Sustainable Extraction Limits Derived from the Recharge Risk Assessment Method – Victoria

CSIRO and SKM

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Abbreviations

CSIRO	Commonwealth Scientific and Industrial Research Organisation
DSE	Department of Sustainability and Environment
GL	Gigalitre
GMA	Groundwater Management Area
GMU	Groundwater Management Unit
GS1*	Groundwater SDL area 1
km^2	kilometres squared
m	metres
MDB	Murray-Darling Basin
MDBA	Murray-Darling Basin Authority
mg/L	Milligrams per Litre
mm	Millimetres
N/A	Not Applicable
RRAM	Recharge Risk Assessment Method
SDL	Sustainable Diversion Limit
SF	Sustainability Factor
SKM	Sinclair Knight Merz
TDS	Total Dissolved Solids
WAVES	Water Atmosphere Vegetation Energy Soil

*The number at the end of the GS code is unique for each groundwater SDL area

Executive Summary

The Murray-Darling Basin Authority has responsibility for development of the Basin Plan for the Murray-Darling Basin (MDB) as specified under the *Water Act 2007*. The Basin Plan must include a number of mandatory conditions, including the development of a sustainable diversion limit (SDL) for the MDB's water resources. SDLs must encompass both surface water and groundwater. The SDL will limit the take of water for consumptive uses and is expressed as a volume.

The Recharge Risk Assessment Method (RRAM) was developed to derive preliminary SDLs to inform the Basin Plan development process.

The RRAM is based on the requirements of the *Water Act 2007* and the expectation that SDLs will reflect an environmentally sustainable level of take. According to the RRAM, the level of take must not compromise the following characteristics of the resource; key environmental assets, key ecosystem functions, the productive base and key environmental outcomes. In general terms, the RRAM is based on setting an extraction limit by applying a sustainability factor to groundwater recharge. For more information regarding the methodology, refer to CSIRO (2010).

In summary, for Victoria, the preliminary RRAM derived extraction limits that were calculated to inform the Basin Plan included;

- extraction limits that were superseded by more rigorous numerical modelling results (i.e. the Victorian Riverine Sedimentary Plain SDL area
- extraction limits that include the results of numerical modelling and the RRAM calculation (i.e. the Ovens-Kiewa Sedimentary Plain SDL area)
- extraction limits set to equal current groundwater use with a potential for further development up to the RRAM extraction limit, where an equivalent reduction in surface water is required to offset the additional groundwater take. This is on the basis of there being a 1:1 relationship between groundwater take and surface water streamflow reduction. This included the groundwater sources in the highlands areas of Victoria (i.e. the Goulburn-Broken Highlands SDL area).
- extraction limits derived from permissible drawdown rates (i.e. the Wimmera-Mallee Border Zone and the West Wimmera SDL areas). These areas are considered exceptional parts of the Basin, in that the developed groundwater resource is essentially considered a fossil resource and an alternate method of deriving a preliminary extraction limit was adopted.

1 Sustainable extraction limits derived from the RRAM – Victoria

1.1 Victorian Riverine Sedimentary Plain (GS14)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the recharge risk assessment method (RRAM) for the Victorian Riverine Sedimentary Plain sustainable diversion limit (SDL) area.

1.1.1 Background

The Victorian Riverine Sedimentary Plain SDL area is largely represented by the Victorian portion of the Southern Riverine Plain groundwater model.

The Sedimentary Plain comprises Tertiary to Quaternary sediments that directly overlie Palaeozoic bedrock. The Sedimentary Plain consists of three main deposits, from oldest to youngest: the Renmark Group, Calivil Formation and Shepparton Formation (CSIRO, 2008a).

The Renmark Group was deposited through the filling of deep channels carved into the surface by an ancient river system and subsequent spilling over into broad sediment sheets. The Renmark Group is up to 200 m thick and forms the basal deposit of almost the entire Murray-Darling Basin (MDB).

The Calivil Formation overlies the Renmark Group and has a relatively uniform thickness of 60 to 80 m. These alluvial fan deposits were formed from streams straying into flat areas carved by the earlier Renmark deposits. In Victoria, the Calivil Formation and Renmark Group together are referred to as the Deep Lead aquifer.

The uppermost unit is the Shepparton Formation which varies in thickness from 70 to 100 m. It is sometimes divided into the sandy upper and more clay-rich lower Shepparton Formations. This separation is not consistent and variations occur locally, with the upper being more clay rich in some areas.

For the purpose of the preliminary RRAM derived extraction limit calculation, two aquifer units will be considered:

1. The ‘shallow aquifer’ which includes the Shepparton Formation aquifer at depths less than 25 m
2. The ‘deep aquifer’ which includes the lower part of the Shepparton Formation and also the Calivil Formation and the Renmark Group aquifer, at depths greater than 25 m.

Two separate extraction limits have been determined, one for the shallow aquifer and one for the deep aquifer.

The sum of 2007/2008 entitlements in this SDL area is 399 GL/year (Table 1). For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

Salinity disposal entitlements

The Shepparton Water Supply Protection Area refers specifically to the Shepparton Formation aquifer. The Shepparton Water Supply Protection Area is intensively irrigated and is serviced by an extensive network of surface water supply channels. As a consequence of the intensive irrigation, the area has been prone to shallow watertables and salinity problems.

G-M Water developed a Salinity Plan to manage the shallow groundwater levels and land salinity in the Water Supply Protection Area. Under this plan, salt could be exported under the Murray-Darling Basin Drainage Strategy, in the way of specific salinity plan bores operating for salt disposal in the winter, provided that a given trigger flow occurs in the River Murray at Torrumbarry Weir. There were 222 of these bores registered by G-M Water at 30 June 2006, with a total potential to dispose of 6.3 GL and in the order of 9230 tonnes of salt from the region annually (G-M Water, 2006).

However, the requirement for private irrigation bores to provide regional salt disposal was reviewed in April 2007 under the Shepparton Irrigation Region Catchment Implementation Strategy. This review concluded that the watertable level reduction due to groundwater pumping for irrigation should allow sufficient leaching of salt from the root zone by irrigation and rainfall to provide salinity control for pastures. Accordingly requirements for off-farm disposal from private shallow irrigation bores have been removed and all remaining salinity disposal entitlement have been removed (G-M Water, 2008).

Table 1. Groundwater take summary for the Victorian Riverine Sedimentary Plain SDL area

Victorian Riverine Sedimentary Plain SDL area	GL/yr*
Total 2007/2008 entitlement	**399**
2007/2008 deep aquifer use (including stock and domestic bores)	90
2007/2008 shallow aquifer use (including stock and domestic bores)	83
Total 2007/2008 use	**173**

*Entitlement and metered use information provided by the Department of Sustainability and Environment. Stock and domestic use is estimated as 2 ML per bore with a stock and domestic use type.

1.1.2 Salinity zoning

The groundwater salinity map for the watertable aquifer and the Calivil Formation aquifer are shown in Figure 1 and Figure 2 respectively. The watertable salinity map will be used to apportion recharge to the shallow aquifer and the Calivil Formation salinity map will be used to apportion recharge to the deep aquifer.

Groundwater salinity is characterised by four salinity zones in the Victorian Riverine Sedimentary Plain SDL area, ranging from 0 to >14,000 mg/L total dissolved solids (TDS). The groundwater salinity distribution is summarised in Table 2.

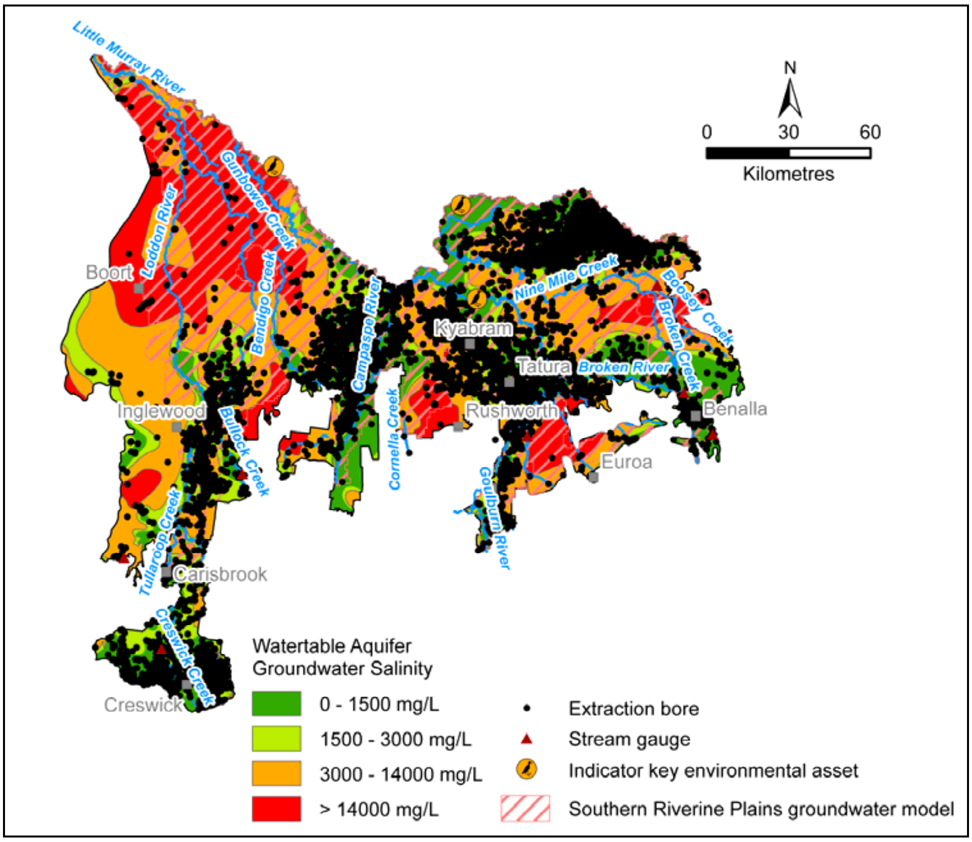

Figure 1. Victorian Riverine Sedimentary Plain watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

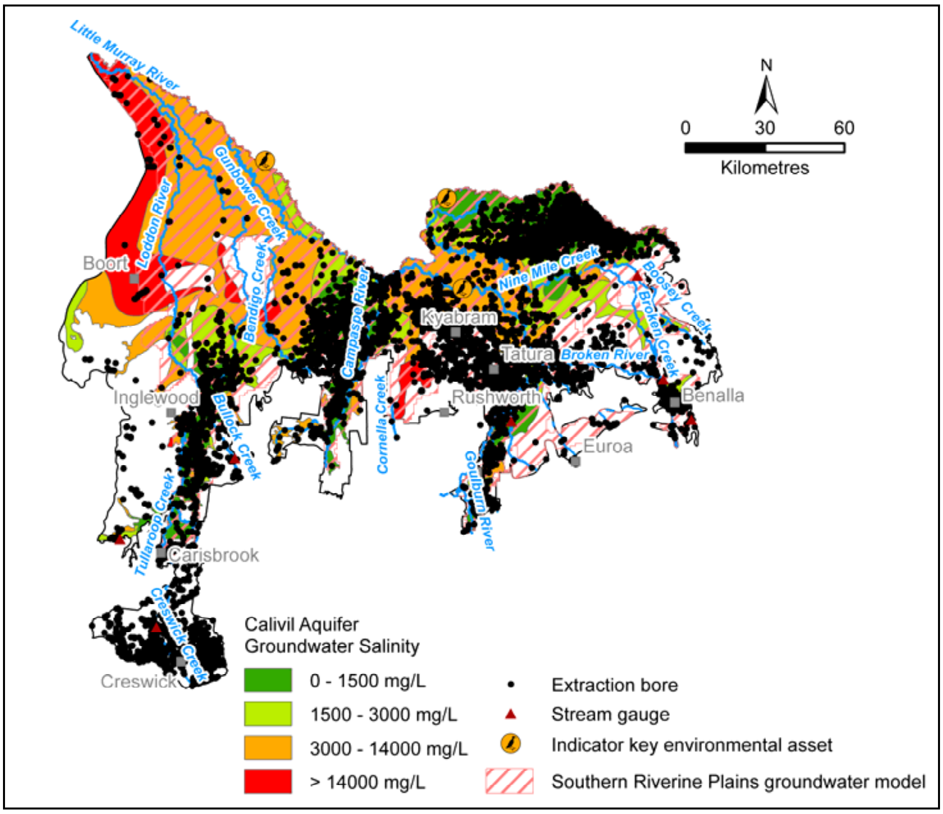

Figure 2. Victorian Riverine Sedimentary Plain Calivil Formation aquifer salinity distribution, from the Pliocene Sands salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 2. Summary of salinity zones in the Victorian Riverine Sedimentary Plain SDL area

Watertable salinity zone	Portion of watertable aquifer salinity map represented by the salinity class	Area of watertable aquifer salinity map represented by the salinity class	Portion of Calivil Formation aquifer salinity map represented by the salinity class	Area of Calivil Formation aquifer salinity map represented by the salinity class
	percent	km^2	percent	km^2
Zone 1 (0–1500 mg/L TDS)	26	5,777	21	3,180
Zone 2 (1500–3000 mg/L TDS)	18	4,144	18	2,705
Zone 3 (3000–14,000 mg/L TDS)	34	7,662	34	5,158
Zone 4 (>14,000 mg/L TDS)	22	4,957	10	1,563
No data	0	0	0	2,738
Total	**100**	**22,540**	**100**	**15,344**

1.1.3 Key environmental assets

The *Water Act 2007* requires that assessment of environmental water needs of the MDB must encompass key environmental assets, including water-dependent ecosystems, ecosystem services, and sites with ecological significance.

The Murray-Darling Basin Authority has identified 18 key environmental asset–hydrologic indicator sites that drive the environmental hydrology of the MDB (MDBA, 2010). These 18 key environmental asset–hydrologic indicator sites have been assessed to determine the objectives, targets and flow regimes required to sustain them. This information was input to the generation of an estimate of the long-term average sustainable diversion limits that will not compromise the water requirements for the rivers, wetlands and floodplains of the MDB.

The Victorian Riverine Sedimentary Plain SDL area encompasses the Lower Goulburn River Floodplain, the Barmah-Millewa Forest and the Gunbower Forest, which are three of the 18 key environmental asset–hydrologic indicator sites identified by the Murray-Darling Basin Authority.

The calibration process of the Southern Riverine Plain groundwater model indicated that groundwater evapotranspiration from forested areas, such as the Gunbower Forest, had a significant influence on the groundwater levels. Furthermore, the predictive scenario modelling results indicated that evapotranspiration was the groundwater discharge process most sensitive to climate change.

In the dry scenarios, decreases in rainfall recharge were largely matched by decreases in groundwater evapotranspiration. This largely correlates to a loss in water availability to groundwater-dependent ecosystems. In practical terms, the modelling results suggested that unless water allocations are reduced in accordance with the reduced rainfall recharge it is possible that groundwater-dependent ecosystems (GDEs) could suffer from reduced water availability as a result of climate change (CSIRO, 2008a).

The key environmental asset resource characteristic is considered at high risk in the Victorian Riverine Sedimentary Plain SDL area.

1.1.4 Key ecosystem function

Figure 3 is for the entire Southern Riverine Plain groundwater model, which extends across the New South Wales/Victoria border. It shows the river loss due to pumping at 2004/2005 levels (244 GL/year) and the river loss when there is no-pumping. The purple line shows the difference between the two and indicates that when 244 GL/year is pumped, approximately 56 GL/year of this water is derived from the river. This equates to a connectivity of 23 percent. However, if surface drains are included in the calculations, then this percentage rises to 42 percent. The model drains are included to represent the effects of regional drainage systems that are aimed at preventing water table rise beneath irrigation areas. In reality the water entering these drains will eventually be discharged to rivers and streams and hence will form part of the surface water resource. Given that there is a direct hydraulic connection between the surface drains and modelled rivers it is believed that it is appropriate to include changes in drain flows in calculations of surface water impacts (CSIRO, 2008a).

There are also a number of unregulated river reaches in the southern portion of the SDL area. These include: Tullaroop Creek, Creswick Creek, Bullock Creek and Broken Creek. It is assumed that these rivers are gaining in nature, in the absence of any other information.

Therefore the Victorian Riverine Sedimentary Plain SDL area is considered at high risk in terms of the key ecosystem function.

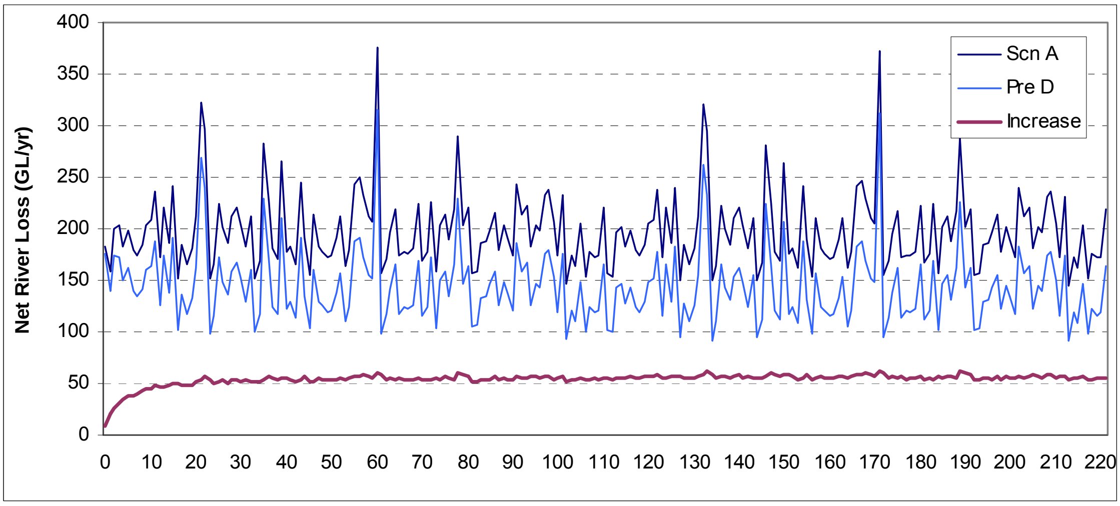

Figure 3. Change in river leakage from the no-development and the 2004/2005 groundwater development scenario; for the Southern Riverine Plains model

1.1.5 Productive base

Recharge

Recharge across the riverine plain is conceptualised to take place via the following mechanisms: leakage from the major river systems, dryland rainfall recharge, infiltration from irrigated areas, leakage from supply/drainage works and some run off from surrounding bedrock areas via small streams. Recharge through the Shepparton Formation to the deeper aquifers is restricted due to the clay-rich nature of the Shepparton Formation. However, recharge via rainfall infiltration where the more permeable Calivil Formation outcrops is considered significant (CSIRO, 2008a).

