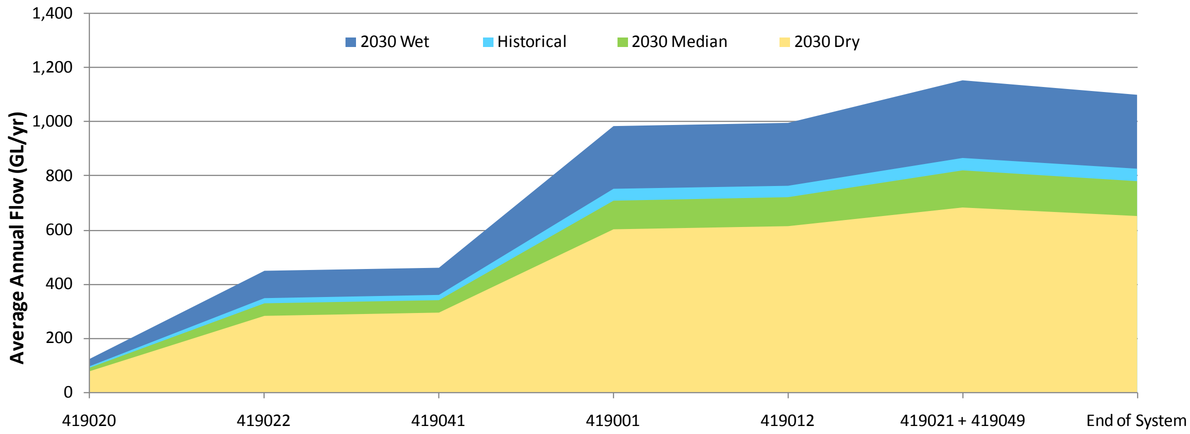

Figure 10. Transect of mean annual flow down the Namoi indicating the point of maximum flow for the region transect summing flows across two locations. The end-of-system is the total of the end-of-system flows for the Namoi River at Goangra (gauge 419026) and Pian Creek at Waminda (gauge 419049).

4.9. Macquarie-Castlereagh

The water availability assessment for the Macquarie-Castlereagh region under the historical climate is about 2% lower than the MDBSY result. For this region the assessment approach is unchanged and no groundwater adjustments were made in MDBSY to the water availability assessment based on modelled streamflow. The small differences are due to minor changes to the without-development model and the addition of three additional years of data.

The water availability assessment is the sum of three individual assessments: for the Macquarie (at the Narromine gauge 421006, Figure 11), the Castlereagh (at the Mendooran gauge 420004) and the Bogan (at Neurie Plains gauge 421039). This total under the historical climate is 1536 GL/yr (Table 6).

Table 6. Water availability components for the Macquarie-Castlereagh region under different climate scenarios.

Component	Water Availability (GL/yr)			
	Historical	Dry 2030	Median 2030	Wet 2030
Macquarie River	1341	1087	1232	1598
Castlereagh River	104	86	103	139
Bogan River	91	68	87	117
Total	**1536**	**1241**	**1422**	**1854**

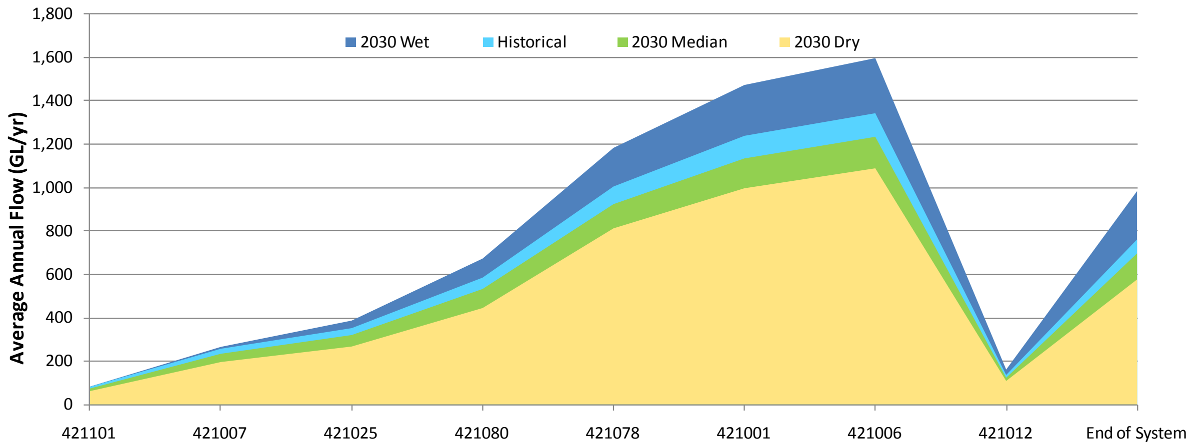

Figure 11. Transect of mean annual flow down the Macquarie River indicating the point of maximum flow at Narromine (421006). The end-of-system flow shown is the combined end-of-system flows for the Macquarie River at Bells Bridge (gauge 412012), the Castlereagh at Coonamble (gauge 420005), the Bogan at Gongolgon (gauge 421003), Marra Creek at Billybingbone Bridge (gauge 421107) and Marthaguy Creek at Carinda (gauge 421011).

The assessment for the median climate change is similar to MDBSY and represents a 7% reduction from the historical value. The wet extreme assessment (a 21% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (19% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

4.10. Barwon-Darling

Water availability assessments for the Barwon-Darling region are problematic and potentially confusing because the region is not a hydrologic catchment. The region itself generates very little streamflow – the majority of water in the Barwon-Darling region is generated in tributary catchments both in Queensland and in New South Wales. Thus, for this region there are three possible assessments:

1. An assessment of only the runoff or streamflow generated within the region.

2. An assessment of the total without-development streamflow for the entire Darling basin at the location of maximum streamflow (the Bourke gauge 425003).
3. As assessment (at the location in the region of maximum streamflow) of the streamflow that enters the region under baseline (current development) conditions together with streamflow generated in the region.

MDBSY reported the first of these in the report for the Barwon-Darling region (CSIRO 2008c) and then reported both of the last two in the final report for the Murray-Darling Basin (CSIRO 2008a). The second assessment is useful in the context of arriving at a summation across the regions of the Basin without any double-counting. The third assessment is indicative of the resource that can currently be managed within the region and so is perhaps most relevant to water planning and management and is indicative of the resource "seen" by water users in the region.

In MDBSY the third assessment was arrived at by a complex combination of "elimination" model runs (where different tributary models where sequentially eliminated from successive linked model runs to determine the contributions from individual tributaries to streamflow at Bourke) together with post-modelling adjustments to ensure a correct water balance was maintained. These adjustments were required because each elimination run leads to a different assessment of river losses and collectively these introduce a bias in the derived results which needs to be corrected.

