Department of **Water**
Government of **Western Australia**

Upper Collie surface and groundwater allocation limits: methods and calculations

Looking after all our water needs

Department of Water

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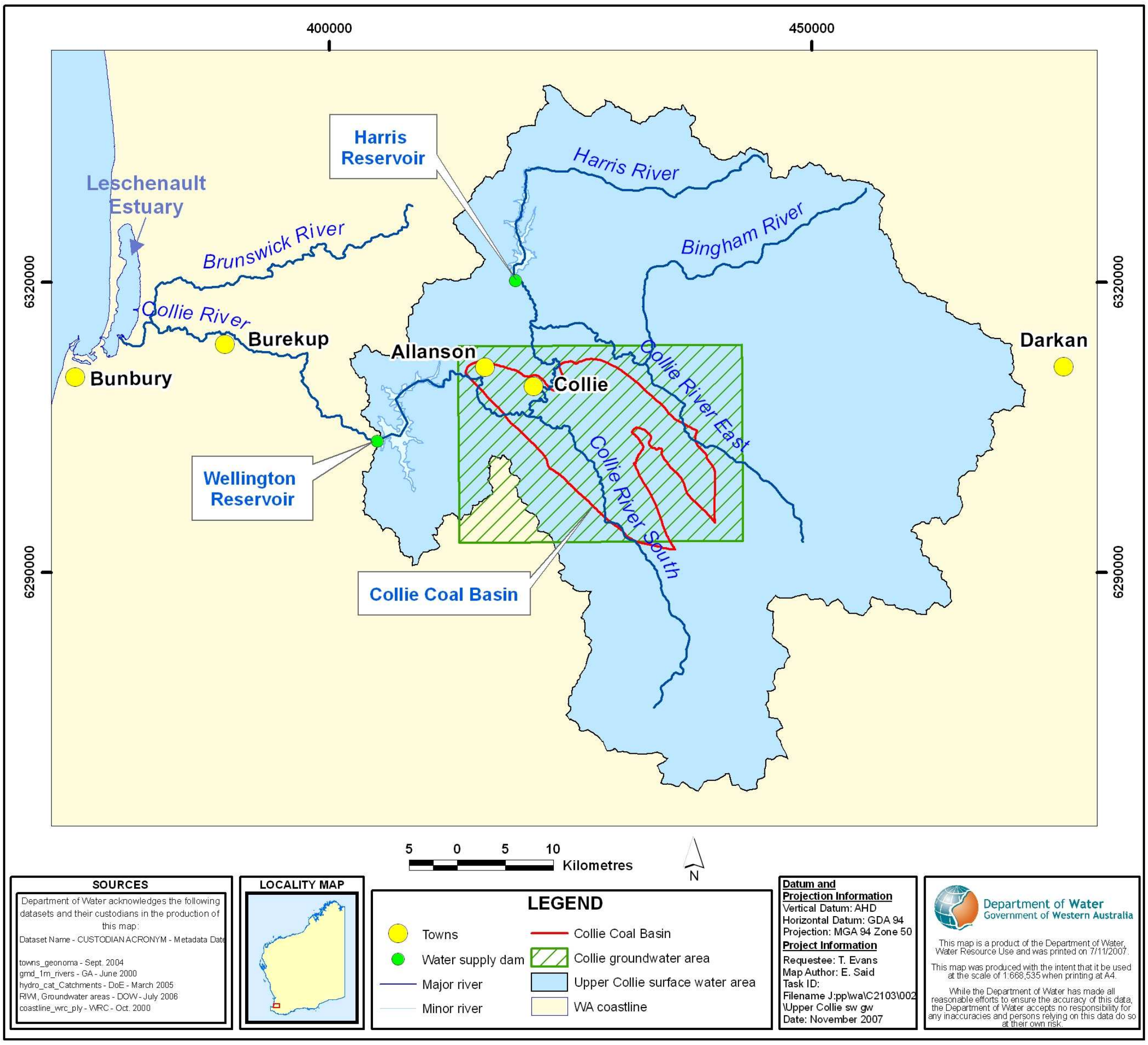

Figure 1 Location of the Upper Collie surface water and groundwater areas

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Summary

The Department of Water has recently released its *Upper Collie water management plan: draft for public comment*. This methods report is one of the key supporting documents to the draft Upper Collie plan as it details the methods, calculations and options we used in determining the annual allocation limits for the groundwater and surface water resources of the Upper Collie area.

We are a transparent organisation and this methods report is part of our commitment to making our technical and decision-making information publicly available.

This report provides the updated:

- water management boundaries at the subarea scale
- allocation limits
- methods and calculations used to determine allocation limits, including the options assessment.

We determined allocation limits by considering all available scientific resource information including river flows, groundwater levels and storage components as well as information on how much water the environment needs. To support our decision process we used the Collie Coal Basin groundwater model to predict changes in groundwater storage over a fifty year period and the LUCICAT model to assess surface water flows throughout the area.

For each water management subarea, we considered a number of allocation limit options. Each allocation limit was selected based on achieving recovery of the groundwater levels in the Cardiff subarea and restoring the quality of the Collie River and Wellington Reservoir to fresh.

A summary of the final allocation limits is provided in Table 1, along with a brief description of the methodology used.

Table 1 Upper Collie ground and surface water resource allocation limits

Subarea	Resource	Allocation limit	Methodology
Surface water resources			
Collie River Central	Wellington Reservoir	85.10	Detailed reservoir modelling
	Mungalup Reservoir	0.50	
	Collie River mainstream	1.00	
Harris River	Harris Reservoir	15.00	Detailed reservoir modelling
Lower Harris	Lower Harris	1.22	30 % of ecological sustainable yield
Collie River East Branch	Collie River East Branch	14.00	100 % of ecological sustainable yield
Collie River Lower East Branch	Collie River Lower East Branch	1.00	< 5 % of ecological sustainable yield
Bingham River	Bingham River	0	0 % of ecological sustainable yield
Collie River South Branch	Collie River South Branch	5.02	30 % of ecological sustainable yield
Groundwater resources			
Cardiff	Nakina	0	Scenario modelling for changes in groundwater storage
	Muja	1.79	
	Lower Collie Group	2.51	
	Stockton	0	
Premier	Nakina	0	Groundwater recharge and use assessment
	Muja	0	
	Lower Collie Group	2.20	
	Stockton	0	

These allocation limits define how much water can be abstracted, in total, within the Upper Collie and will be implemented through licensing and the Upper Collie water management plan. The limits will be reviewed in developing the statutory water management plan, due to be completed by 2011. Until a statutory plan is completed licences will not be issued over these limits, except for dewatering for safe mining practices in the Premier subarea, which is considered outside of the allocation limit.

1 Background

1.1 Surface water

Previously, surface water allocation limits were set only for the Wellington and Harris reservoirs. Aside from this the Upper Collie rivers and tributaries did not have allocation limits. The Upper Collie area was managed as the Upper Collie catchment, with no breakdown of surface water resources within the broader catchment boundary.

In addition to setting allocation limits for the Upper Collie rivers and tributaries, other amendments were necessary. These included:

- reviewing and updating the Harris Reservoir allocation limit to account for rainfall and streamflow reductions since it was last assessed as 17.5 GL/yr in 2000; and
- amending the surface water management area boundaries to manage at a finer scale and account for increased self supply demand.

A summary of the previous surface water management units are provided in Table 2.

Table 2 Previous Collie River surface water management unit, taken from Department of Water, Water Resource Licensing (WRL) system

Drainage division	River basin	Resource	Allocation limit* (GL/yr)
South West Div 6	Collie River	Collie River	Not assessed
		Collie – Harris River	Not assessed
		Tributaries of the Collie River East branch	Not assessed

** Note. The allocation limits of the Harris and Wellington reservoirs, although formally assessed, were not officially recorded in the WRL system.*

1.2 Groundwater

Until now, a single groundwater allocation limit covered the Collie Groundwater Area. The Collie Groundwater Area contains two relatively discreet sub-basins referred to as the Cardiff and the Premier. Mining has now ceased in the Cardiff sub-basin which has highlighted the need to divide the area into two subareas to ensure recovery of groundwater once the need to dewater for safe mining has ceased.

A summary of the previous groundwater management units and allocation limits is provided in Table 3.

Table 3 Previous groundwater allocation limits and resource breakdown

Area	Subarea	Resource	Allocation limit (GL/yr)
Collie	Collie	Collie – Stockton group	0.30
		Collie – Group	22.00

2 Methodology used to assess surface water allocation limits

This section describes the methods and environmental water requirements that were used to estimate the ecological sustainable yields, and potential annual allocation limit options, for each surface water subarea.

Detailed reservoir modelling was completed for the Collie River Central (which includes the Wellington reservoir) subarea and the Harris River (which includes the Harris Reservoir) subarea (Section 4.1 and 4.2). For each of the other subareas, including Lower Harris, East Branch, Lower East, Bingham and South Branch, up to five options were assessed based on the modelled inflows, current use, future demand and water quality in the subarea (Section 4.3).

2.1 Surface water subareas

The Upper Collie catchment has been divided into seven surface water subareas (Figure 2).

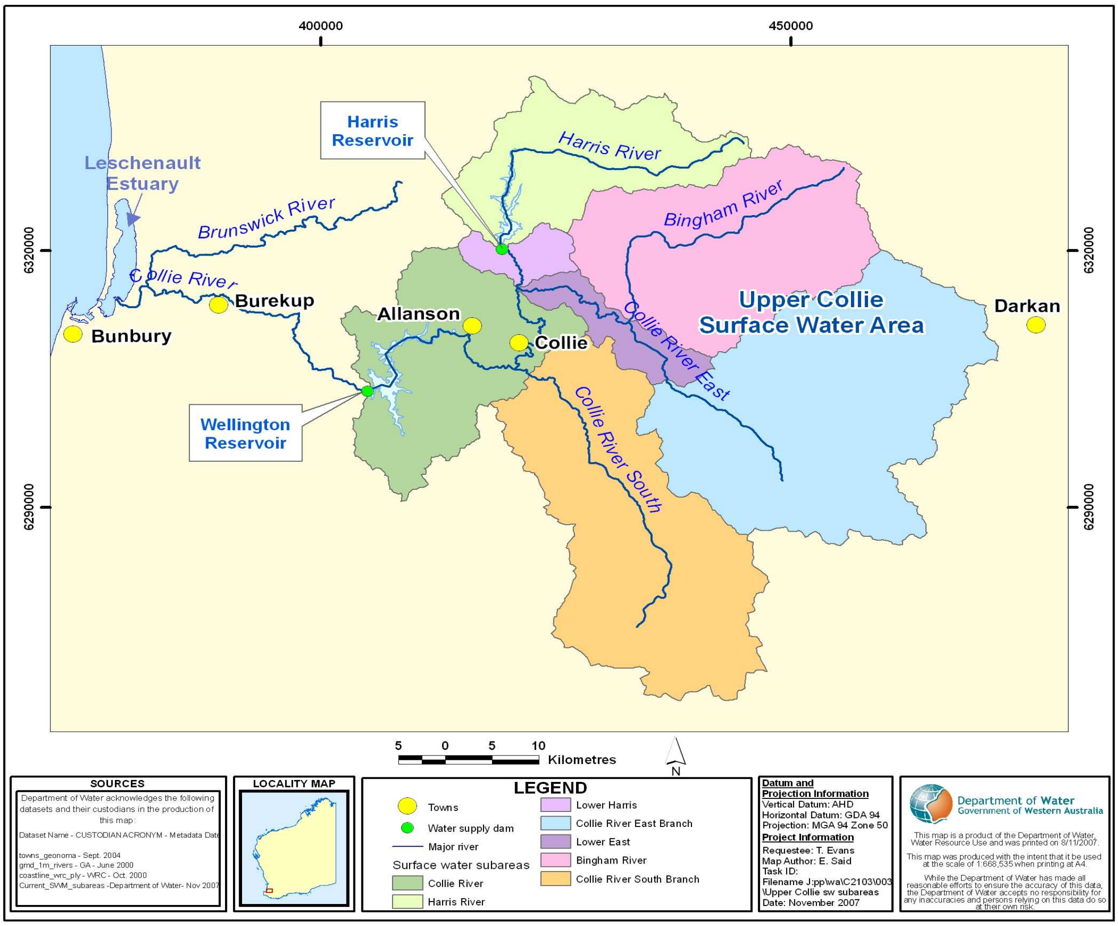

Figure 2 Upper Collie surface water subareas

The subareas differ in that two contain a major reservoir (Collie River Central and Harris subareas) and others are used for private self-supply purposes only (Table 4).

The methodology, used to determine allocation limit options, differs according to the level and type of water use within of subarea.

Table 4 Surface water subarea type and description

Subarea	Type	Description
Collie River Central	Combined	Contains the Wellington Reservoir and private self suppliers diverting from the river
Harris River	Reservoir	Contains the Harris Reservoir only
Lower Harris	Self supply	Contains self suppliers only
Collie River East Branch	Self supply	Contains self suppliers only
Lower East	Self supply	No current licensed use
Bingham	Self supply	No current licensed use
Collie River South Branch	Self supply	Contain self suppliers only

2.2 Surface water ecological water requirements

The ecological water requirements for each subarea have been formally assessed in various studies (Table 5).

Table 5 Upper Collie ecological water requirements

Subarea	Study name	Study date
Collie River central (including Wellington reservoir)	Synthesis report – Lower Collie river ecological water requirements review: stream morphology, riparian vegetation and fish passage. Water and Rivers Commission.	2003
Harris River	Environmental water requirements study: Harris River East Branch of the Collie River (downstream of the confluence) to the South Branch. Prepared for Water Corporation by Welker Environmental Consultancy and Streamtec	2000
Lower Harris	Environmental water requirements study: Harris River East Branch of the Collie River (downstream of the confluence) to the South Branch. Prepared for Water Corporation by Welker Environmental Consultancy and Streamtec	2000
Collie River East Branch	Draft preliminary ecological water requirements of the Collie River East Branch: Risk Assessment of Salinity Mitigation Diversion Scenarios. Currently in preparation by Wetland Research and Management group.	2007
Lower East	Draft preliminary ecological water requirements of the Collie River East Branch: Risk Assessment of Salinity Mitigation Diversion Scenarios. Currently in preparation by Wetland Research and Management group.	2007
Bingham River	Draft preliminary ecological water requirements of the Collie River East Branch: Risk Assessment of Salinity Mitigation Diversion Scenarios. Currently in preparation by Wetland Research and Management group.	2007

Subarea	Study name	Study date
Collie River South Branch	Environmental Water Provisions South Branch of the Collie River Downstream from Western 5 open Cut. Welker and Streamtec consultancy.	2001

This information was used to estimate the *ecological sustainable yield* and potential allocation limit options for each subarea.

The *ecological sustainable yield* in this context is the estimated amount of water that is available after ecological needs are met. Note that:

- Each of the ecological requirements is assessed with current flow levels, which are higher than the pre-clearing natural state.
- The studies differ in that they took place at various periods, had different methodologies, and different levels of detail.
- There are risks associated with using these preliminary ecological water requirements, in that monitoring has not been completed to improve certainty.

2.3 Collie River Central subarea (including the Wellington Reservoir)

The majority of abstraction within the Collie River Central subarea comes from the Wellington Reservoir. In addition to this, there is around 1 gigalitre of private self supply diverted from the Collie River and 0.50 GL abstracted from the Mungalup Reservoir, each year.

In 2003, detailed reservoir modelling was completed by the department's surface water assessment section to determine the allocation limit for the Wellington Reservoir.

The Wellington Reservoir yield and allocation limit assessment was completed using a simple two-layer daily salt and water balance of the reservoir. For further details on the yield assessment refer to appendix A. The water balance was based on actual inflows to the reservoir for the 1975 – 1999 period. Licensed take by self suppliers and abstraction from Mungalup Reservoir was considered as part of the assessment, as reduced flows into the reservoir.

Allocation limit options for the reservoir, in 2003, were assessed based on Harvey Water's entitlement (68 GL) and Water Corporation's application for 20 GL from the reservoir.

