
Santosh K Aryal

May 2011

A report to the Kangaroo Island Natural Resources Management Board
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Kumar Savadamuthu, Michael Good      Department for Water, South Australia
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Useful comments from the South Australian Government Task Force Representatives on the draft of this report are highly appreciated. Thanks are also due to Drs Lu Zhang, Francis Chiew and Richard Cresswell for their helpful suggestions on this report.
EXECUTIVE SUMMARY

CSIRO was asked to provide an independent scientific review of Kangaroo Island water resources management policy developed by the Kangaroo Island Natural Resources Management Board (KINRMB). The policy aims to achieve best practice water resources management that (i) promotes equitable and reasonable use of water by all landholders and water users, and (ii) protects aquatic and riparian and other water dependent ecosystems.

Kangaroo Island (4370 km²) has 20 major rivers most of which are intermittent. Nearly 50 percent of its area is engaged in surface water dependent primary production. The annual rainfall varies across the Island ranging from 400 mm to 900 mm. To achieve its objectives the Board has divided the Island into two management zones (Zone A and Zone B) and plans to use two different methods (Method A and Method B) to calculate the Sustainable Use Limit (SUL) for its water courses.

One of the major tasks of the current project is to review the assumptions and frameworks that underpin these two methods of SUL calculation. Appropriateness and validity of data used to support the policy are also examined including a review of the delineation of the Island’s water resources areas into two zones for policy implementation purpose.

Analysis and interpretation of intensive rainfall and streamflow data were done to understand the underlying hydrological and climatic characteristics of the Island. Insights and outcomes obtained from the analysis provided the basis for many of the comments and advice given in this review. An extensive literature survey was undertaken to learn about the best practice land use management and examine the methods to calculate sustainable diversion limits (SDL) in other Australian jurisdictions and assess their relevance to the Kangaroo Island. There is limited literature on the calculation of SDLs and no straightforward method to calculate them as the SDL depends on the environmental water requirements, and social and economic factors which are hard to quantify. Consultations with the South Australian Department for Water (then Department of Water Land and Biodiversity Conservation) hydrologists, Department of Primary Industries and Resources of South Australia, SA Water and members of the Kangaroo Island water task force were carried out to gain background information on the policy and enquire about the availability of data and relevant literature.

The key findings are:

**Sustainable Use Limit estimation**

1. Based on the rainfall attributes and limited modelled streamflow data in Zone A and Zone B the delineation of these zones appears to be reasonable.

2. The SUL calculated using Method A is not based on established methods. A number of assumptions used in this method have not, or cannot, be substantiated with available data. There is no basis to assume that mean annual flow from a pristine forested catchment should be the required minimum flow in adjacent cleared catchments under natural conditions.

3. Application of Method B (the "25% rule") can lead to all available catchment yields being classified as SUL during the drier years. This will have an impact on the aquatic and riparian ecosystems due to diversion of all available flow most of the time thus relying on the defined threshold flow rate to maintain the minimum flow more frequently. This method, in a number of cases, also requires intensive catchment modelling to derive mean annual adjusted yields at different spatial scales.

4. The recent past (since mid-1990s) has had a drier hydrological regime than the long-term average conditions. Long-term average conditions generate inflated SULs for current conditions.

The SUL estimates can be improved with detailed data and/or more appropriate models. This will also help adopt the extent of reliability of SULs and river flows in the individual catchments.

5. The use of climate change scenario data to derive the water resources management policy is valid and appropriate. This is not reflected in the current use of SULs.
6. In many Australian States and in the ACT, diversions are only allowed when the streamflow is above a certain threshold (e.g. the 80% exceedance daily flow). There are also limits on maximum allowable extraction. The SDL under 80% reliability ranges from 0 to 21 percent and 0 to 23 percent of mean winterfill period flow in Western Australia and Victoria respectively.

**Changes in hydrological and climatic patterns**

7. The rainfall and streamflow in Kangaroo Island post 1997 is significantly lower than the pre 1997 values. For example:
   - Rocky River has experienced a sharp drop in streamflow since 1997. The annual streamflow in every year since 1997 (except 2009) is well below the pre-1997 annual average. The 1997–2009 annual average streamflow is less than half the 1974–1996 average.
   - In the Rocky River the proportion of rainfall that becomes runoff (runoff coefficient) in the recent period (1997–2009) (0.05) is about half the runoff coefficient over the 1974–1996 period. The 90th percentile flow volume for 1974-1996 is now only the 50th percentile of flow.
   - Except for the far west, most of Kangaroo Island has experienced a declining rainfall trend in the recent years. The declining rainfall trend gradually increases east of Parndana. The annual average declining trend over 1997–2009 are 2.4 mm/year in Parndana, 6 mm/year in Kingscote and 13 mm/year in American River.
   - The sharp drop in Rocky River streamflow followed consecutive years of below-average rainfall during 1993-1999, which might have lowered the groundwater sufficiently to break the groundwater surface water connection.
   - The other areas of the Kangaroo Island have also experienced a series of consecutive years of below-average rainfall during the 1990s. The streamflows of these catchments may also show reduction similar to that observed in the Rocky River due to similar reasons. Modelling results for Cygnet River and Timber Creek show such a reduction in the streamflow during recent years.

8. The falling trends of runoffs in all Kangaroo Island catchments together with falling trends in recent rainfall imply that present streamflows are not representative of the past streamflows. In light of these changes, use of climate and streamflow data post mid-1990s is recommended for any future SUL calculations.

**Recommendations for data and modelling**

9. Two additional stream gauging stations in addition to those already suggested in the National Action Plan for Water Quality and Salinity should be installed. A meteorological station capable of measuring potential evaporation data should also be installed.
10. The Board needs to continue its long term monitoring of rainfall and streamflow data stations.
11. Until sufficient observed data is available, the use of modelled streamflow to derive SULs is reasonable.
12. The modelling for SUL calculation should include projected climate scenarios to manage the risk associated with potential climate changes.
13. Difference in streamflow reduction varies depending on the location of plantation in the catchment. Hydrological impact of plantations on catchment can be minimised through proper
planning of the forested area and should be considered in future forest area planning and SUL estimation.
1. BACKGROUND AND SCOPE

CSIRO was asked to provide an independent scientific review of water resources management policy under its natural resources management plan by the Kangaroo Island Natural Resources Management Board (KINRMB). The KINRMB, established under the NRM Act 2004, has developed water resources management policy for providing guidelines for sustainable use of Island’s water resources. The policy aims to achieve best practice water resources management that (i) promotes equitable and reasonable use of water by all landholders and water users, and (ii) protects aquatic and riparian and other water dependent ecosystems.

Kangaroo Island, located off the Fleurieu Peninsula in South Australia, has an area of 4370 sq km. Nearly 50 percent of this area is engaged in primary production most of which is dependent on surface water, also a source of domestic water supply for the Island’s population. There are 53 river/stream catchments in the Island, 20 of which are considered the major ones. The current state of Kangaroo Island’s rivers and streams is highly variable from relatively pristine to highly degraded (KINRMB, 2009; Nilsen, 2006). Most of the watercourses of the Island are intermittent. The Island has a cool temperate Mediterranean climate with warm dry summer and seasonal winter rain with frequent windy days. The annual rainfall varies spatially across the Island ranging from 400 mm to 900 mm (see Appendix A).

1.1. Statement of the Problems/Issues

Surface water system in Kangaroo Island is under pressure to meet a variety of demands, including agriculture and requirements for the maintenance of stream based ecosystem normally referred to as environmental water requirements (EWR), or environmental flows. There is no universally agreed view on how much water is required to maintain the stream ecosystem as the amount of water required is dependent on the types of flora and fauna.

The natural resources management plan for Kangaroo Island identifies that the current level of farm dam development and large scale plantation forestry is a risk to water resources in some areas of the Island and this risk will increase due to predicted climate change over the coming years. To address this risk and achieve its objectives the Board has adopted water resources management policies based on available data and a range of assumptions with the understanding that some of the data may not be adequate or appropriate. Some of the issues are:

(1) To determine sustainable use limits (SULs) for surface water development the Island is divided into two zones (A and B) (see Figure 2-8) with two different applicable methods, Method A and Method B respectively. The 600 mm mean annual rainfall isohyet is used as a basis to broadly separate these two zones. Zone A mostly consists of lateritic plateau landforms while Zone B consists largely of the Central Plains and some of the South Coast regions (KINRMB, 2009). This is based on the assumption that these zones have different rainfall, landform and other attributes that would produce very different rainfall-runoff relationships. This assumption needs reviewing together with the appropriateness of the methods used in the two policy zones in achieving the underlying aims of the KINRM Board. Both methods are used in ungauged catchments.

(2) Appropriateness of the data used to support the policy and need for future key data requirements. Issues related to monitoring of state of water resources and modelling to improve the policies.

(3) Monitoring of long term water quality and quantity to assess the sustainability of water resources in the future. These long term data will help see any changes in trends of improvement or degradation.

(4) Need to develop recommendation for future policy required to further improve the water resources management, if identified by the review.
1.2. Review of Assumptions

The sustainable use limit for a group of catchments in Zone A is based on a mix of observations in the Rocky River catchment (which is considered to be similar in rainfall runoff response to other Zone A catchments). Thus there is a need to establish whether all catchments in Zone A have flow behaviours similar to the gauged Rocky River catchment for Method A to be deemed appropriate.

For catchments in Zone B the sustainable use limits are derived based on earlier methods which have evolved over time. The State NRM Plan (2006) stipulates that until additional information becomes available, 25 percent of the median annual adjusted catchment yield is adopted as the sustainable use limit (Method B) and provides the rationale for this choice.

The review will examine the rationale for the 25 percent rule to decide its appropriateness for the application to areas in Zone B. It will also determine the variability of the flow in Zone B streams to examine the effects of 25 percent of the median annual flow diverted as upper limit on downstream users.

1.3. Review Approach

The reviewer was provided with a compilation of over 20 technical and other reports related to the water resources management plan, study of water resources, plantation forestry and sustainable water calculations. Flyers and other few-pagers were also provided on the calculation of flow volumes using Method A and Method B.

Consultation and discussions with different groups of people from the then Department of Water, Land and Biodiversity Conservation (DWLBC, now Department for Water, DfW), SA Water, Department of Primary Industries and Resource of South Australia (PIRSA) and other stakeholders were done either on a one-to-one basis or as a part of group or during the water task force meetings. Discussion with the DfW hydrologists was also done to see if there are any other catchments in South Australia which may be tested for their physical and climatological similarity with catchments in Zone A to take their streamflow data into account.

To examine the methods and assumptions that provide the basis for the Kangaroo Island water resource management policy, a good understanding of the process and behaviour of catchments on the Island is required. Thus the review aims to take that approach to gain an understanding of catchment hydrology of a number of representative catchments on the Island. The following tasks were undertaken:

1. Review of the documents related to KI water resource studies.
2. Analysis of hydrological data including modelling of different KI rivers in Zone A and Zone B.
3. Presentation of interim results to the Kangaroo Island water task force.
4. Review of the water resources policy based on findings from the hydrological data analysis and based on similar policies in other jurisdictions within Australia.
5. Report findings and make recommendations.

1.4. Outline of the Report

The main report consists of six major chapters describing the review approach, hydrological data analysis, rainfall-runoff modelling and review findings. In the next two chapters hydrological data analysis and streamflow modelling needed to perform the review are described. Review of the methods other related issues are discussed in Chapter 4. The conclusions are given in Chapter 5. Finally, Chapter 6 presents the recommendations including the future policy requirements.
2. HYDROLOGICAL DATA ANALYSIS

To aid the review the hydrological data were analysed to investigate the rainfall-runoff relationships and, rainfall trend and patterns across the Island. Outcomes of the analysis provided basis for many of the comments and recommendations in this review.

2.1. Current State of Hydrological Information in the Island

A recent review (Wen, 2005) found that information on the volume and quality of the island’s water resources and their use is incomplete. Water resources monitoring, evaluation and reporting are fragmented and with no coordinated plan for an integrated monitoring strategy. The only long term streamflow record is for the Rocky River located towards the western end of the Island.

Currently there are about 16 operational rain gauges/pluviometers maintained by the Australian Bureau of Meteorology (BOM). These, together with the data from other closed stations, cover rainfalls from 1865 to present. There are no current evaporation monitoring stations on the Island. The last such station at Parndana was closed in 1984. It is estimated that there are around 8590 farm dams, excluding identified marron ponds, with combined volume of 18570 ML.