For Basin Plan modelling a simpler and more accurate method has been used to arrive at a result for the third type of assessment listed above. This involves a linked model run combining the baseline (current development) tributary models together with the without-development model for the Barwon-Darling itself. This approach, while simpler and more accurate, does not provide the breakdown of the contributions to the water availability assessment from each tributary that is provided by the elimination run method used in MDBSY. The Basin Plan assessment also differs from the MDBSY result due to a significant change in the Barwon-Darling without-development model. NSW Office of Water (the developers and custodians of the model) have altered the flow calibration at Bourke to better represent larger flood flows (Ribbons *pers. comm.* NSW Office of Water). This has added a significant additional volume to the assessed water resource which is attributed to runoff generated on the floodplains of the Darling River and on the lower floodplains of its major tributaries. While a significant fraction of this flow has been attributed to the tributaries by NSW Office of Water modellers, these flows are not represented in the tributary models as they bypass all gauges in these regions and are only indicated by gauged flow measurements downstream on the Darling River. The full amount is therefore attributed to the Barwon-Darling region in this reporting.

Under the historical climate the without-development (for the entire Darling Basin) modelled streamflow at Bourke is assessed to be 4076 GL/yr (Figure 12). The MDBSY assessment was 3515 GL/yr including 30 GL/yr of upward adjustments related to groundwater impacts in tributary catchment. The difference in modelled streamflow between the two assessments is thus 591 GL/yr. While there are three additional years of data in these assessments, the impact of these is trivial; the difference is nearly entirely attributable to changes in the without-developments models – and primarily in the Barwon-Darling model related to floodplain runoff as described in the paragraph above. Under the new assessment, an additional 818 GL/yr of inflows are attributed to floodplain inflows upstream of Walgett from without development tributaries. Overall, this produces a 17% increase in the total assessed resource for the Darling Basin and is indicative of the considerable uncertainty in these assessments given the high variability of streamflow with very large floods, including considerable out-of-channel flows which are either ungauged or poorly gauged.

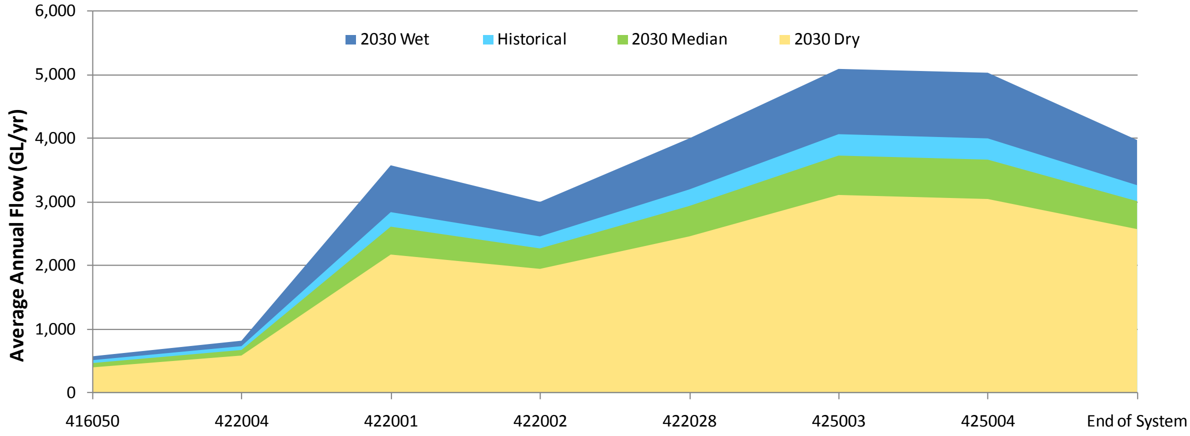

Figure 12. Transect of mean annual flow down the Barwon-Darling River under the second assessment listed above (i.e. both tributaries and the Barwon-Darling under without development conditions). The point of maximum flow occurs at Bourke (425003. The end-of-system flow shown is the total inflow to the Menindee Lakes.

For the third type of assessment described above (transect in Figure 13) the result from Basin Plan modelling is 2289 GL/yr – again considerably higher than the MDBSY assessment. The major difference is again the revised Barwon-Darling without-development model, however the improved modelling method described earlier and different groundwater impacts represented in the tributary baseline flows are also contributing factors. MDBSY accounted for the full (equilibrium) impact of current groundwater use by adjusting the baseline conditions models provided by state agencies for the Condamine-Balonne, Border Rivers, Gwydir and Namoi. In contrast, Basin Plan modelling includes only the projected impact of climate change by 2030, however the overall impact of groundwater use is small for these models, and an adjustment was only made for the Namoi (a lesser adjustment than in MDBSY).

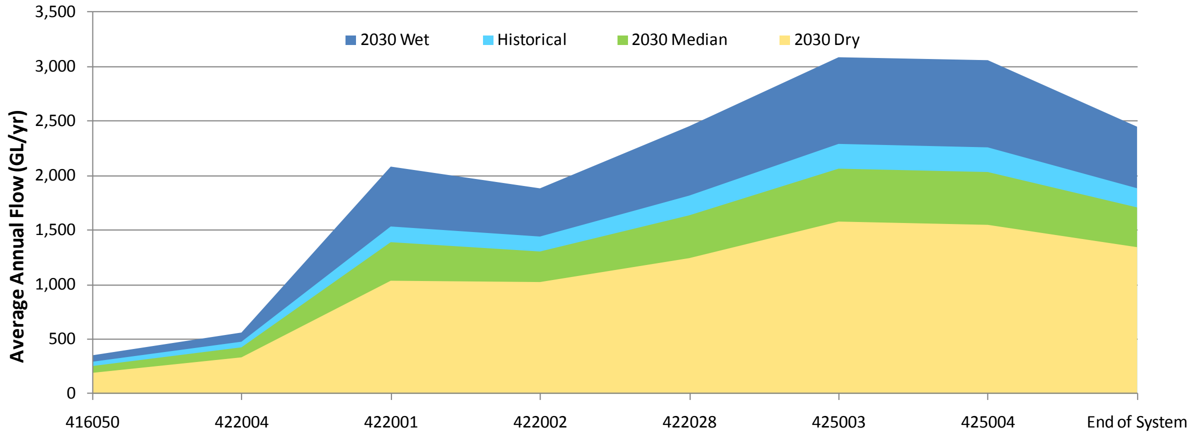

Figure 13. Transect of mean annual flow down the Barwon-Darling River under the third assessment listed above (i.e. tributaries under baseline conditions, Barwon-Darling under without development conditions). The point of maximum flow occurs at Bourke (425003. The end-of-system flow shown is the total inflow to the Menindee Lakes.

Total inflows for the Barwon-Darling region with baseline tributaries are 2764 GL/yr, comprised of 382 GL/yr of internally generated streamflow and 2382 GL/yr of upstream tributary flows. These components were adjusted using efficiency values to calculate the proportion of inflowing water delivered to Bourke (a full description of efficiency values can be found in the Murray subsection below). The majority of inflows (including internal flows) occur upstream of Walgett, hence all upstream efficiencies were assumed to be equivalent. These efficiencies ranged from 81 to 83% depending on the climate scenario, hence the adjusted internally generated streamflow for the Barwon-Darling region is 316 GL/yr under the historical climate scenario (Table 7). This is significantly larger than the MDBSY value (41 GL/yr) due to the recalibration of the without development model described above.

The assessment for the median climate change represents a 9% reduction from the historical value, a larger decrease than reported by MDBSY. The wet extreme assessment (a 55% increase) is more extreme than the MDBSY results due to the recalibrated floodplain inflows. The dry extreme assessment (38% reduction) is also more severe than the MDBSY due to these improvements in the without development model.

