Goulburn-Murray Sedimentary Plain Groundwater Sustainable Diversion Limit Review

Synthesis Report

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Prepared by: Alan Wade

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Aquade Groundwater Services Pty Ltd

ABN 34 146 235 261

PO Box 1266

Richmond North, VIC 3121

0439 373 791

www.aquade.com.au

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List of Acronyms

BDL	Baseline Diversion Limit
DEPI	Department of Environment and Primary Industries
LTAEL	Long-Term average Annual Extraction Limit
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GMA	Groundwater Management Area
GMU	Groundwater Management Unit
MDBA	Murray-Darling Basin Authority
PCV	Permissible Consumptive Volume
PEL	Preliminary Extraction Limit
SDL	Sustainable Diversion Limit
S&D	Stock and Domestic
WSPA	Water Supply Protection Area

1 Introduction

1.1 Background for this Report

The Murray Darling Basin Authority (MDBA) is responsible for developing and overseeing a planning framework for the management of the Murray-Darling Basin's water resources in the national interest. The Murray-Darling Basin Plan (the Basin Plan) is being rolled out by the MDBA over seven years, from 2012 to 2019, to meet this objective. The Basin Plan is an adaptive framework which aims to achieve a balance between environmental, economic and social considerations. It limits consumptive water use by setting long-term average Sustainable Diversion Limits (SDLs) for all surface water and groundwater resources across the Murray-Darling Basin (the Basin). The SDLs will take effect on 1 July 2019.

The SDLs have been set to establish environmentally sustainable limits on the volume of water that can be extracted for consumptive use from Basin water resources, having regard to water availability, environmental objectives and requirements and socio-economic requirements. Information and knowledge used to inform the setting of SDLs can be expected to improve over time. Therefore, the Basin Plan includes a review mechanism. The MDBA may, in consultation with the Basin States and other interested persons, or at the request of the Murray-Darling Basin Ministerial Council, undertake reviews of the Basin Plan, including in relation to whether there should be changes to the SDLs. The reviews must include an up-to-date assessment of climate change risks, and consider all relevant knowledge about the connectivity of surface and groundwater, the outcomes of environmental watering and the effectiveness of environmental works and measures.

In setting SDLs, there were three groundwater resource units where differing views existed between the MDBA and Basin States as to the magnitude of the appropriate SDL and where the difference of opinion could not be resolved prior to the Basin Plan being passed. These are:

- Western Porous Rock SDL resource unit (NSW);
- Eastern Porous Rock SDL resource unit (NSW); and
- Goulburn-Murray Sedimentary Plain SDL resource unit (Victoria).

Therefore, a mechanism was included under Section 6.06 (Clauses 6 to 9) of the Plan that requires a review of the long-term average SDL and the Baseline Diversion Limit (BDL) for each of these resource units within two years of the commencement of the Plan. The review(s) must consider all relevant information about the SDL resource unit, including modelling, State planning and policy arrangements and an evaluation of the appropriateness of any precautionary factors associated with setting the SDL. The Basin Plan also nominates the experts who should be invited to participate in the reviews as the available members of the Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining as well as two individuals with expertise in groundwater or groundwater management nominated by the relevant State.

Reviews of the Western Porous Rock and Eastern Porous Rock (NSW) SDL resource units have been completed (SKM, 2014a) (SKM, 2014b). Aquade has been commissioned to prepare this Synthesis Report for the Goulburn-Murray Sedimentary Plain resource unit. This report is intended to summarise the rationale for both the SDL as evaluated by MDBA and the extraction limit as evaluated by Department of Environment and Primary Industries (DEPI) in Victoria, and to highlight the differences. It includes:

- hydrogeological characteristics of the Goulburn-Murray groundwater source;
- technical information relevant to the review (such as hydrostratigraphy, transmissivity); and
- technical information on how the SDL, BDL and State extraction limit have been determined, including information on methods, assumptions and precautionary/sustainability factors.

This Synthesis Report has been prepared based on information provided by the MDBA and DEPI.

1.2 Structure of This Report

Several studies have been previously undertaken in this area, the results of which have been used to inform the BDL and SDL. Also, the BDL and SDL evaluation process has evolved over time. This report is partitioned into several sections to communicate this evolution and the supporting information.

Section 2 provides a description of the Goulburn-Murray Sedimentary Plain aquifer framework and groundwater resources and contains general background information of relevance to later discussions. It provides summaries of the different methodologies applied by both relevant agencies.

Section 3 is a general description of the hydrologic cycle, the connection between the groundwater cycle and the above-ground part of the cycle, and of how groundwater is recharged in the Murray-Darling Basin.

Section 4 describes the documents reviewed for this synthesis report and extracts information of relevance from those documents regarding the BDL and SDL for the Goulburn-Murray Sedimentary Plain. Section 4.1 covers documents supplied by the MDBA and Section 4.2 covers documents supplied by DEPI. The reference summaries are provided even when the specific report has been superseded, such that the evolution of the concept or issue can be followed.

Due to the large volume of material in the supplied documents, information from Section 4 is further condensed in Sections 5 and 6 to what is considered to be of greatest relevance to the evaluation of BDL and SDL values for the Goulburn-Murray Sedimentary Plain SDL unit. Section 7 summarises the remaining points of significant difference between the MDBA position and the DEPI position regarding the BDL and SDL.

Conclusions of specific pieces of work are included in this report as they were published, regardless of whether they may be incorrect. In general, the author has not discussed or corrected errors unless they are considered to have a significant bearing on the findings.

2 The Goulburn-Murray Sedimentary Plain Area

2.1 Location

Figure 1 illustrates the Groundwater Resource Unit areas that have been previously defined by MDBA across the Basin. This figure is from the Groundwater SDL and BDL Methods Report (MDBA, 2012a). The new Goulburn-Murray Sedimentary Plain resource unit replaces former resource units Ovens-Kiewa Sedimentary Plain and the Victorian Riverine Sedimentary Plain (MDBA, 2012b), which are labelled as Resource Units GS8e and GS8f respectively in Figure 1.

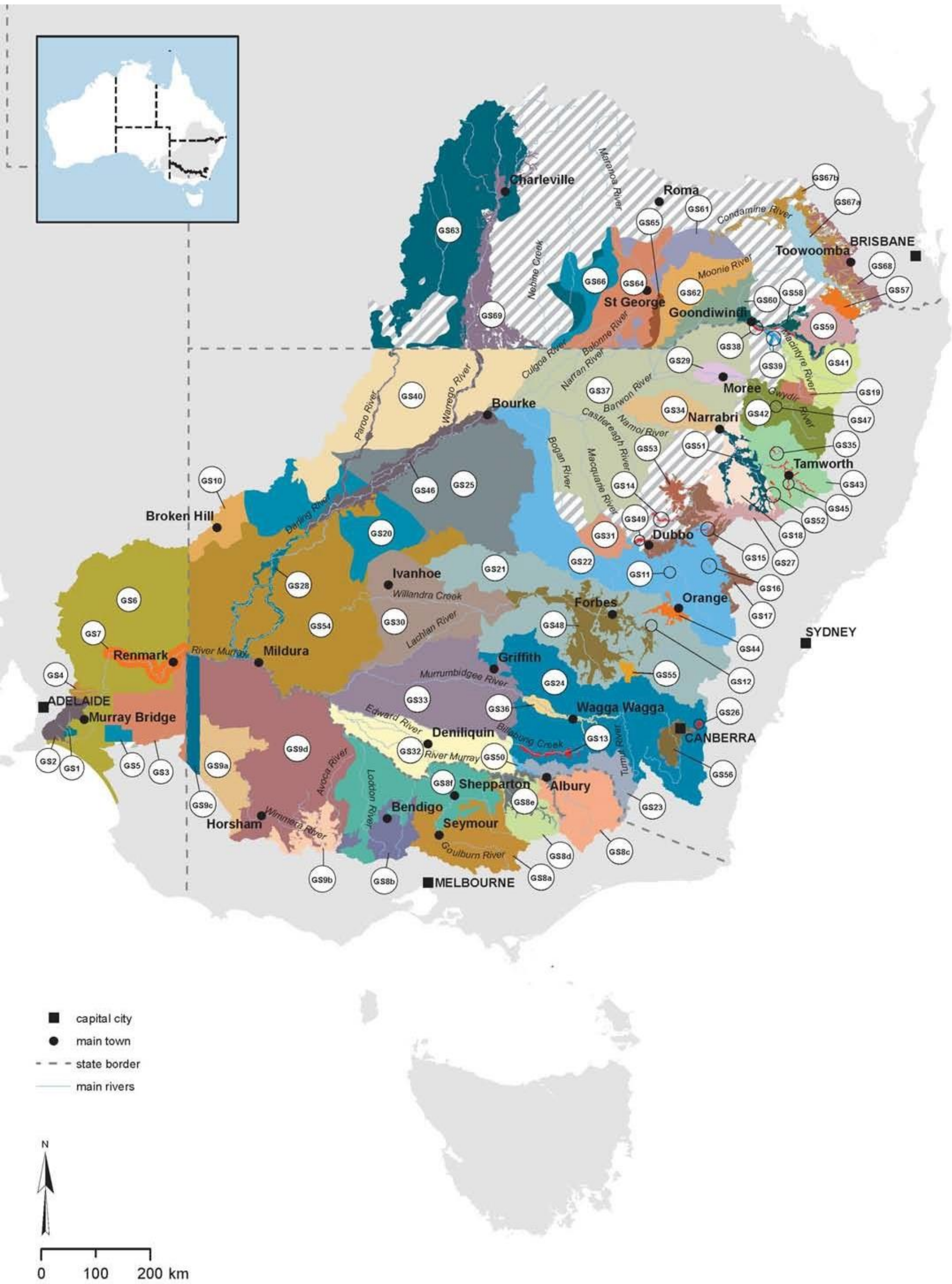

Figure 1: MDBA Groundwater SDL Resource Units

The evolution of/rationale for the definition of the new Goulburn-Murray Sedimentary Plain resource unit is outlined in Section 4, the Synthesis of Relevant Materials. Figure 2 shows the new Goulburn-Murray Sedimentary Plain Resource Unit in more detail. The Goulburn-Murray Sedimentary Plain is located in northern Victoria, bounded to the north by the Murray River and to the south by the Victorian highlands. It extends beneath, but does not include, the Shepparton Irrigation Region (SIR), which is shown in dark grey in Figure 2. The SIR is referred to in the MDBA Methods Report Addendum (MDBA, 2012b) as GS8 Goulburn Murray: Shepparton Irrigation Region. Figure 2 is reproduced without modification from the Northern Victorian MDB Groundwater Model Scenario Report (Beverly, 2014) with the kind permission of the authors. Hence it includes additional information pertaining to the groundwater model used in that report.

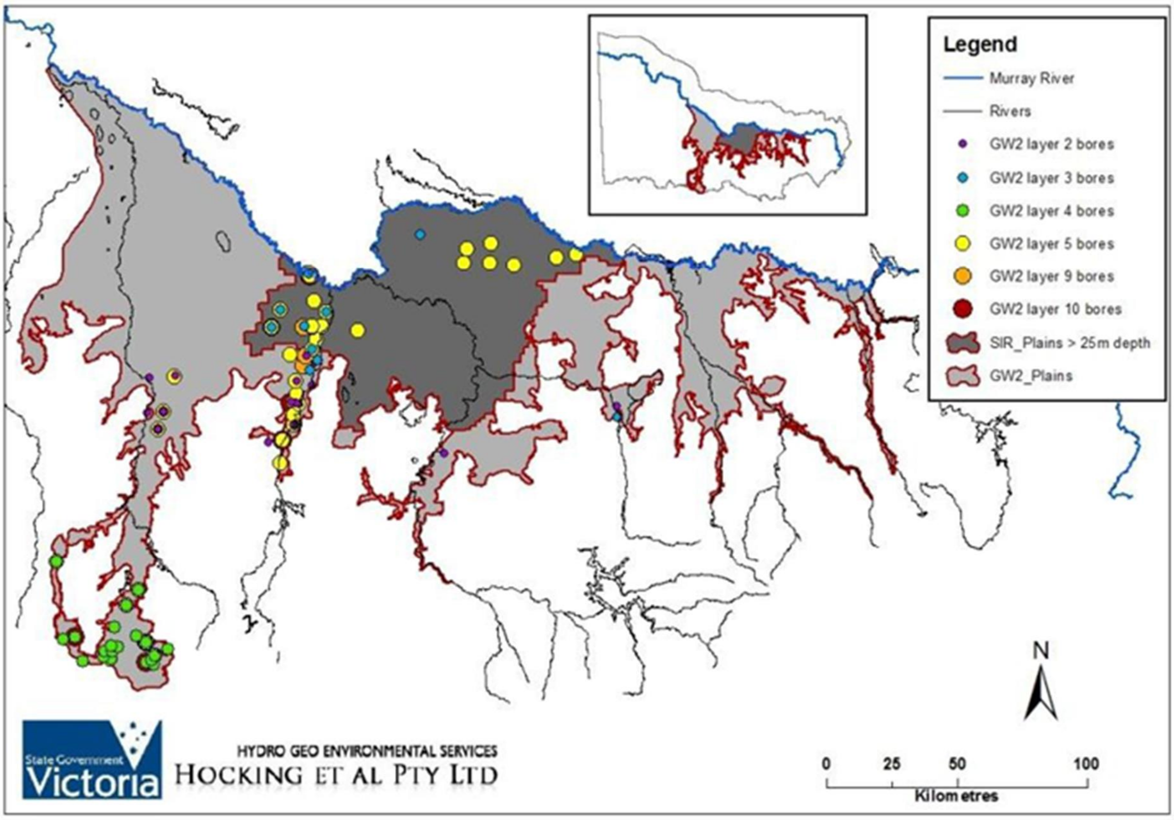

Figure 2: Extent of Goulburn-Murray Sedimentary Plain

2.2 Geology and Hydrogeology

2.2.1 Geological History

The Goulburn-Murray Sedimentary Plain SDL Unit consists of Tertiary to Quaternary sediments (and minor volcanics) that directly overlie Palaeozoic bedrock. The sediments are composed of three main deposits, from deepest (oldest) to shallowest (youngest): Renmark Group, Calivil Formation and Shepparton Formation (Brown, 1989).