Stream flow for ecological water requirements below the Wellington Reservoir

The Wellington Reservoir sits at the end node of the Collie River Central subarea. As a result the critical factor, in estimating the ecologically sustainable yield of this subarea, is the flow to be maintained below the reservoir.

In 2003, Hardcastle *et al* determined the ecological water requirements and required stream flow to be maintained below the Wellington Reservoir (at the Mt Lennard gauging station). Note that this assessment was preliminary and further work is necessary to reduce uncertainty.

Table 6 Monthly stream flow (as Gigalitres per month) required to meet ecological water requirements below the Wellington Reservoir (at the Mt Lennard gauging station)

*Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Macro - invertebrates	2.01	1.81	2.01	1.94	2.01	2.20	2.68	2.68	2.59	2.28	1.94	2.01
Fish passage	-	-	-	-	-	-	-	1.68	0.84	-	-	-
Pool maintenance	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Energy	2.01	1.81	2.01	1.94	2.01	1.94	2.01	2.01	1.94	2.01	1.94	2.01
Total	**2.01**	**1.81**	**2.01**	**1.94**	**2.01**	**2.20**	**2.68**	**3.82**	**3.16**	**2.28**	**1.94**	**2.01**

2.4 Harris River subarea (Harris Reservoir)

All abstraction within this subarea comes from the Harris Reservoir. There are no private self suppliers within the Harris subarea.

Reservoir modelling was completed by the department’s surface water assessment section in August 2007 to estimate the ecological sustainable yield and assess allocation limit options at various reliabilities. The water balance for this assessment was based on actual inflows to the reservoir for the 1975 – 2003 period.

Three allocation limit options were assessed based on optimum reliabilities and current demand scenarios. The three options assessed were: 90 per cent reliability (13 GL); current licences (15 GL); and current demand (17 GL).

Stream flow for ecological water requirements below the Harris Reservoir

The critical factors, in estimating the ecological sustainable yield of the Lower Harris subarea, are the inflows to the Harris Reservoir and the stream flow to be maintained below the reservoir.

The stream flow to meet ecological water requirements within the Lower Harris subarea was determined in 2000 by WEC & Streamtec Consultancy (Table 7). The Tallanalla gauging station is currently used as the compliance point for environmental releases from the Harris Reservoir. It is situated at the lower end of the Lower Harris subarea.

Note that this ecological water requirement and its compliance station are being reviewed as part of the statutory planning process.

Table 7 Stream flow (as Gigalitres per month) required to meet ecological water requirements below the Harris Reservoir

EWR Component	**Jan**	**Feb**	**Mar**	**Apr**	**Ma**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Pools, macro's, energy flows	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.36
Fish									0.32	0.41			0.73
Channel maintenance							0.41						0.41
Riparian veg							0.54						0.54
Salinity mitigation	0.05	0.05	0.05	0.03									0.18
EWP (average)	0.05	0.05	0.05	0.03	0.03	0.03	0.47	0.03	0.33	0.41	0.03	0.03	
*Subarea flows (Lower Harris)	0.01	0	0	0.01	0.04	0.47	0.49	0.55	0.38	0.14	0.08	0.02	2.18
~Total	0.05	0.05	0.05	0.03	0.04	0.47	1.06	0.55	0.58	0.50	0.08	0.03	3.49

** Not a requirement for a reservoir release but a requirement that unregulated flows are maintained from the Lower Harris sub-catchment.*

~ Based on EWR requirement from WEC & Streamtec (2000) plus additional EWP requirement for salinity mitigation releases in Jan, Feb, Mar & April.

2.5 Lower Harris, East Branch, Lower East, Bingham and South Branch subareas

For each subarea that does not contain a major reservoir, up to five allocation limit options were assessed and considered (outlined in stage 3 of the process below).

Each option has varying levels of certainty and different management implications. The main stages and method in developing the allocation limits options are described below.

Stage 1: Mean annual flow

The LUCICAT hydrologic model was used to assess the mean annual flow (MAF) at the end node of each of the five surface water subareas[1]. In most cases each end node represents a Department of Water gauging station. 1975 – 2003 was used as the assessment period, to use the best available data and to reflect the current drying climate.

Two scenarios were modelled:

a Current day land use: including current clearing and plantations. Has a higher mean annual flow than natural pre-clearing state.

b A pre-disturbed state: fully forested conditions. Has a lower mean annual flow than current day situation.

[1] Mean annual flow of the Harris and Collie River Central subareas were also completed, using the LUCICAT model, this indicated what the mean annual flow would be at the end of the subarea if the reservoirs were not there.

Stage 2: Estimate ecological sustainable yield

At the end node (gauging station) of each subarea, the total annual stream flow needed to meet ecological water requirements was assessed. Note that although monthly ecological water requirements provide a more robust estimate of what the ecology needs seasonally only annual (not monthly) information was considered.

The ecological sustainable yields were estimated by subtracting the mean annual ecological water requirement from the mean annual flow.

Estimate of ecologically sustainable yield	=	Mean annual flow (Lucicat)	-	Mean annual ecological water requirement

Note that the ‘ecologically sustainable yields’ were estimated, rather than sustainable yields, because the available studies did not fully consider economic and social impacts. A ‘sustainable yield’ would need to have considered these factors to meet the triple bottom line definition of sustainable.

Stage 3: Potential annual allocation limit options

Option 1: Allocation limit equals 18 per cent of the mean annual flow.

Where there have been no ecological water requirement studies, a notional ecological water requirement in the south west is estimated to be 40 per cent of the mean annual flow. The notional methodologies, amount to a notional ecological sustainable yield of 60 per cent of mean annual flow and a conservative allocation limit of 18 per cent of mean annual flow

Option 2: Allocation limit is 30 per cent of the estimated ecological sustainable yield (based on ecological water requirement studies outlined in Table 5).

In line with the department’s precautionary approach for assessing yield when there is uncertainty surrounding the mean annual flow and ecological requirement components.

Additional work may be needed to confirm the ecological water requirements in some cases. This could be the case for older studies that used superseded methodologies; where it is not clear from the report how the study was done; how results interpreted to come up with flow recommendations; or where the volume recommended is unusually low compared to other studies.

Option 3: Above 30 per cent of the ecological sustainable yield.

Where there is greater certainty of the yield because detailed ecological requirement and/or reservoir modelling has been completed.

Option 4: Equal to the ecological sustainable yield.

A less precautionary option, whilst recognising the economic and social benefits

Option 5: Greater than the ecological sustainable yield.

Where there is a strong social or economic need to abstract water, reducing flows below the levels required to maintain ecological needs at a low level of risk.

Stream flow to meet ecological water requirements

Lower Harris subarea

The stream flow required to meet the ecological water requirements in the Lower Harris subarea are the same as those used in the assessment of the Harris Reservoir and are summarised in Table 7. Due to the construction of the Harris Reservoir in the early 1990s and the reduction in stream flow it caused, stream flow contributions from tributaries discharging to the Harris River channel are critical to maintain the ecological condition downstream of the dam. Welker Environmental Consultancy and Streamtec (2000) recommended that flows from the tributaries in the Lower Harris subarea remain unregulated so risks to the environmental values downstream and through the Collie town-site, were minimised.

Collie River East Branch subarea

The ecological water requirements to be maintained at the end of the subarea (at the Buckingham gauging station) were determined in 2007 by Wetland Research and Management 2007. The department assessed the annual flow necessary to meet the proposed ecological water requirements (Table 8). Note that Wetland Research and Management concluded that a total of 15 GL could be abstracted from this subarea for the salinity mitigation program at a low level of risk to the ecological values, on the proviso that flows from the Bingham River were maintained in their natural state.

Table 8 Stream flow required to meet ecological water requirements at the end node of the East Branch subarea (Buckingham gauging station)

Buckingham				
Flow strata	**Criteria (m^3/sec)**	**Criteria (GL/day)**	**Days**	**EWR (GL)**
Winter high flow	8.8	0.76	8	6.08
Active channel flow	2.7	0.23	24	5.56
Fish passage (large bodied fish)	1.5	0.13	25	3.24
Fish passage (small bodied fish)	0.15	<0.01	70*	0.91
Winter base flow	0.07	<0.01	12	0.07
Summer base flow	0.04	<0.01	35	0.12
Bank inundation	N/A	0	0	0
Annual total EWR (GL/yr)				**16.00**

* Days subtracted from fish passage (large bodied) because (small bodies) met when large bodied occur

Lower East Subarea

The ecological water requirement to be maintained in the middle of the Lower East subarea (at the Coolangatta gauging station) was determined by Wetland Research and Management, 2007. The department determined the stream flow required to meet the proposed ecological water requirements, summarised in Table 9.

Table 9 Stream flow required to maintain ecological water requirements in the middle of the Lower East subarea (Coolangatta gauging station)

Coolangatta				
Flow strata	**Criteria (m^3/sec)**	**Criteria (GL/day)**	**Days**	**EWR (GL)**
Bank inundation	9	0.78	13	10.03
Active channel flow	3	0.26	41	10.63
Fish passage (large bodied fish)	0.2	0.02	74	1.28
Fish passage (small bodied fish)	0.04	<0.01	24*	0.08
Winter base flow	0.01	<0.01	9	<0.01
Summer base flow	0.001	<0.01	71	<0.01
Winter high flow	objective met by bank inundation			
Pools	objective met by summer base flow			
Annual total EWR (GL/yr)				**22.04**
Adjusted annual total EWR*				**25.40**

* Days subtracted from fish passage (large bodied) because (small bodies) met when large bodied occur. The annual environmental flow (of 22.04 GL/yr) equalled 52 per cent of the mean annual flow at Coolangatta. However, since the end of the Lower East subarea was approximately 1.5 Kilometres downstream of the Coolangatta site the environmental flow required at this point was also considered to be 52 per cent of the mean annual flow (i.e. 52 per cent of 48.9 = 25.40).

Therefore annual ecological stream flow is therefore considered to be 25.40 GL/year at the end node.

Bingham River subarea

The ecological water requirement to be maintained at the Bingham subarea node (Palmer gauging station) was assessed in 2007 by Wetland Research and Management. From this work, the department determined the stream flow necessary to meet the proposed environmental water requirement (Table 10).

Table 10 Stream flow required to maintain the ecological water requirement at the end of the Bingham subarea (Palmer gauging station)

Bingham				
Flow strata	**Criteria (m^3/sec)**	**Criteria (GL/day)**	**Days**	**EWR (GL)**
Winter high flow	1.6	0.14	3	0.42
Active channel flow	0.23	0.02	12	0.24
Fish passage (large bodied fish)	0.23	0.02	0	0
Fish passage (small bodied fish)	0.07	<0.01	8*	0.05
Winter base flow	0.02	<0.01	107	0.19
Summer base flow	0	0.0	0	0
Bank inundation	N/A	0	0	0
Annual total EWR (GL/yr)				**0.90**

** Days subtracted from fish passage (large bodied) because (small bodies) met when large bodied occur*

Collie River South Branch subarea

The ecological water requirement to be maintained at the end of the subarea (at the Collie River South gauging station) was determined in 2001 by Welker Environmental Consultancy. The annual stream flow required to meet the ecological water requirement was determined by the department and is summarised below (Table 11).

Table 11 Stream flow required to maintain ecological water requirements at the end of the Collie River South Branch subarea (Collie River South Branch gauging station)

Month	**Channel form (ML)**	**Energy flows (ML)**	**Macro-invertebrates (ML)**	**Fish passage (ML)**	**Riparian vegetation (ML)**	**Seasonal adjustment (ML)**	**EWR (ML)**
Jan		6.1	8.8*				8.8
Feb		5.5	7.9*				7.9
Mar		6.1	8.8*			9.3	9.3
Apr		5.9	8.5*			16.4	16.4
May		6.1	8.8			37.7	37.7
Jun		5.9	8.5			245.1	245.1
Jul		6.1	8.8			502.6	502.6
Aug	558	6.1	8.8	3102.2	699 (2 days)		3102.2
Sep		5.9	8.8	3205.6			3205.6
Oct		6.1	8.8			318.9	318.9
Nov		5.9	8.5			56.9	56.9
Dec		6.1	8.8*				11.4
Annual total EWR (ML/Yr)							**7,522.8**

* *Median flows but do not infer continuous flow for the period*

3 Surface water allocation limit calculations and results

3.1 Collie River Central subarea (Wellington Reservoir)

The abstractable yield of the reservoir was assessed as 85.1 GL/year. Each allocation on the reservoir has a different reliability which indicates the number of years in which a licence holder may abstract their full allocation. Reliabilities vary – with Harvey Water's 68 GL/year at 85 per cent reliability and Water Corporation (application only) at 12 GL/year average plus 5 GL/year at 100 per cent reliability.

For full details on the assessment refer to Appendix A.

The allocation limit option for the entire subarea is 86.6 ML/year. This includes licensed self-supply (1 GL) and the Mungalup reservoir (0.5 GL).

3.2 Harris River subarea (Harris Reservoir)

The results of the Harris Reservoir modelling are provided in Table 12. Potential allocation limits range from 9 GL to 25 ML. Potential limits were considered along with a range of potential storage volumes from 70 GL at full capacity to 30 GL.

Based on inflow statistics for the 1975 to 2003 period the most likely amount of water in the reservoir (starting volume) at 93 per cent reliability would be 35 GL. At this starting volume, 12 GL to 13 GL could be abstracted at optimum (90 per cent) reliability.

Table 12 Harris Reservoir estimated ecologically sustainable yield

Starting Volume	70GL	65GL	60GL	50GL	45GL	40GL	**35GL**	30GL
Prob of starting volume in Jan	0%	15%	31%	40%	51%	56%	**93%**	100%
Annual Draw (GL)	Reliability %	Reliability %	Reliability %	Reliability %	Reliability %	Reliability %	**Reliability %**	Reliability %
9	100	100	100	100	100	100	**100**	100
10	100	100	100	100	100	100	**100**	97
11	100	100	100	100	100	93	**93**	90
12	100	100	100	100	93	93	**90**	90
13	100	100	100	93	93	90	**90**	86
14	100	100	97	90	90	90	**86**	86
15	93	90	90	86	86	86	**83**	79
16	90	90	86	86	86	83	**83**	79
17	86	83	83	83	79	79	**76**	76
19	72	72	72	69	69	66	**66**	66
21	59	59	55	55	52	52	**52**	48
23	48	48	48	45	45	45	**41**	41
25	34	34	31	31	31	28	**28**	28

Assumptions:

1. Annual draw is distributed uniformly throughout the year.
2. Harris Reservoir operated as a stand alone storage.
3. Ecological water requirement defined by WEC & Streamtec (2000) is satisfied before the annual draw is taken (Table 7).
4. Ecological water requirement is defined as a monthly volume. This model assumes a uniform distribution throughout the month.

3.3 Lower Harris, East Branch, Lower East, Bingham and South Branch subareas

Subarea flows under current day land use and a fully-forested catchment

Catchment clearing, within some subareas, has resulted in a greater mean annual flow than what would be experienced if the catchment was fully forested (Table 13).

Table 13 Summary of the cumulative mean annual flow, pre clearing and under current day land use

Subarea	Mean annual flow – pre clearing (GL/yr)	Mean annual flow – current land use (GL/yr)
*Collie River Central (inc Wellington Reservoir)	113.68	148.35
Harris (inc Harris Reservoir)	20.08	19.96
Lower Harris	6.30	7.53
East Branch	15.99	29.11
*Lower East	29.46	48.90
Bingham	9.47	11.66
South Branch	16.13	24.24

** Note that the mean annual flows Collie River Central and Lower East are cumulative, including flows from upstream, not just the subarea contributions.*

Ecological water requirements have been assessed based on current day conditions of increased stream flows. This means that the current ecological water requirements are for a modified system and not a fully forested catchment.

Ecologically sustainable yield of a fully forested catchment

The only option applicable to assessing the ecological sustainable yield under a fully forested catchment is option 1 - by calculating 18 per cent of mean annual flow (Table 14).