Table 7. Components of the water availability assessment at Bourke under baseline development conditions in upstream regions. The values for each region are estimates based on modelled inflows to the Barwon-Darling region from the upstream regions adjusted to values at Bourke using an internally calculated efficiency estimate.

Component	**Water Availability (GL/yr)**			
	Historical	Dry 2030	Median 2030	Wet 2030
Internally generated streamflow	316	195	287	489
Gauged upstream inflows				
Warrego	48	36	44	66
Condamine-Balonne	200	140	174	232
Moonie	59	42	51	73
Border Rivers	424	278	376	513
Gwydir	143	104	133	179
Namoi	540	394	497	757
Macquarie-Castlereagh	478	344	431	646
Ungauged upstream inflows	80	51	68	125
Total	**2289**	**1583**	**2062**	**3080**

4.11. Lachlan

The water availability assessment for the Lachlan River under the historical climate is about 2% lower than the MDBSY assessment. For this region the assessment approach is unchanged and no groundwater adjustments were made in MDBSY to the water availability assessment based on modelled streamflow. The small differences are due to minor changes to the without-development model and the addition of three additional years of data. The water availability assessment is made at the Nanami gauge (412057, Figure 14) and the average annual value over the modelling period is 1114 GL/yr.

The assessment for the median climate change is similar to MDBSY and represents a 13% reduction from the historical value. The wet extreme assessment (a 5% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (28% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

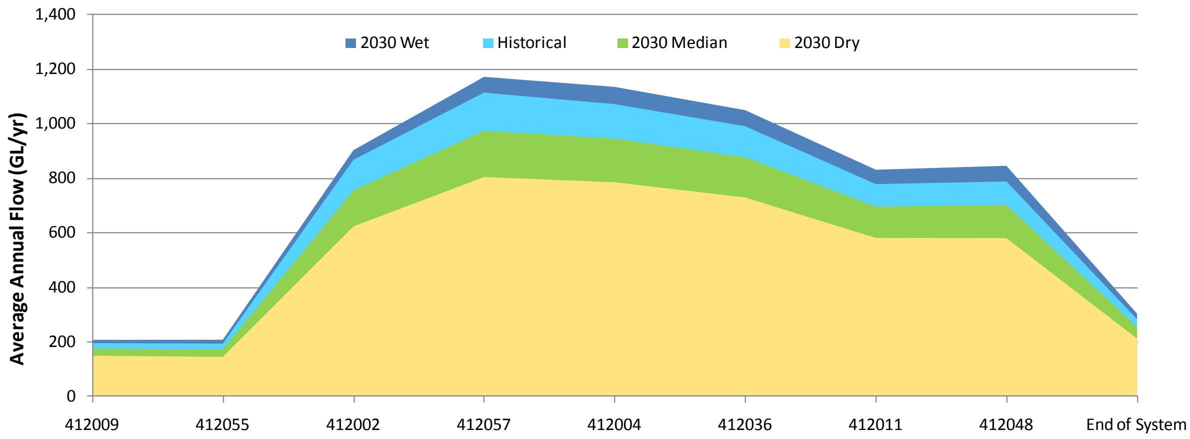

Figure 14. Transect of mean annual flow down the Lachlan River indicating the point of maximum flow at Nanami (412057). The end-of-system flow shown is the combined end-of-system flow for the Lachlan at Oxley (gauge 412026) and Willandra Creek where it leaves the Lachlan River.

4.12. Murrumbidgee

Overall, the water availability assessment for the Murrumbidgee region is very similar to the MDBSY result. However, there are some differences between the two assessments which largely cancel each other out. Firstly, as for other regions the Basin Plan modelling assessment does not include an adjustment for the streamflow leakage induced by current groundwater use that is implicit in the river model calibration; in MDBSY this adjustment added 11 GL/yr to the water availability assessment. Secondly, while both assessments include the net inter-basin transfer from the Snowy Mountains Hydro-electric Scheme (SMHS), in MDBSY the Jounama release was not included (this adds 66 GL/yr to the assessment). The inclusion of an additional three years of data reduces the assessment by 74 GL/yr. It should be noted that the net addition from SMHS at the assessment location (Wagga Wagga, gauge 410001) was reported in MDBSY as 417 GL/yr, however, it was noted that this was because 66 GL/yr of residual catchment inflow to Blowering Dam were included in the modelled Wagga Wagga streamflow. MDBSY did not run the without-development model with the SMHS contribution – this was added to the modelled streamflow assuming no loss between the inflow points and Wagga Wagga. The net SMHS contribution was thus 483 GL/yr.

The more recent Basin Plan modelling has run the Murrumbidgee model with SMHS inflows and assessed the contribution at Wagga Wagga to be 406 GL/yr (including the Jounama release). This value includes the subtraction of 88 GL/yr from Murrumbidgee SMHS inflows due to the 'Water for Rivers' program. Adding this to the mean annual streamflow at Wagga Wagga (3802 GL/yr) gives a water availability assessment under the historical climate for the Murrumbidgee region of 4208 GL/yr (Figure 15).

The assessment for the median climate change is slightly less severe than the MDBSY value and represents an 8% reduction from the historical value due to the improved temperature scaling using in Basin Plan modelling. The wet extreme assessment (a 10% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (23% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

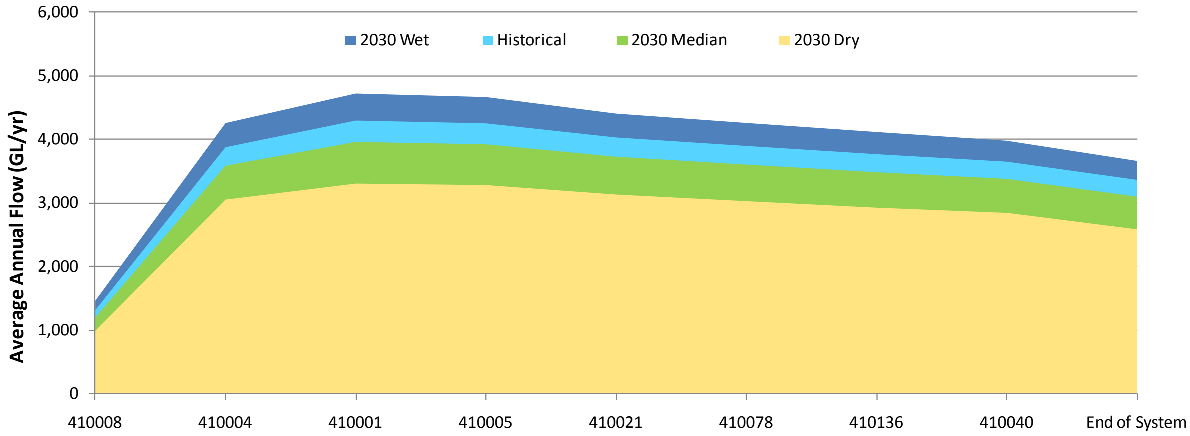

Figure 15. Transect of mean annual flow down the Murrumbidgee River indicating the point of maximum flow at Wagga Wagga (410001). The end-of-system flow shown is the combined end-of-system flow for the Murrumbidgee at Balranald (gauge 410130), Billabong Creek at Darlot (gauge 410134) and Forest Creek downstream of Warriston Weir (gauge 410148).