Table 2-1 and Table 2-2 list the streamflow and rainfall stations respectively selected for data analysis. For streamflow these stations are selected because they are the only stations with a sufficient record. Although started in 1969, Rocky River has only 34 years of complete annual flow record from 1974. Five complete years (2003-2007) of flow data are available for Cygnet River at Koala Lodge. This is measured using a low crested weir and is mostly accurate for low flows (B. Murdoch, pers comm., 2010). Data from the gauging station for Timber Creek at South Coast Road is incomplete for all years of the record. The streamflow of Middle River, which is used for the municipal water supply in the Kangaroo Island, is not gauged. A location map of major rivers and streams of the Island is given in Appendix A.

Since the flow data for Rocky River goes back to the 1970s, only those rainfall stations that started before the 1970s and still operating were considered. Four rainfall stations, spreading from east to west across the Island, were chosen for rainfall data analysis. Of the four stations two are each in Zone A and Zone B. The daily rainfall and potential evaporation data for other stations to drive the models were obtained from the Queensland Government Environmental Protection Agency SILO patched point and gridded data set (Data Drill) (<http://www.longpaddock.qld.gov.au/silo>; Jeffrey et al., 2001).

Table 2-1 Streamflow gauging stations used in data analysis

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<th>Station Name</th>
<th>Commence</th>
<th>Comments</th>
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<td>A5130501</td>
<td>Rocky River upstream Gorge Falls</td>
<td>June 1969</td>
<td>Ongoing</td>
</tr>
<tr>
<td>2</td>
<td>A5131014</td>
<td>Cygnet River upstream Koala Lodge</td>
<td>July 2002</td>
<td>Ongoing</td>
</tr>
<tr>
<td>3</td>
<td>A5131002</td>
<td>Timber Creek at South Coast Road</td>
<td>June 2004</td>
<td>Patchy and incomplete</td>
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Table 2-2 Rainfall stations used in data analysis (maintained by BOM)

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<th>Commence</th>
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<td>American River</td>
<td>Dec 1883</td>
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<tr>
<td>2</td>
<td>M022808</td>
<td>Kingscote at Karinga</td>
<td>September 1909</td>
</tr>
<tr>
<td>3</td>
<td>M022815</td>
<td>Parndana at Pioneer Bend</td>
<td>December 1935</td>
</tr>
<tr>
<td>4</td>
<td>M022817</td>
<td>Flinders Chase at Rocky River</td>
<td>April 1960</td>
</tr>
</tbody>
</table>

A recent study has found that the dominant groundwater source to the Rocky River is from the shallow sedimentary aquifer system in the catchment headwaters rather than the regional fractured rock aquifer system. The groundwater discharge from the latter system is much more saline than the salinity in the Rocky River (Banks, 2010).
2.2. Rocky River Flow

2.2.1. Yearly flow

Figure 2-1 shows Rocky River annual streamflow from 1974 to 2009. The record reveals a sudden and significant drop in the streamflow since 1997. The average annual streamflows for periods 1974-1996 and 1997-2009 are 16810 and 8350 ML respectively, while the long term (1974-2009) average streamflow is 13760 ML. The 1974-1996 average and median flows are nearly same (median flow not shown in the figure), however the median yearly flow during 1997-2009 (short dashed line) is much lower than the average for the same period. This implies that the average value is affected by a few large annual flows during this period, especially the 2009 flow. Since 1997 the Rocky River annual streamflows never reached the annual average streamflow of the previous 23 years. Flow for 2008 and 2009 are at the higher side but it is noted that nearly the entire catchment was severely burned during the December 2007 bushfire.

The effect of streamflow reduction during the recent years is highlighted in Figure 2-2 which shows the yearly flow duration curves for three periods: 1974-1996 and 1997-2009, respectively. The long dashed line shows the long term average.

The flow that used to be 90th percentile flow earlier (pre 1997 period) is the median flow nowadays (1997-2009). The 90th percentile average yearly flow for the period 1997–2009 is around 2700 ML.
Yearly flow duration curve showing the shift in streamflow magnitude.

The annual runoff ratio (runoff/rainfall) shows a distinct fall in 1997-2009 period (Figure 2-3 a). On average, runoff is 10 percent of annual rainfall for the 1974-1996 period dropping to 5 percent during 1997-2009. This implies that for a given rainfall the catchment produces just half the runoff now than before. The reduction in runoff is not caused by a corresponding systematic reduction in rainfall in the catchment as shown by the rainfall runoff scatter plot (Figure 2-3 b) which depicts a much reduced runoff for a given rainfall since 1997. The probable cause of this fall in runoff is also investigated in this review (see Section 2.3.2).

2.2.2. Monthly flow

The plot of monthly river flows for 1973-1996 and 1997-2009 periods shows a shift in the amount and seasonality of the mean monthly flow (Figure 2-4). The highest average monthly flow that used to occur in August during 1973-1996 is no longer experienced nowadays. Instead, since 1997, two higher average monthly flows occur in July and August. Furthermore, these two highest flows are much less than the three highest flows of 1973-1996 period. The change in seasonality of streamflow may also be due to the change in rainfall seasonality. This is investigated in the next section.
Comments: Changes in rainfall-runoff relationships since 1997 are compelling to warrant any future modelling/forecasting using the post-1996 data. Therefore mostly the post 1996 Rocky River flow data are used in the subsequent analysis. It is noted that such a change in rainfall-runoff relationships have also been observed in the catchments of the Murray Darling Basin.

2.2.3. Monthly flow duration curves

The Rocky River monthly flow duration curves (FDC) for each year (Figure 2-5) show that since 1997 the river was perennial only in years 2008 and 2009, attributed to the devastating bushfire in the catchment in December 2007 (DEH, 2008) and above average rainfall of 2009. All major streams in Kangaroo Island are intermittent implying no connection with deeper groundwater table that could help sustain flow during dry summer months (see e.g. Green, 2010). While Green's report contend that it is a counter intuitive to find Rocky River flowing perennially, this study did not find that to be the case (see Figure 2-5). On average 50 percent of the time the monthly flow is less than 200ML. However for the three driest years 1999, 2002, 2006 (not labelled) the monthly flow of 200ML was not exceeded for around 70 percent of the time in 2002, the same for 1999 and 2006 was 58 and 55 percent respectively. These findings would have implications for prescription of sustainable use limits and the ability of SUL to be fulfilled during the dry years.
The flow duration curve for each month (Figure 2-6) shows that the river has zero monthly flow for seven months (November to May) at least once during 1997 to 2009. This suggests that those seven months cannot be relied upon having enough flow in the rivers and any prescribed diversion can only be fulfilled from the remaining months. If needed, these months can be assigned as winter dam fill months. The FDC also shows that only a quarter of time in December and about 18% of time in May the flows are greater than 200 ML. For rest of summer months the flow is well below 200 ML/month and the river stops flowing altogether in summer for most of the years.

Figure 2-6 Monthly flow duration curves for each month for 1997-2009 showing the river stops flowing during December to May most of the years.

2.2.4. Impacts of bushfire on runoff

Fire maps of Kangaroo Island, supplied by the South Australia Government Task Force Representatives (SAGTFR), depict fire events of different magnitude that have occurred in the Island during years 1971-72, 1977-78, 1990-91 and 2007-08. Among them 1977-78 fire was seemingly confined to a relatively small area.

Effects of bushfires can be similar to the forest clearing such that after a bushfire the catchment runoff increases due to the reduction in canopy and understory interception. However as the understory shrubs and tree canopy recovers the runoff starts declining and usually catches up with the original runoff. Figure 2-7 shows annual runoff ratios for Rocky River from 1974 to 2009 with years of bushfire indicated by arrow depicting that the effect of bushfire on runoff did not propagate beyond one to two years. In the case of post 1990-91 bushfire, the runoff ratio increases immediately after the event, but is not sustained during the subsequent years as indicated by the mostly decreasing runoff ratios. In this case, smaller runoff ratios in the following years may be partly due to mostly lower than average annual rainfall since 1991 (see Figure 2-12) although rainfall intensity and seasonality also play a role. It is noted that the subsequent regrowth may also have affected the runoff for the next few years however the decrease in runoff ratio is for an unusually long period, until just before the 2007-08 bushfire. All these imply that the long term change in catchment runoff identified in Figure 2-3 is not solely due to the bushfire events.
2.3. Analysis of Rainfall Data

Analysis of recent rainfall trends revealed that all stations, except for the Flinders Chase towards the west of the Island, show a decreasing annual trend. Figure 2-8 shows rainfall stations across the Island and the rate of change in yearly rainfall since 1997. These stations are in Zone A and Zone B and show distinctly different rainfall decline from station to station. The decline is gradually more severe from west to east of the Island ranging from +1.3 to -13.7 mm/yr per year (Figure 2-8). These suggest that Kangaroo Island has distinct rainfall zones exhibiting difference not only in annual rainfall but also in the amount and direction rainfall trend.

Table 2-3 Average yearly rainfall and rate of change for two different periods

<table>
<thead>
<tr>
<th>Rainfall Station (Station Number)</th>
<th>Yearly rainfall average for</th>
<th>Yearly rate of change rainfall (mm/yr) during</th>
</tr>
</thead>
<tbody>
<tr>
<td>American River (22800)</td>
<td>542</td>
<td>521</td>
</tr>
<tr>
<td>Kingscote at Karinga (22808)</td>
<td>465</td>
<td>473</td>
</tr>
<tr>
<td>Parndana at Pioneer Bend (22815)</td>
<td>614</td>
<td>597</td>
</tr>
<tr>
<td>Flinders Chase Rocky River (22817)</td>
<td>735</td>
<td>717</td>
</tr>
</tbody>
</table>
2.3.1. Seasonality of rainfall in Rocky River catchment.

Rainfall at the Rocky River catchment shows no significant change in seasonality between 1973-1996 and 1997-2009 periods (Figure 2-9). The average July and September rainfalls are 20 mm (15 percent) and 16 mm (22 percent) respectively, lower in 1997-2009 period than in the 1973-1996 period. However, the October to December average monthly rainfalls are higher for in 1997-2009 than that in the 1973-1996 period. These changes in monthly rainfall may be noteworthy but they are not sufficient to cause a large decline in the runoff or the runoff ratio observed in the Rocky River since 1997. This is because the effects of these positive and negative changes should compensate each other to result in a little or no net change in the streamflow.

![Figure 2-9 Rainfall seasonality at Flinders Chase station in the Rocky River catchment.](image)

2.3.2. Interpretation and implications of yearly rainfall trends in the Island

The rainfall at the Rocky River catchment has experienced seven consecutive years of below-average rainfall since 1993 (Figure 2-10 a). Similar phenomena are observed in other three locations on the Island showing five to seven consecutive years of below-average rainfall occurring at different periods (Figure 2-10). This again implies that these areas on the Island experience distinctly different rainfall behaviour. These consecutive years of below-average rainfalls for Parndana, American River and Kingscote (at Karinga) rainfall stations are 1993-1999, 2004-2009 and 2004-2008 respectively.

![Figure 2-10a](image)  
![Figure 2-10b](image)
It seems that during the long term below-average rainfall period the water level in the catchment is lowered due to the mining of groundwater by the vegetation causing a permanent disconnection of the groundwater with the surface water. This interpretation can be supported by the similar instances of long term below-average rainfall causing a steady decline of groundwater since 1975 in the Darling Plateau of the southwest of Western Australia (Croton and Reed, 2007). Instances of streamflow decline have also been observed as a step change in response to the occurrence of below-average rainfall years in this region (Petrone et al., 2010). They suggest that evapotranspiration during a low rainfall years creates deficit in soil moisture storage that is carried into the following years. These all also indicate that the rainfall no longer contributing to groundwater recharge.

Green (2010) suggests that the Rocky River has no connection with the deeper groundwater table although it is unclear if the disconnection is solely due to the below-average rainfall as mentioned above or the watertable has always been below the impermeable base rock. An earlier study (Nilsen, 2006) has found that discharges from groundwater are important source of water at discharge point to maintain permanent pool and swampy wetlands in all Kangaroo Island river catchments. These wet swampy areas help convert rainfall into runoff more efficiently. The SA State NRM Plan (2006) under its Principles for Riparian and Floodplain Management Guidelines states that ‘interactions between surface water and groundwater must be maintained so as to sustain ecological functions and dependent biodiversity that rely on this hydrological connectivity’. These dry years in the Rocky River catchment seem to have changed its flow pattern since 1997. It is hypothesised that catchments at other locations on the Island which also have experienced such long term below-average rainfalls will also show a similar permanent lowering of the streamflow. This will be broadly tested in the next section.