Approximately half of the water extracted from the deeper aquifers is sourced from increased leakage from the overlying Shepparton Formation and the other half from changes in flux across lateral boundaries. The increased leakage from the Shepparton Formation to the Calivil Formation leads to increased river losses.

A zone budget was run for the CSIRO (2008a) calibration model, in order to obtain inflow volumes for the shallow and deep aquifers in the Victorian portion of the Southern Riverine Plain groundwater model. The average annual total inflow for the shallow aquifer over the period 1990–2005, was 498 GL/year (Table 3) and for the deep aquifer, was 262 GL/year (Table 4).

These recharge volumes have been apportioned to the salinity classes, based on the relative size of the salinity class area (Table 5).

Table 3. Water balance for the shallow aquifer, from the calibration model (1990–2005)

Groundwater balance for the shallow aquifer (<25m)	Volume
	GL/yr
Diffuse recharge	335
River recharge	117
Lateral flow (in)	0
GW flow from adjacent zone	8
Upward leakage from underlying aquifer	38
Total inflows	**498**
Discharge to river	37
Lateral flow (out)	0
Pumping	73
GW flow to adjacent zone	6
Leakage to underlying aquifer	168
Drains and evapotranspiration	229
Total outflow	**513**

Table 4. Water balance for the deep aquifer, from the calibration model (1990–2005)

Groundwater balance for the deep aquifer (>25m)	Volume
	GL/yr
Diffuse recharge	17
River recharge	0
Lateral flow (in)	42
GW flow from adjacent zone	34
Downward leakage from overlying aquifer	169
Total inflows	**262**
Discharge to river	0
Lateral flow (out)	38
Pumping	63

GW flow to adjacent zone	118
Leakage to overlying aquifer	37
Drains and evapotranspiration	2
Total outflow	**258**

Table 5. Recharge calculation for the shallow and deep aquifers of the Victorian Riverine Sedimentary Plain

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area of watertable aquifer (%)	26	18	34	22
Recharge to the shallow aquifer (GL/yr)	128	91	169	110
Total recharge to the shallow aquifer (GL/yr)	**498**			
Area of Calivil Formation aquifer (%)	24	21	43	12
Recharge to the deep aquifers (GL/yr)	63	55	113	31
Total recharge to the shallow aquifer (GL/yr)	**262**			

Storage

The specific yield used for the purpose of this storage calculation is 0.10. An average total thickness of 200 m was estimated for the entire sequence of shallow and deep sediments.

Total storage to the Victorian Riverine Sedimentary Plain is approximately 450,000 GL (Table 6).

Table 6. Storage calculation for the Victorian Riverine Sedimentary Plain

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	5,777	4,144	7,662	4,957
Saturated thickness (m)	200	200	200	200
Specific yield	0.1	0.1	0.1	0.1
Total storage (GL)	**115,549**	**82,872**	**153,247**	**99,136**

Storage relative to recharge

The ratio of storage to recharge ranges from 543 to 703. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.1.6 The risk matrix

Table 7 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary;

- the SDL area is ranked high risk in terms of environmental assets, due to the presence of three of the 18 indicator key environmental assets, that are considered to be groundwater dependent and sensitive to groundwater take
- the SDL area is ranked high risk in terms of ecosystem function, given there are unregulated gaining river reaches in the SDL area
- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio is approximately 600
- there is a risk to key environmental outcomes (i.e. groundwater salinity)
- there is a low level of uncertainty given that the recharge is derived from the numerical model results of the Southern Riverine Plain numerical model.

Table 7. Risk matrix

<table>
<tr><th>Risk ranking</th><th>Environmental assets (EAs)</th><th>OR</th><th>Ecosystem function</th><th>OR</th><th>Productive base</th><th>Sustainability factor (SF)</th><th>Key environmental outcome</th><th>Degree of uncertainty</th></tr>
<tr><td>High</td><td>EA that is highly groundwater dependent and highly sensitive to take</td><td></td><td>In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion</td><td></td><td>Storage/ recharge <20</td><td>0.10</td><td rowspan="3">Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes

Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made:

Salinity class 1: reduce SF by 20%

Salinity class 2: reduce SF by 10%

Salinity classes 3 & 4: no reduction</td><td rowspan="2">Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%</td></tr>
<tr><td>Medium</td><td>EA that is highly groundwater dependent and is moderately sensitive to take

EA that is moderately groundwater dependent and is highly sensitive to take</td><td></td><td>The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)</td><td></td><td>Storage/ recharge 20–40</td><td>0.50</td></tr>
<tr><td>Low</td><td>EA that has a low groundwater dependence and low sensitivity to take

EAs do not exist in the SDL area</td><td></td><td>The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)</td><td></td><td>Storage/ recharge >40</td><td>0.70</td><td>Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%</td></tr>
</table>

1.1.7 Preliminary RRAM extraction limit

The preliminary estimated extraction limit resulting from the RRAM for the Victorian Riverine Sedimentary Plain SDL area is 46 GL/year for the shallow aquifer (Table 8) and 24 GL/year for the deep aquifer (Table 9). The RRAM extraction limit was based on the Southern Riverine Plain calibration model results from the MDB SY (CSIRO, 2008a), as these provided the best available information at the time of the RRAM analysis.

The preliminary RRAM extraction limit for the Victorian Riverine Sedimentary Plains SDL area has been superseded by more recent modelling results (CSIRO, 2010b).

Table 8. Preliminary extraction limit summary for the shallow aquifer in the Victorian Riverine Sedimentary Plain SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	128	92	169	110
Sustainability factor	0.08	0.09	0.1	0.1
Extraction limit (GL/yr)	**10**	**8.2**	**17**	**11**

Table 9. Preliminary extraction limit summary for the deep aquifer in the Victorian Riverine Sedimentary Plain SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	63	55	113	31
Sustainability factor	0.08	0.09	0.1	0.1
Extraction limit (GL/yr)	**5.0**	**5.0**	**11**	**3.1**

1.2 Ovens-Kiewa Sedimentary Plain (GS13)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the RRAM for the Ovens-Kiewa Sedimentary Plain SDL area.

1.2.1 Background

The Ovens-Kiewa Sedimentary Plain SDL area represents the alluvial deposits that infilled the paleo-valleys of incised Ordovician bedrock of the Ovens and Kiewa catchments. The alluvial deposits comprise the deeper, coarse grained Calivil Formation and shallower shoe-sting sands, silts and clays of the Shepparton Formation and the recent alluvium of the Coonambidgal Formation (SKM, 2007). The alluvial deposits of the Ovens River valley are represented by the Upper Ovens and Lower Ovens Groundwater Management Units (GMUs) and the alluvial deposits of the Kiewa River valley are represented by the Mullindolingong GMA.

This SDL area is partially represented by the Southern Riverine Plains numerical model (CSIRO, 2010b). For the non-modelled part of the area, 2007/2008 use was 4.6 GL/year (Table 10). Total groundwater use for the entire SDL area is equal to 14.7 GL/yr. For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

Table 10. Groundwater take summary for the non-modelled part of the Ovens-Kiewa Sedimentary Plain SDL area

Ovens-Kiewa Sedimentary Plain SDL area	Non-model area
	GL/yr
Total 2007/2008 entitlement*	**5.4**
2007/2008 metered use for entitlement bores*	0
2007/2008 estimated use for entitlement bores**	3.3
2007/2008 estimated use for stock and domestic bores***	1.3
Total 2007/2008 use	**4.6**

*Entitlement and metered use information provided by the Department of Sustainability and Environment.
**Estimated use is equal to 60% of the entitlement volume.
***Stock and domestic use is estimated as 2 ML per bore with a stock and domestic use type.

1.2.2 Salinity zoning

The groundwater salinity map for the watertable aquifer and the Calivil Formation aquifer can be seen in Figure 4 and Figure 5 respectively. It is evident that the salinity of the Calivil Formation aquifer is the same as that for the watertable aquifer, where the two maps overlap. Therefore the watertable salinity map has been used for the purpose of this assessment, as it provides a full coverage of the SDL area.

Groundwater salinity is characterised by four salinity zones in the Ovens-Kiewa Sedimentary Plain SDL area, ranging from 0 to >14,000 mg/L TDS. Most of the area is characterised by salinity zone 1 groundwater (Table 11).

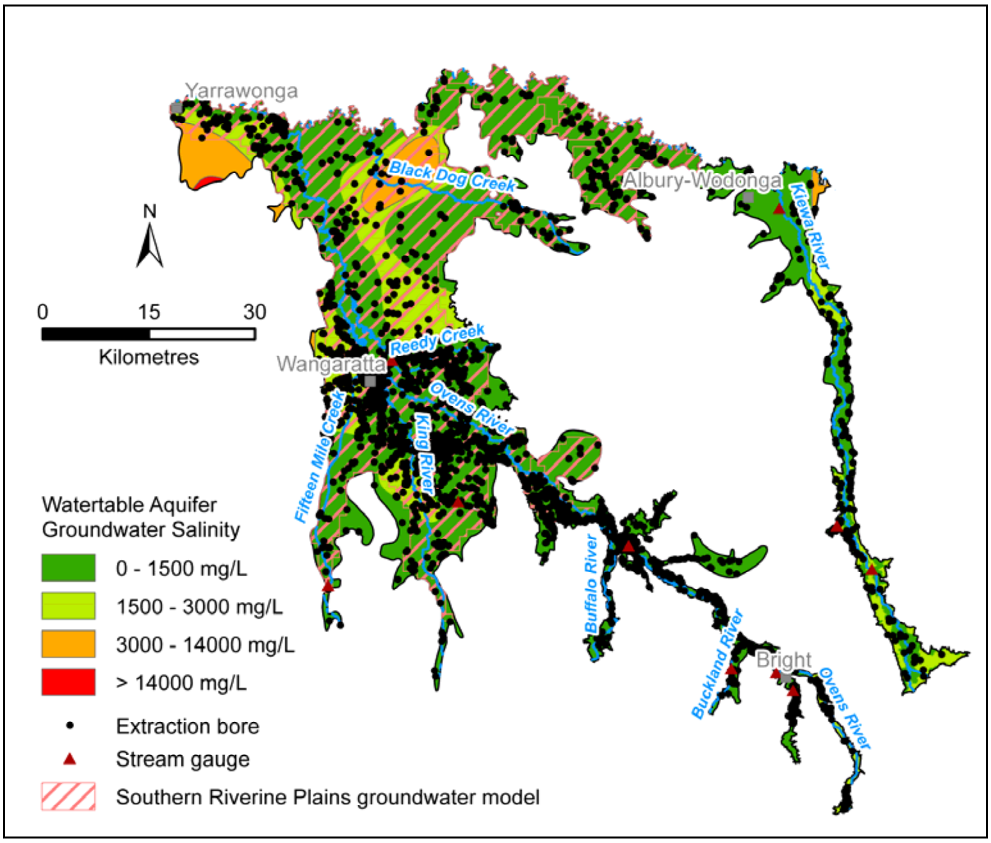

Figure 4 Ovens-Kiewa Sedimentary Plain watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

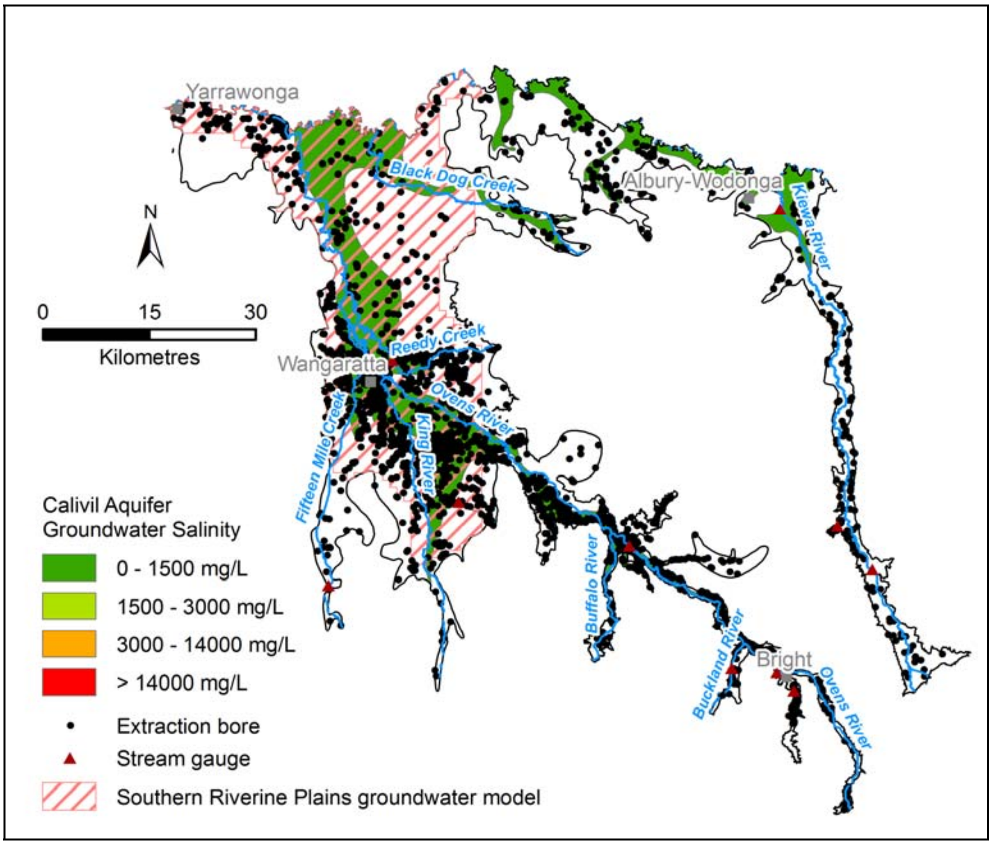

Figure 5. Ovens-Kiewa Sedimentary Plain Calivil Formation salinity distribution, from the Pliocene Sands salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 11. Summary of salinity zones in the Ovens-Kiewa Sedimentary Plain SDL area

Watertable salinity zone	Portion of salinity zone in model domain	Area	Portion of salinity zone in non-modelled area	Area
	percent	km^2	percent	km^2
Zone 1 (0–1500 mg/L TDS)	68	865	84	1093
Zone 2 (1500–3000 mg/L TDS)	26	338	11	140
Zone 3 (3000–14,000 mg/L TDS)	6	72	5	67
Zone 4 (>14,000 mg/L TDS)	0	0	0	3.5
Total	**100**	**1275**	**100**	**1303**

1.2.3 Key environmental assets

The Ovens River is considered a key environmental asset that is dependent on groundwater and sensitive to take. Therefore the key environmental asset is ranked high risk in this SDL area.

1.2.4 Key ecosystem function

Numerical modelling of the Ovens valley concluded that groundwater extractions from the aquifers in the Upper Ovens River Valley have a direct impact on river flows. It was found that in the long term, almost all the water extracted from bores is derived from river depletion, as indicated by a reduction in baseflow or increase in leakage to groundwater (SKM, 2006).

Groundwater is also a significant component of baseflow in the Kiewa River, with the Kiewa River being interpreted as a gaining stream for most, if not all of its length (URS, 2005).

Furthermore, there a number of river reaches in this SDL area that are unregulated and are either conceptualised or reported as being gaining river reaches. The Upper Ovens River was reported as being gaining in nature and largely unregulated (with no major storages) by SKM (2007) and SKM (1996).

The key ecosystem function is considered to be at high risk in this SDL area.

1.2.5 Productive base

Recharge

The Southern Riverine Plain model provides coverage of lower part of the Ovens catchment (the model extent can be seen in Figure 4) and the results of the modelling have been used to derive a preliminary extraction limit for this part of the SDL area. For the SDL model scenario, there was 76 GL/year of inflow to the alluvial aquifers, which includes diffuse recharge and river leakage. This total inflow volume was apportioned to each of the salinity zones within the model domain based on the area of each zone (Table 12).

Table 12. Recharge derived from the Southern Riverine Plain Model for the area represented by the model within the Ovens-Kiewa Sedimentary Plain SDL area

Watertable salinity zone	Portion of area within model domain	Recharge
	percent	GL/yr
Zone 1 (0–1,500 mg/L TDS)	68	52
Zone 2 (1,500–3,000 mg/L TDS)	26	20
Zone 3 (3,000–14,000 mg/L TDS)	6	5
Zone 4 (>14,000 mg/L TDS)	0	0
Total	**100**	**76**

For the remaining part of the SDL area, WAVES recharge modelling has been used to derive an extraction limit.

The WAVES model, historical dry climate scenario indicates that recharge rates vary from 27 to 71 mm/yr between each of the salinity classes. The total volume of recharge to the alluvium in the non-modelled area is 87 GL/year (Table 13).

Table 13. WAVES recharge to the non-modelled part of the Ovens-Kiewa Sedimentary Plain SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	1093	140	67	3.5
WAVES recharge (mm/yr)	69	71	27	28
Recharge (GL/yr)	**75**	**10**	**1.8**	**0.098**

Storage

The thickness of the alluvial sequence extends to depths ranging from 70 m to 90 m below the surface, between Bright and Porepunkah (SKM, 2007). A thickness of 70 m has been used for the purpose of the storage estimate.

The specific yield of the unconfined or semi-confined shallow aquifers range from 0.1 to 0.25 (SKM, 2007). A specific yield of 0.15 has been used for the purpose of the storage estimate.

The total storage estimated for the alluvial sequence is approximately 27,000 GL (Table 14).

Table 14. Storage calculation

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	1,958	478	139	3.5
Saturated thickness (m)	70	70	70	70
Specific yield	0.15	0.15	0.15	0.15
Total storage (GL)	**20,559**	**5,019**	**1,460**	**32**

Storage relative to recharge

The ratio of storage to recharge ranges from 274 to 811 for this SDL area. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.2.6 The risk matrix

Table 15 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary:

- the SDL area is ranked high risk in terms of environmental assets, given the Ovens River is considered a groundwater-dependent ecosystem
- the SDL area is ranked high risk in terms of ecosystem function
- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio exceeds 40
- there is no risk to key environmental outcomes (i.e. groundwater salinity)
- there is a high level of uncertainty in the non-modelled part of the SDL area given that the only input was WAVES diffuse recharge. There is a low level of uncertainty in the modelled part of the SDL area given that the recharge volume was derived from a numerical model.

