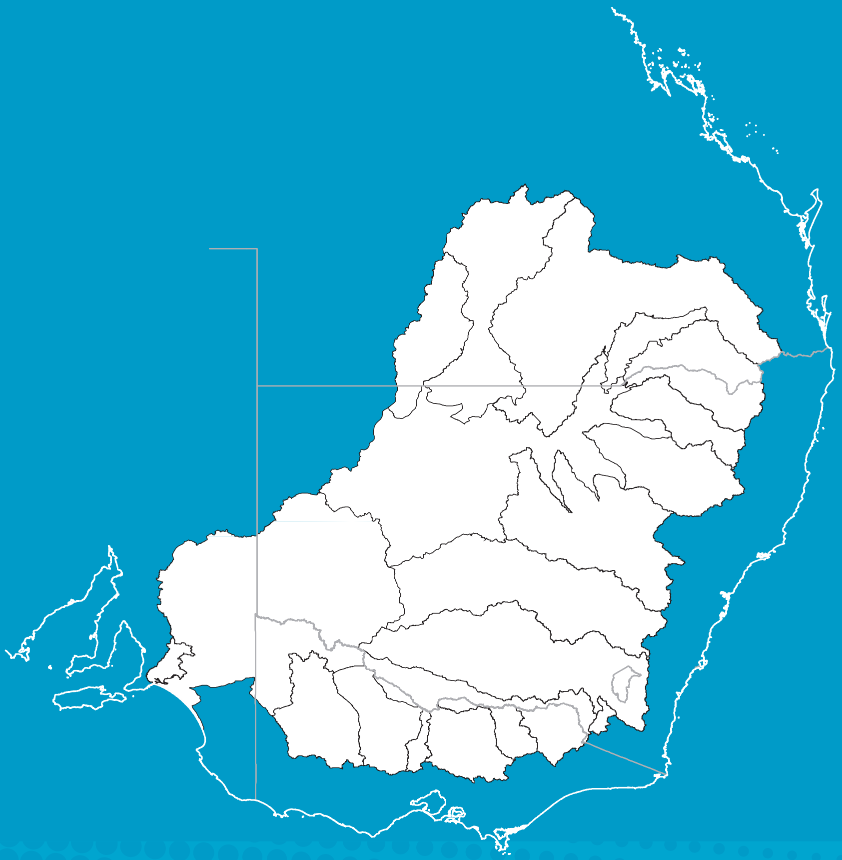
CSIRO



Lessons from the Murray-Darling Basin Sustainable Yields Project

A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project

www.csiro.au

May 2009

Murray-Darling Basin Sustainable Yields Project acknowledgments

The Murray-Darling Basin Sustainable Yields project was undertaken by CSIRO under the Australian Government's Raising National Water Standards Program, administered by the National Water Commission. Important aspects of the work were undertaken by Sinclair Knight Merz; Resource & Environmental Management Pty Ltd; Department of Water and Energy (New South Wales); Department of Natural Resources and Water (Queensland); Murray-Darling Basin Commission; Department of Water, Land and Biodiversity Conservation (South Australia); Bureau of Rural Sciences; Salient Solutions Australia Pty Ltd; eWater Cooperative Research Centre; University of Melbourne; Webb, McKeown and Associates Pty Ltd; and several individual sub-contractors.

Murray-Darling Basin Sustainable Yields Project disclaimers

Derived from or contains data and/or software provided by the Organisations. The Organisations give no warranty in relation to the data and/or software they provided (including accuracy, reliability, completeness, currency or suitability) and accept no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use or reliance on that data or software including any material derived from that data and software. Data must not be used for direct marketing or be used in breach of the privacy laws. Organisations include: Department of Water, Land and Biodiversity Conservation (South Australia), Department of Sustainability and Environment (Victoria), Department of Water and Energy (New South Wales), Department of Natural Resources and Water (Queensland), Murray-Darling Basin Commission.

CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it. Data is assumed to be correct as received from the Organisations.

Citation

CSIRO (2009). Lessons from the Murray-Darling Basin Sustainable Yields Project. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 15pp.

Publication Details

ISSN 1835-095X

Table of contents

1 Background

The Murray-Darling Basin Sustainable Yields Project was the largest, and arguably the most significant, water resource assessment undertaken in Australian history. Called for by the Premiers of the Murray-Darling Basin (MDB) states and the then Prime Minister in the midst of a serious (and ongoing) water crisis, and supported by the National Water Commission, findings on the future security of MDB water resources were delivered by the CSIRO in technical partnership with the state jurisdictions, the Murray-Darling Basin Commission and other Commonwealth agencies in 2007 to 2009. More than 1.4 billion simulations of water balances, generating a million files of results, were translated into 19 regional reports and more than 40 technical reports following onerous technical and peer review. These results and reports can be found at <http://www.csiro.au/partnerships/MDBSY.html>.

The project was widely regarded as both a success and a landmark study, and a worthy basis for building future water policy in the MDB. Some salient lessons on the elements of this success are worth reprising: understanding the role and limitations of science (and scientists) in the policy arena, how uncertainty was dealt with, and how broad ownership of the results was fostered. However, any scientific work of such a scale and operating within severe limitations of available data and time is subject to improvement, both in hindsight and in looking forward to the next opportunity. Improvements might range from refining terms of reference and methods, to accessing better data. In part these lessons derive from how the results were received by peers and by stakeholders in the MDB's water resources. But a larger part of these lessons arise from the scientific contributors themselves, who developed ideas for how the assessment could be improved along the way, if time and resources permitted.

This report summarises these lessons:

- What were the elements of success that bear repeating in the delivery of science into policy?
- What we could have done better within the original assessment, and how we could have communicated or explained the results more effectively?
- Where should we improve assessment methods to offer better or more reliable results?
- What additional analyses would extend the assessment further toward resolving the issue of sustainability?

2 Key elements of success in the original assessment

A research project aimed at delivering to policy-makers can set one of two benchmarks for success. The first is basic to delivery of services: a project on time, on budget and on brief. This benchmark may be sufficient but does not embody the principles reviewed by Davies (1999, 2004) for enhancing evidence for policy-makers:

- The advice must be clear; the focus should not be on the caveats or on descriptions of how complex the problem addressed was (keeping the signal to noise ratio in the advice high).
- The client (the policy-maker) ideally understands the use of research in their practice. Knowing about the different kinds of research that is available, and how to specify the needs for this research and how to critically appraise it, is an increasingly necessary skill for professional policy-makers and practitioners to have. Without such knowledge and understanding it is difficult to see how a strong demand for research evidence can be established and, hence, how getting research into practice can be enhanced.
- Policy-makers and practitioners must come to own the evidence needed to support and implement policy effectively, that is, be able to accept or reject the evidence provided after critically appraising it. This stands in contrast to a position where evidence is solely the property and domain of researchers.
- Policy-makers and practitioners must get buy-in at the most appropriate levels. In government this usually means getting Ministers and senior policy officials to sign up to the ownership of a project and the evidence that goes to support it. This in turn means a commitment to use findings that are contrary to expectations, and not to continue with a policy, programme or project if the available research evidence indicates that this is ineffective. At the level of ‘front-line’ service delivery it means getting key decision-makers to ‘own’ and champion the evidence that supports good practice (Davies, 1999, 2004).
- Evidence is more likely to be used in the policy-making process if there is agreement between policy-makers and researchers, and within the research community, as to what constitutes evidence. Disagreement among researchers over methods, data or interpretation of results can lead to no useful evidence being produced, or to evidence that is technically very good but of little use to policy-makers or anyone else.

In summary, Davies (1999, 2004) and Watson (2005) propose that the most effective means to get evidence in to policy is through integrated teams of policy officials, researchers, specialist consultants, and people who have to implement and deliver front-line services.

The higher benchmark for success for this project was to achieve widespread acceptance among all the stakeholders that the evidence provided is the basis upon which the debate about resource allocation should proceed.

2.1 Developing the terms of reference with the government

The one-line statement from the First Ministers calling for the analysis was the full extent of guidance to CSIRO coming from the 2006 Summit on the Southern Murray-Darling Basin. There was no way to ensure that the above preconditions for successful delivery could be met without significant clarification of the terms of reference. Within days, a meeting was called between senior bureaucrats from the two relevant federal departments and the CSIRO to more specifically articulate what was needed and the basic approach to the project administration.

