Potential impacts of groundwater Sustainable Diversion Limits and irrigation efficiency projects on river flow volume under the Murray-Darling Basin Plan

An Independent review

Q J Wang, Glen Walker and Avril Horne

Melbourne School of Engineering
Water, Agriculture and Environment Program

THE UNIVERSITY OF MELBOURNE

Grounded in Water

Potential impacts of groundwater Sustainable Diversion Limits and irrigation efficiency projects on river flow volume under the Murray-Darling Basin Plan

An Independent review

Q J Wang[1], Glen Walker[2] and Avril Horne[1]

[1]Melbourne School of Engineering, The University of Melbourne

[2]Grounded in Water

October 2018

Version 2018.10.13

Contents

List of Figures

List of Tables

Executive Summary

To rebalance consumptive water use with environmental needs, the Murray-Darling Basin Plan set new Sustainable Diversion Limits (SDLs) for both surface water and groundwater.

For groundwater, there was low use and no extraction limit for much of the Basin prior to the Plan. To meet potential future requirements, groundwater SDLs were set much higher overall than historical use in the Basin. There are areas of the Basin, where groundwater extractions were capped at current levels or even reduced, but the reduced volume in these areas is much smaller than the increased volume in other areas. In the shallow aquifers underlying some surface water irrigation, the SDLs were intentionally set higher than historical use to give flexibility for water logging and salinity control.

For surface water, the SDLs were set to reduce consumptive use and allocate more water for the environment. To meet the SDLs, there have been significant government investments in water recovery through direct buyback of water entitlements from irrigators and through off-farm and on-farm irrigation efficiency projects. The Australian Government is providing $3.1 billion to purchase water entitlements, of which $2.5 billion has been spent. It is also providing more than $8 billion for modernising infrastructure and water efficiency improvements, of which over $4 billion has been spent.

Concerns have been raised that the groundwater SDLs and irrigation efficiency projects may lead to significant reductions in river flow and therefore offset the benefits of surface water recovery for the environment. **This review will address these concerns by answering the following questions:**

(1) Is it likely that the Basin Plan groundwater SDLs will have a material impact on river flow volume?
(2) Is it likely that irrigation efficiency projects, carried out to achieve Basin Plan recovery targets, will have a material impact on return flow to rivers?

The review will also comment on these impacts in a broader context by considering the effects of water trading, water buyback, flow timing and water quality. Impact assessment is based on 2009 levels of development as the starting point.

Impact of groundwater SDLs on river flow volume

Under the Basin Plan, groundwater extraction has significant scope to increase and thus reduce groundwater discharge to, or induce leakage from, rivers. However, there is little evidence of increased groundwater extraction over the past ten years, and it is most unlikely that the total extraction in the Basin will reach the total Baseline Diversion Limit (BDL) for decades, let alone the total SDL. The reasons for this are high salinity, low transmissivity and lack of economic drivers. Nevertheless, as commodity price and technology change, opportunities for groundwater use may increase.

To represent plausible growth over the next 40 years, we have chosen three growth scenarios: no growth, 2%/yr growth and 4%/yr growth, with the 2%/yr growth as the most likely. These scenarios give credence to the expectation that any future growth will be from commitments prior to the Basin

Plan (i.e. BDLs) rather than the 'unassigned' water resulting from the high SDLs. We have also assessed the impact of extraction growth to the full SDLs.

Reduction in river flow from the three growth scenarios is estimated to be between 0 and 360 GL/yr, with 170 GL/yr as the most likely. The reduction caused by extracting 'unassigned' water is only 10 GL/yr within an uncertainty range from 0 to 70 GL/yr. The timeframe for the estimated reduction is 40 years of extraction growth plus additional lag time between extraction and equilibrated river response. The lag time can be 20 years or much longer depending on the catchment.

The estimated reduction differs from the previous estimate of 195 GL/yr by the Murray-Darling Basin Authority (MDBA) for two reasons. Firstly, MDBA had considered the impact of increased groundwater extraction to the full SDLs. Our estimate of this impact is 440 GL/yr, but reaching the full SDLs is extremely unlikely in the foreseeable decades. Secondly, the ground-surface water connectivity factor used in this review is higher than by MDBA. When weighted by growth in extraction, the average connectivity factor used in this review is between 0.2 and 0.3, whereas the value used by MDBA was 0.1. The main discrepancy is that MDBA assigned zero connectivity factor to moderately-connected groundwater units, where groundwater extraction would lead to beneficial environmental and productive impacts, such as reduction of salinity and waterlogging.

The overall values of the connectivity factor used in this review and by MDBA may appear to be low. This is because the values are averages weighted by growth in extraction. The groundwater SDLs have been set as such that no or low growth is allowed for well-connected groundwater units, and high growth for poorly-connected units. Consequently, the averages are weighted towards the lower values. In this review, the values of the connectivity factor for individual groundwater units were determined from reviewing past studies and considering likely locations of groundwater extraction growth.

The slow change and high uncertainty of the estimated impact from this review would suggest that an adaptive management strategy may be appropriate. MDBA had previously considered that the impact from pre-existing entitlements should have already been incorporated into surface water SDLs. However, river models that were used to underpin the surface water SDLs only accounted for impact from some of the current use.

Impact of irrigation efficiency projects on river flow volume

Some water that has been diverted from rivers for irrigation will later return to the rivers either as surface drainage or discharge from groundwater. For a given amount of water diversion from a river to an irrigation scheme, more efficient irrigation generally leads to less return flow to the river. The extent of reduction in return flow caused by irrigation efficiency projects will depend on many factors. To account for these factors, a framework was developed in this review for estimating impacts of off-farm and on-farm irrigation efficiency projects on surface and ground return flows.

The framework was used to assess the irrigation efficiency projects funded by the Commonwealth Government in the implementation of the Murray-Darling Basin Plan. A number of projects funded by the State of Victoria were also included in the assessment. Data needed for the assessment of individual projects was partly supplied by MDBA and the Australian Government Department of Agriculture and Water Resources. Data was also sourced from various project reports. However, to complete the assessment, many assumptions had to be made based on published and grey literature and on our own technical understanding.

The irrigation efficiency projects recover a total of 1179 GL/yr across the Basin, of which 757 GL/yr or 64% is transferred to environmental entitlements. **These irrigation efficiency projects are found to reduce return flow by 121 GL/yr. The reduction represents 10% of the total recovery, or 16% of the recovery transferred to environmental entitlements. An uncertainty range of 90 GL/yr to 150 GL/yr is suggested.**

The largest reduction is in ground return flow, making up 80% of the total reduction in return flow. The timeframe for the reduction in ground return flow is 20 years or much longer depending on the catchment. This timeframe is the lag time between seepage reduction and equilibrated river response.

The lower reduction in surface return flow is consistent with our understanding that irrigation infrastructure and practices in the southern Murray-Darling Basin (MDB) had by 2009 reached a stage when little irrigation water would be released back to rivers via surface drains. This contrasts with the 1980s and early 1990s when irrigation drainage flow to rivers was large. In the 1990s, there were major initiatives in many irrigation districts to reduce salinity and nutrient inputs to rivers. During the Millennium Drought, irrigation drainage flow was further reduced as water allocation became low to extremely low and water trading shifted water to more efficient use.

Water saving from more accurate metering and from irrigation land retirement or system decommissioning represents a significant portion of the total water saving. This portion has relatively low impacts on return flow. On the other hand, water saving projects that heavily rely on reducing seepage have relatively high impacts on return flow. On-farm projects cause larger reduction in return flow relative to environmental recovery (30%) than off-farm projects (10%). This is because a larger portion of water saving comes from reduction in seepage with on-farm projects.

It is noted that reduction in seepage does not translate into reduction in river flow by the same amount. This is because the groundwater system is rarely fully connected to rivers. In our assessment, a simple factor model of ground-surface water connectivity was applied.

Broader context

The impacts of groundwater SDLs and irrigation efficiency projects on river flow should be considered in the context of broader water resource policy and assessment of environmental water needs. Of particular relevance:

- Under the water allocation systems in MDB, irrigation surface return flows are credited for some, but not all, drains and escapes. Irrigation ground return flow is not credited at all. The uncredited surface return flows and the ground return flow are not legally protected as inflows to rivers for the environment or for downstream users. When irrigation in the Basin becomes more efficient, as it has been the case in the last 20 years, return flows diminish. This trend will continue into the future with or without public investments. In contrast, environmental water entitlements transferred from water saving from irrigation efficiency projects are legally protected for environmental use.

- The effect of reduction in river flow due to increased groundwater extraction and irrigation efficiency projects will mostly be on base-flow. The allocation policy for the Murray River would address this through estimation of loss, which is shared among all users prior to any allocations against entitlements. Therefore, reduction in base-flow would not offset environmental water by the same amount.
- Environmental flows are not just about annual volumes of water, but about the "quantity, timing, and quality of freshwater flows". Environmental entitlements allow active management of this water to achieve an environmentally suitable flow regime.
- On water quality, there has been a history of management of irrigation surface return flow in the southern MDB, along with groundwater management, aimed at controlling salinity, nutrients and pesticides entering the river. It is important that water quantity issues are balanced with these water quality issues.
- The timing of impacts on river flow will be a slow process, especially for any growth in groundwater extraction. The Basin Plan has a regular built in review process that will assess basin wide risks. The conceptual frameworks and methods set out in this review can form a basis to keep track of and respond to the impacts of increased groundwater extraction and irrigation changes on river flow.

Recommendations

(1) This review has highlighted that the impacts on river flow from potential increase in groundwater extraction and from the implementation of irrigation efficiency projects are greater than considered at the time when the Basin Plan was developed. As the impacts will manifest mostly in reduced river base-flow, this will cause more water to be released to meet conveyance requirements and critical human water needs. This extra release will be shared by all water entitlement holders. The impacts may become significant during prolonged dry periods. There is sufficient justification for undertaking a project to identify whether the impacts may change the security of water supply for the different users, and what management plan needs to be in place to address the issue.

We recommend that MDBA investigate the implications of the findings from this review on the security of water supply for different users and develop an appropriate management response.

(2) While this review has focused on groundwater SDLs and irrigation efficiency projects, there are other factors that may also impact river flow, including water buyback for the environment, water trading, land use and irrigation changes beyond the government funded irrigation efficiency projects, and climate change. These will affect not just irrigation return flow, but also inflow to rivers from rainfall events through both surface and ground pathways. The impacts from these factors could be significant.

We recommend that MDBA assess impacts on river flow from other factors such as water buyback, water trading, land use and irrigation changes, and climate change. In future reviews of the Basin Plan, the impacts from these factors as well as from groundwater SDLs and irrigation efficiency projects should be explicitly accounted for, including in river modelling that supports the reviews.

(3) There is a need for more intensive and on-going data collection, regular evaluation and review of the impacts on river flow from groundwater SDLs, irrigation efficiency projects and other factors. A systematic program could be initiated by building on the frameworks and methods developed

in this review. On the impact of groundwater SDLs, the program will include monitoring of extraction, identification of areas of increased extraction, and impact assessment for the identified areas. On the impact of irrigation efficiency projects, the program will include the collection of a common set of information from all future irrigation efficiency projects, at both the proposal and completion stages.

We recommend that MDBA implement a program for data collection, regular assessment and review of impacts on river flow from groundwater SDLs, irrigation efficiency projects and other factors, building on the frameworks and methods developed in this review.

(4) The assessment of impacts on river flow from both increased groundwater extraction and irrigation efficiency projects are highly sensitive to the ground-surface water connectivity factor. There is some evidence to suggest that the groundwater conditions in the Southern Riverine Plain (Goulburn-Murray Sedimentary Plain in Victoria and Lower Murray in New South Wales) are changing in response to evolving irrigation landscape and footprint. The ground-surface water connectivity factor may change as a result. A clear understanding of the situation will improve the impact assessment.

We recommend that MDBA coordinate an effort to update groundwater-river models and analyses for the Southern Riverine Plain region of NSW and Victoria, using the latest available hydrological and salinity data.

(5) Among all the groundwater SDL resource units, the greatest impact on river flow from potential increase in groundwater extraction is related to the shallow Shepparton Formation in the Goulburn-Murray Sedimentary Plain (Victoria), the Lower Murray and Lower Murrumbidgee Alluvia (NSW). Both the BDLs and SDLs have been deliberately set high to give flexibility to protect irrigation land from waterlogging and salinity and to reduce salt input to rivers. However, there is the question now if such levels of pumping are needed for such purposes, as irrigation has in recent times significantly reduced its footprint and become much more efficient. If high levels of pumping are taken up for resource use, it may induce leakage from rivers, contravening the original intent of protecting the river. It may also reduce seepage to the lower aquifer.

We recommend that the extraction limits for the shallow Shepparton Formation in the Goulburn-Murray Sedimentary Plain (Victoria), the Lower Murray and Lower Murrumbidgee Alluvia (NSW) are reviewed at the next opportunity to achieve a balanced outcome.

1 Introduction

The Water Act 2007 introduced a number of significant policy reforms aimed at rebalancing water extracted from the Murray-Darling Basin (MDB) with the needs of the environment. The Basin Plan (Australian Government, 2012) set new Sustainable Diversion Limits (SDLs), including for both surface water and groundwater. To shift from historical levels of surface water consumption down to the new SDLs, the Government has been recovering water rights from consumptive users by purchasing water from willing sellers and investing in irrigation infrastructure and efficiency improvements (Productivity Commission, 2018). A total recovery of 2,750 GL of surface water is required. The Australian Government is providing $3.1 billion to purchase water entitlements, of which $2.5 billion has been spent. It is also providing more than $8 billion for modernising infrastructure and water efficiency improvements, of which over $4 billion has been spent.

There have recently been concerns raised as to whether the implementation of these policies has indeed led to the substantive recovery of environmental water as intended (Grafton et al., 2018a, Grafton et al., 2018b, Grafton and Williams, 2018). The concerns are two-fold. Firstly, setting a number of groundwater SDLs that are above the current levels of extractions may impact on river flow and therefore achievement of environmental flow objectives. Secondly, irrigation efficiency projects may not lead to 'real' saving because reduction in return flow has not been fully accounted.

This review was initiated by the Advisory Committee on Social, Economic and Environmental Sciences (ACSEES) of the Murray-Darling Basin Authority (MDBA) to address these concerns. The review will answer the following questions:

(1) Is it likely that the Basin Plan groundwater SDLs will have a material impact on river flow volume?
(2) Is it likely that irrigation efficiency projects, carried out to achieve Basin Plan recovery targets, will have a material impact on return flow to rivers?

The review will also comment on these impacts in a broader context by considering the effects of water trading, water buyback, flow timing and water quality. Impact assessment is based on 2009 levels of development as the starting point.

The following questions are outside the scope of the review:

- What is the potential reduction in return flow by measures pre-Basin Plan?
- What are the appropriate 'utilisation' factors to apply to the water recovery for accounting purposes?
- What is the total volume of water recovery required to achieve Basin Plan objectives, and whether changes in return flow impact on this volume?

2 Potential impact of groundwater SDLs on river flow volume

2.1 Background

The Basin Plan establishes a cap on groundwater extractions across the whole of the Basin for the first time. Extraction limits (SDLs) are set for all management units, called SDL resource units across the Basin (Figure 1). While there were previously areas of high-density groundwater use, much of the Basin had low groundwater use and no prior extraction limits. The low water use is due to poor water quality, the aquifer being of low transmissivity or there having been no economic drivers. As demonstrated by coal seam gas fracking in the northern MDB, extraction rates can increase quickly in areas of low extraction, should either economic drivers or technology change. If so, it would now be subject to extraction limits.

While SDLs have been defined for the units, the main management is through water management plans and the associated arrangements developed by Basin states for the units. These plans may have management zones, with extraction limits and trade rules and/or local management rules. An example of local management zones is the Lower Macquarie SDL unit (GS26) shown in Figure 2. In this case, an extraction limit has been defined for each of the zones. For the review, we need to focus on the Basin scale and work with SDL units. The number of SDL units means that any finer detail would be difficult to work with.

Any increase in groundwater use can reduce surface water flow and hence affect surface water management. The focus of this section is the cumulative impact of increases in mean annual groundwater extraction across the Basin on mean annual river flow. The link between the hazard (extraction) and impact (river flow) is referred to as the connectivity. More specifically, it represents the sensitivity of river flow to groundwater extraction at relevant scales. In the context of this review, the time scale is about 40 years and the spatial scale is the SDL unit. The connectivity will vary across management zones (e.g. Giambastiana and Kelly, 2010) and within management zones.

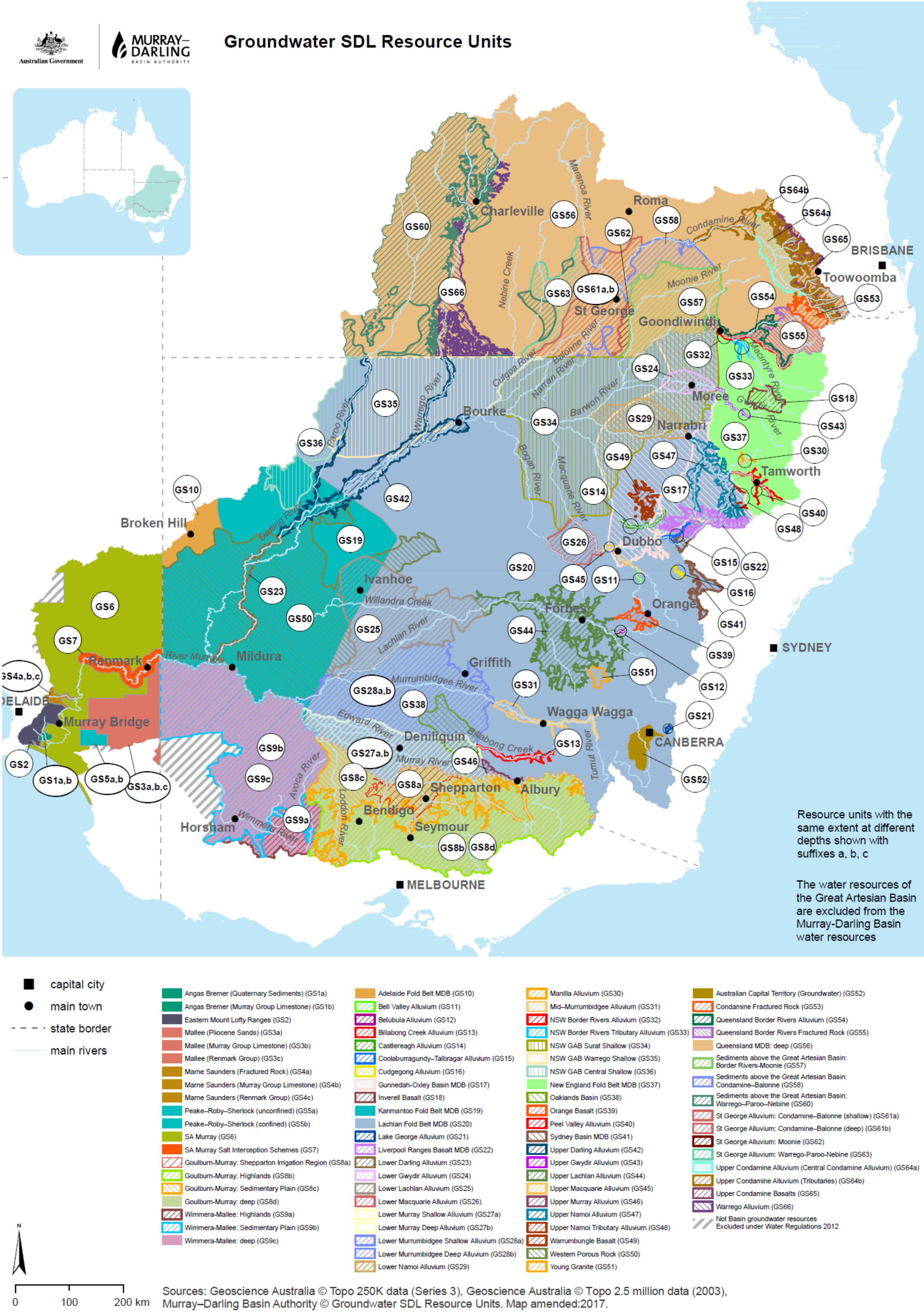

Figure 1. Map of groundwater SDL units across the MDB (MDBA, personal communication)

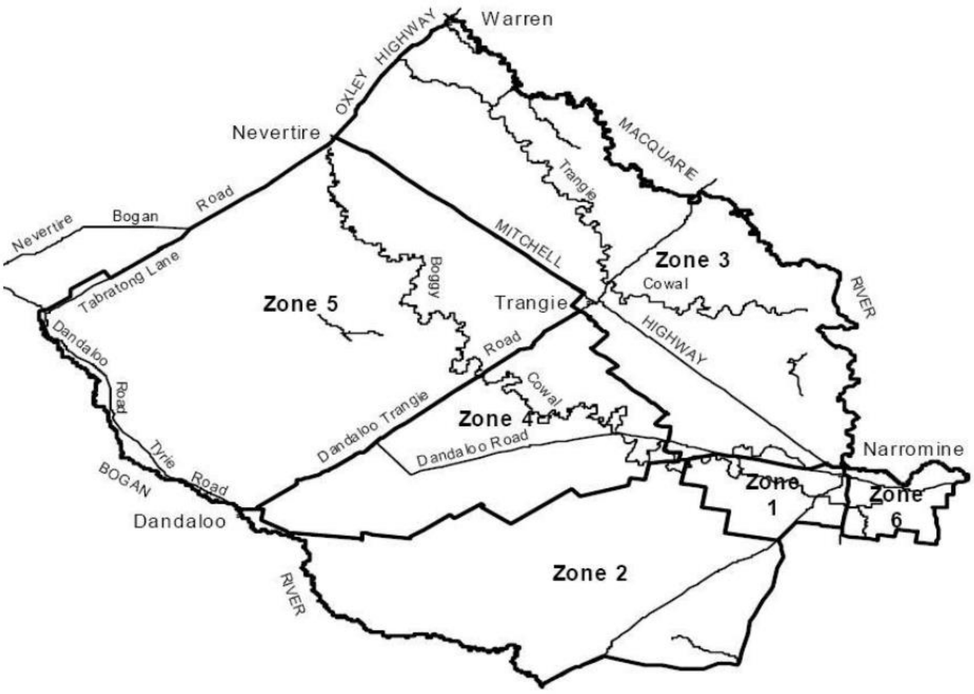

Figure 2. Map of management zones within the Lower Macquarie Alluvium unit (DEWNR, 2003)

The total groundwater SDL established for the Basin (3494 GL/yr) is 1114 GL/yr greater than the agreed interpretation of prior commitments of 2380 GL/yr (known as the Baseline Diversion Limit, or BDL). Importantly, current use is not the same as the BDLs in all units. The BDL total is greater than the mean groundwater extraction of 1335 GL/yr for the period of 2003-2017. Those units where the SDLs exceeds the BDLs are called unassigned units and the volume of water between the BDL and SDL is the unassigned water. The unassigned water units are shown in Figure 3. Unassigned water units have been divided into four categories: Highland, Lachlan Fold Belt, Western and Deep units. These units can be seen to cover most of the MDB, especially when Great Artesian Basin (GAB) related outcrops are excluded. The groundwater extraction data and limits are listed for individual units in Appendix A.