Table 14 Summary of allocation limit options under a fully forested catchment - units in Gigalitres/year

Subarea	Option 1 = 18% of mean annual flow (GL/yr)
Collie River Central (inc Wellington reservoir)	20.46
Harris (inc Harris Reservoir)	3.61
Lower Harris	1.13
East Branch	2.88
Lower East	5.30
Bingham	1.70
South Branch	2.90

Ecological sustainable yields - current day land use

The ecological sustainable yields were determined for the self supply subareas, by subtracting the mean annual ecological water requirement from the current day mean annual flows. The results are presented below (Table 15).

Table 15 Ecologically sustainable yields - units in Gigalitres per year

Subarea	Mean annual flow – current land use (GL/yr)	Ecological water requirement – current land use (GL/yr)	Ecological sustainable yield – current land use (GL/yr)
Lower Harris	7.53	3.47	4.06
East Branch	29.11	16.00	13.11
Lower East	48.90	25.43	23.47
Bingham	11.66	0.90	10.77
South Branch	24.24	7.52	16.72

Allocation limit options

The allocation limit options drawn from the ecological sustainable yields for each of the self supply subareas, under current day land-use are presented below (Table 16).

Table 16 Summary of allocation limit options - units as Gigalitres per year

Subarea	Option 1	Option 2	Option 3	Option 4	Option 5
	= 18% of MAF	= 30% of the ESY	= % of the ESY	= ESY	= > the ESY
Lower Harris	1.35	1.22	-	4.06	-
East Branch	5.24	3.93	4.50	13.11	14.00
Lower East	8.80	7.04	-	23.47	-
Bingham	3.50	3.23	-	10.77	-
South Branch	4.36	5.02	-	16.72	-

4 Surface water allocation limit option analysis

Each allocation limit option was assessed in terms of its capacity to meet the management objective of the sub-area, including the benefits or risks associated with the option. This included capacity to meet current and future demand, impacts on flows, potential impact on the environment and robustness for supporting water trading. The option analysis is summarised in Table 17.

Table 17 Options analysis and recommended allocation limits

Subarea	Use / demands	Allocation limit option	Result (GL/yr)	Reliability (%)	Risk/Benefits
Collie River (inc Wellington Reservoir)	• 68 GL licensed use for Irrigation + 0.50 GL for W Corp. (Mungalup Reservoir) + 1 GL private self supply • Application for 17.1 GL for Water Corporation • Further self supply potential • Stock and domestic • Water quality = marginal	Option 1 = 18% of MAF			n/a
		Option 2 = 30% ESY			n/a
		Option 3 = % ESY	85.10	68 (85%) 12 (av%) 5 (100%)	– Some ecological risk due to low level of confidence in annual EWR & ESY + Meets current licensed demand (Harvey Water) + Meets current application demand (Water Corporation and therefore Verve Energy)
		Option 4 = 100% ESY	120.46		– Very high ecological risk due to low level of confidence in annual EWR & ESY + Reservoir infrastructure constraints + Meets current demand and allows for growth. + Very low reliability and high supply risk due to reduced inflows
		Option 5 = > ESY	n/a		n/a
		Recommended	**86.60**	**As above**	**The limit covers 85.1 GL for Wellington Reservoir, 1 GL for self supply, and 0.5 GL for Mungalup.**
Harris (inc Harris Reservoir)	• 15 GL licensed use for Water Corporation • 2 GL application for Water Corporation • Water quality = fresh	Option 1 = 18% of MAF			n/a
		Option 2 = 30% of ESY			n/a
		Option 3 = % ESY	13.00	90	– Does not meet current licensed demand – Need to recoup licence entitlements (negative signal on Collie water availability for IWSS)
		Option 4 = 100% ESY	15.00	83	– Unable to accept current 2 GL licence application + Meets current licensed demand
		Option 5 = > ESY	17.00	76	– Unsuitably low reliability + Meets current demand
		Recommended	**15.00**	**83**	**Recognising that further work to optimise Collie reservoirs and defining EWR regimes, may change the yield.**

Lower Harris	• 0.50 GL licensed use for grapes • Good potential for increased self supply (divided land currently for sale) • Stock and domestic • Water quality = marginal	Option 1 = 18% of MAF	1.35	98	– Conservative + Meets current demand and allows for growth
		Option 2 = 30% ESY	1.22	98	– Conservative + Meets current demand and allows for growth
		Option 3 = % ESY			n/a
		Option 4 = 100% ESY	4.06	86	– High ecological risk due to uncertainty in EWR & ESY + Meets current demand and allows for growth
		Option 5 = > ESY			n/a
		Recommended	**1.22**	**98**	**Recognising further EWR work is required to review current Harris regime. Allows for some growth.**
East Branch	• 3 GL licensed use for salinity diversion • Requiring 4.50 GL for stage 2 of salinity diversion • Requiring up to 14.00 GL for salinity diversion with desalination • Water quality limits stock and domestic and self supply demand • Water quality = mod. saline	Option 1 = 18% of MAF	5.24	95	– Conservative + Meets current demand and allows for growth + Supports full needs of salinity recovery stage 2 + Benefits to downstream water users and quality of Wellington Reservoir
		Option 2 = 30% ESY	3.93	98	– Conservative – Will not support full needs of salinity recovery stage 2
		Option 3 = % ESY	4.50	98	+ Allows diversion stage 2 for salinity recovery + Benefits to downstream water users and quality of Wellington Reservoir
		Option 4 = 100% ESY	13.11	81	– Ecology may be at risk from reduced water flows but benefit from improved water quality + Allows part diversion for salinity recovery + May allow for viability of desalinisation plant + benefits to downstream water users and quality of Wellington Reservoir
		Option 5 = > ESY	14.00	81	+ Ecology may be at risk from reduced water flows but benefit from improved water quality + Allows for diversion with desalinisation plant for salinity recovery + Benefits to downstream water users and quality of Wellington Reservoir + Reduced saline flows downstream if diversion takes place

		Recommended	**14.00**	**81**	**To support salinity diversion programme "reduction in peak flows benefits system due to increased flows, with high salinity and causing bank erosion and sedimentation downstream" WRM 2007.**
Lower East	• No licensed use • Poor water quality limits demand • Water quality = brackish	Option 1 = 18% of MAF	8.80	100	+ Meets current demand and allows for growth
		Option 2 = 30% ESY	7.04	100	– Conservative to reduce risk of uncertainty in EWR + Meets current demand and allows for growth
		Option 3 = % ESY			n/a
		Option 4 = 100% ESY	23.47	77	– High ecological risk due to uncertainty in EWR & ESY + Meets current demand and allows for growth
		Option 5 = > ESY			n/a
		Recommended	**1.00**	**100**	**Very low limit to reduce impact of diversion. 1 GL available to allow for small development in the area. No risk of need to claw back in the future once diversion begins.**
Bingham	• No licensed use • Stock and domestic • Potential self supply • Water quality = fresh	Option 1 = 18% of MAF	3.50	78	– Conservative + Meets current demand and allows for growth
		Option 2 = 30% ESY	3.23	78	– Conservative – Low level of confidence in annual EWR & ESY + Meets current demand and allows for growth
		Option 3 = % ESY			n/a
		Option 4 = 100% ESY	10.77	43	– Not precautionary – High ecological risk due to low level of confidence in annual EWR & ESY + Meets current demand and allows for growth
		Option 5 = > ESY			n/a
		Recommended	**0**	**-**	**Honour current use but have no additional take. Due to ecological significance of fresh flows into system under diversion regime.** **"Freshwater inputs from the Bingham assist in ameliorating riverine salinity, with the Bingham comprising a greater proportion of flows after diversions than before." WRM 2007.**

South Branch	• 3.10 GL licensed use for filling Lake Kepwari • Stock and domestic • Small amount of self supply & some pasture application • Highly modified system • Water quality = marginal	Option 1 = 18% of MAF	4.36	95	– Conservative + Meets current licensed demand and allows for growth
		Option 2 = 30% ESY	5.02	91	– Conservative – Low level of confidence in annual EWR & ESY + Meets current licensed demand and allows for growth
		Option 3 = % ESY			n/a
		Option 4 = 100% ESY	16.72	60	– High ecological risk due to low level of confidence in annual EWR & ESY + Meets current licensed demand and allows for growth
		Option 5 = > ESY			n/a
		Recommended	**5.02**	**91**	**In line with dept protocol. Unlikely to affect system given higher flows since pre-clearing. EWRs are conservative.**

5 Surface water final allocation limits

The final allocation limits are presented below (Table 18).

Table 18 Surface water subarea final allocation limits

Subarea	Allocation limit (GL/yr)	Justification
Collie River Central (including Wellington Reservoir)	86.60	Honours current entitlements by allowing 85.1GL for Wellington Reservoir, 1 GL for self supply, and 0.5 GL for Mungalup Reservoir.
Harris (including Harris reservoir)	15.00	Honours current entitlements although reliability is not optimal, at only 83%. Recognition that further work is required to optimise Collie reservoirs and to define EWR regimes which may influence yield in future.
Lower Harris	1.20	Honours current entitlements and allows for a small amount of growth whilst maintaining fresh water flows for river health.
Collie River East Branch	14.00	To support salinity diversion programme “reduction in peak flows benefits system due to increased flows, with high salinity and causing bank erosion and sedimentation downstream” WRM 2007.
Lower East Branch	1.00	Very low limit to allow for small development in the area. No risk of need to claw back in the future once diversion begins.
Bingham River	0	No commercial abstraction due to ecological significance of fresh flows into system under diversion regime. “Freshwater inputs from the Bingham assist in ameliorating riverine salinity, with the Bingham comprising a greater proportion of flows after diversions than before.” WRM 2007.
Collie River South Branch	5.00	Honours current entitlements while allowing for growth. A relatively conservative limit to reduce risk to ecology in an already highly disturbed system. Unlikely to adversely affect system given higher flows since pre-clearing.

6 Limitations in the surface water allocation limit methods

Cumulative and non cumulative mean annual flows

The allocation limits were based upon cumulative mean annual flows at each subarea node. This means that the effect of reduced flows from potential upstream take was not considered in the assessment. Any diversion from the Collie River East Branch, Lower Harris or South Branch subareas will impact the inflows and water availability in the Lower East and Collie River Central subareas. Given current low demand, due to poor quality water resources, the risk that flows will be impacted is low given that it’s unlikely that full allocation limits will be reached in these subareas.

Note that the effect of the East Branch diversion on flows and reliabilities of the Wellington Reservoir were assessed and considered in the Collie River Central allocation limit.

As demand increases within the surface water management area, each subarea may require refined allocation limits based on non-cumulative flows. This means the allocation limit may be based on subarea flow contributions only and not based on cumulative flows from upstream of the subarea, as done in this assessment.

Ecological sustainable yields

The ecological sustainable yields have been based on mean annual ecological water requirements - this does not take into consideration seasonal and annual variations in flows. To reduce the risk associated with this methodology, conservative allocation limits have been set for all self supply subareas (except for the East Branch). Period of take rules apply to all licences to manage seasonal flow variation.

Harris reservoir releases

The LUCICAT assessment of flows and allocation limits has not considered any volumes released for salinity mitigation from the Harris Reservoir. In years where the release takes place, the inflow to the Wellington Reservoir will increase. This poses no risk to the allocation limits as set in the plan.

The Harris subarea allocation limit options were based on meeting the ecological water requirements specified by Welker Environmental Consultancy and Streamtec, 2000. At present these are not consistent with the volumes specified in Water Corporation’s current operation strategy or the volumes presently released.

7 Methodology used to assess groundwater allocation limits

Groundwater allocation limits were determined by considering the hydrogeology of the Collie Groundwater Area, recharge and discharge components of the Collie Coal Basin and current and future water demands. A number of potential allocation scenarios were modelled and evaluated.

7.1 Groundwater characteristics

The Collie Coal Basin contains two relatively discreet subareas, the Premier and the Cardiff (refer to Figure 3). Over the past century the groundwater of the Collie Coal Basin has been heavily dewatered for coal mining and abstracted for power station water supply. To manage current and future abstraction and recover groundwater where mining activity has ceased, an allocation limit has been determined for each of the aquifers within each subarea.

The groundwater resources of both the Cardiff and Premier subareas are each split into four separate resources – the Nakina, Muja, Lower Collie Group and the Stockton.

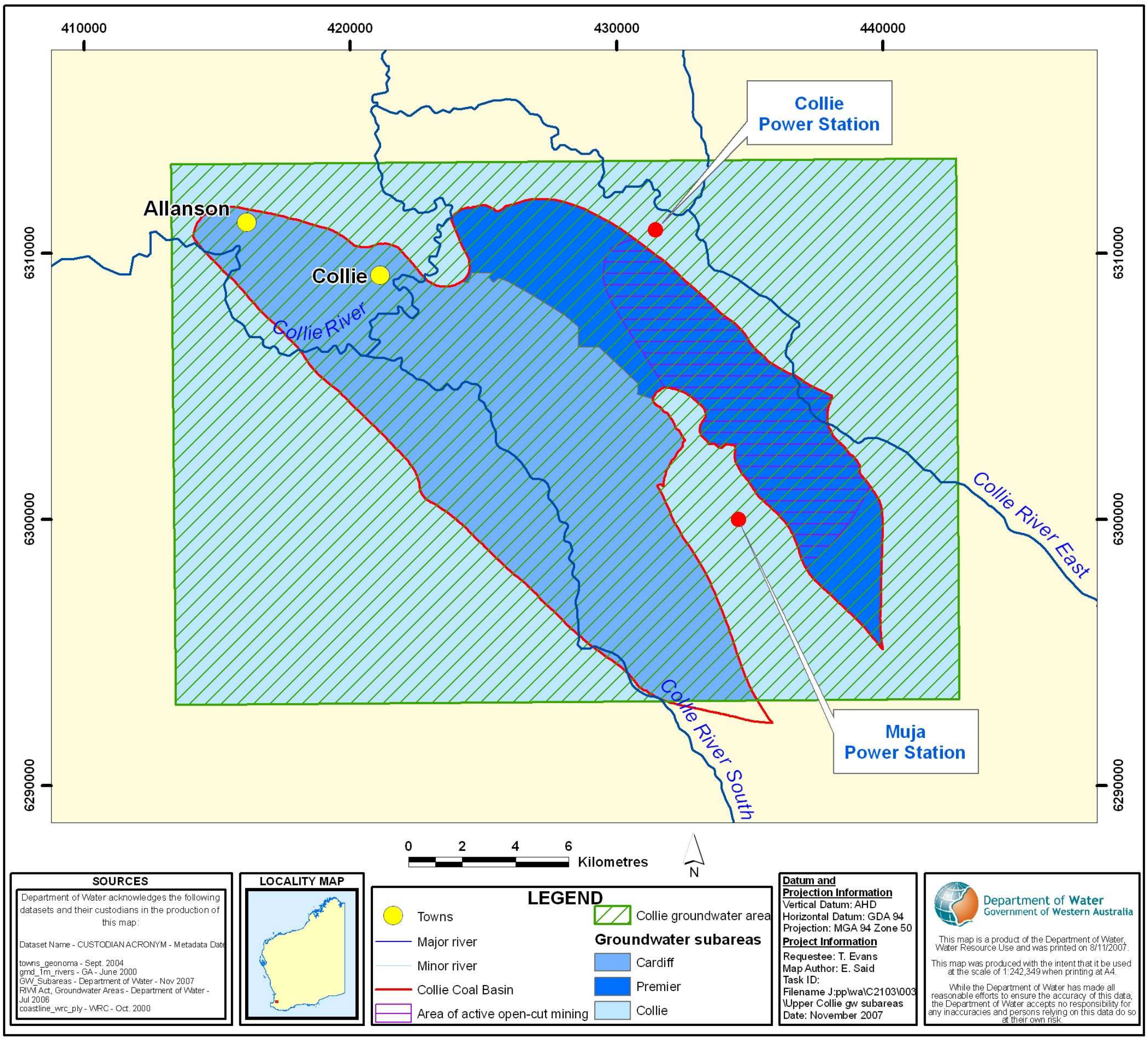

Figure 3 Groundwater subareas – Cardiff and Premier

The hydro-geology of the Collie Coal Basin is complex with multiple aquifers separated by shale and coal seams with numerous faults throughout. The hydro-geological characteristics, recharge components and the water balance are documented in detail in the *Hydrogeology and groundwater resources of the Collie Basin HG 5.* A general description of each aquifers is provided in the *Upper Collie water management plan* (Department of Water, 2008).