Three key resolutions resulted. The first was that the state departments with jurisdiction over water had to be involved and develop ownership over the results, despite initial resentment from some quarters over CSIRO’s announced role in what some saw as their responsibility. This ownership was to be cemented in part through a project Steering Committee with senior representatives from each jurisdiction and the Murray-Darling Basin Commission, and co-chaired by the senior bureaucrats from the National Water Commission (funding the project under the Raising National Water

Standards Program) and the Department of Water (later the Department of the Environment, Water, Heritage and the Arts (DEWHA)).

The second resolution was more fundamental. The First Ministers used the word ‘sustainable’ in their communiqué. This implicitly would involve CSIRO not only assessing and forecasting how much water there was in the system, but determining how much should be used and by whom. The latter necessarily involves the incorporation of values (e.g. the trade-off between environmental and productive use). It was CSIRO’s judgement that any move away from the most objective analysis possible would inevitably prejudice the results with at least one segment of stakeholders (whatever the result) and thus would critically undermine any chance of success with respect to the higher goal of gaining widespread stakeholder acceptance. For a small number of unelected technical specialists to weigh up one benefit against another and form value judgements would have effectively undermined the democratic process; thus it was agreed that greater wisdom lay in limiting the terms of reference to the highest levels of objectivity. The delay of some weeks in making these terms of reference public, however, led to the public making their own (incorrect) inferences about the role of CSIRO: headlines such as ‘Push to limit CSIRO’s power’ (Australian Financial Review, 9 March 2007) appeared. In the end CSIRO established a public website <http://www.csiro.au/partnerships/MDBSY.html> on which it progressively published terms of reference, methods and results over the lifetime of the project.

The third resolution was that the methods used to generate the results not only had to be applied consistently across the MDB, but that they also had to generate metrics that policy is directly based upon or influenced by. Previous water resource studies had, for parts of the MDB, predicted changes in the inflows to rivers resulting from climate or land management. However, the translation of these predicted changes in inflows into changes in security of water entitlements or environmental flows requires subsequent, complex analysis of river regulation and application of water-sharing arrangements. The project was to make these subsequent calculations.

2.2 Getting the jurisdictions on side

The initial reaction from most jurisdictions to the project was cool. However, because they held key data and models that effectively embodied the complex water sharing arrangements for each region of the MDB, their technical partnership was essential. While these jurisdictions formally steered the project, in fact final acceptance and decision-making rested with the Australian Government. The potential for CSIRO to appeal to their respective Premiers (who called for the project) to resolve access and cooperation issues was treated as a last resort and in fact was never exercised. Without the Premiers’ a priori support for the project the necessary cooperation would almost certainly not have been achieved however. To establish a positive working relationship, the jurisdictions were subcontracted to the CSIRO to provide support and access to models in return for the necessary resources to support their contributions. Further, the jurisdictions were given multiple opportunities to review and advise on the accuracy and expression of results prior to their release. All of these strategies were aimed at giving the broadest possible ownership of the results.

2.3 Building the best team

The timelines imposed by the First Ministers, and the ambitious scope of the terms of reference, necessitated assembling a very large and diverse project team. From the beginning CSIRO recognised that in addition to the technical support from the jurisdictions and the Murray-Darling Basin Commission, other organisations had key capabilities that could enhance delivery. While CSIRO retained full responsibility for the ultimate quality and integrity of the project, they drew upon the services and expertise of over 170 scientists and technicians from 12 organisations.

Managing such a large, complex, multi-site and multi-organisation (and technically risky) project demanded a management team with strong project administration but equally strong connection with the policy-makers who commissioned the work. Although the project was only 10 percent of the Flagship by size, by importance it outweighed all other commitments and became its highest priority. As such, the Flagship Director assumed personal responsibility as Project Director with a focus on client liaison and reporting to the CSIRO CEO and Board. One of CSIRO’s leading researchers in the area of water resources management and a senior expert in river hydrology was appointed as Project Manager, with a focus on the internal management of the project and the ultimate quality assurance of the results. This Project Manager was supported by a Project Coordinator, who developed, monitored and executed a highly detailed project work plan with the wider team.

As the project developed, a crucial addition to this team was a senior administrator from DEWHA. This person maintained close contact with the Project Director throughout the life of the project and ensured that the project was appropriately resourced, targeted, expressed and delivered to the best advantage of the policy-makers depending on a result.

2.4 Getting the communication protocol right

On a large, high-visibility research project such as this, clarity is needed on what is communicated and how. For internal delivery directly to the policy-maker, it was determined how the basic series of reports (on each water-sharing region of the MDB) would look, what they would contain, how the Minister would be briefed and how the reports would be released.

Of greater importance is clarity on who could speak to the public and media about the project. It was agreed that only the Project Director was free to publicly represent the project, and he was provided media training and ongoing support to frame in advance responses to likely questions about the research. The Project Director worked closely with the senior departmental administrator to coordinate media releases, stakeholder briefings, and public commentary on results as they were released. Given the immense political and commercial implications of premature, unplanned disclosure of results (‘leaks’), contingency responses were developed beforehand. In a project that would ultimately involve more than 170 people from multiple organisations in an operating environment of great stakeholder anticipation of results, it is a measure of project discipline, the quality of internal communication and collective ethics that on no occasion did results leak outside of agreed protocol.

2.5 Building credibility and gaining acceptance

Research can inform policy if the policy-makers believe in the results. It is an immense advantage to policy-makers, however, if the public also trusts the analyses. CSIRO built upon their established national reputation by implementing, and communicating, a quality review and assurance process that was as comprehensive as practical given the time constraints. An internal technical review panel, led by a senior CSIRO scientist and comprising senior technical experts from among the project partners (including the jurisdictions), reviewed and ultimately approved all results and reports. This panel reported to the Steering Committee through the Project Director; in addition to providing quality assurance, it further reinforced the ownership of the project and its results by the jurisdictions. An additional external review panel, chaired by an eminent water policy expert and consisting of academics from complementary disciplines, reviewed the research methods and their application, reporting directly to the Chair of the Steering Committee. Additionally, an entire high-capacity computing system was dedicated to preserving all the data, model parameters and calculations so that all results were subject to potential audit. It was important not only to have this quality assurance in fact but to also be able to communicate this accountability and expert review to the public.

For evidence to have the best chance of influencing policy, it is ideally uncontestable in the sense that it is widely seen as the best possible analysis. This implies acceptance by technical and professional peers as well as the wider set of stakeholders. An essential feature of gaining acceptance is dealing appropriately with uncertainty in the results. The project had the challenge of encompassing, and explaining, the large variation in future climate projections among the world’s global climate models, as well as uncertainty in the gauging of rivers, groundwater systems and associated hydrological modelling. A separate, parallel analysis of uncertainty was incorporated into every report, and the project took an overall approach of representing the full range of climate projections and carrying that variation through in all of the results. Perhaps more than any other single tactic in the study, the honest depiction of the present limitations of science in painting the future established credibility with stakeholders and widespread acceptance of the results. Meaningful expression and communication of uncertainty in model projections without muddling the overall message remains a cumbersome proposition, however. There was frequent misrepresentation of the uncertainty in the project results in the media, with ‘worst case scenarios’ routinely being the only results reported. This is a known and inevitable feature of competitive journalism however – it is difficult to see how misrepresentation could have been pre-empted.

2.6 Managing the unexpected

No project plan of any size or duration survives intact, and it is the measure of its administration that it can adapt to a changing external or internal environment. Over the course of this project, significant events occurred with the potential to derail delivery of science into policy.

A change in the federal government in November 2007

In the midst of the planned six months of reporting and public releases, not only was the Prime Minister that called for the project out of office, but so was the Minister for Water and chief architect of the nation's water policy (and new federal Water Act) as well as the person to whom the results were delivered. The Minister for Water under the new government did not effectively assume her role until 2008 and had little prior background to the project. The necessary period of handover resulted in a gap in releases of project reports as new communication protocols were developed.

Changes in all four State Premiers

There were changes in all four State Premiers who had called for the project. While none of these changes involved changes in governments, direct and personal ownership of the project by the jurisdictions was potentially compromised.