The large volume of unassigned water is due to low groundwater use in most of these areas and the low risk associated with increase in groundwater extraction in these areas. Risk has been determined by considering four characteristics: (i) aquifer integrity (water levels equilibrating in 50 years) (ii) base-flow (iii) groundwater salinity and (iv) groundwater-dependent ecosystems. The risk to river base-flow is relevant to this review and the assessment of this risk represents the first of three stages in which the connectivity is used in the determination of the SDLs. These are shown in Box 1. The outcome of these three steps is that the SDL determination should not lead to significant impact on river flow from increased extraction in highly connected groundwater units. The final of the three stages is the estimate of the cumulative impact of groundwater extraction on river flow. Reviewing these estimates forms a significant component of this review.

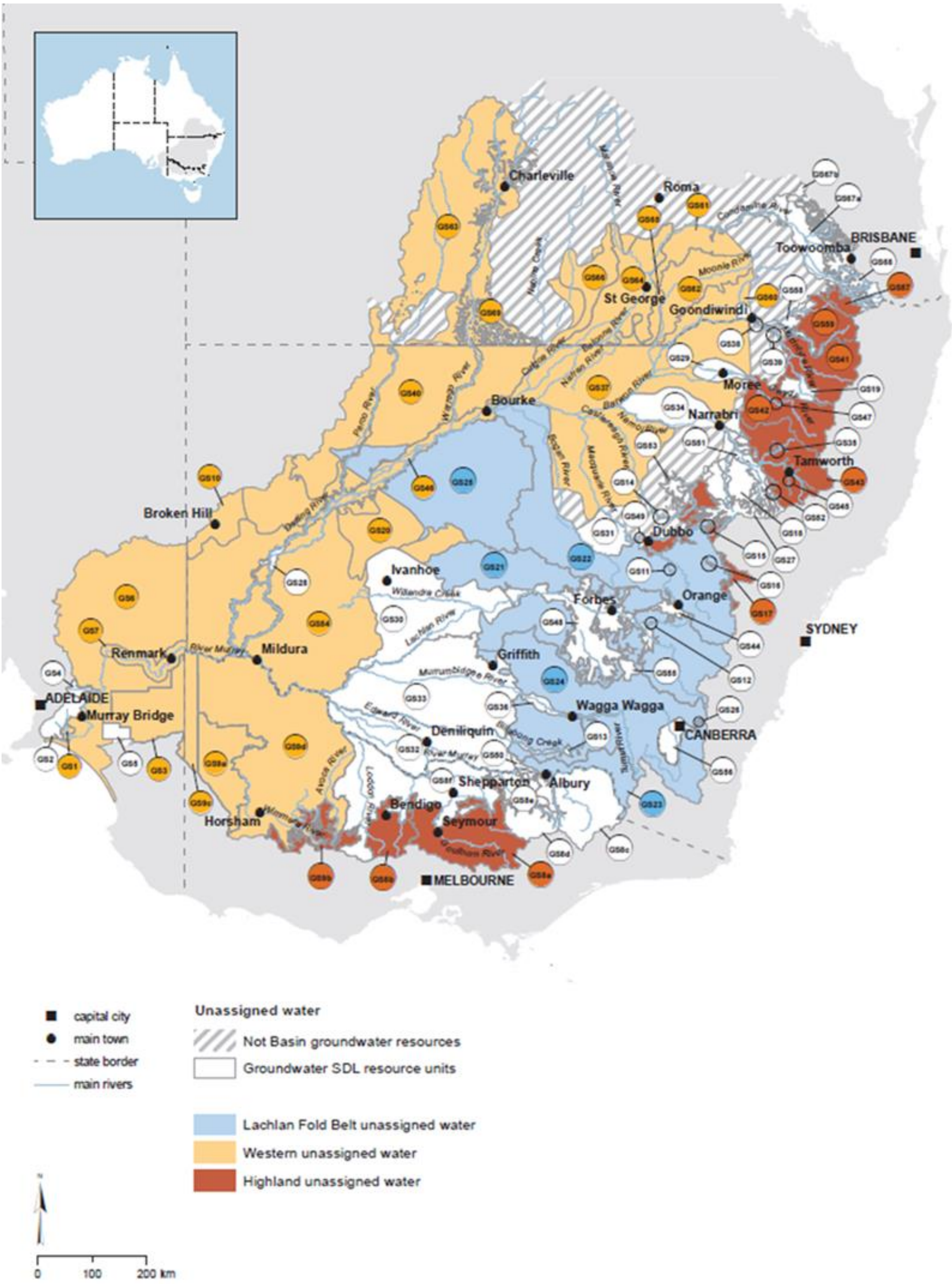

Figure 3. Map of unassigned water units, categorised into three groups: Lachlan Fold Belt, Western and Highland units. This map does not include a fourth group: Deep groundwater units (from MDBA 2012a)

Box 1 – Summary of process to set groundwater SDLs

(1) **First cut** - a Preliminary Elimination Limit (PEL) was set for each of the SDL resource units using a simple risk methodology, and additional groundwater modelling was conducted for more highly used aquifers (MDBA, 2012a). The PEL was assessed against the four characteristics (described earlier in the text), including impact on river base-flow. If the risk to base-flow was identified to be high, the PEL was set to between 2.5 to 5% of diffuse groundwater recharge. This should mean that the impact is less than 2% of river flow.

(2) **Considering connectivity** - the SDL units were assessed (MDBA, 2012a, 2012b) for high connectivity using the broad categorization from PB (2009). If identified as high connectivity, the SDL was set to BDL. For water units with low water use, the SDL was set lower than PEL.

(3) **Cumulative impact** - the cumulative impact of groundwater extraction across SDL units was estimated. This was then used as a basis for revising down the BDL for low use units (MDBA, 2012b).

Figure 4 shows a Western unassigned unit. Much of the area is underlain by saline groundwater, unsuitable for most beneficial uses. The estimated average groundwater use from 2012 to 2017 has been 9.2 GL/yr. The BDL has been set at 68.9 GL/yr, and the SDL at 190.1 GL/yr which is more than 20 times the current use. It is difficult to imagine that without changes in drivers that this SDL will be reached for many decades. Over the next four decades, the groundwater use will most likely be less than the BDL. However, if opportunities to use saline water develop or the commodity prices allow desalination, groundwater extraction can increase quickly and it may be feasible to reach the SDL. In general, it is difficult to predict if, when and where such an increase in extraction will occur, outside of an extrapolation of the current extraction pattern.

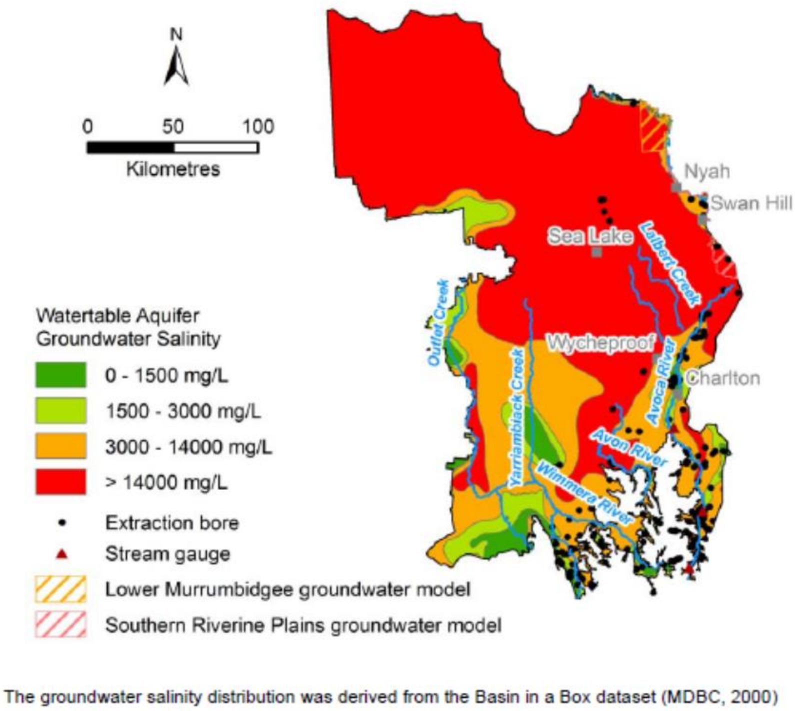

Figure 4. Map of the Wimmera-Mallee sedimentary Plain showing groundwater salinity, streams and sites of groundwater extraction

The likelihood of not reaching the SDL Basin-wide within the next few decades is emphasised by historical use (Figure 5). There needs to be caution in the numbers reported before 2010 as methodology has changed over time. Also, not all uses are metered, and estimates need to be made of the non-metered use. Despite this, it can be seen that there have been no dramatic increases in use over this time. Groundwater use tends to be higher in drier years. Any risk assessment of the impacts of groundwater extraction needs to build in the degree to which groundwater extraction will increase over the next few decades. It is highly likely that most of the growth will occur within commitments that existed prior to the Basin Plan, i.e. within the BDL. MDBA (2012b) has previously argued that the impact of groundwater extraction from prior commitments should have already been built into the surface water diversion limits. We will therefore separate the growth up to the BDL from the growth from the BDL in any unit. Given the difference between current use and the BDL, we might expect that most of the growth over the next few decades will be from the BDL. This would need to be tested.

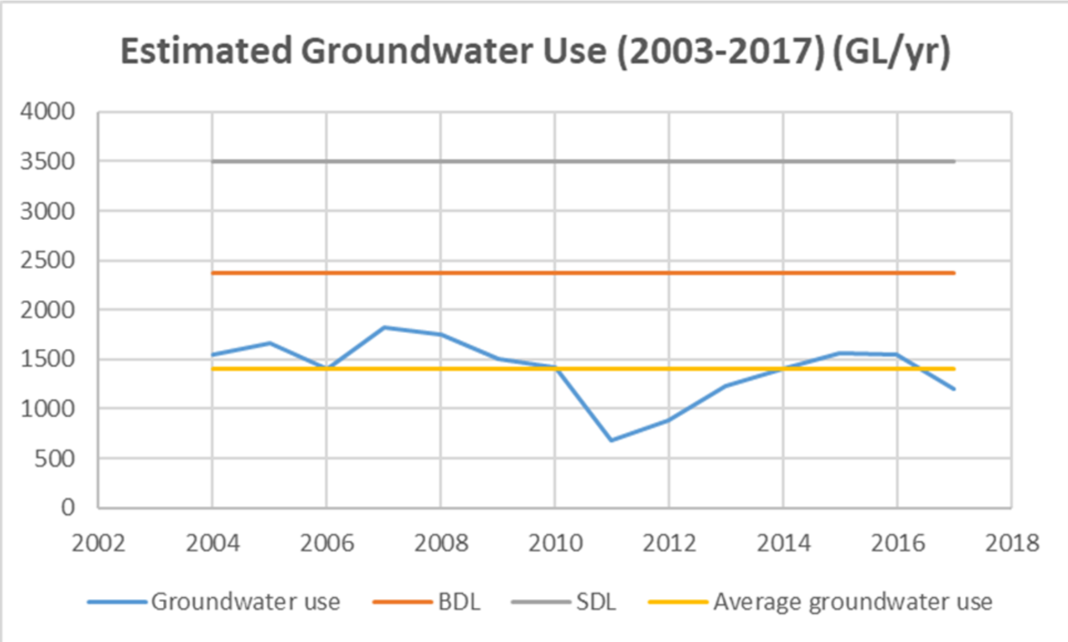

Figure 5. Plot of groundwater extraction from 2003 to 2017 relative to the Basin-wide BDL and SDL (MDBA, personal communication)

2.2 Method to assess impacts on river flow from increased groundwater extraction

The nature of this review means that there can be no significant new modelling or data collection. The approach used is therefore to examine the existing methodologies, literature and datasets. There has been significant previous effort in modelling and collecting information around groundwater and surface water interactions. Appendix A lists the key sources of information used. A risk approach is then applied to assess river flow impacts from increased groundwater use. Given the uncertainty of future groundwater extraction, future scenarios of growth are used.

2.2.1 Application of connectivity factors

A number of previous studies calculate the impact on river flow from changes in groundwater extraction in a single SDL resource unit, by applying a connectivity factor (CF) (REM, 2004; REM, 2006; CSIRO, 2008; MDBA, 2012a-d):

Impact on river flow = change in extraction x SDL unit CF

This calculation is easy to aggregate to estimate cumulative impacts. The calculation can apply directly to extraction data in the Register of Take and be updated on a regular basis.

CF indicates the sensitivity of river flow to groundwater extraction. A groundwater balance means that CF lies between 0 and 1, 0 being 'disconnected' and 1 being fully connected. If the only other affected component of the groundwater balance besides extraction is the change to the groundwater-surface water exchange, this would mean that CF would be 1. However, often loss of water by evaporation through the land surface is affected as well as transpiration by phreatophytic vegetation, causing CF to be less than 1. Given that the time scale of groundwater processes can be very long, CF reflects the impact within a given time; for this review, two to four decades. Given the wide range of hydrogeological environments in the MDB, CF varies widely. Box 2 discusses the challenges in identifying CF value at the SDL unit scale.

Previous studies were reviewed, and CF values identified from these studies (see Appendix B for a discussion). A list of CFs adopted in this review is also provided in Appendix B. There is a high degree of uncertainty in CFs. Much of the uncertainty comes from the spatial and temporal distribution of future extraction, along with uncertainty of hydrogeological parameters. However, given uncertainties, more complex methods for calculating CFs is not warranted. Where there is existing groundwater modelling, modelling outputs can be used to infer CFs (see Appendix B). We provide a lower and higher estimate of CF to test the sensitivity of the impact analysis to the choice of CF.

Box 2: The challenges in determining an appropriate connectivity factor (CF) for an SDL unit

The key consideration for connectivity is the distance to a connected stream. Any separation, greater than a few kilometers, will lead to a time scale greater than a few decades. The conductance between the point of extraction and the stream is also an input, particularly sensitive to any zones of low conductance, such as aquitards or poor connectivity of the groundwater system with the river. Topography will affect discharge to the land surface, e.g. wide floodplains. Finally, CF will change with the level of development, and particularly, groundwater development will tend to reduce connectivity by causing water tables near streams to fall.

As the connectivity is sensitive to the distance to the stream and the conductance between stream and point of extraction, the connectivity would generally relate to distinct zones within the SDL unit. This means that some assumptions need to be made about where extraction occurs. Some common assumptions are:

(1) Same as previous extraction
(2) Favourable areas for extraction
(3) Sites of mineral or gas resources
(4) Sites of drought reserves

The connectivity may change over time, and often reducing in time, as a result of development.

To demonstrate the challenges, we use the example of the Wimmera-Mallee Sedimentary Plain (Figure 4). This SDL unit was given a connectivity of zero, initially because of the disconnect to the River Murray, but later because of the high salinity of the groundwater and the distance to rivers. However, one can see that there are no extraction bores where groundwater is saline and stock and domestic water is supplied through channels and pipes. Bores are located in fresh and brackish groundwater and often not far from streams. Thus, while most of the unit does indeed reflect zero connectivity conditions, the most likely location of any further bores will be in areas that have non-zero connectivity. Most of the growth in extraction over the next few decades will be within the BDL. The extraction of unassigned water is unlikely within that timeframe. The application of the SDL unit-wide CF should obviously not be applied to an individual development, e.g. next to the River Murray in the north. For our purposes, CF should reflect likely zones of extraction over the next decades and while low, would not be zero. Most of the current extraction is in fresh to brackish zones and near streams. The extraction in the future may well be an extrapolation of this current pattern. The extraction at the full SDL value is unlikely to be sustainable, if it occurs only in areas of fresh groundwater, and may not be permitted under local management rules.

2.2.2 Risk assessment and future scenarios

The level of impact that groundwater extraction will have on river flow will depend on the speed at which development occurs from current levels of use, up to the BDL and then to the SDL. We cannot precisely predict the future, especially when human behavior is involved. A standard approach in risk-assessment is to consider future scenarios, where assumptions are clear and impact analysis is transparent. The impact analysis of these future scenarios can then guide decision-making. We consider three simple future extraction scenarios to 40 years, as well as the impact of full implementation of SDL extraction (Box 3). These scenarios may not represent reality, but plausible scenarios from which we can learn. More complex scenarios could be constructed by considering groundwater quality, mineral or gas reserves, urban areas and local management rules and zones. Local management rules will tend to spread the extraction pattern away from 'hotspots' and potentially limit extraction near streams or important ecosystems. This means that for extraction to occur beyond a certain level, there needs to be a beneficial use of poorer quality water and more remote groundwater. The scenarios separate the extraction that occurs within commitments prior to the Basin Plan (BDL) and the unassigned water (volume of water above the BDL). The calculations show that under these scenarios, only low volumes of unassigned water are used in the next 40 years.

Box 3: Risk assessment Scenarios

Three scenarios are adopted in the risk assessment
(1) No growth
(2) 2%/yr growth rate for 40 years, up to the SDL
(3) 4%/yr growth rate for 40 years, up to the SDL
Additionally, impacts of extraction increase to full SDL, with no defined growth trajectory, are also assessed.

Increases of the magnitude of the scenarios were evident in the 1990s and early 2000s. The scenarios are not necessarily meant to reflect reality, but to provide an objective basis for assessing time scales that might be associated with reaching the SDLs. This is especially significant where the SDLs have been set multiple times the current use. The 2%/yr scenario at 40 years should lead to a similar extraction as that from 4%/yr at 20 years. This provides additional guidance on timing. The 4%/yr scenario has only just reached the Basin-wide BDL at 40 years. The calculations (Table 1) show that unless external factors change, most of the increase in groundwater extraction will be from commitments prior to the Basin Plan and only a minor component from unassigned water. It is unclear if the SDL will ever be reached and if so, when.

Table 1. 2057 Extraction under three growth scenarios and to full SDL (GL/yr)

	No growth scenario	2%/yr growth rate scenario	4%/yr growth rate scenario	Full SDL
Growth within BDL		600	699	1044
Growth above BDL		45	164	1114
Total extraction	1335	1980	2198	3494

2.3 Results

The estimates of impacts on river flow for the different growth scenarios and the full SDL are shown in Table 2. These have not included any further time delays for the impacts to occur in the river, once extraction occurs. This means that the estimated impacts may occur after more than 40 years. The original MDBA estimate of 194 GL/yr is for the full SDL. However, if the MDBA suite of connectivity factors is used for the 40 year scenarios, the estimate is reduced for the 2%/yr and 4%/yr scenarios to 107 GL/yr and 142 GL/yr respectively with only 2 GL/yr and 28 GL/yr from unassigned water. The estimates using a revised connectivity factor ('new' with 'low' and 'high' uncertainty band) are also shown in

Table *2*. When compared to the impact estimates using revised connectivity factors, the MDBA estimates appear to be towards the lower end of the revised estimates. The new estimates are about 70% higher than the MDBA estimate at 40 years, but there is a wide band due to the uncertainty in CFs.

Table 2. Reduction in river flow (GL/yr) under growth scenarios and full SDL using 4 suites of connectivity factors.

	2%/yr growth rate				**4%/yr growth rate**				**Full SDL**			
	MDBA	New	Low	High	MDBA	New	Low	High	MDBA	New	Low	High
Within BDL	104	164	90	237	114	197	106	285	123	302	148	437
Above BDL	2	9	5	15	28	51	23	71	71	137	46	230
Total	**107**	**172**	**95**	**252**	**142**	**248**	**129**	**356**	**194**	**439**	**194**	**666**

Unless external factors change, we would expect the 4%/yr to be an upper limit on the growth of extraction. The estimated impact of 356 GL/yr on river flow at 40 years, using the high connectivity estimate should be considered an upper limit on impacts. The 2% growth rate almost all occurs within commitments prior to the Basin Plan and there may be greater confidence that this may occur. The impact of this should be less than 252 GL/yr and more likely about 172 GL/yr, with the impact of using unassigned water being less than 15 GL/yr. The main groundwater units contributing to the increase are the Lachlan Fold Belt (32 GL/yr), Upper Lachlan Alluvium (26 GL/yr), Shepparton Irrigation Area (20) GL/yr, Goulburn-Murray Sedimentary Plain (Deep) (20 GL/yr) and Mid-Murrumbidgee Alluvium (12 GL/yr).

The main discrepancies between the MDBA estimates and revised estimates are for the Goulburn Sedimentary Plain and for the Lachlan Fold Belt. MDBA had made a policy decision to provide the greatest flexibility for groundwater pumping in the shallow aquifers of the Southern Riverine Plain (Shepparton Irrigation Area, Lower Murray and Murrumbidgee) to avoid land salinization and waterlogging and salt inputs to rivers. The BDLs and SDLs were consequently set high and the connectivity factors were set at zero. The connectivity factor had previously been set at 0.6 for the Goulburn-Murray/Shepparton area. Analysis of groundwater modelling outputs developed for the Draft Basin Plan shows that the connectivity should be in the range of 0.3 to 0.6. Also, the connectivity factor for the deep aquifers had been set at zero, whereas a low value of 0.1 is more consistent with modelling outputs.

The Lachlan Fold Belt covers a large area from the more dissected landscapes in the east to more subdued landscapes in the west. Groundwater is used for stock and domestic use and for small horticultural developments. The connectivity is likely to be higher in the east and lower in the west. CF has alternated in previous studies between 0.3 and 0.6, reflecting the different expectations as to where groundwater extraction will occur.

There has also been a policy decision to set CFs for some western groundwater units on the basis that discharge to the river system is saline. The relevant governments have developed expensive pumping schemes in the western MDB to reduce saline water from entering the river. Apart from these pumping schemes, there does not appear to be much evidence of saline groundwater being extracted. Some mooted mining developments may change this. It is likely that better quality groundwater will be extracted, where it is available and allowed by local management rules.