Table 15. Risk matrix

<table>
<tr><th>Risk ranking</th><th>Environmental assets (EAs)</th><th>OR</th><th>Ecosystem function</th><th>OR</th><th>Productive base</th><th>Sustainability factor (SF)</th><th>Key environmental outcome</th><th>Degree of uncertainty</th></tr>
<tr><td>High</td><td>EA that is highly groundwater dependent and highly sensitive to take</td><td rowspan="3"></td><td>In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion</td><td rowspan="3"></td><td>Storage/ recharge <20</td><td>0.10</td><td rowspan="3">Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes

Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made:

Salinity class 1: reduce SF by 20%

Salinity class 2: reduce SF by 10%

Salinity classes 3 & 4: no reduction</td><td rowspan="2">Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%</td></tr>
<tr><td>Medium</td><td>EA that is highly groundwater dependent and is moderately sensitive to take

EA that is moderately groundwater dependent and is highly sensitive to take</td><td>The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge 20–40</td><td>0.50</td></tr>
<tr><td>Low</td><td>EA that has a low groundwater dependence and low sensitivity to take

EAs do not exist in the SDL area</td><td>The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge >40</td><td>0.70</td><td>Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%</td></tr>
</table>

1.2.7 Preliminary RRAM extraction limit

The preliminary estimated extraction limit resulting from the RRAM for the Ovens-Kiewa Sedimentary Plain SDL area is 12 GL/year. This includes 7.7 GL/year for the area represented by the numerical model (Table 16) and 4.3 GL/year for the non-modelled area (Table 17).

The RRAM extraction limit for the modelled part of the SDL area was based on the MDB Sustainable Yields Project Southern Riverine Plain numerical modelling results (CSIRO, 2008a) as these provided the best available information at the time of the RRAM analysis. The preliminary RRAM extraction limit for the modelled part of the Ovens Kiewa Sedimentary Plain SDL area has been superseded by more recent modelling results (CSIRO, 2010b).

The preliminary estimated extraction limit resulting from the RRAM for the non-modelled part of the SDL area is 4.3 GL/year. This extraction limit can be increased to equal current use (i.e. 4.6 GL/year) given the highly connected nature of the system. The extraction limit for this SDL area for groundwater and surface water should be set taking into account the connectivity and to eliminate double accounting.

Table 16. Preliminary extraction limit summary for the modelled part of the Ovens-Kiewa Sedimentary Plain SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	52	20	4.6	0.0
Sustainability factor	0.1	0.1	0.1	N/A
Extraction limit (GL/yr)	**5.2**	**2.0**	**0.5**	**N/A**

Table 17. Preliminary extraction limit summary for the non-modelled part of the Ovens-Kiewa Sedimentary Plain SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	75	10	1.8	0.098
Sustainability factor	0.05	0.05	0.05	0.05
Extraction limit (GL/yr)	**3.7**	**0.50**	**0.091**	**0.0049**

1.3 Wimmera-Mallee Sedimentary Plain (GS18)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the RRAM for the Wimmera-Mallee Sedimentary Plain SDL area.

1.3.1 Background

The Wimmera-Mallee Sedimentary Plain SDL is located in north-western Victoria between the River Murray and the South Australia border. The SDL area contains three predominant aquifers which are both confined and unconfined in nature. The Tertiary Confined Sands Aquifer (TCSA) contains Tertiary sands and gravels and is confined by the Ettrick Formation and Geera Clay over most of the SDL area. This SDL area is not considered to receive modern-day recharge. The overlying Murray Group Limestone Aquifer (MGLA) is confined or semi-confined where it occurs in the north-western portion of the SDL area by the Bookpurnong Beds. The Loxton-Parilla and Woorinen Sands overlie these units and constitute the water table aquifer (URS, 2008). The RRAM methodology will be applied solely to the watertable aquifer for this SDL area.

Salt interception schemes (SISs) are located along the River Murray between the South Australia border and Robinvale, within the SDL area. Typically, the alluvial plain within the Murray Trench consists of alluvial sediments overlying Channel Sands, or directly overlying the Parilla Sands in the southeast of the area. These are overlain by fine grained alluvial sediments such as the clays of the Coonambidgal Formation which can act as a semi-confining layer in many locations.

There are two functioning salt interception schemes (SISs) within this SDL area, known as the Mildura-Merbein and Barr Creek Salt Drainage Diversion Schemes. The schemes pump shallow groundwater from the above mentioned sediments. The Mildura-Merbein scheme consist of a series of groundwater bores which pump saline groundwater from the alluvial aquifers along the River Murray to decrease the volumes of saline groundwater discharge to the river. The Barr Creek Salt Drainage Diversion Scheme is a series of drains which capture shallow saline groundwater. The primary aim of the SISs is to reach river salinity targets at Morgan. The water is disposed of in evaporation basins some distance away from the river where it is lost via recharge to the groundwater at that location or via evaporation. There are a number of other proposed schemes which are not yet operational.

SIS volumes reported by CSIRO (2008a) for 2004/05 were 1.9 and 6.8 GL/year for Mildura-Merbein SIS and Barr Creek Salt Drainage Diversion Scheme respectively (totalling 8.7 GL/year).

Groundwater use (excluding that from the SISs) is summarised in Table 18. The estimated total 2007/2008 groundwater use was 0.59 GL/year. This use is most likely to occur in shallow bores near the rivers and creeks, where the aquifer is freshened by flood or river recharge. For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

Table 18. Groundwater take summary for the Wimmera-Mallee Sedimentary Plain SDL area

Wimmera-Mallee Sedimentary Plain SDL area	GL/yr
Total 2007/2008 entitlement*	**0.14**
2007/2008 metered use for entitlement bores*	0.0
2007/2008 estimated use for entitlement bores**	0.084
2007/2008 estimated use for stock and domestic bores***	0.51
Total 2007/2008 use	**0.59**

*Entitlement and metered use information provided by the Department of Sustainability and Environment.
**Estimated use is equal to 60% of the entitlement volume.
***Stock and domestic use is estimated as 2 ML per bore with a stock and domestic use type.

1.3.2 Salinity zoning

The watertable aquifer contains all four salinity zones and is dominated by salinity zones 3 and 4 with localised areas of salinity zones 1 and 2 which are influenced by leakage from surface water features (see Figure 6 and Table 19).

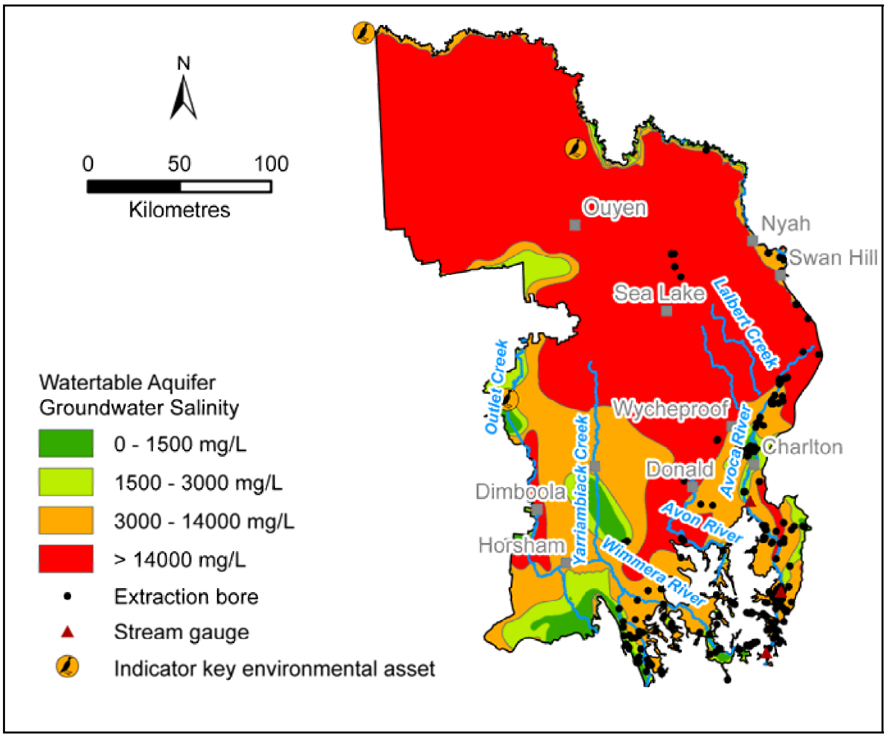

Figure 6. Wimmera-Mallee Sedimentary Plain watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 19. Summary of watertable salinity zones in the Wimmera-Mallee Sedimentary Plain SDL area

Watertable salinity zone	Portion of total area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	3	1,590
Zone 2 (1500–3000 mg/L TDS)	6	3,035
Zone 3 (3000–14,000 mg/L TDS)	23	11,063
Zone 4 (>14,000 mg/L TDS)	67	31,556
Water body	0	0
Total	**100**	**47,244**

1.3.3 Key environmental assets

The Water Act requires that assessment of environmental water needs of the MDB must encompass key environmental assets, including water-dependent ecosystems, ecosystem services, and sites with ecological significance.

The Murray-Darling Basin Authority has identified 18 key environmental asset–hydrologic indicator sites that drive the environmental hydrology of the MDB (MDBA, 2010). These 18 key environmental asset–hydrologic indicator sites have been assessed to determine the objectives, targets and flow regimes required to sustain them. This information was input to the generation of an estimate of the long-term average sustainable diversion limits that will not compromise the water requirements for the rivers, wetlands and floodplains of the MDB.

The Wimmera-Mallee Sedimentary Plain SDL area encompasses the Wimmera River Terminal Wetlands, the Hattah Lakes and the Riverland-Chowilla Floodplain (includes Lindsay, Wallpolla and Mulcra Islands), which are three of the 18 key environmental asset–hydrologic indicator sites identified by the Murray-Darling Basin Authority. These assets have not been identified as being groundwater-dependent ecosystems, and it is not believed that they would be sensitive to groundwater take.

However, the River Murray channel contains a number of potentially groundwater-dependent ecosystems that may be sensitive to groundwater take. River Red Gums and other vegetation on the Murray floodplain are known to use groundwater to varying degrees and many stands can be classified as opportunistically groundwater dependant (according to the classification system of Hatton and Evans (1998)). This means that when shallow and relatively freshwater in the unsaturated zone is exhausted (by plant water use or by evaporation), vegetation will use water from the capillary fringe of the groundwater table to avoid water stress if it is sufficiently fresh and not too deep. Any fall in shallow fresh groundwater has the potential to adversely impact the health of ecosystems by decreasing the accessibility of groundwater for plant use. However, the lowering of saline groundwater levels on the floodplain potentially creates benefits by removing saline water and inducing river recharge of fresher water which could have a positive impact on the floodplain ecosystems either in situ or further downstream. Although this has not been investigated in detail, it is considered that there is a low risk of the SISs and other groundwater extraction adversely impacting the key environmental assets in this SDL area.

1.3.4 Key ecosystem function

The Wimmera and Avoca Rivers are thought to receive baseflow while the numerous semi-permanent wetlands and lakes associated with the dune systems are thought to be disconnected from the shallow aquifer (SKM, 2009). The Wimmera River and its tributaries are largely unregulated.

The River Murray is highly regulated with frequent lock structures controlling the water levels. The shallow alluvial aquifer is in good connection with the river and any pumping is likely to decrease baseflow. The purpose of the SISs is to directly decrease this baseflow such that salt loads entering the river are decreased and hence decreased baseflow is thought to be a positive impact. It is likely that this pumping has also induced river recharge and the freshening of shallow alluvial aquifers between the pumps and the river.

The overall risk to the key ecosystem function in this SDL area is low. A reduction in baseflow to both the Wimmera and Avoca Rivers and the River Murray is not likely to adversely impact the rivers, given that groundwater is saline in this SDL area.

1.3.5 Productive base

Recharge

Modelled dryland diffuse groundwater recharge derived from WAVES modelling (Crosbie et al., 2010) has been used to calculate recharge to the watertable aquifer. The dry climate scenario for a median 15-year period, results in a recharge rate of 9.7, 9.4, 8.0 and 13 mm/year for salinity zones 1, 2, 3 and 4 respectively. This results in a total recharge of 544 GL/year for the watertable aquifer within the SDL area. Recharge mechanisms such as leakage from lakes and wetlands and preferential recharge through sink holes have not been included in this case.

Table 20. Recharge calculation for the Wimmera-Mallee Sedimentary Plain SDL area – WAVES recharge

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	1,590	3,035	11,063	31,556
Diffuse recharge from WAVES modelling (mm/yr)	9.7	9.4	8.0	13
Total recharge (GL/yr)	**15**	**28**	**88**	**412**

Storage

The Loxton-Parilla Sands are thought to have a total thickness up to 60 m (URS, 2008) and a saturated thickness has been assumed of 30 m, after SKM (2009) estimated the saturated thickness in northern West Wimmera GMA. Due to a lack of specific information, a typical specific yield for shallow marine sediments of variable grain size of 10 percent has been adopted (Johnson, 1967). Based on these assumptions, the total combined groundwater storage estimate for all salinity zones is 141,732 GL (Table 21).

Table 21. Storage calculation for the Wimmera-Mallee Sedimentary Plain SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	1,590	3,035	11,063	31,556
Saturated thickness (m)	30	30	30	30
Specific yield	0.1	0.1	0.1	0.1
Total storage (GL)	**4,770**	**9,105**	**33,189**	**94,668**

Storage relative to recharge

The ratio of storage to recharge ranges from approximately 230 and 377. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.3.6 The Risk Matrix

Table 22 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary:

- the SDL area is ranked low risk in terms of environmental assets, since there were none identified as groundwater dependent in this SDL area
- the SDL area is ranked low risk in terms of ecosystem function, since high salinity groundwater exists in this SDL area and baseflow to rivers is reduced intentionally by SISs
- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio is greater than 40
- there is a risk to key environmental outcomes (i.e. groundwater salinity)
- there is a high uncertainty associated with this SDL area given that the RRAM is derived from diffuse groundwater recharge derived from WAVES modelling only. It does not include other potential components of groundwater recharge, including river leakage, irrigation returns, throughflow etc.

Table 22. Risk matrix

<table>
<tr><th>Risk ranking</th><th>Environmental assets (EAs)</th><th>OR</th><th>Ecosystem function</th><th>OR</th><th>Productive base</th><th>Sustainability factor (SF)</th><th>Key environmental outcome</th><th>Degree of uncertainty</th></tr>
<tr><td>High</td><td>EA that is highly groundwater dependent and highly sensitive to take</td><td rowspan="3"></td><td>In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion</td><td rowspan="3"></td><td>Storage/ recharge <20</td><td>0.10</td><td rowspan="3">Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes

Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made:
Salinity class 1: reduce SF by 20%

Salinity class 2: reduce SF by 10%

Salinity classes 3 & 4: no reduction</td><td rowspan="2">Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF
Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%</td></tr>
<tr><td>Medium</td><td>EA that is highly groundwater dependent and is moderately sensitive to take
EA that is moderately groundwater dependent and is highly sensitive to take</td><td>The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge 20–40</td><td>0.50</td></tr>
<tr><td>Low</td><td>EA that has a low groundwater dependence and low sensitivity to take
EAs do not exist in the SDL area</td><td>The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge >40</td><td>0.70</td><td>Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF
Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%</td></tr>
</table>

1.3.7 Preliminary RRAM extraction limit

The extraction limit resulting from the RRAM for the Wimmera-Mallee Sedimentary Plain SDL area is 285 GL/year. This is higher than the sum of 2007/2008 entitlements (0.14 GL/year) and use (0.56 GL/year). This means there is a volume of unassigned water (285 GL/year) associated with this SDL area.

Table 23. Preliminary extraction limit for the Wimmera-Mallee Sedimentary Plain SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	15	28	88	412
Sustainability factor	0.42	0.47	0.53	0.53
Extraction limit (GL/yr)	**6.5**	**13**	**47**	**218**

Where the volume of unassigned water is greater than 50 GL/year and greater than one-hundred times the volume of current use, the preliminary RRAM derived extraction limit is superseded by an extraction limit equivalent to the high sustainability factor applied to recharge for that particular SDL area. Using the high sustainability factor, the extraction limit resulting from the RRAM is 27 GL/year.

Table 24. Preliminary extraction limit for the Wimmera-Mallee Sedimentary Plain SDL area – revised sustainablility factor

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	15	28	88	412
Sustainability factor	0.04	0.045	0.05	0.05
Extraction limit (GL/yr)	**0.62**	**1.3**	**4.4**	**21**

1.4 West Wimmera (GS15)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the RRAM for the West Wimmera SDL area.

1.4.1 Background

The West Wimmera SDL area is located in western Victoria, next to the South Australia border and is equivalent to Hydrogeological Province 3 of the Border Zone (BGARC, 2009). The SDL area has three main aquifers which are both confined and unconfined in nature. The Tertiary Confined Sands Aquifer (TCSA) contains Tertiary sands and gravels and is confined by the Ettrick Formation over most of the SDL area. The overlying Murray Group Limestone (MGL) aquifer is unconfined in a small area in the southwest and confined or semi-confined across the majority of the SDL area by the Bookpurnong Beds. Overlying the MGL and Bookpurnong Beds are the Loxton-Parilla and Woorinen Sands. The watertable aquifer is found in the Loxton-Parilla Sands (URS, 2008).

Groundwater development has mostly occurred in the MGL since the generally poor quality of the watertable aquifer has limited use. There is also increasing pressure to exploit the deeper TCSA.

The RRAM analysis will focus on the watertable aquifer, given it is recharged via diffuse rainfall. The two deeper aquifers have not received recharge within a modern time frame (i.e. within hundreds of years) and therefore the RRAM does not apply to these aquifers. Extraction limits have been set for the two deeper aquifers based on the precedents set by the Border Zone Groundwater Agreement Review Committee (BGARC) and these results are summarised in the discussion section of this chapter.

Table 25 shows the summary of groundwater take in the West Wimmera SDL area. This water is predominantly taken from the MGL (Chris Guest, GWMWater, 2010, pers. comm.). There is no extraction occurring from the watertable, 1.9 GL/year occurring from the MGL and 0.8 GL use from the TCSA (DSE, 2010a). For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

Table 25. Groundwater take summary for the West Wimmera SDL area

West Wimmera SDL area	GL/yr
Total 2007/2008 entitlement*	**3.2**
2007/2008 metered use for entitlement bores*	1.4
2007/2008 estimated use for entitlement bores*	0.1
2007/2008 estimated use for stock and domestic bores*	1.2
Total 2007/2008 use	**2.7**

*Entitlement and use information provided by GWMWater.