Discovery of undisclosed data and errors of interpretation in jurisdictional models

The complex sequence of analyses and reporting depended on getting all the available data from multiple external sources on time. In several cases the project was informed after all analyses had been completed for a region and converted into reports that extra data had come to light; analyses had to be re-run and reports modified accordingly. Similarly, the complexity of models coupled with poor documentation of their construction resulted in misinterpretation or embedded model errors that similarly required work to be repeated.

The deepening drought

Throughout the project, the water supplies of the MDB continued to deteriorate. The consequences were (i) multiple demands upon the jurisdiction's technical capacity in responding to contingency planning, limiting their ability to deliver into this project; and (ii) increased political and social tensions surrounding the project and thus more intense pressure to release results promptly.

The water policy and planning processes

Many if not most of the regions under analysis were in some phase of planning or implementation of water sharing arrangements, industry or entitlement restructuring, or litigation over water sharing arrangements. The first regional report released was used as rationale to stop a planned auction of water entitlements. Later, project analyses and data would be subpoenaed even prior to their finalisation in support of a lawsuit between entitlement holders and a state government. In some regions, water assessments and forecasts completed prior to the project were released as part of community consultation only weeks ahead of the project's reports being released, with the potential to both confuse the public and compromise the credibility of any and all science-based evidence.

In the end

The project delivered the final regional results in July 2008, some five months beyond the anticipated delivery date. For the most part, this delay was attributed to a combination of the above factors, exacerbated by the internal project bottlenecks including protracted review and revision processes.

2.7 Delivery

The delivery and release of the project’s regional reports were tightly managed. The finalised reports were delivered to the client (DEWHA and the National Water Commission) and accepted, and a date was established with the Minister for the report’s release. Each release of a report (or set of reports) was orchestrated identically as follows.

A briefing was held in, and hosted by, the principle jurisdiction governing the region or regions in question (e.g. the briefing for the Lachlan regional report was held in New South Wales). Representatives of key stakeholder groups were invited to a ‘lock-up’ situation two hours prior to the public release of the reports. Stakeholders typically consisted of representatives from irrigation interests, water utilities, conservation interests, state water and environmental departments, DEWHA and the National Water Commission.

At this briefing, reports (consisting of a one- to two-page fact sheet of highlights, an 8- to 12-page summary report, and a full regional report of 80 to 230 pages) were made available with time given for study. The Project Director and Project Manager then described the project, how analyses were carried out and the results for the specific region. Questions were answered on the methods and results. The senior administrator from DEWHA then outlined the government’s water reform program, and how and where these results would fit into that program; questions from stakeholders on these policy aspects and implications of the project were subsequently answered. At the prescribed hour of the public release (via the Internet), the briefing was adjourned.

Typically, a media release from the Ministry would alert media to the report’s release, and the Project Director would directly and promptly handle all media enquiries.

This release process embodied several key tactics. The first addresses the need to maintain absolute confidentiality of potentially commercially valuable information until it was publicly available, while giving key stakeholders the best possible understanding of the results before they were asked for comment by those they represented or by the media. The lock-up briefing served that purpose to good advantage.

The second important feature of the briefings was that they were hosted by the relevant state jurisdiction, with departmental policy and technical staff present and available for comment on the results as well as their implications to state water planning and policy. By recognising the jurisdiction’s role in the technical review of analyses and reports, a sense of peer unanimity and cross-jurisdictional ownership of the results was reinforced.

The third salient feature of the briefings was that each and every one was delivered personally by the most senior people responsible for the project including the senior administrator from DEWHA and the two most senior CSIRO team members. These three people became, over the series of releases, a consistent, authoritative public face of the project. As a team, they briefed not only on the technical results but also how those results would likely feed into federal water policy.

3 Hindsight: what we could have done better in the original assessment

In retrospect, there are a few decisions that are worth revisiting, and a larger set of relatively minor technical issues or errors that have needed redress.

Characterising level of water use

The decision to characterise the level of water use as a percentage of available water for each region was intended to provide some relative scaling across the regions, which was useful. However, the association of adjectives with each of the use classes (high, very high, etc.) implied a judgement on appropriateness or sustainability. While representing no technical inaccuracy, such terminology raised objections from a number of stakeholders and in hindsight this categorisation was counterproductive.

Future development scenarios

The development scenarios with respect to groundwater were highly problematic. In the end, the project decided the most objective and defensible estimate of future development were those levels indicated in jurisdictional groundwater plans (in some cases, draft plans). Some stakeholders objected to these projections because they saw the realisation of these levels of development was not likely or feasible due to practical limitations of the formations. While the actual volumetric implications of reduced streamflow in these cases were generally quite small compared to other risks to the resource, it would have been better (if possible) to arrive objectively at an agreed projection of development in these systems.

Similarly, projections about farm dam development hinged on assumptions about the nature and effectiveness of current and future policies regards their construction, and some of these assumptions can be considered contentious.

More specific issues arose following the release of the reports and subsequent briefings to stakeholders.

Water transfers from the Snowy Mountains Hydro-electric Scheme

The inclusion of water transfers from the Snowy Mountains Hydro-electric Scheme (SMHS) into the Murray and Murrumbidgee rivers in the modelling and reporting is both a matter of record and necessarily incorporated into any analysis of current water resource use and management, as all of this water is notionally diverted for use. Some stakeholders object to including these volumes in both the numerator and denominator in calculating and reporting the relative level of surface water use. This is purely an issue of perception and reporting (all of the water balance estimates are transparent and separately identifiable and reported), but the explanation and interpretation of the level of use could have been communicated better. Importantly, the approach taken to dealing with the SMHS transfers is the same as that taken in the New South Wales Water Sharing Plan for the Murrumbidgee Regulated River Water Source. Furthermore, the Water Act 2007 states (Part 2, Div 1, Section 21(6)) that the Basin Plan must not be inconsistent with the provisions of the licence issued under the Snowy Hydro Corporatisation Act. Thus the Basin Plan cannot determine the volumes of transfers from the SMHS, but once transferred into the Basin these resources are to be managed in line with requirements of the Basin Plan. In the Murrumbidgee, some stakeholders assert they have access to more accurate data on the actual historical volumes of water transferred from the SMHS into the Murrumbidgee which could be used to improve the river model; at the time of writing this report these data had not been provided to CSIRO for consideration.

Level of surface water use in the Murrumbidgee

The relative level of surface water use for the Murrumbidgee region includes as a component of the consumptive use the water diverted into the Lowbidgee Flood Control and Irrigation District. Some stakeholders in the Murrumbidgee region assert that these volumes should be only partly considered as a consumptive use and partly considered as an environmental use. Some stakeholders have indicated they have access to data to describe the historical apportioning of these volumes; at the time of writing this report these data had not been provided to CSIRO for consideration.

Level of surface water use in the Gwydir

The relative level of surface water use for the Gwydir region is based on an assessment of water availability at the point of maximum river flow in the region. While this is the consistent approach adopted for water availability assessment in this project, it should be recognised (as pointed out by some stakeholders in the Gwydir region) that the river inflows downstream of this point in the Gwydir region are a greater proportion of the total than in other regions. These downstream inflows are an important resource for some water users in the region. As noted in the report for the Gwydir region, the project's approach to assessing water availability does, in this region, differ from that taken by New South Wales Government in developing a water sharing plan. Thus the relative level of surface water use determined in this project for the region, while consistent with the approach taken elsewhere, is higher than would be the case if downstream inflows were included in the available resource assessment.

Groundwater entitlements in New South Wales

The assessments were based on the state water management policies in place at the time. Since these assessments were made, the New South Wales Government has placed an embargo on the issuing of any further groundwater entitlements in the New South Wales portion of the MDB (1 July 2008, <http://www.naturalresources.nsw.gov.au/mediarelnr/mr20080701_3887.html>). This embargo does not apply to areas where water sharing plans are already in place. However, it is outside of these water sharing plan areas across New South Wales where the largest increases in groundwater extractions could potentially have occurred prior to the embargo. The fact that these assessments are not consistent with the most recent policy position of the New South Wales Government is a matter that has been raised by multiple New South Wales stakeholder groups, including at all the New South Wales briefings in December 2008. It is further noted that many stakeholder groups have misinterpreted the future development scenario as being a prediction from CSIRO about what was likely to occur, rather than a worst case assessment of what could potentially occur under the policy at the time.

In all cases, the project responded to stakeholder enquiries regarding the accuracy or interpretation of results.