A CF average, weighted by growth in extraction, of between 0.1 and 0.3 is used in this review. The low values are due to the limitations on SDLs for highly connected groundwater systems and the lower connectivity of the western unassigned units. If the values were two to three times higher, the impacts would also be two to three times larger.

The high uncertainty around impacts and their slow development means that adaptive management of impacts should be feasible. As better data on groundwater extraction becomes available, the assessment of impacts can be reviewed and actions designed to mitigate any negative effects.

MDBA has incorporated impacts of current groundwater extraction in their river modelling for three river valleys. The impacts of future groundwater extraction have not previously been incorporated into river models to assess impacts on management objectives. The impacts of future extraction from within the BDL have not been further considered by MDBA, as it is believed that these should have already been incorporated in surface water management plans prior to the Basin Plan (MDBA, 2012b). The estimated impacts of the extraction of unassigned water have been further considered in the setting of the SDLs. The cumulative impact of the Draft Plan groundwater SDLs on streamflow had been estimated but were in the range of 75-150 GL/yr. As this level of impact was considered to be unacceptable (MDBA, 2012b), the groundwater SDLs were reduced to bring them into the acceptable range.

The reduced groundwater inputs to rivers will mostly affect low flows. Some of the reduced inflows will be from saline or brackish groundwater. Hence, the main impacts are likely to be the volume and quality of low flows, especially during extended dry periods. This may affect the operation of the river and the efficiency with which water is delivered at those times. Unfortunately, the river models are less accurate for low flows, and can overestimate the low flows during dry periods. The impacts of groundwater extraction may add to other factors, such as reduced run-off and higher losses.

2.4 Discussion

The potentially large increase in groundwater extraction could lead to reduction in river flow. However, the long-time scales over which this growth in extraction may occur and the long-time responses for the impact to be manifested in the river means that impacts are likely to be gradual. The large volume of unassigned water reflects the low current use in many areas of the MDB. This low use is due to high salinity, low transmissivity and lack of economic drivers. While this is not expected to change quickly, changes in technology and commodity prices mean that this situation could change into the future. Without such changes, we would expect that most of the growth in extraction over the coming decades to occur from commitments that existed prior to the Basin Plan, rather than from the unassigned water.

The magnitude of the impacts is larger than the previous estimates by MDBA, but less than those by other commentators. There are two main sources of difference. The first is that some other studies have focussed on reaching the full SDL, rather than what is likely within the next few decades. Secondly, CFs have been assumed that are either higher or lower than those in this review. The most common reason for selection of a high connectivity factor is the assumption that more extraction will occur from highly connected units. The most common reason for the selection of a lower value is that a zero connectivity is assigned, where there are trade-offs, in which the environmental benefits from increased extraction outweigh the costs associated with reduced river flow. There is some uncertainty with the value of CF, the main one being the lack of knowledge of the location and timing of future extraction.

The estimate of the impact of groundwater extraction over the next 40 years is between 0 and 360 GL/yr, with 170 GL/yr as the most likely. The large range is due to uncertainties in the growth of extraction and the connectivity factors that would apply. The slow evolution of impacts and the high uncertainty suggest that adaptive management of impacts may be appropriate. The main impacts will be for low flow conditions during extended dry periods, with both volume and quality being affected.

One of the areas causing a large part of the estimated impact is the Goulburn-Murray Sedimentary Plain. A high BDL has been set to encourage pumping from shallow aquifers to avoid land salinization and water logging and to reduce saline inflows to river. The hydrological settings for this area and the NSW Lower Murray appear to be changing due to reduced irrigation recharge. This may lead to a lower requirement for pumping to avoid waterlogging and salinity.

3 Potential impact of irrigation efficiency projects on return flow to rivers

3.1 Background

The Commonwealth Government has been investing in a range of irrigation efficiency projects under the Sustainable Rural Water Use and Infrastructure Program, to recover water to 'bridge the gap' to the Sustainable Diversion Limits (SDLs). The projects aim to improve the operation of off-farm delivery systems and help irrigators improve on-farm water use efficiency (see Box 4). The water saving generated from these projects is shared between the Australian governments for environmental use, and irrigators for consumptive use.

Major off-farm irrigation efficiency initiatives include the Goulburn Murray Water (GMW) Connections project in Victoria, the Private Irrigation Infrastructure Operators Program (PIIOP) in New South Wales (NSW), and the Nimmie-Caira Project in NSW. Major on-farm irrigation efficiency programs include the Victoria Farm Modernisation program, the On-Farm Irrigation Efficiency Program (OFIEP) in southern MDB, and the South Australian River Murray Sustainability Program (SARMS). A full list of projects under various programs and funding rounds were provided by MDBA. These are consolidated by major programs and catchments. A number of projects funded by the State of Victoria, including the Northern Victoria Irrigation Renewal Project (NVIRP or GMW Connections Stage 1), are also included in the assessment.

Box 4: Examples of on-farm and off-farm project activities

Examples of off-farm projects are:

- GMW Connections – channel rationalisation, automation and remediation, service point replacement and rationalisation
- Decommissioning – Campaspe, Nimmie-Caira
- Infrastructure upgrade & part land retirement (Macquarie 32% & 68% water saving; PIIOP Round 2 Murray Irrigation Limited 23% & 77% water saving)
- Metering (NSW Metering)
- Piping (e.g. NSW Basin Pipes, VIC Robinvale Pipeline, WMPP/LMP)

Examples of activities of on-farm projects are:

- Drainage reuse
- Laser grading
- Improving gravity channel surface irrigation
- Installing or improving pipe and riser
- Installing or improving sprinkler
- Installing or improving micro or drip irrigation
- Automation, irrigation scheduling, soil moisture monitoring
- Piping, plastic lined or upgraded channel
- Improving pipes

Concerns have been raised that these irrigation efficiency projects may not lead to 'real' saving because reduction in return flow has not been accounted for (Grafton et al., 2018a; Grafton et al., 2018b; Grafton and Williams, 2018). Return flow refers to the water that has been diverted from rivers for irrigation but later makes its way back to the rivers either as surface drainage (surface return) or discharge from groundwater (ground return). For a given amount of water diversion from a river to an irrigation scheme, more efficient irrigation generally leads to less return flow to the river (Perry, 2007, 2011; Lankford, 2012; Scott et al., 2014; Linstead, 2018; Grafton et al., 2018). The real issue being addressed here is the extent of reduction in return flow as a result of the irrigation efficiency projects.

Although the assessment period for this review is post 2009, it is important to acknowledge that there has been a long history of irrigation efficiency improvements driven by water quality controls, low water allocations, and water trading. There had already been significant reduction in surface return flow prior to 2009 (refer to Appendix D on analysis of drain flow data).

3.2 A framework for estimating impact on return flow

There is no existing method or approach suitable for estimating impact on return flow from irrigation efficiency projects of the scale and variety as under the Basin Plan. Figure 6 provides a conceptualisation of (a) off-farm irrigation delivery and drainage (b) on-farm irrigation and drainage, and (c) groundwater system, in the context of water saving from irrigation efficiency projects and surface and ground return flows to rivers.

For off-farm irrigation efficiency projects that improve channel irrigation delivery, water saving may be sourced from reductions in evaporation from channel water surface, in seepage under the channel bed and lower channel banks, in leakage through structures or holes and cracks in channel banks, and in outfall, which is unscheduled flow through channel outfall (flow escape) structures (DSE, 2012). Water saving may also be achieved from more accurate metering of water going to farms, and from decommissioning of an irrigation area.

Not all the outfall from an irrigation area become surface return flow. Some of the outfall volume may be diverted after entering a drain either back to supply channels or directly to farms for irrigation. The bank leakage may be lost as evapotranspiration in channel reserve areas, move downward as seepage, get used by nearby farmers, or find its way to drains. The conceptualisation of surface return flow and seepage for off-farm irrigation efficiency projects that improve pipe irrigation delivery is similar.

For on-farm irrigation efficiency projects, water saving may be sourced from reduction in evaporation, seepage and irrigation runoff. Water saving may also come from more accurate metering, to a standard required for receiving funding for on-farm irrigation efficiency projects. Not all the irrigation runoff that leaves farms becomes surface return flow, as some may be diverted after entering district drains, either back to supply channels or directly to farms for irrigation.

We assume that off-farm and on-farm seepage enters the groundwater store. Reduction in seepage from the irrigation efficiency projects may lead to change in ground return flow. To estimate the response of ground return flow to any seepage reduction, we adopt the very simple connectivity factor (CF) model, used in the Section 2 for estimating the impact of changed groundwater extraction on river flow volume. Reduction in seepage is considered to have the same effect as an increase in extraction from the shallow aquifer of the same volume.

Detailed methods for estimating return flows are given in Box 5 and 6. Irrigation efficiency and water recovery projects generally lead to changes in the total amount of water available for farm applications. Our methods account for these changes and their impacts on return flows, as well as the direct impacts of the water saving on return flow.

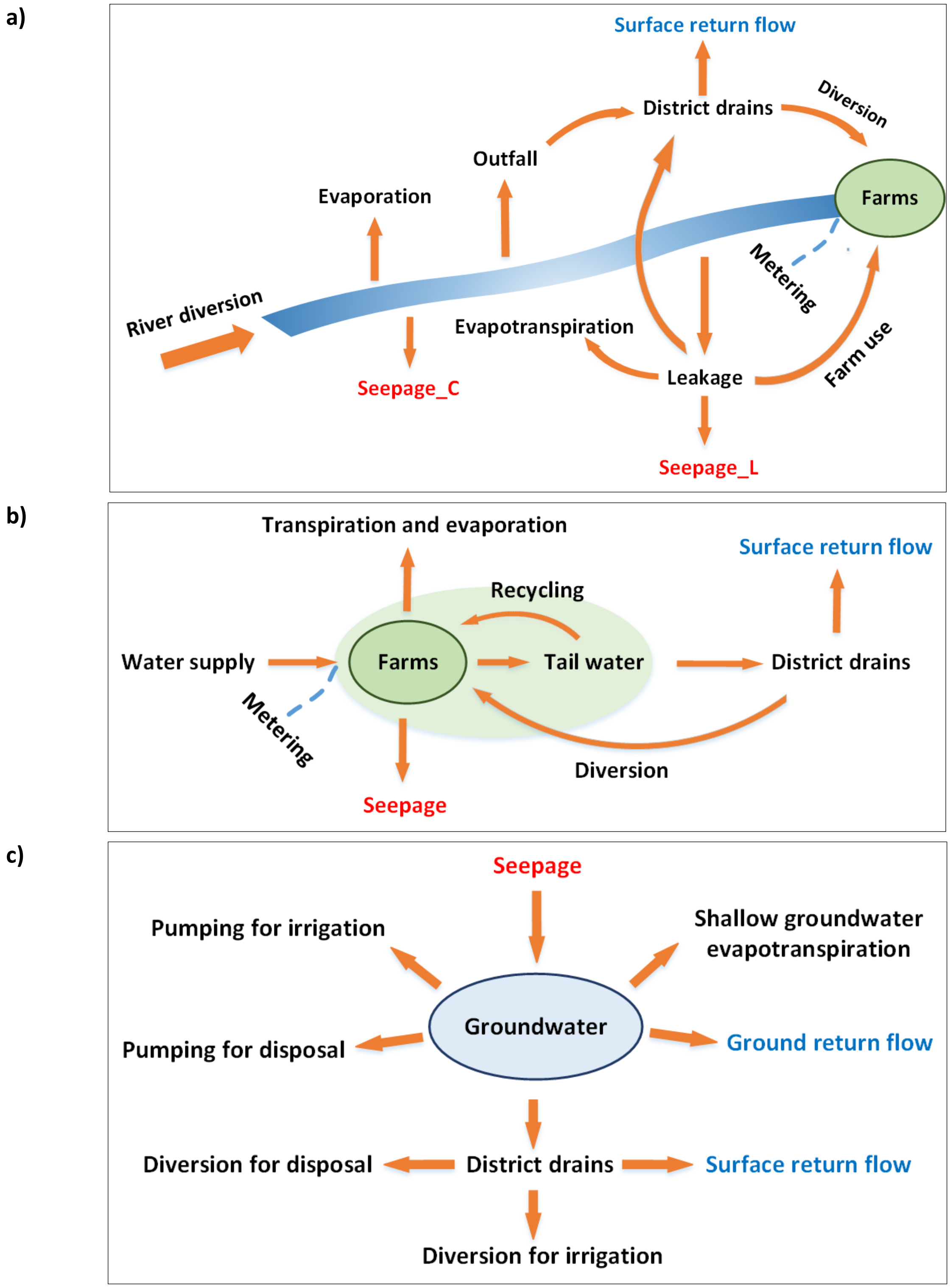

Figure 6. Conceptual diagrams of irrigation water pathways. a) Off -farm delivery and drainage; b) On-farm delivery and drainage; c) Groundwater system

Box 5: Equations for estimating impacts of an off-farm irrigation efficiency project on return flows. These equations should be read in conjunction with Figure 6.

Equations 1: Saving allocation	**Equation 2: Sources of saving**
Total recovered water = Recovered water for environment + Recovered water for farms + Recovered water for urban supply	Total recovered water = Reduction in evaporation + Reduction in seepage_C + Reduction in leakage + Reduction in channel outfall + Saving from metering + Saving from retiring irrigation land
Equation 3: Breakdown of leakage Reduction in leakage = Reduction in evapotranspiration + Reduction in seepage_L + Reduction in leakage to farms + Reduction in leakage to district drains	**Equation 4: Net decrease in farm water** Net decrease in water applied to farms = Saving from metering + Reduction in leakage to farms + DDD x Reduction in leakage to district drains + DDD x Reduction in channel outfall + Saving from retiring irrigation land – Recovered water for farms
Equation 5: Surface return flow Reduction in surface return flow = (1 – DDD) x Reduction in channel outfall + (1 – DDD) x Reduction in leakage to district drains + (1 – DDD) x FRD x Net decrease in water applied to farms	**Equation 6: Ground return flow** Reduction in ground return flow = CF x (Reduction in seepage_C + Reduction in seepage_L) + CF x FRG x Net decrease in water applied to farms

Parameters:

DDD - Fraction of district drainage water diverted for irrigation
FRD - Fraction of water applied becoming farm runoff to district drains
FRG - Fraction of water applied becoming farm recharge to groundwater
CF - Groundwater and river connectivity

Box 6: Equations for estimating impacts of an on-farm irrigation efficiency project on return flows. These equations should be read in conjunction with Figure 6.

Equations 7: Saving allocation	**Equation 8: Sources of saving**
Total recovered water = Recovered water for environment + Recovered water for farms	Total recovered water = Reduction in evaporation + Reduction in seepage + Reduction in farm irrigation runoff to district drains + Saving from metering
Equation 9: Net recovered water for farms Net recovered water for farms = Recovered water for farms – DDD x Reduction in farm irrigation runoff to district drains – Saving from metering	**Equation 10: Surface return flow** Reduction in surface return flow = (1 – DDD) x Reduction in farm irrigation runoff – (1 – DDD) x FRD x Net recovered water for farms
Equation 11: Ground return flow Reduction in ground return flow = CF x Reduction in seepage – CF x FRG x Net recovered water for farms	

Parameters:

DDD - Fraction of district drainage water diverted for irrigation
FRD - Fraction of water applied becoming farm runoff to district drains
FRG - Fraction of water applied becoming farm recharge to groundwater
CF - Groundwater and river connectivity

3.3 Data and assumptions

Impacts of irrigation efficiency projects on surface and ground return flows are estimated at the level of consolidated projects. MDBA and the Australian Government Department of Agriculture and Water Resources (DAWR) provided project data on water recovery and allocation of water saving between environment, irrigation and, in one project, urban use. DAWR provided data on the sources of water saving (such as from reductions in evaporation, seepage, leakage, escapes, metering) for some of the projects. We also gathered data from project review or final reports, audit reports and technical assessment reports, both published and unpublished, for some of the projects. To complete the assessment, many assumptions had to be made. We relied on information from technical reports and papers and on our understanding of irrigation and hydrology related to the irrigation efficiency projects. These assumptions are helpful for assessing the magnitude of the overall impacts. They are not for providing accurate results at individual project level. Detailed information on data and assumptions can be found in Appendix E.

Irrigation return flows in some surface drains are credited under the Diversion Formula Register for MDB. Reductions in return flows in these drains should lead to reductions in diversion, and therefore have no impacts on net environmental water recovery. According to URS (2010), the On-Register irrigation return flows represent 60% of all irrigation return flows in MDB in 2008-09. The results presented in our report include impacts on both On-Register and Off-Register irrigation return flows.

There is potential interaction with water balance processes driven by rainfall events, reducing rainfall runoff and rainfall recharge to the groundwater. This issue is outside the scope of this project and has not been investigated.

3.4 Results and discussion

The estimated impacts of both off-farm and on-farm irrigation efficiency projects are summarised in Table 3 and Table 4. Detailed results for all consolidated projects are given in Appendix F. There is a total reduction of 121 GL/yr return flow. The reduction represents 10% of the total recovery, or 16% of the recovery transferred to environmental entitlements. The largest impact is on ground return flow, making up 80% of the total reduction.

Irrigation efficiency projects in Victoria contribute the largest reduction in return flow. This is a result of the very large water recovery program, mostly in the Goulburn Murray Irrigation District, and the high ground- surface water CF values used in our calculation. Projects in the New South Wales Murray have a high impact in terms of both the reduction volume and in relativity to the environmental recovery (22%). Projects in the South Australian Murray result in large reduction in return flow relative to environmental recovery (33%). In both cases, this is largely due to the high ground-surface water CF values used in our calculation.

Projects in the Murrumbidgee contribute a large volume of environmental recovery but have a low impact on return flow (5%). There are two reasons for this. Firstly, the Nimmie-Caira project is land retirement, which generally has less impact on return flow, and the surface return flow impact was already accounted by the project. Secondly, low values of ground-surface water CF are used in our calculation for Murrumbidgee.

Overall, on-farm projects cause larger reduction in return flow relative to environmental recovery (30%) than off-farm projects (10%). This is because a larger proportion of water saving comes from reduction in seepage with on-farm projects, while off-farm projects also include land retirement which tends to cause less reduction in return flow.

Saving from accurate metering accounts for 255 GL/yr, or 22% of the total saving of 1179 GL/yr. The impact on river flow from this saving is generally much less than the impact from the same amount of saving but due to seepage reduction, as the water saved from metering would previously have mostly been used by crop evapotranspiration.

Table 3. Estimated impacts of irrigation efficiency projects by catchment

Catchment	Total Recovery (GL/yr)	Env. Recovery (GL/yr)	% to Env.	Reduction in surface return (GL/yr)	Reduction in ground return (GL/yr)	**Reduction in total return (GL/yr)**
Goulburn / Broken / Loddon / Campaspe	310.0	161.9	52%	4.5	29.3	**33.8**
Vic Murray	230.7	126.0	55%	3.9	21.4	**25.4**
Macquarie	53.3	37.3	70%	1.7	2.3	**4.1**
NSW Murray	195.1	134.8	69%	6.2	24.0	**30.2**
Murrumbidgee	300.6	249.2	83%	7.7	3.9	**11.6**
SA Murray	89.3	48.3	54%	0.0	15.9	**15.9**
TOTAL	**1179.0**	**757.4**	**64%**	**22.9**	**96.9**	**121.0**

Table 4. Estimated impacts on-farm and off-farm irrigation efficiency projects

	Total Recovery (GL/yr)	Env. Recovery (GL/yr)	% to Env.	Reduction in surface return (GL/yr)	Reduction in ground return (GL/yr)	**Reduction in total return (GL/yr)**
Off-farm	812.7	531.3	65%	17.0	35.2	**52.2**
On-farm	366.3	226.0	62%	7.0	61.7	**68.9**
Total	**1179.0**	**757.4**	**64%**	**24.1**	**96.9**	**121.0**

The framework we have adopted provides a high-level assessment of return flows; there are many uncertainties in the input values going into the estimation. The two most influential inputs to the estimation of return flows are (i) the percentage of saving sourced from reduction in seepage and (ii) the ground-surface water CF. If both inputs are 10% larger than the values used, the reduction in total return flow will be close to 140 GL/yr. Conversely if both inputs are 10% smaller, the reduction will be close to 100 GL/yr. **A range of 90 – 150 GL/yr may be considered as a nominal uncertainty band for the 121 GL/yr estimate.**

It takes time for groundwater return flow (or river flow) to respond to reduced seepage in a catchment. Groundwater modelling used in the Murray-Darling Basin Sustainable Yields project estimated the time needed for groundwater-surface water exchange flux to equilibrate. This varies across catchments. The response times are respectively 20, 180 and 50 years for the Goulburn-Murray, Murrumbidgee and Macquarie. Where response times are greater than 40 years, CF values used reflect the fraction of the response within 40 years.

4 Broader context of the potential impacts

When considering the impacts on river flow from groundwater SDLs and irrigation efficiency projects, there are several important aspects of water resource policy and assessment of environmental water needs that are highly relevant. The impacts must be assessed within a broader context.

4.1 Diminishing return flows

Under the water allocation systems in the MDB, irrigation surface return flows are credited for some, but not all, drains and escapes at irrigation district level. According to URS (2010), the credited irrigation return flows represent 60% of all irrigation return flows in MDB in 2008-09. Irrigation ground return flow is not credited at all. The uncredited surface return flows and the ground return flow are not legally protected as inflows to rivers for the environment or for downstream users.

There has been a long history of changes in water management in the Basin, driven largely by climate variation and water scarcity, water quality concerns and commodity values. As the recent Productivity Commission report recognises, there are a number of factors that will impact on return flows, including for example "*water trade, the crop choice and land management decisions of individual landholders, and broader changes in land use*" (Productivity Commission, 2018). As irrigation in the Basin becomes more efficient, return flows diminish. This trend will continue into the future with or without public investments.

In contrast, environmental water entitlements transferred from water saving from irrigation efficiency projects are legally protected for environmental use.

4.2 Socialised river operation

The allocation policy for the Murray River and the various tributaries is clearly defined. Importantly, before any water is allocated to entitlement holders (be they irrigators or environment entitlement holders), water is allocated to meet conveyance requirements and critical human water needs (CHWNs). Conveyance water includes for example storage losses, delivery losses along the river system, and in the case of the Murray River, conveyance to the South Australian border. The allocations are determined monthly, with the requirements for conveyance water and CHWNs based on the worst available record for that month (i.e. the largest volume required). The remainder of water is then allocated to state water shares and on to entitlement holders through allocation announcements. If conveyance water and CHWNs were not as planned for, this is adjusted for the following month (Figure 7).