1.4.2 Salinity zoning

The watertable aquifer contains all four salinity zones and is dominated by salinity zones 1 and 2 in the west with areas of salinity zone 3 and 4 on the eastern and northern boundaries (see Figure 7 and Table 26). The MGL aquifer contains all four salinity zones with groundwater quality decreasing from west to east (see Figure 8 and Table 27). The TCSA shows a similar distribution to the MGL aquifer but is generally more saline (see Figure 9 and Table 28).

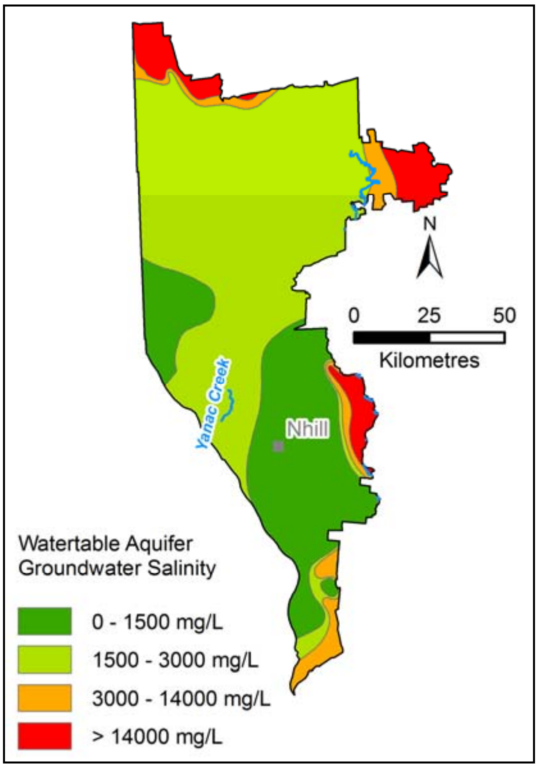

Figure 7. West Wimmera watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 26. Summary of salinity zones in the West Wimmera SDL area

Watertable salinity zone	Portion of total area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	28	2,898
Zone 2 (1500–3000 mg/L TDS)	59	6,148
Zone 3 (3000–14,000 mg/L TDS)	6	577
Zone 4 (>14,000 mg/L TDS)	8	807
Water body	0	0.0
Total	**100**	**10,430**

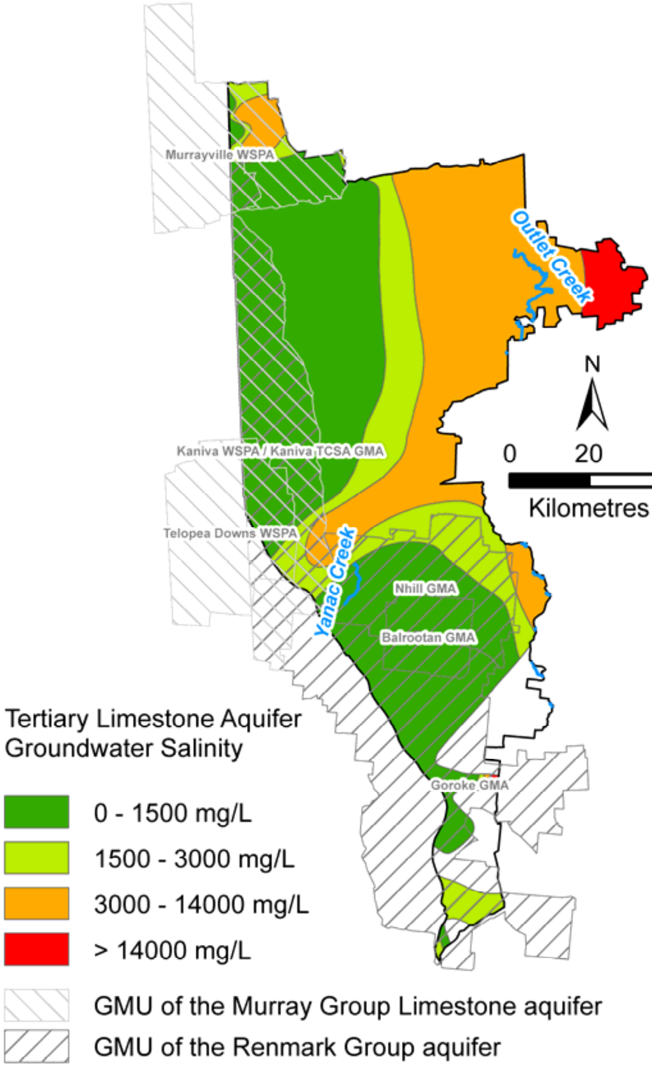

Figure 8. West Wimmera MGL aquifer salinity distribution, from the Murray Group Limestone salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 27. Summary of MGLA salinity zones in the West Wimmera SDL area

Watertable salinity zone	Portion of total MGL area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	69	6475
Zone 2 (1500–3000 mg/L TDS)	19	1803
Zone 3 (3000–14,000 mg/L TDS)	11	1061
Zone 4 (>14,000 mg/L TDS)	0.1	8.0
Water body	0.0	0.0
Total	**100**	**9347**

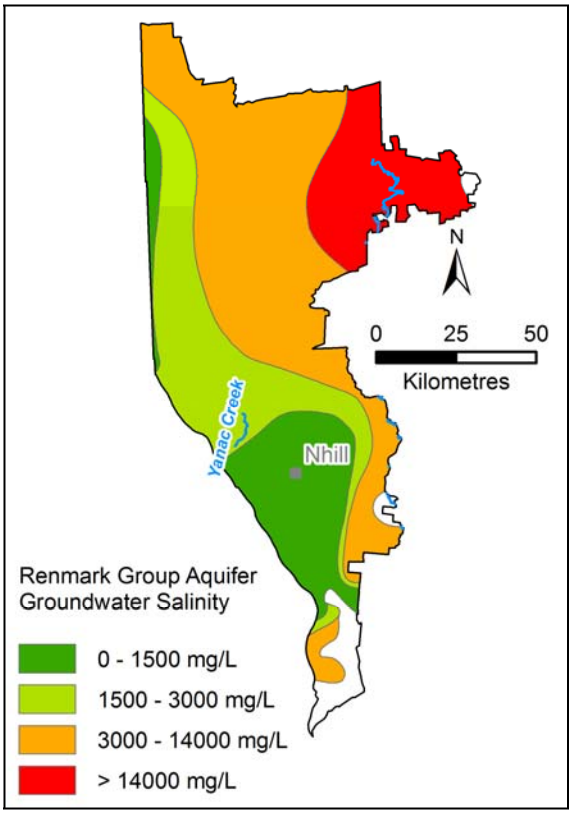

Figure 9. West Wimmera TCSA salinity distribution, from the Upper Renmark salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 28. Summary of TCSA salinity zones in the West Wimmera SDL area

Watertable salinity zone	Portion of total area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	17	1,750
Zone 2 (1500–3000 mg/L TDS)	24	2,432
Zone 3 (3000–14,000 mg/L TDS)	44	4,399
Zone 4 (>14,000 mg/L TDS)	14	1,451
Total	**100**	**10,031**

1.4.3 Key environmental assets

There are no key environmental assets that have been identified as groundwater dependent and sensitive to groundwater extraction as part of this RRAM assessment, that are associated with the West Wimmera SDL area.

1.4.4 Key ecosystem function

There are a number of semi-permanent creeks, wetlands and lakes associated with the dune systems; however these are thought to be disconnected from the shallow aquifer (SKM, 2009). The majority of groundwater pumping occurs at some distance and down hydraulic gradient from the Wimmera River (located to the north of the SDL area) and hence there is a low risk of reducing baseflow and impacting the key ecosystem function.

1.4.5 Productive base

Recharge

Modelled dryland diffuse groundwater recharge derived from WAVES modelling (Crosbie et al., 2010) has been used to calculate recharge to the alluvial aquifer. The historical dry climate scenario, results in recharge rates ranging from 3.62 to 12.84 mm/year for the salinity classes. This results in a total recharge of 50 GL/year within the SDL area.

Table 29. Recharge calculation for the West Wimmera SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	2898	6148	577	807
Diffuse recharge (mm/yr)	4.6	3.6	8.6	13
Total recharge (GL/yr)	**13**	**22**	**5.0**	**10**

Storage

The Loxton-Parilla Sands are thought to have a total thickness up to 60 m (URS, 2008). A saturated thickness of 30 m has been estimated based on the SKM (2009) estimate for the northern West Wimmera GMA. Due to a lack of specific information, a typical specific yield for shallow marine sediments of variable grain size of 10 percent has been adopted (Johnson, 1967). Based on these assumptions, the combined groundwater storage estimates for all salinity zones in the SDL area is 31,289 GL (Table 30).

Table 30. Storage calculation for the West Wimmera SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	2,898	6,148	577	807
Saturated thickness (m)	30	30	30	30
Specific yield	0.1	0.1	0.1	0.1
Total storage (GL)	**8,693**	**18,443**	**1,732**	**2,421**

Storage relative to recharge

The ratio of storage to recharge ranges from 242 to 838. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.4.6 The risk matrix

Table 31 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary:

- the SDL area is ranked low risk in terms of environmental assets, given that there are groundwater dependent assets that are sensitive to take in the SDL area
- the SDL area is ranked low risk in terms of ecosystem function, given that the surface water features are disconnected from the shallow groundwater system
- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio is greater than 40
- there is a risk to key environmental outcomes (i.e. groundwater salinity)
- there is a high uncertainty associated with this SDL area given that the RRAM is derived from diffuse groundwater recharge derived from WAVES modelling only. It does not include other potential components of groundwater recharge, including river leakage, irrigation returns, throughflow etc.

Table 31. Risk matrix

<table>
<tr><th>Risk ranking</th><th>Environmental assets (EAs)</th><th>OR</th><th>Ecosystem function</th><th>OR</th><th>Productive base</th><th>Sustainability factor (SF)</th><th>Key environmental outcome</th><th>Degree of uncertainty</th></tr>
<tr><td>High</td><td>EA that is highly groundwater dependent and highly sensitive to take</td><td rowspan="3"></td><td>In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion</td><td rowspan="3"></td><td>Storage/ recharge <20</td><td>0.10</td><td rowspan="3">Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes

Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made:

Salinity class 1: reduce SF by 20%

Salinity class 2: reduce SF by 10%

Salinity classes 3 & 4: no reduction</td><td rowspan="2">Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%</td></tr>
<tr><td>Medium</td><td>EA that is highly groundwater dependent and is moderately sensitive to take

EA that is moderately groundwater dependent and is highly sensitive to take</td><td>The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge 20–40</td><td>0.50</td></tr>
<tr><td>Low</td><td>EA that has a low groundwater dependence and low sensitivity to take

EAs do not exist in the SDL area</td><td>The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge >40</td><td>0.70</td><td>Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%</td></tr>
</table>

1.4.7 Preliminary RRAM extraction limit

Loxton Parilla Sands

The preliminary extraction limit resulting from the RRAM for the water table aquifer of the West Wimmera SDL area is 24 GL/year (Table 32). This is greater than the volume of current use for the watertable aquifer (0.0 GL/year). This means there is a volume of unassigned water (24 GL/year) associated with this SDL area.

The volume of unassigned water is much greater if all aquifers are considered (i.e. 51 GL/year). Given that the volume of unassigned water is greater than 50 GL, and that it is more than ten times the volume of current use, the extraction limit for the watertable aquifer has been recalculated with a medium sustainability factor.

This results in an extraction limit of 12 GL/year for the watertable aquifer (Table 33).

Table 32. Preliminary extraction limit for the West Wimmera SDL area (low risk sustainability factor)

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	13	22	5	10
Sustainability factor	0.42	0.47	0.53	0.53
Extraction limit (GL/yr)	**5.6**	**10**	**2.6**	**5.5**

Table 33. Preliminary extraction limit for the West Wimmera SDL area (medium risk sustainability factor)

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	13	22	5	10
Sustainability factor	0.2	0.23	0.25	0.25
Extraction limit (GL/yr)	**2.7**	**5.1**	**1.2**	**2.6**

Murray Group Limestone

There are three groundwater management areas that overlap this SDL area that represent the MGL: the Murrayville Water Supply Protection Area, the Telopea Downs Water Supply Protection Area and the Kaniva Water Supply Protection Area, these management areas can be seen in Figure 8. The calculated permissible consumptive volume (PCV) for the Murrayville Water Supply Protection Area was calculated based on the precedents set by the BGARC and includes an allowance of groundwater take from aquifer storage. The PCV Murrayville Water Supply Protection Area equates to 11 GL/year (Murrayville Groundwater Supply Protection Area Consultative Committee, 2001).

A permissible annual volume (PAV) was determined for the Telopea Downs Water Supply Protection Area, to equate to 13 GL/year and for the Kaniva Water Supply Protection Area; 7.0 GL/year (DSE, 2010b). However, since these areas were declared water supply protection areas, there has been an embargo on new licences, pending finalisation of the management plans.

To derive an extraction limit for the MGL aquifer in the West Wimmera SDL area that corresponds to the area of good quality groundwater and excluding areas under national park the PCV for the Murrayville Water Supply Protection Area and the PAV for the Telopea Downs and Kaniva Water Supply Protection Areas, have been manipulated to account for this area.

The current total PCV and PAV extraction limit for the three management units, is 31 GL/year. However, only 52 percent of the area represented by the water supply protection areas occurs within the SDL area. If the current total extraction limit (i.e. 31 GL/year) is reduced to 52 percent of this volume, this equates 13 GL/year (refer to Table 34).

The total SDL area is larger than the area covered by the groundwater management units (GMUs). If the extraction limit (i.e. 13 GL/year) was scaled up to account for the larger SDL area (excluding areas where groundwater salinity is greater than 3000 mg/L and also excluding areas of national park) the extraction limit would equate to approximately 26 GL/year.

This is greater than the volume of 2007/2008 groundwater use from the MGL aquifer, which equates to 1.9 GL/year. Therefore, there is 24 GL/year of unassigned water.

Table 34. GMU extraction limit summary for the MGL aquifer in the West Wimmera SDL area

GMU	Total area	Total PCV	Percentage area in the SDL area	Area in the SDL area	Corresponding PCV in the SDL area
	km^2	GL/yr	percent	km^2	GL/yr
Murrayville Water Supply Protection Area	1578	11*	38	607	4.2
Telopea Downs Water Supply Protection Area	1226	13**	24	297	3.3
Kaniva Water Supply Protection Area	1824	7.0***	83	1509	5.7
Total PCV within the West Wimmera SDL area					**13**

*The Murrayville Water Supply Protection Area PCV was derived from the Murrayville Area Groundwater Management Plan 2001.
**The Telopea Downs Water Supply Protection Area PAV was derived from the 2003/2004 Victorian Water Accounts.
***The Kaniva Water Supply Protection Area PAV was derived from the 2003/2004 Victorian Water Accounts.

Tertiary Confined Sands Aquifer

The BGARC 24th Annual Report summarises the management prescriptions for the TCSA, which were set in 2001 (BGARC, 2009). In summary, the volumes available for allocation are based on a proportion of throughflow. Due to the extensive nature of the TCSA and its hydraulic behaviour, the states extended the approach applied in the designated area to the whole aquifer system outside the designated area. For areas outside the designated area, the PCV is set at 0.50 x (0.75 x throughflow volume) (BGARC, 2009).

Within the West Wimmera SDL area, the Balrootan, Goroke, Kaniva TCSA and Nhill GMUs represent the TCSA. All of these GMUs have PCVs, with the exception of the Balrootan GMU which has an extraction limit but does not have an extraction limit type defined.

The combined extraction limit for the portion of these units that reside within the West Wimmera SDL area (representing an area of 4630 km^2) is 4 GL/year (Table 35). This area largely coincides with the area of good quality groundwater, outside of national park areas, in the SDL area (i.e. 3245 km^2). Therefore this extraction limit of 4 GL/year has been adopted. This is greater than the volume of 2007/2008 groundwater use, 0.8 GL/year (DSE, 2010a), and means there is a volume of unassigned water equal to 3.2 GL/year.

Table 35. GMU extraction limit summary for the TCSA in the West Wimmera SDL area

GMU	Total area	Total PCV*	Percentage area in the SDL area	Area in the SDL area	Corresponding PCV in the SDL area
	km^2	GL/yr	percent	km^2	GL/yr
Balrootan	424	0.98	100	424	0.98
Goroke	3386	2.2	43	1449	0.94
Kaniva TCSA	1824	1.1	83	1509	0.91
Nhill	1248	1.2	100	1248	1.2
Total PCV Within the West Wimmera SDL area					**4.03**

*All PCV/PAV volumes were derived from the 2004/2005 Victorian State Water Report.

Extraction limit summary for all aquifers in the West Wimmera SDL area

For the Loxton-Parilla Sand watertable aquifer, the extraction limit is derived from the RRAM and equates to 12 GL/year and given there is no extraction in this SDL area, there is also 12 GL/year of unassigned water.

For the MGL aquifer, the extraction limit is based on an extrapolation of the existing extraction limits of the Murrayville Water Supply Protection Area, the Telopea Downs Water Supply Protection Area and the Kaniva Water Supply Protection Area. The extrapolation is extended to the additional area of good quality groundwater (less than 3000 mg/L TDS), outside the areas of national park, given that these limits are used by the BGARC. The extraction limit equates to 25.5 GL/year. Given that there is 1.9 GL/year from the limestone aquifer, there is an unassigned water component of 24 GL/year.

For the TCSA, the extraction limit is based on the existing extraction limits of the Balrootan, Goroke, Kaniva TCSA and Nhill management areas. These management areas represent an area approximately equivalent to the area of good quality groundwater outside national park areas and therefore this extraction limit was adopted; 4 GL/year. Given that there is 0.8 GL/year from the TCSA, there is an unassigned water component of 3.2 GL/year.

The total combined extraction limit is 42 GL/year and this includes 39 GL/year of unassigned water.

1.5 Wimmera-Mallee Border Zone (GS17)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the RRAM for the Wimmera-Mallee Border Zone SDL area.

1.5.1 Background

The Wimmera-Mallee Border Zone SDL area is located in far western Victoria, between the SA Border and the West Wimmera SDL area. The SDL area has three main aquifers which are both confined and unconfined in nature. The Tertiary Confined Sands Aquifer (TCSA) contains Tertiary sands and gravels and is confined by the Ettrick Formation and Geera Clay over most of the SDL area. The overlying Murray Group Limestone (MGL) aquifer is confined or semi-confined across the majority of the SDL area by the Bookpurnong Beds with the exception of the southernmost section. Overlying the MGL and Bookpurnong Beds are the Loxton - Parilla and Woorinen Sands. The water table aquifer is found in the Loxton - Parilla Sands although there are some areas where these sediments are unsaturated.