Groundwater recharge and discharge

The groundwater balance, including recharge, discharge and storage components, was assessed by the department in 1999. This is after mining activity and disturbance. The allocation limit options were developed using the department's 1999 groundwater model. At the time of the assessment the volume of groundwater stored within the basin was estimated to be 7,100 GL, with an annual recharge of around 20 GL/yr. The model and its components are documented in *Groundwater Model of the Collie Basin, Western Australia, Report HG 15*.

The groundwater balance schematic is provided in Appendix B.

The amount of rainfall recharge to the Collie Coal Basin has been estimated at 18.7 GL/yr. This is approximately 10 per cent of the average rainfall from the 1979 to 1999 (840 mm). In addition to recharge from rainfall, the Collie Coal Basin also receives a small amount (0.7 GL/yr) of recharge from the Collie River east and south branches, giving a total recharge estimate for the Collie Coal Basin of 19.4 GL/yr.

The recharge and discharge component for the aquifer resources of the Cardiff and Premier subareas are summarised below (Table 19).

Table 19 Cardiff and Premier subareas recharge and discharge components

Subarea	Aquifer resource	Recharge (GL/yr)	Discharge (GL/yr)	Total (GL/yr)
Cardiff	Nakina	0	0	0
	Muja	5.30	0.10	5.20
	Lower Collie Group	6.60	3.60	3.00
	Stockton Group	0.60	0	0.60
	Total	**12.50**	**3.70**	**8.80**
Premier	Nakina	0	0	0
	Muja	0.20	0	0.20
	Lower Collie Group	4.50	0.03	4.47
	Stockton Group	0.30	0.10	0.20
	Total	**5.00**	**0.13**	**4.87**

Climate change

To accommodate for the drying climate, a 10 per cent reduction to recharge was considered and factored in to all groundwater modelling scenarios.

This reduction is a low estimate of drying climate impacts given that it equates to only a 5 per cent reduction in rainfall.

Taking into account a 10 percent reduction in recharge due to reduced rainfall, the total recharge for the Cardiff and Premier subareas is 7.92 GL/year and 4.38 GL/year, respectively.

A summary of the final recharge for each aquifer after reductions in rainfall is provided below (Table 20).

Table 20 Total recharge reduction after decreased rainfall

Subarea	Resource	Total recharge (GL/yr)	Total recharge - 10 % (GL/yr)
Cardiff	Nakina	0	0
	Muja	5.20	4.68
	Lower Collie Group	3.00	2.70
	Stockton Group	0.60	0.54
	Total	**8.80**	**7.92**
Premier	Nakina	0	0
	Muja	0.20	0.18
	Lower Collie Group	4.47	4.02
	Stockton Group	0.20	0.18
	Total	**4.87**	**4.38**

7.2 Groundwater-dependent ecosystems

The groundwater-dependent ecosystems considered in the assessment are the pools of the Collie River south and east branches. The pools are those identified by the Collie Water Advisory Group (CWAG), in 1996 and 1999, and are considered to hold significant social value to the local communities of Cardiff and Buckingham. The pools are:

1. Long
2. Walker
3. B. Cox
4. Cardiff
5. Grahams
6. Piavaninis
7. Chinamans
8. Buckingham Bridge/town (East Branch)
9. Duderling (East Branch).

There are no other currently known or documented groundwater-dependent ecosystems.

7.3 Groundwater use

Considering how much groundwater is used in each subarea, formed a significant part of assessing the potential allocation limits.

In the Cardiff subarea, various use scenarios were modelled to assess the effect of water use on groundwater levels. In the Premier subarea, dewatering abstractions were considered separately to actual consumptive groundwater use so that allocation limits were designed to ensure the resource would not be over-allocated, once dewatering operations cease.

Cardiff subarea

There are currently thirteen licences to abstract water from the Cardiff subarea. The majority of abstraction (99%) occurs for power station water supply with a small amount for private irrigation purposes and unlicensed domestic use.

Power station use

Verve Energy currently has four licensed borefields within the Cardiff subarea – the Cardiff, WD6, W2 and ACIRL. The security of supply to Verve Energy's borefields was considered in the assessment through recognition of actual use over the past six years, current allocations and proposed future allocations.

Six year average use

Verve Energy's six year average use (2000 - 2006) is provided in Table 21. Actual use has been sourced from URS (2004) *Triennial Collie Basin Groundwater resource Review*; URS (2005) *Annual Collie Basin Groundwater resource review*; and Verve Energy monthly report (to June 2005 and June 2006).

Table 21 Verve Energy's historic use figures (units in gigalitres per year)

Borefield	**2000/01**	**2001/02**	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**6 yr total**	**average**
Cardiff	2.82	2.74	3.18	2.73	2.60	0.48	14.56	2.43
WD6	1.43	1.13	1.11	1.23	0.88	0.76	6.54	1.09
W2	0.49	0.83	1.11	1.15	0.26	0	3.84	0.64
ACIRL	0.19	<0.01	0.07	0.06	<0.01	0	0.33	0.06
Stockton	0	0	0	0	0	0	0	0
Total	4.93	4.70	5.47	5.17	3.75	1.24	25.26	4.21

Future use

The department is currently renewing Verve Energy's groundwater licences. A total reduction in groundwater entitlements has been negotiated. Verve is currently refurbishing the Stockton borefield (within the Cardiff sub-area) for potential future use. The proposed spread of draw across each borefield is summarised in Table 22.

The proposed allocations are based on *Verve Energy's Power Station Water Use Strategy* (2006), whilst taking into account the failure of the Shotts borefield (in the Premier subarea) in March 2007.

Table 22 Verve Energy's proposed future groundwater licence allocations

Borefield	Current licence entitlement (GL/yr)	Proposed licence entitlement (GL/yr)	Aquifer resource
WD6	3.65	2.00	Muja
W2	5.10	1.00	Muja
ACIRL	0.73	0.00	Muja
Cardiff	3.65	2.60	Lower Collie
Stockton	0.00	4.44	Lower Collie
Total	**13.13**	**10.04**	

Note: Overall a total decrease in total licence allocation is proposed. However the proposed increase in licence entitlement from the Lower Collie Group would result in over-allocation of the Lower Collie Group due to the location of the refurbished Stockton borefield.

Private users

In addition to power station licences there are 9 private licences to abstract groundwater totalling 0.05 GL/yr.

The department is not aware of any potential future applications for private use within the Cardiff subarea at this stage.

Table 23 Summary of licensed demands on the Cardiff subarea (as gigalitres per year)

Resource	Six year average use (GL/yr)	Current licences (GL/yr)	Proposed future use (GL/yr)
Nakina	0	0	0
Muja	1.79	9.49	3.01
Lower Collie Group	2.51	3.73	7.08
Stockton Group	0	0	0
Total	4.30	13.22	10.09

Stock and domestic use

The department estimates that 0.15 GL/year is abstracted from the Cardiff subarea for general stock and domestic purposes. This has been calculated based on the number of properties depending on groundwater (which is 100 properties in Cardiff) multiplied by the standard stock and domestic entitlement of 1500 kL/year.

Within the Cardiff subarea it is difficult to ascertain which aquifer the stock and domestic bores draw water from. Based on the depths to each aquifer, it is likely that shallow domestic bores draw from both the Muja and Lower Collie Group aquifers.

Premier subarea

There are currently four licences to abstract water from the Premier subarea. The majority of abstraction occurs for mine dewatering and some for power station water supply. A small amount of groundwater is also abstracted for unlicensed domestic use.

Mine dewatering

Griffin Coal and Wesfarmers Premier Coal are licensed to dewater mine pits to allow for safe mining conditions. Currently the total allocation for mine dewatering each year is 49 GL. This total may increase in the future as new coal deposits are extracted.

From 2000 – 2006, the average abstracted for mine dewatering was 9.16 GL/yr.

Power station use

Verve Energy is licensed to abstract from the Shotts production bores (4.4 GL/yr) for power generation purposes. This licence is currently being renewed and it is likely that it will be reduced to 2 GL/yr, due to a reduction in yield.

The six year average use for the period 2000 - 2006 is 1.49 GL from the Shotts borefield.

Private users

There are no other licensed private users within the Premier subarea.

The department is not aware of any potential future applications for private use within the Premier subarea, at this stage.

Table 24 Summary of consumptive demands on the Premier subarea (as gigalitres per year)

Resource	Six year average use (GL/yr)	Current licences (GL/yr)	Proposed future use (GL/yr)
Nakina	0	0	0
Muja	0	0	0
Lower Collie Group	10.65	53.40	^51 plus
Stockton Group	0	0	0
Total	**10.65**	**53.40**	**51.00**

Stock and domestic use

The department estimates that 0.03 GL/yr is abstracted from the Premier subarea for general stock and domestic purposes. This is an estimate only and was calculated based on the number of properties depending on groundwater (20 in Premier), multiplied by the standard stock and domestic entitlement of 1500 kL/year.

Based on aquifer location and the likely bore depth range, stock and domestic bores are likely to abstract form the Lower Collie Group aquifer within the Premier subarea.

7.4 Groundwater modelling – Cardiff subarea

Collie Coal Basin model

For the Cardiff subarea the Collie Coal Basin groundwater model was used as a predictive tool to determine how groundwater levels and storage are likely to respond to pumping over the long-term (50 years).

Cardiff subarea scenario modelling

Six allocation scenarios were modelled for the Cardiff subarea, refer to Table 25.

Table 25 Cardiff subarea potential allocation scenarios

Number	Scenario	Total potential annual abstraction (GL/year)
1	No abstraction	0
2	Six year average use	4.3
3	Zero recovery or depletion of groundwater	5.5
4	Recharge	8.8
5	Proposed future allocations (Verve Energy's draft licence renewals	10.09
6	Current allocation (licensed use)	13.22

Each scenario was modelled under a 10 per cent reduction in recharge to accommodate for reduced rainfall in recent times.

Abstraction from the neighbouring subarea (Premier) and its influence on groundwater storage (through leakage) in the Cardiff was also considered.

The scenarios were evaluated over a 10 to 50 year period against three key factors, these include:

1. the degree and rate of groundwater recovery or groundwater depletion
2. potential impacts on groundwater-dependent river pools
3. potential impacts and security of supply for:
    a. private users
    b. current power stations.

8 Groundwater allocation limit calculations and results

8.1 Scenario results

Impacts from Premier abstraction

The Cardiff subarea is separated from its neighbouring subarea, the Premier subarea, by a basement (granite) high referred to as the Stockton Ridge. The ridge extends across the majority of the divide; however, there is a small area of water exchange from the Cardiff subarea into the Premier subarea through the Allanson (Lower Collie Group) aquifer.

To determine the influence that heavy abstraction in the Premier subarea may have on the recovery of the Cardiff subarea (through leakage into the Premier), two sub-sets of model runs were completed and the results compared.

1. Recovery of storage without any influence from Premier (abstraction from the Premier was not included).
2. Recovery of storage with influence from Premier (six year average abstraction from the Premier was included and modelled).

Comparison of the two scenarios indicated that abstraction from the Premier would impact on the Cardiff subarea, reducing the groundwater storage recovery rate. The exact extent of impact however was difficult to ascertain.

The influence Premier abstraction has on groundwater storage of the Cardiff therefore was considered in all other scenarios.

The degree and rate of groundwater recovery or depletion

The degree and rate of groundwater recovery or depletion under each scenario is presented in Figure 4. It shows that:

- in the no abstraction and average use scenarios, groundwater storage increases
- In the total recharge, current and future allocation scenarios, groundwater storage decreases.

Impacts on groundwater-dependent ecosystems

The water levels of the seven groundwater-dependent pools within the Cardiff subarea were assessed under each scenario. The results for two scenarios, current use and current allocations, are presented in figures 4 and 5 respectively. The graphs show that:

- under the average use scenario, pool water levels increase
- under the current allocation scenarios (and therefore under the recharge and future allocation scenarios), pool water levels decline.

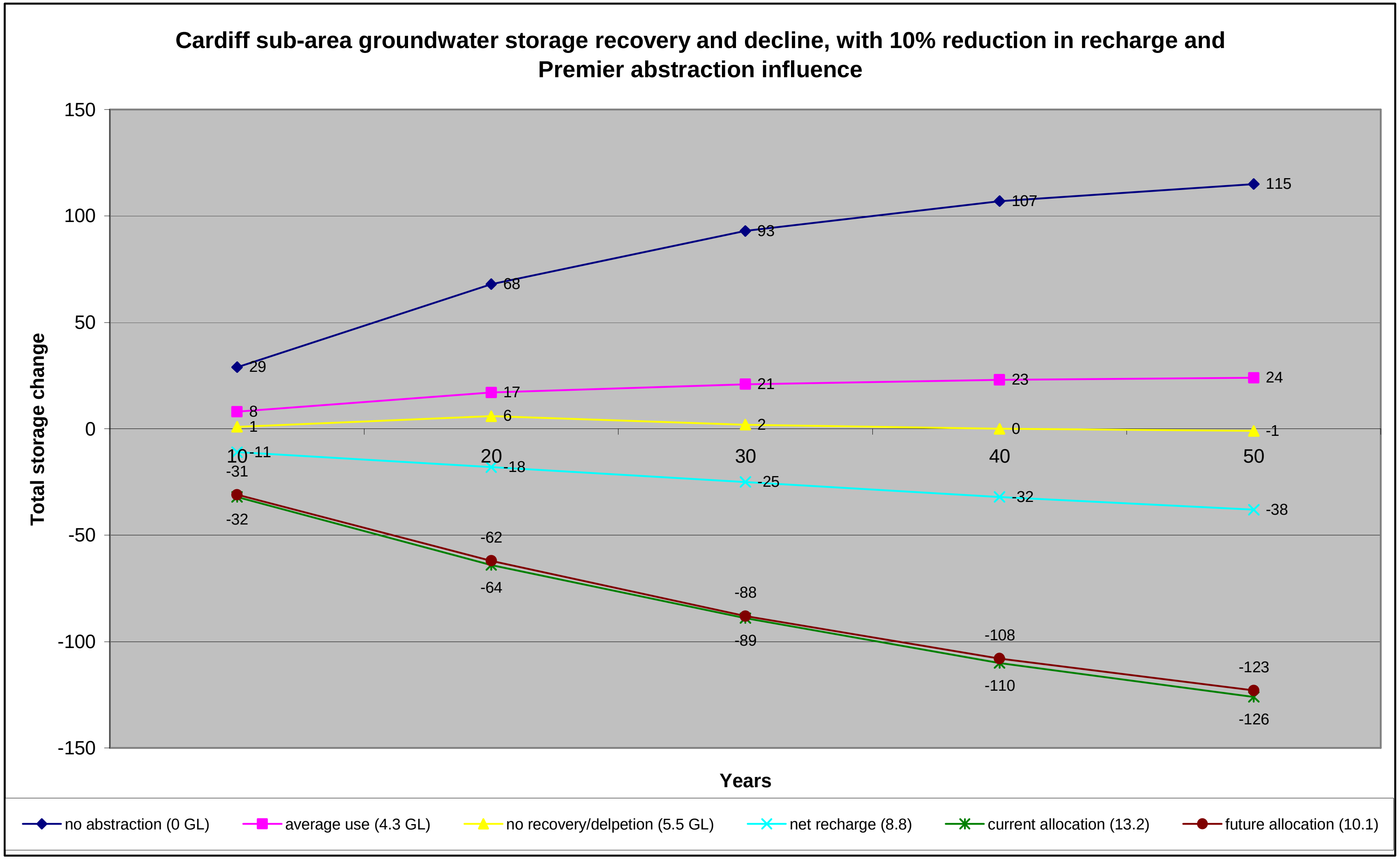

Figure 4 Cardiff subarea storage recovery/depletion, with 10 per cent reduction in recharge and Premier abstraction influence