4.13. Ovens

The water availability assessment for the Ovens under the historical climate is 48 GL/yr (3%) lower than the MDBSY result. The assessment approach is unchanged and there are no groundwater issues to consider; however, the addition of three dry years to the modelling period and minor improvements to the without-development model have led to the small reduction. The water availability assessment is made on the Ovens River at Peechelba (gauge 403241) – the end of system gauge at which inflows to the Murray River are assessed and the average annual value over the modelling period is 1728 GL/yr. The Ovens model was not used for water planning scenario modelling in Basin Plan modelling, hence less detailed reported processes were established and a transect down the Ovens River is not presented in this study.

The assessment for the median climate change is similar to MDBSY and represents a 13% reduction from the historical value. The wet extreme assessment (a 1% increase) is less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (32% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

4.14. Goulburn-Broken

The water availability assessments for the areas covered by the Goulburn Simulation Model (GSM) – the Goulburn-Broken, Campaspe and Loddon – have all changed from MDBSY due to improvements to the without-development model by the Victorian Department of Sustainability and Environment (the developers and custodians of this REALM model). The changes relate to various assumptions regarding differences in losses between the current and without-development model. These differences are documented in some detail in file notes prepared by SKM and held by MDBA; a brief summary is provided here.

In MDBSY, the without-development GSM was a variation on the baseline model with storage volumes, diversions and demands set to zero. However, for Basin Plan modelling, a special purpose without-development model has been used which has no storages or demand nodes. The more significant differences in the GSM are due to loss changes; those losses attributed to river regulation have been excluded from the improved without-development model (an overall gain of 157 GL/yr). Additionally, evaporative losses from Lake Mokoan/Winton Swamp have been reduced because storage volume has been reduced to 7 GL (from 27 GL in the earlier model) reflecting the decommissioning of Lake Mokoan as an irrigation supply storage. The largest changes in losses are for the Goulburn component of the model (where losses are increased by 166 GL/yr compared to the MDBSY model); lesser changes have occurred in the Campaspe and Loddon components of the model decreasing losses compared to the MDBSY version by 9 GL/yr and 4 GL/yr to losses respectively (see below).

These improvements to the GSM have led (in spite of the inclusion of an additional three drier than average years) to a 4% increase (compared to the MDBSY result) in the assessed water availability under the historical climate. The difference is mostly attributable to a 157 GL/yr reduction in the modelled losses for the region. The assessment for the region is made on the Goulburn River downstream of McCoy’s Bridge (gauge 405232) and the water availability assessment is 3368 GL/yr (Figure 16).

The assessment for the median climate change is slightly less severe than MDBSY and represents an approximate 13% reduction from the historical value (compared to 14% in MDBSY) due to the improved temperature scaling using in Basin Plan modelling. Similar to the MDBSY result, the wet extreme assessment produces a 2% decrease. The wet extreme of the future climate range is thus drier than the historical long-term average. The dry extreme assessment (32% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

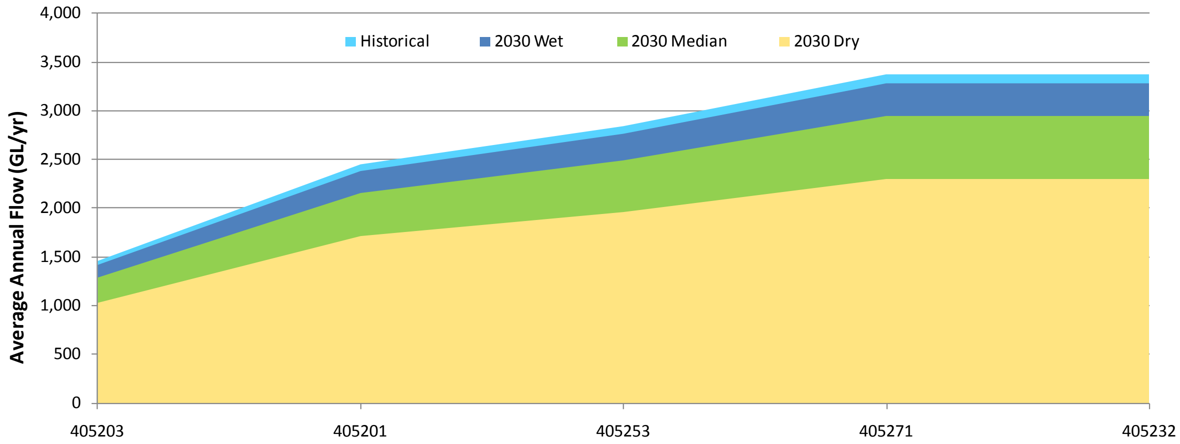

Figure 16. Transect of mean annual flow down the Goulburn River indicating the point of maximum flow downstream of McCoys Bridge (405232). This gauge is also the single end-of-system flow point for the region.

4.15. Campaspe

The GSM has been improved to correct an error in the Campaspe region of the MDBSY without-development model. In the REALM model, the magnitude of the loss arc immediately downstream of Lake Eppalock is dependent on the storage capacity of the lake. However, the earlier without-development model included a storage capacity of zero, hence the capacity of the associated loss arc was zero. The improved model includes the river loss downstream of Eppalock. The improvements to the GSM have led (in spite of the inclusion of an additional three drier than average years) to a small increase (2% higher than the MDBSY result) in the assessed water availability under the historical climate. The difference is a combination of a 9 GL/yr reduction in the modelled losses for the region offset partially by the additional dry years in the modelling period. The assessment for the region is made on the Campaspe River at the Campaspe Weir (gauge 406203) and the water availability assessment is 281 GL/yr (Figure 17).

The assessed reduction for the median climate change is a similar proportion to the MDBSY result (~16%). The wet extreme assessment (a 4% decrease) is slightly less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (39% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

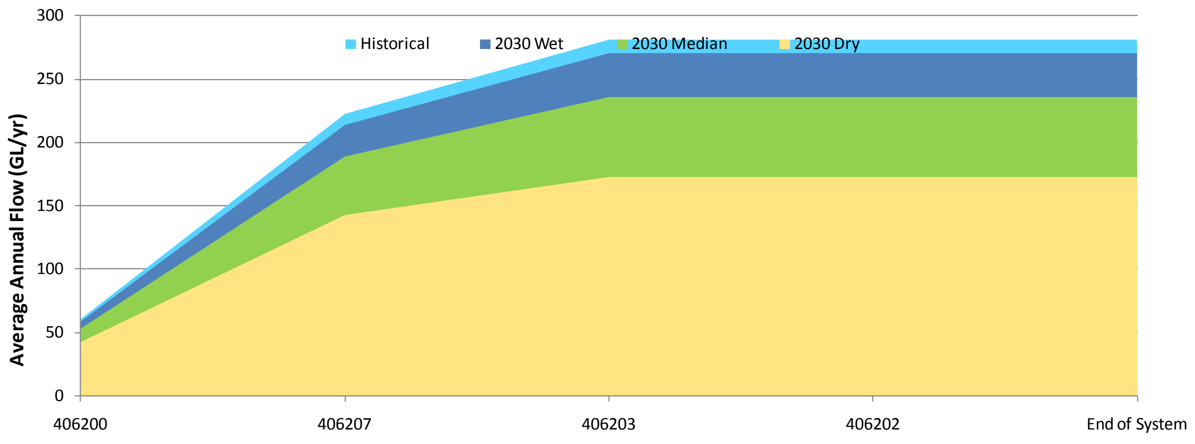

Figure 17. Transect of mean annual flow down the Campaspe River indicating the point of maximum flow at Campaspe Weir (406203). The end-of-system flow point for the region is the flow to the Murray indicated by the gauge on the Campaspe River at Echuca (406265).