During a time of relatively low sea level in the early to mid-Tertiary period, an ancestral Murray River system eroded palaeovalleys into the Palaeozoic bedrock. The palaeovalleys are approximately aligned with the current rivers flowing north to the Murray River (e.g. Loddon, Campaspe). The palaeovalleys typically broaden from tens of metres to several kilometres in width from south to north until they reach the ancestral Murray Valley, i.e. the Murray Trench, which was considerably broader/more extensive than its tributary palaeovalleys.

During subsequent periods of marine transgression (sea level rise), the sediments of the Renmark Group, the Calivil Formation, and the Shepparton Formation were deposited within the eroded landscape, with the thickest sediments forming where the ancestral rivers had cut deepest into the early Tertiary landscape. All three units generally pinch out towards the highlands.

The Eocene-Oligocene aged Renmark Group was deposited first, through the filling of the deepest channels carved into the Palaeozoic surface by the ancient river system. The Renmark Group is up to 200 m thick and forms the basal deposit of almost the entire Murray geological Basin. The Miocene-Pliocene aged Calivil Formation overlies the Renmark Group and has a thickness of up to 80 m. The upper surface of the Renmark Croup is an erosional unconformity, i.e. the Calivil Formation has incised into the Renmark Group to form valleys filled with coarser grained materials. In contrast, the upper surface of the Calivil Formation is relatively flat. As they are both relatively high-energy fluvial sequences, the Renmark Group and Calivil Formation are dominated by sand, interbedded with layers of clay and silty clay. They also include some coals and gravels.

In the central parts of the Basin, including the northern part of the Goulburn-Murray Sedimentary Plain, the Renmark Group can typically be differentiated from the overlying Calivil Formation. However, moving up the palaeovalleys towards the Victorian highlands it becomes more challenging to differentiate between these two units.

2.2.2 Aquifers and Aquitards

An aquifer is a geological formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit water to wells and springs at economic rates. An aquitard is a unit of low-permeability that can store groundwater and also transmit it slowly but does not transmit water to wells and springs at economic rates.

The hydraulic conductivity, K, of an aquifer or aquitard is a coefficient describing the rate at which water can move through it. It has units of length per time. The transmissivity, T, of an aquifer is the product of its hydraulic conductivity and thickness. It controls the rate of lateral groundwater flow (lateral flux) through the aquifer and controls how much drawdown is generated at, and in the vicinity of, a pumping bore. That drawdown is inversely proportional to T, i.e. a high T results in relatively little drawdown compared to a low T.

In the Riverine Plains, the Calivil Formation and Renmark Group together form the primary aquifer and conduit for regional groundwater flow due to their relatively high transmissivity and lateral continuity compared to other formations. In Victoria, the Calivil Formation and the Renmark Group together are commonly referred to as the Deep Lead aquifer and this name is used hereafter in this report. Due to its high transmissivity, this is the most significant aquifer utilised by irrigators in the region. Yields of several ML/day are commonly obtained from irrigation bores in this aquifer.

Towards the highland areas, the Sedimentary Plain sequence also includes some Newer Volcanics basalts which flowed down the same palaeovalleys within which the sediments were deposited, typically directly above the Calivil Formation. The Newer Volcanics is also an aquifer.

Also above the Calivil Formation, the Plio-Pleistocene Shepparton Formation consists predominantly of overbank floodplain clays with some interbedded channel sand aquifers. Sand and gravel deposits within the Shepparton Formation are generally much less laterally and vertically extensive than in the underlying Calivil Formation, particularly in the northern part of the Sedimentary Plain area. Where present, the sands range from ribbon-like in distribution to semi-continuous sheets (Tickell, 1987). In contrast, the overbank clays of the Shepparton Formation, are laterally continuous and extensive. This is consistent with the depositional environment, which was fluvial, but of lower energy than the depositional environment of the older formations. Where present, the ribbon-like sands are commonly referred to as prior stream deposits as they were deposited in ancestral river and stream channels.

For most of the Goulburn-Murray Sedimentary Plain, the Shepparton Formation acts as an aquitard which confines the Deep Lead aquifer, due to its laterally extensive clays. Aquitards have low hydraulic conductivity but are not impermeable. They restrict, but do not prevent, vertical leakage. Thus, the Calivil/Renmark aquifer is hydraulically insulated, but not isolated, from the shallower groundwater in the Shepparton Formation.

The water table typically occurs in the upper part of the Shepparton Formation. The Shepparton Formation varies in thickness from less than 20 m to approximately 100 m. The SIR forms part of the Victorian Riverine Plains (Figure 2). The boundary between the SIR and the Goulburn-Murray Sedimentary Plains SDL Unit is set within the Shepparton Formation at a depth of 25 m. This depth is selected for management purposes rather than to correspond with a lithological or formation boundary. The characteristics of the Deep Lead Aquifer and the Shepparton Formation are summarised in Table 1.

Table 1: Characteristics of Deep Lead and Shepparton Formation in Goulburn-Murray Sedimentary Plain Area

Attribute	Deep Lead Aquifer	Shepparton Formation
Age	Eocene to Pliocene	Pliocene to Pleistocene
Thickness	Up to approximately 200 m	Up to approximately 100 m
Dominant lithology	Sand	Clay
Other lithologies	Clay layers with varying lateral continuity	Sand ï typically in ribbons (prior stream deposits) surrounded by clay but sands are dominant over clay in places, particularly close to the highlands
Hydraulic conductivity of dominant lithology (m/day)	25 to 260	$1x10^{-5}$ to $1x10^{-2}$ (Arad & Evans, 1987)
Transmissivity (m^2/day)	740 to 16,000	80-270 (in the sands only)
Salinity	Variable fresh (<1,500 mg/L) to saline (>14,000 mg/L)	Variable from <1,500 to >14,000 mg/L

Note: Unless otherwise stated, hydraulic properties are from a summary of previous work in northern Victoria compiled for a study in the Campaspe Valley (Hyder, 2006).

Figure 3 illustrates the salinity of the groundwater in the shallow Shepparton Formation in the study area. This figure is reproduced from a report of the Southern Riverine Plains (SRP) Groundwater Model (CSIRO & SKM, 2010b). (As the SRP Model included the Lower Murray area in NSW, this figure extends beyond the Goulburn-Murray area of Victoria into NSW.) Note this figure does not show the salinity in the Deep Lead aquifer.

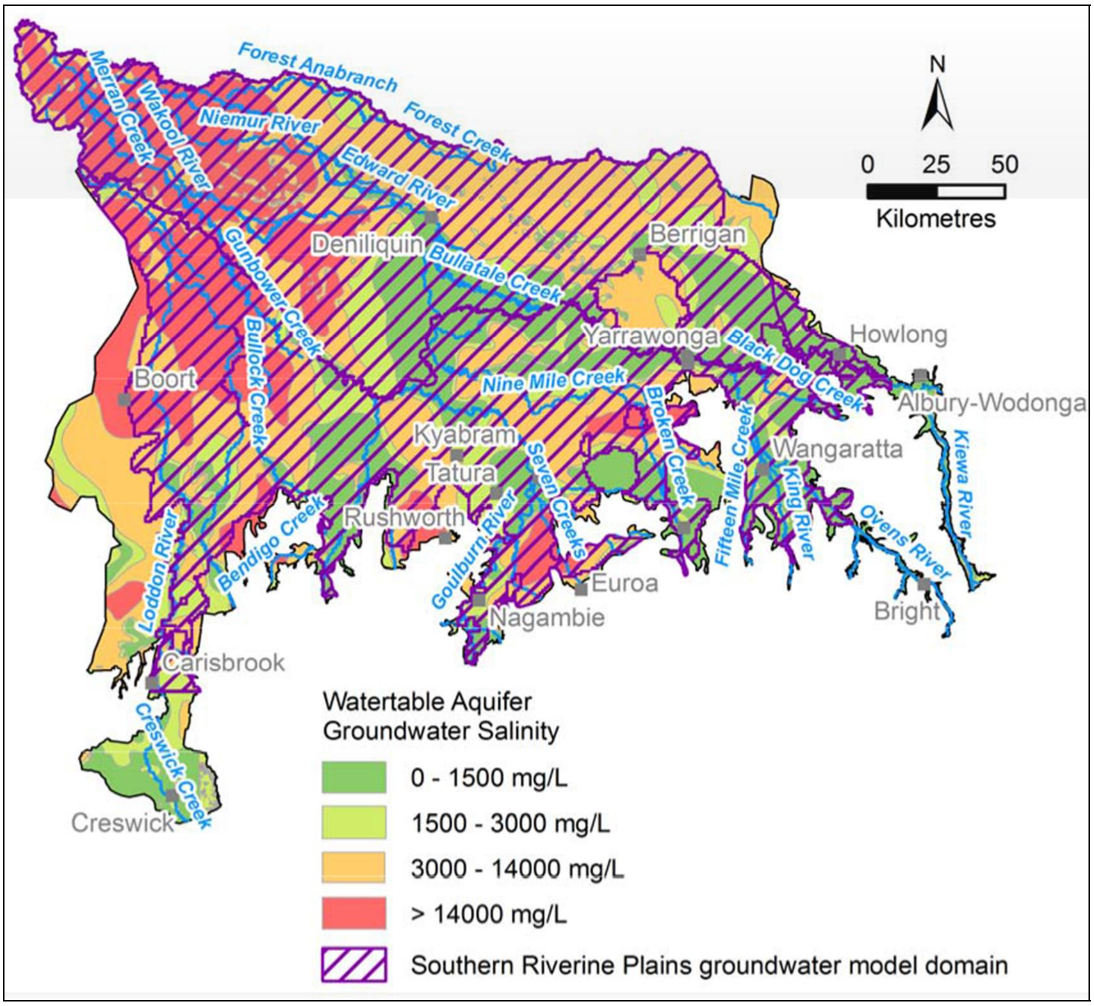

Figure 3: Groundwater Salinity at the Water Table in Northern Victoria and Southern NSW

2.3 Groundwater Management ï MDBA

Under the Water Act (s22(1) Item 6), the Basin Plan must include maximum long-term annual average quantities of water that can be taken, on a sustainable basis from:

1. The Basin Water resources as a whole; and
2. The water resources, or particular parts of the water resources, of each water resource plan area.

SDLs are defined as the maximum long-term annual average quantities of water that can be taken on a sustainable basis. For both groundwater and surface water, SDLs must reflect the environmentally sustainable level of take (ESLT) for a water resource, which is defined as the level at which water can be taken from that water resource without compromising:

- key environmental assets (KEA) of the water resource; or

- key ecosystem functions (KEF) of the water resource; or
- the productive base (PB) of the water resource; or
- key environmental outcomes (KEO) for the water resource.

To meet the ESLT requirements for groundwater, a groundwater SDL must:

1. maintain KEAs that have any dependence on groundwater;
2. maintain base flow groundwater contributions to rivers and streams (this is a KEF);
3. ensure that productive use of the aquifer is sustainable without compromising the hydrogeological integrity of the aquifer (PB); and
4. protect against decreasing groundwater quality, in particular salinisation of the groundwater resource (KEO).

In developing the proposed Basin Plan, the MDBA has considered the existing state groundwater management frameworks and has drawn on the expertise and knowledge held by the states. The proposed Basin Plan is the first time that:

- a limit on groundwater use is being established across the Basin. This is in contrast to surface water, where a cap has been in place since the mid-90s; and
- a consistent management arrangement is to be applied across all the Basin's groundwater resources.

The requirement to set SDLs is just one element of the Basin Plan that should be considered in parallel to the other elements (e.g. water resource plan requirements, Water Quality and Salinity Management Plan) that are required to deliver a healthy working Basin. Importantly, the SDL sets the regional upper limit for groundwater use. It is intended that, within the limit set by the SDL, localised impacts will be managed through water management arrangements in water resource plans which will be developed and implemented by the Basin states and accredited by the Authority.

The BDL for each groundwater SDL resource unit represents the MDBA's determination of the limits on groundwater use under existing water management arrangements and describes the baseline against which SDLs are assessed. BDLs are evaluated as follows:

1. where a water management plan or proposed plan exists, the BDL is the plan limit unless the plan limit is greater than the level of entitlement, in which case the BDL is the entitlement;
2. where there is no plan, the BDL is the entitlement along with the effect of any rules managing extraction; and
3. where there is a cross-border agreement for groundwater management, the extraction limit under the agreement is the BDL.

All BDLs include an estimate of existing stock and domestic (S&D) extraction.

The Baseline Diversion Limit (BDL) and Sustainable Diversion Limit (SDL) for the Goulburn-Murray Sedimentary Plains area are set out in the Basin Plan as:

- BDL – 203.5 GL/yr.
- SDL – 203.5 GL/yr.

2.4 Groundwater Management ï DEPI Victoria

Groundwater in Victoria is managed through Groundwater Management Units (GMUs), of which there are three types, Water Supply Protection Areas (WSPAs), Groundwater Management Areas (GMAs) and Unincorporated Areas.

- A WSPA is an area declared under the Victorian Water Act to protect groundwater or surface water resources through the development of a management plan.
- A GMA is an area where groundwater has been, or has the potential to be, intensively developed. GMA boundaries are defined for the purposes of ongoing management.
- An Unincorporated Area is an area where limited development or use of groundwater has occurred. This is usually because the resource is low-yielding, its quality has limited its use, or there is limited information about resource availability.