**Comments on low R^2 values of fitted curves in Figure 2-10**

The trend in rainfall data was examined using simple least square fit which showed a small but consistent trend. The R^2 values of the yearly data were low. The low R^2 value in the trend does not necessarily mean a lack of trend in the data and can merely indicate a large standard deviation. When the yearly rainfall data were filtered using a few years of moving average the trend line and the R^2 improved. Figure 2-11 shows the annual rainfall at the four rainfall stations given in Figure 2-10 together with the simple moving averages using 15 and 20 points to show a long term trend. Trend lines fitted to these points depict the same declining trend and explain 69% to 58% of the data respectively for the Flinders Chase at Rocky River stations. These values for Parndana are 0.24 and 0.44; for Kingscote (at Karinga) are 0.02 and 0.12; and for American River are 0.22 and 0.34 respectively. Although the R^2 for Kingscote data has not improved much, indicating a continuing scatter in the filtered data, the R^2 values for the rest have improved reasonably well.
2.3.3. Other trend measures

Cumulative Residual Plots

The cumulative difference from the mean (cumulative residual) plots show different change points for the four stations (Figure 2-12). For Flinders Chase at Rocky River station (Figure 2-12a) the change point is in about 1993 and since then the rainfall has been lower than average for majority of the years. For American River (Figure 2-12d) the turning point is at around 2001 and since then the annual rainfalls have been below long term average. For Pambana at Pioneer Bend and Kingscote at Karinga rainfall stations also the recent drier periods are quite apparent.
Figure 2-12 Cumulative departures from mean (cumulative residual) plots for four rainfall stations used in the report showing recent change points.

**Double mass curve**

The double mass curve requires two stations with good correlation and with one station unaffected by the change to detect any trends. They are good tool for detecting unusual changes to a suspect station but cannot be used in finding overall change due to an underlying reason that affects all stations in the area. Therefore double mass curve for trend analysis was not used in this review.

**Mann-Kendall Trend Test**

The Mann-Kendall trend test (Mann, 1945; Kendall, 1975) is a non parametric test to analyse trend in time series data. The Mann-Kendall trend test (http://www.toolkit.net.au/Tools/TREND) applied to 1973 to 2009 rainfall does not show any statistically significant trend for long term rainfall data for stations other than American River which shows a falling trend at 0.05 significance level. However the trend test using 1997 to 2009 rainfall data showed a falling trend for Kingscote at Karinga at 0.05 significance level, American River at 0.01 significance level and no statistically significant trends for Flinders Chase and Parndana stations.

**Concluding Remarks**

Although not all trend measures used showed a falling rainfall trend in all stations in unison, among those measures more than one of them showed a long or short term rainfall falling trend for each of the stations.
3. STREAMFLOW MODELLING AND FLOW HINDCASTING

The majority of major rivers on Kangaroo Island are located in Zone A except for the Cygnet River and Timber Creek about half of whose downstream areas are in Zone B. Streamflow modelling of Eleanor Rivers in Zone A and, Cygnet River and Timber Creek was carried out to generate synthetic flow data. The aim is to examine their rainfall-runoff relationships.

Four rainfall-runoff models (AWBM, IHACRES, SIMHYD and Sacramento) were tested for their ability to reproduce observed Rocky River flow in calibration. Based on their calibration performance, Sacramento model (Burnash et al., 1973) was used further for streamflow modelling in above three catchments. The Sacramento is a lumped conceptual daily rainfall-runoff model with 18 parameters and five moisture stores. The model is used in New South Wales and Queensland within the IQQM framework. It was also used in the South West Western Australia Sustainable Yields and Northern Australia Sustainable Yields Projects (CSIRO, 2009a &b).

3.1. Model Calibration

Daily streamflow data from 1997 to 2009 of the Rocky River catchment was used to perform split sample testing of the model using 1997-2003 data for calibration and 2004-2009 data for validation. The rainfall data from the Australian Bureau of Meteorology (BOM) Flinders Chase rainfall station (22817) was used together with potential evapotranspiration data from the SILO patched point data set. In the calibration, the rainfall-runoff model was optimised using an automated optimiser to maximise an objective function that incorporates the Nash-Sutcliffe efficiency test (NSE) (Nash and Sutcliffe, 1970) of the daily runoff together with the constraint that the total modelled runoff over the calibration period is within five percent of the total observed runoff.

The NSE is an estimate of the variance in model error between simulated and observed data. Values can vary from $-\infty$ to 1, with 1 indicating a perfect fit and a value of zero indicating that the model is no better than assuming an average flow over the period. An undue influence of high flows can be an issue with this indicator; however the NSE is a reliable statistic for assessing the goodness of fit of hydrological models and is recommended for a variety of model types (ASCE, 1993; McCuen et al., 2006).

3.2. Parameter Transfer to Estimate Flow from Ungauged Catchments

The model parameter values are unique to the input climate and catchment characteristics on which they are calibrated. Since there is no proven method to transfer these parameters to other catchments, the transfer of model parameters from gauged to ungauged catchments were done on the basis of nearest neighbours using proximity as the determinant of similarity. Researchers have found that parameters transposed from nearest neighbours give the better runoff results (Viney et al., 2009a and 2009b; Zhang and Chiew, 2009, Chiew, 2010). For example, Merz and Blöschl (2004) suggest that spatial proximity may be a better similarity measure for transposing catchment model parameters in space than physiographic catchment attributes. Some research found that taking the mean of calibrated parameters from two neighbouring gauged catchments and applying those to the ungauged catchment model showed “surprisingly good” results (Hogue et al., 2006). However if there is a substantial difference between the land use patterns of neighbouring catchments then flow calculated using transferred parameter may need to adjusted for changed land used conditions. In many of the CSIRO’s sustainable yield projects (e.g. CSIRO, 2007) parameter transfer based on nearest neighbours have been used to derive flow for ungauged catchments.

Streamflow from the Eleanor River catchment in Zone A was derived using parameter transferred from the calibrated model for the Rocky River catchment. For the reasons described in Section 2.2, Rocky River parameters from 1997-2009 and 1974-1996 were used separately. The streamflow for the Eleanor River was also modelled using parameters from the calibrated model for the Cygnet River (at Koala Lodge). This was done because the Eleanor River catchment, which lies entirely in Zone A, has
its land use more similar to the Cygnet River than to the Rocky River. Based on the discussion of Eleanor Rivers flood history with a local farmer with farming properties in the catchment (Richard Trethewey, Pers. Comm, 2010) the flow values for Eleanor River derived using the Cygnet River parameters were adopted.

Similarly the calibrated model parameters for the Cygnet River (using its five years of available data) were also used to generate its own past streamflow and that of the Timber Creek catchment. A subsequent test of the modelled flow from the Timber Creek using partially available observed data shows the parameter transfer has produced a reasonably good result (Section 3.3.3).

### 3.3. Hindcasting of Streamflows

Streamflow from 1973 to 2009 for the three catchments were generated using climate data for the same period. For the Cygnet River parameter set from the calibrated model using the available 2003-2007 streamflow data was used to derive the remaining streamflows in the river for 1973-2009. Input climate data from Parndana rainfall station (22815) were used. The same parameter set was used to derive streamflow for the Timber Creek at South Coast Road using climate data from the SILO Data Drill at the centre of the catchment area.

#### 3.3.1. Streamflow characteristics of Eleanor River

The yearly streamflow for Eleanor River shows the lowering of long term average (Figure 3-1). The rainfall data obtained from SILO data drill shows that catchment has experienced six continuous years of below average rainfall since 1994. As a result, and for the reasons described in Section 2.3.2, only twice (years 2000, 2009) in the last 16 years the annual streamflow of the Eleanor River has exceeded the pre-1993 average. The average yearly modelled streamflow for 1973-1993 is 21270 ML while that for the 1994-2009 period is 14090 ML, suggesting a 34 percent decline. The river had some of the lowest streamflows in 1994, 1982, 1977 and 2002. Highest flow was in 1992. The other higher flows were in 1981, 1983, 1984 and 1989. Rainfall runoff scatter plot shows that rainfall threshold for runoff is about 450 mm (Figure 3-2), implying that annual rainfall under that amount would not produce streamflow in the catchment.

![Figure 3-1 Eleanor River streamflow determined using calibrated parameters from Cygnet River showing mostly below average flow since 1994. The green and orange solid lines are annual average flow for 1973-1993 and 1994-2009 periods respectively. Dashed line shows the long term annual average flow.](image)

The modelled annual runoff ratio of Eleanor River catchment shows a 25 percent drop in average runoff ratio in 1994-2009 compared with that during the 1973-1993 (Figure 3-3). This implies that for a given rainfall the runoff from the Eleanor River during the recent years is less than in the past.
3.3.2. Streamflow characteristic of Cygnet River at Koala Lodge

Streamflow of the Cygnet River at Koala Lodge from 1973 to 2009 shows an annual falling trend of 334ML/year. Similar to the Rocky River catchment the Cygnet River catchment also has experienced about seven consecutive years of below-average rainfall from 1993 to 1999 as indicated by the rainfall data at the Parndana station. The effect of this low rainfall period is clearly seen on the runoff behaviour of the Cygnet River. For years 1997-2009 there is a falling trend in runoff of 186 ML/year/year which otherwise had a much stronger falling trend of 1390 ML/year/year for the 1997-2008 period. The average flow for 1973-1996 is 40760 ML while the same for 1997-2009 is only 29120 ML, a drop of 30 percent. The falling trends of runoff together with falling trends in recent rainfall imply that present streamflows are not representative of that of the past.

Highest modelled flood was in 1984 while the other higher flows were in 1981, 2000, 1992 and 1983. Year 2006 was the driest followed by 1977, 1976, 1999, 1994 and 1982. Rainfall threshold for runoff is estimated to be about 400 mm.
3.3.3. Streamflow characteristics of Timber Creek

Long term modelled streamflow from 1973 to 2009 shows no significant long term trend (Figure 3-5), however, a decreasing trend in streamflow of 408ML/year/year is observed since 1997 (Figure 3-6). This can be attributed to the consecutive years of below-average rainfall during 2004-2008 and below-average rainfall for most of the years during the 1990s (Figure 2-10 c). The effects of these may be seen in the future streamflows. Modelled data shows that although a higher than average rainfalls have produced higher than average runoffs in 2000 the runoff ratio for 1997-2009 (0.08) is sill less than the long term average (0.10).

The average flow for 1973-1996 is 15240 ML while the same for 1997-2009 is 12140 ML which amounts to a drop of 20 percent. The driest year was 1977 while years 1976, 2006, 2002 and 1999 were also dry years. The year with largest flow was 2000 followed by 1989, 1992 and 1978. The rainfall threshold for runoff is about 400 mm.

**Testing modelled Timber Creek Streamflows**

Four years of partial flow data for 2004-2006 and 2009 is available for the Timber Creek which was used to test the performance of the model. The observed flows for Timber Creek were missing mostly for earlier or later months of the years so the flow record for the main winter months, when most of the flows occur, were still available for a useful comparison. Figure 3-7 shows a scatter plot of observed and modelled streamflows for those four years. The plots show that the modelled flow is slightly larger than observed flow which can be attributed to the missing observations.
Figure 3-5 Modelled streamflow of Timber Creek at South Coast Road. The horizontal dashed line shows the long term average and the solid straight line shows the long term trend.

Figure 3-6 Modelled streamflow of Timber Creek since 1997 showing a falling trend (solid straight line).

Figure 3-7 (a) Scatter plot of partially observed and modelled Timber Creek yearly streamflows. The fitted line is the 1:1 line, (b) Yearly flow hydrograph from partially observed and modelled Timber Creek flow data.
Observed and modelled streamflows in all catchments examined in this review showed a falling trend which is more pronounced during recent years (since 1994 or 1997). The major causes of these drops can be attributed to two factors:

(i) The consecutive and long-term below average rainfall experienced by the catchments in the 1990s which would have led to the lowering the groundwater permanently and loss of connection between surface water and groundwater (see Section 2.3.2 for justification). These connections between the groundwater and surface water are important in creating a wet antecedent condition in the lower valleys of a river for runoff to ensue from subsequence rainfalls. This interpretation is further validated by the almost halving of the runoff ratio during recent years such that same amount of rainfall gives a much lower runoff now than it did before.