The impacts on river flow from groundwater SDLs and irrigation efficiency projects will apply mostly through changes in base-flow to the river. This will most likely impact on the required conveyance water. This is important as the impacts are not attributed against the environmental share of the resource but are socialised across all entitlement holders (the majority of which are irrigators). In other words, the conveyance needs may change, which would reduce the total pool of water then available for allocation, and potentially, in wetter years, any unallocated above SDL water.

Due to the allocation policy, it does not make sense to compare the values of estimated impact on river flow (from groundwater SDLs and irrigation efficiency projects) directly with the recovery of environmental water. System water resource modelling could be used to demonstrate this more clearly, looking specifically at any implications for above cap water.

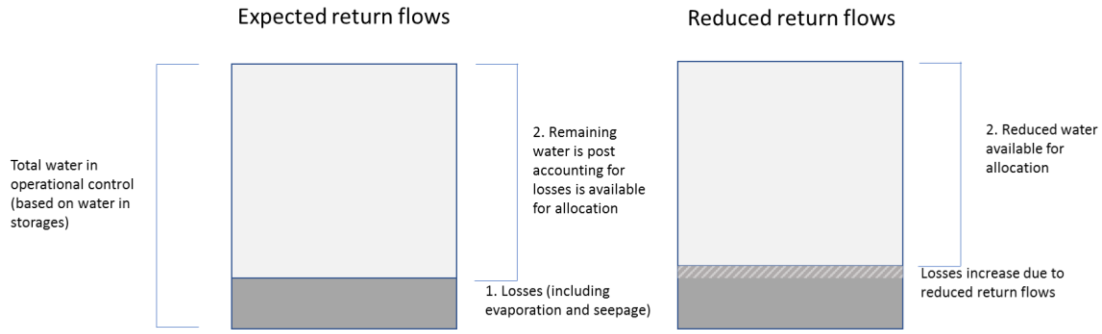

Figure 7. Simplified representation of allocation policy for the Murray River

4.3 Alternative water recovery mechanisms

Reallocating water from consumptive use to the environment requires a mechanism to enable this transfer. Water reallocation can take many forms, including administrative agreements, negotiated settlements and market-based transactions (Garrick et al., 2018). The Commonwealth Government has committed to using voluntary recovery mechanisms, through market-based transactions and administrative agreements through funded infrastructure efficiency projects.

This review has focussed on the infrastructure efficiency projects. However, any reallocation process will change the net water use on-farm and thus impact return flows. The buyback process is effectively the same as retiring an area of irrigated land (an aspect of some infrastructure efficiency projects).

We conducted a preliminary analysis to calculate the impact of water recovery if the same amounts were achieved through buybacks in the same geographical distribution as the irrigation efficiency projects. Assuming the irrigation delivery loss volume remains the same and the delivery efficiency before the buybacks is 90%, the reduction in return flow is about 5% of the buyback volume. This is considerably lower than the 16% of the environment recovery through on-farm and off-farm WUE projects. This is because most of the water recovery through buybacks is from reduction in evapotranspiration, that is, water previously used for crop production under irrigation. Water trading should have a similar effect for the region of water exit.

4.4 Volume a coarse measure of environmental benefit

The focus of the debate around return flows and impacts of groundwater SDLs has been based on the annual volume of returned environmental water in comparison to the stated Basin Plan target. However, the real objective of the water recovery is to achieve environmental objectives in the Basin.

Environmental flows are not just about annual volumes of water, but about the "***quantity, timing, and quality*** *of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being"* (Arthington et al., in press). Many of the environmental objectives targeted in the Basin Plan require targeted high flow events at specified times and for given durations. The impact of the groundwater SDLs and irrigation efficiency projects is most likely to be seen in base-flow.

The transfer of water to environmental water entitlements provides a parcel of water that is legally protected and can be actively managed to achieve environmental outcomes (Horne et al., 2017b). The legal protection is important as it provides the same rights and protection as is afforded to irrigation entitlements. The ability to actively manage means that environmental water can be called from storage to meet the timing and magnitude of flow required by the environment. The recovered environmental water is a relatively small proportion of the natural river flow in these systems, with current water holdings at less than 6% of average system inflows (the rainfall that makes it into the river system) (Webb et al., 2018). This is a very limited volume of water that requires environmental water managers to make selective decisions about where, when and how water is delivered for environmental benefits (Horne et al., 2017a, Webb et al., 2018). While this is a relatively new management approach, it has the potential to significantly increase the environmental outcomes achievable with a given bucket of environmental water (Horne et al., accepted).

While the basin wide environmental objectives may take decades to realise, an independent group of researchers leading monitoring across the basin state that they are generally seeing environmental changes of the types and magnitudes expected at this stage of the plan (Webb et al., 2018).

Environmental water is also about the quality of freshwater flows. There has been a history of irrigation return flow management in the southern MDB, along with groundwater management, aimed at controlling salt, nutrients and pesticides entering the river. It is important that water quantity issues are balanced with these water quality issues. For example, for 1 GL of 30,000 EC groundwater seeping into the river, more than 100 GL of fresh water is needed to dilute it to less than 300 EC.

4.5 The importance of adaptive management

The MDB system is a dynamic system, with social, ecological and climatic changes through time. The way in which these systems interact can be predicted through modelling, however new information and interactions will occur over time. The concern over return flows is an example where changes to system allocation processes and operations, wider catchment behaviour and climate change may all impact on the importance of accounting for return flows. The Basin Plan has a regular built in review process that will assess basin wide risks. The method and conceptual framework set out in this review can form a basis for tracking the risks from return flows.

5 Conclusions

This review was to answer the following questions:

(1) Is it likely that the Basin Plan groundwater SDLs will have a material impact on river flow volume?
(2) Is it likely that irrigation efficiency projects, carried out to achieve Basin Plan recovery targets, will have a material impact on return flow to river?

The review also sought to comment on these impacts in a broader context by considering the effects of water trading, water buyback, flow timing and water quality. Impact assessment was based on 2009 levels of development as the starting point.

Answer to question (1):

- The total groundwater SDL for MDB has been set 1114 GL/yr higher than the total baseline entitlement (or BDL) prior to the Basin Plan, which in turn is 1335 GL/yr higher than the average groundwater extraction between 2003 and 2017. Although there is no evident trend in historic use, plausible growth scenarios over the next 40 years indicate that the total groundwater use will almost all be from prior commitments within the BDL.
- The impact on river flow under these scenarios is in the range of 0 to 360 GL/yr, with 170 GL/yr as the most likely. The high uncertainty is associated with the growth in groundwater extraction and ground-surface water connectivity factors. Impacts are likely to be significant for low flow during extended dry periods and would affect both quantity and quality.
- MDBA had previously considered that the impact from pre-existing entitlements should have already been incorporated into surface water SDLs. However, in the river modelling for the development of the Basin Plan, only current levels of groundwater extraction were incorporated.
- There is some evidence to suggest that the groundwater conditions in the Southern Riverine Plain (Goulburn-Murray Sedimentary Plain in Victoria and Lower Murray in New South Wales) are changing in response to changed irrigation (efficiency and footprint). The impacts of increased ground water extraction on river flow are sensitive to any change in connectivity factor. Better information on this would improve assessment.

Answer to question (2):

- The irrigation efficiency projects recover a total of 1179 GL/yr across the Basin, of which 757 GL/yr or 64% is transferred to environmental entitlements. These projects are estimated to reduce return flow by 121 GL/yr. An uncertainty range of 90 GL/yr to 150 GL/yr is suggested.
- The largest reduction is in ground return flow, making up 80% of the total reduction in return flow. For this reason, impacts are likely to be significant for low flow during extended dry periods.
- The lower reduction in surface return flow is consistent with our understanding that by 2009 irrigation infrastructure and practices in the southern MDB had reached a stage when little irrigation water would be released back to rivers via surface drains. This contrasts with the 1980s and early 1990s when irrigation drainage flow to rivers was large. In the 1990s, there were major initiatives in many irrigation districts to reduce salinity and nutrient inputs to rivers. During the Millennium Drought, irrigation drainage flow was further reduced as water allocation became low to extremely low and water trading shifted water to more efficient use.

- Water saving from more accurate metering and from irrigation land retirement or system decommissioning represents a significant portion of the total water saving. This portion has relatively low impacts on return flow. On the other hand, water saving projects that heavily rely on reducing seepage have relatively high impacts on return flow. On-farm projects cause larger reduction in return flow relative to environmental recovery (30%) than off-farm projects (10%). This is because a larger portion of water saving comes from reduction in seepage with on-farm projects.
- With changing irrigation efficiency and footprint, processes of runoff and seepage driven by rainfall events may change and therefore impact on river flow through both surface and ground pathways. This aspect was not covered in this review, and a future investigation is warranted.

Comments on impacts in a broader context:

- Under the water allocation systems in MDB, irrigation surface return flows are credited for some, but not all, drains and escapes. Irrigation ground return flow is not credited at all. The uncredited surface return flows and the ground return flow are not legally protected as inflows to rivers for the environment or for downstream users. When irrigation in the Basin becomes more efficient as it has been the case in the last 20 years, return flows diminish. This trend will continue into the future with or without public investments. In contrast, environmental water entitlements transferred from water saving from irrigation efficiency projects are legally protected for environmental use.
- The effect of reduction in river flow due to increased groundwater extraction and irrigation efficiency projects will mostly be on base-flow. The allocation policy for the Murray River would address this through estimates of loss, which are socialised prior to any allocations against entitlements. Therefore, reduction in base-flow would not offset environmental water by the same amount.
- Environmental flows are not just about annual volumes of water, but about the "quantity, timing, and quality of freshwater flows". Environmental entitlements allow active management of this water to achieve an environmentally suitable flow regime.
- On water quality, there has been a history of irrigation return flow management in the southern MDB, along with groundwater management, aimed at controlling salinity, nutrients and pesticides entering the river. It is important that water quantity issues are balanced with these water quality issues.
- The timing of impacts from return flows will be a slow process, especially for any growth in groundwater extraction. The Basin Plan has a regular built in review process that will assess basin wide risks. The method and conceptual framework set out in this review can form a basis to keep track the impacts of increased groundwater extraction and irrigation changes on river flow.

6 References

ARTHINGTON, A. H., BHADURI, A., BUNN, S. E., JACKSON, S., THARME, R. E., TICKNER, D., YOUNG, B., ACREMAN, M., BAKER, N., CAPON, S., HORNE, A. C., KENDY, E., MCCLAIN, M. E., POFF, N. L., RICHTER, B. & WARD, S. in press. The Brisbane declaration and Global Action Agenda on Environmental Flows (2018). *Frontiers in Environmental Science*.

AUSTRALIAN GOVERNMENT 2012. Basin Plan. Murray-Darling Basin Authority.

CARDNO 2017. Audit of Irrigation Modernisation Water Recovery 2016/17 Irrigation Season. . Victoria: Audit Report prepared for Victorian Department of Environment, Land, Water and Planning.

CHRISTEN, E., HORNBUCKLE, J., WHITTEN, S., MACDONALD, F. & MEYER, W. 2009. Assessment of the water saving possible by changed irrigation system and management for a competitive tendering process. *IAL conference.*

CSIRO 2008. Water availability in the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. . Canberra, Australia: CSIRO.

CSIRO & SKM 2010a. Groundwater modelling report – Lower Gwydir. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010b. Groundwater modelling report – Lower Lachlan. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010c. Groundwater modelling report – Lower Macquarie. Australia: CSIRO: Water for a Healthy Country National Research Flagship Report.

CSIRO & SKM 2010d. Groundwater modelling report – Lower Murrumbidgee. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010e. Groundwater modelling report – Lower Namoi. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010f. Groundwater modelling report – Mid Murrumbidgee. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010g. Groundwater modelling report – Southern Riverine Plains. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010h. Groundwater modelling report – Upper Condamine. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010i. Groundwater Modelling Report – Upper Lachlan. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010j. Groundwater modelling report – Upper Macquarie. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

CSIRO & SKM 2010k. Groundwater modelling report – Upper Namoi. Australia: CSIRO: Water for a Healthy Country National Research Flagship.

DELWP 2018. Review of VFMP and On-Farm Efficiency in the Goulburn Murray Irrigation District (GMID) – Options Review. Melbourne, Victoria: Department of Environment, Land, Water and Planning.

DNR 2003. A guide to the Water Sharing Plan for the Lower Macquarie Groundwater Sources. Technical Report, Department of Sustainable Natural Resources.

DSE 2010. Wimmera-Mallee Pipeline Project - Waranga Channel Water Savings Unpublished paper prepared by the Office of Water, Department of Sustainability and Environment.

DSE 2012. Water Savings Protocol Technical Manual for the Quantification of Water Savings (Version 4). Melbourne, Victoria: Department of Sustainability and Environment.

EVANS, R. 2007. The impact of groundwater use on Australia's river. Technical report, Land and Water Australia, Canberra

FEEHAN CONSULTING 2015. Drain diversion strategy (DDS) assumptions - Review. Victoria: Report prepared for Goulburn Broken Catchment Management Authority.

GIAMBASTIANA, B. M. S & KELLY, F. J. 2010. Macquarie-Bogan catchment groundwater hydrographs. UNSW report, Connected Waters Initiative.

GARRICK, D. E., DE STEFANO, L., TURLEY, L., AGUILAR-BARAJAS, I., SCHREINER, B., DE SOUZA, R., O'DONNELL, E. & HORNE, A. C. 2018. Dividing the Water, Sharing the Benefits: Rural Water for Thirsty Cities. Report prepared for the World Bank.

GOVERNMENT OF NSW 2003. Water Sharing Plan for the Lower Macquarie Groundwater Sources 2003.

GRAFTON, R. Q., MACDONALD, D., PATON, D., HARRIS, G., BJORNLUND, H., CONNOR, J. D., QUIGGIN, J., WILLIAMS, J., CRASE, L., KINGSFORD, R. M. & WHEELER, S. 2018a. The Murray Darling Basin Plan is not delivering – there's no more time to waste. *The Conversation*, 5 February, 2018.

GRAFTON, R. Q., WILLIAMS, J., PERRY, C. J., MOLLE, F., RINGLER, C., STEDUTO, P., UDALL, B., WHEELER, S. A., WANG, Y., GARRICK, D. & ALLEN, R. G. 2018b. The paradox of irrigation efficiency. *Science,* 361**,** 748-750.

GRAFTON, R. Q. & WILLIAMS, J. G. 2018. Submissionto the Murray Darling Basin Royal Comission - Failures to Deliver on the Key Objectives of the Water Act 2007

HERITAGE COMPUTING 2010a. Peer reivew of the Lower Murrubmidgee Numberical Groundwater Model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010b. Peer reveiw of the Lower Gwydir Numerical Groundwater Model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010c. Peer review o fthe Upper Lachlan Alluvium numerical groundwater model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010d. Peer review of the Lower Lachlan Numberical Groundwater Model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010e. Peer review of the Lower Lachlan numerical groundwater model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010f. Peer review of the Lower Macquarie Numberical Groundwater Model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010g. Peer review of the Lower Namoi Alluvium numerical groundwater model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010h. Peer review of the Mid Murrumbidgee numerical groundwater model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010i. Peer review of the Sourthern Riverine Plains numerical groundwater model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010j. Peer review of the Upper Condamine numerical groundwater model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010k. Peer review of the Upper Macquarie Alluvium numerical groundwater model. Winmalee, NSW: Heritage Computing.

HERITAGE COMPUTING 2010l. Peer review of the Upper Namoi Alluvium numerical groundwater model. Winmalee, NSW: Heritage Computing.

HOLLAND, G., COLLETT, K., CHRISTEN, E. & MCLOUGHLIN, R. 2018. A Framework for quantifying irrigation application efficiency arising from incremental adoption of irrigation technologies. *OZWater 19.*

HORNE, A., KAUR, S., SZEMIS, J., COSTA, A., WEBB, J. A., NATHAN, R., STEWARDSON, M., LOWE, L. & BOLAND, N. 2017a. Using optimization to develop a "designer" environmental flow regime. *Environmental Modelling & Software,* 88**,** 188-199.

HORNE, A., KAUR, S., SZEMIS, J. M., COSTA, A. M., NATHAN, R., WEBB, J. A., STEWARDSON, M. J. & BOLAND, N. accepted. Can ecological outcomes be improved through active management of environmental water? *Journal of Water Resources Planning and Management*.

HORNE, A. C., O'DONNELL, E. L. & THARME, R. E. 2017b. Chapter 17 - Mechanisms to Allocate Environmental Water. *Water for the Environment.* Academic Press.

JACOBS 2017. Re-conceptualisation of the Barr Creek Catchment. Victoria: Final Report prepared for North Central Catchment Management Authority.

JACOBS 2018. Shepparton Irrigation Region – salinity effect on the Murray River at 2015 levels of development,. Victoria: Final Report prepared for Goulburn-Murray Water.

LANKFORD, B.A. 2012. Fictions, fractions, factorials, fractures and fractals; on the framing of irrigation efficiency. Agricultural Water Management 108: 27-38.

LINSTEAD, C. 2018. The Contribution of Improvements in Irrigation Efficiency to Environmental Flows. *Frontiers in Environmental Science,* 6.

MCBURNIE, M. K. 2017. PIIOP Modernisation Project—Final Report. Prepared for Narromine Irrigation Board of Management.

MDBA 2012a. Addendum to the proposed groundwater baseline and sustainable diversion limits: Methods Report. *MDBA Publication 62/12.* Canberra: Murray-Darling Basin Authority.

MDBA 2012b. Groundwater Sustainable Diversion Limit Resource Unit Summary Report Cards. *MDBA Publication No 49/12.* Canberra: Murray-Darling Basin Authority.

MDBA 2012c. Potential water savings from the proposed Nimmie-Caira System enhanced environmental water delivery project, unpublished report.

MDBA 2012d. The proposed Groundwater Baseline and Sustainable Diversion Limits: Methods Report. . *MDBA Publication No: 16/12.* Canberra: Murray-Darling Basin Authority.

MI 2006. Licence Compliance Report. Murrumbidgee Irrigation Limited.

MI 2007. Licence Compliance Report. Murrumbidgee Irrigation Limited.

MIL 2014. Drainage/Supply Escape Extraction Policy.: Murray Irrigation Limited.

NSW OFFICE OF WATER 2010. Assessment of risk to NSW Murray-Darling Basin shared water resources – 2008. Sydney: NSW Office of Water.

PARSONS S., EVANS R. AND HOBAN M. 2008. Surface–groundwater connectivity assessment. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 35pp.

PB 2009. Groundwater-surface water connectivity - Practical approaches for identifying and accounting. Sydney: PB.

PERRY, C. 2007. Efficient irrigation; inefficient communication; flawed recommendations. Irrigation and Drainage, 56(4), 368-378.

PERRY, C. 2011. Accounting for water use: Terminology and implications for saving water and increasing production. *Agricultural Water Management,* 98**,** 1840-1846.

PERRY, C. J. 2017. Does Improved Irrigation Technology Save Water? A Review of the Evidence. Discussion Paper on Irrigation and Sustainable Water Resources Management in the Near East and North Africa. Food and Agriculture Organisation of the United Nations.

PRODUCTIVITY COMMISSION 2018. Murray-Darling Basin Plan: Five-year assessment, Draft Report. Canberra, Australia.

RASSAM, D. W., JOLLY, I. & PICKETT, T. 2011. Guidelines for Modelling Groundwater-Surface Water Interactions in eWater Source: Towards Best Practice Model Application. . Canberra: eWater Cooperative Research Centre.

RASSAM, D. W. & WERNER, A. D. 2008. Review of groundwater–surfacewater interaction modelling approaches and their suitability for Australian conditions. *eWater Technical Report.* Canberra: eWater Cooperative Research Centre.

REM 2004. Summary of Estimated Impact of Groundwater Use on Streamflow in the Murray-Darling Basin. Adeliade: REM.

REM 2006. Evaluation of the connectivity between surface water and groundwater in the Murray-Darling Basin. Adelaide: REM.

RICHARDSON S., WALKER G.R., BARNETT B., DAAMEN C., DAVIES P., EVANS R.S., EVANS W.R., GOODE A., PRITCHARD J. & WAKLAWIK V. 2008. Groundwater management unit prioritisation and assessment ranking. A report to the Australian Government from the CSIRO Murray Darling Basin Sustainable Yields Project. 33pp. CSIRO, Australia.

RMCG 2009. Background Report to Support the Farm Works Guidelines. Unpublished report prepared for Goulburn Murray Integrated Farm Modernisation Program.

RMCG 2015. Shepparton Irrigation Region Drainage Program Review - Phase A Final Report. Victoria: Prepared for Goulburn Murray Water and Goulburn Broken Catchment Management Authority.

SCOTT, C. A., VICUÑA, S., BLANCO-GUTIÉRREZ, I., MEZA, F. & VARELA-ORTEGA, C. 2014. Irrigation efficiency and water-policy implications for river basin resilience. *Hydrol. Earth Syst. Sci.,* 18**,** 1339-1348.

SKM 2001. Projections for groundwater extraction rates and implications for water demand and competition for surface water. Murray-Darling Basin Commission Report.

SKM 2010. NVIRP Stage 2 Business Case : Stage 2 Effects on River Murray Salinity. Unpublished report.

SKM & CSIRO 2008. Development and implementation of methods to consistently assess risks to shared water resources in the Murray-Darling Basin: Risk Assessment Guidelines for 2008. Canberra: SKM.

SUSTAINABLE SOILS MANAGEMENT PTY LTD 2012. Final Project Report under the Private Irrigation Infrastructure Operators Program in New South Wales. Prepared for the Board of Marthaguy Irrigation Scheme Pty Limited.

SUSTAINABLE SOILS MANAGEMENT PTY LTD unknown. Tenandra Scheme Modernisation Project Final Report.

TENNAKOON, S. D., RICHARDS, M., S & HARRIS, G. 2012. Water use efficiency in the Australian cotton industry. *In:* WIGGINGTON, D. (ed.) *Waterpak: A Guide for Irrigation Management in Cotton and Grain Farming Systems.* Cotton Research and Development Corporation.

TICEHURST, J. & CURTIS, A. 2016. Improving on-farm water use efficiency amongst irrigators in the Campaspe River system and the Rochester Irrigation Area. EH Graham Centre for Agricultural Innovation, Charles Sturt University.

URS 2010. Final Report: Murray-Darling Basin return flows investigation. Canberra: Report to the Murray-Darling Basin Authority.