4.16. Loddon-Avoca

The hydrology and water management of Loddon-Avoca region is represented by the Loddon component of the GSM and a stand-alone REALM model for the Avoca. Both these models were used in MDBSY; however the Avoca model has not been used during the development of the Basin Plan as this simple model does not explicitly represent consumptive water use, and outflows terminate in the Kerang Lakes and do not reach the Murray River.

The Loddon component of the GSM has been improved by excluding spills from Talbot and Evansford reservoirs. In the prior without-development model these spills were excess flows that were incorrectly duplicated as Tullaroop Reservoir inflows. The above improvements to the GSM have led (in spite of the inclusion of an additional three drier than average years) to a 10% increase in the assessed water availability for the Loddon River compared to the MDBSY result due to a reduction in the modelled losses. The assessment for the Loddon River is made downstream of Laanecoorie Weir (gauge 407203) and the water availability assessment is 220 GL/yr (Figure 18). In MDBSY, the additional assessment for the Avoca River (at Coonooer Bridge, gauge 408200) was 84 GL/yr under the historical climate. This estimate has not been updated by Basin Plan modelling, however, as the baseline and without-development models are the same for the Avoca, no changes to the model would be expected and the additional three years of flow data would have minimal affect on the long-term average.

The assessed reduction for the Loddon River for the median climate change (15%) is somewhat less severe than the MDBSY result (18%) due to the improved temperature scaling used for Basin Plan modelling. The wet extreme assessment (a 12% decrease) is more extreme than the MDBSY results, which indicated a 5% decrease under the wet scenario. This can also be attributed to the improved temperature scaling used for Basin Plan work. The dry extreme assessment (45% reduction) although very large is also less severe than the MDBSY due to these improvements in temperature scaling.

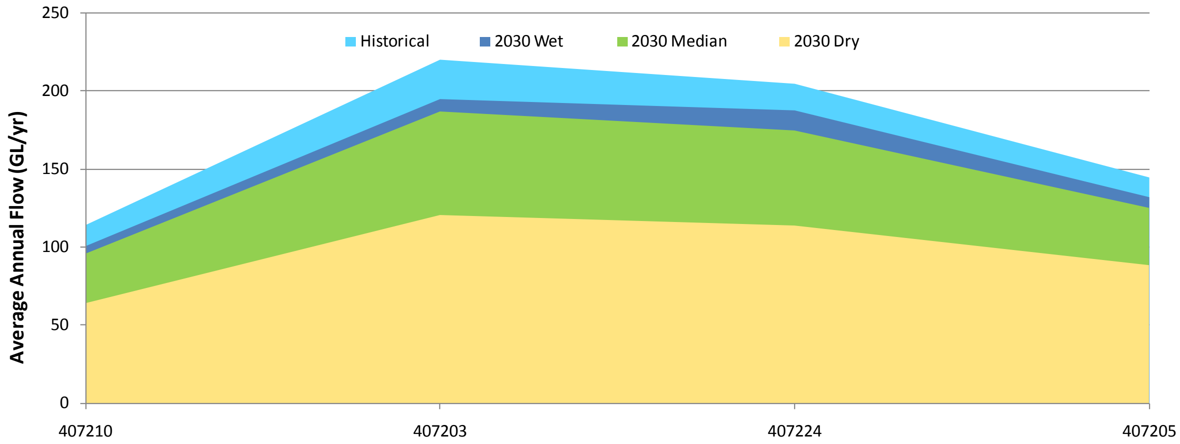

Figure 18. Transect of mean annual flow down the Loddon River indicating the point of maximum flow at Laanecoorie Weir (407203). The end-of-system flow point for the region is the flow to the Murray indicated by the gauge on the Loddon River at Appin South (407205).

4.17. Murray

As for the Barwon-Darling region, water availability assessments for the Murray region are problematic and potentially confusing because the region is not a hydrologic catchment. However, unlike the Barwon-Darling the Murray region does generate significant streamflow. For this region there are three possible assessments:

1. An assessment of only the runoff or streamflow generated within the region.
2. An assessment of the total without-development streamflow for the entire Murray-Darling Basin at the location of maximum streamflow (the Wentworth gauge 425010).
3. An assessment (at the location in the region of maximum streamflow) of the streamflow that enters the region under baseline (current development) conditions together with streamflow generated in the region.

MDBSY reported each of these assessments and these are all updated below. The second of these assessments is useful in the context of arriving at a summation across the regions of the Basin without any double-counting. The third assessment is indicative of the resource that can currently be managed within the region and so is perhaps most relevant to water planning and management and is indicative of the resource “seen” by water users in the region.

4.17.1. Internally Generated Streamflow

The total modelled streamflow generated within the Murray region is 5,482 GL/yr under the historical climate (a very similar result to that reported by MDBSY). This is comprised of inter-basin transfers from the Snowy River via SMHS, reregulated SMHS flows from the Upper Murray (Geehi and Tooma rivers) and inflows from non-SMHS Murray sub-catchments (Table 8).

Table 8. "Internal" water availability components for the Murray region under different climate scenarios.

Component	**Water Availability (GL/yr)**			
	Historical	Dry 2030	Median 2030	Wet 2030
Snowy River Transfers (via SMHS)	527	465	509	535
Geehi and Tooma Rivers (via SMHS)	648	515	611	683
Murray sub-catchments	4307	2996	3856	4439
Total	**5482**	**3976**	**4976**	**5657**

4.17.2. Without-Development Streamflow at Wentworth

The modelled average streamflow at Wentworth on the Murray under the historical climate for without-development conditions across the entire MDB is 15,128 GL/yr – a similar result to MDBSY (Figure 19). This is comprised of the internally generated streamflow of 5482 GL/yr and the inflows from upstream regions (Barwon-Darling, Murrumbidgee, Ovens, Goulburn-Broken, Campaspe and the Loddon; Table 9). These components are adjusted according to 'efficiency' values; these represent the proportion of inflowing water delivered to Wentworth. The efficiency values for the Barwon-Darling and Murrumbidgee contributions are assumed to be 100% (i.e. maximum efficiency). This is consistent with the MDBSY result, which found that >99% of the flow at the end of the Barwon-Darling and Murrumbidgee rivers would reach Wentworth (CSIRO 2008a).