(ii) The yearly rainfall towards the east of the Island has shown a gradual (in eastward direction) and large declining trend since 1997. As the rainfall and runoff processes are nonlinear this would affect the streamflow in greater proportion.
4. REVIEW OF THE METHODS

4.1. Delineation of Zone A and Zone B

Delineation of Zone A and Zone B is based on the yearly rainfall hyetograph of Kangaroo Island. Zone A comprises the areas that are above 600 mm/year rainfall. The major land use of Zone A is grazing, cropping, modified pasture and forestry. Some native forest also exits, mostly at the upstream areas of Stunsail Boom River catchment. Method A is applied to catchments of Zone A based on the expectation that the historical rainfall runoff data for the Rocky River is typical of the desired natural state of runoff for the catchments of that zone and hence can be extrapolated to those catchments. The remaining parts of the Kangaroo Island under water resources management area are in Zone B. Areas in Zone B experience annual average rainfall between 475 mm to 600 mm. Most of the land use in this area is grazing, cropping and modified pasture together with some forestry toward the east. The Cygnet River at Koala Lodge and the Timber Creek at South Coast Road have nearly half of their downstream catchment areas in Zone B. No other major river catchment is located fully within Zone B.

**Comments:** Delineation of Zone A and Zone B is justifiable. Although the delineation is based on the long term yearly rainfall values, further rainfall and streamflow analysis done in this review suggests that these two zones do seem to behave differently hydrologically. As shown in Figure 2-8 and Table 2-3 the recent annual rainfall trend in these two zones are also quite different. For example, areas in Zone A have much lower rainfall declining trend. These areas have also experienced episodes of below-average rainfall much earlier than that by the areas in Zone B (Figure 2-10). Effects of the two rainfall patterns are reflected in the modelled streamflow response from catchments of these two zones such that Zone B catchments have not undergone the sudden decline in runoff found in the Zone A catchments. The effects of recent drying of Zone B catchments can be partially seen in recent runoff from the Cygnet River and the Timber Creek.

4.2. Review of Method A

Method A provides steps to calculate the Sustainable Use Limit (SUL) for further development in catchments and subcatchments in Zone A (see Appendix B). The method assumes the total flow calculated using the annual average runoff ratio of the Rocky River and annual average rainfall of the catchment in question as the minimum required catchment flow under natural condition. It uses a series of empirical factors and formula to calculate the surplus flow available for further development. A few of those factors and formulations have no documentary evidence to support their appropriateness. The method does not take into account the variability of the streamflow and reliability of the SUL. It also does not incorporate processes and procedures to account for waters to the downstream landholders. Some of the explicit and implicit assumptions used in the method are examined below.

1. Historical rainfall runoff relation for the Rocky River catchment can be applied to other catchments of Zone A.

**Comments:** The yearly runoff ratios in Rocky River have been found to be quite different during the recent years indicating that runoff ratio derived from the past data is not representative of the present catchment rainfall runoff behaviour.
2. Streamflow volume calculated using catchment’s average annual rainfall and average runoff ratio of Rocky River is the minimum catchment flow for Zone A catchments under natural condition to be maintained.

**Comments:** As the runoff rate of Rocky River goes down (see Figure 2-3) the requirement for minimum flow to be maintained for all other catchments of Zone A also decreases. This, as per Method A, results in an increase in the calculated SUL. A comparison of Figure 2-3 and Figure 3-3 shows that the runoff ratios, calculated from observed Rocky River and modelled Eleanor River streamflow data respectively, are different. So the minimum flow requirements for Rocky River and other catchments may not change in tandem.

3. Nominal volume available based on average annual runoff volume can be used to determine sustainable diversion volume by applying 20 percent precautionary buffer.

**Comments:** The 20 percent precautionary buffer seems to provide a factor of safety based on the expectation that following uncertainties can be covered by the buffer: (i) the use of tanh relation (ii) estimation of average runoff from average rainfall (iii) accuracy in the estimation of areas of forest and other land use type in the calculation, and (iv) use of the 15 percent factor to convert runoff from cleared land to runoff from the forested land.

Given the rainfall and runoff variability of the Rocky River catchment the 20 percent buffer may not cover for the drier periods thus allowing more diversion than SUL calculated by the method. Issues related to all other uncertainties and inaccuracies arisen from the above are discussed below.

4. Validity of annual average runoff and rainfall input for sustainable use limit calculation.

**Comments:** The annual flow duration curves shown in Figure 2-2 clearly show that over the years the flow statistics have changed, and so have the rainfall patterns (Table 2-3). Figure 2-3 shows that year to year variability in runoff is also quite large. Therefore SUL calculated based on average rainfall and runoff cannot be relied on being available every year.

As discussed in Section 4.6, in most of the other jurisdictions in Australia the sustainable flow is much less that given by the average annual flow.

5. Annual average runoff for cleared land is calculated using tanh function

**Comments:** The tanh rainfall runoff relationship is primarily used for infilling long term runoff values based on observed rainfall (Grayson et al., 1996) using curve fitting of the rainfall runoff plot. Nowhere in its formulation its applicability to cleared or any other land use type is suggested. The tanh relation cannot be used without runoff data to calculate initial and continuing losses.

6. Runoff from forested catchments is 15 percent of the runoff from cleared catchments (calculated using the tanh function).

**Comments:** Greenwood et al. (2007a, b) report that the streamflow reduction due to forest plantation on cleared land vary from 60 to 100 percent with average maximum reduction of 85 percent in South Australian catchments. Such reductions depend on the type of species planted and how the understorey is managed. The tree water use also depends on the age of the plantation and changes as the forest matures. Zhang et al. (2010) found that in selected catchments across Australia, the expansion of plantation accounted for 28 to 100 percent reduction in observed total streamflow.

However global analysis of afforestation data found that depending on the species and rainfall zones, the annual runoff on average reduced by 44 and 31 percent (up a maximum 75 percent) when grasslands and shrublands were reforested (Farley et al., 2005).

Given the above, for a new plantation the use of 85% reduction in runoff due to commercial forestry may be reasonable however for a mature forest this value would need a revision. The reduction in runoff should be decided based on existing the forest type and forest age and should also depend on the mean annual rainfall.
Concluding remarks:
The main issue with Method A is the use of hydrologic characteristics of a vegetated pristine catchment as benchmark (in quantity and duration) for most other catchments on the Island with significantly modified environment. Hydrological analyses of observed and modelled streamflow data show that rainfall runoff behaviours of Rocky River and other rivers of the Island are different implying a corresponding different minimum flow regimes.

The assumptions inherent in Method A can also be contested from a hydrogeomorphological perspective. When catchment vegetation is cleared there is an immediate increase in streamflow due to the reduced canopy interception. Depending on the extent of thinning and on the rainfall, the streamflow may continue to increase for a few more years before coming to a new steady-state. If the forest clearing is permanent (e.g. conversion to agricultural land) the groundwater level may begin to rise due to the reduced plant water use caused by lower evapotranspiration (see e.g. Ruprecht and Stoneman, 1994; Bari and Smettem, 2006). This can give rise to permanent wet areas along the riparian zone due to the possible intersection of watertable with the landscape and increased groundwater discharge. Green (2010) reports incised creek lines in cleared catchments of the Island due to increased overland surface flow without permanent riparian wet areas.

Regular occurrences of large areas of wooded swamps along the creek lines in the headwaters of Rocky River catchment have been observed (Green, 2010). These areas function as the ‘source areas’ that efficiently convert the rain fallen over them into runoff generating the ‘saturation excess overland flow’ (Dunne and Black, 1970). Occurrences of such source areas are not usual in the cleared catchment and instances of no such areas have been reported. This suggests cleared catchments have a different hydrological regime which is quite different to that of the forested catchment, and the riparian zone ecology and aquatic biology of these two types of catchment are different. Therefore streams of these two catchment type may require different minimum flows for environmental purposes.

Therefore the key underlying assumption of Method A that mean annual flow of a fully vegetated catchment is appropriate minimum flow for adjacent cleared catchments with possibly similar rainfall, geology and topography cannot be sustained.

4.3. Review of Method B

The Method B, also known the ‘25% rule”, stipulates that 25 percent of the median annual adjusted catchment yield (MAACY) should be used as an indication of the sustainable use limit of the catchment. The term ‘adjusted’ is defined as the natural catchment discharge with the impact of farm dam and forestry removed. Not much published information exists on how this is applied in a catchment with multiple downstream users with existing and proposed developments. This review of Method B is based on the discussion with the South Australian Department for Water (DfW) hydrologists and information obtained from DWLBC publications about how the method is applied at a catchment, subcatchment or a property level. The information obtained from the SAGTFR describing the steps to calculate available is given in Appendix B. Although the method description for Method B is not comprehensive it lists the steps to calculate the available water (AW) using this method.

The assessment of available water within the Sustainable Use Limits is made at three different scales and in the following order: catchment, sub-catchment/management zone, and finally at the property level. The purpose of the catchment scale assessment is to determine if there is any available water within the catchment’s Sustainable Use Limit. Method B is based on a number of assumptions relating to the prior water commitments (e.g. existing farm dams) and to the need for fulfilling the wetland water requirements (WWR) if any, before any available water (AW) for further development is available (Greenwood et al., 2007a). However the provision of WWR does not exist in KI policy for SUL calculation.

It seems that the net allocation to farm dams excludes any evaporative and seepage losses from the farm dam storages (implied by “another 25% of the captured catchment runoff can be expected to be lost to evaporation and seepage”, DWLBC Factsheet No. 81). This is perhaps based on the assumption that the dam storages will be topped-up using additional water over and above the 25 percent allocation to make up for those losses. Whether or not same provision also applies to the pumped diversions is unclear.
The available water for further development is calculated as:

$$AW = 0.25 \text{(MAACY)} - 0.5 \text{(existing farm dam capacity)} - \text{(exiting forest water use)}$$

In determining the $AW$ only 50 percent of the farm dam storage capacity is used to reduce the available water for further use (unlike in Method A), assuming that only half of the available dam capacity can be effectively utilised. Water used by existing forestry is calculated by assuming 85% of the average annual adjusted runoff (AAR) from the area is used by the forest, however how the annual adjusted catchment yield (AAR) is calculated is not described. If AAR is the median average annual adjusted catchment yield then the above relationship becomes:

$$AW = 0.25 \text{(MAACY)} - 0.5 \text{(existing farm dam capacity)} - 0.85 \text{(MAACY Ap/At)}$$

where $A_p$ is the plantation area in the catchment and $A_t$ is the total catchment area. During any scale of the calculation if the $AW$ is equal to or less than zero no further development upstream is allowed.

**Comments:**

The 25 percent rule is adopted until additional information is available (SA State NRM Plan, 2006). However the application of Method B is not simple and requires long term flow data, either observed or modelled, at different catchment/subcatchment scales. Even its application based on the observed streamflow data of a catchment with existing farm dams and plantation forestry is not straightforward. This is because the observed data cannot be used as median annual adjusted catchment yield (MAACY) under those conditions. The observed flow data may be used to calibrate a model which is then used to generate past flow data using no development scenario to determine adjusted catchment yields. This requires modelling the effects of forest cover change and farm dams on streamflow, which is a nontrivial exercise. Although impact of farm dams can be simulated using models like CHEAT (Nathan et al., 2005).

In areas where observed data are unavailable the catchment yields need to be modelled using parameter transfer (e.g. as done in this review) and the above steps taken to determine the mean adjusted annual catchment yield.

From the calculated SUL the deduction of 50 percent of farm dam capacity to determine the available water needs to be reviewed as the assumption behind this may not be sound. There may be cases when waters to the full capacity of the farm dams are retained and used, especially in smaller dams which can readily fill up to their full capacity. For seven catchments in south west of Western Australia typically, for every 1 ML of farm dams in a catchment, the mean annual flow is reduced by approximately 1 ML (SKM, 2007). It is noted that in Method A the impact of a farm dam on flow is calculated by reducing the average flow by one ML per ML of the dam capacity (see Appendix B). Thus no scaling factor is applied to lessen the impact of farm dam capacity on SUL.