VANGUARD BUSINESS SERVICES 2016. Final Project Report under Round One of the Private Irrigation Infrastructure Operators Program in NSW. Prepared for Trangie Nevertire Co-operative Ltd.

WEBB, A., RYDER, D., DYER, F., STEWARDSON, M., GRACE, M., BOND, N., FRAZIER, P., YE, Q., STOFFELS, R., WATTS, R. J., CAPON, S. & WASSENS, S. 2018. It will take decades, but the Murray Darling Basin Plan is delivering environmental improvements. *The Conversation*.

WOOD, M. & FINGER, L. 2006. Influence of irrigation methods on water use and production of perennial pastures in northern Victoria. *Australian Journal of Experimental Agriculture,* 46**,** 1605-1614.

Appendix A: Extraction data and scenarios for groundwater SDL units

The main report describes the aggregate extraction rates across MDB. In this Appendix, we provide details for individual groundwater units. The first column shows the code, which can be used to identify the unit on the map in the main text. Each unit sits in a Water Resource Planning Area, which is shown in the third column. The next columns show the BDL, SDL and average use for the period (2003-2017), as provided by MDBA. The unassigned water units are colour-shaded, in addition to the units where entitlements are to be recovered. Additional details on the units, as defined at the time of the Draft Basin Plan can be found in MDBA (2012c).

The remaining columns represent the details on the scenarios. The Full SDL is the stage when extraction reaches the SDL. This is partitioned into the volume above current use and below the BDL and the volume of the unassigned water. The data relevant to 40 years of growth at 2%/yr and 4%/yr are shown, together with the same partitioned components. The impacts on river flow under these scenarios will be shown in Appendix C.

Extraction data and scenarios **(GL/yr)**

SDL Resource Unit code	SDL resource unit	WRP area	State	BDL	SDL	Average use	Un-assigned water	Full SDL	Full SDL above BDL	Full SDL within BDL	4% growth rate	4% growth rate above BDL	4% growth rate within BDL	2% growth rate	2% growth rate above BDL	2% growth rate within BDL
GS1a	Angas Bremer (Quaternary Sediments)	Eastern Mount Lofty Ranges	SA	0.00	1.09	0.00	SDL > BDL	1.09	1.09	0.00	0.26	0.26	0.00	0.18	0.18	0.00
GS1b	Angas Bremer (Murray Group Limestone)	Eastern Mount Lofty Ranges	SA	6.57	6.57	2.35	SDL = BDL	6.57	0.00	4.21	6.38	0.00	4.03	4.42	0.00	2.06
GS2	Eastern Mount Lofty Ranges	Eastern Mount Lofty Ranges	SA	34.70	38.50	2.93	SDL > BDL	38.50	3.80	31.77	7.87	0.00	4.94	5.45	0.00	2.52
GS3a	Mallee (Pliocene Sands)	South Australian Murray Region	SA	0.00	41.40	0.00	SDL > BDL	41.40	41.40	0.00	0.26	0.26	0.00	0.18	0.18	0.00
GS3b	Mallee (Murray Group Limestone)	South Australian Murray Region	SA	63.60	63.60	34.99	SDL = BDL	63.60	0.00	28.61	63.60	0.00	28.61	63.17	0.00	28.17
GS3c	Mallee (Renmark Group)	South Australian Murray Region	SA	0.00	2.00	0.00	SDL > BDL	2.00	2.00	0.00	0.26	0.26	0.00	0.18	0.18	0.00
GS4a	Marne Saunders (fractured rock)	Eastern Mount Lofty Ranges	SA	2.09	2.09	0.41	SDL = BDL	2.09	0.00	1.68	1.33	0.00	0.92	0.92	0.00	0.51
GS4b	Marne Saunders (Murray Group Limestone)	Eastern Mount Lofty Ranges	SA	2.38	2.38	1.46	SDL = BDL	2.38	0.00	0.92	2.38	0.00	0.92	2.38	0.00	0.92
GS4c	Marne Saunders (Renmark Group)	Eastern Mount Lofty Ranges	SA	0.50	0.50	0.00	SDL = BDL	0.50	0.00	0.50	0.26	0.00	0.26	0.18	0.00	0.18
GS5a	Peake–Roby–Sherlock (unconfined)	South Australian Murray Region	SA	3.41	3.41	0.45	SDL = BDL	3.41	0.00	2.95	1.44	0.00	0.99	1.00	0.00	0.54

SDL Resource Unit code	SDL resource unit	WRP area	State	BDL	SDL	Average use	Un-assigned water	Full SDL	Full SDL above BDL	Full SDL within BDL	4% growth rate	4% growth rate above BDL	4% growth rate within BDL	2% growth rate	2% growth rate above BDL	2% growth rate within BDL
GS5b	Peake–Roby–Sherlock (confined)	South Australian Murray Region	SA	2.58	2.58	1.27	SDL = BDL	2.58	0.00	1.31	2.58	0.00	1.31	2.47	0.00	1.20
GS6	SA Murray	South Australian Murray Region	SA	1.80	64.80	0.64	SDL > BDL	64.80	63.00	1.16	1.93	0.13	1.16	1.34	0.00	0.69
GS7	SA Murray Salt Interception Schemes	South Australian Murray Region	SA	13.20	28.60	10.90	SDL > BDL	28.60	15.40	2.30	28.59	15.39	2.30	19.79	6.59	2.30
GS8a	Goulburn-Murray: Shepparton Irrigation Region	Goulburn-Murray	Vic	244.10	244.10	50.83	SDL = BDL	244.10	0.00	193.27	132.41	0.00	81.58	91.67	0.00	40.84
GS8b	Goulburn-Murray: Highlands	Goulburn-Murray	Vic	38.30	68.70	12.30	SDL > BDL	68.70	30.40	26.00	32.25	0.00	19.94	22.32	0.00	10.02
GS8c	Goulburn-Murray: Sedimentary Plain	Goulburn-Murray	Vic	203.50	223.00	123.31	SDL > BDL	223.00	19.50	80.19	223.00	19.50	80.19	222.14	18.64	80.19
GS8d	Goulburn-Murray: deep	Goulburn-Murray	Vic	0.00	20.00	0.00	SDL > BDL	20.00	20.00	0.00	0.26	0.26	0.00	0.18	0.18	0.00
GS9a	Wimmera-Mallee: Highlands	Wimmera-Mallee	Vic	1.26	2.75	0.62	SDL > BDL	2.75	1.49	0.64	1.88	0.62	0.64	1.30	0.04	0.64
GS9b	Wimmera-Mallee: Sedimentary Plain	Wimmera-Mallee	Vic	68.90	190.10	9.18	SDL > BDL	190.10	121.20	59.72	24.14	0.00	14.95	16.71	0.00	7.53
GS9c	Wimmera-Mallee: deep	Wimmera-Mallee	Vic	0.00	20.00	0.00	SDL > BDL	20.00	20.00	0.00	0.26	0.26	0.00	0.18	0.18	0.00
GS10	Adelaide Fold Belt MDB	NSW MDB Fractured Rock	NSW	3.61	6.90	2.14	SDL > BDL	6.90	3.29	1.47	5.83	2.22	1.47	4.03	0.42	1.47

SDL Resource Unit code	SDL resource unit	WRP area	State	BDL	SDL	Average use	Un-assigned water	Full SDL	Full SDL above BDL	Full SDL within BDL	4% growth rate	4% growth rate above BDL	4% growth rate within BDL	2% growth rate	2% growth rate above BDL	2% growth rate within BDL
GS11	Bell Valley Alluvium	Macquarie-Castlereagh Alluvium	NSW	3.29	3.29	1.24	SDL = BDL	3.29	0.00	2.05	3.29	0.00	2.05	2.41	0.00	1.17
GS12	Belubula Alluvium	Lachlan Alluvium	NSW	2.88	2.88	1.68	SDL = BDL	2.88	0.00	1.19	2.88	0.00	1.19	2.88	0.00	1.19
GS13	Billabong Creek Alluvium	Murray Alluvium	NSW	7.50	7.50	2.12	SDL = BDL	7.50	0.00	5.38	5.76	0.00	3.64	3.99	0.00	1.87
GS14	Castlereagh Alluvium	Macquarie-Castlereagh Alluvium	NSW	0.62	0.62	0.08	SDL = BDL	0.62	0.00	0.54	0.47	0.00	0.39	0.33	0.00	0.24
GS15	Coolaburragundy–Talbragar Alluvium	Macquarie-Castlereagh Alluvium	NSW	3.47	3.47	1.96	SDL = BDL	3.47	0.00	1.51	3.47	0.00	1.51	3.47	0.00	1.51
GS16	Cudgegong Alluvium	Macquarie-Castlereagh Alluvium	NSW	2.53	2.53	1.64	SDL = BDL	2.53	0.00	0.89	2.53	0.00	0.89	2.53	0.00	0.89
GS17	Gunnedah-Oxley Basin MDB	NSW MDB Porous Rock	NSW	22.10	127.50	5.93	SDL > BDL	127.50	105.40	16.17	15.68	0.00	9.75	10.85	0.00	4.92
GS18	Inverell Basalt	NSW MDB Fractured Rock	NSW	4.15	4.15	1.13	SDL = BDL	4.15	0.00	3.03	3.19	0.00	2.06	2.21	0.00	1.08
GS19	Kanmantoo Fold Belt MDB	NSW MDB Fractured Rock	NSW	8.91	18.70	8.22	SDL > BDL	18.70	9.79	0.69	18.70	9.79	0.69	14.97	6.06	0.69
GS20	Lachlan Fold Belt MDB	NSW MDB Fractured Rock	NSW	142.40	259.00	80.07	SDL > BDL	259.00	116.60	62.33	208.44	66.04	62.33	144.31	1.91	62.33
GS21	Lake George Alluvium	Murrumbidgee Alluvium	NSW	1.27	1.27	0.26	SDL = BDL	1.27	0.00	1.01	0.94	0.00	0.68	0.65	0.00	0.39
GS22	Liverpool Ranges Basalt	NSW MDB Fractured Rock	NSW	2.16	2.16	1.83	SDL = BDL	2.16	0.00	0.32	2.16	0.00	0.32	2.16	0.00	0.32

SDL Resource Unit code	SDL resource unit	WRP area	State	BDL	SDL	Average use	Un-assigned water	Full SDL	Full SDL above BDL	Full SDL within BDL	4% growth rate	4% growth rate above BDL	4% growth rate within BDL	2% growth rate	2% growth rate above BDL	2% growth rate within BDL
GS23	Lower Darling Alluvium	Darling Alluvium	NSW	2.23	2.23	0.74	SDL = BDL	2.23	0.00	1.49	2.19	0.00	1.45	1.51	0.00	0.77
GS24	Lower Gwydir Alluvium	Gwydir Alluvium	NSW	33.00	33.00	34.01	SDL = BDL	33.00	0.00	-1.01	33.00	0.00	-1.01	33.00	0.00	-1.01
GS25	Lower Lachlan Alluvium	Lachlan Alluvium	NSW	117.00	117.00	105.50	SDL = BDL	117.00	0.00	11.50	117.00	0.00	11.50	117.00	0.00	11.50
GS26	Lower Macquarie Alluvium	Macquarie-Castlereagh Alluvium	NSW	70.70	70.70	37.67	SDL = BDL	70.70	0.00	33.03	70.70	0.00	33.03	67.99	0.00	30.32
GS27a	Lower Murray Shallow Alluvium	Murray Alluvium	NSW	81.90	81.90	3.96	SDL = BDL	81.90	0.00	77.94	10.55	0.00	6.59	7.31	0.00	3.35
GS27b	Lower Murray Deep Alluvium	Murray Alluvium	NSW	88.90	88.90	59.12	SDL = BDL	88.90	0.00	29.78	88.90	0.00	29.78	88.90	0.00	29.78
GS28a	Lower Murrumbidgee Shallow Alluvium	Murrumbidgee Alluvium	NSW	26.90	26.90	4.58	SDL = BDL	26.90	0.00	22.32	12.18	0.00	7.59	8.43	0.00	3.85
GS28b	Lower Murrumbidgee Deep Alluvium	Murrumbidgee Alluvium	NSW	273.60	273.60	211.19	SDL = BDL	273.60	0.00	62.41	273.60	0.00	62.41	273.60	0.00	62.41
GS29	Lower Namoi Alluvium	Namoi Alluvium	NSW	88.30	88.30	82.09	SDL = BDL	88.30	0.00	6.21	88.30	0.00	6.21	88.30	0.00	6.21
GS30	Manilla Alluvium	Namoi Alluvium	NSW	1.23	1.23	0.21	SDL = BDL	1.23	0.00	1.02	0.81	0.00	0.60	0.56	0.00	0.35
GS31	Mid-Murrumbidgee Alluvium	Murrumbidgee Alluvium	NSW	53.50	53.50	36.73	SDL = BDL	53.50	0.00	16.77	53.50	0.00	16.77	53.50	0.00	16.77

SDL Resource Unit code	SDL resource unit	WRP area	State	BDL	SDL	Average use	Un-assigned water	Full SDL	Full SDL above BDL	Full SDL within BDL	4% growth rate	4% growth rate above BDL	4% growth rate within BDL	2% growth rate	2% growth rate above BDL	2% growth rate within BDL
GS32	NSW Border Rivers Alluvium	New South Wales Border Rivers Alluvium	NSW	8.40	8.40	5.01	SDL = BDL	8.40	0.00	3.39	8.40	0.00	3.39	8.40	0.00	3.39
GS33	NSW Border Rivers Tributary Alluvium	New South Wales Border Rivers Alluvium	NSW	0.41	0.41	0.17	SDL = BDL	0.41	0.00	0.24	0.41	0.00	0.24	0.41	0.00	0.24
GS34	NSW GAB Surat Shallow	New South Wales Great Artesian Basin Shallow	NSW	6.57	15.50	2.20	SDL > BDL	15.50	8.93	4.37	5.98	0.00	3.78	4.14	0.00	1.94
GS35	NSW GAB Warrego Shallow	New South Wales Great Artesian Basin Shallow	NSW	0.65	33.40	0.65	SDL > BDL	33.40	32.75	0.00	1.95	1.30	0.00	1.35	0.70	0.00
GS36	NSW GAB Central Shallow	New South Wales Great Artesian Basin Shallow	NSW	0.25	8.83	1.16	SDL > BDL	8.83	8.59	-0.92	3.28	3.03	-0.92	2.27	2.02	-0.92
GS37	New England Fold Belt MDB	NSW MDB Fractured Rock	NSW	32.90	55.10	19.96	SDL > BDL	55.10	22.20	12.94	52.15	19.25	12.94	36.10	3.20	12.94
GS38	Oaklands Basin	NSW MDB Porous Rock	NSW	0.00	2.50	0.00	SDL > BDL	2.50	2.50	0.00	0.26	0.26	0.00	0.18	0.18	0.00
GS39	Orange Basalt	NSW MDB Fractured Rock	NSW	10.70	10.70	0.90	SDL = BDL	10.70	0.00	9.80	2.61	0.00	1.70	1.80	0.00	0.90
GS40	Peel Valley Alluvium	Namoi Alluvium	NSW	9.34	9.34	6.67	SDL = BDL	9.34	0.00	2.67	9.34	0.00	2.67	9.34	0.00	2.67
GS41	Sydney Basin MDB	NSW MDB Porous Rock	NSW	3.12	19.10	0.47	SDL > BDL	19.10	15.98	2.65	1.48	0.00	1.01	1.02	0.00	0.56

SDL Resource Unit code	SDL resource unit	WRP area	State	BDL	SDL	Average use	Un-assigned water	Full SDL	Full SDL above BDL	Full SDL within BDL	4% growth rate	4% growth rate above BDL	4% growth rate within BDL	2% growth rate	2% growth rate above BDL	2% growth rate within BDL
GS42	Upper Darling Alluvium	Darling Alluvium	NSW	6.29	6.59	1.95	SDL > BDL	6.59	0.30	4.34	5.34	0.00	3.39	3.70	0.00	1.74
GS43	Upper Gwydir Alluvium	Gwydir Alluvium	NSW	0.72	0.72	0.07	SDL = BDL	0.72	0.00	0.65	0.45	0.00	0.38	0.31	0.00	0.24
GS44	Upper Lachlan Alluvium	Lachlan Alluvium	NSW	94.20	94.20	51.79	SDL = BDL	94.20	0.00	42.41	94.20	0.00	42.41	93.41	0.00	41.62
GS45	Upper Macquarie Alluvium	Macquarie-Castlereagh Alluvium	NSW	17.90	17.90	13.00	SDL = BDL	17.90	0.00	4.90	17.90	0.00	4.90	17.90	0.00	4.90
GS46	Upper Murray Alluvium	Murray Alluvium	NSW	14.10	14.10	9.84	SDL = BDL	14.10	0.00	4.26	14.10	0.00	4.26	14.10	0.00	4.26
GS47	Upper Namoi Alluvium	Namoi Alluvium	NSW	123.40	123.40	90.35	SDL = BDL	123.40	0.00	33.05	123.40	0.00	33.05	123.40	0.00	33.05
GS48	Upper Namoi Tributary Alluvium	Namoi Alluvium	NSW	1.77	1.77	0.20	SDL = BDL	1.77	0.00	1.57	0.79	0.00	0.59	0.55	0.00	0.34
GS49	Warrumbungle Basalt	NSW MDB Fractured Rock	NSW	0.55	0.55	0.51	SDL = BDL	0.55	0.00	0.04	0.55	0.00	0.04	0.55	0.00	0.04
GS50	Western Porous Rock	NSW MDB Porous Rock	NSW	63.10	226.00	30.85	SDL > BDL	226.00	162.90	32.25	80.46	17.36	32.25	55.70	0.00	24.86
GS51	Young Granite	NSW MDB Fractured Rock	NSW	7.11	7.11	1.44	SDL = BDL	7.11	0.00	5.67	4.01	0.00	2.57	2.78	0.00	1.33
GS52	Australian Capital Territory (Groundwater)	Australian Capital Territory (groundwater)	ACT	2.27	3.16	0.58	SDL > BDL	3.16	0.89	1.69	1.76	0.00	1.18	1.22	0.00	0.64

SDL Resource Unit code	SDL resource unit	WRP area	State	BDL	SDL	Average use	Un-assigned water	Full SDL	Full SDL above BDL	Full SDL within BDL	4% growth rate	4% growth rate above BDL	4% growth rate within BDL	2% growth rate	2% growth rate above BDL	2% growth rate within BDL
GS53	Condamine Fractured Rock	Condamine-Balonne	Qld	0.81	1.48	0.45	SDL > BDL	1.48	0.66	0.37	1.42	0.60	0.37	0.98	0.17	0.37
GS54	Queensland Border Rivers Alluvium	Queensland Border Rivers - Moonie	Qld	14.00	14.00	10.40	SDL = BDL	14.00	0.00	3.60	14.00	0.00	3.60	14.00	0.00	3.60
GS55	Queensland Border Rivers Fractured Rock	Queensland Border Rivers - Moonie	Qld	10.10	10.50	7.35	SDL > BDL	10.50	0.40	2.75	10.50	0.40	2.75	10.50	0.40	2.75
GS56	Queensland MDB: deep	Condamine-Balonne	Qld	0.00	100.00	0.01	SDL > BDL	100.00	100.00	-0.01	0.30	0.30	-0.01	0.21	0.21	-0.01
GS57	Sediments above the Great Artesian Basin: Border Rivers-Moonie	Queensland Border Rivers - Moonie	Qld	0.14	46.90	0.22	SDL > BDL	46.90	46.76	-0.08	0.83	0.69	-0.08	0.57	0.43	-0.08
GS58	Sediments above the Great Artesian Basin: Condamine–Balonne	Condamine-Balonne	Qld	0.66	18.10	0.47	SDL > BDL	18.10	17.44	0.19	1.48	0.82	0.19	1.02	0.37	0.19
GS60	Sediments above the Great Artesian Basin: Warrego–Paroo–Nebine	Warrego-Paroo-Nebine	Qld	1.21	99.20	0.90	SDL > BDL	99.20	97.99	0.30	2.61	1.40	0.30	1.81	0.60	0.30
GS61b	St George Alluvium: Condamine–Balonne (deep)	Condamine-Balonne	Qld	12.60	12.60	11.05	SDL = BDL	12.60	0.00	1.55	12.60	0.00	1.55	12.60	0.00	1.55

SDL Resource Unit code	SDL resource unit	WRP area	State	BDL	SDL	Average use	Un-assigned water	Full SDL	Full SDL above BDL	Full SDL within BDL	4% growth rate	4% growth rate above BDL	4% growth rate within BDL	2% growth rate	2% growth rate above BDL	2% growth rate within BDL
GS61a	St George Alluvium: Condamine–Balonne (shallow)	Condamine-Balonne	Qld	0.77	27.70	0.64	SDL = BDL	27.70	26.93	0.13	1.94	1.17	0.13	1.34	0.57	0.13
GS62	St George Alluvium: Moonie	Queensland Border Rivers - Moonie	Qld	0.01	0.69	0.01	SDL > BDL	0.69	0.68	0.00	0.29	0.28	0.00	0.20	0.19	0.00
GS63	St George Alluvium: Warrego–Paroo–Nebine	Warrego-Paroo-Nebine	Qld	0.12	24.60	0.10	SDL > BDL	24.60	24.48	0.01	0.53	0.41	0.01	0.36	0.25	0.01
GS64a	Upper Condamine Alluvium (Central Condamine Alluvium)	Condamine-Balonne	Qld	81.40	46.00	39.94	SDL < BDL	46.00	-35.40	41.46	46.00	0.00	6.06	46.00	0.00	6.06
GS64b	Upper Condamine Alluvium (Tributaries)	Condamine-Balonne	Qld	45.50	40.50	27.71	SDL < BDL	40.50	-5.00	17.79	40.50	0.00	12.79	40.50	0.00	12.79
GS65	Upper Condamine Basalts	Condamine-Balonne	Qld	79.00	79.00	61.80	SDL = BDL	79.00	0.00	17.20	79.00	0.00	17.20	79.00	0.00	17.20
GS66	Warrego Alluvium	Warrego-Paroo-Nebine	Qld	0.70	10.20	0.69	SDL > BDL	10.20	9.50	0.01	2.06	1.36	0.01	1.43	0.72	0.01
			TOTALS	**2,380**	**3,494**	**1,335**		**3,494**	**1,114**	**1,044**	**2,198**	**164**	**699**	**1,980**	**45**	**600**

Appendix B: Estimation of connectivity factors

In conducting the review, it has not been possible to do any new field work or modelling. Rather, we have reviewed the methodology and literature and analysed existing datasets. In particular, the following sources were investigated:

(1) MDBA (2012a;2012b;2012c) description of the methodology and underlying data for the determination of the BDL and SDL for the Basin Plan;
(2) MDBA (personal communication, 2018) GW Actual Take by SDL resource unit (2003-4 to present) Excel spreadsheet;
(3) Groundwater modelling studies by CSIRO and SKM (2010a-k) conducted for the preparation of the Draft Basin Plan;
(4) Reviews of these modelling studies by Heritage Computing (2010a-l);
(5) MDBSY water availability reports (CSIRO, 2007a-d; CSIRO, 2008a-i), Rassam *et al*., (2008), Richardson et al. (2008), Parsons et al. (2008);
(6) REM reports (2004, 2006) assessment of groundwater extraction on surface water impacts and connectivity in the MDB for the MDBC;
(7) PB report (2009) on pragmatic approaches to assessment of groundwater-surface water connectivity;
(8) CRC eWater reports on modelling groundwater-surface water fluxes (Rassam and Werner, 2008; Rassam *et al.*, 2011);
(9) Risk assessment reports (NSW Office of Water ,2008; SKM and CSIRO, 2008 and SKM, 2009); and
(10)Reports by R. Evans for LWA and SKM for MDBC: SKM (2001), Evans (2007).