Groundwater development has mostly occurred in the MGL aquifer since it is reasonably accessible and of good quality. There is also increasing pressure to exploit the deeper TCSA.

The RRAM analysis will focus on the watertable aquifer, given it is recharged via diffuse rainfall. The two deeper aquifers do not received recharge within a modern timeframe (i.e. within hundreds of years) and therefore the RRAM does not apply to these aquifers. Extraction limits have been developed for the two deeper aquifers based on the precedents set by the Border Zone Groundwater Agreement Review Committee (BGARC) and these results are summarised in the later section of this chapter.

The only aquifer with any development is the MGL, with no extraction currently occurring from the water table aquifer or the TCSA. Groundwater take from the MGL of the Wimmera-Mallee border Zone is equal to 8.9 GL/yr and is summarised in Table 36. For more information regarding the source of the entitlement and use information, refer to CSIRO (2010).

Table 36 Groundwater Take Summary for the Wimmera-Mallee Border Zone SDL area

Wimmera – Mallee Sedimentary Plain SDL area	GL/year
Total 2007/2008 Entitlement*	13
2007/2008 Metered Use for Entitlement Bores*	6.0
2007/2008 Estimated Use for Entitlement Bores*	1.2
2007/2008 Estimated Use for Stock & Domestic Bores*	1.7
Total 2007/2008 Use	8.9

*Entitlement and use information provided by GWMW

1.5.2 Salinity Zoning

The watertable aquifer contains all four salinity zones and is dominated by salinity zone 1 and salinity zone 4. The poorer quality water is found to the north; grading southwards to lower salinity groundwater (see Figure 10 and Table 37 Summary of Water Table Salinity Zones in the Wimmera-Mallee Border Zone SDL area). The MGLA contains salinity zone 1 groundwater in the south and also grades to more saline groundwater northwards (see Figure 11 and Table 38). The TCSA has a similar salinity zoning with fresher salinity groundwater to the south, and more saline water in the north.

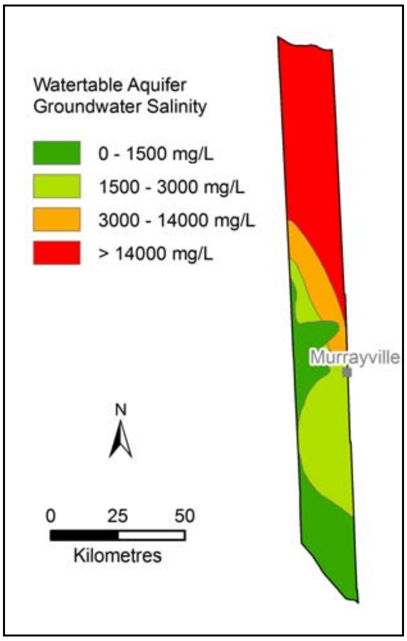

Figure 10 Wimmera-Mallee Border Zone watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 37 Summary of Water Table Salinity Zones in the Wimmera-Mallee Border Zone SDL area

Watertable Salinity Zone	Portion of Total Area (%)	Area (km^2)
Zone 1 (0 – 1,500 mg/L TDS)	24	973
Zone 2 (1,500 – 3,000 mg/L TDS)	26	1,020
Zone 3 (3,000 – 14,000 mg/L TDS)	10	397
Zone 4 (> 14,000 mg/L TDS)	40	1,606
Water Body	0	0
Total	**100**	**3,995**

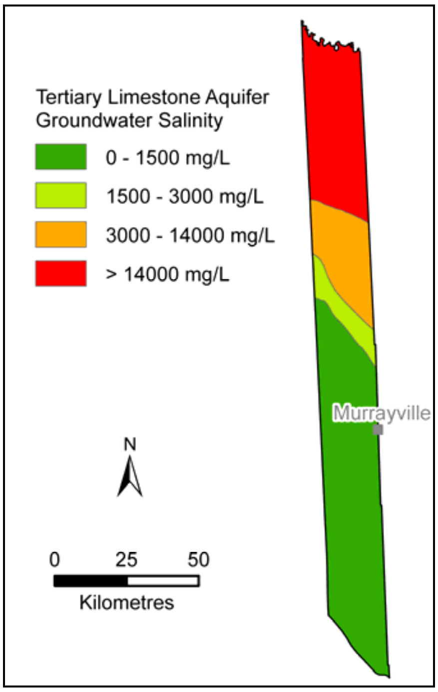

Figure 11 Wimmera-Mallee Border Zone MGL salinity distribution, from the Murray Group Limestone salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 38 Summary of MGL Salinity Zones in the Wimmera-Mallee Border Zone SDL area

Watertable Salinity Zone	Portion of Total Area (%)	Area (km^2)
Zone 1 (0 – 1,500 mg/L TDS)	56	2,240
Zone 2 (1,500 – 3,000 mg/L TDS)	6	230
Zone 3 (3,000 – 14,000 mg/L TDS)	15	591
Zone 4 (> 14,000 mg/L TDS)	23	935
Water Body	0	0
Total	**100**	**3,995**

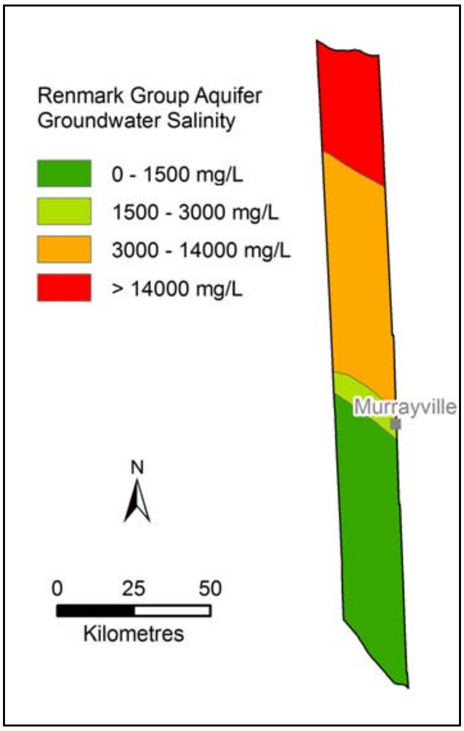

Figure 12 Wimmera-Mallee Border Zone TCSA salinity distribution, from the Murray Group Limestone salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 39 Summary of TCSA Salinity Zones in the Wimmera-Mallee Border Zone SDL area

Watertable Salinity Zone	Portion of Total Area (%)	Area (km^2)
Zone 1 (0 – 1,500 mg/L TDS)	40	1,589
Zone 2 (1,500 – 3,000 mg/L TDS)	4	186
Zone 3 (3,000 – 14,000 mg/L TDS)	36	1,439
Zone 4 (> 14,000 mg/L TDS)	20	781
Water Body	0%	0.0
Total	**100**	**3,995**

1.5.3 Key Environmental Assets

There are no key environmental assets that have been identified as groundwater dependent and sensitive to groundwater extraction as part of this RRAM assessment, that are associated with the Wimmera-Mallee Border Zone SDL area.

1.5.4 Key Ecosystem Function

There are no major rivers or significant surface water features which receive groundwater discharge from the water table aquifer in this SDL area and hence there is a low risk of impacts on Key Ecosystem Function.

1.5.5 Productive Base

1.5.5.1 Recharge

Modelled dryland diffuse groundwater recharge derived from WAVES modelling (Crosbie *et al.*, 2009) has been used to calculate recharge to the alluvial aquifer. The historical dry climate scenario, results in recharge rates ranging from 2.58 to 6.51 mm/yr for each of the salinity zones. This results in a total recharge of 21 GL/year to the watertable aquifer within the SDL area.

Table 40 Recharge Calculation

	Salinity Zone 1	Salinity Zone 2	Salinity Zone 3	Salinity Zone 4
Area (km2)	973	1,020	397	1,606
Diffuse Recharge (mm/yr)	6.9	7.5	5.2	2.6
Total Recharge (GL/yr)	**6.7**	**7.7**	**2.1**	**4.1**

1.5.5.2 Storage

The Loxton – Parilla Sands are thought to have a total thickness up to 60 m (URS, 2008) and watertables are thought to be deep in this region with the sediments unsaturated in areas. Hence a saturated thickness has been assumed to be approximately 15 m. A specific yield value of 10 % has been used (Johnson, 1967), as it is typical of a shallow marine sediments with variable grain size. Based on these assumptions, the combined groundwater storage estimates for all salinity zones in the SDL area is 5,993 GL (Table 41).

Table 41 Storage Calculation

	Salinity Zone 1	Salinity Zone 2	Salinity Zone 3	Salinity Zone 4
Area (km2)	973	1,020	397	1,606
Saturated Thickness (m)	15	15	15	15
Specific Yield	0.1	0.1	0.1	0.1
Total storage (GL)	**1,459**	**1,530**	**591**	**2,409**

1.5.5.3 Storage Relative to Recharge

The ratio of storage to recharge ranges from 199 to 588. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.5.6 The Risk Matrix

Table 42 provides a summary of the risk ranking associated with; Key Environmental Assets, Key Ecosystem Function, the Productive Base, the Key Environmental Outcome and the uncertainty inherent in the RRAM calculation. In summary;

- The SDL area is ranked low risk in terms of Environmental Assets, given that there are no groundwater dependent assets that are sensitive to take in the SDL area
- The SDL area is ranked low risk in terms of Ecosystem Function, given that the surface water features are not thought to receive significant groundwater discharge
- The SDL area is ranked low risk in terms of the Productive Base, given that the storage/recharge ratio is far greater than 40
- There is a risk to key environmental outcomes (i.e. groundwater salinity)

- There is a high uncertainty associated with this SDL area given that the RRAM is derived from diffuse groundwater recharge derived from WAVES modelling only. It does not include other potential components of groundwater recharge, including river leakage, irrigation returns, throughflow etc

Table 42 Risk Matrix

Risk Ranking	Environmental Assets	OR	Ecosystem Function	OR	Productive Base	Sustainability Factor	Key Environmental Outcome	Degree of Uncertainty
High	EA that is highly groundwater dependent and highly sensitive to take		In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion.		Storage / Recharge < 20	0.10	Where there is no risk to the Key Environmental Outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the Salinity Classes. Where there is a risk to the Key Environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made: Salinity Class 1: reduce SF by 20% Salinity Class 2: reduce SF by 10% Salinity Class 3 & 4: no reduction	Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%.
Medium	EA that is highly groundwater dependent and is moderately sensitive to take EA that is moderately groundwater dependent and is highly sensitive to take		The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. > 50 % impact of pumping on stream flow within 50 years)		Storage / Recharge between 20-40	0.50		
Low	EA that has a low groundwater dependence and low sensitivity to take EAs do not exist in the SDL area		The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. < 50 % impact of pumping on stream flow within 50 years)		Storage / Recharge > 40	0.70		Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%.

1.5.7 Preliminary RRAM Extraction Limit

1.5.7.1 Loxton Parilla Sands

The preliminary RRAM derived extraction limit for the watertable aquifer in the Wimmera-Mallee Border Zone SDL area is 9.7 GL/yr (Table 43). This is greater than the volume of current use from the watertable aquifer (0 GL/yr). This means there is a volume of unassigned water (9.7 GL/yr) associated with this SDL area.

Table 43 Preliminary Extraction Limit

	Salinity Zone 1	Salinity Zone 2	Salinity Zone 3	Salinity Zone 4
Recharge (GL/yr)	6.7	7.7	2.1	4.1
Sustainability Factor	0.42	0.47	0.53	0.53
Extraction Limit (GL/yr)	2.8	3.6	1.1	2.2

1.5.7.2 Murray Group Limestone

The Border Zone Groundwater Agreement Review Committee (BGARC) has set a Permissible Rate of Potentiometric Surface Lowering for the Murray Group Limestone in the Border Zone region which comprises this SDL area (BGARC, 2009). The SDL area is entirely represented by parts of the Border Zone areas; 11B, 10B, 9B and 8B.

The PAVs for these units were calculated based on the precedents set by the BGARC. The current prescriptions are based on taking a proportion of groundwater in storage being equivalent to a drawdown of storage under unconfined conditions of 0.05 m/year. The full equation used for these calculations is;

Area of groundwater quality less than 3,000 mg/L (km2) x drawdown rate (cm) x Specific Yield

The PAVs for each Border Zone unit were based on this calculation; however, in Zone 9B where existing allocation exceeded the calculated PAV, the PAV was set at the current allocations.

The total current PAV for each of the Border Zone Units in the SDL area, equates to 21 GL/yr.

The portion of these zones that fall within the SDL area boundary is summarised in Table 44 and indicates that the PAV relative to the SDL area is approximately 14 GL/yr.

This is greater than the volume of 2007/2008 groundwater use from the MGL aquifer, which equates to 8.9 GL/yr. This means there is unassigned water associated with this SDL area (5.2 GL/year).

Table 44 GMU Extraction Limit Summary for the MGL aquifer in the Wimmera-Mallee Border Zone SDL area

GMU	Total Area (km^2)	Total PCV (GL/yr)	Percentage Area in the SDL area	Area in the SDL area (km^2)	Corresponding PCV in the SDL area (GL/yr)
ZONE 10B	1113	6.7	100%	1113	6.7
ZONE 11B	2102	1.8	100%	2102	1.8
ZONE 8B	557	6.8	4%	20	0.24
ZONE 9B	1109	6.0*	89%	984	5.3
Total PCV Within the Wimmera Mallee Border Zone SDL area (GL/yr)			**14**		

*note that the PAV for zone 9B was calculated at 2.5 GL/yr based on a managed rate of decline, however the total allocation volume at the time was 6.0 GL/yr and this was the adopted PAV

1.5.7.3 Tertiary Confined Sands Aquifer

The BGARC 24th Annual Report summarises the management prescriptions for the TCSA, which were set in 2001 (BGARC, 2009). In summary, the volumes available for allocation are based on a proportion of throughflow. Due to the extensive nature of the TCSA and its hydraulic behaviour, the states extended the approach applied in the Designated Area to the whole aquifer system outside the Designated Area. For Zones 5B to 11B the PAV is set at 0.25 x (0.75 x throughflow volume).

The total current PAV for each of the Border Zone Units in the SDL area, equates to 1.5 GL/yr.

The portion of these zones that fall within the SDL boundary is summarised in Table 45 and indicates that the PAV relative to the SDL area is approximately 1.1 GL/yr. There is currently no extraction occurring from the TCSA (BGARC, 2009). This means there is a volume of unassigned water in the SDL area (1.1 GL/year).

Table 45 GMU Extraction Limit Summary for the TCSA aquifer in the Wimmera-Mallee Border Zone SDL area

GMU	Total Area (km^2)	Total PCV (GL/yr)	Percentage Area in the SDL area	Area in the SDL area (km^2)	Corresponding PCV in the SDL area (GL/yr)
ZONE 11B	2102	0.00	100%	2102	0.00
ZONE 10B	1113	0.56	100%	1113	0.56
ZONE 9B	1109	0.63	89%	984	0.56
ZONE 8B	557	0.33	4%	20	0.01
Total PCV Within the Wimmera Mallee Border Zone SDL area (GL/yr)					1.1

1.5.7.4 Extraction Limit Summary for all aquifers in the Wimmera-Mallee Border Zone SDL area

For the Loxton Parilla Sand watertable aquifer, the extraction limit is derived from the RRAM and equates to 9.7 GL/yr.

For the MGL aquifer and the TCSA, the extraction limit was derived by adjusting the BGARC defined extraction limits for zones 11B, 10B, 9B and 8B, based on the portion of each zone that actually resides within the SDL area. The extraction limit equates to 14 GL/yr for the MGL and 1.1 GL/yr for the TCSA.

The total combined extraction limit is 25 GL/yr, with a total unassigned water volume of 16 GL/year.

1.6 Goulburn-Broken Highlands (GS9)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the RRAM for the Goulburn-Broken Highlands SDL area.

1.6.1 Background

The Goulburn-Broken Highlands SDL area predominantly falls outside any existing GMUs (North Central Unincorporated Area). However, two small GMUs, being Alexandra GMA and Kinglake GMA, are within the SDL area bounds. The Goulburn-Broken Highlands SDL area is directly south of the Mid Goulburn GMA and the Shepparton Irrigation Water Supply Protection Area. The sum of 2007/2008 groundwater extraction in this SDL area is 9.8 GL/year (Table 46). For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

The aquifers of the Goulburn-Broken Highlands SDL area are mostly fractured rock aquifers with some superficial alluvial cover in small areas. The fractured rocks are typically Devonian igneous rocks (granite) and volcanic rocks (ignimbrite, rhyolite, e.g. Marysville Group), and deformed sandstone and mudstone of various Palaeozoic ages (Carboniferous to Ordovician, e.g. Walhalla Group) (Heislers, 1993; GSV, 2010). These rocks are considered to be basement rocks where they underlie thicker sequences of Murray Basin sediments to the north, e.g. in the Victorian Riverine Sedimentary Plain SDL area. In the Goulburn-Broken Highlands SDL area these rocks will be considered as a single fractured rock aquifer.

Virtually no irrigation occurs within the Goulburn-Broken Highlands SDL area, with the exception of irrigation within the Kinglake GMA. The aquifer is generally low-yielding, with typical yields of less than 0.5 L/sec (Dimos et al., 1994; Hennessy et al., 1994), but can be more productive in zones of intense faulting and jointing.

Table 46. Groundwater take summary for the Goulburn-Broken Highlands SDL area

Goulburn-Broken Highlands SDL area	GL/yr
Total 2007/2008 entitlement*	**9.2**
2007/2008 metered use for entitlement bores*	0.0
2007/2008 estimated use for entitlement bores**	5.5
2007/2008 estimated use for stock and domestic bores***	4.3
Total 2007/2008 use	**9.8**

*Entitlement and metered use information provided by the Department of Sustainability and Environment.
**Estimated use is equal to 60% of the entitlement volume.
***Stock and domestic use is estimated as 2 ML per bore with a stock and domestic use type.

1.6.2 Salinity zoning

Groundwater quality in the fractured rock aquifers of this SDL area varies from very good in the high-altitude and high-rainfall areas (e.g. near Mansfield) to poor in the lowlands further north (Dimos et al., 1994; Hennessy et al., 1994). All four salinity zones are present in the SDL area, with groundwater TDS ranging from less than 1500 mg/L to more than 14,000 mg/L. The groundwater salinity distribution can be seen in Figure 13 and is summarised in Table 47.