The use of the factor 0.85 to calculate the forest water use from plantation areas is within the 80 to 100 percent reduction in streamflow that have been reported to occur after deforestation although this reduction is also dependent on the vegetation type and rainfall zone (Vertessy et al., 2003). However as discussed earlier (Method A, Point 6), the forest water use decreases as the forests mature and the water use may be lower.

In Western Australia and Victoria the range of the percentage mean annual winter flow extracted under 80 percent reliability vary from 0 to 21 percent and 0 to 23 percent, respectively. As a comparison, the SDL was determined to be around nine percent, on average, (cf. 25 percent in Method B) of the mean annual flow in south west Western Australian gauged catchments (SKM, 2008b, page 124). Although it is not guaranteed to be adequate for sustainable ecosystems, for unregulated catchments in the ACT the maximum diversion is set at 10% of flow above the 80 percent exceedance flow. This is done to avoid unnatural occurrence of zero flow or low flow periods or unnaturally prolonging those periods which are undesirable for ecological reasons. They are also done to keep the streamflow within the natural variability of flow regime. Method B does not prevent unnatural occurrence of low flows for a prolonged period. The number of zero flow days are expected to increase significantly after plantation are established (Lane, 2003; Zhang et al. 2010) affecting the ability to maintain a minimum threshold flow rate as stipulated by the KI SUL policy.

Therefore the 25 percent value used in Method B is higher than those adopted in other Australian states. Whether it is too high or too low for the Kangaroo Island conditions can only be determined by taking into account all other socio-economic considerations.
Regardless, as this method requires long term observed or modelled flow data to calculate the median adjusted annual catchment yield, the rationale for the use of Method B is hard to justify. With the amount of information needed to implement Method B, it may be possible to come up with a SUL that better reflects the flow variability of an individual catchment. This includes prescribing the SULs in terms of volume per unit catchment area for different catchments.

Reliability of extraction based on Method B

Even though diversion of only 25 percent of mean annual adjusted flow is allowed under this method, it is quite possible for all stream water to be allocated as sustainable diversion during the drier years. For example, the long term mean annual flow for the Timber Creek is 12540 ML (Figure 4-1). As per the Method B, assuming under no-existing-development and no WWR, the SUL is 3135 ML which is more than yearly flow for four years (1977, 1976, 2002 and 2006) out of 37 years. During these years extracting flow volume given by Method B would divert all waters leaving no downstream flow. This can result in river flow outside of the natural flow regime. The flow duration curves for before and after extraction cases (Figure 4-1) show that about 10 percent of times no water available for downstream use in the Timber Creek after extracting the amount of water given by Method B.

![Figure 4-1 Yearly flow duration curve for Timber Creek showing the effect of water diversion under Method B (shown as ‘after extraction’).](image)

In the above example the SUL and its reliability is done using annual flow values using Method B. It is noted that the annual SUL and its reliability can also be calculated using monthly or daily flows data applying monthly or daily extraction threshold limits (see SKM, 2008a, b).

Equitability

A simple analysis suggests that Method B may not be equitable for all water users along a stream. As an illustration Figure 4-2 shows three serially downstream subcatchments (C1, C2, C3) with (assumed) no existing development and three separate land holders. Since the Method B is calculated from catchment scale to subcatchment scale it can be easily shown that a large development utilising full catchment SUL in subcatchment C3 ceases the possibility of any further developments on the other two upstream subcatchments. This is because landholder of subcatchment C3 is assign the flow given by SUL based on flow passing through the end of subcatchment C3, which is the flow from the whole catchment. While a similar full utilisation of SUL in subcatchments C1 or C2 still leaves the allowable waters for the downstream subcatchments.

A mention of the areas in the upper reaches being less attractive to development due to the potential for the wetland water requirement for lower reaches be partially offset by upstream contribution is also found in Greenwood et al. (2007a).
General remarks

1. Terms ‘average’ and ‘median’ as well as ‘annual adjusted catchment yield’ and ‘annual adjusted catchment runoff’ are used in various documents with possibly similar meaning thus creating unnecessary confusion. The State NRM Plan (2006, page 79) uses the term ‘median adjusted catchment yield’ which should be used in all documents.

2. Calculation of AAR is not described in any of the documents, thus this review was unable to comment on that. Comments have already been made on the use of tanh function for calculation the flow from cleared land.

4.4. Validity and Appropriateness of the Data Used in Support of the Policy

Factors identified as the threats to the water resources of the Kangaroo Island include climate change and over-development of the farm dams and plantation forestry. These factors have the potential to impact on in-stream and riparian habitat including the loss of sustainable ecosystems of the wider flooding areas. Threats also exist for the change in river/stream morphology affecting the river course, erosion and deposition which poses risks to the in-stream habitat.

Climate change data

The climate change impacts for the Kangaroo Island are adopted from a CSIRO study (Suppiah et al., 2006) which lists the range of global warming and associated change in rainfall centred for 2030 and 2070 on the Island. These impacts are based on the climate change simulations conducted for the International Panel of Climate Change, Fourth Assessment Report (IPCC AR4). These results are the average of 11 of 13 best performing Global Climate Models (GCM) for South Australia based on scenarios described in Special Report on Emission Scenarios (SRES, 2000) which assume no explicit policies to limit greenhouse gas emissions. The SRES high and low scenarios cover the range given by two IPCC CO₂ stabilisation scenarios at 450 ppm by 2100 and 550 ppm by 2150 (Suppiah et al., 2006).

Comments: This is the only study that has investigated the impact of future climate change on Kangaroo Island. As mentioned above it used the average from 11 of 13 best performing GCMs for South Australia used in the IPCC AR4 with the full SRES scenario range. In absence of any other and further studies and given the use of latest knowledge on climate change in this work, the currency and validity of the climate change scenario and impact is justified. Furthermore, given the nonlinear nature
of rainfall runoff response such that a small reduction in rainfall results in a much larger reduction in
the runoff (CSIRO, 2009a) the range of rainfall decrease found in the climate change study may pose
a risk to the Island’s water resources. Therefore the use of climate change scenario data to derive the
water resources management policy is appropriate.

Streamflow data
Under Method A the long term Rocky River data are used to determine average runoff from
catchments in Zone A.

Comments: As described in Section 4.2 the use of long term Rocky River streamflow data to
determine runoffs from other Zone A catchments may lead to unreliable SULs as there is no basis to
suggest that that the mean annual discharge for a fully vegetated catchment is appropriate minimum
flow for the adjacent cleared catchments. During the recent years (1997-2009) streamflows in the
Rocky River have shown a marked decline and they do not accurately represent the past long term
flows. Furthermore the runoff coefficients derived from the modelled data from other catchments within
Zone A are very different to that of the Rocky River. Annual rainfalls in the eastern region of the
Kangaroo Island have shown decline of varying degrees in the recent years which has a potential to
decrease the streamflow in the region. Some of these decreases are already apparent in the modelled
results of three rivers examined in this review. Therefore the use of the long term streamflow data is
inappropriate to base the management decision as that can lead to an overestimation of available
flow. A possible alternative to this approach is discussed in Section 6.3.

Volume 1 of the Natural Resource Management Plan lists the estimated annual average water yield
for major catchment derived from the tanh rainfall-runoff relationship (KINRMB, 2009, Pg. 52). As
noted in Section 4.2, the tanh rainfall runoff relationship is primarily used for infilling long term runoff
values based on observed rainfall using the curve fitting of rainfall runoff plot thus its use to calculate
those annual yield is of concern.

4.5. Do Methods A and B Meet the Objectives of the Policy?

The ability of sustainable use limit calculation methods to meet the following objectives of the water
resources management policy is examined. The terms sustainable use limit (SUL) and sustainable
diversion limits (SDL) are used with similar meaning in this subsection.

1. Best practice water resources management

Comments: There is no clear definition of best management water resources management
stipulated in the policy. The other factors such as environmentally sustainable diversion limits (SDL) or
SUL which are part of the best management practice are also not defined in a quantititative way. The
SDL or SUL are based on environmental, socio-economic and ecological sustainability perspectives.
In general, the best practice water resources management should regulate the streamflow and define
the SUL such that streamflow remains with the natural stream variability and causes no adverse and
irreversible damage to the ecosystem. For example flow after the diversion should not be below the
driest year (see e.g. Lang et al., 2008). This will ensure a minimum environmental flow in the stream.
The number of zero flow days are expected to increase significantly after plantation are established
Lane, 2003; Zhang et al. 2010) thus affecting the ability to maintain a minimum threshold flow rate.
However with careful planning hydrologic impact of plantation can be minimised (see Vertessy et al.
2003 for further details). Likewise, the Mercar et al. (2010) report describes an approach to model the
impact of plantation expansion on catchment yield which allows the modelling of the effects of intra-
catchment variation in rainfall, soil and other plantation management on catchment streamflow
response. For a given extent of plantation (ha), it shows difference in streamflow reduction varies
depending on the location of plantation in the catchment.

The SUL for any catchment also depends on the variability of the streamflow such that for a stream
with highly variable flow a mean annual flow or a value close to that may result in unreliable as well as
unsustainable extraction limits. This will have an impact on the aquatic and riparian ecosystems due to
diversion of all available flow most of the time thus relying on the defined threshold flow rate to maintain the minimum flow. If the above criteria of best practice water resource management is adopted then a water use limit based on the average/median runoff will not be appropriate. As a comparison, the SDL was determined to be around nine percent, on average, (cf. 25 percent in Method B) of the mean annual flow in south west Western Australian gauged catchments (SKM, 2008b, page 124).

As explained in Section 4.2, Method A calculates the volume of available water based on average runoff coefficient using the average rainfall. The calculation is based on assumptions and methods that can lead to an inaccurate determination of SUL. It does not deal with variation and reliability of available flow leading to over/under extraction. It also does not incorporate processes and procedures to account for waters to the downstream users.

As discussed in Section 4.3 the SUL based on Method B can provide for environmental water and downstream consumptive use during the normal flow years, however in the drier years the method may lead to little or no flow downstream. The catchments with high extraction limits to the mean annual flow ratio tend to be those with low year-to-year variability in flow evident by a high baseflow component inflow (SKM, 2008b, page 124) and low interannual coefficient of variability (CV). Although no definitive information groundwater surface water connectivity of all catchments Kangaroo Island is available it is most likely that Island’s major rivers are disconnected with the regional groundwater systems or have limited connections(Green, 2010) thus they a have a very low baseflow component during especially during summer months. Therefore a large percent of annual flow rate as SUL in these rivers can lead to more days of flow governed by the minimum threshold flow rate. The interannual CV of modelled streamflow of Timber Creek is 0.68 suggesting a larger year-to-year variability.

2. Protection of aquatic and riparian ecosystem

**Comments:** The Australian and New Zealand Environment Conservation Council (ANZECC) Guidelines provide key indicators to measure and assess any risk to desired environmental aspect such as aquatic ecosystem. Different levels of protections for different categories of aquatic ecosystem condition are envisaged that is worked out in conjunction with the conditions of the aquatic and riparian ecosystems. The level of protection is the level of stream water quality desired by the stakeholders and implied by the adapted management goals (ANZECC, 2000). It defines three categories of ecosystem conditions ranging from high conservation/ecological value systems to highly disturbed systems. Differing levels of protection may be appropriate for different usage of water such as drinking water, recreation, primary industries and sustenance of aquatic and riparian ecosystem.

In absence of a level of protection desired it is not possible to ascertain whether or not the sustainable use limit calculation method will be able meet its objectives. For the protection of aquatic and riparian ecosystem flow of enough volume is required to (i) maintain near stream ecosystem that is supported by the bankfull or overbank floods (ii) flush the debris and sediments as the movement of sediment is important for maintaining healthy aquatic ecosystems, and (iii) maintain the channel structure. Similarly small floods scour out fine sediment that accumulates in riffles and damage the fish habitats, water plants and other aquatic life. The small floods also help the river maintain its natural channel form. There have been numerous studies showing the effects insufficient water on the floodplain on biodiversity of animal and plant species (see Lloyd et al, 2004).

3. Provide for ecologically sensitive use of water resources that supports social economical development.

**Comments:** See Point 2.

4. Promote reasonable access to water so that the use of water by landholders does not detrimentally impact on the ability of other landholders to use water.

**Comments:** As described in Section 4.2 Method A provides the basis for calculating the SUL for further development in Zone A. The calculated divertible runoff volume is based on the determination of streamflow based on a number of assumptions which are examined above. Setting aside the validity of the assumptions, it calculates the flow generated for the average rainfall conditions, which,
as described for Point 2, can be substantially larger than flow available in the stream for during the
drier years. Method B also has the potential to be inequitable (Section 4.3).