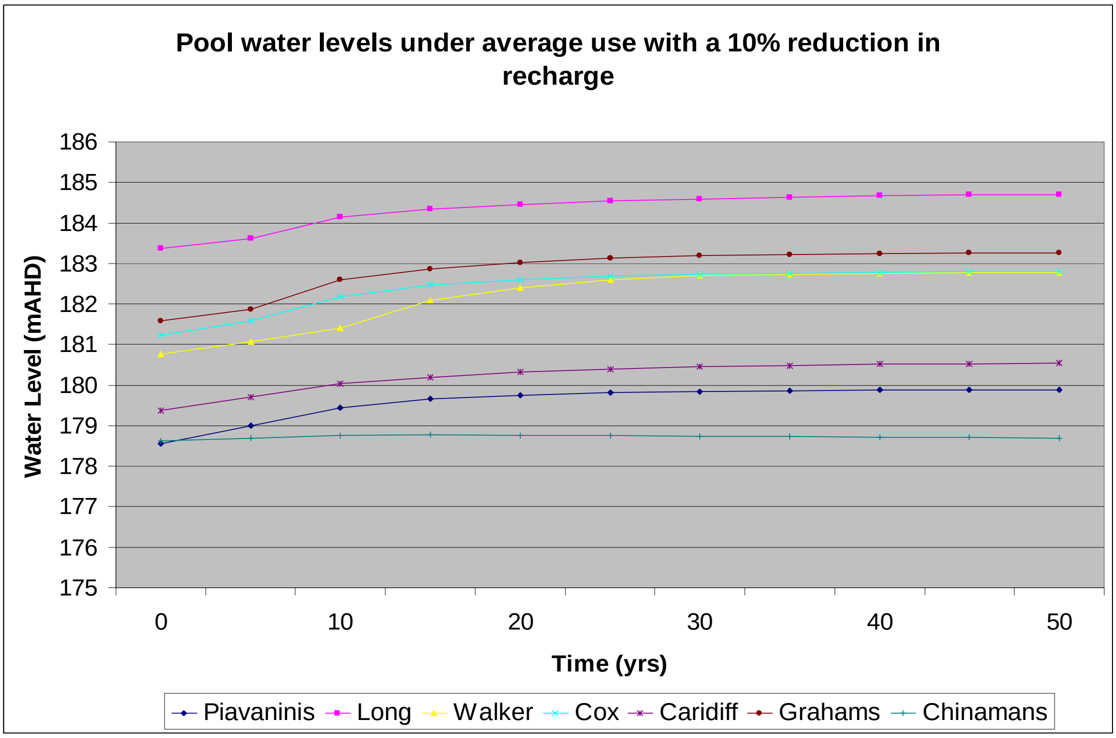

Figure 5 Pool water level recovery under the average use scenario

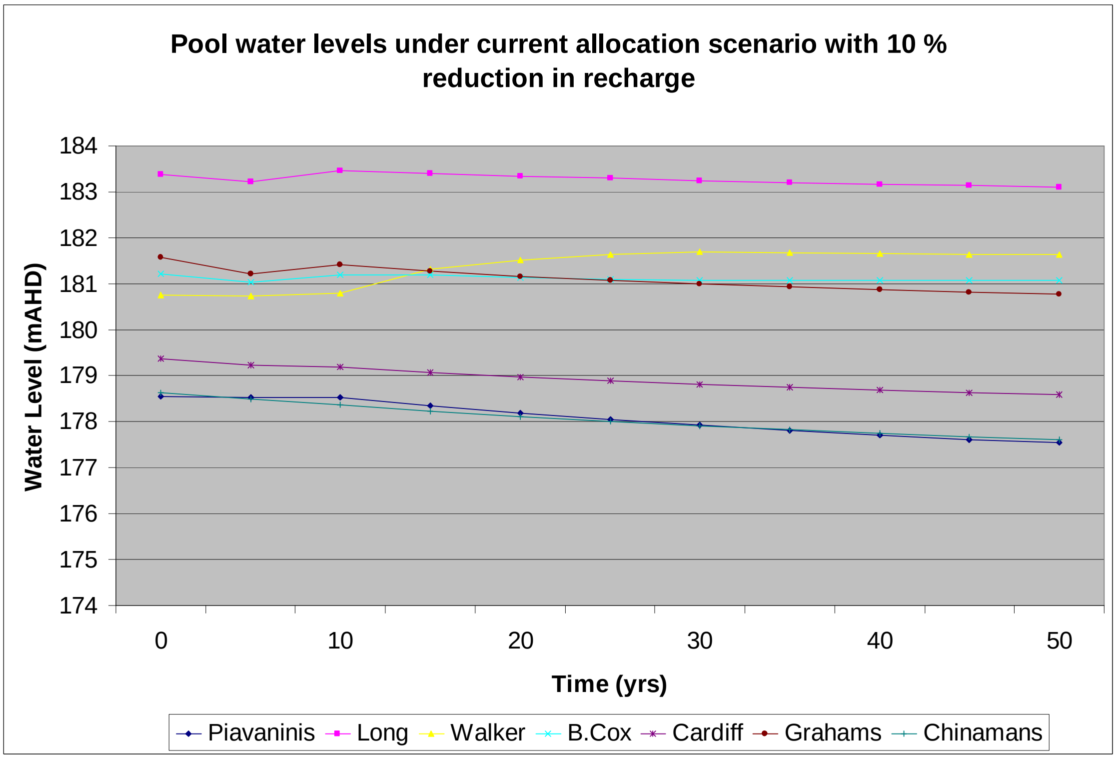

Figure 6 Pool water level declines under the current allocation scenario

Impacts and security of supply for groundwater users

Private users

Specific monitoring bores were identified in Collie and Cardiff, to act as key reference sites to assist in assessing potential impacts on private users. The sites are summarised in Table 26.

Table 26 Key monitoring bores in close proximity to current private users

Bore	Location	Easting	Northing	Drilled depth (m)	Aquifers monitored
CRM 63/98	Cardiff	425950.88	6300861.17	15	Collie Group*
CRM 61/98	Cardiff	427316.89	6301241.17	21	Collie Group*
CRM 23/98	Collie	419562.87	6308171.16	39	Collie Group*
CRM 32/98	Collie	421848.86	6306681.14	12	Collie Group*
CRM 33/98	Collie	423163.87	6307061.16	13	Collie Group*

** The Muja and Lower Collie Group aquifers are collectively referred to as the Collie Group.*

Through the Collie Coal Basin model the sites were assessed in relation to changes in water levels and/or pressure heads (indicating the potential impact on groundwater users) under each of the six allocation scenarios.

The results are presented as hydrographs in Figure 7 and Figure 8. The graphs show that:

- In the no abstraction and average use scenarios, private groundwater users have security of supply
- In the net recharge, current allocation and future allocation scenarios, private users are likely to be impacted from regional groundwater draw-downs.

Power stations

To assess potential impacts on the power industry borefields a similar process was used. As there were no suitable monitoring bores, synthetic bores were created in the location of the current power stations borefields. Synthetic bore locations are given in Table 27.

Table 27 Synthetic bores to be assessed for potential impacts on the power industry

Borefield	Central bore/monitoring bore	Easting	Northing	Depth (m)	Aquifers drawn
Cardiff	Synthetic bore 1	431891.82	6297355.27	390	Lower Collie group
WD2	Synthetic bore 2	427177.88	6299051.32	125	Muja
WD6	Synthetic bore 3	427735.89	6296994.14	125	Muja

The results are presented in Figure 7 and Figure 8. The graphs show that:

- Verve Energy has security of supply for its power station borefields in the no abstraction and average use scenarios
- Verve Energy is likely to be impacted from regional groundwater draw-downs in the net recharge, current allocation and future allocation scenarios.

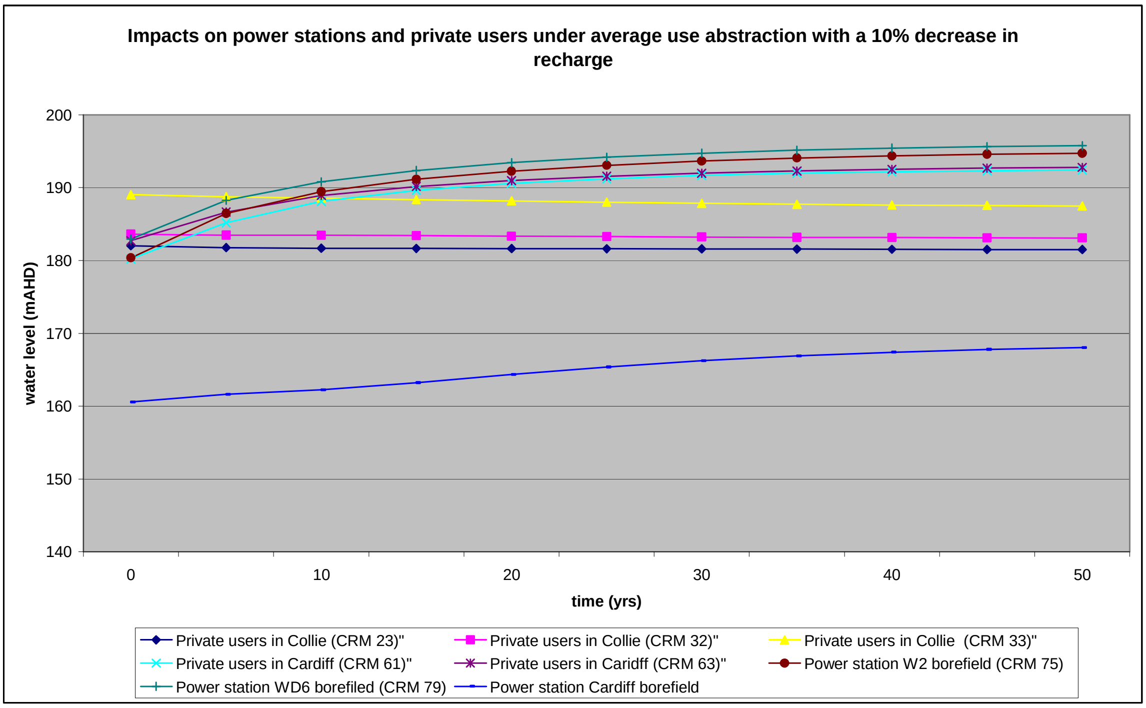

Figure 7 Impacts on groundwater users, under the average use scenario

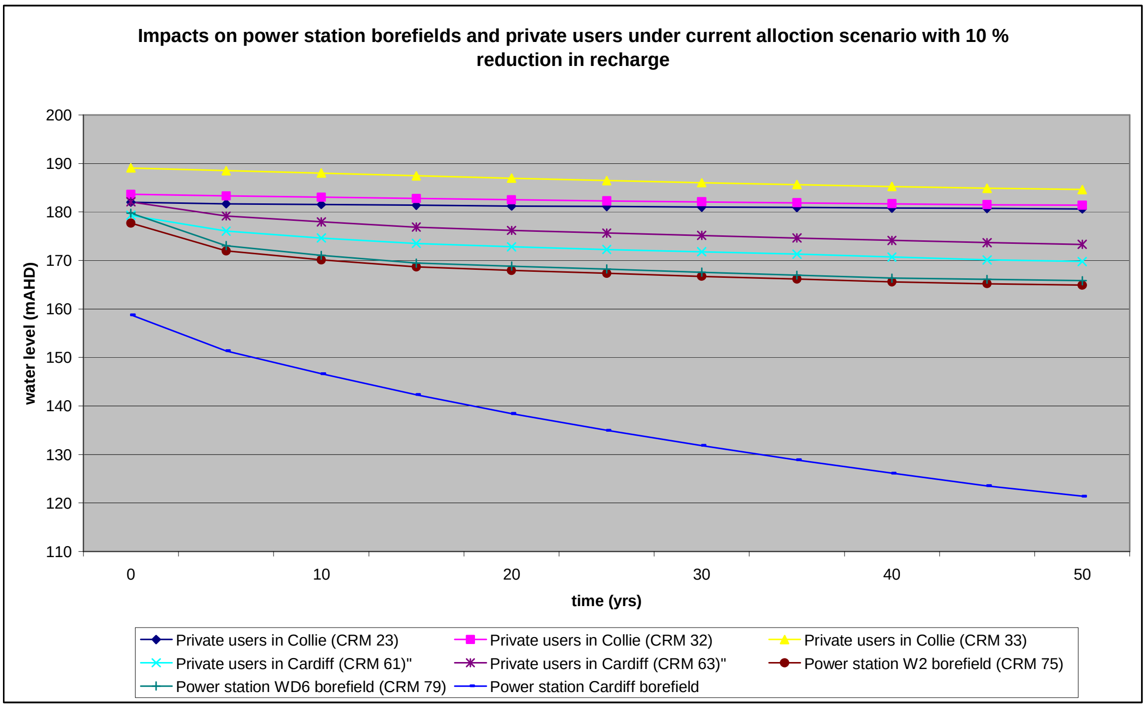

Figure 8 Impacts on groundwater users, under the current allocation scenario

9 Groundwater allocation limit options and analysis

9.1 Cardiff subarea allocation limit options

The allocation limit options for the Cardiff subarea (in total) are presented in Figure 9 and summarised in Table 28. The total recharge, current and future allocation scenarios are highlighted in red as these scenarios all resulted in regional groundwater declines.

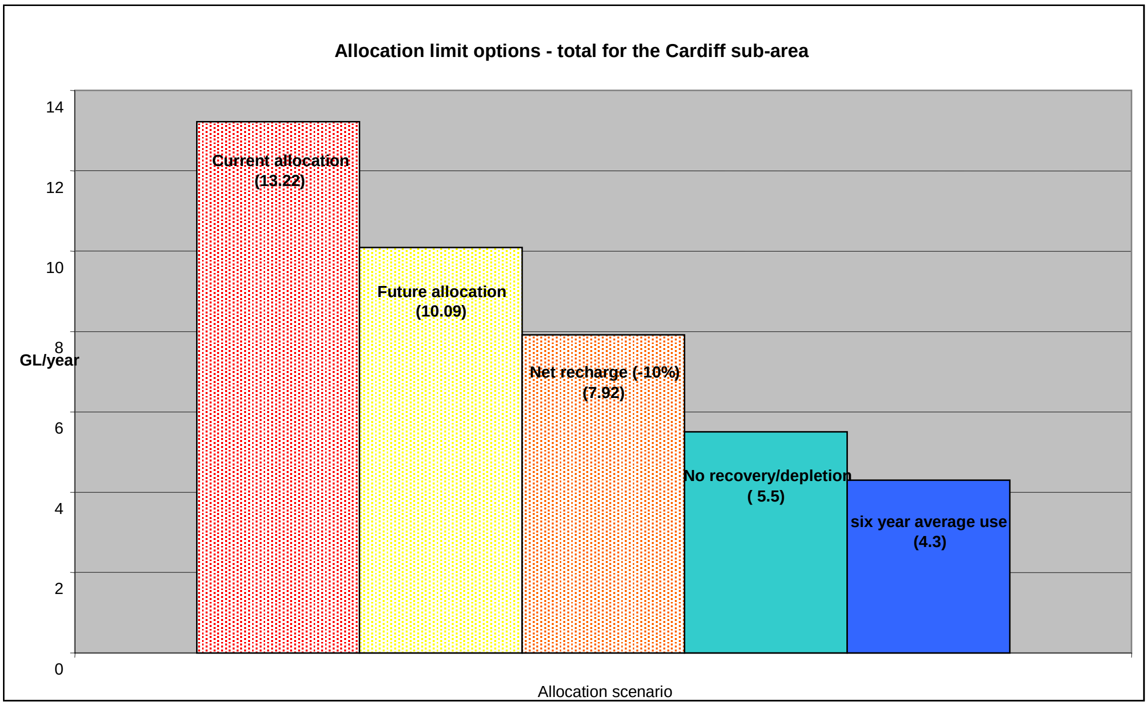

Figure 9 Allocation limit options for the Cardiff subarea (in total)

Table 28 Summary of allocation limit options (as gigalitres per year)

Resource	Current licensed use	Proposed future use	Total recharge (- 10%)	Zero recovery or depletion*	Six year average use
Nakina	0	0	0	0	0
Muja	9.49	3.01	4.94	3.25	1.79
Lower Collie Group	3.73	7.08	2.85	1.87	2.51
Stockton Group	0	0	0.57	0.40	0
Total	13.22	10.09	7.92	5.50	4.30

** Divided proportionally (in comparison to recharge) into the Muja, Lower Collie and Stockton Group*

The allocation limit options that result for the Muja and Lower Collie Group are presented in Figure 10 and Figure 11.