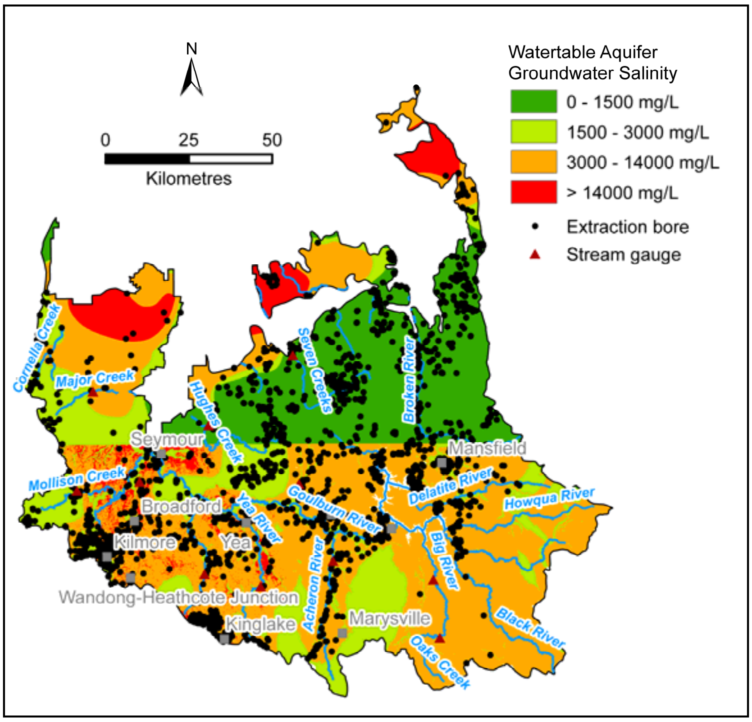

Figure 13. Goulburn-Broken Highlands watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 47. Summary of salinity zones in the Goulburn-Broken Highlands SDL area

Watertable salinity zone	Portion of area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	23	3,347
Zone 2 (1500–3000 mg/L TDS)	21	3,081
Zone 3 (3000–14,000 mg/L TDS)	48	7,103
Zone 4 (>14,000 mg/L TDS)	7	988
Water bodies	1	186
Total	**100**	**14,519**

1.6.3 Key environmental assets

There are no key environmental assets that have been identified as groundwater dependent and sensitive to groundwater extraction as part of this RRAM assessment, that are associated with the Goulburn-Broken Highlands SDL area.

1.6.4 Key ecosystem function

Although parts of the Goulburn and Broken Rivers are regulated, many of their tributaries are unregulated and many reaches in the SDL area have been defined as gaining river reaches (CSIRO, 2008b). For example, the reach of the Broken River above the Gowangardie Weir is estimated to have an annual baseflow index of 0.41 (SKM, 2001). Therefore, there is considered to be a high risk of groundwater extraction affecting ecosystem function in this SDL area.

1.6.5 Productive base

Recharge

Given that the aquifer being assessed for the Goulburn-Broken Highlands SDL area is the surficial fractured rock aquifer, an estimate of watertable recharge is appropriate. The bounds of the SDL area coincide with catchment boundaries and therefore calculation of throughflow as a component of recharge is not necessary. Additionally, recharge from irrigation can be discounted as irrigation is virtually absent in the SDL area. The estimate of watertable recharge is derived from dryland diffuse groundwater recharge modelled using WAVES (Crosbie et al., 2010). The historical climate scenario for a dry 15-year period results in a recharge rate of 69, 65, 61 and 28 mm/year for salinity class 1, 2, 3 and 4 respectively. This results in a total recharge of 891 GL/year within the SDL area (Table 48).

Table 48. Recharge calculation for the Goulburn-Broken Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	3347	3081	7103	988
WAVES recharge (mm/yr)	69	65	61	28
Total recharge (GL/yr)	**232**	**201**	**431**	**27**

Storage

The fractured rock aquifer of this SDL area can contain large amounts of groundwater in storage due to its lateral extent and significant thickness, which can exceed several hundred metres (Heislers, 1993). However, the utility of such aquifers is limited to the development of secondary porosity (i.e. fractures), and, although fractures have been documented as deep as 400 m, for example in the Ovens Highlands SDL area (Kenny, 1925), the weathered zone is generally considered to be the more productive part of the aquifer. The weathered zone in rocks similar to those of the Goulburn-Broken Highlands SDL area can extend up to 80 to 100 m deep (Shugg, 1987; Tweed et al., 2005). Therefore, a nominal thickness of 100 m is applied to the storage calculation. Given that the depth to the watertable in highland areas is very variable and can exceed 50 m (SKM and GHD, 2009), an average depth to water of 25 m is assumed, resulting in a saturated thickness of 75 m.

The average yield from bores in the Goulburn-Broken Highlands SDL area is low (ranging from 0.2 to 1.6 L/sec), and is mainly dependent on the density and connectivity of fracture porosity in the host rock, which is in turn dictated by lithology (Heislers, 1993). Representative measured values of fracture porosity are not available; therefore, specific yield values of similar rock types have been used as an estimate instead. Typically, granite has a specific yield of 0.001, clay a value of 0.02, siltstone a value of 0.12 and sandstone a value of 0.08 to 0.21 (Johnson, 1967; Heath, 1983). Sandstone and mudstone are the dominating lithologies of this SDL area, and therefore an average of the sandstone and siltstone values (0.13) is used to calculate the average aquifer storage.

Total storage of the surficial fractured rock aquifer is approximately 141,556 GL (Table 49).

Table 49. Storage calculation for the Goulburn-Broken Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	3,347	3,081	7,103	988
Saturated thickness (m)	75	75	75	75
Specific yield	0.13	0.13	0.13	0.13
Total storage (GL)	**32,636**	**30,042**	**69,250**	**9,628**

Storage relative to recharge

The ratio of storage to recharge ranges from 141 to 357 over the different salinity classes. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.6.6 The risk matrix

Table 50 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary:

- the SDL area is ranked low risk in terms of environmental assets, given that no EAs exist within the SDL area
- the SDL area is ranked high risk in terms of ecosystem function, given that unregulated rivers and streams exist in the area and are dependent on baseflow

- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio far exceeds 40
- there is no risk to key environmental outcomes (i.e. groundwater salinity)
- there is a high uncertainty associated with this SDL area given that the RRAM is derived from diffuse groundwater recharge derived from WAVES modelling only. It does not include other potential components of groundwater recharge, including river leakage, irrigation returns, throughflow etc.

Table 50. Risk matrix

Risk ranking	Environmental assets (EAs)	OR	Ecosystem function	OR	Productive base	Sustainability factor (SF)	Key environmental outcome	Degree of uncertainty
High	EA that is highly groundwater dependent and highly sensitive to take		In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in streamflow depletion		Storage/ recharge <20	0.10	Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made: Salinity class 1: reduce SF by 20% Salinity class 2: reduce SF by 10% Salinity classes 3 & 4: no reduction	Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%
Medium	EA that is highly groundwater dependent and is moderately sensitive to take EA that is moderately groundwater dependent and is highly sensitive to take		The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)		Storage/ recharge 20–40	0.50		
Low	EA that has a low groundwater dependence and low sensitivity to take EAs do not exist in the SDL area		The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)		Storage/ recharge >40	0.70		Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%

1.6.7 Preliminary RRAM extraction limit

The preliminary RRAM derived extraction limit for the Goulburn-Broken Highlands SDL area is 45 GL/year (for all salinity classes) (Table 51). This is greater than the 2007/2008 volume of groundwater extraction (9.8 GL/year). However, given the high level of groundwater and surface water connectivity, the groundwater extraction limit will be set at current use. Further development of the groundwater system is feasible up to the RRAM derived extraction limit of 45 GL/year, where an equivalent reduction in surface water is required to offset the additional groundwater take on the basis of a 1:1 relationship between groundwater take and surface water streamflow reduction.

Table 51. Preliminary extraction limit for the Goulburn-Broken Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	232	201	431	27
Sustainability factor	0.05	0.05	0.05	0.05
Extraction limit (GL/yr)	**12**	**10**	**22**	**1.4**

1.7 Loddon-Campaspe Highlands (GS10)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the RRAM for the Loddon-Campaspe Highlands SDL area.

1.7.1 Background

The Loddon-Campaspe Highlands SDL area consists entirely of land that is not incorporated into any GMU (North Central Unincorporated Area). The SDL area is split into a western and an eastern part, which are separated by the Mid-Loddon, Upper Loddon and Spring Hill Water Supply Protection Areas. The Southern Campaspe Plains GMA lies directly to the north of the eastern part of the Loddon-Campaspe Highlands SDL area. The sum of 2007/2008 groundwater extraction in this SDL area is 9.4 GL/year (Table 52). For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

The aquifers of the Loddon-Campaspe Highlands SDL area are mostly fractured rock aquifers with some superficial alluvial cover in small areas. The aquifer rocks are typically deformed sandstone and mudstone of Ordovician age (e.g. Castlemaine Group, GSV, 2010) and Devonian igneous rocks (granite or granodiorite). Some more minor areas consist of outcrop of Quaternary basalt, Older Volcanics, Cambrian shale, or Permian diamictite (Bacchus Marsh Formation) (Heislers, 1993; GSV, 2010). These rocks are considered to be basement rocks where they underlie thicker sequences of Murray Basin sediments to the north, e.g. in the Victorian Riverine Sedimentary Plain SDL area. In the Loddon-Campaspe Highlands SDL area these rocks will be considered as a single fractured rock aquifer.

Virtually no irrigation occurs within the Loddon-Campaspe Highlands SDL area. The aquifer is generally low-yielding, with a typical yield of less than 0.5 L/sec (Dimos et al., 1994), but can be more productive in zones of intense faulting and jointing.

Table 52. Groundwater take summary for the Loddon-Campaspe Highlands SDL area

Loddon-Campaspe Highlands SDL area	GL/yr
Total 2007/2008 entitlement*	**7.0**
2007/2008 metered use for entitlement bores*	0.0
2007/2008 estimated use for entitlement bores**	4.2
2007/2008 estimated use for stock and domestic bores***	5.2
Total 2007/2008 use	**9.4**

*Entitlement and metered use information provided by the Department of Sustainability and Environment.
**Estimated use is equal to 60% of the entitlement volume.
***Stock and domestic use is estimated as 2 ML per bore with a stock and domestic use type.

1.7.2 Salinity zoning

Shallow groundwater quality in the fractured rock aquifers of this SDL area varies from very good in the vicinity of the Campaspe River, Wild Duck Creek and part of the Loddon River to poor in the other regions (e.g. the Ordovician sediments north of Bendigo) (Dimos et al., 1994; Figure 14). All four salinity zones are present in the SDL area, with groundwater TDS ranging from less than 1,500 mg/L to more than 14,000 mg/L. The groundwater salinity distribution can be seen in Figure 14 and is summarised in Table 53.

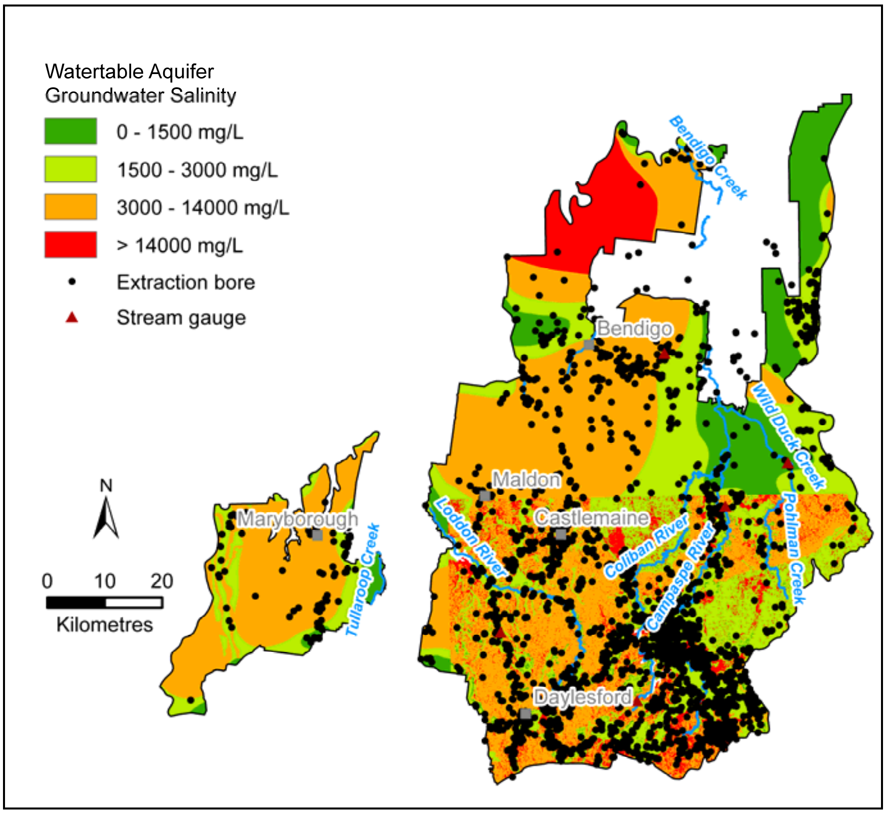

Figure 14 .Loddon-Campaspe Highlands watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 53. Summary of salinity zones in the Loddon-Campaspe Highlands SDL area

Watertable salinity zone	Portion of area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	12	797
Zone 2 (1500–3000 mg/L TDS)	30	1935
Zone 3 (3000–14,000 mg/L TDS)	47	2990
Zone 4 (>14,000 mg/L TDS)	10	668
Water bodies	<1	30
Total	**100**	**6420**

1.7.3 Key environmental assets

There are no groundwater dependent key environmental assets that are sensitive to groundwater extraction associated with the Loddon-Campaspe Highlands SDL area.

1.7.4 Key ecosystem function

Although parts of the Loddon and Campaspe Rivers are regulated, many of their tributaries are unregulated, and several stream reaches in the SDL area have been defined as gaining river reaches (CSIRO, 2008c; 2008d). For example, the reach of the Campaspe River above Redesdale is estimated to have an annual baseflow index of 0.59 (SKM, 2001). Therefore, there is considered to be a high risk of groundwater extraction affecting ecosystem function in this SDL area.

1.7.5 Productive base

Recharge

Given that the aquifer being assessed for the Loddon-Campaspe Highlands SDL area is the surficial fractured rock aquifer, an estimate of watertable recharge is appropriate. The up-gradient boundaries of the SDL area coincide with catchment boundaries and therefore calculation of throughflow as a component of recharge is not necessary. Additionally, recharge from irrigation can be discounted as irrigation is virtually absent in the SDL area. The estimate of watertable recharge is derived from dryland diffuse groundwater recharge modelled using WAVES (Crosbie et al., 2010). The historical climate scenario for a median 15-year period results in a recharge rate of 20 mm/year for salinity class 1, 49 mm/year in salinity class 2, 25 mm/year in salinity class 3, and 33 mm/year in salinity class 4. This results in a total recharge of 206 GL/year within the SDL area (Table 54).

Table 54. Recharge calculation for the Loddon-Campaspe Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	797	1935	2990	668
WAVES recharge (mm/yr)	20	49	25	33
Total recharge (GL/yr)	**16**	**95**	**73**	**22**

Storage

The fractured rock aquifer of this SDL area can contain voluminous amounts of groundwater in storage due to its significant thickness, which can exceed several hundred metres (Heislers, 1993). However, the utility of such aquifers is limited to the development of secondary porosity (i.e. fractures), and, although fractures have been documented as deep as 400 m in, for example, the Ovens Highlands SDL area (Kenny, 1925), the weathered zone is generally considered to be the more productive part of the aquifer. The weathered zone in rocks similar to those of the Loddon-Campaspe Highlands SDL area can extend up to 80 to 100 m deep (Shugg, 1987; Tweed et al., 2005). Therefore, a nominal thickness of 100 m is applied to the storage calculation. Given that the depth to the watertable in highland areas is very variable and can exceed 50 m (SKM and GHD, 2009), an average depth to water of 25 m is assumed, resulting in a saturated thickness of 75 m.

The average yield from bores screened in older fractured rocks in the Loddon-Campaspe Highlands SDL area is generally low (ranging from 0.4 to 1.9 L/sec), but is slightly higher in the young basalt deposits (4.4 L/sec) (Heislers, 1993). The average bore yield is mainly dependent on the density and connectivity of fracture porosity in the host rock, which is in turn dictated by lithology (Heislers, 1993). Representative measured values of fracture porosity are not available; therefore, specific yield values of similar rock types have been used as an estimate instead. Typically, granite has a specific yield of 0.001, clay a value of 0.02, basalt a value of 0.08, siltstone a value of 0.12 and sandstone a value of 0.08 to 0.21 (Johnson, 1967; Heath, 1983). Sandstone and mudstone are the dominating lithologies of this SDL area, and therefore an average of the sandstone and siltstone values (0.13) is used to calculate the average aquifer storage.

Total storage of the surficial fractured rock aquifer is approximately 62,307 GL (Table 55).

Table 55. Storage calculation for the Loddon-Campaspe Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	797	1,935	2,990	668
Saturated thickness (m)	75	75	75	75
Specific yield	0.13	0.13	0.13	0.13
Total storage (GL)	**7,768**	**18,871**	**29,156**	**6,512**

Storage relative to recharge

The ratio of storage to recharge ranges from 199 to 486 over the different salinity classes. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.7.6 The risk matrix

Table 56 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary:

- the SDL area is ranked low risk in terms of environmental assets, given that no groundwater dependent ecosystems exist within the SDL area
- the SDL area is ranked high risk in terms of ecosystem function, given that unregulated rivers and streams exist in the area and are dependent on baseflow
- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio far exceeds 40
- there is no risk to key environmental outcomes (i.e. groundwater salinity)
- there is a high uncertainty associated with this SDL area given that the RRAM is derived from diffuse groundwater recharge derived from WAVES modelling only. It does not include other potential components of groundwater recharge, including river leakage, irrigation returns, throughflow etc.