4.6. Methodologies Applied in Other States and Nationally

In most of the Australian states including those in the Murray Darling Basin (MDB Plan, 2010a) the
sustainable diversion limits are still being set. However some guidelines have been proposed or
adapted in a number of states that define the environmental water requirements (EWR) and determine
the allowable water extraction for different purposes. The following is only intended as a snapshot
rather than a detailed analysis of those policies.

There is not much literature on the calculation of SDLs. In general, there is no straightforward method
to calculate them as SDL depends on EWR and social and economic factors which are hard to
quantify. In some states (e.g. Victoria, Tasmania and Western Australia) formula for calculating the
sustainable diversion limit or the allowable extraction limits are suggested based purely on
hydrological and environmental considerations, while other states e.g. Queensland and NSW they are
still being worked out. The description of SDLs in some of those states is given below:

4.6.1. Victoria

In Victorian Government’s white paper (State of Victoria, 2004) the need to establish a environmental
water reserved is proposed which sets aside an environmental water reserve to maintain biodiversity
and aquatic ecosystem. These are the part of Streamflow Management Plans under the Water Act
1999 which aims to provide a balanced and sustainable sharing of streamflows between all users in
unregulated catchments. The sustainable diversion limits derived for Victoria is based on an
overarching principle of allowing the extraction within the range of natural flow variability (SKM, 2009).
The assumption is that if the resulting flow regime in the stream after extract is within the natural range
then the ecological functions that rely on the flow will also be within their natural range of frequency
and duration. The diversions are also based on the concept of (i) minimum flow threshold (MFT) below
which no diversion is allowed, and (ii) maximum extraction rate (MER) which stipulates a cap on
diversion even in cases when water is available. This is done to maintain aquatic and riparian
ecosystem that rely on the higher streamflow flow or on flows in the floodplain. The SKM (2009) report
states that in Victoria currently:

1. The winter dam fill period is from July to October (inclusive)
2. MFT = max{0.3 mean daily flow, 95th percentile of median July to October daily flow}
3. MER = 50th percentile – 80th percentile of median July to October daily flow.

The SDL volume thus determined ranged from 0 to 23 percent of the mean winter flow in Victoria
(Nathan et al., 2002).

4.6.2. Western Australia

The SDLs in unregulated catchments in the south-west of Western Australia are developed using the
similar process to the one used in Victoria. The basic tenet of the SDL is to maintain the winter flow
regime after extractions within the natural variation for that period (Lang et al., 2008).

The three rules used to calculate the SDL are similar to that used for Victoria except for the winterfill
period is set from July to September and MER is calculated differently. The SDL volume thus
determined using an 80 percent reliability ranged from 0 to 21 percent of the mean winterfill period
flow (SKM, 2008b). The SDLs for ungauged catchments are calculated using the regional prediction
equations derived though regression analysis.
4.6.3. Australian Capital Territory

The Environmental Flow Guidelines (EFG) (1999, 2006) of the ACT state environmental flows as the flows of water in streams and rivers that are necessary to maintain aquatic ecosystems. The EFG include provision for protection of not only the low flows but other components of the natural flow, which are: (i) base flow (ii) small floods (riffle maintenance flows) (iii) larger floods (pool or channel maintenance flows), and (iv) special purpose flows.

The EFG define the base flow as ‘the flow component contributed mostly by groundwater, and is the minimal volume of water that the stream needs to support the fish, plants, insects, and protect water quality’. The purpose of the small and larger floods is to move out sediment deposits and maintain channel forms. The special purpose flows are flows designed for a particular ecological need, for example the flow needed to maintain habitat of a specific species, if any.

**Baseflow/low flow calculations**

The EFG assesses the low/base flows in non water supply catchments as the streamflow that is exceeded 80 percent of time (80% exceedance) calculated using daily data on periods not more than a month.

The maximum diversion limit (MDL) is set at 10% of the flow volume above 80% exceedance, i.e.,

$$\text{MDL} = 0.1(\text{Flow} – 80\% \text{ exceedance flow})$$

The guideline also provides for the maximum extraction rate to maintain the flushing flow defined as the flood events with 1:1.5-2.5 years annual recurrence interval. This is done to ensure that naturally high flows are protected.

The EFG has established each component of environmental flows for each of the ecosystem types and for specific reaches within the water supply catchments. These are listed in a table providing specific guidelines (Section 5, EFG, 2006). The table specifies flow requirements for any given river reach, e.g. "maintain a flow of 150 ML/day for 3 consecutive days every 2 months”.

In the water supply catchments, environmental flows are not as strict to ensure adequate drinking water supply during drier periods. An alternative approach has been adopted that identifies ecological values that are expected to be maintained by environmental flows and the associated flows required at different river reaches during different stages of droughts.

4.6.4. New South Wales

In addition to the cap on extraction in the Murray Darling Basin, NSW is allocating water for the environmental flow provision and have prepared statutory water sharing plan to most of the major river systems for protecting the water for the environment including natural variability of flows such as low, moderate and high flow (NSW, 2010). The plan is designed to:

- limit extractions so that between 56 percent and 80 percent of the average annual water in the regulated river systems will be retained in the river in the inland systems
- replicate natural flow patterns or events so as to provide water when and where it will best meet environmental needs – returning additional water to the environment over and above that required under the Murray Darling Basin cap

Among others, the main objectives are to maintain or mimic natural flow variability in all rivers for improved survival of ecosystems and aquatic biodiversity and to reduce frequency of algal bloom.

Details water sharing plans have been made in NSW for different water management areas that stipulate water sharing rules for the environmental needs of the rivers and direct how water is to shared among different water users. This includes ‘cease to pump’ trigger when flow goes below a given values, with provision for some limited permissible extraction for hygiene and health purposes (e.g. dairy washdowns, fruit washing, animal hygiene).
4.6.5. Tasmania

Tasmanian Draft Water Management Plans are prepared for a number of catchments in the State to provide frameworks for managing catchments’ water resources as per the Water Management Act 1999. Some of the objectives are to (i) maintain ecological processes and genetic diversity for aquatic and riparian ecosystems (ii) promote sustainable use of water resources, and (iii) provide for the fair allocation of water to meet community’s need. The water licences are allocated with different levels of surety for water allocation depending on the purpose. For example use such as domestic, public health, consumption by livestock and firefighting has highest priority with Surety Level 1 (DPIPWE, 2009). Surface water may be taken for stock and domestic use on riparian properties without a licence in accordance with Part 5 of the Act which deals with right to take water and other provisions.

The surface water yield of each subcatchment for each of the direct take and storage allocation periods has been determined using a hydrological model, which utilises rainfall, evaporation and estimated infiltration data. The water allocation limits are established to indentify allocation limit in each catchment consistent with meeting the above objectives of the plan. These allocations are based on 80 percent reliability of flow. For each catchment water allocation limits for irrigators is calculated as:

\[ \text{Allocation limit} = (A - B) + [(C - A) \times 0.2] \]

Where,

\[ A = \text{yield at 80 percent reliability (based on flow and modelled data from 1970 to 2003)}; \]
\[ B = \text{the volume of water deemed necessary for stock and domestic use (including firefighting) and for the basic ecological functions of the freshwater environment (30 percentile flow calculated monthly).} \]
\[ C = \text{yield at 50 percent reliability (based on flow and modelled data from 1970 to 2003).} \]

The water plan also stipulates “cease to take provision” which prohibits taking of water, other than through rights under Part 5 of the Act and Surety Level 1 allocation, when the measured flow drops below a given threshold.

4.6.6. South Australia

The State Natural Resources Management Plan 2006 is a statutory plan which provides the direction for ecologically sustainable management of natural resources under the NRM Act 2004. The Act requires the NRM Plan to set out the principles and policies to fulfil objectives of the Act.

In many reports published by the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC, now the Department for Water) sustainable use limits and water required for the environmental flow is suggested (Greenwood et al. 2007a; Vanlaarhoven and van der Wielen, 2009). These include the 25 percent rule, the Method B in KINRM WR policy.

For environmental water requirement purposes in the Mount Lofty Region a range of flows are defined for the flow season of interest such as low flow, which is a flow with 80 percent exceedance probability (calculated on non zero flow), bank full or overbank flow. A table is derived to list the type of aquatic flora and fauna supported by these flow during different season (e.g. low flow, transition and high flow).

For the catchments with no gauging record use of hydrological models are suggested for generating flow data.

4.6.7. Murray Darling Basin

The Murray Darling Basin Plan (MDB, 2010a) sets out the process for developing SDLs based on the environmental water requirements and economic impacts of meeting them. The final SDL will then be proposed by optimising the EWR and socio-economic impacts taking into account the key
environmental assets and key ecosystem functions as required by the Water Act 2007. The ecosystem functions are defined as the physical, chemical and biological processes that contribute to the self maintenance of an ecosystem.

The MDB Plan has derived methods to determine the EWR based on different environmental objectives such as protection and restoration of water dependent ecosystems that support significant biodiversity and support listed threatened species and ecological communities (MDB, 2010b).

The MDB Plan proposes three potential scenarios targeting additional water to the environment which reduces the current diversion limits for surface water such that water available for the environment increased to between 67 and 71 percent of the inflow at the Basic scale.

Relevance to Kangaroo Island

The guidelines given in the water plan of all States under their respective Water Acts are highly relevant to the water resources management of the Kangaroo Island. Some of main points are:

2. Most of the States have water extraction protocols that stipulate the priority of extraction such that water for domestic and livestock, food security, hygiene and fire fighting has the priority over all other use. In Kangaroo Island this is dealt with using a “on permit basis” system which specifies that if an activity falls under broader public interest (e.g. public water supply, management of dry land salinity) application for the permit may be considered.

3. Tasmania has most of its estimation of water and SDL guidelines for smaller ungauged streams done using the modelled flow data. In Victoria and Western Australia SDLs for ungauged catchments are determined by the regional prediction equations derived through regression analysis.

4. In most States' water plan the water extraction is only allowed when the flow is above the 80 percent exceedance level. This is in contrast with the defined threshold flow rate of KINRM Plan which allows extraction of water above 90 percent exceedance level or 2 L/s whichever is greater.

6. The Murray Darling Basin Plan proposal seems use more detailed process of deriving the SDLs based on the calculated EWR and socio-economic consideration. That way it does not have a fixed flow level above which the SDL is prescribed.

Comments: Majority of the sustainable diversion limits specified in Australian States' water plans rely on the streamflow data to be available to calculate the exceedance limits, for example, in Tasmania streamflows are either gauged or modelled.

In Victoria and Western Australia the sustainable use limits are based on the overarching principles of allowing the extraction within the range of natural flow variability. A similar principle may be relevant for Kangaroo Island to protect the environmental flow and also provide a sustainable and reliable flow entitlement to the landholders. Some of the methods and rules derived for other States may be implemented in Kangaroo Island for the same reasons. These include increasing the lower limits above which water can be extracted and lowering the maximum limits on extraction. The approach taken in the MDB Plan may be more accurate and desirable but it requires more work. The water available for diversion under the MDB Plan proposed scenario is between 30 to 33 percent of the mean annual flow which is higher than those proposed in other states described above.
5. CONCLUSIONS

The quantity of water that can be sustainably diverted depends on how much water is required for the environmental flow to sustain aquatic ecosystem and other biodiversity at a desired level in the catchment together with other social and economical factors. The environmental water requirement (EWR) to maintain a fair condition of freshwater ecosystems ranges globally from 20 to 50 percent of the mean annual river flow in a basin. It is shown that even at estimated modest levels of EWR (25 percent of total flow), parts of the world are already, or soon will be classified as environmentally water scarce or environmentally water stressed (Smakhtin et al., 2004). In Western Australia and Victoria the range of the percentage mean annual winter flow extracted under 80 percent reliability vary from 0 to 21 percent and 0 to 23 percent, respectively. For unregulated catchments in the ACT, ecological flow is set as the maximum diversion at 10 percent of flow above the 80 percent exceedance flow. This is done to avoid unnatural occurrence of zero flow or low flow periods or unnaturally prolonging those periods which are undesirable for ecological reasons. They are also done to keep the streamflow within the natural variability of flow regime.