More specifically, the analysis involved the following steps:

(1) Review the MDBA current estimates of the cumulative impact of groundwater extraction in the MDB within the context of the above literature;
(2) Understand the evolution of connectivity factors used in the analysis;
(3) For SDL units contributing most of the increase in groundwater extraction, review these factors using existing data; and
(4) For highlighted areas, use groundwater modelling outputs to estimate connectivity factors.

The connectivity factor is also required for the irrigation ground return flow risk assessment, noting that in this case, the connectivity factor relates the sensitivity of river flow impact to changed irrigation recharge rather than groundwater extraction. These irrigation ground return flows are mostly for shallow floodplain alluvial aquifers, many of which were modelled as part of the preparation of the Draft Basin Plan.

The connectivity factor describes the impact on river flow within a time frame following a change in groundwater extraction or recharge, expressed as a ratio with the magnitude of the change in groundwater extraction or recharge. The time frame for the SDL unit connectivity factor has been defined to be 40 years. Our groundwater scenarios have considered the change in groundwater extraction over 40 years. When this is combined with the time response, we are considering the fraction of the impact that occurs over a period of 40-80 years. However, for the purposes of the review, we have used this impact even though some of this occurs beyond the 40 year period that we set at the outset. By doing this, the impact estimate for a growth scenario should be higher than the 40 year value.

REM (2006), Evans (2007) and PB (2009) have reviewed the main drivers for the connectivity factor and how these may vary across the MDB. Parsons et al. (2008) have mapped the magnitude and direction of groundwater-surface water fluxes along the main tributaries of the MDB. They have also mapped the stretches, where the flux is 'maximum losing' or 'disconnected' i.e. those areas where further extraction will not further increase losses from the river. Maximum losing conditions mean the connectivity factor may be zero for adjacent SDL resource units.

The theory underlying the connectivity factor quantifies the impact from a known extraction point. The above references describe the main influences, including distance from the stream, zones of low conductance (aquitards and 'disconnected streams'), transmissivity of aquifers and topography as it affects evapotranspiration. When applying this to a whole SDL unit for future extraction, these factors may vary considerably. The main uncertainty is the location of any future extraction. Generally, assumptions are explicitly or implicitly made with the extraction pattern, including:

(1) Pattern for future extraction being similar to that for current extraction;
(2) Areas of mineral or gas reserves or new resources; and
(3) Areas of increased demands, including urban supplies and drought contingency.

Hydrogeological parameters and distance from streams could be lumped into different zones within the SDL resource unit. Sometimes, these are reflected in management zones within the unit. Because of the scale of this study and the sheer number of SDL resource units, it is not feasible to disaggregate the SDL unit into smaller zones. There is likely to be greater confidence in extrapolating from current conditions as this may occur within existing commitments and regulations and likely to be similar to current conditions. Extraction itself may lead to changed connectivity as water tables fall below the level of surface streams.

The connectivity factors used by MDBA are with a few exceptions those used in Richardson et al. (2008). These have evolved from those in REM (2004, 2006) and considerations of Evans (2007). The REM reports involved discussions with the relevant state agencies. PB (2009) provided a broad categorization of units with high connectivity and units with low connectivity. As part of the technical studies supporting the Basin Plan, the RRAM analysis (MDBA, 2012c) provided a risk assessment for each unit. There is a strong alignment between the RRAM analysis, the PB review and the connectivity factors defined by Richardson et al. (2008). Subsequent to these studies, the connectivity for a few units were changed, including:

(1) Lachlan Fold Belt: Based on expert advice, the CF was changed (from 0.3) to a range of between 0.3 and 0.6 '. Current methodology uses 0.3 again.
(2) Shepparton Formation-related SDL units: connectivity factor was set to zero due to benefits of pumping from these aquifers.
(3) Goulburn-Murray Sedimentary Plain: also set to zero, presumably due to PB (2009) recommendation on floodplain alluvium.
(4) Deep groundwater systems: assigned zero connectivity.
(5) NSW Great Artesian Basin Shallow WRP area: changed to zero, but changed back to 0.17.

Most of these changes are minor. The Shepparton-related aquifers are the most significant. The BDL and SDL for these units were set high (above current groundwater extraction) to enable maximum flexibility for protection of land from waterlogging and salinity and to reduce salt loads to streams. The connectivity was set to zero, recognizing the trade-offs between these positive benefits and the negative aspect of reduced leakage from rivers. This combination has the potential to affect the final river flow impact significantly. Previously, the Goulburn-Murray Sedimentary Basin (Victorian side) had been categorized as moderate connectivity, with a connectivity factor of 0.6. The equivalent systems in the Lower Murray (NSW side) had always been zero. To review both this inconsistency and the changed value, the modelling outputs were used to derive a connectivity factor, as described later.

The Lachlan Fold Belt also has the potential to make a significant difference. The unit covers a large area of the MDB and while extraction is of a low intensity, the total volume is high. The discussion on the connectivity factor reflects the variability of the unit. We have chosen a higher value reflecting the discussion in MDBA (2012b).

In reviewing the connectivity factors, most of the prior connectivity factors were retained. However, a number of them were adjusted as follows:

(1) Some of the western units had a change from 0 to 0.1 to reflect parts of the unit, where groundwater was fresh to brackish and in proximity to the stream,
(2) Some of the deeper aquifers within the floodplain alluvia were assigned a non-zero value, according to groundwater modelling output.

As recognition of the uncertainty, we considered also the lower and upper limits of the connectivity factors. This will result in a band of impacts for each growth scenario. The specific values are given in Appendix C.

An objective and transparent approach to estimating connectivity is the comparison of groundwater modelling outputs for different scenarios. In the preparation of the Draft Basin Plan, a number of groundwater models were developed for major floodplain alluvial and mid-valley alluvial systems. Scenarios included development scenarios, changed irrigation recharge and changed climate conditions. By choosing the scenarios with which to compare outputs carefully, we can analyse the connectivity for different processes. For example, if we are interested in the connectivity with extraction in the deep aquifer, one would choose scenarios which differs only in the amount of extraction from that aquifer. Similarly, if we are interested in irrigation returns from changed irrigation seepage, we would compare two scenarios with different irrigation recharge rates. In this way, we can derive a range of connectivity factors for different processes. The model outputs are for 2010-2060 and the connectivity factors reflect that time-scale. In the case of the Southern Riverine Plain, another unpublished model with a finer mesh and more focus on stream processes was used to cross-check conclusions.

Appendix C: Connectivity and river flow impact data for growth scenarios.

The main text has provided information on the aggregated river flow impacts across the MDB for the different extraction scenarios. This Appendix contains two Tables that provide the data by SDL unit. In the first Table, the information on the connectivity and total impact is given. For the second, the impact is partitioned into that within the BDL and above the BDL. There are four different values for the connectivity. The first is that currently being used by MDBA. The second is the value assigned after review of the connectivity, as described in Appendix B. The third and fourth are the considered to be the lower and upper limits for the connectivity factor for that unit. Often, this is 0.1 below and 0.1 above the assigned value.

C.1 River flow Impact for different growth scenarios

		connectivity				total Full SDL				total 4% growth rate				total 2% growth rate			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS1a	Angas Bremer (Quaternary Sediments)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02
GS1b	Angas Bremer (Murray Group Limestone)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.21
GS2	Eastern Mount Lofty Ranges	0.00	0.00	0.00	0.10	0.00	0.00	0.00	3.56	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.25
GS3a	Mallee (Pliocene Sands)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS3b	Mallee (Murray Group Limestone)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	2.86	0.00	0.00	0.00	2.86	0.00	0.00	0.00	2.82
GS3c	Mallee (Renmark Group)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02
GS4a	Marne Saunders (fractured rock)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.05
GS4b	Marne Saunders (Murray Group Limestone)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.09
GS4c	Marne Saunders (Renmark Group)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02

		connectivity				total Full SDL				total 4% growth rate				total 2% growth rate			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS5a	Peake–Roby–Sherlock (unconfined)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS5b	Peake–Roby–Sherlock (confined)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS6	SA Murray	0.00	0.10	0.00	0.10	0.00	6.42	0.00	6.42	0.00	0.13	0.00	0.13	0.00	0.07	0.00	0.07
GS7	SA Murray Salt Interception Schemes	0.00	0.30	0.20	0.40	0.00	5.31	3.54	7.08	0.00	5.31	3.54	7.08	0.00	2.67	1.78	3.56
GS8a	Goulburn-Murray: Shepparton Irrigation Region	0.00	0.50	0.20	0.70	0.00	96.64	38.65	135.29	0.00	40.79	16.32	57.11	0.00	20.42	8.17	28.59
GS8b	Goulburn-Murray: Highlands	0.60	0.60	0.40	0.70	33.84	33.84	22.56	39.48	11.97	11.97	7.98	13.96	6.01	6.01	4.01	7.02
GS8c	Goulburn-Murray: Sedimentary Plain	0.00	0.20	0.10	0.40	0.00	19.94	9.97	39.88	0.00	19.94	9.97	39.88	0.00	19.77	9.88	39.53
GS8d	Goulburn-Murray: deep	0.00	0.00	0.00	0.10	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02
GS9a	Wimmera-Mallee: Highlands	0.50	0.50	0.20	0.60	1.06	1.06	0.43	1.28	0.63	0.63	0.25	0.75	0.34	0.34	0.14	0.41
GS9b	Wimmera-Mallee: Sedimentary Plain	0.00	0.10	0.00	0.20	0.00	18.09	0.00	36.18	0.00	1.50	0.00	2.99	0.00	0.75	0.00	1.51
GS9c	Wimmera-Mallee: deep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

		connectivity				total Full SDL				total 4% growth rate				total 2% growth rate			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS10	Adelaide Fold Belt MDB	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.19
GS11	Bell Valley Alluvium	0.60	0.60	0.50	0.70	1.23	1.23	1.03	1.44	1.23	1.23	1.03	1.44	0.70	0.70	0.59	0.82
GS12	Belubula Alluvium	0.15	0.15	0.05	0.40	0.18	0.18	0.06	0.48	0.18	0.18	0.06	0.48	0.18	0.18	0.06	0.48
GS13	Billabong Creek Alluvium	0.37	0.37	0.27	0.47	1.99	1.99	1.45	2.53	1.35	1.35	0.98	1.71	0.69	0.69	0.51	0.88
GS14	Castlereagh Alluvium	0.60	0.60	0.50	0.70	0.32	0.32	0.27	0.38	0.23	0.23	0.19	0.27	0.15	0.15	0.12	0.17
GS15	Coolaburragundy–Talbragar Alluvium	0.60	0.60	0.50	0.70	0.91	0.91	0.76	1.06	0.91	0.91	0.76	1.06	0.91	0.91	0.76	1.06
GS16	Cudgegong Alluvium	0.96	0.96	0.86	1.06	0.86	0.86	0.77	0.95	0.86	0.86	0.77	0.95	0.86	0.86	0.77	0.95
GS17	Gunnedah-Oxley Basin MDB	0.00	0.00	0.00	0.10	0.00	0.00	0.00	12.16	0.00	0.00	0.00	0.97	0.00	0.00	0.00	0.49
GS18	Inverell Basalt	0.35	0.35	0.25	0.45	1.06	1.06	0.76	1.36	0.72	0.72	0.52	0.93	0.38	0.38	0.27	0.49
GS19	Kanmantoo Fold Belt MDB	0.00	0.00	0.00	0.10	0.00	0.00	0.00	1.05	0.00	0.00	0.00	1.05	0.00	0.00	0.00	0.68
GS20	Lachlan Fold Belt MDB	0.30	0.50	0.20	0.60	53.68	89.47	35.79	107.36	38.51	64.19	25.67	77.02	19.27	32.12	12.85	38.54
GS21	Lake George Alluvium	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.04
GS22	Liverpool Ranges Basalt	0.32	0.32	0.22	0.42	0.10	0.10	0.07	0.14	0.10	0.10	0.07	0.14	0.10	0.10	0.07	0.14

		connectivity				total Full SDL				total 4% growth rate				total 2% growth rate			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS23	Lower Darling Alluvium	0.00	0.10	0.00	0.20	0.00	0.15	0.00	0.30	0.00	0.14	0.00	0.29	0.00	0.08	0.00	0.15
GS24	Lower Gwydir Alluvium	0.13	0.13	0.03	0.23	-0.13	-0.13	-0.03	-0.23	-0.13	-0.13	-0.03	-0.23	-0.13	-0.13	-0.03	-0.23
GS25	Lower Lachlan Alluvium	0.00	0.10	0.00	0.20	0.00	1.15	0.00	2.30	0.00	1.15	0.00	2.30	0.00	1.15	0.00	2.30
GS26	Lower Macquarie Alluvium	0.22	0.22	0.12	0.32	7.27	7.27	3.96	10.57	7.27	7.27	3.96	10.57	6.67	6.67	3.64	9.70
GS27a	Lower Murray Shallow Alluvium	0.00	0.50	0.20	0.60	0.00	38.97	15.59	46.76	0.00	3.30	1.32	3.96	0.00	1.67	0.67	2.01
GS27b	Lower Murray Deep Alluvium	0.00	0.10	0.00	0.20	0.00	2.98	0.00	5.96	0.00	2.98	0.00	5.96	0.00	2.98	0.00	5.96
GS28a	Lower Murrumbidgee Shallow Alluvium	0.02	0.02	0.00	0.12	0.45	0.45	0.00	2.68	0.15	0.15	0.00	0.91	0.08	0.08	0.00	0.46
GS28b	Lower Murrumbidgee Deep Alluvium	0.02	0.02	0.00	0.12	1.25	1.25	0.00	7.49	1.25	1.25	0.00	7.49	1.25	1.25	0.00	7.49
GS29	Lower Namoi Alluvium	0.00	0.10	0.00	0.20	0.00	0.62	0.00	1.24	0.00	0.62	0.00	1.24	0.00	0.62	0.00	1.24
GS30	Manilla Alluvium	0.15	0.15	0.05	0.40	0.15	0.15	0.05	0.41	0.09	0.09	0.03	0.24	0.05	0.05	0.02	0.14
GS31	Mid-Murrumbidgee Alluvium	0.73	0.73	0.50	0.83	12.24	12.24	8.39	13.92	12.24	12.24	8.39	13.92	12.24	12.24	8.39	13.92
GS32	NSW Border Rivers Alluvium	0.31	0.31	0.21	0.41	1.05	1.05	0.71	1.39	1.05	1.05	0.71	1.39	1.05	1.05	0.71	1.39

		connectivity				total Full SDL				total 4% growth rate				total 2% growth rate			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS33	NSW Border Rivers Tributary Alluvium	0.31	0.31	0.21	0.41	0.07	0.07	0.05	0.10	0.07	0.07	0.05	0.10	0.07	0.07	0.05	0.10
GS34	NSW GAB Surat Shallow	0.17	0.17	0.00	0.27	2.26	2.26	0.00	3.59	0.64	0.64	0.00	1.02	0.33	0.33	0.00	0.52
GS35	NSW GAB Warrego Shallow	0.17	0.17	0.00	0.27	5.57	5.57	0.00	8.84	0.22	0.22	0.00	0.35	0.12	0.12	0.00	0.19
GS36	NSW GAB Central Shallow	0.17	0.17	0.00	0.27	1.30	1.30	0.00	2.07	0.36	0.36	0.00	0.57	0.19	0.19	0.00	0.30
GS37	New England Fold Belt MDB	0.32	0.32	0.22	0.50	11.25	11.25	7.73	17.57	10.30	10.30	7.08	16.10	5.17	5.17	3.55	8.07
GS38	Oaklands Basin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS39	Orange Basalt	0.30	0.30	0.20	0.50	2.94	2.94	1.96	4.90	0.51	0.51	0.34	0.85	0.27	0.27	0.18	0.45
GS40	Peel Valley Alluvium	0.83	0.83	0.73	0.93	2.21	2.21	1.95	2.48	2.21	2.21	1.95	2.48	2.21	2.21	1.95	2.48
GS41	Sydney Basin MDB	0.00	0.00	0.00	0.10	0.00	0.00	0.00	1.86	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.06
GS42	Upper Darling Alluvium	0.12	0.12	0.02	0.30	0.56	0.56	0.09	1.39	0.41	0.41	0.07	1.02	0.21	0.21	0.03	0.52
GS43	Upper Gwydir Alluvium	0.52	0.52	0.42	0.62	0.34	0.34	0.27	0.40	0.20	0.20	0.16	0.23	0.12	0.12	0.10	0.15
GS44	Upper Lachlan Alluvium	0.62	0.62	0.52	0.72	26.29	26.29	22.05	30.53	26.29	26.29	22.05	30.53	25.80	25.80	21.64	29.96
GS45	Upper Macquarie Alluvium	0.42	0.42	0.32	0.52	2.06	2.06	1.57	2.55	2.06	2.06	1.57	2.55	2.06	2.06	1.57	2.55

		connectivity				total Full SDL				total 4% growth rate				total 2% growth rate			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS46	Upper Murray Alluvium	0.80	0.80	0.60	0.80	3.41	3.41	2.55	3.41	3.41	3.41	2.55	3.41	3.41	3.41	2.55	3.41
GS47	Upper Namoi Alluvium	0.18	0.18	0.08	0.28	5.95	5.95	2.64	9.25	5.95	5.95	2.64	9.25	5.95	5.95	2.64	9.25
GS48	Upper Namoi Tributary Alluvium	0.18	0.18	0.08	0.40	0.28	0.28	0.13	0.63	0.11	0.11	0.05	0.24	0.06	0.06	0.03	0.14
GS49	Warrumbungle Basalt	0.31	0.31	0.21	0.41	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02
GS50	Western Porous Rock	0.00	0.10	0.00	0.20	0.00	19.52	0.00	39.03	0.00	4.96	0.00	9.92	0.00	2.49	0.00	4.97
GS51	Young Granite	0.25	0.25	0.15	0.45	1.42	1.42	0.85	2.55	0.64	0.64	0.39	1.16	0.33	0.33	0.20	0.60
GS52	Australian Capital Territory (Groundwater)	0.30	0.30	0.20	0.40	0.77	0.77	0.52	1.03	0.36	0.36	0.24	0.47	0.19	0.19	0.13	0.26
GS53	Condamine Fractured Rock	0.60	0.60	0.50	0.70	0.62	0.62	0.52	0.72	0.58	0.58	0.49	0.68	0.32	0.32	0.27	0.38
GS54	Queensland Border Rivers Alluvium	0.31	0.31	0.21	0.41	1.12	1.12	0.76	1.47	1.12	1.12	0.76	1.47	1.12	1.12	0.76	1.47
GS55	Queensland Border Rivers Fractured Rock	0.60	0.60	0.50	0.70	1.89	1.89	1.58	2.21	1.89	1.89	1.58	2.21	1.89	1.89	1.58	2.21
GS56	Queensland MDB: deep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

		connectivity				total Full SDL				total 4% growth rate				total 2% growth rate			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS57	Sediments above the Great Artesian Basin: Border Rivers-Moonie	0.00	0.00	0.00	0.10	0.00	0.00	0.00	4.67	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.04
GS58	Sediments above the Great Artesian Basin: Condamine–Balonne	0.00	0.00	0.00	0.10	0.00	0.00	0.00	1.76	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.06
GS60	Sediments above the Great Artesian Basin: Warrego–Paroo–Nebine	0.00	0.00	0.00	0.10	0.00	0.00	0.00	9.83	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.09
GS61 b	St George Alluvium: Condamine–Balonne (deep)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.15
GS61 a	St George Alluvium: Condamine–Balonne (shallow)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	2.71	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.07
GS62	St George Alluvium: Moonie	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02

		connectivity				total Full SDL				total 4% growth rate				total 2% growth rate			

SDL code	SDL resource unit	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high
GS63	St George Alluvium: Warrego–Paroo–Nebine	0.00	0.00	0.00	0.10	0.00	0.00	0.00	2.45	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.03
GS64 a	Upper Condamine Alluvium (Central Condamine Alluvium)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.61
GS64 b	Upper Condamine Alluvium (Tributaries)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	1.28	0.00	0.00	0.00	1.28	0.00	0.00	0.00	1.28
GS65	Upper Condamine Basalts	0.35	0.35	0.25	0.45	6.02	6.02	4.30	7.74	6.02	6.02	4.30	7.74	6.02	6.02	4.30	7.74
GS66	Warrego Alluvium	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.07
				Totals		**194**	**439**	**194**	**666**	**142**	**248**	**129**	**356**	**107**	**172**	**95**	**252**

C.2 River flow Impact for different growth scenarios and partitioned into components within and above the BDL

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS1a	Angas Bremer (Quaternary Sediments)	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS1b	Angas Bremer (Murray Group Limestone)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.21
GS2	Eastern Mount Lofty Ranges	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.18	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.25
GS3a	Mallee (Pliocene Sands)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS3b	Mallee (Murray Group Limestone)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.86	0.00	0.00	0.00	2.86	0.00	0.00	0.00	2.82
GS3c	Mallee (Renmark Group)	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS4a	Marne Saunders (fractured rock)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.05
GS4b	Marne Saunders (Murray Group Limestone)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.09