GMUs in Victoria have a volume of entitlement named a Permissible Consumptive Volume (PCV), which is an administrative volume that caps the total volume of groundwater that can be used. PCVs are the legal limit on the total volume of groundwater that can be licensed in a groundwater area. PCVs are formally made separate to specific management plans and exist independently of any restrictions placed on usage from time to time by such plans. As such, any management plans must work within the parameters of PCVs. Historically, PCVôs have been the volume of groundwater entitlement in the relevant GMU when it was declared rather than an extraction limit which is based on sustainability criteria. Victoria then manages the impact of groundwater extraction through rules that restrict the extraction volumes based on groundwater level trigger points.

The Goulburn-Murray Sedimentary Plains SDL Unit includes the Katunga, Lower Campaspe Valley and Loddon Highlands WSPAs and the Mid-Loddon, Lower Ovens, Mid-Goulburn, Mullindolingong and Barnawartha GMAs. Table 2 provides DEPIôs proposed extraction limits for the Goulburn-Murray Sedimentary Plain, including all the individual components from the WSPAs and unincorporated areas. To obtain this breakdown, DEPI, with Goulburn-Murray Water (GMW), reviewed groundwater licenced entitlements across the area and assigned licenses to either the sedimentary plain (minus the SIR) or Palaeozoic bedrock by a GIS method. This is described in more detail in Section 4.

Based on the combined total of the entitlement, stock and domestic and salt interception totals in Table 2, DEPI (DEPI, 2014) recommended a BDL of 217,911 ML (Table 3 of (DEPI, 2014)). (Note that, in that table, DEPI include a comment that the entitlement total includes 60,577 ML licensed in Katunga WSPA. However, in Table 2 below the total for Katunga is slightly less, at 60,509 ML.)

2.5 Groundwater Extraction

Groundwater is extracted from the Goulburn-Murray Sedimentary Plain resource unit primarily for irrigation and primarily during the summer months. Some groundwater is also extracted for stock and domestic use, town water supply (e.g. Elmore in the Campaspe Valley) and salt interception schemes (Barr Creek, Pyramid Creek).

Table 2: DEPI Breakdown of Licensed Entitlements, S&D and Salt Interception in the Goulburn-Murray Sedimentary Plain

Subarea	Licensed Entitlements (ML/yr.)	Stock and Domestic (ML/yr.)	Salt Interception (ML/yr.)	Comments
Katunga WSPA	60,509	1,612		Katunga Licensed Entitlements make up 29% of the total for the SDL area
Lower Campaspe WSPA	57,086	456		Lower Campaspe Licensed Entitlements make up 28% of the total for the SDL area
Loddon Highlands WSPA	18,092	784		Although a highlands area, this is included in the Sedimentary Plains because it is primarily Deep Lead and basalt aquifers
Upper Ovens WSPA	3	656		
Mid Loddon GMA	32,177	760		
Lower Ovens GMA	15,054	3,766		
Mid-Goulburn GMA	11,238	452		
Mullindolingong GMA	114	122		Kiewa Area
Barnawartha GMA	180	80		
Unincorporated, but Attributed to Specific Catchments	10,943	84		(attributed to Avoca, Broken, Campaspe, Goulburn, Kiewa, Loddon, or Ovens catchments)
Unincorporated Areas	74			
Bungaree WSPA	70			Bungaree WSPA is mostly south of the divide forming the southern edge of the Murray-Darling Basin, but it extends slightly north of the divide.
Barr Creek & Pyramid Creek			3600	Salt interception projects.
Total	**205539**	**8772**	**3600**	**Combined Total = 217,911 ML**

Table Notes: The table provided by DEPI to illustrate this breakdown of entitlements is entitled: Tbl Composite 5 GMWater Lic SDL.xls. The entitlements are rounded to the nearest ML. They may not sum exactly to the total due to rounding. The figures in this table apply only to licenses that occur in the Sedimentary Plain part of the areas listed.

Irrigation bores in the Goulburn-Murray Sedimentary Plain resource unit typically target the Deep Lead aquifer where the transmissivity is sufficiently high that yields of several ML/day can be achieved with drawdown in the bore of just a few metres during pumping. Groundwater extraction for irrigation is typically most highly concentrated in areas of the resource unit where the Deep Lead aquifer is laterally extensive and groundwater quality in it is suitable. The Katunga WSPA, located south and west of Cobram, and the Lower Campaspe Valley WSPA, located to the south and west of Echuca, each have an area of approximately 2,100 km^2, which is a combined area of less than 25% of the Goulburn-Murray Sedimentary Plain resource unit. However, due to the typically high yields and good water quality of the Deep Lead aquifer in these WSPAs, the total combined licensed entitlements for these WSPAs is more than 117 GL/yr., which is more than half of the total entitlements for the Goulburn-Murray Sedimentary Plain resource unit (Table 2). Between them, the Katunga and Lower Campaspe WSPAs, accounted for more than 2/3 of the total annual metered extraction in 2011/12 total (DEPI, 2013).

Extraction bores for stock and domestic (S&D) purposes are widespread throughout the resource unit (DEPI, 2013), typically targeting sands in both the Shepparton Formation and the Deep Lead. Typically, S&D bores are installed in the shallowest aquifer which has an acceptable salinity for the intended purpose.

There are two Salt Inception Schemes (SISs) located near Kerang in the northwest of the Goulburn-Murray Sedimentary Plain which are operated under the Basin Salinity Management Strategy to intercept saline groundwater before it reaches the River Murray. The schemes are located at Barr Creek and Pyramid Creek. The Barr Creek SIS has been in operation since 1968 and the Pyramid Creek SIS has been in operation since 2007.

2.6 Groundwater Monitoring

Extensive groundwater monitoring takes place using several hundred monitoring bores across the Goulburn-Murray Sedimentary Plain. Most of the monitoring bores are associated with the State Observation Bore Network (SOBN) of Victoria. DEPI manages the SOBN, which monitors groundwater levels and quality at approximately 2,500 sites throughout the State, many on a quarterly basis. Information obtained from the SOBN is used to inform groundwater assessments for groundwater management purposes.

3 Groundwater and the Hydrologic Cycle

A conceptual diagram of the Hydrologic Cycle is shown in Figure 4 (reproduced herein with the kind permission of Howard Perlman, USGS). Groundwater is a significant component of the Hydrologic Cycle, such that, excluding ice and snow, the volume of freshwater stored as groundwater around the Earth is approximately 100 times greater than the volume stored as surface freshwater in lakes and rivers (Shiklomanov, 1993). However, groundwater moves much more slowly than freshwater, such that its residence time in the ground may be tens of thousands of years.

In the natural environment, all groundwater is originally recharged from the ground surface, either by infiltration from rainfall or from surface water as shown in Figure 4. Groundwater ultimately discharges naturally from the ground either by seepage to surface water (e.g. springs, baseflow of rivers) or by evapotranspiration.

Anthropogenic influence has added irrigation and irrigation infrastructure as an additional mechanism of groundwater input and groundwater extraction using wells as an additional mechanism of groundwater output.

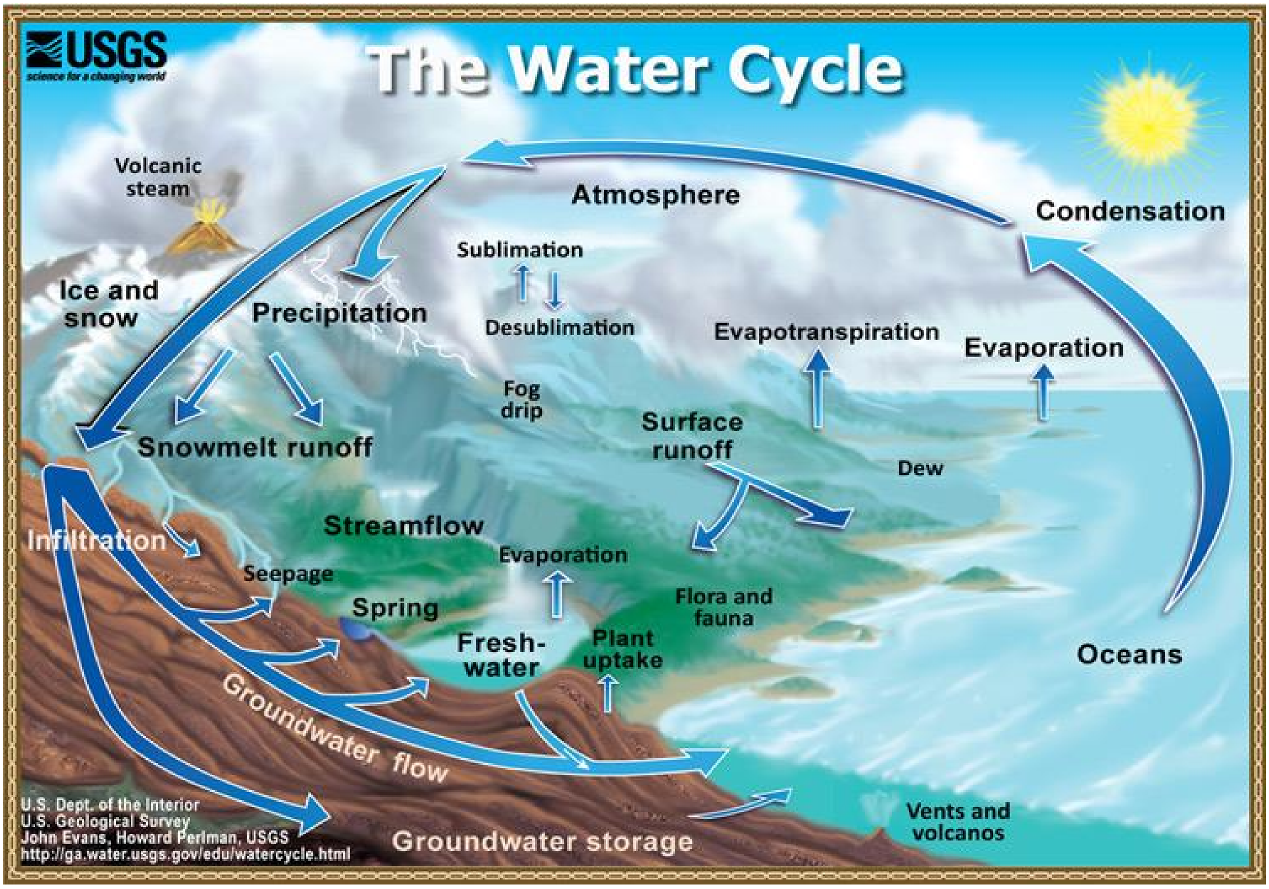

Figure 4: The Hydrologic Cycle

Key inputs (additions to storage) to groundwater in the Murray-Darling Basin consist of:

- infiltration from rainfall;
- infiltration from irrigation;

- infiltration from natural watercourses (rivers and streams);
- infiltration from manmade watercourses/irrigation infrastructure (channels, reservoirs)

Key outputs (subtractions from storage) from groundwater in the Murray-Darling Basin consist of:

- evapotranspiration;
- discharge/seepage to surface water (rivers, wetlands, etc.);
- extractions for consumptive and other use

When the resource is in a steady state, the inputs balance the outputs such that there is no change in groundwater storage and no change in groundwater level. When the outputs exceed the inputs such that the system is not in a steady state, there is a decrease in storage and groundwater levels decrease with time. This can be caused by an increase in groundwater extraction. However, this does not mean that groundwater extraction will ultimately drain the groundwater flow system. The rate of input (the recharge rate) to groundwater is partly dependent on the groundwater levels within the system. When groundwater levels are lowered by extraction in a regional flow system, the net recharge rate will typically increase due to increased hydraulic gradients from surface water to groundwater and an increase in the area of recharge relative to the area of discharge.

4 Synthesis of Relevant Material

A considerable volume of reference material was provided to support this review. This section of the report provides a summary of the content and key outputs/findings of all materials provided as relevant to the Goulburn-Murray Sedimentary Plain SDL resource unit.

The references are summarised and considered below in the context of the timeframe for the Plan. The MDBA initially prepared a **Draft Basin Plan**, published in **November 2011**, which formed the basis of a public consultation process. A 20 week period followed to enable people to receive briefings, attend round tables and public meetings and to prepare submissions in response to the Plan. Following the consultation and submissions process, a **Revised Draft Basin Plan** was published on **28 May 2012**.

According to the process outlined in the Water Act 2007, the Authority was then required to seek comments from members of the Murrayï Darling Basin Ministerial Council. The MDB Ministerial Council comprises ministers from each of the Basin States and the ACT. It has an advisory role in the preparation of the Basin Plan by the Murrayï Darling Basin Authority. Ministers had six weeks to respond to the Authority on the Revised Draft Plan.

Following consideration of the Ministerial Council comments, the MDBA prepared an **Altered Proposed Basin Plan** in **August 2012.** The Minister adopted the Basin Plan in November 2012.

4.1 MDBA Reference Material

Table 3 lists the references received from the MDBA. They are discussed below.

4.1.1 Proposed BDLs and SDLs: Methods Report

The Methods Report (MDBA, 2012a) documents the methods used to set Baseline Diversion Limits (BDLs) and Sustainable Diversion Limits (SDLs) for groundwater resource units (Reference 7 in Table 3). The definitions and purpose of BDLs and SDLs are provided in Section 2.3.

The Methods Report (MDBA, 2012a) states that both numerical groundwater modelling and a Recharge Risk Assessment Method (RRAM) provide mechanisms for evaluating the potential volume of water available for consumptive use in groundwater SDL areas. The RRAM is a methodology to evaluate the potential volume of water available for consumptive use based on multiplying the estimated recharge by a ñsustainability factorò. The sustainability factor represents the fraction of recharge that can be extracted without compromising the environmentally sustainable level of take for the resource unit.