Table 56. Risk matrix

<table>
<tr><th>Risk ranking</th><th>Environmental assets (EAs)</th><th>OR</th><th>Ecosystem function</th><th>OR</th><th>Productive base</th><th>Sustainability factor (SF)</th><th>Key environmental outcome</th><th>Degree of uncertainty</th></tr>
<tr><td>High</td><td>EA that is highly groundwater dependent and highly sensitive to take</td><td rowspan="3"></td><td>In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion</td><td rowspan="3"></td><td>Storage/ recharge <20</td><td>0.10</td><td rowspan="3">Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes

Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made:

Salinity class 1: reduce SF by 20%

Salinity class 2: reduce SF by 10%

Salinity classes 3 & 4: no reduction</td><td rowspan="2">Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%</td></tr>
<tr><td>Medium</td><td>EA that is highly groundwater dependent and is moderately sensitive to take

EA that is moderately groundwater dependent and is highly sensitive to take</td><td>The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge 20–40</td><td>0.50</td></tr>
<tr><td>Low</td><td>EA that has a low groundwater dependence and low sensitivity to take

EAs do not exist in the SDL area</td><td>The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge >40</td><td>0.70</td><td>Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%</td></tr>
</table>

1.7.7 Preliminary RRAM extraction limit

The preliminary estimated extraction limit resulting from the RRAM for the Loddon-Campaspe Highlands SDL area is 10 GL/year (Table 57). This extraction limit has been superseded to equate to current use (i.e. 9.4 GL/year).

Table 57. Preliminary extraction limit for the Loddon-Campaspe Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	16	95	73	22
Sustainability factor	0.05	0.05	0.05	0.05
Extraction limit (GL/yr)	**0.79**	**4.7**	**3.7**	**1.1**

1.8 Ovens Highlands (GS12)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the Ovens Highlands SDL area.

1.8.1 Background

The Ovens Highlands SDL area covers an area that contains sections of two GMUs and a small area of the North Central Unincorporated Area. The Lower Ovens GMA overlaps with the west of the SDL area and the Upper Ovens Water Supply Protection Area lies in the eastern part of the SDL area. The sum of 2007/2008 extraction in this SDL area is 3.2 GL/year (Table 58). For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

The aquifers of the Ovens Highlands SDL area are mostly fractured rock aquifers with some superficial alluvial cover in small areas. The aquifer rocks are dominated by deformed sandstone and mudstone of Ordovician age (e.g. Adaminaby Group, GSV, 2010). There are also significant deposits of Devonian igneous rocks (granite or granodiorite) and an area of Devonian volcanic rocks in the southwest (e.g. rhyolite and ignimbrite). Some more minor areas consist of outcrop of Older Volcanics and Carbonaceous mudstone and sandstone (Heislers, 1993). These rocks are considered to be basement rocks where they underlie thicker sequences of Murray Basin sediments to the north, e.g. in the Ovens-Kiewa Sedimentary Plain SDL area. In the Ovens Highlands SDL area these rocks will be considered as a single fractured rock aquifer.

Virtually no irrigation occurs within the Ovens Highlands SDL area. The aquifer is generally low-yielding, with a typical yield of less than 0.5 L/sec (Hennessy et al., 1994), but can be more productive in zones of intense faulting and jointing.

Table 58. Groundwater take summary for the Ovens Highlands SDL area

Ovens Highlands SDL area	GL/yr
Total 2007/2008 entitlement*	**3.2**
2007/2008 metered use for entitlement bores*	0.0
2007/2008 estimated use for entitlement bores**	1.9
2007/2008 estimated use for stock and domestic bores***	1.3
Total 2007/2008 use	**3.2**

*Entitlement and metered use information provided by the Department of Sustainability and Environment.
**Estimated use is equal to 60% of the entitlement volume.
***Stock and domestic use is estimated as 2 ML per bore with a stock and domestic use type.

1.8.2 Salinity zoning

All four salinity zones are present in the SDL area, with groundwater TDS ranging from less than 1,500 mg/L to more than 14,000 mg/L. However, the majority of the region hosts high-quality groundwater due to the high rainfall rates over much of the high altitude areas. An area of brackish groundwater exists in the region of the granitic pluton west of Rutherglen (Hennessy et al., 1994). The groundwater salinity distribution can be seen in Figure 15 and is summarised in Table 59.

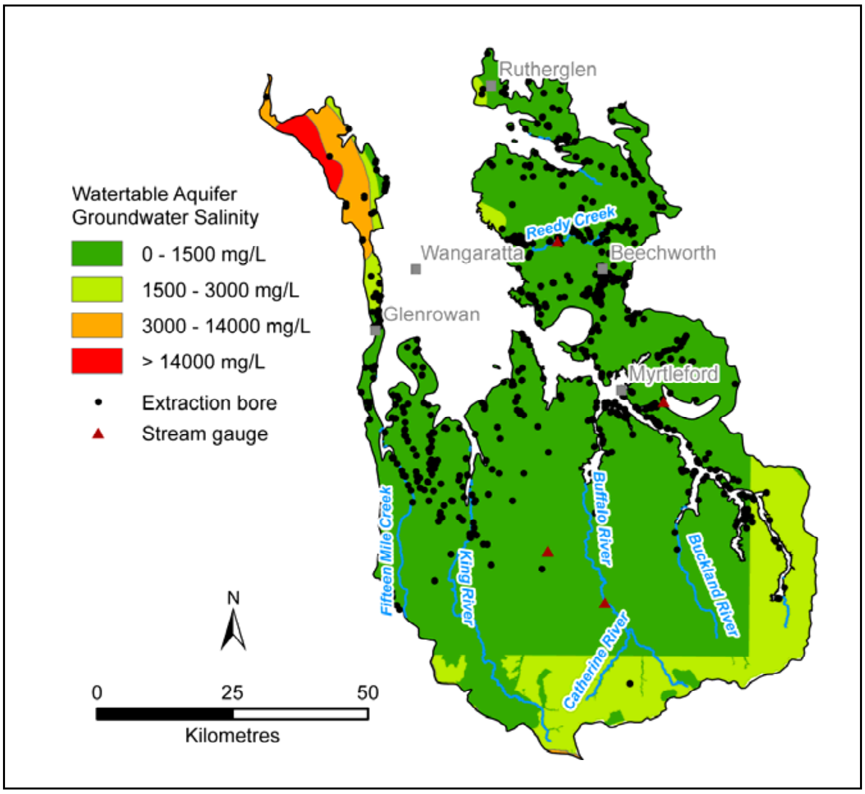

Figure 15. Ovens Highlands watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 59. Summary of salinity zones in the Ovens Highlands SDL area

Watertable salinity zone	Portion of area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	81	4658
Zone 2 (1500–3000 mg/L TDS)	16	898
Zone 3 (3000–14,000 mg/L TDS)	2	139
Zone 4 (>14,000 mg/L TDS)	1	54
Water bodies	<1	11
Total	**100**	**5759**

1.8.3 Key environmental assets

The entire Ovens Highlands region is considered an environmental asset that is groundwater dependent and sensitive to take. The key environmental asset is therefore at high risk.

1.8.4 Key ecosystem function

Although parts of the Ovens, Buffalo and King Rivers are regulated, many of their tributaries are unregulated and several reaches of the Ovens River have been identified as gaining river reaches (CSIRO, 2008e). For example, the reach of the Ovens River above Bright is estimated to have an annual baseflow index of 0.57 (SKM, 2001). Therefore, there is considered to be a high risk of groundwater extraction affecting ecosystem function in this SDL area.

1.8.5 Productive base

Recharge

Given that the aquifer being assessed for the Ovens Highlands SDL area is the surficial fractured rock aquifer, an estimate of watertable recharge is appropriate. The up-gradient boundaries of the SDL area coincide with catchment boundaries and therefore calculation of throughflow as a component of recharge is not necessary. Additionally, recharge from irrigation can be discounted as irrigation is virtually absent in the SDL area. The estimate of watertable recharge is derived from dryland diffuse groundwater recharge modelled using WAVES (Crosbie et al., 2010). The historical climate scenario for a dry 15 year period results in a recharge rate of 96, 111, 52 and 62 mm/year for salinity class 1, 2, 3 and 4 respectively. This results in a total recharge of 557 GL/year within the SDL area (Table 60).

Table 60. Recharge calculation for the Ovens Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	4658	898	139	54
WAVES recharge (mm/yr)	96	111	52	62
Total recharge (GL/yr)	**446**	**100**	**7.1**	**3.3**

Storage

The fractured rock aquifer of this SDL area can contain voluminous amounts of groundwater in storage due to its significant thickness, which can exceed several hundred metres (Heislers, 1993). However, the utility of such aquifers is limited to the development of secondary porosity (i.e. fractures), and, although fractures have been documented as deep as 400 m in this SDL area (Kenny, 1925), the weathered zone is generally considered to be the more productive part of the aquifer. The weathered zone in rocks of the Ovens Highlands SDL area can extend up to 100 m deep (Shugg, 1987). Therefore, a nominal thickness of 100 m is applied to the storage calculation. Given that the depth to the watertable in highland areas is very variable and can exceed 50 m (SKM and GHD, 2009), an average depth to water of 25 m is assumed, resulting in a saturated thickness of 75 m.

The average yield from bores screened in the fractured rocks in the Ovens Highlands SDL area is generally low (ranging from 0.5 to 1.2 L/sec) (Heislers, 1993). The average bore yield is mainly dependent on the density and connectivity of fracture porosity in the host rock, which is in turn dictated by lithology (Heislers, 1993). Representative measured values of fracture porosity are not available; therefore, specific yield values of similar rock types have been used as an estimate instead. Typically, granite has a specific yield of 0.001, clay a value of 0.02, basalt a value of 0.08, siltstone a value of 0.12 and sandstone a value of 0.08 to 0.21 (Johnson, 1967; Heath, 1983). Sandstone and mudstone are the dominating lithologies of this SDL area, and therefore an average of the sandstone and siltstone values (0.13) is used to calculate the average aquifer storage.

Total storage of the surficial fractured rock aquifer is approximately 56,043 GL (Table 61).

Table 61. Storage calculation for the Ovens Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	4,658	898	139	54
Saturated thickness (m)	75	75	75	75
Specific yield	0.13	0.13	0.13	0.13
Total storage (GL)	**45,412**	**8,757**	**1,352**	**522**

Storage relative to recharge

The ratio of storage to recharge ranges from 88 to 158 over the different salinity classes. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.8.6 The risk matrix

Table 62 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary:

- the SDL area is ranked high risk in terms of environmental assets, given that the entire SDL area is considered an environmental asset that is groundwater dependent and sensitive to take
- the SDL area is ranked high risk in terms of ecosystem function, given that unregulated rivers and streams exist in the area and are dependent on baseflow
- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio exceeds 40
- there is no risk to key environmental outcomes (i.e. groundwater salinity)
- there is a high uncertainty associated with this SDL area given that the RRAM is derived from diffuse groundwater recharge derived from WAVES modelling only. It does not include other potential components of groundwater recharge, including river leakage, irrigation returns, throughflow etc.

Table 62. Risk matrix

<table>
<tr><th>Risk ranking</th><th>Environmental assets (EAs)</th><th>OR</th><th>Ecosystem function</th><th>OR</th><th>Productive base</th><th>Sustainability factor (SF)</th><th>Key environmental outcome</th><th>Degree of uncertainty</th></tr>
<tr><td>High</td><td>EA that is highly groundwater dependent and highly sensitive to take</td><td rowspan="3"></td><td>In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion</td><td rowspan="3"></td><td>Storage/ recharge <20</td><td>0.10</td><td rowspan="3">Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes

Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made:

Salinity class 1: reduce SF by 20%

Salinity class 2: reduce SF by 10%

Salinity classes 3 & 4: no reduction</td><td rowspan="2">Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%</td></tr>
<tr><td>Medium</td><td>EA that is highly groundwater dependent and is moderately sensitive to take

EA that is moderately groundwater dependent and is highly sensitive to take</td><td>The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge 20–40</td><td>0.50</td></tr>
<tr><td>Low</td><td>EA that has a low groundwater dependence and low sensitivity to take

EAs do not exist in the SDL area</td><td>The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge >40</td><td>0.70</td><td>Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%</td></tr>
</table>

1.8.7 Preliminary RRAM extraction limit

The preliminary estimated extraction limit resulting from the RRAM for the Ovens Highlands SDL area is 28 GL/year (Table 63). This is greater than the volume of current use (3.2 GL/year). However, given the high level of groundwater and surface water connectivity, the groundwater extraction limit will be set at current use. Further development of the groundwater system is feasible up to the RRAM derived extraction limit of 28 GL/year, where an equivalent reduction in surface water is required to offset the additional groundwater take on the basis of a 1:1 relationship between groundwater take and surface water streamflow reduction.

Table 63. Preliminary extraction limit for the Ovens Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	446	100	7.1	3.3
Sustainability factor	0.05	0.05	0.05	0.05
Extraction limit (GL/yr)	**22**	**5.0**	**0.36**	**0.16**

1.9 Murray Highlands (GS11)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the Murray Highlands SDL area.

1.9.1 Background

The Murray Highlands SDL area consists entirely of land that is not incorporated into any GMU (North Central Unincorporated Area). This SDL area surrounds a branch of the Ovens-Kiewa Sedimentary Plain SDL area, which coincides with the Mullindolingong GMA and the Kiewa River valley. The sum of 2007/2008 groundwater extraction in this SDL area is 4.4 GL/year (Table 64). For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

The aquifers of the Murray Highlands SDL area are mostly fractured rock aquifers with some superficial alluvial cover in small areas. The Murray Highlands SDL area is a geologically complex area and the rock types that constitute the watertable aquifer are accordingly numerous. In the vicinity of the Kiewa River valley the dominant rock type is Ordovician schist or gneiss (Omeo Metamorphic Complex), whereas the eastern and central zones are typically composed of deformed sandstone and mudstone of Ordovician age (e.g. Adaminaby Group or Bendoc Group) and Devonian or Silurian igneous rocks (granite or granodiorite) (GSV, 2010). Some more minor areas consist of outcrop of Devonian ignimbrite and other volcanic rock types (e.g. Dartella Volcanic Group). These rocks are considered to be basement rocks where they underlie thicker sequences of Murray Basin sediments, e.g. in the Kiewa River valley. In the Murray Highlands SDL area these rocks will be considered as a single fractured rock aquifer.

Virtually no irrigation occurs within the Murray Highlands SDL area, though very a small amount is applied in the region of alluvial sediment near Mitta Mitta.

Table 64. Groundwater take summary for the Murray Highlands SDL area

Murray Highlands SDL area	GL/yr
Total 2007/2008 entitlement*	**4.8**
2007/2008 metered use for entitlement bores*	0.0
2007/2008 estimated use for entitlement bores**	2.9
2007/2008 estimated use for stock and domestic bores***	1.4
Total 2007/2008 use	**4.4**

*Entitlement and metered use information provided by the Department of Sustainability and Environment.
**Estimated use is equal to 60% of the entitlement volume.
***Stock and domestic use is estimated as 2 ML per bore with a stock and domestic use type.

1.9.2 Salinity zoning

Shallow groundwater quality in the fractured rock aquifers of this SDL area is generally very high due to the fast drainage and high rainfall in high-altitude areas. Although three salinity zones are present in the SDL area, with groundwater TDS ranging from less than 1500 mg/L to more than 3000 mg/L, salinity zone 1 (0–1500 mg/L TDS) dominates. The groundwater salinity distribution can be seen in Figure 16 and is summarised in Table 65.

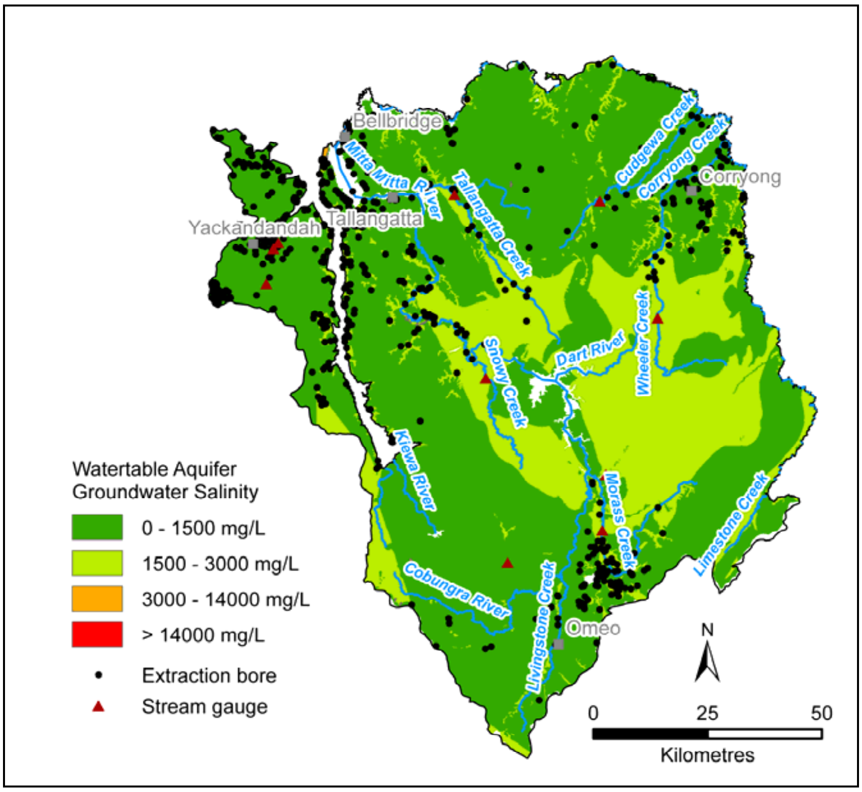

Figure 16. Murray Highlands watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 65. Summary of salinity zones in the Murray Highlands SDL area

Watertable salinity zone	Portion of area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	71	8,338
Zone 2 (1500–3000 mg/L TDS)	27	3,171
Zone 3 (3000–14,000 mg/L TDS)	<1	7.7
Zone 4 (>14,000 mg/L TDS)	0	0.0
Water bodies	2	220
Total	**100**	**11,737**

1.9.3 Key environmental assets

There are no key environmental assets that have been identified as groundwater dependent and sensitive to groundwater extraction as part of this RRAM assessment, that are associated with the Murray Highlands SDL area.

1.9.4 Key ecosystem function

Although parts of the River Murray and the Mitta Mitta River are regulated, most of their tributaries are unregulated, and are likely to be heavily reliant on baseflow (CSIRO, 2008a; Shugg, 1987). For example, a reach of the Snowy Creek above its confluence with the Mitta Mitta River is estimated to have an annual baseflow index of 0.63 (SKM, 2001). Therefore, there is considered to be a high risk of groundwater extraction affecting ecosystem function in this SDL area.