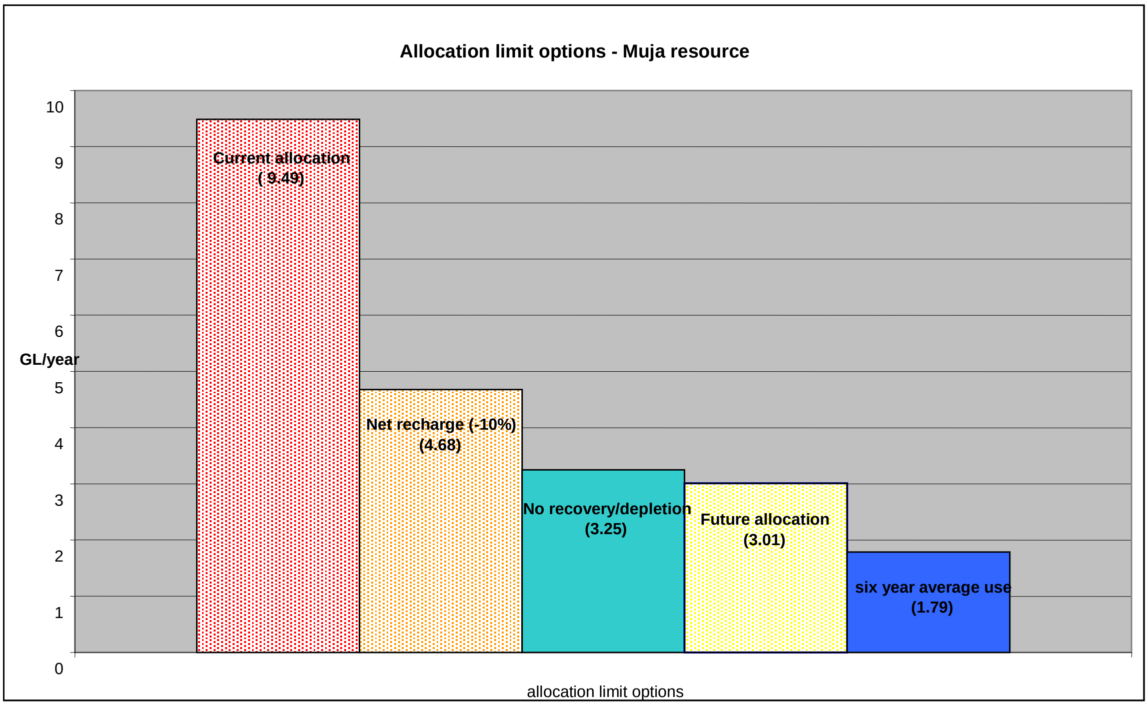

Figure 10 Allocation limits options for the Muja resource

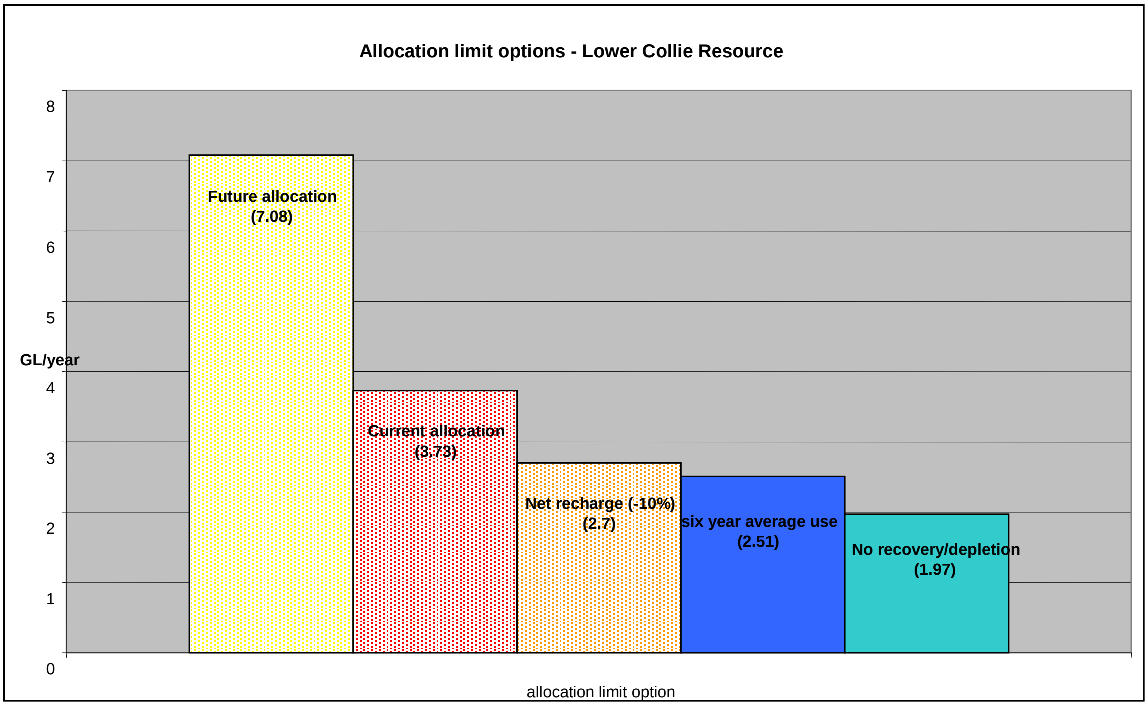

Figure 11Allocation limit options for the Lower Collie Group

Table 29 provides a summary of each allocation limit options and the evaluation of risks and benefits.

Table 29 Cardiff sub-area allocation limit options assessment summary table

Potential allocation limit option	Total for subarea	Resource	Total for each resource	Risks and benefits
Six-year average use	4.30	Nakina	0	+ Allows for some recovery + Meets Verve Energy's actual water use demand + Accommodates for reduced rainfall + Security of supply for private and power station demand over time + No surface water intrusion (maintenance of water quality) + No further impact on GDEs. Pool water level recovery. Supplementation not needed in the long-term – Does not allow for any growth in demand from Verve Energy, however Wellington Reservoir water available – Does not allow for any growth in demand from private users in Collie or Cardiff – Verve Energy's currently negotiated licence renewals would need to be scaled back – Will result in a C4 (over allocated) resource – Trading policy and unused entitlement recouping policy would need to be introduced.
		Muja	1.79	
		Lower Collie Group	2.51	
		Stockton	0	
No recovery or depletion	5.50	Nakina	0	+ No recovery, no depletion + Meets Verve Energy's overall water use demand + Security of supply for private and power station demand + No surface water intrusion (maintenance of water quality) – Does not meet current use demand from Lower Collie aquifers – Does not allow for any growth in demand from Verve Energy, however Wellington Reservoir water available – No further impact on GDEs. Pool water levels may not recover. Supplementation would be needed in the long-term – Does not allow for any growth in demand from private users in Collie or Cardiff – Verve Energy's currently negotiated licence renewals would need to be scaled back – Will result in a C4 (over allocated) resource – Trading policy and unused entitlement recouping policy would need to be introduced.
		Muja	3.25	
		Lower Collie Group	1.87	
		Stockton	0.4	

Potential allocation limit option	Total for subarea	Resource	Total for each resource	Risks and benefits
Net recharge (-10%)	7.92	Nakina	0	+ Meets Verve Energy's actual water use demand + Accommodates for climate change + Allows for some growth in actual water use demand from Verve Energy – No recovery, some depletion over time – Private and power station security of supply may be compromised in the long-term as levels decline – Surface water intrusion could occur (water quality would decrease) – Further impact on GDEs. Pool water levels would not recover. Supplementation would be needed in the long-term – Does not allow for any growth in demand from private users in Collie or Cardiff – Verve Energy's currently negotiated licence renewals would need to be scaled back – Will result in a C4 (over allocated) resource – Trading policy and unused entitlement recouping policy would need to be introduced.
		Muja	4.94	
		Lower Collie Group	2.85	
		Stockton	0.57	
Proposed future licensed use	10.09	Nakina	0	+ Meets Verve Energy's actual water use demand + Allows for some growth in actual water use demand from Verve Energy + Verve Energy's currently negotiated licence renewals could be issued – No recovery, depletion would occur – Impacts on private and power station security of supply may be compromised in the long-term as levels declined – Surface water intrusion could occur (decreased water quality) – Further impact on GDEs. Pool water levels would not recover. Supplementation would be needed in the long-term – Does not allow for any growth in demand from private users in Collie or Cardiff – Will result in a C4 (over allocated) resource – Trading policy and unused entitlement recouping policy would need to be introduced.
		Muja	3.01	
		Lower Collie Group	7.08	
		Stockton	0	

9.2 Premier subarea allocation limit options

The potential allocation limit options for the Premier subarea are limited due to the requirement to dewater the groundwater resource for safe mining practices.

Coal mining and the need for mine dewatering will continue for up to 30 years. This will result in:

- Groundwater drawdown throughout the entire Premier subarea
- Reductions in base flow to rivers and Stockton lake
- Impacts on identified groundwater-dependent river ecosystems (river pools)
- Impacts on other users – Verve Energy's Shotts borefield and domestic users
- Water quality deterioration from the intrusion of saline surface water and groundwater acidification.

Three potential allocation options were assessed. Each option required a different management position these are summarised alongside the allocation limit options in Table 30.

Table 30 Premier subarea potential allocation scenarios

No	Scenario	Total potential annual abstraction (GL/yr)	Management position
1	Total recharge (minus 10 % for reduced rainfall)	4.20	The allocation limit cannot be exceeded and will not be altered for the duration of the plan. Licences for mine dewatering are to be considered outside of the allocation limit.
2	Moving allocation limit that represent all allocations (to allow for mine dewatering and over abstraction)	53.40	Allocation limit moves to represent any increase (or decrease) in demand (dewatering or other users).
3	Current demand (not including mine dewatering)	2.20	No further commercial licences will be issued. Licences for mine dewatering are to be considered outside of the allocation limit.

The management risks, implications and merits are summarised for each allocation limit option in Table 31.

Table 31 Premier sub-area allocation limit options assessment summary table

Potential allocation limit option	Total for subarea (GL/yr)	Resource	Total for each resource (GL/yr)	Risks and benefits
Total recharge (minus 10 % for reduced rainfall)	4.20	Nakina	0	+ Based on scientific understanding of resource and recharge + Promotes understanding of actual availability for consumptive use + Private licences will not need to be recouped when mining has ceased and management objective changes to groundwater recovery + Limit would be more defendable in an appeal situation, if licence applications were refused for other users + Trading may proceed when allocation limit is reached by all other users, except mine dewatering + Reduces risk of unused dewatering entitlements being allocated for other consumptive use - Licensing system does not currently support dewatering as a separate category of use (but should be easy to account for in Collie due to low number of licences whilst system upgrades proceed) - Will not allow for any additional significant (>2 GL) allocation of groundwater - Does not provide for security of supply both water quality and quantity due to dewatering impacts
		Muja	0.1	
		Lower Collie Group	4.0	
		Stockton	0.1	
Moving allocation limit	53.40	Nakina	0	+ Represents current allocations + Meets all current and future demand - Over abstraction of the groundwater resource likely to continue after mining has ceased, due to other users - Unlimited growth and potential for defacto dewatering to occur - Compensation risk if recoup required in future - Would not allow for maximum recovery of the resource when mining ceases - Licences could not be refused on the grounds of exceeding the allocation limit - Increased administration requirements to update the licensing and DWAID systems to reflect the moving allocation limit with every licence application and dewatering change - High management risk with false
		Muja	0	
		Lower Collie Group	53.40	
		Stockton	0	

Potential allocation limit option	Total for subarea (GL/yr)	Resource	Total for each resource (GL/yr)	Risks and benefits
				availability signal if mine dewatering licences are returned and limit not lowered - Inconsistent to overall water management objectives state wide and locally - Trading would not be possible (no water efficiency incentive)
Current demand (not including mine dewatering)	2.20	Nakina	0	+ Private licences will not need to be recouped when mining has ceased and management objective changes to recovery + Limit would be more defendable in an appeal situation, if licence applications were refused for other users + Trading may proceed when allocation limit is reached by all other users, except mine dewatering + Reduces risk of unused dewatering entitlements being allocated for other consumptive use - Licensing system does not currently support dewatering as a separate category of use (but should be easy to account for in Collie due to low number of licences whilst system upgrades proceed) - Will not allow for any additional significant (>2 GL) allocation of groundwater - Does nor provide for security of supply both water quality and quantity due to dewatering impacts
		Muja	0	
		Lower Collie Group	2.20	
		Stockton	0	

10 Groundwater final allocation limits

10.1 Cardiff subarea

In line with the Cardiff groundwater recovery objective and based on the benefits/risks outlined in Table 32, six year average use figures were selected as the allocation limits for each of the resources.

Table 32 Final allocation limits for the resources of the Cardiff subarea

Resource	Allocation limit (GL/yr)
Nakina	0
Muja	1.79
Lower Collie Group	2.51
Stockton	0
Total	**4.30**

The allocation limits for the Cardiff subarea support:

- the recovery of the groundwater table over time
- meets the average actual use (based on actual use from 2000 - 2006)
- maintains water quality and quantity requirements for current users
- allows for the recovery of historically impacted groundwater-dependent pools and the likely cessation of the pool supplementation program in the medium term.

10.2 Premier subarea

The most suitable allocation limit option for the Premier subarea is based on the current demand from Verve Energy (through the Shotts borefield) and domestic users (2.20 GL/yr). This limit:

- meets actual current demand
- reduces the risks and management implications associated with expected impacts on the water resource from mining.

No further commercial licences will be issued and all mine dewatering licences will be considered outside of the allocation limit

Table 33 Final allocation limits for the resources of the Premier subarea

Resource	Allocation limit (GL/yr)
Nakina	0
Muja	0
Lower Collie Group	2.20
Stockton	0
Total	**2.20**

11 Groundwater allocation limit limitations

Climate change

The current recharge areas in the Collie Coal Basin model are not climate based and therefore climate change can not be applied. However, in this method a standard 10 per cent reduction in recharge was applied to each area which is not technically precise, but still results in a reduction of overall recharge.

Ideally to determine recharge and reductions resulting from climate change, a soil water balance should be completed and then reductions in rainfall should be reapplied. It is also difficult to ascertain what potential evaporation and plant transpiration changes occur in altered climates into the future.

Stock and domestic use

Stock and domestic use is estimated and as such is considered as conservative.

Impacts on other users

Assessing the impacts on other users was assessed broadly using the regional model and looking at predicted drawdown on recovery in storage across the subarea caused from cumulative abstraction. This type of assessment does not take into consideration the impacts of abstraction (of a certain volume) from one (or more) draw points impacting each other at a specific site, for example a large abstraction from Verve Energy's WD2 borefield may impact private users in Cardiff due the cone of depression it causes in the local vicinity.

Assessment of the impacts on other users was completed using a limited number of criteria sites.