In areas where there is a ñfit-for purposeò numerical groundwater model, the model is the preferred tool for evaluating the volume of water available for consumptive use. In the Goulburn-Murray area, the SRP Model is available and, based on an independent review of the model (see below), is considered fit for this purpose.

Table 3. MDBA Reference Material

Reference Number	Title	Citation	Date
1	Groundwater Modelling Report ï Southern Riverine Plains	(CSIRO; SKM, 2010)	November 2010
2	Southern Riverine Plains Groundwater Model Calibration Report - A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project (Goode and Barnett, 2008)	(CSIRO, 2008)	September 2008
3	Peer Review of the Southern Riverine Plains Numerical Groundwater Model	(Merrick, Woolley, & Hillier, 2010)	October 2010
4	Notice by the Victorian and NSW Governments under Section 43A(7) of the Water Act 2007	NA	July 2012
5	MDBA response to state comments in s43(a) notice Groundwater	NA	29 July 2012
6	Victorian Riverine Sedimentary Plain Report Card	NA	2012
7	The Proposed Groundwater Baseline and Sustainable Diversion Limits ï Methods Report	(MDBA, 2012a)	2012
8	Addendum to The Proposed Groundwater Baseline and Sustainable Diversion Limits ï Methods Report	(MDBA, 2012b)	17 July 2012
9	Dryland Diffuse Groundwater Recharge Modelling across the Murray-Darling Basin	(CSIRO and SKM, 2010)	October 2010
10	Peer Review Basin Plan (Groundwater)	(Woolley, 2010)	April 2010
11	Basin Plan	(MDBA, 2012c)	November 2012

4.1.2 Peer Review of Basin Plan

Reference 10 in Table 3 was a peer review of the Basin Plan (Woolley, 2010). The intent of this peer review was primarily a review of the methods and approach for evaluation of SDLs. This reference is considered first because it provides comment on the MDBA approach to groundwater management as outlined above in Section 2.3 and Section 4.1.1. Note that this peer review predates the Basin Plan by more than two years. It is understood that it considers the Guide to the Basin Plan rather than the Basin Plan itself and does not provide comment on the Basin Plan as adopted by the Minister. Also, the review represents the opinion of its authors in April 2010, which is not necessarily the opinion of the MDBA (personal communication, Peter Hyde, MDBA, September 2014).

The review notes that the Water Act 2007 constrains the Plan, in that it ñ*gives precedence to maintenance of environmental factors over maintenance of groundwater withdrawals*ò and ñ*makes it clear that the need for improvement of environmental outcomes may in some cases over-ride the need to maximise the availability of water for consumptive purposes*ò.

It also points out that the fourth Criterion for Maintenance of Current River Flows, i.e. ñ*the sustainable extraction limit must be equal to or less than the current level of groundwater extraction*ò (and which was one of the criteria of the Southern Riverine Plains Groundwater Model-see below), bears no obvious connection with ñ*maintenance of current environmental river flows*ò This condition does not allow for increases in extraction limits.

With respect to WAVES recharge modelling and the RRAM, the review stated that the WAVES recharge modelling approach is very thorough and the results are ñof the right orderòwhen compared to recharge rates estimated using groundwater models. However, the review also stated that there is considerable uncertainty in the calculated recharge rates and ñ*this approach does not attempt to estimate recharge due to river leakage, flooding, or irrigation recharge. In many places these components can form a substantial amount of total recharge. It follows that SDLs based on the WAVES approach will tend to be underestimates of the sustainable volumes of available water (all else being equal)".*

The review considered that the application of an uncertainty factor to evaluate SDLs from numerical models is a reasonable approach. However, it stated that the upper limit of the SDL could be raised from 90% of the calibrated recharge to 95% of the calibrated recharge.

4.1.3 Southern Riverine Plains Groundwater Model

References 1, 2, and 3 in the above table concern the Southern Riverine Plains (SRP) Groundwater Model. The SRP Model was originally developed for the Murray-Darling Basin Sustainable Yields Project (CSIRO, 2008). The area of this model is shown in Figure 3. This three-dimensional numerical model covers almost all of the area of the Goulburn-Murray Sedimentary Plain as well as an area of the riverine plains in NSW known as the Lower Murray area. The SRP Model simulates the Shepparton Formation in two layers and also includes a layer to simulate the Calivil Formation and a layer to simulate the Renmark Group.

4.1.3.1 Model Setup and Purpose

The SRP model was originally constructed to assess the relative impacts of different climate scenarios and of groundwater pumping on groundwater resources rather than to investigate or evaluate extraction limits (Goode and Barnett, 2008). Findings included evidence of strong connection and groundwater flow between Victoria and NSW (which justified the cross-border model), long-term linkage between groundwater and surface water across the riverine plains, the potential sensitivity of groundwater evapotranspiration (ET) and, consequently, groundwater dependent ecosystems (GDEs) to climate change, and the significant time lag on the order of decades between a change in conditions and a new steady state condition.

In 2010, the SRP model was recalibrated to more recent groundwater extractions and measured groundwater response and applied in the running of various scenarios based on assumed future climate and future development options (CSIRO & SKM, 2010b). In updating the SRP Model, its areal extent was modified slightly from its original incarnation (CSIRO, 2008) by extending the grid to cover the Lower Ovens area. However, the SRP model was not extended to include the most upstream parts of the Oven-Kiewa sedimentary plain.

The model was used to investigate differences in aquifer performance between the different scenarios simulated, over model runs of 50 years in duration, and to inform Basin Plan SDLs. An attempt was made to delineate the magnitude of river flow depletion that can be attributed to the groundwater extraction, by comparison with a no-pumping scenario (CSIRO & SKM, 2010b). The different scenarios simulated were assessed against four criteria aimed at determining the sustainability of the particular scenario. These criteria were:

1. Stabilisation of groundwater levels by completion of model run, i.e. within 43 years of extraction at the new rate simulated.
2. Stabilisation of extraction (productive base). This effectively means that no model cell can run dry.
3. Prevention of dewatering of confined aquifers, i.e. prevention of unconfined conditions in formerly confined aquifers (productive base). To meet this criterion the predicted groundwater levels must remain above the top of the confined aquifer.
4. Maintenance of current environmental river flows (key environmental outcome). This criterion mandates that the sustainable extraction limit must be equal to or less than the current level of groundwater extraction. The current level of groundwater extraction was defined as the average over the five year period 2004 - 2008. As described in the discussion of the Review of the Basin Plan, the connection between this extraction limit requirement and maintenance of current environmental river flows is not clear.

Compliance with the criteria was evaluated using resource condition indicator (RCI) sites which are locations within the model where predicted groundwater levels are reviewed and compared to the criteria. RCI sites do not necessarily correspond to the locations of actual bores.

The scenarios modelled included no pumping (Scenario 1), pumping at current levels of entitlement (Scenario 2), pumping at a proposed SDL (Scenario 3), pumping at proposed SDL under different climatic and irrigation conditions (Scenarios 5,6 and 7), and pumping at the proposed SDL except pumping in the SIR reduced to 120GL/year, to avoid dry model cells (Scenario 3a).

4.1.3.2 Model Results

The scenario modelling results found that, in the Victorian part of the model, for all pumping scenarios there was a breach of Criterion 1. Criterion 2 was also breached in the SIR in all scenarios except one in which extraction rates in the SIR were reduced. There were no breaches of Criterion 3. However, Reference 1 states that Criterion 4 was breached in all scenarios in the Victorian Riverine Plains and the Lower Ovens SDL units due to the comparatively high entitlement volumes compared to current extraction.

ñ*Key messages*" from the modelling used to inform the Basin Plan SDL included the following:

- ñ*Groundwater extraction at a level approaching the current entitlement would not be sustainable across the Southern Riverine Plains. This is largely due to the very high entitlement volumes in the Shepparton irrigation region*ò (Note that the SIR is not subject to review and a different approach was taken to determining its SDL in the Basin Plan.)
- Induced river losses to the groundwater system, caused by groundwater pumping, were significant.

In Scenario 3a, the rate of groundwater extraction simulated was approximately 209 GL/yr. in the Victorian Riverine Plain (not including the SIR and not including the upper part of the Ovens-Kiewa system which was outside the model area). This simulation effectively demonstrated that this rate of extraction was feasible but Criterion 4 would be breached and Criterion 1 would be breached in some areas.

A more conservative extraction limit than the rate simulated was suggested in the report, which included application of a precautionary factor to allow for model uncertainty. With application of this uncertainty factor, the suggested extraction limit was 174 GL/yr. for the Victorian Riverine Plain excluding the SIR but including the Ovens-Kiewa Sedimentary Plain, i.e. for the new Goulburn-Murray Sedimentary Plain area.

The RRAM was used to evaluate a SDL for the non-modelled part of the Goulburn-Murray Sedimentary Plain, i.e. in the upstream parts of the Ovens-Kiewa Sedimentary Plain. This is a method of estimating a SDL based on an estimate of diffuse recharge. The methodology for evaluating the recharge rate is described below. **The RRAM method does not include consideration of river recharge, which is likely to be a significant, if not the dominant, mechanism for recharge in this area.** Based on the implementation of the RRAM method outside the model area, it was recommended that an additional 4.6 GL/yr. be added to the proposed SDL for the Ovens-Kiewa area and, consequently, to the Goulburn-Murray Sedimentary Plain SDL.

4.1.3.3 Independent Review of SRP Model

The SRP Model peer review (Reference 3) found that the SRP Model is: ñ*fit for purpose, where the purpose is SDL determination*ò, based on the ñ*satisfactory*ò technical appraisal. The peer review also stated that: ñ*Modelling has demonstrated that usage at the levels of entitlements is sustainable except in the Shepparton Irrigation Region*ò. Note that Reference 1 stated that there was localised breach of Criterion 1. Therefore, Criterion 1 would only be met assuming local management rules can address this breach.

The review noted that the model report was lacking an illustration of the conceptualisation and was lacking a sensitivity analysis and verification. The review also found that the model did not include the upstream parts of the Ovens-Kiewa Sedimentary Plain and did not specifically include simulation of flood recharge. Flood recharge would contribute additional recharge to the water balance. The review points out that ñ*flood recharge determined as a calibration parameter is one of the main recharge factors in the Mid Murrumbidgee and some other areas, and although the areas are not directly comparable this does highlight the need to account for flood recharge in all these alluvial aquifer systems*ò.

The model review states that the significant reduction in proposed SDLs due to model uncertainty ñ*appears to be a severe reduction, especially since one of the reasons for reduction is the lack of flood recharge in the model which, if accounted for, is likely to increase the SDL estimate*ò. This observation was subsequently taken into account in determining the SDL for the resource unit in the Basin Plan.

4.1.4 Dryland Diffuse Recharge Modelling

Reference 9 in Table 3 concerns Dryland Diffuse Recharge Modelling (CSIRO and SKM, 2010a). This is of relevance to the RRAM, which was used by MDBA to evaluate the SDL over a minor portion of the Goulburn-Murray Sedimentary Plains. The RRAM was developed to calculate a sustainability factor which, when multiplied by the estimated recharge, gives an estimate of that proportion of the recharge that can be withdrawn from an aquifer on a sustainable basis.

The purpose of the modelling was to estimate the average annual diffuse recharge rate across the Basin over a period of 114 years of rainfall records, investigate variability in the recharge rate, and support groundwater modelling and the RRAM being implemented across the Basin. This recharge modelling did not include consideration of groundwater recharge from surface water.

The recharge modelling initially used the Water Vegetation Energy and Solute (WAVES) model to calculate diffuse recharge for a typical soil/vegetation/climate association. The results were then extrapolated/upscaled to the Basin level using soil type, vegetation type and average annual rainfall as co-variates. The upscaling method relied upon regression relationships between rainfall and recharge based on the WAVES modelling at 20 control points. These regression relationships were then used to match recharge against the SILO rainfall grid and thus upscale to a recharge grid across the entire Murray Darling Basin. This grid was then integrated at the SDL resource unit level to provide an estimate of recharge in each unit.

The rainfall data used in the study spanned the years 1895 to 2009. The spatially upscaled recharge estimates were an average for the period 1895 to 2006. The work also produced estimates of recharge under future climate projections using data from 15 Global Circulation Models (GCM). The results were reported as recharge scaling factors giving the scenario recharge as a proportion of the historical recharge. These scaling factors were then used to scale estimates of current recharge.

The analysis undertaken derived recharge scaling factors for different combinations of rainfall years under different future climate projections as a way of displaying the variance in changes that may result based on current projection uncertainty. Projections ranged across essentially a continuum between wet years in a future wet climate to dry years in a future dry climate.

The historical diffuse recharge estimates for the parts of the basin that are within the Goulburn-Murray Sedimentary Plain were 15 mm/yr. for the Victorian Sedimentary Plain resource area and 75 mm/yr. for the Ovens Kiewa Sedimentary Plain (GS8e and GS9f in Figure 1). The modelling showed that diffuse recharge in the Goulburn-Murray area could be approximately twice as great during historical 15-year wet periods in comparison to historical 15-year dry periods. That is, average recharge for the Victorian Sedimentary Plain resource unit could range between approximately 10 and 20 mm/yr.

The report recognises that there is considerable uncertainty associated with the absolute recharge figures and addresses this by emphasizing predictions of change/variation in recharge under different climatic conditions rather than the absolute values of recharge. It should be noted that the recharge and variation in recharge estimated by this modelling is the recharge at the water table, which is typically in the Shepparton Formation in the Riverine Plain. It does not necessarily follow that this recharge migrates to the Deep Lead confined aquifers, the source of most of the groundwater extraction in the Goulburn-Murray Sedimentary Plain. The recharge to the Deep Lead originating from diffuse recharge is less than the total diffuse recharge at the water table. Therefore, this diffuse recharge modelling would be expected to overestimate the recharge to the Deep Lead.