4 Looking forward: challenges to providing more accurate and precise water resource assessments

Opportunities to improve the accuracy and precision of estimates of future water align with the areas giving greatest uncertainty in the project's results. Chapter 5 of each regional report provides a detailed assessment of where data and models were strong or weak. Here we summarise these issues.

4.1 Climate modelling

The biggest uncertainty in modelling future water availability is the future climate change projections. There was strong consensus among the climate science community at the time of the project regarding the interpretation of the Intergovernmental Panel on Climate Change Fourth Assessment Report global climate modelling, which the project adopted. That is, we accepted that there was no agreed way to objectively and reliably differentiate among the many global climate models in terms of their performance in predicting the future. Further analysis also indicated that there is little difference in the future rainfall projections for the MDB from the better and poorer global climate models assessed against different measures. Therefore, the full variation among these models in predicting the climate of the MDB at 2030 was represented, across three global warming scenarios. The result is a rather wide range in possible water futures. Therefore, a key area for scientific advance is improvement in climate change and climate modelling science such that the global climate models give more reliable and consistent future climate (in particular rainfall) projections. This improvement, together with an agreed and defensible scientific approach to use a smaller range of global climate models for climate change impact studies, will lead to a more accurate and smaller range of possible water futures.

Secondly, the low spatial resolution global climate modelling results must be downscaled to provide the catchment-scale climate to drive the hydrological models. In the present project, we empirically scaled the long-term daily climate records by a seasonal and daily ratio of historical and future climate. It is likely that statistical and dynamic downscaling methods can better account for changes in future rainfall characteristics, especially as these methods improve and when they are used to downscale more certain future projections from global climate models. Thus another key area for scientific advance is the development of improved statistical and dynamic downscaling methods, and the testing and application of the methods in the context of the hydrological applications here.

4.2 Catchment water yield modelling

A consistent daily rainfall-runoff modelling approach was used to estimate the historical and recent catchment water yield and daily runoff across the MDB. The approach reliably estimated runoff and the variability in runoff over time, particularly in the upland areas in the south and south-east where most of the runoff in the MDB comes from. The estimation of catchment water yield in ungauged catchments and daily runoff characteristics will become more accurate with ongoing research endeavours in Australia and overseas. The key areas of research include:

- regionalisation approaches to obtain parameter values for ungauged catchments
- output averaging of ensemble modelling results from many rainfall-runoff models
- using remotely sensed data to constrain model calibration and parameterisation.

The future runoff across the MDB was modelled by driving the rainfall-runoff model with future climate inputs generated by the global climate models. The same parameter values determined from calibrating the models against historical runoff were used to model the future runoff. Whilst this approach may be reasonable for estimating future runoff in 2030, other considerations need to be taken into account for projections and extrapolations into a more distant future.

The key research areas relating to this include:

- potential changes in the hydrological processes in a warmer and drier climate (e.g. runoff sensitivity to rainfall and temperature and surface–groundwater interactions)

- changes in land surface conditions and processes and surface-atmosphere feedbacks
- consideration of climate change impact in the context of other drivers of runoff (like farm dams, plantations and bushfires).

4.3 River modelling

The practicalities of project timelines and jurisdictional participation limited the project to (mostly) existing river models. Linking these to inflow forecasts, to groundwater models and to each other for basin-wide modelling was a big software engineering challenge. While providing a unique and ongoing platform for simulating scenarios of change, the models in fact do not easily lend themselves to scenario modelling of fundamental changes to water resource and sharing arrangements, as the platform compiled models representing the current set of water sharing arrangements – much of which is 'hard-wired'.

Furthermore, there are a number of known minor problems with the linked modelling used to deliver the project results. Some have been subsequently rectified; others should be rectified prior to any additional scenario modelling – for example in the development of the new Basin Plan. These problems are summarised in the table below. Fixes which have led to report revisions are listed in Appendix A.

Region(s)	Issue	Status
Paroo, Warrego, Condamine-Balonne, Moonie	The IQQM models for these regions represent the ultimate allowable level of water resource development under current planning arrangements. This differs from the current actual level of development. For the Border River model, the level of development in both the Queensland and New South Wales portions is intended to reflect the current level of development	No change required
Border Rivers	Model for original runs had an error in the location of the Talwood gauge on the lower Weir River	Model fixed, rerun and errata issued to regional report
Border Rivers	While error in original model did not propagate to downstream models, some Border Rivers region numbers in the whole of basin report and some MDB totals are now in error. The error in MDB total is relatively minor (~1%)	No errata to be issued
Gwydir	Value for supplementary access in Appendix B of whole of basin report should be 178, 0%, 2%, 5%, 3%, 0%, 0%, 0% 2%, 5%, 0%, 2% and 8% not 40, 34%, 72%, 5%, 41%, 77%, 4%, 33%, 73%, 5%, 27%, 64% and 8%.	No errata to be issued
Gwydir	A feedback exists around the water ordering of Colly Farms in the lower Gwydir, as water is ordered from both the Gwydir system and the Barwon-Darling system. This feedback is not represented in the linked modelling but is small from both a regional and basin-wide perspective	No change required
Macquarie-Castlereagh	Some factoring of flows was required to link the six models which represent this region. This may have introduced mass balance errors	Should be checked prior to further scenario modelling
Barwon-Darling	In the linked modelling the connections for the Lower Darling and Talywalka Creek into the Murray model were switched. This error does not affect mass balance in either this or the Murray region	Model connections have now been fixed
Barwon-Darling	The level of water use in the Barwon-Darling model is higher (230 GL/year on average) than the cap reduction (to 173 GL/year) imposed in 2006 by the New South Wales Government	Model should be updated for any further scenario runs
Murrumbidgee	As the project was only provided with inflows from the Snowy Mountains Hydro-electric Scheme (SMHS) models, the start and end storage volumes for the SMHS in the modelling are unknown. Potentially, water is being 'mined' from the SMHS storages through the model runs. As the total storage volume for the SMHS is substantial this is a significant issue.	Information on SMHS storage levels should be considered in any further scenario runs
Murrumbidgee	The 'without-development' and current models for the Murrumbidgee region use different approaches to accounting for the Blowering and Tantangara inflows. For Blowering, this is due to the omission of local catchment inflows from Tumut at Jounama Pondage in the 'without-development' model.	This should be corrected prior to any further scenario runs
Murrumbidgee	Late in the project new groundwater extraction data were received from the New South Wales Government for the Mid-Murrumbidgee groundwater system. While the groundwater model was rerun, the interactions with the river model were not rerun	This has not been fixed in the linked modelling framework
Goulburn-Broken, Campaspe, Loddon-Avoca	Surface–groundwater fluxes calculated in ML/month were erroneously originally assumed to be ML/day. In the project timelines the models could not be rerun; however, this error was declared and its implications described in the relevant reports	This error has now been fixed in the linked modelling framework

Region(s)	Issue	Status
Goulburn-Broken, Campaspe, Loddon-Avoca	While mass balance through the Waranga Western Channel to the Wimmera region was manually set to be correct, the Goulburn Simulation Model (GSM) has not been dynamically linked to the Wimmera REALM model	This should be fixed prior to any further scenario runs
Goulburn-Broken, Campaspe, Loddon-Avoca	The Food-Bowl Modernisation Project (involving efficiency improvements and a pipeline to Melbourne) is not included in the GSM as used	Should be considered for inclusion in any further scenario runs
Wimmera	Only Stage 1 of the Wimmera Pipeline Project was included in the modelling	Additional stages of the pipeline project should be considered in any further scenario runs
Eastern Mt Lofty Ranges	The Eastern Mt Lofty Ranges WaterCRESS models are not linked to the Murray model in the linked modelling framework, and thus inflows from this region to the lower river and Lower Lakes are not explicitly represented.	Consideration should be given to a more realistic representation of the connections in this region for any further scenario runs
Entire Murray-Darling Basin	While multiple feedbacks between models are included in the modelling system, and while multiple iteration of the linked models were run, adequate convergence was not checked for all variables affected by these feedbacks	Convergence of key variables should be checked in any further scenario runs

We anticipate the delivery of the River Manager tool via the eWater CRC will enable this more complete and advanced treatment of options as well as offering an operational tool for managing the water resources in the MDB.

The river models used in the project were analysed to assess their suitability for the project purposes, the reliability of the results, and the most important sources of uncertainty, both internal and external to the models. This provides some valuable insights for going forward.