Efficiencies for the remaining regions (the internally generated streamflow and contributions from the rivers south of the Murray) were assumed to be equivalent. This combined efficiency was calculated from the modelled flow at Wentworth after subtracting the Barwon-Darling and Murrumbidgee contributions; efficiency values ranged from 83 to 85%, depending on the climate scenario (a wetter scenario returned a higher flow delivery efficiency value compared to a drier scenario). These values are also consistent with those presented by the MDBSY project; the proportion of end of system flow arriving at Wentworth (under an historical climate) ranged from 81 to 86% for the Ovens, Goulburn, Campaspe and Loddon rivers (CSIRO 2008a).

Although this overall assessment is very similar to the MDBSY result it reflects several differences described above for the upstream regions that largely cancel each other out: different inclusions of groundwater development impacts on streamflow, significant changes in some without-development models notably, the Barwon-Darling IQQM, Murrumbidgee IQQM and the GSM REALM) and the addition of three dry years of flow record to the modelling period.

Table 9. Components of the water availability assessment at Wentworth for without-development conditions across the entire MDB. The values for each region (excluding the Barwon-Darling and Murrumbidgee) are estimates based on modelled inflows to the Murray region from the upstream regions adjusted to values at Wentworth using internally calculated efficiency estimates.

Component	**Water Availability (GL/yr)**			
	Historical	Dry 2030	Median 2030	Wet 2030
Internally generated streamflow	4680	3292	4191	4765
Upstream regions				
Barwon-Darling	2399	1893	2204	2919
Murrumbidgee	3335	2572	3072	3626
Ovens	1475	975	1271	1469
Goulburn-Broken	2875	1903	2477	2767
Campaspe	240	142	199	228
Loddon-Avoca	124	73	105	111
Total	**15,128**	**10,850**	**13,519**	**15,885**

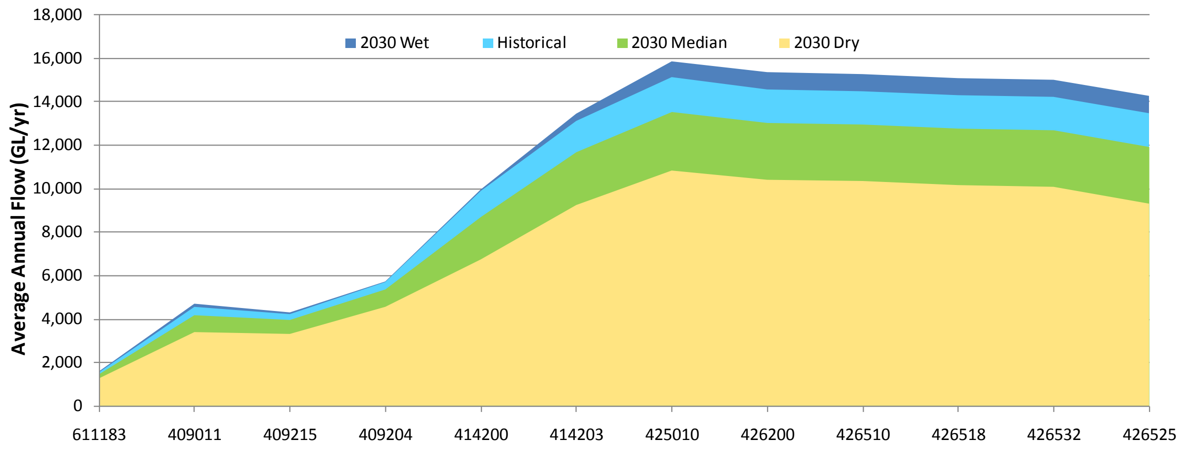

Figure 19. Transect of mean annual without-development flow down the Murray River for without-development conditions across the entire MDB indicating the point of maximum flow at Wentworth (425010). The end-of-system flow point for the region is the flow through Goolwa Barrages (gauge 426252) at the mouth of the Murray.

4.17.3. Baseline Water Availability For The Murray Region

The modelled average streamflow at Wentworth on the Murray under the historical climate for baseline (developed) conditions in upstream regions is 10,524 GL/yr (Figure 20). This is comprised of (Table 10) the internally generated streamflow and the baseline inflows from upstream regions (Barwon-Darling, Murrumbidgee, Ovens, Goulburn-Broken, Campaspe and the Loddon). Similar to the without development scenario described above, all inflows have been adjusted according to efficiency values to provide estimates of the contributions to Wentworth within the constraint provided by the total modelled flow at Wentworth for baseline upstream conditions and without-development conditions in the Murray model. Note that the internally generated streamflow value is different to that presented in Table 9 above; this is due to the different efficiency values calculated for the baseline tributaries model run.

The water availability calculated here is a significantly different result from MDBSY (6% lower) primarily because of an improved modelling approach has been used to determine this value. This method involves the linking of baseline models for the upstream regions to the without-development model for the Murray region; this provides a directly modelled assessment at Wentworth. In MDBSY this assessment was determined through series of multiple "elimination" runs in which individual upstream regions were sequentially removed from a complete without-development Basin-wide setup. Subsequent post-modelling calculations for the case with developed conditions in the tributary region provided an indirect assessment at Wentworth. The advantage of the elimination run approach is that efficiency calculations are not required to assess the contributions at to Wentworth of individual regions; however, the overall Wentworth assessment is less accurate as the post-modelling calculations require significant assumptions regarding loss scaling between development and without-development cases.

In addition to the difference in modelling methods compared to MDBSY, this result is also affected by the differences described earlier for the upstream regions: different inclusions of groundwater development impacts on streamflow, significant changes in some without-development models (notably, the Barwon-Darling IQQM, Murrumbidgee IQQM and the GSM REALM) and the addition of three dry years of flow record to the modelling period. As noted for the Basin-wide without-development conditions case, these latter differences largely balance each other; the difference to the MDBSY result in Table 10 is therefore primarily attributable to the improved modelling method.

Table 10. Components of the water availability assessment at Wentworth for baseline development conditions in upstream regions. The values for each region (excluding the Barwon-Darling and Murrumbidgee) are estimates based on modelled inflows to the Murray region from the upstream regions adjusted to values at Wentworth using internally calculated efficiency estimates.

Component	**Water Availability (GL/yr)**			
	Historical	Dry 2030	Median 2030	Wet 2030
Internally generated streamflow	4670	3284	4178	4766
Upstream regions				
Barwon-Darling	1252	863	1117	1646
Murrumbidgee	1603	978	1368	1849
Ovens	1437	938	1234	1437
Goulburn-Broken	1384	722	1094	1304
Campaspe	127	44	94	113
Loddon-Avoca	51	25	43	49
Total	**10,524**	**6,854**	**9,128**	**11,164**