4.1.5 Addendum to Methods Report

Reference 8 in Table 3, the Addendum to the Methods Report (MDBA, 2012b), documents a number of changes that were made to the methods used to set BDLs and SDLs for groundwater resource units for the Basin Plan between the publication of the draft (28 November 2011) and revised draft (28 May 2012) Basin Plans. This addendum was published 16 July 2012.

The revisions resulted in a significant Basin-wide groundwater SDL decrease from 4,340 GL/y total to 3,184 GL/yr. The reduction was in response to:

- Concerns raised in the submissions on groundwater received during the 20 week consultation period following the release of the draft Basin Plan.
- A subsequent review of the groundwater methods and assessments by the MDBA and independent groundwater experts.

This addendum report provided information on the review of the groundwater SDL assessments, including an explanation of how the potential impacts of groundwater take on surface water were accounted for when setting the groundwater SDL, a discussion on data quality and how it was considered in the review and changes to deep groundwater SDL resource units. It also outlined requested changes in groundwater SDL resource unit boundaries and SDLs made by New South Wales (NSW), South Australia (SA) and Victoria.

Victoria requested a number of changes to the arrangements for the Victorian groundwater elements of the draft Basin Plan, i.e. changes to:

Å Proposed Groundwater Boundaries for Victoria;

Å The Definition of Groundwater SDL Resource Units;

Å Victorian Riverine Sedimentary Plain Groundwater BDL;

Å Victorian Riverine Sedimentary Plain Groundwater SDL; and

Å Lower Ovens groundwater management area BDL & SDL.

In response to the completion of the Groundwater SAFE (Secure Allocations, Future Entitlements) project that considered groundwater management boundaries in Victoria, the state requested changes to the spatial coverage of the SDL resource units in the state. The MDBA agreed to the Victorian proposal for two groundwater SDL resource units that match the Victorian groundwater Water Resource Plan (WRP) areas, namely the Goulburn-Murray groundwater SDL resource unit (GW2 area); and the Wimmera-Mallee groundwater SDL resource unit (GW3 area). The new SDL resource units include subunits differentiated by descriptions of the groundwater resources. The detailed changes to the Victorian SDL resource units are provided in Table 4.

The two SDL resource units include descriptions of groundwater resources to differentiate the groundwater systems within each of the new SDL resource units. The detailed changes to the Goulburn-Murray groundwater SDL resource unit are provided in Table 4. The new Goulburn-Murray Sedimentary Plains unit consists of the former Victorian Riverine Sedimentary Plain and the former Ovens-Kiewa Sedimentary Plain (GS8f and GS8e respectively in Figure 1)

Table 4: Changes to the Goulburn-Murray Groundwater WRP Area

Draft Basin plan (28 November 2011) SDL resource units	Revised Draft Basin Plan (28 May 2012) Groundwater resource description
(GS8f) Victorian Riverine Sedimentary Plain (shallow; Shepparton Formation)	GS8 Goulburn Murray: Shepparton Irrigation Region
• GS8f Victorian Riverine Sedimentary Plain (deep; Renmark Group and Calivil Formation) • GS8e Ovens-Kiewa Sedimentary Plain	GS8 Goulburn Murray: Sedimentary Plains
• GS8a Goulburn-Broken Highlands • GS8b Loddon-Campaspe Highlands • GS8c Murray Highlands • GS8d Ovens Highlands	GS8 Goulburn Murray: Highlands
Not specified	GS8 Goulburn Murray: Deep

The BDLs and SDLs for the Goulburn-Murray Sedimentary Plain in the Revised Draft Basin Plan are the sum of the BDLs and SDLs of the 2 former SDL resource units in the Draft Basin Plan.

4.1.5.1 BDL

In its submission regarding the draft Basin Plan, Victoria requested that the MDBA set the BDL at 193 GL/y for the former Victorian Riverine Sedimentary Plain (deep) SDL resource unit, which was based on the PCV for all the Victorian management areas within the SDL resource unit.

In determining the BDL of 175 GL/y for this former resource unit in the draft Basin Plan (28 November 2011) the MDBA incorporated the rule that restricts groundwater use to 70% of entitlement in the Katunga WSPA, which it contends is consistent with the application of basin-wide BDL policy (section 6.2). Victoria asserted that the BDL should not include the effect of this rule, as a change in circumstance can prompt the Victorian Minister to amend the restriction to enable greater (or lesser) groundwater use.

The MDBA contended that it has applied BDL policy (MDBA 2012b) consistently across the Basin. Accordingly, in the revised Draft Basin Plan, the MDBA did not accept the Victorian request, asserting that it would not be consistent with the Basin wide BDL policy (MDBA 2012b). MDBA contended that doing so in this case would have been inconsistent with for other SDL resource units in the Basin.

Victoria requested that, for the Ovens-Kiewa Sedimentary Plain SDL resource unit, the state PCVs plus stock and domestic (S&D) use (i.e. 39.0 GL/y) be considered as the BDL. The MDBA received data and information from Victoria that showed that the entitlement volume plus S&D in the resource unit was 28.5 GL/y. Under the MDBA BDL policy, the BDL is set at the current entitlement volume plus S&D. Accordingly the MDBA did not accept the Victorian request as it would be inconsistent with the Basin wide BDL policy (MDBA 2012a).

Victoria requested in a 9 July 2012 Appendix G Notice by Murray-Darling Basin Ministerial Council under Section 43a(4) of the Water Act 2007 that, for the Goulburn-Murray Sedimentary

Plain groundwater area, the MDBA increase the BDL from 203.5 GL to 217.9 GL, based on Table 2 above. In the Revised Draft Basin Plan, the MDBA left the BDL for this area unchanged.

4.1.5.2 SDL

In its submission on the draft Basin Plan (28 November 2011), Victoria stated that the model used to determine the SDL for the former Victorian Riverine Sedimentary Plain (deep) SDL resource unit (GS8f in Table 4) did not take into account episodic flood recharge which results in an underestimate of the resources capacity for productive use. It also indicated that the peer review of the model (Merrick, Woolley, & Hillier, 2010) states that the uncertainty factor of approximately 42 GL, applied to reduce the SDL, is unnecessarily high. Victoria contended that these 2 factors are sufficient to warrant the removal of the uncertainty factor and increase the SDL from 127.0 GL/y to 168.9 GL/y.

The MDBA reviewed the modelling results and associated peer review recommendations and determined that an SDL of 168.9 GL/y represents an environmentally sustainable level of take. Consequently, this figure was adopted as the proposed SDL for the Revised Draft Basin Plan. This decision of the MDBA reflects its acceptance of the case made by Victoria to increase the groundwater SDL for the former Victorian Riverine Sedimentary Plain (deep), i.e. GS8f in Table 4, by 41.9 GL/y.

For the former Ovens-Kiewa Sedimentary Plain SDL resource unit (GS8e in Table 4), Victoria requested that the SDL be considered to be the state PCVs plus S&D use (39.0 GL/y). The SDL of 30.54 GL/y for the resource unit in the draft Basin Plan (28 November 2011), was informed by a numerical groundwater model, the SRP Model, in the majority of the system and the RRAM process in the other part of the resource unit. Accordingly, the MDBA did not accept the Victorian request as it is the MDBA's assessment that the Victorian request would lead to a SDL that would be higher than the environmentally sustainable level of take.

Note, the SDLs for the Ovens-Kiewa Sedimentary Plain SDL resource unit and Victorian Riverine Sedimentary Plain (deep) SDL resource unit in the draft Basin Plan (28 November 2011) are now combined into the SDL for the Goulburn-Murray Sedimentary Plain SDL in the revised draft Basin Plan (28 May 2012).

4.1.6 S43A-7 Ministerial Council Notice, 28 August 2012

Reference 4 in Table 3, is a notice via the Ministerial Council from the Victorian and NSW Governments, under Section 43A(7) of the Water Act 2007. In this document, Victoria and NSW acknowledge concerns regarding potential impacts of groundwater extraction on surface water and on the environmental benefits from the MDBA's proposed surface water SDLs. However, both states requested that the MDBA consider increases in specific groundwater SDLs as requested by individual jurisdictions, provided that the requesting jurisdiction demonstrates that the requested increase "*will not have a detrimental impact on any related surface water resources*".

In this document, Victoria stated the position that the MDBA's BDL and SDL for the Goulburn-Murray Sedimentary Plain groundwater area are unreasonably conservative. Victoria stated that PCVs are the legal limit on the total volume of groundwater that can be licensed in a groundwater area, and groundwater is then managed via a range of tools within the PCVs to ensure groundwater is not over-extracted. Victoria expressed the view that the Victorian PCVs should be used as the "plan limits" for the purposes of setting both the BDLs and the SDLs.

Victoria summed the PCVs for the Katunga Water Supply Protection Area and the Lower Ovens Groundwater Management Area, plus the entitlement volumes outside the groundwater management areas and estimates of the domestic and stock and salt interception schemes to make a total of 217.9 GL, as shown in Table 2. Therefore, Victoria considered that both the BDL and SDL for the Goulburn-Murray Sedimentary Plain groundwater area should be set at 217.9 GL.

The MDBA had previously chosen not to fully recognise Victoria's PCVs for the Goulburn-Murray Sedimentary Plain area. For the Katunga Water Supply Protection Area, the MDBA used 70% of the PCV as the BDL.

Victoria contended that this is unreasonable as it was inconsistent with:

- The MDBA's policy for setting BDLs at "plan limits"; and
- Recent technical reviews and analysis prepared for Katunga and the Lower Ovens about what is the sustainable limit.

Victoria therefore reiterated a request to increase both the BDL and SDL values for the Goulburn-Murray Sedimentary Plain groundwater area to 217.9 GL, incorporating 100 per cent of Victoria's PCVs, including the full PCVs for both the Lower Ovens and Katunga.

Victoria stated that the State's groundwater policy settings and frameworks will ensure that these changes will not impact surface water SDLs. Victoria also requested consideration of the feasibility of developing a groundwater SDL adjustment mechanism such that SDLs can be adjusted in the future as new scientific and hydrogeological information becomes available.

4.1.7 MDBA Response to 28 August 2012 S43A-7 Ministerial Council Notice

The MDBA stated that no additional information regarding this area had been provided regarding the BDL and that the BDL remains at 203.5 GL/yr. The MDBA was in agreement to increase the SDL to be equal to the BDL, i.e. 203.5 GL/yr., but did not agree to increase the SDL to 217.9 GL/yr.

4.1.8 Victorian Riverine Sedimentary Plain Report Card

Reference 6 in Table 3, the Victorian Riverine Sedimentary Plain Report Card, is an unpublished report card provided for this review by the MDBA. It is understood that the Report Card reflects the most up-to-date assessment by MDBA. This is the Report Card for that part of the Goulburn-Murray Sedimentary Plain, not including the Ovens-Kiewa Sedimentary Plain resource unit.

The report card provides a high level summary of the Baseline Diversion Limit (BDL) and Sustainable Diversion Limit (SDL) for the Victorian Riverine Sedimentary Plain SDL resource unit, based on the SRP Model. In the report card, the BDL and SDL for the Victorian Riverine Sedimentary Plain are each 175 GL.

The report card includes the statement that the SDL for the Goulburn-Murray Sedimentary Plain sub-unit (as described in the Basin Plan) includes Ovens-Kiewa Sedimentary Plain and was increased to the BDL after the Authority decided that the Preliminary Extraction Limit (PEL) of 199.5 GL/y was not significantly different to the BDL of 203.5 GL/y. **Both the BDL and SDL for the Goulburn-Murray Sedimentary Plain sub-unit are, therefore, 203.5 GL/yr., comprising 175 GL/yr. for the Victorian Riverine Sedimentary Plain and 28.5 GL/yr. for the Ovens-Kiewa Sedimentary Plain.**

4.2 Victorian Government Reference Material

Table 5 lists the references received from DEPI. They are discussed below.

Table 5. Victorian Government Reference Material

Reference Number	Title	Citation	Date
12	Victorian Water Accounts 2011ï 2012: A statement of Victorian water resources	(DEPI, 2013)	2012
13	DEPI Spreadsheet: Tbl Composite 5 GMWater Lic SDL		2012
14	DEPI Memorandum: Victoriaŝ groundwater licence entitlement determination for the Murray-Darling Basin Plan.		28 March 2012
15	DEPI Northern Victoria Groundwater Model, Conceptualisation and Calibration	(Beverly & Hocking, 2014)	2014
16	Northern Victorian MDB groundwater model scenario report	(Beverly, Baker, Hocking, & Cheng, 2014)	June 2014
17	Expert Review of the Northern Victoria (Murray Darling Basin) Groundwater Model	(Merrick N. P., 2014)	July 2014
18	Northern Victoria Groundwater Model: SDL for Northern Victorian Murray-Darling Basin Sedimentary Plains	(DEPI, 2014)	May 2014

4.2.1 Victorian Water Accounts 2011-2012

Appendix B of Reference 12 provides the total groundwater entitlements and usage for all of the components of the Goulburn-Murray groundwater SDL resource unit, including the WSPAs and GMAs within the Goulburn-Murray Sedimentary Plain SDL resource unit. It does not include allocation of the licenses in unincorporated areas to the different components of the Goulburn-Murray groundwater SDL resource. In terms of its relevance to this synthesis report, it is effectively superseded by the documents described below.