Model uncertainties

Generally the river models were adequate for the project purposes, particularly when contrasting the uncertainties in the river model with those in climate and development scenarios. River model projections were considered least robust for temporal flow patterns, for low flows, and in strongly losing, complex reaches, often near the end-of-system where several of the environmental assets are located. Due to the accumulation of uncertainties down the system, the future trajectory of river flows and associated outcomes was most uncertain for the lower Murray and Darling rivers. In terms of the types of outcomes, the most uncertain were those related to infrequent droughts and floods (often chosen as indicators for environmental assets) and end-of-system flows. Targeted additional on-ground data collection and better use of on-ground and satellite data in river modelling can reduce these model uncertainties considerably, but do not reduce uncertainties about changes in climate and development.

The greatest uncertainties in projected river flows until 2030 were (in approximately decreasing order and generalised across the MDB):

- background climate variability
- rainfall projections by climate models
- farm dam expansion projections
- river model structural uncertainty.

The next tier of uncertainties is associated with:

- water delivery efficiency and return flows
- changes in wind speed and radiation
- changes in land cover and use (e.g. recovery after bushfires).

At local scale other uncertainties can be important, such as surface–groundwater interactions and plantation forestry projections. Some of these uncertainties can be reduced through further research and development, but large uncertainty in climate projections is likely to remain. Rainfall history (1895 to 2006) suggests that even without a (further) greenhouse gas-induced climate trend, prolonged very dry or wet conditions are entirely feasible: historical 20-year sequences exist that are more extreme than the extreme global climate model predictions.

The overriding influence of background climate variability stresses the importance of a risk-based approach. However, just as fiscal policies need to be specified before their likely outcomes and risks can be assessed through economic modelling, selected water management actions need to be specified before hydrological risk analysis. This was not possible in this project. As a result, the project results do indicate where the weak points are under the current water management regime, but this must be considered an (important) first step in supporting an appropriate response. To realize the full benefit and usefulness of assessments such as these, the range of management responses under consideration need to be defined in some detail prior to assessing the outcomes and the associated balance of probabilities.

4.4 Groundwater modelling

The prioritisation approach to groundwater modelling was effective, practical and widely accepted by stakeholders in the project. This acceptability arises from broad recognition that aquifers are fundamentally more difficult to characterise than surface water systems. The obverse of this is recognition that subsequent investigations of specific parameters of key aquifer systems will yield greater reliability and agreement on their potential yield. Over the course of the project, such needs have been identified, such as the need for improved estimates of permeability of river bed material in the Border Rivers region, controlling surface–groundwater interactions.

Some key knowledge gaps prevented the project from providing confidence in some key areas. While there can never be comprehensive information on groundwater across the whole MDB, the prioritisation framework has enabled a ranking of the relative importance of groundwater management units and hence a determination of the minimum assessment required for each ranking. Thus, for the majority of the MDB, the information obtained, although sparse, is appropriate for a study of this scale. The following sub-sections describe some key gaps that need to be addressed for future assessments.

Extraction data

Better groundwater extraction data are essential for improving hydrological analyses. Issues around the quality of current data range from inconsistency of data between states; availability of data on unincorporated areas, stock and domestic supplies and Great Artesian Basin aquifers; changing boundaries for groundwater management units; availability of historical extraction data; lack of metering in some areas; and the ability to match groundwater extraction data to surface water subcatchments.

Upgraded models

Analyses for many of the higher priority areas did not meet the minimum assessment specified for that priority ranking. Some of the criteria used to decide on the appropriateness of an analysis included quality of data and peer review, which may not be possible within any scope, let alone within this project. Several of the numerical groundwater models underpinning groundwater sharing plans could be improved with longer calibration period, inclusion of irrigation recharge, consistency in estimation of diffuse recharge, larger model area and the application of a steady-state calibration.

Salt analysis

Many of the major groundwater systems occur in sub-humid and semi-arid areas. For such areas, salinity may be the major constraint to groundwater extraction, but time constraints prevented the analysis of salinity. Groundwater salinisation issues may be caused by leaching of salt from unsaturated zones, leakage from a saline aquifer either above or below the productive aquifer, lateral entrainment of saline groundwater or concentration of salt related to recycling of irrigation water. Salinity issues are relevant to Southern Riverine Plain, Lower Lachlan, Lower Macquarie, Lower Gwydir, Upper Condamine, Angas-Bremer and Mallee groundwater management units amongst others. Land salinisation issues are relevant in a number of these as surface water irrigation and dryland clearing lead to increased recharge, in excess of groundwater extraction at least for part of the aquifer, and rising watertables.

Surface–groundwater interactions

Surface–groundwater interactions were analysed for the first time at this scale. This analysis needed to cope with variable extraction volumes, variable data and differing hydrogeological conceptualisations. The scale of approach naturally leads to inadequacies at the scale required for local management. An associated report analyses the strengths and weakness of the ‘dynamic equilibrium approach’ which was used to estimate water levels. This approach in surface water modelling uses a long climate sequence to provide a range of outputs that are then further analysed to estimate water availability. However, the dynamic equilibrium approach – when applied to groundwater models – leads to several problems associated with running numerical groundwater models outside of the conditions for which they were initially created and calibrated. An alternative approach, which may have more merit, is to use stochastic modelling to better represent the range of conditions but to limit the analysis to 20 or 30 years of simulation from the current groundwater state.

Surface–groundwater connectivity

The project developed a map of potential groundwater fluxes to and from streams for many of the major tributaries of the MDB. These fluxes were represented as classes of high, medium and low fluxes for losing and gaining streams as well as maximum losing streams. The estimates of fluxes depend on estimates of hydraulic conductivity and also the time the hydraulic gradients were calculated. Our analyses have shown that despite this, the general patterns are appropriate, but further work is required to generate robust estimates of actual fluxes to and from streams.

5 Toward a more complete sustainability assessment

Forecasts of the likely amount of water available at some future point are essential to planning. Additional understanding of both ecological response and values, as well as economic and social response to potential changes in water sharing arrangements, would greatly add to the evidence underpinning a new sustainable diversion limit. For the MDB, these analyses could take the following form and sequence.

Prioritisation of ecological and cultural assets

In rebalancing the level of usage across the MDB, a logical first step would be an inventory of those assets that require flows of water for their health or maintenance. The project only identified a subset of the most prominent of the ecological assets (key wetlands, etc.), and did not attempt to identify cultural (Indigenous) assets. A more comprehensive map of these assets is required, and would require significant advice and direction from Indigenous communities and organisations such as the Murray Land Lower Darling Indigenous Nations.

Prioritisation of these assets would in part reflect their significance to the community in general and to Indigenous peoples in particular in the case of cultural sites, and would highlight how maintaining the health and integrity of these sites serves to underpin the health of the entire MDB.

Establishing cultural flow requirements

Having identified, with Indigenous communities, the important cultural sites, additional advice is required to quantify the flow regimes necessary to ensure their value to those communities.

Determining ecological response to varying flow regimes

Despite scientific studies of the ecology of many parts of the MDB, in general we do not have relatively simple response functions relating the ecological health of a particular site to a specific change in flow regime. These are necessary to establish the potential value of increasing water flow through these diverse systems, a likely first step in assessing proposed changes in diversions.

Modelling the change scenarios in water sharing arrangements that would deliver the desired cultural and ecological flows

With a knowledge of the important cultural and ecological sites, and their flow requirements or responses, proposed changes in diversions can be evaluated in terms of how well they deliver on these objectives.

Analysis of economic and social consequences of these change scenarios.

It is equally clear that diversion scenarios will have differing economic and social impacts, and that any complete analysis underpinning a new Basin Plan would want to consider this.

6 Summary

A number of elements in the Murray-Darling Basin Sustainable Yields Project contributed to its success. The project made methodological and analytic choices that could potentially have been improved, in hindsight. Should a similar assessment ever be undertaken again, advances in methods and the extension of ecological, cultural and economic considerations would greatly enhance the body of evidence underpinning future MDB policy and management.

References

Davies P (1999) What is evidence-based education? British Journal of Educational Studies 47(2), pp 108–121.

Davies P (2004) Is evidence-based government possible? The Jerry Lee Lecture, Campbell Collaboration Colloquium, Washington.

Watson RT (2005) Turning science into policy: challenges and experiences from the science-policy interface. Philosophical Transactions of the Royal Society 360, pp 471–477.