1.9.5 Productive base

Recharge

Given that the aquifer being assessed for the Murray Highlands SDL area is the surficial fractured rock aquifer, an estimate of watertable recharge is appropriate. The up-gradient boundaries of the SDL area coincide with catchment boundaries and therefore calculation of throughflow as a component of recharge is not necessary. Additionally, recharge from irrigation can be discounted as irrigation is virtually absent in the SDL area. The estimate of watertable recharge is derived from dryland diffuse groundwater recharge modelled using WAVES (Crosbie et al., 2010). The historical climate scenario for a dry 15-year period results in recharge rates of 91, 82 and 33 mm/year for salinity class 1, 2 and 3 respectively. Salinity class 4 does not exist in this SDL area. This results in a total recharge of 1017 GL/year within the SDL area (Table 66).

Table 66. Recharge calculation for the Murray Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	8338	3171	7.8	0.0
WAVES recharge (mm/yr)	91	82	33	N/A
Total recharge (GL/yr)	**756**	**261**	**0.26**	**N/A**

Storage

The fractured rock aquifer of this SDL area can contain voluminous amounts of groundwater in storage due to its significant thickness, which can exceed several hundred metres (Heislers, 1993). However, the utility of such aquifers is limited to the development of secondary porosity (i.e. fractures), and, although fractures have been documented as deep as 400 m in, for example, the Ovens Highlands SDL area (Kenny, 1925), the weathered zone is generally considered to be the more productive part of the aquifer. The weathered zone in rocks similar to those of the Murray Highlands SDL area can extend up to 80 to 100 m deep (Shugg, 1987; Tweed et al., 2005). Therefore, a nominal thickness of 100 m is applied to the storage calculation. Given that the depth to the watertable in highland areas is very variable and can exceed 50 m (SKM and GHD, 2009), an average depth to water of 25 m is assumed, resulting in a saturated thickness of 75 m.

The average yield from bores screened in older fractured rocks in the Murray Highlands SDL area is generally low (ranging from 0.6 to 1.9 L/sec) (Heislers, 1993). The average bore yield is mainly dependent on the density and connectivity of fracture porosity in the host rock, which is in turn dictated by lithology (Heislers, 1993). Representative measured values of fracture porosity are not available; therefore, specific yield values of similar rock types have been used as an estimate instead. Typically, granite has a specific yield of 0.001, clay a value of 0.02, basalt a value of 0.08, siltstone a value of 0.12 and sandstone a value of 0.08 to 0.21 (Johnson, 1967; Heath, 1983). Sandstone and mudstone are the dominating lithologies of this SDL area, and therefore the average value for the sandstone specific yield range (i.e. 0.15) has been used to calculate the average aquifer storage.

Total storage of the surficial fractured rock aquifer is approximately 129,564 GL (Table 67).

Table 67. Storage calculation for the Murray Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	8338	3171	7.8	0.0
Saturated thickness (m)	75	75	75	N/A
Specific yield	0.15	0.15	0.15	N/A
Total storage (GL)	**93,803**	**35,674**	**88**	**N/A**

Storage relative to recharge

The ratio of storage to recharge ranges from 124 to 338 over the different salinity classes. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.9.6 The risk matrix

Table 68 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary:

- the SDL area is ranked low risk in terms of environmental assets, given that no EAs exist within the SDL area
- the SDL area is ranked high risk in terms of ecosystem function, given that unregulated rivers and streams exist in the area and are dependent on baseflow
- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio exceeds 40
- there is no risk to key environmental outcomes (i.e. groundwater salinity)
- there is a high uncertainty associated with this SDL area given that the RRAM is derived from diffuse groundwater recharge derived from WAVES modelling only. It does not include other potential components of groundwater recharge, including river leakage, irrigation returns, throughflow etc.

Table 68. Risk matrix

<table>
<tr><th>Risk ranking</th><th>Environmental assets (EAs)</th><th>OR</th><th>Ecosystem function</th><th>OR</th><th>Productive base</th><th>Sustainability factor (SF)</th><th>Key environmental outcome</th><th>Degree of uncertainty</th></tr>
<tr><td>High</td><td>EA that is highly groundwater dependent and highly sensitive to take</td><td rowspan="3"></td><td>In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion</td><td rowspan="3"></td><td>Storage/ recharge <20</td><td>0.10</td><td rowspan="3">Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes

Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made:

Salinity class 1: reduce SF by 20%

Salinity class 2: reduce SF by 10%

Salinity classes 3 & 4: no reduction</td><td rowspan="2">Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%</td></tr>
<tr><td>Medium</td><td>EA that is highly groundwater dependent and is moderately sensitive to take

EA that is moderately groundwater dependent and is highly sensitive to take</td><td>The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge 20–40</td><td>0.50</td></tr>
<tr><td>Low</td><td>EA that has a low groundwater dependence and low sensitivity to take

EAs do not exist in the SDL area</td><td>The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)</td><td>Storage/ recharge >40</td><td>0.70</td><td>Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF

Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%</td></tr>
</table>

1.9.7 Preliminary RRAM extraction limit

The preliminary estimated extraction limit resulting from the RRAM for the Murray Highlands is 51 GL/year (Table 69). This is greater than the volume of current use (4.4 GL/year). However, given the high level of groundwater and surface water connectivity, the groundwater extraction limit will be set at current use. Further development of the groundwater system is feasible up to the RRAM derived extraction limit of 51 GL/year, where an equivalent reduction in surface water is required to offset the additional groundwater take on the basis of a 1:1 relationship between groundwater take and surface water streamflow reduction.

Table 69. Preliminary extraction limit for the Murray Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	756	261	0.26	0
Sustainability factor	0.05	0.05	0.05	N/A
Extraction limit (GL/yr)	**38**	**13**	**0.013**	**N/A**

1.10 Wimmera-Avoca Highlands (GS16)

This chapter describes the derivation of the preliminary estimated extraction limit resulting from the Wimmera-Avoca Highlands SDL area.

1.10.1 Background

The Wimmera-Avoca Highlands SDL area consists entirely of land that is not incorporated into any GMU (North West Unincorporated Area). This SDL area can be subdivided into eastern and western parts, which are separated by the alluvium deposits in the valley of Mount William Creek, west of Stawell within the Wimmera-Mallee Sedimentary Plain SDL area. Groundwater use is minimal in this SDL area and limited to a 2007/2008 estimated use of 0.15 GL/year for stock and domestic purposes only (Table 70). For more information regarding the source of the entitlement and use information, refer to CSIRO (2010a).

The aquifers of the Wimmera-Avoca Highlands SDL area are mostly fractured rock aquifers with some superficial alluvial cover in small areas. Overall, the dominant rock type is the Cambrian St Arnaud Group (marine sandstone, mudstone and shale), the outcrop boundary of which is mainly coincident with the boundary of the eastern part of the SDL area (GSV, 2010). The western region is predominantly composed of the deformed Silurian Grampians Group (sandstone). Minor outcrops of Devonian granite are also present in the Wimmera-Avoca Highlands SDL area. These rocks are considered to be basement rocks where they underlie thicker sequences of Murray Basin sediments in surrounding regions, i.e. in the Wimmera-Mallee Sedimentary Plain SDL area. In the Wimmera-Avoca Highlands SDL area these rocks will be considered as a single fractured rock aquifer, and act as the water table.

Virtually no irrigation occurs within the Wimmera-Avoca Highlands SDL area. The aquifer is generally low-yielding, with a typical yield of less than 0.5 L/sec (Dudding et al., 1993), but can be more productive in zones of intense faulting and jointing.

Table 70. Groundwater take summary for the Wimmera-Avoca Highlands SDL area

Wimmera-Avoca Highlands SDL area	GL/yr
Total 2007/2008 entitlement*	**0.0**
2007/2008 metered use for entitlement bores*	0.0
2007/2008 estimated use for entitlement bores**	0.0
2007/2008 estimated use for stock and domestic bores***	0.15
Total 2007/2008 use	**0.15**

*Entitlement and metered use information provided by the Department of Sustainability and Environment.
**Estimated use is equal to 60% of the entitlement volume.
***Stock and domestic use is estimated as 2 ML per bore with a stock and domestic use type.

1.10.2 Salinity zoning

Shallow groundwater quality in the fractured rock aquifers of this SDL area is variable, but is dominated by brackish to very poor quality water (Dudding et al., 1993). All four salinity zones are present in the SDL area, with groundwater TDS ranging from less than 1,500 mg/L to more than 14,000 mg/L, but the majority of the shallow groundwater has a TDS greater than 3,000 mg/L. The notable exception is the western part of the SDL area, which is dominated by the Grampians Group sandstone. The groundwater salinity distribution can be seen in Figure 17 and is summarised in Table 71.

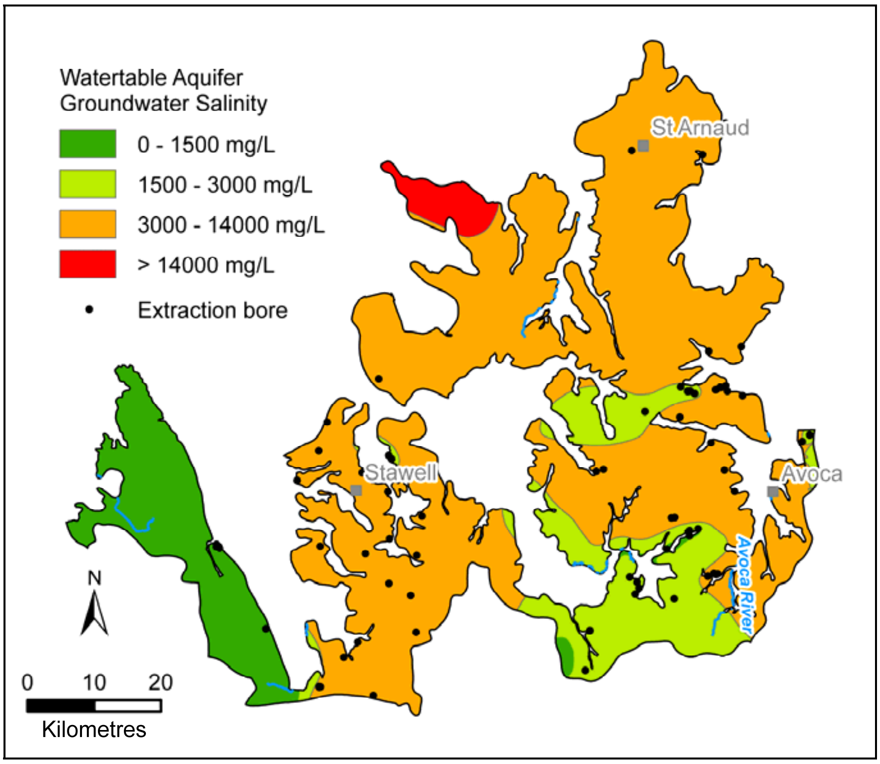

Figure 17. Wimmera-Avoca Highlands watertable aquifer salinity distribution, from the shallow salinity layer of the MDBA Basin in a Box dataset (MDBA, 2000)

Table 71. Summary of salinity zones in the Wimmera-Avoca Highlands SDL area

Watertable salinity zone	Portion of area	Area
	percent	km^2
Zone 1 (0–1500 mg/L TDS)	12	500
Zone 2 (1500–3000 mg/L TDS)	14	549
Zone 3 (3000–14,000 mg/L TDS)	71	2846
Zone 4 (>14,000 mg/L TDS)	2	86
No data	1	21
Total	**100**	**4001**

1.10.3 Key environmental assets

There are no key environmental assets that have been identified as groundwater dependent and sensitive to groundwater extraction as part of this RRAM assessment, that are associated with the Wimmera-Avoca Highlands SDL area.

1.10.4 Key ecosystem function

Although the Wimmera catchment is regulated (SKM, 2001; CSIRO, 2007), the Avoca River above Avoca is a gaining stream (CSIRO, 2008c), with an annual baseflow index of 0.19 at Amphitheatre, upstream of Avoca (SKM, 2001). Although the Avoca and Amphitheatre locations are within the bounds of the Wimmera-Mallee Sedimentary Plain SDL area, many unregulated tributaries to the Avoca and Wimmera Rivers rise in the hills of the Wimmera-Avoca Highlands SDL area and are most likely reliant on similar baseflow inputs. Therefore, there is considered to be a high risk of groundwater extraction affecting ecosystem function in this SDL area.

1.10.5 Productive base

Recharge

Given that the aquifer being assessed for the Wimmera-Avoca Highlands SDL area is the surficial fractured rock aquifer, an estimate of watertable recharge is appropriate. The up-gradient boundaries of the SDL area coincide with catchment boundaries and therefore calculation of throughflow as a component of recharge is not necessary. Additionally, recharge from irrigation can be discounted as irrigation is virtually absent in the SDL area. The estimate of watertable recharge is derived from dryland diffuse groundwater recharge modelled using WAVES (Crosbie et al., 2010). The historical climate scenario for a dry 15 year period results in recharge rates of 32, 31, 13 and 1.0 mm/year for salinity class 1, 2, 3 and 4 respectively. This results in a total recharge of 71 GL/year within the SDL area (Table 72).

Table 72. Recharge calculation for the Wimmera-Avoca Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	500	549	2846	86
WAVES recharge (mm/yr)	32	31	13	1.0
Total recharge (GL/yr)	**16**	**17**	**38**	**0.086**

Storage

The fractured rock aquifer of this SDL area can contain voluminous amounts of groundwater in storage due to its significant thickness, which can exceed several hundred metres (Heislers, 1993). However, the utility of such aquifers is limited to the development of secondary porosity (i.e. fractures), and, although fractures have been documented as deep as 400 m in, for example, the Ovens Highlands SDL area (Kenny, 1925), the weathered zone is generally considered to be the more productive part of the aquifer. The weathered zone in rocks similar to those of the Wimmera-Avoca Highlands SDL area can extend up to 80 to 100 m deep (Shugg, 1987; Tweed et al., 2005). Therefore, a nominal thickness of 100 m is applied to the storage calculation. Given that the depth to the watertable in highland areas is very variable and can exceed 50 m (SKM and GHD, 2009), an average depth to water of 25 m is assumed, resulting in a saturated thickness of 75 m.

The average yield from bores screened in older fractured rocks in the Wimmera-Avoca Highlands SDL area is generally low (Dudding et al., 1993). The average bore yield is mainly dependent on the density and connectivity of fracture porosity in the host rock, which is in turn dictated by lithology (Heislers, 1993). Representative measured values of fracture porosity are not available; therefore, specific yield values of similar rock types have been used as an estimate instead. Typically, granite has a specific yield of 0.001, clay a value of 0.02, basalt a value of 0.08, siltstone a value of 0.12 and sandstone a value of 0.08 to 0.21 (Johnson, 1967; Heath, 1983). Sandstone and mudstone are the dominating lithologies of this SDL area, and therefore an average of the sandstone and siltstone values (0.13) is used to calculate the average aquifer storage.

Total storage of the surficial fractured rock aquifer is approximately 38,811 GL (Table 73).

Table 73. Storage calculation for the Wimmera-Avoca Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Area (km^2)	500	549	2,846	86
Saturated thickness (m)	75	75	75	75
Specific yield	0.13	0.13	0.13	0.13
Total storage (GL)	**4,877**	**5,348**	**27,751**	**835**

Storage relative to recharge

The ratio of storage to recharge ranges from 305 to 9709 over the different salinity classes. This indicates that there is a low risk of the productive base of the aquifer being jeopardised by factors such as climate change and short-term over extraction of the groundwater resource.

1.10.6 The risk matrix

Table 74 provides a summary of the risk ranking associated with: key environmental assets, key ecosystem function, the productive base, the key environmental outcome and the uncertainty inherent in the RRAM calculation. In summary:

- the SDL area is ranked low risk in terms of environmental assets, given that no EAs exist within the SDL area
- the SDL area is ranked high risk in terms of ecosystem function, given that unregulated rivers and streams exist in the area and are dependent on baseflow
- the SDL area is ranked low risk in terms of the productive base, given that the storage/recharge ratio far exceeds 40
- there is a risk to key environmental outcomes (i.e. groundwater salinity)
- there is a high uncertainty associated with this SDL area given that the RRAM is derived from diffuse groundwater recharge derived from WAVES modelling only. It does not include other potential components of groundwater recharge, including river leakage, irrigation returns, throughflow etc.

Table 74. Risk matrix

Risk ranking	Environmental assets (EAs)	OR	Ecosystem function	OR	Productive base	Sustainability factor (SF)	Key environmental outcome	Degree of uncertainty
High	EA that is highly groundwater dependent and highly sensitive to take		In the current state, groundwater discharge provides baseflow to the unregulated river reach. Groundwater extraction is likely to result in stream flow depletion		Storage/ recharge <20	0.10	Where there is no risk to the key environmental outcome (i.e. uniform groundwater salinity) there is no reduction to the SF for any of the salinity classes Where there is a risk to the key environmental outcome, as a measure to reduce risk to groundwater quality, the following reductions are made: Salinity class 1: reduce SF by 20% Salinity class 2: reduce SF by 10% Salinity classes 3 & 4: no reduction	Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 50%
Medium	EA that is highly groundwater dependent and is moderately sensitive to take EA that is moderately groundwater dependent and is highly sensitive to take		The rivers in the SDL area are regulated and they are highly connected to the groundwater system (i.e. >50% impact of pumping on streamflow within 50 years)		Storage/ recharge 20–40	0.50		
Low	EA that has a low groundwater dependence and low sensitivity to take EAs do not exist in the SDL area		The rivers in the SDL area are regulated or unregulated and they have low-moderate connection with the groundwater system (i.e. <50% impact of pumping on streamflow within 50 years)		Storage/ recharge >40	0.70		Where the uncertainty is low (e.g. good quality time series data, recharge well understood, metered extraction) there is no further reduction to the SF Where there is high uncertainty associated with the SDL (e.g. no numerical model available for comparison, uncertain hydrogeology, poor extraction data) the SF is further reduced by 25%

1.10.7 Preliminary RRAM extraction limit

The preliminary estimated extraction limit resulting from the RRAM for the Wimmera-Avoca Highlands SDL area is 3.3 GL/year (Table 75). This is greater than the volume of current use (0.15 GL/year). However, given the high level of groundwater and surface water connectivity, the groundwater extraction limit will be set at current use. Further development of the groundwater system is feasible up to the RRAM derived extraction limit of 3.3 GL/year, where an equivalent reduction in surface water is required to offset the additional groundwater take on the basis of a 1:1 relationship between groundwater take and surface water streamflow reduction.

Table 75. Preliminary extraction limit for the Wimmera-Avoca Highlands SDL area

	Salinity zone 1	Salinity zone 2	Salinity zone 3	Salinity zone 4
Recharge (GL/yr)	16	17	38	0.086
Sustainability factor	0.04	0.045	0.05	0.05
Extraction limit (GL/yr)	**0.64**	**0.76**	**1.9**	**0.0043**

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