4.2.2 DEPI Spreadsheet and Memorandum Regarding Entitlement Determination

The spreadsheet (Reference 13 in Table 5) lists all the licenses in the GMW area and separates them into Sedimentary Plains, Hardrock and Shepparton Irrigation Region in line with the MDBA SDL area boundaries. It is understood that this is an export of a MS Access table.

It is understood that basalt areas which overlie the Deep Lead aquifers within the highland valleys (e.g. in the Loddon Highlands) are included in the Goulburn-Murray Sedimentary Plain.

In 2012, Victoria had recently improved its information on bore locations. The result was that groundwater use and entitlement could be accounted for more accurately in terms of both volume and location. The memorandum (Reference 14 in Table 5) explains how DEPI, with help from GMW, reviewed groundwater licenced entitlements across the area and assigned licenses from unincorporated areas to either the sedimentary plain (minus the SIR) or the Palaeozoic bedrock by a GIS method.

DEPI compiled groundwater licence information from a range of sources and aligned this with the proposed SDL areas. The assignment of aquifer (i.e. sedimentary or Palaeozoic) was made using GIS, based on boundaries derived by DEPI's SAFE project.

Licensed information (bore location and the water register) was joined, taking account that;

- there are a number of multiple water licences that relate to one works id;
- there are a number of multiple works-ids that relate to single water licences and the water register does not portion the volume to the respective works id. DEPI spilt the volumes equally to each works-id.

This was the methodology used to evaluate the breakdown of entitlements shown in Table 2, which sums to a combined total of 217.9 GL.

4.2.3 Northern Victoria Groundwater Model

A new groundwater model, the Northern Victoria (NVic) Groundwater Model, has recently been developed to assess current and potential future water use availability, to support agriculture under climate change and altered water resource allocations. The NVic model has been developed under the governance of a steering committee consisting of DEPI and GMW personnel.

Project findings are expected to quantify groundwater sustainability in each of the current Victorian groundwater management and water protection areas as well as to provide an evidence-based modelling platform capable of evaluating the hydrological and agricultural impacts of sustainable diversion limits in the context of climate change. References 15, 16, 17, and 18 listed in Table 5 all pertain to this groundwater model.

The following is from Reference 15:

"The specific objectives of the groundwater model include:

1. *Predict the impact of reviewed SDL scenarios associated with various climate and pumping regimes on modelled criteria;*
2. *Determine the flux between groundwater and surface water systems in key groundwater management units (GMUs). The model should be calibrated to within an acceptable range in baseflow, particularly on major streams;*
3. *Determine the resource potential in the Murray Trench;*
4. *Determine the impacts of entitlement reduction program in NSW on Katunga heads and groundwater gradients;*
5. *Determine the rate of recharge to deep lead aquifer system."*

Reference 15 describes the NVic model conceptualisation and calibration, Reference 16 concerns the data sources, groundwater model construct, calibration criteria and results pertaining to agreed scenarios. The scenarios were jointly developed by the MDBA and the DEPI Water and Natural Resources Division with consultation with the relevant water authorities. It also presents a review of SDL volumes for Northern Victoria, based on the new model. This report is intended to provide an updated \analysis of the SDL for the Goulburn Murray Sedimentary Plain SDL area.

Reference 17 is a peer review of References 15 and 16. Reference 18 explains DEPI's arguments for recommending increases in the BDL and SDL for the Goulburn-Murray Sedimentary Plains SDL area.

4.2.3.1 Model Description

The area of this model is shown in Figure 5, reproduced with the kind permission of the authors of Reference 16. The NVic Model covers an area of 182,340 km^2 encompassing the entire extent of the Victorian regions within the Murray Darling Basin, including the bedrock highlands, plus the catchment area of the Murray River in New South Wales. It includes the entire areas covered by the regional water authorities GMW and Grampians Wimmera Mallee Water (GWMW). It does not include the catchment areas of the more northern tributaries of the Murray River (e.g. Darling, Murrumbidgee). The SRP model covers approximately 28% of the NVic model extent (see Figure 3).

Apart from the difference in areal coverage, the following are the major differences between the NVic and SRP models in the Goulburn-Murray Sedimentary Plain area, based on the model reports and the independent review of those reports (Section 4.2.3.3):

- Specific simulation of flood recharge events in NVic model;
- Higher rates of recharge in the NVic model;
- Inclusion of the Palaeozoic basement rocks beneath the Tertiary sediments in the model;
- Significantly higher Upper Shepparton specific yield (Sy) in the NVic model (5-12%) compared with the SRP model (0.01%);
- Significantly lower transmissivity (T) and higher storativity (S) for the Deep Lead aquifer.

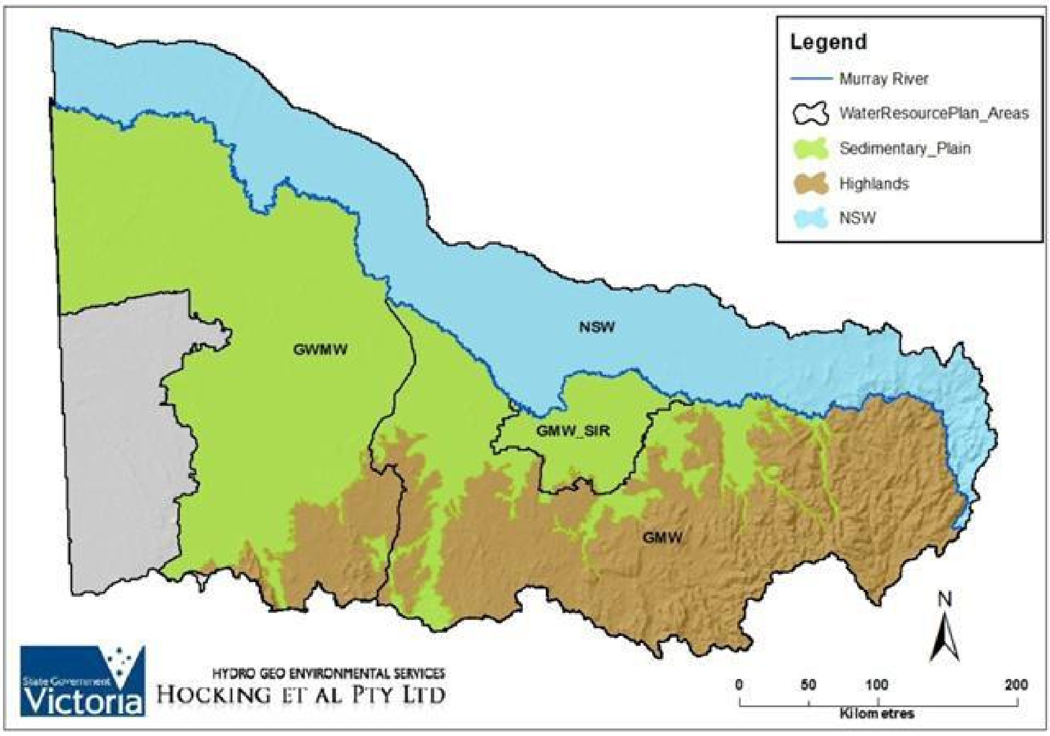

Figure 5: NVic Model Area

Flood-induced episodic recharge was simulated by maintaining saturation in the surface soil layer in areas of mapped flood extents. The duration of inundation was arbitrarily set as 5 days, unless specific information was available. However, there is no subsequent quantification of flood inputs as the flood volumes are included in the "*Total diffuse recharge*" (Merrick N. P., 2014).

4.2.3.2 Model Scenarios and Sustainability Criteria

The main outputs of the NVic model are detailed water balances for eight reporting regions, for four pumping scenarios and four climate sequences. These outputs were assessed in probability terms against the four sustainability criteria developed by MDBA for the Basin Plan.

The sustainability criteria were effectively the same as those listed above in the description of the SRP Model (see Section 4.1.3.1). The SRP model used a visual rather than a quantitative assessment approach to define a stabilised flat level for Criterion 1. In the NVic model, the final interpretation of the first criterion was effectively that, to be ñvisually flatò and comply with Criterion 1, the rate of decline of groundwater levels should be no more than 0.5 m per 10 years during the final 5 years of the simulation.

The interpretation of Criterion 2, regarding model cells not drying out, was the model must maintain pumping at the required rate for 95% of the duration of the scenario model run. The interpretation of Criterion 3, that confined aquifers must not become unconfined, was the predicted groundwater levels at all RCI sites must remain above the top of a confined aquifer for 95% or more of the duration of the scenario model run.

The fourth criterion was that the sustainable extraction limit must be equal to or less than the current level of groundwater extraction. In the NVic model, the criterion adopted was that the average annual net groundwater flux to rivers for the year 2060 must **not** be less than or equal to the average annual net groundwater flux to rivers over the calibration-validation period, i.e. the period 1990-2010. (Note that the word ñnotò was erroneously omitted from Reference 16.)

As for the SRP model, compliance with the criteria was evaluated using RCI sites, which are locations within the model where groundwater levels are reviewed and compared to the criteria. RCI sites do not necessarily correspond to the locations of actual bores. Figure 2 shows the locations of the NVic model RCI sites which are within the Goulburn-Murray Sedimentary Plain.

The scenario analysis is reported in Reference 16 for the eight reporting regions, averaged from 2011 to 2061. The different pumping scenarios were intended to cover the main differences between the current SDL volumes in the MDB Plan and the current management framework in place in Victoria. The four pumping scenarios were agreed by a Steering Committee with representatives from DEPI, MDBA and Goulburn Murray Water (GMW), as follows:

Scenario 1: This scenario is based on the ñ3Aò pumping scenario reported in the SRP Model (CSIRO & SKM, 2010b) in which groundwater extractions were set at licensed entitlement from all licensed bores (except Katunga which was capped at 70% of entitlement), and pumping from the SIR area was capped at 120 GL/year. This scenario differed from the SRP Model ñ3Aò scenario by including D&S extractions with an assumed annual extraction rate of 2 ML/yr. per bore uniformly assigned throughout the year.

Scenario 2: Identical to Scenario 1 with the exception that groundwater extractions within the Katunga WSPA region are set at 100% licensed entitlements.

Scenario 3: Identical to Scenario 2 but with an increased extraction rate from the Lower Ovens region of 25,200 ML/yr. this is an increase of 5,195ML/yr. for this area such that the current PCV is simulated rather than the licensed entitlement is 20,005ML. This scenario explores the options of additional extractions to support future development of the Wangaratta region.

Scenario 4: The extraction rates of Scenario 2 are increased to 120% licence entitlement across the entire domain, with the exception of the Lower Ovens region in which Scenario 3 is enforced.

Each pumping scenario was evaluated under different climatic conditions, which affected recharge. The different climatic conditions simulated consisted of ñ*median*ò, ñ*wet*ò, ñ*dry*ò and ñ*average*ò. The difference between ñ*median*ò and ñ*average*ò involved how the average climate was evaluated, i.e. using mean data or median data.

Table 6 summarises the Goulburn-Murray Sedimentary Plains simulated pumping rates in the different pumping scenarios in the NVic model.

The scenario results for the Goulburn-Murray Sedimentary Plains part of the model are provided in water balance Tables 10-13 in Section 3.2 of Reference 16, the Scenario Report. The water balance tables do not differentiate between the shallow aquifers and the Deep Lead.

The evaluation results of the four scenarios based on the MDBA criteria are summarised in Table 59 to Table 62 of Reference 16 for key reporting regions, including the Goulburn-Murray Sedimentary Plain SDL area. Table 7 herein summarises the results for the Goulburn-Murray Sedimentary Plain SDL area, under what is considered to be average climate conditions. For Criteria 1 and 3, the % compliance figure is understood to be the percentage of RCI bores in which the criterion was complied with.

Table 6. Summary of Goulburn-Murray Sedimentary Plain Simulated Pumping Rates in NVic Model

Scenario Number	Intended Extraction Rate to be Simulated (GL/yr.)	Actual Extraction Rate Simulated (GL/yr.)[1]	Comments
1	199.7	178	Variation on SRP Model ñ3a Scenarioò, 70% for Katunga
2	217.9	196	Intended rate: 100% of Katunga entitlement
3	222.9	199	Intended rate: 100% of Katunga entitlement plus additional 5GL for Lower Ovens
4	260.5	234	Target of 20% more extraction than Scenario 2

Note: The actual rates simulated are from Table 11 and Appendix C of Reference 18. The difference between intended and actual simulated rates is understood to be due to model cells drying out at shallow depth in a localised area such that pumping could not be simulated at the target rate. This is discussed further below.

Table 7 shows that the percentage compliance with Criterion 1 was between 47 and 50%, with the lowest compliance at the highest simulated extraction rate, which would be expected. Under a considerably wetter climate, there was significantly greater compliance with Criterion 1 and under a significantly dryer climate, significantly less compliance with Criterion 1 (not shown in Table 7). This would also be expected because, in a wetter climate there would be more recharge partially balancing the increased extraction. It is understood from Reference 18 that non-compliance with Criterion 1 was localised in the Campaspe area, which is an area of relatively intensive groundwater usage. The level of compliance with Criterion 1 is also a function of the duration of the simulation. In all scenarios, groundwater levels were tending asymptotically towards a new equilibrium rather than declining at a continuous rate. For any RCI locations where compliance with Criterion 1 was not achieved within the 50-year constraint, steady groundwater levels would be achieved in a longer timeframe.