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS4c	Marne Saunders (Renmark Group)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02
GS5a	Peake–Roby–Sherlock (unconfined)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS5b	Peake–Roby–Sherlock (confined)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS6	SA Murray	0.00	6.30	0.00	6.30	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.12	0.00	0.07	0.00	0.07
GS7	SA Murray Salt Interception Schemes	0.00	4.62	3.08	6.16	0.00	4.62	3.08	6.16	0.00	1.98	1.32	2.64	0.00	0.69	0.46	0.92	0.00	0.69	0.46	0.92	0.00	0.69	0.46	0.92
GS8a	Goulburn-Murray: Shepparton Irrigation Region	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	96.64	38.65	135.29	0.00	40.79	16.32	57.11	0.00	20.42	8.17	28.59
GS8b	Goulburn-Murray: Highlands	18.24	18.24	12.16	21.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.60	15.60	10.40	18.20	11.97	11.97	7.98	13.96	6.01	6.01	4.01	7.02
GS8c	Goulburn-Murray: Sedimentary Plain	0.00	3.90	1.95	7.80	0.00	3.90	1.95	7.80	0.00	3.73	1.86	7.45	0.00	16.04	8.02	32.08	0.00	16.04	8.02	32.08	0.00	16.04	8.02	32.08
GS8d	Goulburn-Murray: deep	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS9a	Wimmera-Mallee: Highlands	0.75	0.75	0.30	0.89	0.31	0.31	0.12	0.37	0.02	0.02	0.01	0.02	0.32	0.32	0.13	0.38	0.32	0.32	0.13	0.38	0.32	0.32	0.13	0.38
GS9b	Wimmera-Mallee: Sedimentary Plain	0.00	12.12	0.00	24.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.97	0.00	11.94	0.00	1.50	0.00	2.99	0.00	0.75	0.00	1.51
GS9c	Wimmera-Mallee: deep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS10	Adelaide Fold Belt MDB	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.15
GS11	Bell Valley Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	1.23	1.03	1.44	1.23	1.23	1.03	1.44	0.70	0.70	0.59	0.82
GS12	Belubula Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.18	0.06	0.48	0.18	0.18	0.06	0.48	0.18	0.18	0.06	0.48
GS13	Billabong Creek Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.99	1.99	1.45	2.53	1.35	1.35	0.98	1.71	0.69	0.69	0.51	0.88
GS14	Castlereagh Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.32	0.27	0.38	0.23	0.23	0.19	0.27	0.15	0.15	0.12	0.17
GS15	Coolaburragundy–Talbragar Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.91	0.76	1.06	0.91	0.91	0.76	1.06	0.91	0.91	0.76	1.06
GS16	Cudgegong Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.86	0.77	0.95	0.86	0.86	0.77	0.95	0.86	0.86	0.77	0.95
GS17	Gunnedah-Oxley Basin MDB	0.00	0.00	0.00	10.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.62	0.00	0.00	0.00	0.97	0.00	0.00	0.00	0.49
GS18	Inverell Basalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	1.06	0.76	1.36	0.72	0.72	0.52	0.93	0.38	0.38	0.27	0.49

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	SDL resource unit	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high
GS19	Kanmantoo Fold Belt MDB	0.00	0.00	0.00	0.98	0.00	0.00	0.00	0.98	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.07
GS20	Lachlan Fold Belt MDB	34.98	58.30	23.32	69.96	19.81	33.02	13.21	39.63	0.57	0.95	0.38	1.14	18.70	31.17	12.47	37.40	18.70	31.17	12.47	37.40	18.70	31.17	12.47	37.40
GS21	Lake George Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.04
GS22	Liverpool Ranges Basalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.07	0.14	0.10	0.10	0.07	0.14	0.10	0.10	0.07	0.14
GS23	Lower Darling Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.30	0.00	0.14	0.00	0.29	0.00	0.08	0.00	0.15
GS24	Lower Gwydir Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.13	-0.13	0.03	-0.23	-0.13	0.13	0.03	-0.23	-0.13	0.13	0.03	0.23
GS25	Lower Lachlan Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.00	2.30	0.00	1.15	0.00	2.30	0.00	1.15	0.00	2.30
GS26	Lower Macquarie Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.27	7.27	3.96	10.57	7.27	7.27	3.96	10.57	6.67	6.67	3.64	9.70
GS27a	Lower Murray Shallow Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.97	15.59	46.76	0.00	3.30	1.32	3.96	0.00	1.67	0.67	2.01
GS27b	Lower Murray Deep Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.98	0.00	5.96	0.00	2.98	0.00	5.96	0.00	2.98	0.00	5.96
GS28a	Lower Murrumbidgee Shallow Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.45	0.00	2.68	0.15	0.15	0.00	0.91	0.08	0.08	0.00	0.46

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS28b	Lower Murrumbidgee Deep Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25	1.25	0.00	7.49	1.25	1.25	0.00	7.49	1.25	1.25	0.00	7.49
GS29	Lower Namoi Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	1.24	0.00	0.62	0.00	1.24	0.00	0.62	0.00	1.24
GS30	Manilla Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.05	0.41	0.09	0.09	0.03	0.24	0.05	0.05	0.02	0.14
GS31	Mid-Murrumbidgee Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.24	12.24	8.39	13.92	12.24	12.24	8.39	13.92	12.24	12.24	8.39	13.92
GS32	NSW Border Rivers Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.05	1.05	0.71	1.39	1.05	1.05	0.71	1.39	1.05	1.05	0.71	1.39
GS33	NSW Border Rivers Tributary Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.05	0.10	0.07	0.07	0.05	0.10	0.07	0.07	0.05	0.10
GS34	NSW GAB Surat Shallow	1.52	1.52	0.00	2.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.74	0.00	1.18	0.64	0.64	0.00	1.02	0.33	0.33	0.00	0.52
GS35	NSW GAB Warrego Shallow	5.57	5.57	0.00	8.84	0.22	0.22	0.00	0.35	0.12	0.12	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS36	NSW GAB Central Shallow	1.46	1.46	0.00	2.32	0.52	0.52	0.00	0.82	0.34	0.34	0.00	0.55	-0.16	-0.16	0.00	-0.25	-0.16	-0.16	0.00	-0.25	-0.16	-0.16	0.00	-0.25
GS37	New England Fold Belt MDB	7.10	7.10	4.88	11.10	6.16	6.16	4.24	9.63	1.03	1.03	0.71	1.60	4.14	4.14	2.85	6.47	4.14	4.14	2.85	6.47	4.14	4.14	2.85	6.47

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS38	Oaklands Basin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS39	Orange Basalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.94	2.94	1.96	4.90	0.51	0.51	0.34	0.85	0.27	0.27	0.18	0.45
GS40	Peel Valley Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.21	2.21	1.95	2.48	2.21	2.21	1.95	2.48	2.21	2.21	1.95	2.48
GS41	Sydney Basin MDB	0.00	0.00	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.06
GS42	Upper Darling Alluvium	0.04	0.04	0.01	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.52	0.09	1.30	0.41	0.41	0.07	1.02	0.21	0.21	0.03	0.52
GS43	Upper Gwydir Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.34	0.27	0.40	0.20	0.20	0.16	0.23	0.12	0.12	0.10	0.15
GS44	Upper Lachlan Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.29	26.29	22.05	30.53	26.29	26.29	22.05	30.53	25.80	25.80	21.64	29.96
GS45	Upper Macquarie Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.06	2.06	1.57	2.55	2.06	2.06	1.57	2.55	2.06	2.06	1.57	2.55
GS46	Upper Murray Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.41	3.41	2.55	3.41	3.41	3.41	2.55	3.41	3.41	3.41	2.55	3.41
GS47	Upper Namoi Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.95	5.95	2.64	9.25	5.95	5.95	2.64	9.25	5.95	5.95	2.64	9.25
GS48	Upper Namoi Tributary Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.28	0.13	0.63	0.11	0.11	0.05	0.24	0.06	0.06	0.03	0.14
GS49	Warrumbungle Basalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	SDL resource unit	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high	MDBA	New	low	high
GS50	Western Porous Rock	0.00	16.29	0.00	32.58	0.00	1.74	0.00	3.47	0.00	0.00	0.00	0.00	0.00	3.23	0.00	6.45	0.00	3.23	0.00	6.45	0.00	2.49	0.00	4.97
GS51	Young Granite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42	1.42	0.85	2.55	0.64	0.64	0.39	1.16	0.33	0.33	0.20	0.60
GS52	Australian Capital Territory (Groundwater)	0.27	0.27	0.18	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.51	0.34	0.68	0.36	0.36	0.24	0.47	0.19	0.19	0.13	0.26
GS53	Condamine Fractured Rock	0.40	0.40	0.33	0.46	0.36	0.36	0.30	0.42	0.10	0.10	0.08	0.12	0.22	0.22	0.18	0.26	0.22	0.22	0.18	0.26	0.22	0.22	0.18	0.26
GS54	Queensland Border Rivers Alluvium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	1.12	0.76	1.47	1.12	1.12	0.76	1.47	1.12	1.12	0.76	1.47
GS55	Queensland Border Rivers Fractured Rock	0.24	0.24	0.20	0.28	0.24	0.24	0.20	0.28	0.24	0.24	0.20	0.28	1.65	1.65	1.38	1.93	1.65	1.65	1.38	1.93	1.65	1.65	1.38	1.93
GS56	Queensland MDB: deep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS57	Sediments above the Great Artesian Basin: Border Rivers-Moonie	0.00	0.00	0.00	4.68	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.04	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	-0.01

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS58	Sediments above the Great Artesian Basin: Condamine–Balonne	0.00	0.00	0.00	1.74	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02
GS60	Sediments above the Great Artesian Basin: Warrego–Paroo–Nebine	0.00	0.00	0.00	9.80	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03
GS61b	St George Alluvium: Condamine–Balonne (deep)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.15
GS61a	St George Alluvium: Condamine–Balonne (shallow)	0.00	0.00	0.00	2.69	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
GS62	St George Alluvium: Moonie	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GS63	St George Alluvium: Warrego–Paroo–Nebine	0.00	0.00	0.00	2.45	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

		Full SDL above BDL				4% growth rate above BDL				2% growth rate above BDL				Full SDL below BDL				4% growth rate within BDL				2% growth rate within BDL			
SDL code	**SDL resource unit**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**	**MDBA**	**New**	**low**	**high**
GS64a	Upper Condamine Alluvium (Central Condamine Alluvium)	0.00	0.00	0.00	-3.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.15	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.61
GS64b	Upper Condamine Alluvium (Tributaries)	0.00	0.00	0.00	-0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.78	0.00	0.00	0.00	1.28	0.00	0.00	0.00	1.28
GS65	Upper Condamine Basalts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.02	6.02	4.30	7.74	6.02	6.02	4.30	7.74	6.02	6.02	4.30	7.74
GS66	Warrego Alluvium	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Totals	**71**	**137**	**46**	**230**	**28**	**51**	**23**	**71**	**2**	**9**	**5**	**15**	**123**	**302**	**148**	**437**	**114**	**197**	**106**	**285**	**104**	**164**	**90**	**237**

Appendix D: Historical changes in surface return flow

For a given amount of water diversion from a river to an irrigation scheme, more efficient irrigation generally leads to less return flow to the river (Perry, 2011; Scott et al., 2014; Perry, 2017; Grafton et al., 2018b; Linstead, 2018). To assess the impact of an irrigation efficiency project on return flow, it is important to understand the performance of the irrigation scheme just before the project. Here we briefly illustrate historical changes in surface return flow from major irrigation districts in MDB to highlight the development situation in 2009 before the major investment in irrigation efficiency projects for recovering water to 'bridge the gap' to the Sustainable Diversion Limits (SDLs) under the Murray-Darling Basin Plan.

The most comprehensive data compilation, review and analysis of return flow in MDB was conducted by URS (2010) for historical period up to 2008/09. They found that irrigation return flows had declined significantly since 1993/94. They concluded that:

> *"As the extended drought breaks, it is considered unlikely that return flows will increase again to levels experienced prior to 1997/98. This is because since that time significant changes in irrigation practice have occurred to more water use efficient operations, and there has been substantial investment in infrastructure modernisation, drainage capture and reuse, and trade of water entitlements (in some areas involving permanent exit of irrigated agriculture).*
>
> *It considered that return flows in average allocation and rainfall years may converge to levels slightly above 2002/03 - 2004/05 (reduced allocation and drought) levels but less than 1997/98 - 2000/01 (normal allocation) levels."*

Other regional studies also confirmed the significant decline of irrigation return flows (Feehan Consulting, 2015; JACOBS, 2017; JACOBS, 2018; RMCG, 2015).

We illustrate the historical changes by plotting drain flows passing some long-term monitoring stations in major irrigation districts. The data was provided by MDBA. For the two stations in the NSW Murray Irrigation District, some of the missing records were infilled by correlations with stations immediately up or down the drains. For the two stations in the Murrumbidgee Irrigation District, only monthly data was available, while daily flows are plotted for all other stations. It should be noted that the drain flows include both irrigation return flow and runoff from rainfall events.

In the Goulburn Murray and NSW Murray Irrigation Districts (Figures D.1, D.2 and D.4), significant reduction in drain flows started before year 2000. There was little base-flow by 2005, and significant flow events were mainly due to rainfall. This pattern has remained post the Millennium Drought.

In the Coleambally and Murrumbidgee irrigation districts (Figures D.5 and D.6), there was a significant decline in drain flows as the Millennium Drought took hold. From the Murrumbidgee Irrigation Annual Licence Compliance Reports (MI, 2006, 2007 and after), both Yanco Main Southern and Gogeldrie Main Southern drains were blocked in the 2006/07 season and have remained so since. Drainage water is pumped back into the Stuart Canal for supplying customers downstream. Only during periods of heavy rainfall will water flow down the drains.

In the Lower Murray Irrigation District (Figure D.3), drainage water is mainly from subsurface drains. While base-flow was observed during the Millennium Drought in some of the drains, the total volume was low. After the drought, the base-flow volume has recovered to about the 2005 level.

These examples of historical drain flows are consistent with findings by URS (2010). In the 1990s, there were major initiatives in many irrigation districts to reduce salinity and nutrient inputs to rivers. The low to extremely low water allocation during the Millennium Drought and water trading meant that water became highly valuable. Water was moved to locations where it could be more efficiently applied. Irrigators made improvements to their irrigation systems and established or extended on-farm water reuse. In NSW, there has been legislative requirement for irrigators to prevent on-farm irrigation runoff. Rural water corporations invested in modernisation of supply infrastructure. For salinity and nutrient controls and for water resource use, district drainage diversion was systematically encouraged and managed (Feehan Consulting, 2015, MIL, 2014). The combination of reduced farm irrigation runoff, reduced supply outfall and active drainage diversion led to significantly reduced surface return flow.

By 2009, irrigation infrastructure and practices had significantly changed as such that the system had the capacity to release little irrigation water for return to river. For this reason, the scope for irrigation efficiency projects to further reduce surface return flow became low.

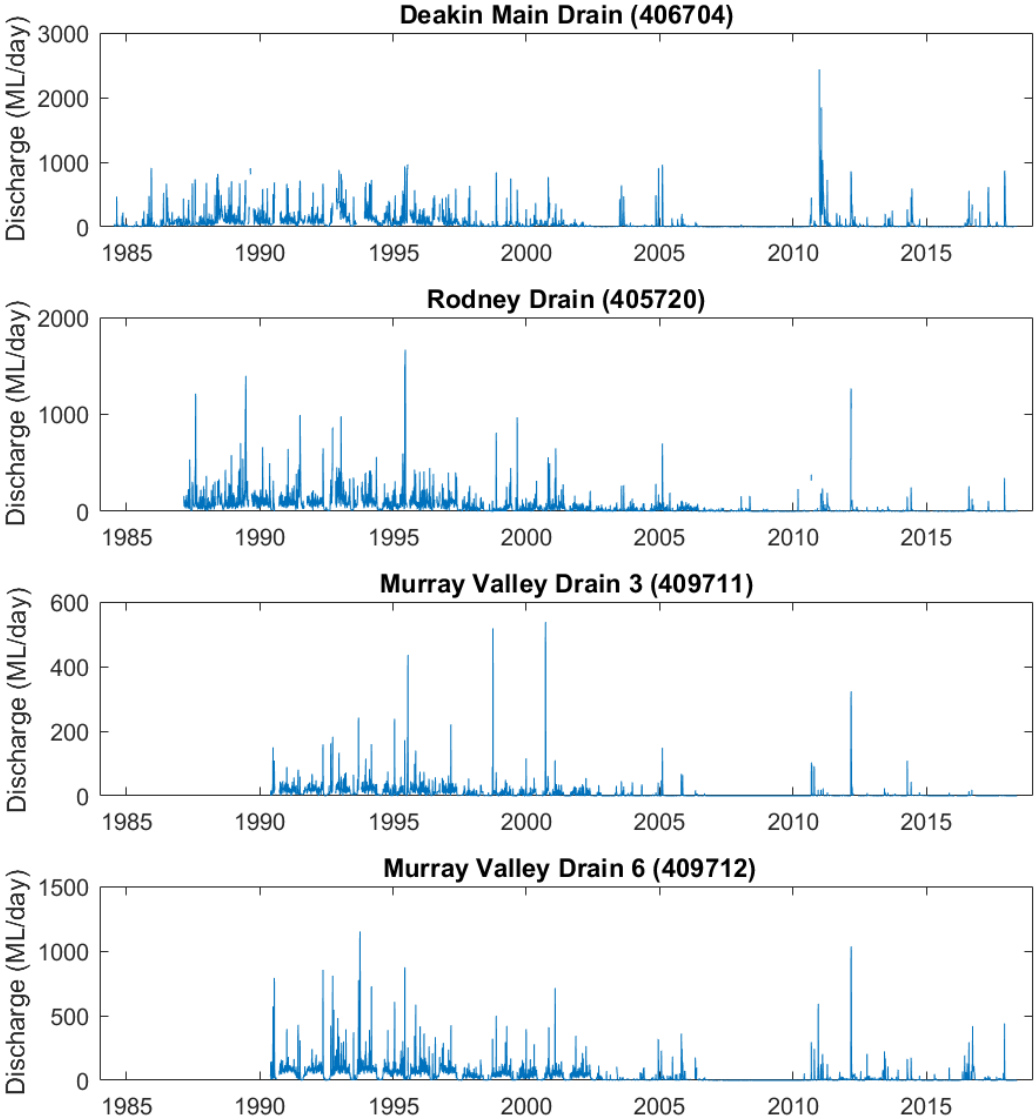

Figure D.1. Daily drain flows at locations in the Goulburn Murray Irrigation District (1)

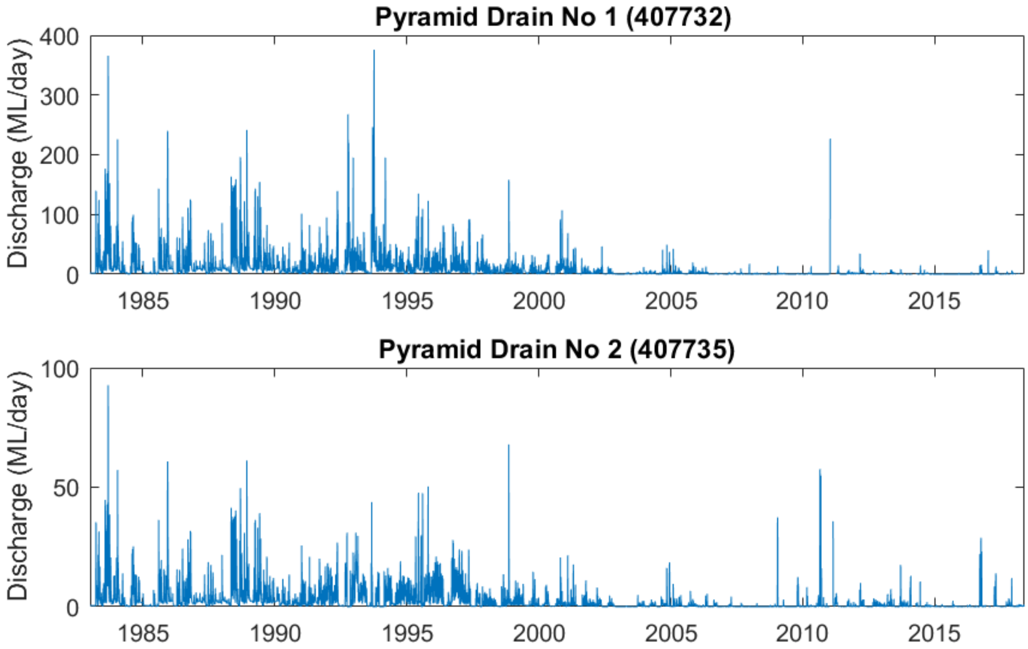

Figure D.2. Daily drain flows at locations in the Goulburn Murray Irrigation District (2)