Neither Method A nor Method B seem to provide enough safeguard against diversion of water needed to maintain the aquatic and riparian ecosystems during dry years. The observed and modelled streamflow data analysis of four Kangaroo Island rivers examined in this review found SUL can be more than the catchment yield for up to 10 percent of the time under Method B. In catchments with high year-to-year variability in streamflow, given by high interannual coefficient of variation (CV), a larger percent of annual flow rate as SUL can lead to more days of natural flow governed by the minimum threshold flow rate. The interannual CV of modelled streamflow of Timber Creek is 0.68 suggesting a larger year to year variability. Also, Method B may not be equitable and those at the downstream of the system are advantaged. Method A derives sustainable use limit using unverified methods and is based on flow calculation using the annual average rainfall and annual average runoff coefficients which can lead to unreliable SULs.

The streamflow at Rocky River has undergone a sudden and large change since the mid-1990s such that the average flow since then is much lower than the average streamflow of prior 25 years. Therefore past streamflows are no longer representative of the streamflows since the mid-1990s. One of the reasons attributed to the change in flow is the seven years of consecutive below-average rainfall experienced by the catchment during 1993 -1999 leading to the permanent lowering of groundwater and its disconnection to the surface flows. The SA State NRM Plan (2006) states that interactions between surface water and groundwater must be maintained to sustain ecological functions and dependent biodiversity that rely on this hydrological connectivity. Similar prolong periods of below-average rainfall phenomena are observed in other parts of the Kangaroo Island giving rise to suspicion that these areas of the Kangaroo Island must have undergone a similar reduction in flow during the recent times. Modelled streamflows show varying degrees of falling trends in all of those catchments implying again that any flow diversion based on the past data is no longer appropriate. The future climate change could also affect the reliability and appropriateness of SULs calculated using earlier streamflow data such that its continued use may be undesirable. For example, new modelling under a set of adopted climate change scenarios in Victoria suggested that the earlier SDL would need to be reduced by more than 60 percent in western and north-central regions (SKM, 2009).

The main conclusions, not in any order of importance, are:

- The SUL calculated using Methods A and B may not be available to use during drier years. These methods may need to be replaced with a data and model driven sustainable use limits calculations with a better reliability during drier years. A more detailed modelling can help a better estimation of the effects of forestry and farm dams on the river flow.
- The modelling for SUL calculation may need to include the effects of projected climate scenario on future streamflow in order to manage the risk associated with potential climate changes.
- Delineation of Zones A and B seems to be correct.
• Rocky River has undergone a large change in flow pattern since 1997. This may have also happened in other catchments of Kangaroo Island for similar reasons.

Finally, findings from this review are based on observed flows and modelled flows of ungauged catchments using parameter transfer from model calibrated on the Kangaroo Island rivers for which flow data is available. The flow thus calculated in those ungauged catchments will have some uncertainties, calculation of which is beyond the scope of present review.
6. RECOMMENDATIONS

6.1. Future Policy Requirements

Consistent with other water plans across Australia and the South Australian State NRM plan, the aim of the KINRM water policy is to protect and maintain the aquatic ecosystems as well as ensuring the equitable use of water resources to achieve the best practice water resources management.

The policy however, does not stipulate the level of protection required for the given state of water resources in the Island. A highly degraded system may require a high degree of protection whereas a system that is less degraded may need less protection with a proper monitoring plan. To come up with a sustainable use plan the policy must determine what is the extent of the protection of aquatic ecosystem is required. To maintain the natural spread of ecosystem, a wide range of flow that mimics the natural flow regime is necessary. This would mean the flow that help maintain ecosystem of the flood plain and well those close to the stream bed. Various levels of flow are also needed to fulfil a range of functions such and clearing of silt and other debris from channels to maintain the channel shape and river morphology.

Therefore for sustainable water use any future policy may consider:

1. Stipulating larger threshold for and lower upper cap on, the diversion from stream. This will have implications for farm dam intake and plantations.
2. Setting plans for monitoring and evaluation of the plan. This policy should set out the principles and framework to be used to monitor and evaluate the effectiveness of the plan in achieving its objectives including SUL provisions.

These, along with the other provisions of SDL as adopted for Victorian and Western Australian catchments such as winter dam fill periods and reliability-of-supply measures, can help provide a better control on water resources management.

Adaptive management which responds to new knowledge, changing demand and community expectation of ecosystem protection should be adopted. SUL may vary from year to year however it may not be practical to provide SUL on a yearly basis. The SUL should be reviewed after every a few years to reflect the changed rainfall and runoff regime in catchments as is the requirement for the Regional Plan to get reviewed every five years.

6.2. Key Data Requirements

All of the above require extensive and intensive data gathering including those on the streamflow. While sufficient data are being gathered intensive modelling is needed to generate streamflow data for different rivers and streams as done in this review for SUL calculation.

Data on the state of stream and land degradation is also required which can provide guidelines for the level of protection required for each stream/river. These data also help in assessing the effectiveness of the implemented water resources policy.

Streamflow gauging stations

Li (2005) lists more than 50 catchments on Kangaroo Island including their land use and drainage density. Of these 16 catchments are identified for the proposed upgrade of surface water monitoring as a part of National Action Plan for Salinity and Water Quality (now ceased). Some additional gauging stations that are proposed in the first round are shown in Table 6-1. Given the large variation in rainfall trends during the recent years along the east west direction of the Island, its effect on the corresponding streamflow response needs to be ascertained to revalue flow regimes of the Island rivers. Therefore proposed installation of the gauging stations should be implemented on a priority basis. This review suggests establishing of two additional stations on Western and Chapman Rivers.
Some of these gauging stations are also needed to create redundancy in the monitoring so that when one station fails the data from nearby stations can be used to fill in the missing data.

There are no major streams that are completely within Zone B, however Cygnet River and Timber Creek catchments are partly in this zone, therefore a gauging station at the boundary of each of these two zones in those two catchments is suggested. Station A5131008 (Timber Creek at the upstream of South Coast Road) and Station A5131001 (Cygnet River at Huxtable Forest) fall under this category.

Table 6-1 Suggested new streamflow gauging stations (NAP, 2001)

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5131014</td>
<td>Cygnet River at Koala Lodge</td>
<td>Not fully operational</td>
</tr>
<tr>
<td>A5131001</td>
<td>Cygnet River at Huxtable Forest</td>
<td>Not fully operational</td>
</tr>
<tr>
<td>A5130507</td>
<td>Cygnet River at Playford Highway</td>
<td>Not fully operational</td>
</tr>
<tr>
<td>A5131002</td>
<td>Timber Creek at South Coast Road</td>
<td>Not fully operational</td>
</tr>
<tr>
<td>A5131008</td>
<td>Timber Creek at u/s South Coast Road</td>
<td>Proposed</td>
</tr>
<tr>
<td>A5131015</td>
<td>Middle River u/s of Reservoir</td>
<td>Proposed</td>
</tr>
<tr>
<td>A5131009</td>
<td>Eleanor River</td>
<td>Proposed</td>
</tr>
<tr>
<td>A5131003</td>
<td>Harriet River</td>
<td>Just installed</td>
</tr>
<tr>
<td>A5131005</td>
<td>Harriet River</td>
<td>Proposed</td>
</tr>
<tr>
<td>A5131006</td>
<td>Harriet River</td>
<td>Proposed</td>
</tr>
<tr>
<td>A5131011</td>
<td>South West River</td>
<td>Proposed</td>
</tr>
<tr>
<td>A5131012</td>
<td>South West River</td>
<td>Proposed</td>
</tr>
<tr>
<td>A5131007</td>
<td>Stunsail Boom River</td>
<td>Just installed</td>
</tr>
<tr>
<td>A5131013</td>
<td>Stunsail Boom River</td>
<td>Proposed</td>
</tr>
<tr>
<td>A5131004</td>
<td>Smith Creek @ North Cote Road</td>
<td>Closed</td>
</tr>
<tr>
<td>A5030503</td>
<td>Wilson Creek @ SE Penneshaw</td>
<td>Closed</td>
</tr>
<tr>
<td>?</td>
<td>Western River</td>
<td>Proposed in this review</td>
</tr>
<tr>
<td>?</td>
<td>Chapman River</td>
<td>Proposed in this review</td>
</tr>
</tbody>
</table>

Climate data
There is no meteorological station in the Island currently measuring the evaporation data. The last station at Parndana ceased monitoring evaporation in 1984. As mentioned above, since there is a large variation in the rainfall along the east west direction of the Island at least one meteorological station measuring evaporation and other climate data should be installed. This is quite important for the future modelling of rivers as evaporation data is one the main inputs in many lumped conceptual hydrological models.

Except for one or two locations, there is reasonably good density of rainfall stations providing the long term rainfall data. Three closed stations (M022818, M022821 and M022827) could be restarted to increase the rainfall station density in Eleanor, Harriet and Stunsail Boom Rivers.

6.3. Modelling Requirements

There is a need to carry out a detailed modelling on the rivers of Kangaroo Island to derive the past streamflow data so that a detailed statistical analysis can be done to determine minimum flow threshold and other flow caps. The aim is to come up with SULs in ways similar to the SDLs in Victoria, Western Australia or in Tasmania. In any case, the implementation of Method B depends on the estimate of mean annual flow.

As discussed earlier, long term streamflow records for majority of catchments studied in this review are found to be not quite representative of the streamflow observed since about 1997. Therefore water allocation based on the long term streamflow data may lead to an erroneous distribution of the available resources. Any future modelling should carefully consider the past flow data and should only use the most relevant period in the modelling as used in this review for the Rocky River. Example of
such use of recent flow data is also found in CSIRO, (2009a). The future climate change could also affect the reliability and appropriateness of SULs calculated using earlier streamflow data such that its continued use may be undesirable. Therefore modelling for SUL calculation may need to include the effects of projected climate scenario on future streamflows in order to manage the risk associated with potential climate changes.

Although earlier modelling study of Middle River has used AWBM as the main hydrological model but, based on comparison done in this review using AWBM, IHACRES, SIMHYD and Sacramento the latter gave a better fit to the Rocky River observed data. Therefore use of the Sacramento model for future modelling is recommended.

6.4. Monitoring and Evaluation

The State NRM Plan provides for a program for monitoring and evaluating the effectiveness of the plan and for getting reviewed every five years to provide for the opportunity for adaptive management if any changes to rainfall or streamflow are evident (SAGTFR, 2011). The monitoring and evaluation program will provide the framework for evaluating the effectiveness of the Plan’s various elements, including compliance with the sustainable use limits and environmental water requirements. The monitoring and evaluation plan will assess the present state of the streams and evaluate their response to the implementation of the policy. This will provide useful feedback for any future modification and research that may be required (Section 6.1).

The review of Regional Plan needs to be comprehensive and should include review of all underlying assumptions and methods in light of new data. Since methods A and B are not related to the absolute values of rainfall and streamflows, any changes in rainfall or streamflow will not change the uncertainties associated with methods A and B.
REFERENCES


CSIRO, (2009a) Surface water yields in south-west Western Australia. A report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, Australia.


DWLBC (undated) Sustainable limits of surface water use in South Australia, Fact Sheet 81, Department of Water, Land and Biodiversity Conservation.


GSA (Undated) Managing the water resources impacts of plantation forests: A Statewide policy framework, Government of South Australia, pg. 37.


Murray Darling Basin Authority (2010b) Assessing environmental water requirements Foreword and introduction, pg 23.


SA State NRM Plan (2006), South Australian Department of Water Land and Biodiversity Conservation, pg. 110.

SKM (2007) Impacts of farm dams in seven catchments in Western Australia, Final report to the Department of Water, WA, pg. 77.

SKM (2008a) Approach for determining sustainable diversion limits for south west Western Australia, Final report to the Department of Water, WA, pg. 83.

SKM (2008b) Estimation of sustainable diversion limits for south west Western Australian catchments: Regaionalisation of sustainable diversion limits for catchments, Final report to the Department of Water, WA.


Kangaroo Island has 53 catchments, 20 of which are considered the major ones. Figure A-1 shows the location of some of the major rivers in the Island. Streamflow monitoring sites are also shown. The streamflows from the following four rivers were modelled.

1. **Rocky River**: The Rocky River catchment (216 km²) is located within Flinders Chase National Park at the western end of the Island. The major land use of the catchment is dense native vegetation which is relatively free from the impact of human disturbance.