Table 7. Criteria Compliance for Goulburn-Murray Sedimentary Plains in NVic Model (Average Climate)

Scenario Number	% Compliance w/ Criterion 1	% Compliance w/ Criterion 2	% Compliance w/ Criterion 3	Compliance w/ Criterion 4[1]
1 ï Variation on SRP Model ñ3a Scenarioò	50	97	>99	X
2 ï As for Scenario 1 but with Katunga extraction at 100% of entitlements	50	97	>99	X
3 ï As for Scenario 2 but with additional 5GL/yr. extraction in Lower Ovens	48	97	>99	X
4 ï As for Scenario 2 but with 20% additional extraction	47	96	>99	X

Note: X = Non compliance

The % compliance with Criteria 2 and 3, regarding model cells remaining wetted and confined aquifers remaining confined, was more than 95% and more than 99% respectively in all scenarios. The failure to simulate the planned extraction rates is understood to have taken place primarily in upper model layers representing shallow extraction in the Campaspe area of the model.

Non-compliances with Criteria 1, 2, and 3 in the model scenarios would be partly due to the increased extraction being simulated at existing points of extraction. In reality, supplementary extraction would be likely to take place from new bores at locations some distance away from existing bores. Therefore, the compliance evaluation was conservative for these criteria. In particular, the failure to simulate 100% of the intended extraction is considered to be an artefact of the modelôs distribution of simulated extraction rather than a failure of Criterion 2.

There may be some areas where sustainability criteria would, in reality, not be met in the event of localised high rates of groundwater extraction. However, local management rules are used in Victoria to ensure groundwater extraction is sustainable.

Compliance with Criterion 4 was not achieved in any of the pumping scenarios. This is to be expected if the simulated future pumping is greater than the actual pumping in the calibration/validation period and there is sufficient hydraulic communication between the confined Deep Lead and the water table and sufficient time for the effect of pumping to be felt at the water table. The difference in the net groundwater flux to rivers between the different model scenarios was relatively small considering the difference in the simulated extraction rates:

There was only a 10 GL/yr. decrease in net groundwater flux to rivers between Scenario 1 and Scenario 4 (for an increase in extraction rate in the SDL Area of 56 GL/yr.) and only a 3 GL/yr. decrease in net groundwater flux to rivers between Scenario 1 and Scenario 3 (for an increase in extraction rate in the SDL Area of 21 GL/yr.).

Note that, if the model scenarios all represent increases in extraction compared to the calibration/validation period, Criteria 1 and 4 are effectively mutually exclusive. If Criterion 1 were fully met, i.e. the system reaches a new steady state by the end of the model run, it can be expected that the total inflows, including the net flux from rivers to groundwater, would increase, such that Criterion 4 is not met. As long as there is any connection between surface water and groundwater, which there always is, increasing the extraction rate can be expected to decrease the net groundwater flux to rivers by the year 2060 in comparison to the calibration-validation period. Climatic variations made little difference to compliance with Criterion 2 and none to 3 and 4.

4.2.3.3 Independent Review of NVic Model

The review (Reference 17 in Table 5) states that the “*main objectives*”, i.e. objectives 1 and 2 above, have been “*satisfied thoroughly*”. Therefore, the review considers the model to be fit for purpose. However, the review notes that it is not clear whether objectives 3 to 5 have been met. The review notes that the groundwater hydrographs (level trends) have generally the right trends, although there are some large offsets, with the Upper Loddon appears to be the weakest area.

The review notes that, in calibration, a weighting of a factor of ten was given to the Resource Condition Indicator (RCI) bores. These are bores that were later used during forward predictions. The review also notes that there is significant clustering of the chosen bores, rather than the selection of a representative bore for each area.

The review states that calibration performance statistics are very good and the groundwater hydrographs generally have the right trends, although there are some large differences in observed and computed heads. With respect to the scenario analysis (Reference 16), the review notes that the water balance analysis is thorough and “*the final product is extremely well designed and reported*”.

The review states that the calibrated parameter distributions and ranges are plausible, including S and VCONT, which is a term incorporating the vertical hydraulic conductivity. However, the comment is made in the review that the range used in the sensitivity analysis of the parameters K_h and S_s, i.e. doubling and halving of the values, is insufficient.

The NVic model review was undertaken by the same reviewer as the SRP Model review. Compared to the SRP Model, the review of the NVic model notes:

- There is a significant difference between the recharge values in the different models but the spatial patterns of recharge agree reasonably well.
- Unlike the SRP Model, recharge from specific flood events was included in the NVic model but how much of the extra diffuse recharge in the NVic model is attributed to this is not known.

- Irrigation recharge was included in both models, but only the NVic model had a calibration constraint on the adopted magnitudes.

In addition to consideration of the independent review report, the author appreciates having had an opportunity to discuss the model reviews with their primary author, Noel Merrick, for this synthesis report. With respect to the differences in aquifer properties between the models, the reviewer noted that an existing model that is fit for purpose does not exclude a subsequent model from being fit for purpose, even if the models differ substantially. The reviewer also noted that the calibration and representation of the stratigraphy was undertaken more thoroughly in the NVic model than in the SRP model (personal communication, Noel Merrick, August 2014).

The NVic model review concludes with the following statement:

ñ*On balance, it would appear that the NVic model should be a better indicator of sustainable groundwater volumes than the SRP model.*ò

4.2.4 Boundary, BDL and SDL of Goulburn-Murray Sedimentary Plain

Reference 18 provides DEPIs recommended values for the BDL and SDL for the Goulburn-Murray Sedimentary Plain area and provides a rationale for the proposed increases. It includes water balance tables for the Goulburn-Murray Sedimentary Plains, which were extracted from Reference 16, i.e. generated using the NVic model.

In addition to requesting an increase in both the BDL and SDL for the area, this document requests a change in the definition of the boundary between the sedimentary plain and the highlands, which affects the boundary of the Goulburn-Murray Sedimentary Plain SDL area.

4.2.4.1 Requested Boundary Revision

As described above in Section 2, the sedimentary plain aquifers extend as fill of palaeovalleys from highlands to the north. The palaeovalley sediments become thinner and narrower moving up the palaeovalleys towards the south. DEPI proposes that, for the purpose of defining boundaries between sedimentary plain and highland SDL units in Victoria, the definition of the ñhighlandsòboundary in a palaeovalley is the first point where, moving south up a palaeovalley, the maximum alluvial thickness in a section across the valley is less than 10m (typically at a narrow point across the valley). The alluvial sediments typically do not thicken beyond that point further up the palaeovalley. However, if they do, the flow system is likely to be a local system with discharge to the local surface water such that it does not contribute significant flow to the Deep Lead flow system of the sedimentary plain.

The Newer Volcanics of Victoria extend over the divide at some locations where lava flows followed the partially-filled palaeovalleys. Although they are hard igneous rock rather than sediments, these basalts are not Palaeozoic bedrock. They are younger than the Calivil Formation and overlie it. Therefore, DEPI proposes that they should be considered part of the sedimentary plains anywhere where the combined thickness of the Newer Volcanics and Tertiary sediments is greater than 10 m. DEPI also proposes that, if a bedrock outlier is separated from the central Victorian highlands by sediments and/or basalt of more than 10 m combined thickness, then it should be considered part of the Sedimentary Plains. This is because it is more likely to be in hydraulic connection with the surrounding sedimentary plains than the highlands.

Figure 6 illustrates how the new definition of the bedrock/sedimentary plains SDL unit boundaries would alter the areas. The current sedimentary plain/highland boundary is shown as a dashed red line and the proposed new boundary is in pink. Overall, it appears the effect of the proposed boundary change would be to increase the total area considered to be highlands slightly and to decrease the total area considered to be sedimentary plain. The exception is in an area to the west of Bendigo. However, it is understood that the groundwater in this area is largely saline such that this does not significantly affect allocations.

4.2.4.2 BDL

The current management plan for the Katunga area incorporates a level-based trigger that restricts use to 70% of entitlement if the trigger is met. DEPI argues that this is a management trigger, and not the "plan limit". It is understood (personal communication, Simon Baker, DEPI, August 2014) that it has been in place since 2003, which was a time of relatively intensive groundwater use in response to drought conditions. DEPI's position is that basing the BDL on 70% of entitlement effectively **permanently** reduces Katunga licence holders' groundwater entitlements by 30% without any recognition of this loss, whereas the level-based trigger is not a permanent reduction in entitlement. It is reviewed at least every five years and can change based on this review.

Therefore, DEPI maintains that the BDL for Katunga should not include the reduction of 30%. DEPI contends that the component of the Goulburn-Murray Sedimentary Plain BDL relating to Katunga should be based on the most recent PCV for the area (gazetted in 2013), which is 60,577 ML/yr., rather than the current value of 42,405 ML/yr. Note that the PCV of 60,577 ML/yr. is 799 ML/yr. greater than it was in 2011-12, i.e. than it was in Reference 12.

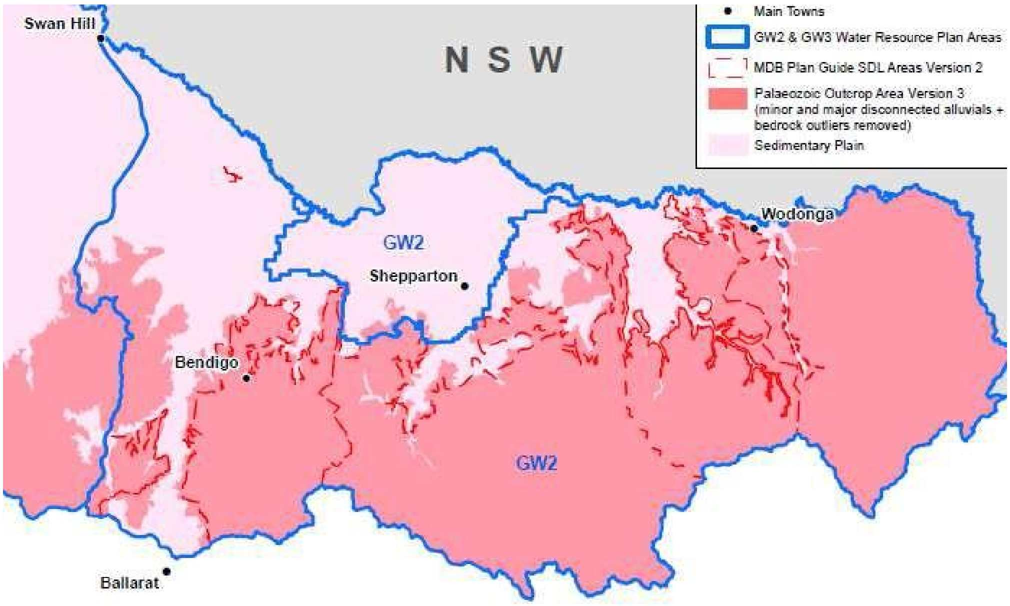

Figure 6: Differences in SDL Areas due to Redefining the Sedimentary Plain Boundary

DEPI reiterates the licensed entitlement, S&D and salt interception totals listed above in Table 2 to justify a total BDL for the Goulburn-Murray Sedimentary Plain of 217.9 GL/yr. In doing so, DEPI states the total of 205,539 ML/yr. in licensed entitlements includes 60,577 ML/yr. for the Katunga WSPA. In fact it appears to include 60,509 ML/yr. of licensed entitlements in the Katunga WSPA (as shown in Table 2). If the Katunga component were 60,577 ML/yr., the total would be slightly greater, at 218.0 GL/yr. rounded to the nearest 0.1 GL/yr.

4.2.4.3 SDL

DEPI uses the NVic Model to support an argument for an increase in the SDL from 203.5 GL/yr. to 222.9 GL/yr. Reference 18 highlights the fact that the NVic model output shows that there is only a 3 GL/yr. decrease in net groundwater flux to rivers in this SDL area between simulated extraction at 178 GL/yr. (Scenario 1) and simulated extraction at 199 GL/yr. (Scenario 3). To date it is understood that the model has not been successfully used to simulate groundwater extraction at 222.9 GL/yr. (Table 6). However, it is understood it has been used to simulate groundwater extraction at 234 GL/yr. (Scenario 4 in Tables 6 and 7).

DEPI proposes that the SDL for the Goulburn-Murray Sedimentary Plains incorporate the proposed BDL volume of 217.9 GL/yr. **plus** an additional 0.8GL in the Katunga area **plus** an additional 5GL of groundwater from the Lower Ovens area . DEPI states that this is intended to reflect the current PCV for the Katunga WSPA and the Lower Ovens GMA.

5 Summary of MDBA Approach

This section is intended to condense the main points from Section 4.1.

5.1 The Plan

The MDBA aims to set consistent limits to groundwater extraction across the basin using the Basin Plan. The BDL for each groundwater SDL resource unit represents the MDBA's determination of the limits on groundwater use "under existing water management arrangements" and describes the baseline against which SDLs are assessed. The SDL of a groundwater SDL resource unit is the maximum long-term annual average quantity of water that can be taken on a sustainable basis. SDLs must reflect the environmentally sustainable level of take (ESLT) for a water resource.

One of the stated criteria regarding groundwater extraction in the Plan is that the sustainable groundwater extraction limit must be equal to or less than the current level of groundwater extraction. The rationale is given as maintenance of environmental river flows. However, a peer review of the basin plan stated that the connection between the two is not obvious.

In areas where there is a "fit-for purpose" numerical groundwater model available, the model is the preferred tool for evaluating the SDL. The alternate method, with the acronym RRAM, is based on estimated diffuse recharge. It is considerably less favourable because it does not include recharge from rivers, flooding or irrigation, which make up a significant proportion of recharge in the Basin.

5.2 The SRP Model

The SRP Model was used to evaluate SDL's over an area of the riverine plains which included nearly all of the Goulburn-Murray Sedimentary Plain. The model was used to recommend SDLs by simulating future pumping scenarios under different climatic conditions. However, the scenarios simulated did not include increasing the rate of extraction to higher rates than were taking place in the period 2004-2008, because of the environmental river flows criterion.