Appendices

Appendix A — Department of Water memorandum: Wellington Reservoir yield estimation

TO: A/Manager, Resource Allocation

FROM: A/Senior Engineer, Hydrology & Water Resources

CC: Manager, South West Region Manager, Hydrology & Water Resources Manager, Salinity & Land Use Impacts Program Manager, Strategic Development & Planning

DATE: 4 June 2003

FILE NO: IF99

Introduction

The Collie River is regulated by Wellington Dam, approximately 35 km east of Bunbury. Wellington Dam was originally constructed in 1933 to provide summer irrigation water to farm lands between Collie and Bunbury. Wellington Dam was last raised in 1961 to provide a total storage capacity of 186 Mm^3.

Upstream of Wellington Dam, the Collie River has two main tributaries, Collie River South Branch and Collie River East Branch (Figure 1). Large areas of the East Branch catchment have been cleared for agriculture. In the late 1960s, increases in the salinity of the once fresh Collie River were observed and these have continued until at present the mean annual salinity flowing into Wellington Reservoir from the Collie River is 885 mg/L

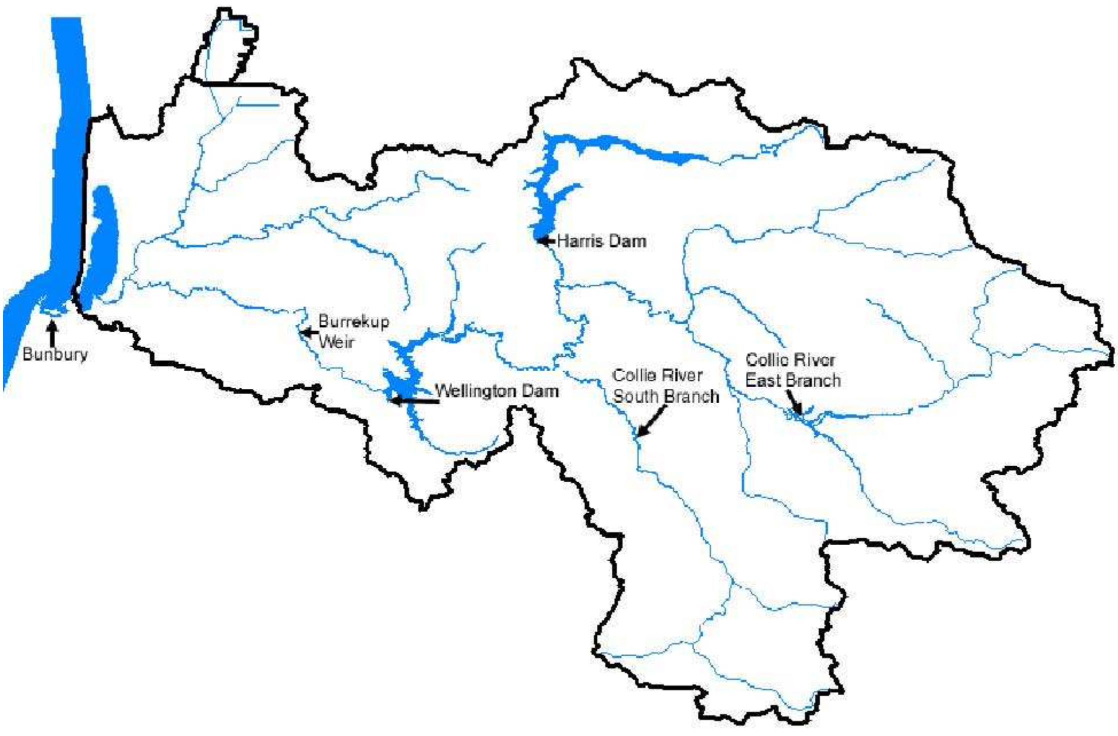

Figure 1 Collie River Basin

A simple two-layer daily salt and water balance of the Wellington Reservoir has been developed to assess the impact of catchment management options on yield reliabilities and water quality.

Reservoir behaviour

Over the last thirty years many studies [Loh, 1974; Loh, 1977; Loh and Stokes, 1977 and Fischer et al, 1979] have examined the issue of increased salinity in Wellington Reservoir. From these studies we have an understanding of the physical behaviour of the reservoir.

At the start of winter, the reservoir is in a well-mixed state. The early winter inflows typically have a high salt load from salt accumulated in the catchment over summer. With a density greater than the water in the reservoir, these winter inflows typically flow to the bottom of the reservoir with some dilution through entrainment.

Conversely summer/autumn inflows typically have a low salt load and tend to the surface of the reservoir. Over the summer months, strong solar heating results in stratification of the water body. By May, with cooling surface waters and strong mixing winds, the water body again tends to a homogeneous system.

Model development previous models

Loh and Stokes [1977] introduced a scour policy for Wellington Reservoir to remove the first salt laden flows from the reservoir in winter. This was aimed at improving the quality of the remaining water for the summer irrigation season. The model developed to determine the scour policy was a two-layer representation of the salinity structure in the reservoir and operated on a monthly time-step.

The monthly time-step resulted in a simplification of the physical processes but ignored entrainment, wind mixing and diffusion of salt between layers [Loh and Stokes, 1977]. Additionally, problems were encountered with draw salinities, as the monthly time-step could not adequately track the changing layer interface level in relation to the off-take valve.

During the late 1970s the Centre for Water Research at the University of Western Australia developed a complex, two-dimensional dynamic reservoir simulation program (DYRESM) to model the mixing processes in reservoirs of medium size [Imberger et al, 1978]. DYRESM operates on a daily time-step with hourly calculations of the meteorological functions. Meares et al [1985] modified DYRESM to simulate two reservoirs in series. This enabled the combined Harris-Wellington system to be modelled. Construction of Harris Dam was completed in 1989 to supply fresh water to the Great Southern Towns Water Supply (GSTWS) and provide fresh salinity mitigation water to Wellington reservoir. Hookey and Loh [1985] used the modified two-dam version of DYRESM to assess the impact of the Harris reservoir on irrigation salinities from Wellington reservoir.

Martens et al [1991] developed the Harris-Wellington Decision Support System (HWDSS), incorporating core components of the DYRESM model, as an operational tool to determine when scouring from Wellington reservoir should commence.

One of the problems with the DYRESM model is the extensive data requirement. Detailed daily meteorological data are required including short wave solar radiation, sunshine ratio, average ambient air temperature, wind run and average vapour pressure. Many of these parameters are not commonly available. Karafilis and Ruprecht [1994] derived sinusoidal

functions for the meteorological parameters to provide a longer data set for their DYRESM simulations to improve the Wellington scour policy.

New model development

As noted previously, the meteorological data requirements for DYRESM are very restrictive. For the Wellington dam catchment the complete data set is only available from 1974 to 1982. Additionally, DYRESM cannot handle the variable nature of the environmental water provisions (EWPs) from the reservoir. This led to the need to identify a simplified model with less intensive data requirements.

Sinclair Knight Merz [1998] developed a modified DYRESM with a new heater algorithm based on pan evaporation. While this solved some of the data problems there were still operational issues with the model.

The new Wellington Reservoir Daily Water Balance model (TwoRes) is a semi-empirical, two layer, daily water and salt balance of Wellington and Harris reservoirs. TwoRes is fundamentally a daily time step version of the Loh and Stokes [1977] model.

The semi-empirical daily water balance model assumes two layers in the water body, a 'salty' dense bottom layer and a 'fresh' surface layer. On 1 May of every year, the two layers are merged to produce a single layered homogenous water body. Inflows from May through September are added to the bottom layer while inflows from October through April are added to the top layer.

TwoRes operates on a daily time-step with the current analysis period from 1 April 1974 to 31 September 2001. Reservoir inflows are separated into Collie River (as recorded at Mungalup Tower) and 'Local' inflows. Western Power, Irrigation and Water Corporation draws from the reservoir have been modelled with individual restriction rules. Scour from the reservoir is calculated through an implementation of the scour policy in the model.

Due to constraints on the original version of TwoRes, Harris reservoir has not been modelled with Wellington reservoir. Given that Harris Dam would typically overflow at the same time as Wellington Dam the impact of the lower salinity Harris water entering Wellington reservoir would not be significant on Wellington reservoir salinities. It was considered that not including Harris reservoir provides a conservative estimate of the Wellington salinities.

As with the earlier two-layer model, no allowance has been made for mixing in the reservoir other than on 1 May when the two layers are combined into a single homogenous layer. Entrainment, wind mixing and diffusion are not explicitly modelled. The DYRESM model requires wind data to enable wind mixing to be calculated however, the simplified daily model has incorporated this physical process in an empirical fashion, based on knowledge of the reservoir behaviour. Similarly diffusion between layers has been ignored and the cold winter inflows are assumed to instantaneously appear in the bottom layer and as such entrainment is not incorporated in the model.

Model calibration

The model was calibrated against a mixed data set. Storage levels in Wellington reservoir were available for the calibration period, 1974 to 1982, and converted into volumes from the storage-elevation-surface area data.

Immediately downstream of Wellington dam the stream gauging station Collie River – Wellington Flume (AWRC 612013) records continuous flow and salinity for all releases from Wellington reservoir. This includes scour, spills and irrigation releases. As scour and spills occur in winter months and irrigation releases occur from October to May, the data was separated for calibration. Similarly, the streamflow gauging station was used to obtain daily scour volumes from Wellington reservoir. Figure 2 shows the TwoRes calibration results.

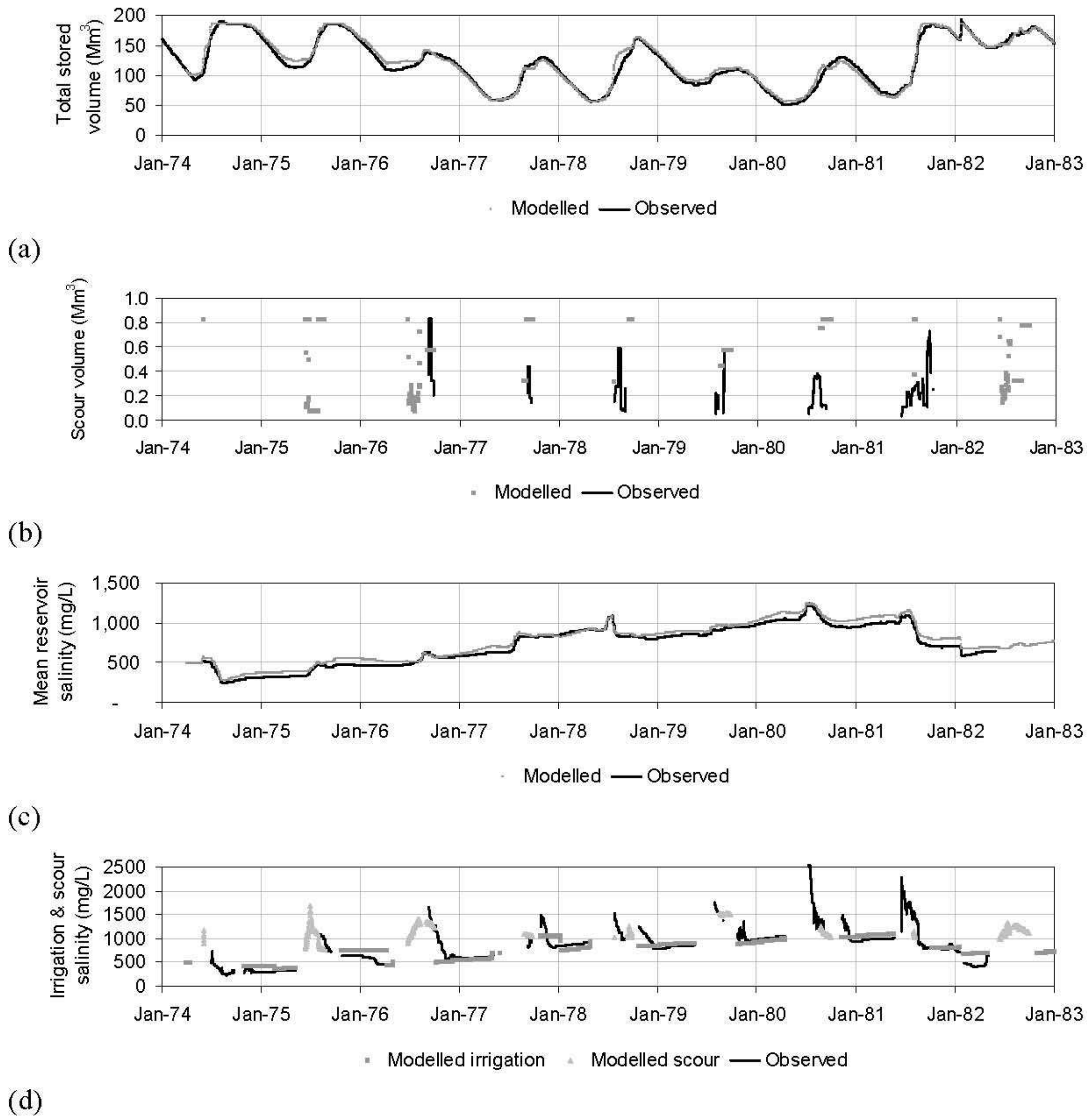

Figure 2 TwoRes calibration graphs for Wellington Reservoir (a) daily volume stored in Wellington reservoir, (b) daily scour volume, (c) daily mean Wellington reservoir salinity and (d) daily irrigation and scour salinities from Wellington reservoir.

As would be expected, the mass balance is relatively simple to achieve and this is reflected in the calibration of total stored volume in Wellington Reservoir. The mean reservoir salinity also calibrated very well.

Scour from Wellington reservoir can occur between 1 June and 30 September and is based on; the difference in salinity between the top and bottom of the reservoir (salinity differential), the salinity at the bottom of the reservoir, and the combined volume of water stored in Harris and Wellington reservoirs. Additionally, the monthly scour volume cannot exceed the monthly inflow volume. While this scour policy has been coded into the model, actual operation of the scour valve is more flexible.

The TwoRes model tended to scour slightly later and more frequently at the maximum allowable rate than is evident from the observed data. The biggest potential contributor to the model scour error is the simplification to a two-layer model. While the actual water body has a continual variation in salinity with depth, the model simplifies this to just two salinity values. This would not cause a significant difference in the mean reservoir salinity but can result in large differences between the observed and modelled salinity differential. This would then cause the scour to be triggered at different times. This also accounts for the differences in the daily scour salinity calibration. The scour salinity values are comparable but the timing is slightly out.

There was no timing issue with the irrigation releases as these are relatively stable in their start and finish dates throughout the observed data. Similarly, the model performed well for the daily irrigation salinity values.

Environmental water provisions

A discussion paper on proposed EWPs for the lower Collie River was prepared by WEC [2002]. It was agreed within the Water and Rivers Commission that the EWPs presented in WEC [2002] were conservative and as such additional investigations were commissioned to refine these values. Table 1 summarises the revised EWPs (after Hardcastle et al, 2003) for the reach of the Collie River between Wellington Dam and Burekup Weir.

Table 1 Monthly EWP breakdown (units as gigalitres per year)

*Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Macro - invertebrates	2.01	1.81	2.01	1.94	2.01	2.20	2.68	2.68	2.59	2.28	1.94	2.01
Fish passage	-	-	-	-	-	-	-	1.68	0.84	-	-	-
Pool maintenance	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Energy	2.01	1.81	2.01	1.94	2.01	1.94	2.01	2.01	1.94	2.01	1.94	2.01
Total	**2.01**	**1.81**	**2.01**	**1.94**	**2.01**	**2.20**	**2.68**	**3.82**	**3.16**	**2.28**	**1.94**	**2.01**

Two additional EWP component building blocks were specified in the WEC [2002] report – channel maintenance and riparian flow. Both of these components are distinguished from the other components in that they are not annual releases. Channel maintenance was defined as a 9,568 ML release in July or August with an average recurrence interval of 3 years. This was based on a flow rate of 150 m^3s^{-1} in the mid-reaches of the Collie River and a 24 hour flood event. Similarly the riparian component was defined as a 10,345 ML release in any winter month with an average recurrence interval of 2 years.