Appendix A Regional reports errata

Lachlan

Erratum #	Chapter	Section	Page	Errata
1	6 Groundwater assessment	6.6.3	103	Replacement Table 6-19 – connectivity units changed to percents (from fractions)
2	6 Groundwater assessment	6.6.3	104	Para 1, Line 5 – replace 16 GL/year with 26 GL/year

1 Table 6-19. Surface-groundwater connectivity showing an estimate of the volumetric impact extraction has on streamflow in groundwater management units under Scenario D

Code	Name	Current Entitlements	Future Extraction	Difference	Connectivity	Stream Impact
		GL/y			percent	
N21	Belubula Valley Alluvium	6.29	6.29	0.00	15%	0.00
N801	Orange Basalt	6.23	6.44	0.21	30%	0.06
N802	Young Granite	7.75	7.75	0.00	25%	0.00
N811	Lachlan Fold Belt	33.46	119.19	85.73	30%	25.72
	Total	**53.73**	**139.67**	**85.94**		**25.78**

2 [Replacement paragraph]

The impacts of groundwater extraction on streamflow listed in Table 6-19 are distributed to the relevant surface water subcatchments or stretches of river. Streamflow losses of less than 2 GL/year in a subcatchment (Table 6-20) would be difficult to observe and thus only subcatchments where the estimated impact from groundwater extraction exceeds a 2 GL/year reduction in streamflow are considered further. Calculation using original future extraction data showed this cut-off discounts about 15 GL/year of impacts reducing the total estimated impact from about 26 GL/year (Table 6-19) to about 11 GL/year.

Wimmera

Erratum #	Chapter	Section	Page	Errata
1	4 River system modelling	4.3.1	45	Replacement Table 4-6 – channel / pipe loss moved from unattributed fluxes to diversions

1 Table 4-6. River system model average annual water balance under scenarios O, A, B and C in the Wimmera region

River system model average annual water balance	O	A	B	Cwet	Cmid	Cdry
Model start date	Jan-1903	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2004	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A			
Storage volume						
Change over period	-6.5	-12.5	0%	0%	0%	1%
Inflows						
Subcatchments						
Directly gauged	19.7	18.5	-52%	-5%	-17%	-46%
Indirectly gauged	264.5	255.1	-52%	-5%	-20%	-52%
Transfers from other basins	65.0	58.2	-29%	3%	-4%	-29%
Sub-total	**349.2**	**331.8**	**-48%**	**-4%**	**-17%**	**-48%**
Diversions						
Licenced private diversions	40.5	34.0	-57%	-3%	-16%	-61%
Urban diversions	8.4	7.2	-16%	2%	-1%	-16%
Sub-total	**48.9**	**41.2**	**-50%**	**-2%**	**-14%**	**-53%**
Channel / pipe loss	94.8	79.6	-41%	0%	-9%	-42%
Sub-total	**143.7**	**120.8**	**-0.9**	**0.0**	**-0.2**	**-0.9**
Outflows						
End-of-system outflow						
D/S Lake Buloke	14.7	13.7	-46%	-5%	-16%	-38%
Yarriambiack Creek	6.4	6.7	-71%	-12%	-36%	-74%
D/S Lake Brambruk	0.2	0.5	-100%	-35%	-100%	-100%
Internal model spills	4.0	3.8	-63%	-8%	-27%	-66%
Sub-total	**25.3**	**24.7**	**-57%**	**-8%**	**-25%**	**-53%**
Net evaporation*						
Headworks storages	39.3	40.2	-46%	1%	-12%	-42%
Lakes	113.7	118.5	-56%	-8%	-26%	-57%
Sub-total	**153.0**	**158.6**	**-54%**	**-6%**	**-22%**	**-53%**
Sub-total	**178.3**	**183.3**	**-54%**	**-6%**	**-23%**	**-53%**
Unattributed fluxes						
River unattributed loss	37.5	39.2	-10%	-2%	-7%	-12%

* Evaporation from private licensed storages (GL/y) is not included as it is already accounted in diversions

Border Rivers

Erratum #	Chapter	Section	Page	Errata
1	Executive Summary			Key messages – Historical climate and current development (Scenario A), second paragraph, lines 1 and 2 – replace 1208 GL/year with 1090 GL/year, replace 242 GL/year with 124 GL/year and replace 34 percent with 38 percent
2	Executive Summary			Key messages – Future climate and current development (Scenario C), second paragraph
3	4 River system modelling	4.1.1	43	The second last paragraph, lines 3 and 4 – replace 242 GL/year with 124 GL/year, and replace 1208 GL/year with 1090 GL/year.
4	4 River system modelling	4.1.2	43	First key message – replace 1208 GL/year with 1090 GL/year and replace 34 percent with 38 percent
5	4 River system modelling	4.1.2	44	Fifth key message – replace 10 percent with 9 percent
6	4 River system modelling	4.3.2	52	Replacement Figure 4-2
7	4 River system modelling	4.3.2	53	Replacement Table 4-7 – replacement values for the Weir River and the total
8	4 River system modelling	4.3.2	53	Water Availability sub-section, second last section, line 2: replace 188 GL with 175 GL and 5592 GL with 5080 GL
9	4 River system modelling	4.3.2	53	Replacement Figure 4-3
10	4 River system modelling	4.3.2	54	Replacement Figure 4-4
11	4 River system modelling	4.3.4	57	Replacement Table 4-12 – replacement values for reaches 4162021 and 4160011
12	4 River system modelling	4.3.4	57	Replacement Figure 4-9
13	4 River system modelling	4.3.6	69	Replacement Table 4-19
14	4 River system modelling	4.5	71	Additional reference
15	Appendix B River Water modelling reach mass balances		132	Replacement table - subcatchment 4162021
16	Appendix B River Water modelling reach mass balances		133	Replacement table – subcatchment 4160011

1 [Replacement paragraph]

Current average surface water availability is 1090 GL/year – comprised of 905 GL/year in the Macintyre and Dumaresq rivers, 124 GL/year in the Weir River and 61 GL/year in Whalan Creek. Average diversions are 38 percent of average available water. This is a high level of use which has reduced the reliability of supply for water users in the region and has reduced end-of-system flows. New South Wales general security water is highly utilised – 82 percent of the available water is utilised. Queensland medium security water in the Glenlyon system is also highly utilised – 73 percent of theavailable water is used. (The river model used assumes that Queensland medium security water is fully utilised in the Coolmunda system.) River flows are highly regulated – Glenlyon Dam regulates 88 percent of inflows under current levels of development and Pindari Dam regulates 70 percent of inflows. Of the constructed storage capacity in the region around 40 percent is in the form of on-farm ring tanks.

2 [Replacement paragraph]

Under the best estimate 2030 climate average water availability would be reduced by 9 percent, end-of-system flows by 12 percent lower and total diversions by 2 percent. However, the impacts on diversions would differ by ‘water product’: in New South Wales both general security and supplementary use would fall by 1 percent. In Queensland, both medium security and unsupplemented use would fall by 3 percent. Town water supply would be unaffected.

3 [Replacement paragraph]

Analysis of the pre-development flows along the Border Rivers system indicates that it changes from a gaining to a losing stream (point of maximum average annual flow) at the Boggabilla gauge (416002). The pre-development average annual flow at this gauge over the modelling period is 905 GL/year. The Weir River and Whalan Creeks also contribute 124 and 61 GL/year respectively, making the total available flow 1090 GL/year.

4 [Replacement paragraph]

Current average water availability is 1090 GL/year. The current level of use is high – 38 percent of average available water is diverted for use. The high level of use has reduced end-of-system flows and has reduced the reliability of supply for water users.

5 [Replacement paragraph]

Under the best estimate 2030 climate scenario, average water availability is reduced by 9 percent and end-of-system flows are reduced by 12 percent.