In the SRP Model report, a SDL of significantly less than the simulated rate of extraction was recommended for the Goulburn-Murray Sedimentary Plain, i.e. 157.5 GL/yr. The simulations in fact showed that a rate of approximately 209 GL/yr. was sustainable (assuming local management rules can address a localised breach of Criterion 1 regarding stabilisation of groundwater levels), except that this rate was greater than the current level of extraction, so it did not meet Criterion 4, the environmental river flows criterion.

Independent review of the SRP Model stated it was "*fit for purpose, where the purpose is SDL determination*". It also stated that: "*Modelling has demonstrated that usage at the levels of entitlements is sustainable except in the Shepparton Irrigation Region*".

The review also stated that the SRP Model is conservative for use in evaluating the SDL (i.e. likely to underestimate it), even without application of an uncertainty factor to lower the estimate, because it does not account for flood recharge. Therefore, the SDL could be greater than 209 GL/yr. for the modelled area of the Goulburn-Murray Sedimentary Plain if flood modelling were also taken into account.

The RRAM was used to evaluate an additional sustainable extraction rate for that part of the Goulburn-Murray Sedimentary Plain SDL area which is outside the SRP Model (in the Upper Kiewa/Ovens). Using this method, it was recommend that an additional 4.6 GL/yr. be added to account for this area. This does not include consideration of river recharge, which would be significant in this area. Therefore, the supplemental SDL for the Upper Kiewa/Ovens is likely to be more than 4.6 GL/yr. Adding the Ovens-Kiewa figure of 4.6 GL/yr. from outside the model domain evaluated from RRAM, to the total of 209 GL/yr. for the modelled area, the total would be 213.6 GL/yr.

5.3 Definition of the Goulburn-Murray Sedimentary Plain SDL Area

In July 2012, MDBA agreed to the definition of Goulburn-Murray Sedimentary Plain SDL Unit suggested by DEPI, i.e. the area shown in Figure 2. Previous SDL units Victorian Riverine Sedimentary Plan (deep) and the Ovens-Kiewa Sedimentary Plain were combined into this single SDL unit.

5.4 BDL and SDL Values

MDBA did not increase the BDL for the new SDL Area in the consultation period between the Draft Plan in November 2011 and the Altered Proposed Basin Plan in August 2012. The BDL remained at 203.5 GL/yr. However, MDBA increased the SDL from 157.5 GL/yr. to 203.5 GL/yr., the same as the BDL, during the course of the consultation and submission process in 2012.

Both the latest BDL and the latest SDL for the Goulburn-Murray Sedimentary Plain SDL Unit are understood to comprise 175 GL/yr. for the Victorian Riverine Sedimentary Plain and 28.5 GL/yr. for the Ovens-Kiewa Sedimentary Plain.

In limiting the BDL to 203.5 GL/yr., the MDBA incorporated a rule that restricts groundwater use to 70% of entitlement in the Katunga WSPA. The MDBA contends that this is consistent with the application of its basin-wide BDL policy.

6 Summary of DEPI Approach

This section is intended to condense the main points from Section 4.2.

6.1 BDL Based on Re-evaluation of entitlements in the New SDL Unit

In 2012, DEPI, with help from GMW, reviewed groundwater licenced entitlements across the Goulburn-Murray area and assigned licenses from unincorporated areas to either the sedimentary plain (minus the SIR) or the Palaeozoic bedrock by a GIS method. In this way, DEPI improved the level of accuracy regarding groundwater use and licenced entitlements in the Goulburn-Murray Sedimentary Plain SDL unit. This was the methodology used to evaluate the breakdown of entitlements shown in Table 2, which sums to a combined total of 217.9 GL

DEPI contends that the component of the Goulburn-Murray Sedimentary Plain BDL relating to Katunga should be based on the most recent PCV for Katunga in its entirety, i.e. 60,577 ML/yr., rather than 70% of entitlements which is the position of MDBA. Therefore, DEPI states that the BDL for the new Goulburn-Murray Sedimentary Plain SDL Unit should be 217.9 GL/yr. In doing so, DEPI considered the boundary between the sedimentary plain and the highlands to be defined as described below.

6.2 Sedimentary Plain-Highland Boundary

Based on recent work in Victoria, DEPI proposes that, for the purpose of defining the boundary between sedimentary plain and highland SDL units in Victoria, the definition of the ĩhighlandsò boundary is the first point where, moving towards the highlands, the maximum alluvial thickness in a section across the valley is less than 10 m (typically at a narrow point across the valley). In addition, due to the age of the Newer Volcanics, DEPI considers the Newer Volcanics to be part of the sedimentary plains in areas where they are interbedded with the sediments of the sedimentary plains, such that the combined thickness of the Newer Volcanics and tertiary sediments is greater than 10 m.

6.3 The Northern Victoria Model and the SDL

The Northern Victoria (NVic) Groundwater Model, has recently been constructed. It includes all of that part of Victoria which is within the Murray-Darling Basin. The objectives of the model include prediction of the impacts of different groundwater pumping scenarios under different climatic conditions and evaluation of groundwater-surface fluxes in key GMUs. An independent review has stated that the model is fit for purpose and satisfied the above objectives thoroughly. The independent review, undertaken by the same reviewer as the review of the SRP Model, also noted several ways in which the NVic model was an improvement over the earlier SRP model.

In May 2014, DEPI proposed that the SDL for the Goulburn-Murray Sedimentary Plain be increased from 203.5 GL/yr. to 222.9 GL/yr. This new total of 222.9 GL/yr. consists of the proposed BDL volume of 217.9 GL/yr. **plus** an additional 5GL of groundwater from the Lower Ovens area. This is intended to reflect the current PCV for the Lower Ovens GMA as well as Katunga WSPA.

DEPI attempted to simulate an extraction rate of 222.9 GL/yr. using the NVic Model but, due to model cells locally drying up, it is understood that this extraction rate was not able to be simulated. This is considered to be an artefact of the model rather than an indication that Criterion 2, regarding the productive base of the aquifer, will not be met. Notwithstanding this model issue, in support of a proposed increase in the SDL, DEPI highlighted the fact that the model predicted only a 3 GL/yr. decrease in net groundwater flux to rivers in this SDL area, between simulated extraction at 178 GL/yr. and simulated extraction at 199 GL/yr., which is an increase in the extraction rate of 21 GL/yr.

Although the model was not used to simulate groundwater extraction at 222.9 GL/yr. (Table 6), it was used to simulate groundwater extraction at a higher rate of 234 GL/yr. (Scenario 4 in Tables 6 and 7). The level of compliance with the different criteria was not significantly worse in this high extraction rate scenario than in the other scenarios.

7 Discussion of Significant Differences

7.1 Definition of SDL Area Boundary

DEPI has advocated a boundary definition between the sedimentary plain and the highlands based on the alluvial thickness, such that the boundary can be moved if new geological information becomes available. This affects the location of the boundary of the Goulburn-Murray Sedimentary Plain SDL unit. However, it is understood that this would not make a significant difference to extraction limits. In the reports reviewed for this synthesis, MDBA has not expressed an opinion regarding this new boundary definition.

7.2 BDL and SDL

Table 8 summarises the current differences considered to be of greatest significance between the most recent MDBA position and the most recent DEPI position.

Table 8: Significant Differences between MDBA Position and DEPI Position

Item	MDBA	DEPI Victoria
BDL	**203.5 GL/yr.**	**217.9 GL/yr.**
Katunga Component of BDL	42.4 GL/yr., i.e. 70% of entitlement	60.6 GL/yr., i.e. 100% of most recent PCV
SDL	**203.5 GL/yr.**	**222.9 GL/yr.**
Lower Ovens Component of SDL	20.2 GL/yr.	25.2GL/ yr., to include Lower Ovens PCV

Note: All diversion limits in this table are rounded to the nearest 0.1 GL/yr.

The most significant difference in the accounting between MDBA and DEPI is for the Katunga WSPA. The MDBA includes 70% of entitlement for the Katunga WSPA whereas DEPI advocates inclusion of 100% of the PCV for the Katunga WSPA. MDBA contends that using a value of 70% is consistent with the application of basin-wide BDL policy which is that, where restrictions are in place, they can be used as the BDL. However, DEPI argues that the 70% limitation is a local management trigger, which is reviewed at least every five years, and should not be adopted as the ñplan limitò DEPIÕs position is that basing the BDL on 70% of entitlement effectively permanently reduces Katunga licence holdersÕ groundwater entitlements by 30% without any recognition of this loss.

MDBAÕs position regarding the SDL is that it should be the same as the BDL. DEPIÕs position is that it should also incorporate an additional 5GL of groundwater from the Lower Ovens area. DEPI states that this is intended to reflect the current PCV for the Lower Ovens GMA.

The numerical models used by MDBA and DEPI to evaluate extraction limits and support arguments for different SDLÕs are different in several ways (e.g. model extent, recharge rate at ground surface, aquifer properties in key layers, how they account for flood recharge). These differences each have different consequences in terms of how conservative the models are when used to evaluate sustainable extraction rates. However, the combined effect of these differences on how conservative the models are relative to each other is not known.

The NVic Model was used to simulate a greater extraction rate than both the current agreed SDL and the SDL proposed by DEPI in Table 8. The greatest reported rate simulated using the SRP Model was 209 GL/yr.

Although the models are different in aspects of their setups and inputs, they are not significantly different in their results. Both models indicate that groundwater could be extracted at higher rates than 200 GL/yr., and higher rates than the rates simulated during calibration, without significantly compromising MDBA's sustainability Criteria 2 and 3. Both models show minor local breaches of Criterion 1 regarding stabilisation of groundwater levels. Both models also show that, in the long term, groundwater cannot be extracted at higher rates without adversely affecting the net long-term flux between groundwater and surface water. Thus, Criterion 4 regarding prevention of flow impacts to surface water is not satisfied under any pumping scenario in which the future extraction rate simulated is greater than the past rate used in calibration.

8 References

Arad, A., & Evans, R. (1987). The Hydrogeology, Hydrochemistry and Environmental Isotopes of the Campaspe River Aquifer System, North-Central Victoria, Australia. *Journal of Hydrology*, 23.

Beverly, C. B. (2014). *Northern Victorian MDB groundwater model scenario report.* Melbourne: Victorian Government Department of Environment and Primary Industries.

Beverly, C., & Hocking, M. (2014). *DEPI Northern Victoria Groundwater Model Conceptualisation and Calibration.* Rutherglen: DEPI.

Beverly, C., Baker, S., Hocking, M., & Cheng, X. (2014). *Northern Victorian MDB groundwater model scenario report.* Melbourne: DEPI.

Brown, C. a. (1989). *Geology of the Murray Basin.* Canberra: Bureau of Mineral Resources.

CSIRO. (2008). *Southern Riverine Plains Groundwater Model Calibration Report .* Canberra: CSIRO.

CSIRO and SKM. (2010). *Dryland Diffuse Groundwater Recharge Modelling Across the Murray-Darling Basin.* Canberra: Commowealth Government of Australia.

CSIRO and SKM. (2010a). *Dryland Diffuse Groundwater Recharge Modelling Across the Murray-Darling Basin.* Canberra: Commowealth Government of Australia.

CSIRO, & SKM. (2010b). *Groundwater modelling report – Southern Riverine Plains. CSIRO: Water for a Healthy Country National Research Flagship.* MDBA.

CSIRO; SKM. (2010). *Groundwater modelling report – Southern Riverine Plains. CSIRO: Water for a Healthy Country National Research Flagship.* MDBA.

DEPI. (2013). *Victorian Water Accounts 2011-2012.* Melbourne: Victorian Goverment.

DEPI. (2014). *Northern Victoria Groundwater Model - SDL for Northern Victorian Murray-Darling Basin Sedimentary Plains.* Melbourne: Victorian Goverment Department of Environment and Primary Industries.

Goode and Barnett. (2008). *Southern Riverine Plains Groundwater Model Calibration Report: A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project.* Canberra: CSIRO.

Hyder. (2006). *Campaspe Valley Conceptual Hydrogeological Model Final Report.* prepared for GMW.

MDBA. (2012a). *The Proposed Groundwater Baseline and Sustainable Diversion Limits: Methods Report.* Canberra: MDBA Publication No 16/12.

MDBA. (2012b). *Addendum to the proposed Groundwater Baseline and Sustainable Diversion Limits: Methods Report.* Canberra: MDBA Report 62/12.

MDBA. (2012c). *Basin Plan.* Canberra: MDBA.

MDBA. (2012c). *Basin Plan.* Canberra: MDBA.

Merrick, N. P. (2014). *Expert Review of Northern Victoria (Murray-Darling Basin) Groundwater Model.* Hydro Simulations.

Merrick, N. P., Woolley, D. R., & Hillier, J. R. (2010). *Peer Review of the Southern Riverine Plains Numerical Groundwater Model.* Report Number LHC2010/25, Heritage Computing.

Shiklomanov, I. (1993). "World Fresh Water Resources", Chapter in Book: Water in Crisis: A Guide to the World's Fresh Water Resources, edited by Peter H. Gleick. In P. H. Gleick (Ed.). New York: Oxford University Press.

SKM. (2014a). *Western Porous Rock Groundwater Sustainable Diversion Limit Review - Interim Synthesis Report.*

SKM. (2014b). *Eastern Porous Rock Water Resource Plan Area Review - Synthesis Report.*

Stephenson, B. a. (n.d.).

Tickell, S. a. (1987). *Groundwater resources and associated salinity problems of the Victorian part of the Riverine Plan. .* Vic. Geol. Survey .

Woolley, D. M. (2010). *Peer Review: Basin Plan (Groundwater).* Heritage Computing.

9 Limitations

Scope of Services

This document (the report) has been prepared in accordance with the scope of services set out in the contract, or as otherwise agreed, between the client and Aquade (scope of services). In some circumstances, the scope of services may have been limited by a range of factors such as time or budget constraints.

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