There are still some hydrological concerns with these two EWP components. Both components suggest a peak flow rate of around 150 m^3s^{-1} in the Collie River between Wellington Dam and Burekup Weir and WEC [2002] states that this magnitude flow has a recurrence interval of 3 years. Figure 3 shows the peak annual flood flows for the Mt Lennard gauging station. This suggests that the 3 year average recurrence interval (ARI) flow is around 30 m^3s^{-1} while a flow of 150 m^3s^{-1} has an ARI of around 15 to 20 years.

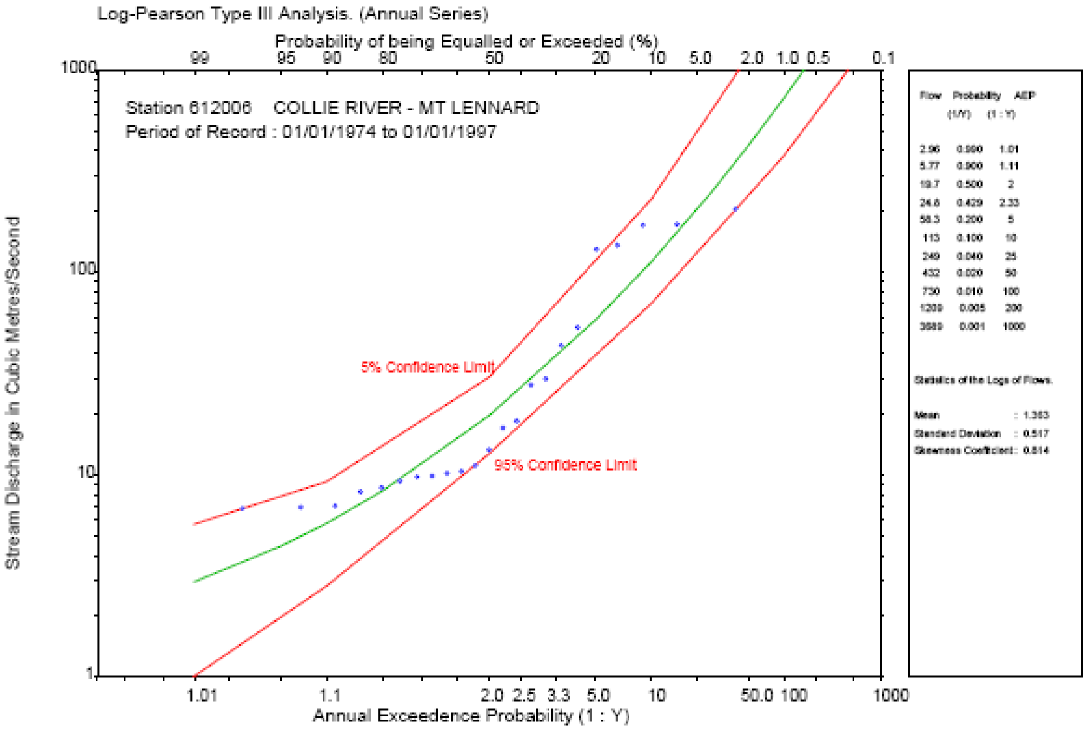

Figure 3 Flood frequency curve for the Collie River at Mt Lennard (612006)

Additionally, WEC [2002] suggests the channel maintenance release should occur as a 24 hour flood event. In comparison, the January 1982 flood event had a peak flow of around 170 m^3s^{-1} and duration of approximately 9 days.

The Wellington Dam scour valve is only capable of releasing a maximum of around 8 m^3s^{-1}. As such any EWP greater than 8 m^3s^{-1} can only be met when the dam overflows. Due to the concern with the channel maintenance and riparian EWP components they have not been explicitly modelled. Assessment of the modelled scenarios has been based on satisfying the EWPs shown in Table 1 and the frequency of spill events from Wellington Dam.

Modelling scenarios

Mauger et al [2001] identified a number of catchment management options for the Collie River catchment to reduce the Wellington reservoir inflow salinity from 885 mg/L to 500 mg/L. The results of the catchment management options were presented as annual flow and salinity for the Mungalup Tower gauging station on the Collie River (AWRC 612002). These catchment management options included:

(i) groundwater pumping,

(ii) upland + lowland tree plantings,

(iii) lowland tree plantings,

(iv) groundwater pumping + upland and lowland tree plantings, and

(v) desalination.

The historical Wellington reservoir inflow salinity data exhibits a rising trend. As the non-stationary salinity data is unsuitable to use in assessing catchment management options the LUCICAT model [Bari et al, 2002] was used to generate a daily flow and salinity data set with the 2001 plantings under hydrologic equilibrium. This data set was then used as a base for the catchment management options.

The LUCICAT model was used to generate daily Wellington reservoir inflow and salinity values for various catchment management options [Bari et al, 2003]. Differences were noted between the annual values reported by Mauger et al [2001] and the corresponding results from Bari et al [2003]. Until the differences between the two model results could be explained it was decided to calibrate the LUCICAT 2001 Plantings results against the results from Mauger et al [2001]. This daily data was then scaled to match the flow and salinity reported in Mauger et al [2001] for the various catchment management options.

For the simulations, the monthly EWPs were applied uniformly across each month. Similarly the Western Power demand of 5.1 Mm^3/year was applied uniformly throughout the year and the Irrigation demand of 68 Mm^3/year was applied uniformly across irrigation season (1 October to 30 April). The monthly Water Corporation demands are shown in Table 2 and were distributed uniformly through each month. The draws for all three users are sourced from the middle off-take of Wellington Dam (off-take level 149.95 mAHD).

Table 2 Water Corporation monthly demand

	Demand (Mm3)
January	2.2
February	
March	2.0
April	2.0
May	
June	
July	
August	
September	2.2
October	2.2
November	2.2
December	2.2

Table 3 summarises the TwoRes modelling results for the various catchment treatment scenarios. Figure 4 shows the daily supply salinity distribution for Western Power for the 2001 Reforestation scenario compared with the Groundwater pumping scenario. While there is a significant reduction in the supply salinities there are still occasions where the supply salinity exceeds 1,200 mg/L.

Table 3 Summary of modelling results for various catchment treatment scenarios

	Base case	2001 reforestation	Groundwater pumping	Upland & lowland plantings	Lowland trees	Groundwater pumping + trees	Desalination
Irrigation reliability (68 Mm^3/yr)	89%	85%	85%	85%	85%	85%	85%
Mean irrigation salinity (mg/L)	815	822	631	640	639	636	627
Maximum irrigation salinity (mg/L)	1,477	1,808	1,279	1,248	1,218	1,283	1,261
Western Power reliability (5.1 Mm^3/yr)	-	100%	100%	100%	100%	100%	100%
Mean annual Western Power salinity (mg/L)	-	867	664	679	676	670	660
Maximum Western Power salinity (mg/L)	-	1,808	1,279	1,252	1,278	1,319	1,298
Mean annual Water Corporation supply (Mm^3)	-	12.0	11.8	11.7	12.0	12.5	12.5
Median annual Water Corporation supply (Mm^3)	-	14.2	14.3	13.9	14.2	14.6	14.7
Mean annual Water Corporation salinity (mg/L)	-	761	595	610	609	610	602
Maximum Water Corporation salinity (mg/L)	-	1,808	1,279	1,058	1,065	1,283	1,261
Wellington annual spill frequency	63%	44%	48%	33%	33%	48%	48%
Wellington mean annual spill (Mm^3)	55.9	42.6	44.1	30.0	33.6	43.3	45.4
Mean annual scour (Mm^3)	13.4	11.4	2.8	0.6	0.9	1.5	1.6

Base case – 2001 Reforestation inflows but does not include Western Power or Water Corporation draws

Conclusions

With the 2001 Reforestation inflows to Wellington reservoir, the modelling suggests it is possible to supply 5.1 Mm^3/year at 100% reliability to Western Power and an average of

12.0 Mm^3/year to the Water Corporation while satisfying the environmental water provisions. The additional draw from the reservoir results in a small reduction in the mean annual scour and annual spill frequency.

While the various catchment treatment scenarios have up to 19.0 Mm^3/year less inflow, modifications to the scour policy allow similar supplies and reliabilities for Western Power and the Water Corporation to be achieved as under the 2001 plantings scenario.

It should be noted that the supply salinities for Western Power and the Water Corporation exceed 1,200 mg/L at times, even under the various catchment treatment scenarios. These salinities may not be acceptable to Western Power or the Water Corporation.

Further refinement is required on the reservoir inflows and salt loads. The current method of scaling the 2001 plantings data set to match steady state values reported in Mauger et al [2001] is not entirely satisfactory.

While the EWPs have recently been reviewed for some of the building block components, the channel maintenance and riparian components were not included. It is recommended that these components be reviewed, as there are still some hydrological concerns with the EWPs as defined in WEC [2002].

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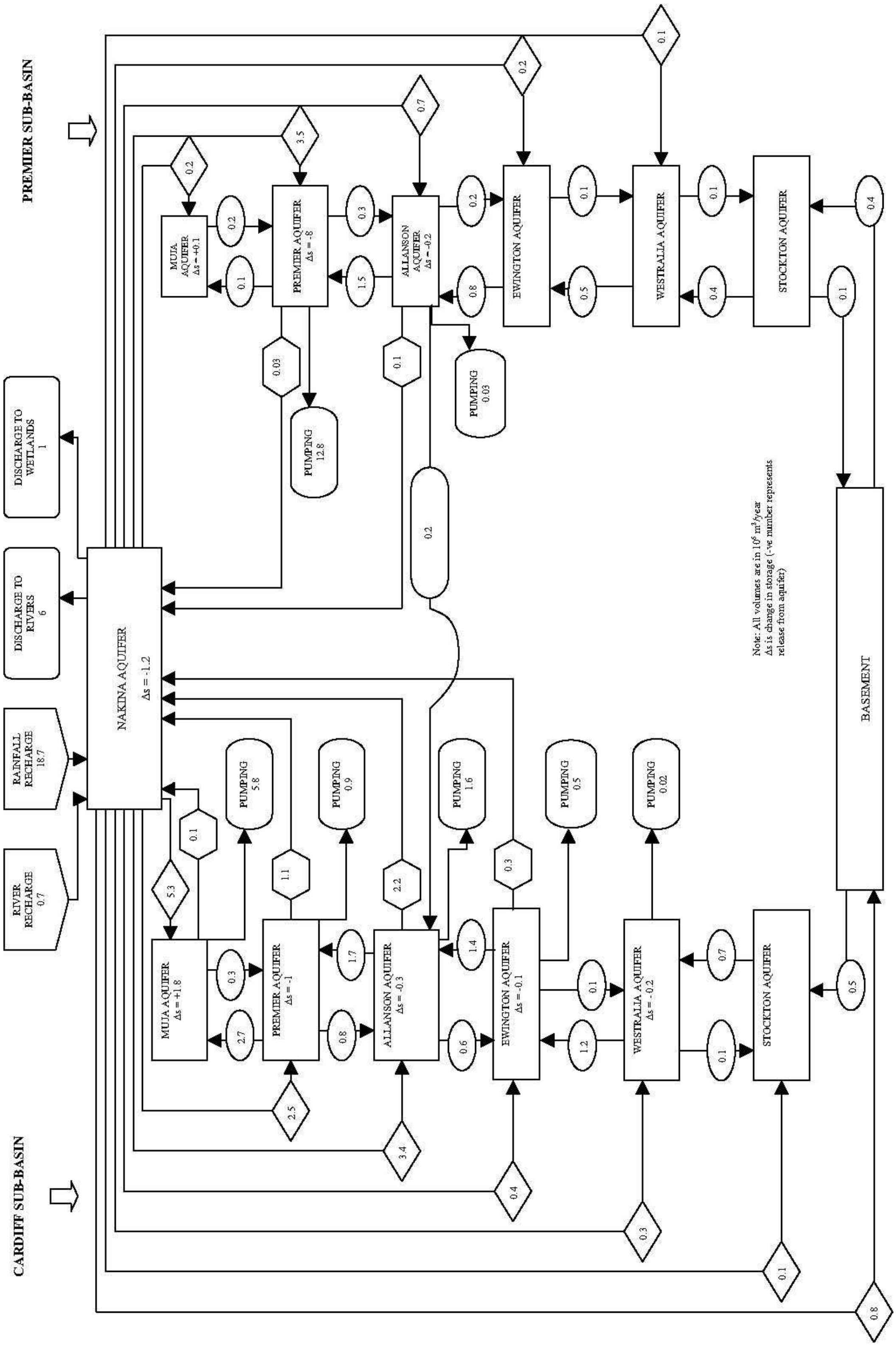
Appendix B — Groundwater balance of the Collie Coal Basin as assessed in 1999 (derived from the groundwater model)



Glossary

Abstraction	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
Allocation Limit	The amount of water set aside for annual licensed use.
Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock. Aquifer types include unconfined, confined and artesian.
Base flow	The component of streamflow supplied by groundwater discharge.
Confined Aquifer	An aquifer lying between confining layers of low permeability strata (such as clay, coal or rock) so that the water in the aquifer cannot easily flow vertically.
Consumptive use	The use of water for private benefit consumptive purposes including irrigation, industry, urban and stock and domestic use.
Dewatering	Removing underground water to facilitate construction or other activity. It is often used as a safety measure in mining below the water table or as a preliminary step to development in an area.
Drawdown	The lowering of a watertable resulting from the removal of water from an aquifer or reduction in hydraulic pressure.
Ecologically sustainable yield	The amount of water that can be abstracted/extracted over time from a water resource while maintaining the ecological values (including assets, functions and processes).
Ecological values	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems.
Ecological water requirement	The water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.
Environment	Living things, their physical, biological and social surroundings, and interactions between all of these.
Environmental Water Provision	The water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social, cultural and economic impacts. They may meet in part or in full the ecological water requirements.
Gigalitre	A volumetric measure equal to one million kilolitres or one billion litres.
Groundwater	Water which occupies the pores and crevices of rock or soil beneath the land surface.

Groundwater Area	Are the boundaries that are proclaimed under the *Rights in Water and Irrigation Act* and used for water allocation planning and management.
Groundwater-dependent ecosystem	An ecosystem that is dependent on groundwater for its existence and health.
Groundwater recharge	The rate at which infiltration water reaches the water table.
Groundwater subarea	Areas defined by the Department of Water within a Groundwater Area, used for water allocation planning and management.
Fit-for-purpose	Water use is matched to an appropriate quality
Kilolitre	A unit of volume in the metric system, equal to 1000 litres. Weighs approximately one tonne.
Licence	A quantity of water specified on a formal permit which entitles the licence holder to 'take' water from a watercourse, wetland or underground source, in accordance with the *Rights in Water and Irrigation Act 1914*.
Megalitre	A volumetric measure equal to one thousand kilotlitres or one million litres
Over-allocated	Sum of water access entitlements is more than 100 per cent of sustainable yield.
Reliability	The frequency with which water allocated under a water access entitlement is able to be supplied in full. Referred to in some states as "high security"and "general security".
Self supply	Water diverted from a source by a private individual, company or public body for their own individual requirements.
Salinity	The measure of total soluble salt or mineral constituents in water. Water resources are classified based on salinity in terms of total dissolved salts (TDS) or total soluble salts (TSS). Measurements are usually in milligrams per litre (mg/L) or parts per thousand (ppt).
Social value	A particular in-situ quality, attribute or use that is important for public benefit, welfare, state or health (physical and spiritual).
Social water requirement	Elements of the water regime that are needed to maintain social and cultural values.
Subarea	A sub-division within a surface or groundwater area, defined for the purpose of managing the allocation of groundwater resources. Subareas are not proclaimed and can therefore be changed internally without being gazetted.
Surface water management area	Areas defined by the Department of Water, used for water allocation planning and management that are generally hydrologic basins or parts of basins.

Unconfined aquifer	Is the aquifer nearest the surface, having no overlying confining layer. The upper surface of the groundwater within the aquifer is called the watertable. An aquifer containing water with no upper non-porous material to limit its volume or to exert pressure. see Aquifer

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