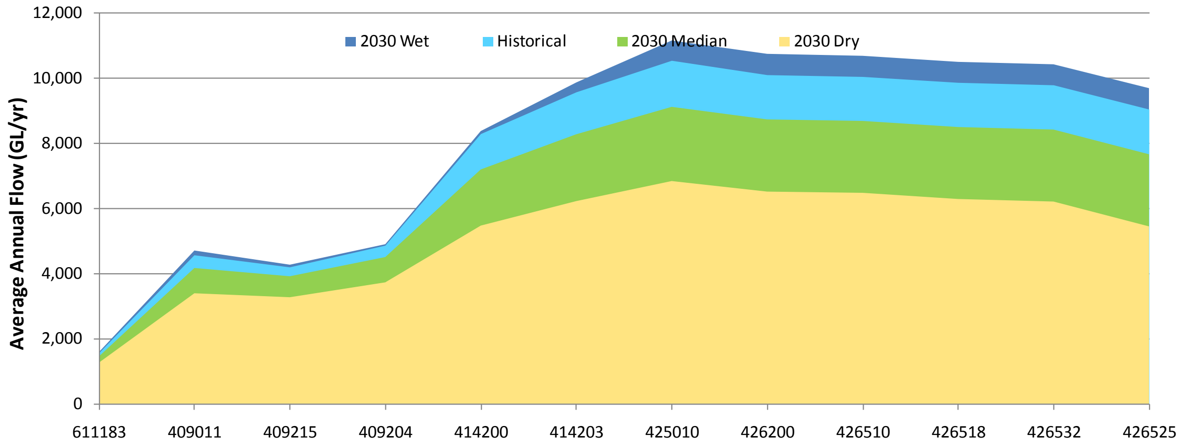

Figure 20. Transect of mean annual without-development flow down the Murray River for baseline (developed) conditions in upstream regions indicating the point of maximum flow at Wentworth (425010). The end-of-system flow point for the region is the flow through Goolwa Barrages (gauge 426252) at the mouth of the Murray.

4.18. Wimmera

The water availability assessment for the Wimmera region under the historical climate is about 1 GL/yr (less than 1%) lower than the MDBSY assessment. The without-development model is unchanged, the assessment approach is unchanged and there are no groundwater issues to consider. The small difference is due the addition of three additional years of data. The water availability assessment is made on the Wimmera River at Lochiel Railway Bridge gauge (415246, Figure 21) and the average annual value over the modelling period is 218 GL/yr. The assessment included a 60 GL/yr inter-basin transfer from the Glenelg River.

The assessment for the median climate change is less severe than for MDBSY and represents a 14% reduction from the historical value compared to the 21% reduction reported by MDBSY due to the improved temperature scaling used for *Basin Plan* work. The wet extreme assessment (a 4% decrease) is slightly less extreme than the MDBSY results due to the improved temperature scaling used for *Basin Plan* work. The dry extreme assessment (45% reduction) is also less severe than the MDBSY due to these improvements in temperature scaling.

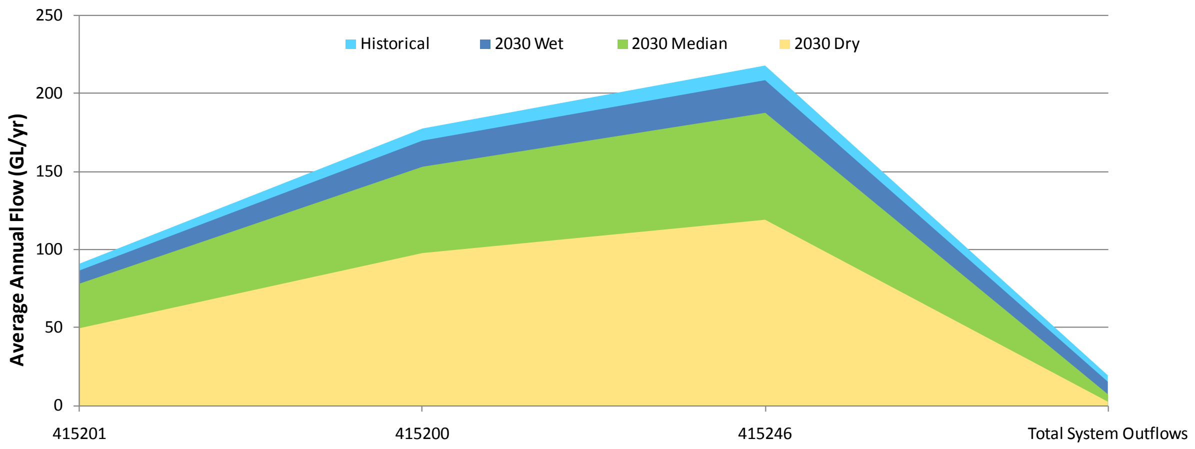

Figure 21. Transect of mean annual flow down the Wimmera River indicating the point of maximum flow at Lochiel Railway Bridge (415246). The end-of-system flows are the combined flows for the three main outflow points (downstream of Lake Buloke on the Avon River, Yarriambiack Creek and downstream of Lake Brambruk on the Wimmera River) plus other minor modelled outflows.

4.19. Eastern Mount Lofty Ranges

No new hydrologic modelling has been undertaken for the Eastern Mount Lofty Ranges as a part of the development of the *Basin Plan* and consequently the water availability assessment from MDBSY has not been updated. Although the addition of three dry years to the long-term record will make a small difference to the long-term average, this is likely to be less than a 1% reduction, as indicated by the ~0.5% reduction in the assessment for the Wimmera. In the Basin totals of Table 2, the value used for the Eastern Mount Lofty Ranges is the MDBSY assessment for the period 1895–2006 of 120 GL/yr.

5. End of Basin Flows

Results are presented below for "end of Basin" flows – that is, flows over the barrages – this being the most downstream location in the BigMOD (the model used to represent the Murray from downstream of the South Australian border). It is important to realise that flows at the barrages are not measured – only modelled. The water balance in the lower Murray is calibrated over periods when the barrages are closed thus simplifying closure of the mass balance. The calibration for the lower river takes account of the measured flow to South Australia, measured diversions in South Australia, estimates of unmeasured diversions in South Australia and the measured variations in the levels of the Lower Lakes. Key calibration parameters are "pan evaporation" factors for the lower river and for the Lower Lakes. These are not strictly pan evaporation factors (factors used to convert standard pan evaporation measurements to estimates of open water evaporation such as that from a lake). Rather they are calibration factors which account for the net losses in the lower river and lakes to ensure accurate modelling of the lower lake levels. While evaporation is a major component of this net loss, these factors also account for inflows to the river and lakes from the Eastern Mt Lofty Ranges (assumed to be zero in BigMOD), any surface-groundwater fluxes (assumed to be zero in BigMOD), transpiration losses via fringing vegetation along the lower river (assumed to be zero in BigMOD).

Because the loss calibration for the lower river and lakes is based on measurements entirely from the period of history when the barrages have been in place, the calibration is most accurate for the "with barrages" condition. For modelling without-development conditions, the Lower Lakes are modelled as having a maximum level at mean sea level and the simulation of barrage operations is removed. This reduces the modelled losses but these losses are not directly calibrated. The dynamics of the saltwater-freshwater interface in the absence of the barrages is likely to be complex and no attempt is made to model this complexity in BigMOD.

The modelled without-development flow at the barrages for the period 1895–2009 is 13,467 GL/yr including SMHS transfers. Thus at the barrages, around 11% (or 1661 GL/yr) of the without-development streamflow at Wentworth has been naturally lost – noting that this estimate is for net rather than total loss. Estimates of the net loss associated with the Lower Lakes are around 800 – 900 GL/yr (or about half of the total modelled loss from Wentworth to the barrages), however, in the absence of detailed measurements it is not possible to accurately partition losses associated with the Lower Lakes from losses associated with the lower river. In the absence of SMHS transfers the modelled without-development flow at the barrages is 12,503 GL/yr.