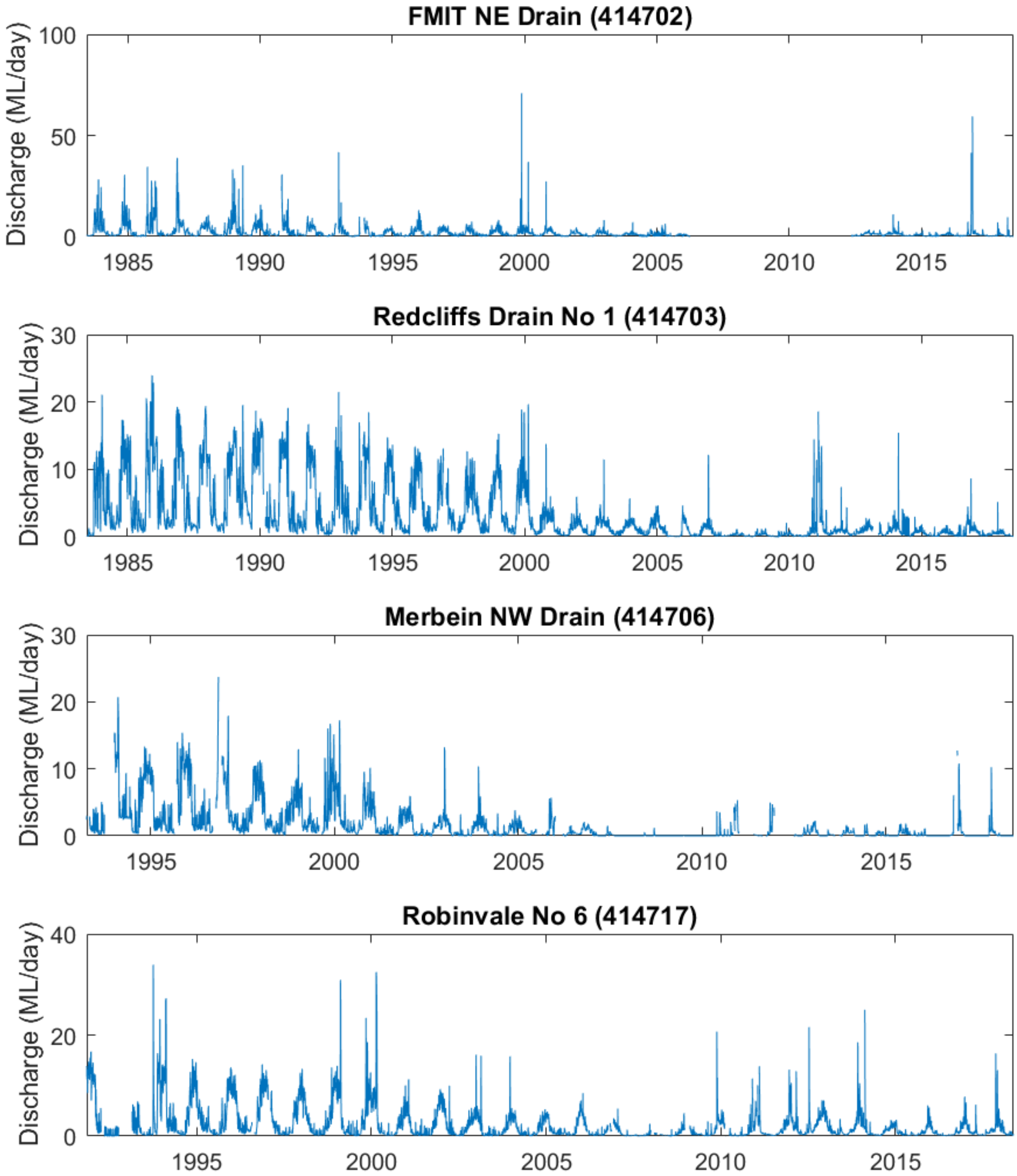

Figure D.3. Daily drain flows at locations in the Lower Murray Irrigation District

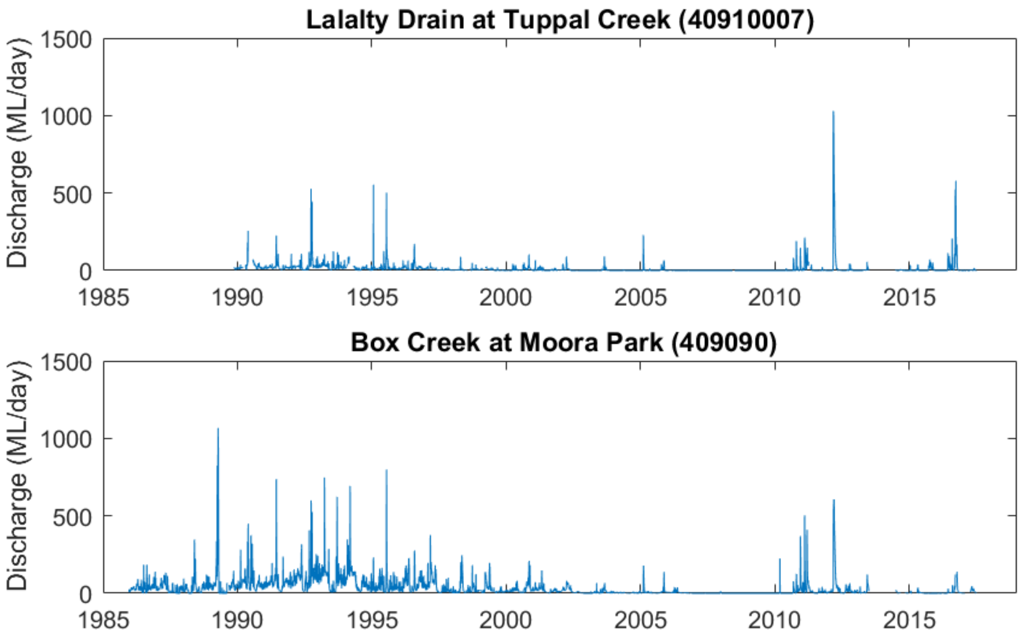

Figure D.4. Daily drain flows at locations in the NSW Murray Irrigation District

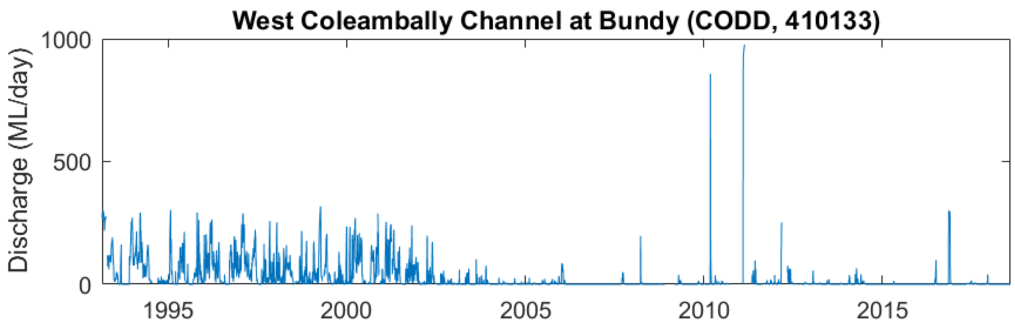

Figure D.5. Daily drain flow at a location in the Coleambally Irrigation District

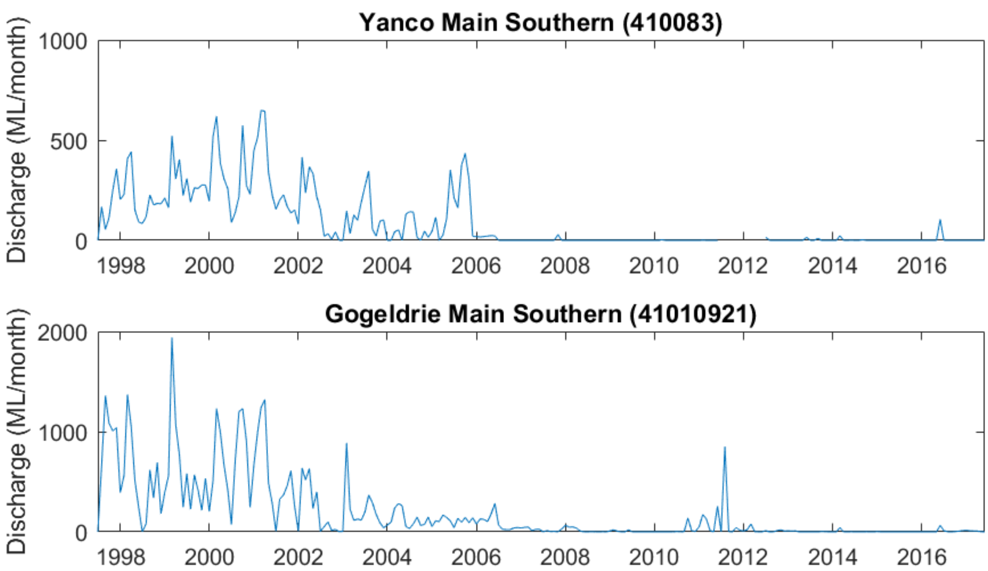

Figure D.6. Monthly drain flows at locations in the Murrumbidgee Irrigation District

Appendix E: Data and assumptions for estimating return flows

Impacts of irrigation efficiency projects on return flows are estimated at the level of consolidated projects. Data and assumptions are described below.

E.1 Water recovery and allocation

- Data for consolidated projects on total water recovery and on percentages of the recovery going to the environment and farms was provided by MDBA and DAWR. For Stage 1 of the GMW Connections project (also known as Northern Victoria Irrigation Renewal Project or NVIRP), one third of the recovery was allocated for urban supply. For this project, some of the saved water is used to mitigate the impact of reduced outfall on local environmental features. This mitigating flow volume has been subtracted from the total saved water when calculating the final project saving.

E.2 Sources of water saving - Victoria

- **GMW Connections project.** Data from the 2016/17 audit report (Cardno, 2017) is used for calculating the percentages of water saving sourced from reductions in evaporation (2%), seepage (8%), leakage (19%) and outfall (24%), and from metering (47%). The audit was conducted based on Water Savings Protocol Technical Manual (DSE, 2012). We further assume a breakdown of the leakage term to evapotranspiration (20%), seepage (20%), farm use (30%) and drainage water (30%), based on information from an unpublished report on Stage 2 Business Case (SKM, 2010) and consultation with experts.
- **Wimmera Mallee Pipeline Project (WMPP).** Water saving is assumed to be sourced from reductions in evaporation (11%), seepage (26%) and leakage (63%), based on information from an unpublished government report (DSE, 2010). We further assume a breakdown of the leakage term to be the same as for the GMW Connections project. All assumptions used for WMPP are also applied to the **Robinvale Pipeline project**.
- **Victoria Farm Modernisation on-farm projects.** We assume that water saving is sourced from reductions in evaporation (5%), seepage (65%) and farm irrigation runoff (30%). The assumption is based on an understanding of the mix of technologies being implemented by the projects (DELWP, 2018, Appendix 2), technical reports (RMCG, 2009; Ticehurst and Curtis, 2016) and published papers (Wood and Finger, 2006; Christen et al., 2009; Tennakoon et al., 2012; Holland et al., 2018). The assumption used for the Victoria Farm Modernisation projects is applied to all **OFIEP and NVIRP on-farm projects**.
- **Campaspe Decommissioning project.** All water saving is treated as from land retirement.
- **Sunraysia modernisation project.** The project replaced approximately 24 kilometres of open channels with pipeline and installed channel automation in the remaining 20 kilometres of open channels, including 19 regulating structures. We assume that 80% of the water saving is from replacing channels with pipeline, and 20% from channel automation. For the channel replacement, we apply the assumptions used for WMPP. For channel automation, we assume all saving is from reduction in outfall.

E.2 Sources of water saving – New South Wales

- **NSW Murray PIIOP**. According data from DAWR[1], 48% of the total water saving is from irrigation land retirement. Of the remaining water saving, which is from infrastructure upgrade, DAWR provided a breakdown to reductions in evaporation (13%), seepage (34.5%), leakage (theft) (14%) and escape (3.5%), and saving from metering (35%). The escape here refers to the net amount of water returning to the river at the system level and is therefore surface return flow. We further assume a breakdown of the leakage (theft) term to evaporation (20%), seepage (20%) and farm use (60%).
- **Murrumbidgee PIIOP.** DAWR provided data on percentages of water saving sourced from reductions in evaporation (23%), seepage (30%), leakage (theft) (15%) and escape (5%), and from metering (27%). We consider 23% of the water saving from reduction in evaporation as too high. We decreased evaporation to 13% and increased seepage to 40%, erring on the side of greater impact on return flow. We further assume a breakdown of the leakage (theft) term to evaporation (20%), seepage (20%) and farm use (60%).
- **Nimmie-Caira Enhanced Environmental Water project.** From our study of an unpublished MDBA technical report (MDBA, 2012c) on assessment of water saving of this project, the impact on surface return flow was already accounted for by the project when calculating water saving. However, impact on ground return flow was not considered. In our analysis, we adopt a net decrease of 51GL/yr water applied to farms (MDBA, 2012c) and calculate its impact on ground return flow.
- **PIIOP Macquarie.** Modernisation of four irrigation schemes was undertaken under this program, including Marthaguy, Narromine, Tenandra and Trangie Nevertire. From project reports (McBurnie, 2017, Sustainable Soils Management Pty Ltd, 2012, Sustainable Soils Management Pty Ltd, year unknown, Vanguard Business Services, 2016), 68% of the total water saving is from irrigation land retirement. For the remaining water saving from irrigation infrastructure upgrade, we adopt the final breakdown percentages used for the Murrumbidgee PIIOP.
- **NSW Metering Scheme project.** The project installed accurate water meters at unregulated, regulated and groundwater extraction points in the southern-connected catchments of the NSW Murray-Darling Basin. As detailed information is unavailable to us, we assume that all water saving is from surface water metering.
- **NSW Basin Pipes Stock and Domestic project**. We adopt the breakdown percentages used for the infrastructure upgrade components of the PIIOP projects in the same regions.
- **NSW OFIEP on-farm projects.** DAWR provided data on percentages of water saving sourced from reductions in evaporation (12%), seepage (42%) and escape (3%), and from metering (43%). Again, the escape here refers to the net amount of water returning to the river at the system level and is therefore surface return flow.

[1] DAWR provided estimates of sources of water saving for major projects in NSW and South Australia. The estimates were derived by examining water loss reports related to key irrigation networks. The reports included Hotspots assessments, Irrigation Modernisation Plans, applications for funding for the On-Farm Irrigation Efficiency Program, Private Irrigation Infrastructure Operators Program (PIIOP) in NSW and South Australian efficiency measures programs, and additional reporting from grant recipients. The information in these reports was generally not in a format that could be used, directly and consistently, for estimating the sources of water saving. Judgement had to be applied to reach the final estimates for different projects. The DAWR estimates were further considered, and at least in one case revised, by the review team.

E.3 Sources of water saving – South Australia

- **On-farm projects.** DAWR provided data on percentages of water saving sourced from reduction in evaporation (10%), seepage (25%), leakage (theft) (65%). We further assume a breakdown of the leakage (theft) term to evaporation (75%) and seepage (25%), as the leakage is mostly from above ground pipes.
- **Off-farm projects.** We assume all saving is from reduction in leakage (theft), with a further breakdown to evaporation (75%) and seepage (25%).

E.4 Parameters

- **DDD** - Fraction of district drainage water diverted for irrigation. A value of 95% is assumed for DDD for Victoria, for reason that nearly all the irrigation water entering the drains was diverted for irrigation (Appendix D). A value of 0% is used for NSW, as the escape term in the data provided by DAWR is the net amount of water returning to the river at irrigation system level. For SA, a value of 0% is used as there is no drainage diversion for irrigation.
- **FRD** - Fraction of water applied becoming farm runoff to district drains. A value of 10% is used for Victoria (RMCG, 2009). A value of 3% is used for NSW for two reasons. Firstly, NSW has legislation preventing farm irrigation runoff. Secondly, DDD value is set to 0% for NSW, and therefore FRD is the net escape after drainage reuse at irrigation system level is taken into account. In SA, farm irrigation runoff is diverted to disposal basins for salinity control. As our return flow estimation equations have not formally included a term on drainage diversion to disposal basins, we factor this practice into the value for FRD to account for net irrigation runoff at system level. As there is little net runoff in SA, we adopt a value of 0% for FRD.
- **FRG** - Fraction of water applied becoming farm recharge to groundwater. A value of 10% is used for all projects.
- **CF** - Groundwater and river connectivity. Values of CF are taken from Section 3. These are:
    - Broken 0.4, Campaspe 0.1, Goulburn 0.4, Loddon 0.1, Vic Murray (above choke) 0.5, Vic Murray (below choke) 0.2
    - Macquarie 0.2, NSW Murray (above choke) 0.4, NSW (below choke) 0.2, Murrumbidgee 0.05
    - SA Murray 0.5

Appendix F: Detailed results for return flows by region

Table F.1 Return flow results for the Goulburn, Broken, Loddon and Campaspe

Project	Type	Total Recovery (GL/yr)	Env. Recovery (GL/yr)	% Transferred	Reduction in surface return (GL/yr)	Reduction in ground return (GL/yr)	Reduction in total return (GL/yr)
Broken							
OFIEP	On-Farm	0.3	0.2	68%	0.0	0.1	0.1
Vic Farm Modernisation	On-Farm	0.5	0.3	55%	0.0	0.1	0.1
Broken Total		**0.8**	**0.5**	**60%**	**0.0**	**0.2**	**0.2**
Campaspe							
OFIEP	On-Farm	0.2	0.1	68%	0.0	0.0	0.0
Vic Farm Modernisation	On-Farm	0.1	0.1	55%	0.0	0.0	0.0
(VIC) NVIRP Campaspe Decom	Off-Farm	68.4	22.6	33%	0.3	0.7	1.0
Campaspe Total		**68.7**	**22.8**	**33%**	**0.3**	**0.7**	**1.1**
Goulburn							
GMW Connections	Off-Farm	51.0	51.0	100%	1.0	4.1	5.0
NVIRP on-farm	On-Farm	8.1	4.1	50%	0.1	1.9	2.0
OFIEP	On-Farm	35.7	24.3	68%	0.6	8.6	9.2
Vic Farm Modernisation	On-Farm	26.3	14.7	56%	0.4	6.2	6.6
(VIC) NVIRP Stage 1	Off-Farm	103.2	34.1	33%	1.8	6.9	8.6
(VIC) WMPP/LMP*	Off-Farm	1.8	1.4	78%	0.0	0.3	0.3
Goulburn Total		**226.1**	**129.5**	**57%**	**4.0**	**27.9**	**31.8**
Loddon							
OFIEP	On-Farm	0.8	0.6	68%	0.0	0.1	0.1
(VIC) NVIRP Stage 1	Off-Farm	4.5	1.5	33%	0.1	0.1	0.2
(VIC) WMPP	Off-Farm	9.1	7.1	78%	0.1	0.4	0.5
Loddon Total		**14.4**	**9.1**	**64%**	**0.2**	**0.5**	**0.7**
TOTAL		**310.0**	**161.9**	**52%**	**4.5**	**29.3**	**33.8**

Table F.2 Return flow results for the Victorian Murray

Project	Type	Total Recovery (GL/yr)	Env. Recovery (GL/yr)	% Transferred	Reduction in surface return (GL/yr)	Reduction in ground return (GL/yr)	Reduction in total return (GL/yr)
Vic Murray (above choke)							
GMW Connections	Off-Farm	36.3	18.1	50%	0.6	2.7	3.3
NVIRP on-farm	On-Farm	7.8	3.9	50%	0.1	2.3	2.4
OFIEP	On-Farm	11.8	8.0	68%	0.2	3.5	3.7
Vic Farm Modernisation	On-Farm	15.9	8.9	56%	0.3	4.7	5.0
Vic Murray (above choke) Total		**71.7**	**39.0**	**54%**	**1.2**	**13.2**	**14.4**
Vic Murray below choke)							
GMW Connections	Off-Farm	32.9	32.9	100%	0.6	1.3	1.9
NVIRP on-farm	On-Farm	4.6	2.3	50%	0.1	0.5	0.6
OFIEP	On-Farm	12.9	8.8	68%	0.2	1.6	1.8
Sunraysia Modernisation	Off-Farm	7.8	7.0	90%	0.1	0.6	0.7
Vic Farm Modernisation	On-Farm	10.8	6.0	56%	0.2	1.3	1.5
(VIC) NVIRP Stage 1	Off-Farm	87.8	29.0	33%	1.5	2.9	4.4
(VIC) Robinvale Pipeline	Off-Farm	2.2	1.1	50%	0.0	0.1	0.1
Vic Murray (above choke) Total		**159.0**	**87.0**	**55%**	**2.7**	**8.2**	**11.0**
TOTAL		**230.7**	**126.0**	**55%**	**3.9**	**21.4**	**25.4**

Table F.3 Return flow results for the Macquarie

Project	Type	Total Recovery (GL/yr)	Env. Recovery (GL/yr)	% Transferred	Reduction in surface return (GL/yr)	Reduction in ground return (GL/yr)	Reduction in total return (GL/yr)
Basin Pipes	Off-Farm	10.2	7.1	70%	0.5	0.9	1.4
Irrigated Farm Modernisation	On-Farm	4.2	2.9	70%	0.1	0.4	0.5
PIIOP	Off-Farm	38.9	27.2	70%	1.2	1.5	2.7
TOTAL		**53.3**	**37.3**	**70%**	**1.7**	**2.3**	**4.1**

Table F.4 Return flow results for the NSW Murray

Project	Type	Total Recovery (GL/yr)	Env. Recovery (GL/yr)	% Transferred	Reduction in surface return (GL/yr)	Reduction in ground return (GL/yr)	Reduction in total return (GL/yr)
NSW Murray							
Basin Pipes	Off-Farm	8.2	5.7	70%	0.3	1.3	1.6
NSW Metering Pilot	Off-Farm	0.2	0.1	70%	0.0	0.0	0.0
NSW Murray (above choke)							
NSW Metering	Off-Farm	2.4	1.7	70%	0.0	0.1	0.1
OFIEP	On-Farm	77.7	52.8	68%	2.6	13.4	16.0
PIIOP	Off-Farm	86.9	60.8	70%	2.6	8.2	10.8
NSW Murray (below choke)							
NSW Metering	Off-Farm	7.7	5.4	70%	0.2	0.1	0.3
OFIEP	On-Farm	11.8	8.0	68%	0.4	1.0	1.4
PIIOP	Off-Farm	0.2	0.2	70%	0.0	0.0	0.0
TOTAL		**195.1**	**134.8**	**69%**	**6.2**	**24.0**	**30.2**

Table F.5 Return flow results for the Murrumbidgee

Project	Type	Total Recovery (GL/yr)	Env. Recovery (GL/yr)	% Transferred	Reduction in surface return (GL/yr)	Reduction in ground return (GL/yr)	Reduction in total return (GL/yr)
Basin Pipes	Off-Farm	14.9	10.4	70%	0.8	0.3	1.1
Nimmie-Caira (Land Decomm.)	Off-Farm	132.6	132.6	100%	0.0	0.3	0.3
NSW Metering Pilot	Off-Farm	0.2	0.1	70%	0.0	0.0	0.0
OFIEP	On-Farm	51.8	35.2	68%	1.7	1.1	2.8
PIIOP	Off-Farm	101.2	70.8	70%	5.2	2.2	7.4
TOTAL		**300.6**	**249.2**	**83%**	**7.7**	**3.9**	**11.6**

Table F.6 Return flow results for the SA Murray

Project	Type	Total Recovery (GL/yr)	Env. Recovery (GL/yr)	% Transferred	Reduction in surface return (GL/yr)	Reduction in ground return (GL/yr)	Reduction in total return (GL/yr)
OFIEP	On-Farm	13.2	9.0	68%	0.0	2.5	2.5
PIIP-SA	Off-Farm	3.5	2.7	77%	0.0	0.4	0.4
SA SPP Project Design Funding	Off-Farm	0.6	0.6	100%	0.0	0.1	0.1
SARMS	On-Farm	72.0	36.0	50%	0.0	13.0	13.0
TOTAL		**89.3**	**48.3**	**54%**	**0.0**	**15.9**	**15.9**