6

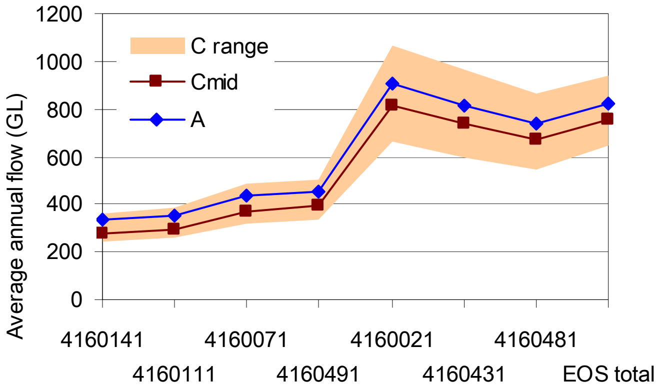


Figure 4-2. Transect of Dumaresq-Macintyre average annual river flow under pre-development scenarios A and C

7 Table 4-7. Annual water availability for pre-development Scenario A and relative change under pre-development scenarios C and D

Water Availability	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y						
Dumaresq-Macintyre	904.7	18%	-10%	-26%	17%	-11%	-27%
Weir River	124.5	11%	-4%	-16%	-100%	-100%	-100%
Whalan Creek	61.1	30%	-16%	-38%	21%	-24%	-44%
Total	**1090.3**	**18%**	**-9%**	**-26%**	**4%**	**-22%**	**-37%**

8 [Replacement paragraph]

A time series of total annual water availability under pre-development Scenario A is shown in Figure 4-3. The lowest annual water availability was 175 GL in 1935 while the highest annual water availability was 5080 GL in 1955.

9

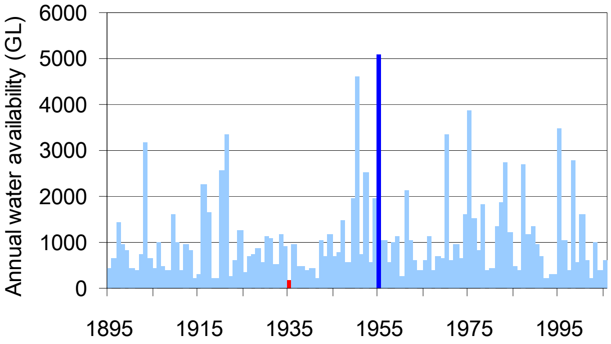


Figure 4-3. Pre-development Scenario A water availability

10

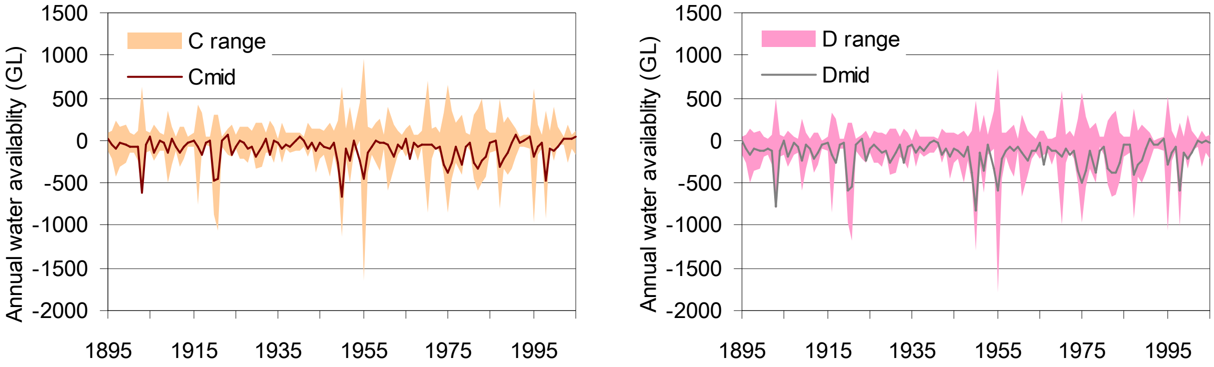


Figure 4-4. Time series of change in total water availability relative to pre-development scenario A under (a) pre-development Scenario C and (b) pre-development Scenario D

11

Table 4-12. Change in total diversions in each subcatchment relative to Scenario A

Region	Reach	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
		GL/y	percent change from Scenario A					
Pindari	4160191	0.0	0%	0%	0%	0%	0%	0%
	4160061	0.2	0%	0%	0%	0%	0%	0%
	4160181	0.7	4%	2%	-2%	2%	-1%	-5%
	4160121	0.0	0%	0%	0%	0%	0%	0%
	4160381	10.9	2%	2%	-6%	2%	0%	-10%
Coolmunda	4164091	0.7	5%	1%	-16%	5%	1%	-16%
	4164021	1.5	4%	1%	-12%	4%	1%	-12%
	4164151	14.0	5%	1%	-17%	5%	1%	-17%
Glenlyon	4160141	0.0	0%	0%	0%	0%	0%	0%
	4160111	0.0	0%	0%	0%	0%	0%	0%
	4160071	4.5	8%	-2%	-16%	4%	-7%	-22%
	4160491	4.5	8%	-4%	-16%	4%	-8%	-21%
	4160021	43.4	8%	-1%	-17%	5%	-4%	-21%
Weir River	4162021	26.5	3%	2%	-3%	3%	3%	-3%
Bogabilla to EOS	4160431	158.3	8%	-2%	-17%	6%	-5%	-20%
	4160481	51.7	10%	-4%	-21%	8%	-7%	-24%
	4160011	94.7	10%	-3%	-19%	-28%	-6%	-21%
	4160013	0.1	9%	-23%	-51%	12%	-18%	-53%
	4160281	0.0	0%	0%	0%	0%	0%	0%
	Total	**411.5**	**8%**	**-2%**	**-17%**	**-2%**	**-5%**	**-19%**

12

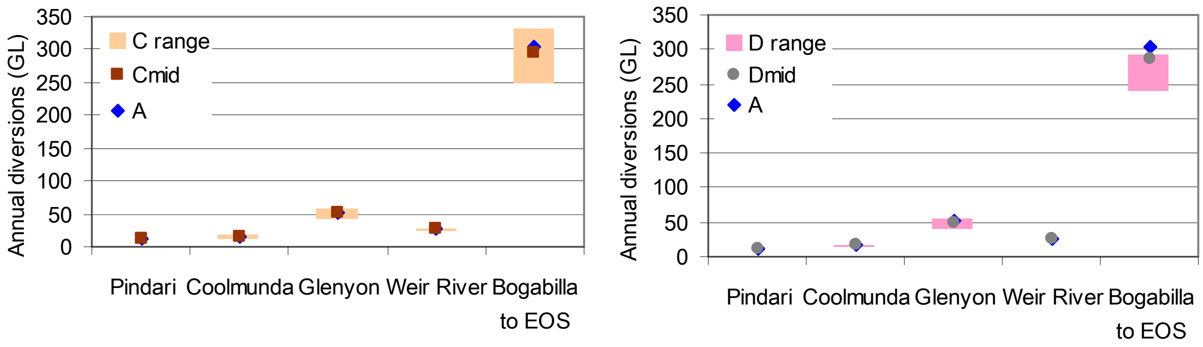


Figure 4-9. Total average annual diversions for subcatchments under (a) scenarios A and C and (b) scenarios A and D

13

Table 4-19. Relative level of available water not diverted for use under scenarios A, C and D

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Relative level of non-diverted water	percent						
Non-diverted water as a percentage of total available water	62%	65%	59%	58%	61%	54%	52%
Non diverted share relative to Scenario A non-diverted share	100%	118%	91%	74%	104%	78%	63%
Proportion of pre-development cross border flows	59.5%	73.6%	52.9%	41.0%	71.3%	50.9%	39.1%

14 [Additional reference]

DNRW (2008) in prep, Weir River IQQM Calibration Report, Queensland Department of Natural Resources and Water.