Table 11. Summary of end of Basin flows (with and without SMHS transfers) for without-development conditions under historical and 2030 climate change scenarios.

		Historical Climate		2030 Climate								
				Median			Dry Extreme			Wet Extreme		
		Average	CV	Average	CV	% Change from Historical	Average	CV	% Change from Historical	Average	CV	% Change from Historical
With SMHS transfers	Flow at Wentworth	15,128	0.50	13,519	0.48	-11%	10,850	0.48	-28%	15,855	0.49	4%
	Flow at Barrages	13,467	0.56	11,910	0.55	-12%	9323	0.57	-31%	14,294	0.56	6%
Without SMHS transfers	Flow at Wentworth	14,150	0.54	12,574	0.53	-11%	10,020	0.52	-29%	14,874	0.53	5%
	Flow at Barrages	12,503	0.61	10,979	0.61	-12%	8512	0.62	-32%	13,302	0.61	6%

The median climate change scenario reduces without-development flows (including SMHS transfers) at the barrages by 12% (Table 11); the dry extreme scenario reduces the without-development flows by 31% and the wet extreme scenario increases without-development flows by 6%. This median scenario result is very similar to MDBSY (7% higher) while the climate extremes are somewhat less severe reflecting the improved temperature scaling for 2030 (Table 11). SMHS transfers contribute 964 GL/yr (7%) at the barrages under an historical climate, and the percentage is similar under future climate scenarios. Furthermore, SMHS transfers decrease the variability of flow at Wentworth and the barrages; under the historical climate, the coefficient of variation at the barrages increases from 0.56 to 0.61 when removing the SMHS contribution.

6. Unmodelled Diversions

The values above were obtained directly from models representing rivers without human development – the 'natural condition'. As described in Section 2, these without-development models are essentially modified versions of the models representing current water resource planning arrangements. These 'current condition' models are calibrated to recent observed flows and include a measurement of water diverted for use. However, a small proportion (<3%) of diverted water is not represented in these models. This slight inaccuracy is inherited by the without-development models, which therefore underestimate flows under natural conditions.

For this reason, MDBA Basin Plan work has added these unmodelled diversions to the water availability to better represent the resource available for use. These diversions contribute a long-term average of 275 GL/yr Basin-wide (Murray-Darling Basin Authority 2010). Adding this to the water availability in Table 2 gives a total Basin-wide water availability of 23,313 GL/yr. Unlike the results in Table 2, this aggregated value includes an unmodelled component and is therefore not directly comparable to the MDBSY results.

7. References

Chiew, F.H.S. and McMahon, T.A., 1991. The applicability of Morton's and Penman's evapotranspiration estimates in rainfall-runoff modelling, Water Resources Bulletin, American Water Resources Association, vol. 27, No. 4, 611-620.

Chiew FHS, Cai W and Smith IN, 2009b. Advice on defining climate scenarios for use in Murray-Darling Basin Authority Basin Plan modelling, CSIRO report for the Murray-Darling Basin Authority. MDBA Publication no. 33/09 MDBA Technical Report Series: Basin Plan: BP01 ISBN (online) 978-1-921557-37-8 MDBA Technical report series: Basin Plan ISSN 1837-2813.

Chiew F.H.S., Teng J., Kirono D., Frost A.J., Bathols J.M., Vaze J., Viney N.R., Young W.J., Hennessy K.J. and Cai W.J. 2008a. Climate data for hydrologic scenario modelling across the Murray-Darling Basin, A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia, 42 pp. (ISSN 1835-095X),

http://www.csiro.au/resources/HydrologicScenarioModellingMDBSY.html.

Chiew F.H.S., Vaze J., Viney N.R., Jordan P.W., Perraud J.-M., Zhang L., Teng J., Young W.J., Penaarancibia J., Morden R.A., Freebairn A., Austin J., Hill P.I., Wiesenfeld C.R. and Murphy R. 2008b. Rainfall-runoff modelling across the Murray-Darling Basin, A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia, 70 pp. (ISSN 1835-095X), http://www.csiro.au/resources/Rainfall-runoffModellingMDBSY.html.

CSIRO and Australian Bureau of Meteorology 2007. Climate Change in Australia. Technical report. http//www.climatechangeinaustralia.gov.au.

CSIRO 2007. Overview of Project Methods. A report from CSIRO to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 12pp.

CSIRO 2008a. Water Availability in the Murray-Darling Basin. A report from CSIRO to the Australian Government. CSIRO, Canberra, Australia. 67pp.

CSIRO 2008b. Water Availability in the Gwydir. A report from CSIRO to the Australian Government. CSIRO, Canberra, Australia. 134pp.

CSIRO 2008c. Water Availability in the Barwon-Darling. A report from CSIRO to the Australian Government. CSIRO, Canberra, Australia. 108pp.

CSIRO 2009a. Surface water yields in south-west Western Australia. A report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project. 195pp.

CSIRO 2009b. Water availability for Tasmania. Report one of seven to the Australian Government for the CSIRO Tasmania Sustainable Yields Project, CSIRO Water for a Healthy Country Flagship, Australia.

IPCC 2007. Climate Change 2007: The Physical Basis. Contributions of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. http://www.ipcc.ch.

Jeffrey, S.J., Carter, J.O., Moodie, K.B. and Beswick, A.R. 2001. Using spatial interpolation to construct a comprehensive archive of Australian climate data, Environmental Modelling and Software, 16, 309 - 330, doi:10.1016/S1364-8152(01)00008-1.

Murray-Darling Basin Authority 2010, Guide to the proposed Basin Plan: Overview, Murray-Darling Basin Authority, Canberra. MDBA publication no. 60/10. ISBN (print) 978-1-921557-72-9.

Morton F.I., 1983. Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. Journal of Hydrology 66, 1-76.

Podger G., Yang A., Brown A., Teng J., Power R., Seaton S. 2010. Proposed River Modelling Methods and Integrated River System Modelling Framework Design for use in Basin Plan Modelling. A Report to the Murray-Darling Basin Authority. 103pp.

Post D.A., Chiew F.H.S., Vaze J., Teng J. and Perraud J.M. 2008. Future runoff projections (~2030) for southeast Australia. South Eastern Australian Climate Initiative Report, 32 pp. http://www2.mdbc.gov.au/subs/seaci/docs/reports/SEACI_RunoffProjections.pdf.

Vaze J., Chiew F.H.S., Perraud J.M., Viney N.R., Post D.A., Teng J., Wang B., Lerat J. and Goswami M. 2010. Rainfall-runoff modelling across southeast Australia: datasets, models and results. Submitted.

Viney N.R., Perraud J., Vaze J., Chiew F.H.S., Post D.A. and Yang A. 2009. The usefulness of bias constraints in model calibration for regionalisation to ungauged catchments. In: 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australian and New Zealand and International Association for Mathematics and Computers in Simulation, Cairns, July 2009, http://www.mssanz.org.au/modsim09, (ISBN 978-0-9758400-7-8), pp. 3421–3427.