15

Subcatchment 4162021

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y						
Storage volume							
Initial storage	1.10	1.08	1.08	1.08	1.08	1.08	1.08
Final storage	1.12	1.17	1.12	1.07	1.17	1.13	1.07
Average annual change	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Inflows							
Indirectly gauged	466.75	560.89	428.03	339.26	558.35	425.86	337.44
Sub-total	**466.75**	**560.89**	**428.03**	**339.26**	**558.35**	**425.86**	**337.44**
Diversions							
QLD usage							
Unsupplemented access	26.49	27.19	27.03	25.72	27.26	27.16	25.74
Sub-total	**26.49**	**27.19**	**27.03**	**25.72**	**27.26**	**27.16**	**25.74**
Outflows							
End-of-system outflow	113.67	136.89	105.28	79.99	136.17	104.61	79.46
Net evaporation	20.69	21.53	21.03	19.98	21.49	20.98	19.93
Effluent losses	0.00	0.00	0.00	0.00	0.00	0.00	0.00
River unattributed losses	305.90	375.22	274.68	213.58	373.43	273.10	212.31
Sub-total	**440.26**	**533.64**	**401.00**	**313.55**	**531.09**	**398.70**	**311.70**
Unattributed fluxes							
Total	0.01	0.06	0.00	0.00	0.00	0.00	0.00
Mass balance error (%)	0%	0%	0%	0%	0%	0%	0%

16

Subcatchment 4160011

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y						
Inflows							
Directly gauged	326.05	393.42	292.13	234.27	379.95	279.40	222.11
Indirectly gauged	222.58	274.46	201.34	151.08	270.56	197.96	148.32
Sub-total	**548.63**	**667.89**	**493.47**	**385.35**	**650.51**	**477.37**	**370.43**
Diversions							
NSW usage							
General security - on allocation	9.35	10.22	9.05	7.58	9.99	8.68	7.11
General security - off allocation	11.08	11.59	11.10	9.84	11.50	10.90	9.66
Unregulated	0.56	0.64	0.50	0.44	0.63	0.51	0.44
High security - town water supply	0.26	0.26	0.26	0.25	0.26	0.25	0.25
QLD usage							
Medium security - on allocation	4.88	5.42	4.58	3.36	4.99	4.13	2.95
Medium security - off allocation	33.95	38.26	32.34	26.04	37.54	31.35	25.43
Unsupplemented access	34.64	37.86	33.63	29.41	37.47	33.15	28.92
Sub-total	**94.71**	**104.24**	**91.47**	**76.92**	**102.38**	**88.97**	**74.76**
Outflows							
End-of-system outflow	325.79	403.16	289.50	224.45	390.68	278.53	214.14
Effluent losses	91.14	118.52	77.57	53.80	116.87	76.40	52.87
River unattributed losses	37.00	42.03	34.93	30.17	40.59	33.47	28.67
Sub-total	**453.93**	**563.70**	**402.00**	**308.42**	**548.13**	**388.40**	**295.68**
Unattributed fluxes							
Total	-0.01	-0.06	0.00	0.00	0.00	0.00	0.00
Mass balance error (%)	0%	0%	0%	0%	0%	0%	0%

Murrumbidgee

Erratum #	Chapter	Section	Page	Errata
1	6 Groundwater assessment	6.2	96	Replacement Table 6.1 – change Long-term average extraction limit for Mid-Murrumbidgee Alluvium (N13) to 68.6 Gl/y (and total to 911.9 Gl/y) and remove footnote (4)

1 Table 6-1. Categorisation of groundwater management units, including annual extraction, entitlement and recharge details

Code	Name	Priority	Assessment	Entitlement	Extraction[(1)] 2004/05	Long-term average extraction limit	Recharge[(2)]
					GL/y		
N02	Lower Murrumbidgee Alluvium (d/s of Narrandera)	very high	thorough	280.0	323.8	[(3)]280.0	[(3)]400.0 (plus basic landholder rights)
N13	Mid-Murrumbidgee Alluvium (u/s of Narrandera)	high	thorough	80.1	48.2	68.6	12.1
N14	Billabong Creek Alluvium (u/s of Mahonga)	low	simple	7.2	5.7	7.4	12.3
N612	Western Murray Porous Rock	very low	minimal	0.1	0.1	5.6	7.9
N802	Young Granite	low	simple	1.1	0.7	1.4	2.3
N811	Lachlan Fold Belt	low	simple	37.8	27.5	541.9	1086.7
A1	Australian Capital Territory	very low	minimal	1.0	0.5	7.0	78.9
	Total			**407.3**	**406.5**	**911.9**	**1600.2**

(1) Current groundwater extraction for macro groundwater sharing plan areas is based on metered and estimated data provided by DWE. Data quality is variable depending on the location of bores and the frequency of meter reading.

(2) This value incorporates all sources of recharge in water sharing plan (WSP) areas but represents only rainfall recharge in macro plan areas. Where indicated the recharge volume does not include the amount of groundwater available for basic rights, which is an additional volume. The volume of recharge does not include recharge to national park areas, which has generally been allocated to environmental purposes and is not available for consumptive use.

(3) Source: DIPNR, 2006.

Macquarie-Castlereagh

Erratum #	Chapter	Section	Page	Errata
1	4 River system modelling	4.3.1	47	Replacement Table 4-6. Irrigation return (from groundwater) moved from diversions to inflows

1 Table 4-6. River system model average annual water balance under scenarios O, A0, A, C and D

	O	A0	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/01/1890	01/07/1895							
Model end date	30/06/2001	30/06/2006							
	GL/y			percent change from Scenario A					
Storage volume									
Change over period	-1.3	0.3	0.3	1.8	-0.1	-2.8	1.7	-0.3	-2.9
Inflows									
Subcatchments									
Directly gauged	1155.0	1124.2	1124.2	1428.9	1043.9	839.3	1387.4	1004.7	802.1
Indirectly gauged	1063.2	1042.9	1043.0	1325.5	979.8	825.4	1300.8	956.0	802.3
Unattributed effluent return	415.4	394.4	396.6	516.3	365.3	309.5	509.8	359.6	304.0
Irrigation return (from groundwater)	0.0	0.0	15.0	18.9	14.5	13.3	18.5	14.4	13.3
Sub-total	**2633.6**	**2561.4**	**2578.7**	**3289.5**	**2403.5**	**1987.5**	**3216.5**	**2334.7**	**1921.8**
Diversions									
Licenced private diversions									
General security - on allocation	329.8	319.8	321.7	365.5	307.8	263.5	360.8	302.4	258.4
General security - off allocation	32.0	31.0	31.0	34.4	29.6	26.7	34.1	29.3	26.3
High security irrigation	5.1	5.1	5.1	5.0	5.3	5.6	5.0	5.3	5.6
Sub-total	**366.9**	**355.9**	**357.8**	**404.9**	**342.7**	**295.8**	**399.9**	**337.0**	**290.4**
Town water supply	27.8	27.9	27.9	28.0	27.8	27.4	27.9	27.8	27.3
Sub-total	**394.7**	**383.8**	**385.7**	**432.9**	**370.5**	**323.2**	**427.8**	**364.7**	**317.7**
Outflows									
End-of-system outflow to									
Macquarie - Carinda	109.2	104.9	106.7	145.7	90.7	71.5	143.4	88.8	69.8
Castlereagh at Barwon	76.5	73.1	73.1	103.9	71.6	52.0	95.3	64.4	45.6
Bogan - Gongolgon	202.1	195.6	195.8	282.8	185.9	153.6	271.8	175.7	143.6
Marthaguy	149.7	135.0	135.9	189.5	120.1	92.2	186.4	117.7	90.3
Marra	75.9	70.9	71.4	97.6	62.9	52.4	96.4	62.1	51.6
Sub-total	**613.3**	**579.4**	**582.9**	**819.4**	**531.3**	**421.7**	**793.4**	**508.7**	**400.9**
Net evaporation									
Windamere Dam	9.3	8.7	8.8	10.6	8.5	7.2	10.3	8.0	6.8
Ben Chifley Dam	1.5	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.4
Burrendong Dam	44.7	43.8	44.0	46.6	44.6	41.3	46.3	44.3	41.0
Warren Weir	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.3	0.3
Macquarie Marshes	242.6	233.2	239.3	294.1	218.5	175.7	290.4	214.8	172.4
Marra, Marthaguy, Castlereagh reaches	15.3	18.8	19.0	20.5	19.4	17.7	17.5	15.8	14.1
Sub-total	**313.6**	**311.7**	**318.3**	**380.1**	**297.5**	**247.3**	**372.7**	**289.4**	**239.5**
Sub-total	**926.9**	**891.2**	**901.2**	**1199.6**	**828.8**	**669.1**	**1166.1**	**798.1**	**640.4**
Unattributed fluxes									
River unattributed loss	1320.7	1290.2	1295.5	1660.6	1207.5	1000.3	1626.2	1175.3	968.6
Additional information (not in mass balance)									
Net evaporation private storages (on farm storage)	5.2	5.4	5.4	6.5	4.8	3.7	6.4	4.7	3.6

Contact Us

Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au

Enquiries

More information about the project can be found at www.csiro.au/mdbsy. This information includes the full terms of reference for the project, an overview of the project methods and the project reports that have been released to-date.