2. **Eleanor River**: Eleanor River catchment (263 km²) is located at the middle of the southern half of Kangaroo Island. Agriculture is the predominant land use including grazing and cropping.

3. **Cygnet River**: Cygnet River catchment is the largest catchment in the Kangaroo Island (~600 km²) draining 12 percent of the land area. The main channel is 90 km long flowing from west to east. Agriculture is predominant land use (~77%) including grazing and cropping. Native vegetation and forestry occupy 19 and 4 percent of the catchment area, respectively (Nilsen, 2006).

4. **Timber Creek**: Timber Creek catchment (245 km²) is located east of Eleanor River catchment. The creek terminates at Murray Lagoon which is the largest inland lake on the Island. The major land use in the catchment is agriculture including grazing and pasture with some cropping.

![Figure A-1 Major catchments and streamflow monitoring sites in Kangaroo Island (Source: DWLBC, Government of South Australia)](image)

The annual average rainfall isohyets of Kangaroo Island (Figure A-2) show a large rainfall gradient from west to east. Higher rainfall areas towards the west of the catchment are within Zone A.
Figure A-2 Rainfall isohyets of annual average rainfall in Kangaroo Island (Source: Nilsen, 2006)
APPENDIX B: METHODS A AND B

1. Method A

The following methodology has been endorsed by the Kangaroo Island NRM Board as an interim approach to determining the sustainable use limits for further development in those catchments and sub-catchments on the lateritic plateau landform. The catchments and sub-catchments for which this methodology applies are shown as Zone A in the attached Policy Zones Map and hence the methodology is called methodology A. For the remaining catchments and sub-catchments on the Island, shown as Zone B, the sustainable use limits for further development have been determined using the 25% rule, i.e. methodology B.

Adoption of methodology A for the Zone A catchments and sub-catchments rather than the 25% rule is founded on the expectation that the historical rainfall runoff data for the Rocky River catchment is typical of the desired natural state runoff for the catchments of that zone and hence can be extrapolated to those catchments.

The application of both methodology A and B to the various catchments and sub-catchments across the Island has been endorsed as an interim approach, to be complemented by a review of the policy with the full involvement of key stakeholders and independent assessment of the underpinning science.

The Unit Runoff Methodology

1. Use Rocky River rainfall runoff relationship as basis for determining the required minimum catchment flow under natural conditions ($R_{\text{natural}}$) on a catchment scale for those catchments on the lateritic plateau landform, i.e. those catchments with an average annual rainfall $\geq$600mm – Zone A in the Policy Zone Map.

2. Apply average annual rainfall for each catchment to determine the estimated runoff rate under native vegetation (prior to clearing).

3. Apply the runoff rate to the total area of the catchment to determine required minimum catchment flow under natural conditions – $R_{\text{natural}}$.

4. Determine the area of land within each catchment that is native vegetation and calculate average annual runoff by applying the same runoff rate – $R_{\text{native}}$.

5. Determine the area of land within each catchment that is cleared land and calculate average annual runoff by applying the Tanh runoff value for cleared land applying that to catchment – $R_{\text{cleared}}$.

6. Adjust the average annual runoff for the cleared land to account for the impact of existing farm dams by using the estimated dam capacity for dams built in the cleared area as the average volume taken out of the catchment - $\text{adj} R_{\text{cleared}}$.

7. Determine the area of forest within each catchment and calculate average annual runoff by applying 0.15 x Tanh runoff value for cleared land applying that to catchment – $R_{\text{forest}}$.

8. Calculate the total estimated runoff volume from the catchment under existing land uses $R_{\text{exist}} = R_{\text{native}} + R_{\text{forest}} + \text{adj} R_{\text{cleared}}$.

9. Calculate the nominal volume available for further development by subtracting the required minimum catchment flow under natural conditions from the estimated runoff volume under existing land uses - $\text{nom} R_{\text{available}} = R_{\text{exist}} - R_{\text{natural}}$. 
10. Apply a 20% precautionary factor to calculate remaining volume available for further development that may be taken up by further farm dams or forest development or combination of both, i.e. \( R_{\text{available}} = 0.8 \times R_{\text{nominal}} \).

11. The hydrological impact of an additional ha of forest development is calculated as the difference between the runoff rate for cleared land and the runoff rate for forest, i.e. 0.15 \( \times \text{Tanh} \) for the catchment.

   For example:
   Cleared land runoff = 150mm
   Forest runoff = 0.15 \( \times \) 150mm = 23mm
   Forest uses 150mm less 23 mm, i.e. 127mm or 1.27ML/ha more than cleared land
   Allowable forest area = \( R_{\text{available}} \) ha = \( \frac{R_{\text{available}}}{1.27} \)

12. The hydrologic impact of a farm dam is calculated as 1ML reduction in average flow per ML of dam capacity

13. No further development is permissible in those sub-catchments that are already over allocated as determined by this methodology, i.e. where \( R_{\text{available}} \) is less than or equal to zero
### South West River

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>15400ha</td>
</tr>
<tr>
<td>Average Annual Rainfall</td>
<td>750mm</td>
</tr>
<tr>
<td>Average Annual Runoff is the required minimum catchment flow under natural conditions $R_{natural}$</td>
<td>61mm 15400ha $\geq 9394ML$</td>
</tr>
<tr>
<td>Estimated runoff from native vegetation $R_{native}$</td>
<td>61mm 6600ha 4026ML</td>
</tr>
<tr>
<td>Estimated runoff from forested land $R_{forest}$</td>
<td>20mm 3616ha 723ML</td>
</tr>
<tr>
<td>Estimated runoff cleared land $R_{cleared}$</td>
<td>133mm 5184ha 6895ML</td>
</tr>
<tr>
<td>Adjusted runoff from cleared land $adj R_{cleared}$</td>
<td>Total farm dam capacity of existing dams equals 746ML 6149ML</td>
</tr>
<tr>
<td>Nominal volume available for further development $nomR_{available}$</td>
<td>1504ML</td>
</tr>
<tr>
<td>Precautionary buffer 20%</td>
<td>301ML</td>
</tr>
<tr>
<td>Remaining volume available for further development $R_{available}$</td>
<td>1203ML</td>
</tr>
</tbody>
</table>

NB: 1 The average rainfall and natural runoff values used in this working example are for demonstration purposes only. They are not necessarily the real numbers for the catchment, because that data was not available at the working team workshop. The actual average annual rainfall and the natural runoff calculated form the Rocky River relationship have been used for the calculations adopted within the NRM Plan.
Harriet

<table>
<thead>
<tr>
<th>Catchment area</th>
<th>15192ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Annual Rainfall(^1)</td>
<td>711mm</td>
</tr>
<tr>
<td>Average Annual Runoff is the required minimum catchment flow under natural conditions (R_{natural})</td>
<td>40mm 15192ha (\geq 6077\text{ML})</td>
</tr>
<tr>
<td>Estimated runoff from native vegetation (R_{native})</td>
<td>40mm 3056ha 1222ML</td>
</tr>
<tr>
<td>Estimated runoff from forested land (R_{forest})</td>
<td>17mm 2340ha 398ML</td>
</tr>
<tr>
<td>Estimated runoff cleared land (R_{cleared})</td>
<td>112mm 9796ha 10972ML</td>
</tr>
<tr>
<td>Adjusted runoff from cleared land (adjR_{cleared})</td>
<td>Total farm dam capacity of existing dams equals 2153ML 8819ML</td>
</tr>
<tr>
<td>Nominal volume available for further development (nomR_{available})</td>
<td>4362ML</td>
</tr>
<tr>
<td>Precautionary buffer 20%</td>
<td>872ML</td>
</tr>
<tr>
<td>Remaining volume available for further development (R_{available})</td>
<td>3490ML</td>
</tr>
</tbody>
</table>

NB: \(^1\) The average rainfall and natural runoff values used in this working example are for demonstration purposes only. They are not necessarily the real numbers for the catchment, because that data was not available at the working team workshop. The actual average annual rainfall and the natural runoff calculated from the Rocky River relationship have been used for the calculations adopted within the NRM Plan.
2. Method B

Determining Sustainable Use Limits and available water in Zone B - The 25% Rule Methodology

The following methodology is to be used to determine Sustainable Use Limits for new dam and forestry developments at a catchment, subcatchment and property scale in Zone B.

The assessment of available water within the Sustainable Use Limits will be made at three different scales and in the following order; catchment, then sub-catchment/management zone, and finally property.

The Sustainable Use Limit at a property scale is calculated for the entire catchment contributing to the proposed dam or forest.

Where properties cross more than one sub-catchment/management zone then each part of the property within each sub-catchment should be assessed separately to establish if the water required for the development is available at the property scale.

Determining Sustainable Use Limits in Zone B

The Sustainable Use Limit (SUL) at a catchment, subcatchment and property scale is calculated as follows;

\[ \text{SUL (ML)} = \left( \frac{\text{Catchment Area} \times \text{Average Runoff Rate for catchment}}{100} \right) \times 0.25 \]

Note: The Sustainable Use Limits and Available Water for catchments and subcatchments in Zone A are contained in the KI NRM Plan 2009.
Determining Available Water in Zone B

The Available Water at a catchment, subcatchment and property scale is calculated as follows;

1. Catchment scale

The purpose of the catchment scale assessment is to determine if there is any available water (AW) within the catchment’s Sustainable Use Limit. The following formulae show how the available water is calculated. These results are shown in table SUL.

\[
AW_{catchment} = SUL_{catchment} - FDU_{catchment} - PFU_{catchment}
\]

\[
FDU_{catchment} = FDC_{catchment} \times 0.5
\]

\[
PFU_{catchment} = PFA_{catchment} \times AAR_{catchment} \times 0.85
\]

If \( AW_{catchment} \leq 0 \) then no dams/forestry can occur. If \( AW_{catchment} > 0 \) then proceed to sub-catchment scale assessment.

Terms:

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW catchment</td>
<td>available water in catchment within the catchment’s sustainable use limit (ML)</td>
</tr>
<tr>
<td>SUL catchment</td>
<td>sustainable use limit for the catchment (ML/year)</td>
</tr>
<tr>
<td>FDU catchment</td>
<td>water use from farm dams (ML/year)</td>
</tr>
<tr>
<td>FDC catchment</td>
<td>total farm dam volume in catchment (ML)</td>
</tr>
<tr>
<td>PFU catchment</td>
<td>water use from commercial forestry (ML/year)</td>
</tr>
<tr>
<td>PFA catchment</td>
<td>area of commercial forestry in catchment (ha)</td>
</tr>
<tr>
<td>AAR catchment</td>
<td>average annual adjusted runoff for catchment (mm/year/ha)</td>
</tr>
</tbody>
</table>

Note: The Sustainable Use Limits and Available Water for catchments in Zone B are contained in the KI NRM Plan 2009.
2. Sub-catchment or management zone scale

The same assessment is completed on all the sub-catchments/management zones that contain activities that are recognised as intercepting water resources under the policy (dam/forestry).

The purpose of this is to ensure that new development does not access all remaining water in the sub-catchments, which would result in inequitable water allocation. The following formulae show how the available water is calculated. These results are shown in [table SUL].

\[ AW_{\text{sub-catchment}} = SUL_{\text{sub-catchment}} - FDU_{\text{sub-catchment}} - PFU_{\text{sub-catchment}} \]

\[ FDU_{\text{sub-catchment}} = FDC_{\text{sub-catchment}} \times 0.5 \]

\[ PFU_{\text{sub-catchment}} = PFA_{\text{sub-catchment}} \times AAR_{\text{sub-catchment}} \times 0.85 \]

If \( AW_{\text{sub-catchment}} \leq 0 \) then no dams/forestry can occur. If \( AW_{\text{sub-catchment}} > 0 \) for any sub-catchment then proceed to a property scale assessment.

<table>
<thead>
<tr>
<th>Terms:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( AW_{\text{sub-catchment}} ) = available water in sub-catchment within the sub-catchment’s sustainable use limit (ML)</td>
</tr>
<tr>
<td>( SUL_{\text{sub-catchment}} ) = sustainable use limit for the sub-catchment (ML/year)</td>
</tr>
<tr>
<td>( FDU_{\text{sub-catchment}} ) = water use from existing farm dams (ML/year)</td>
</tr>
<tr>
<td>( FDC_{\text{sub-catchment}} ) = total volume of existing farm dams in sub-catchment (ML)</td>
</tr>
<tr>
<td>( PFU_{\text{sub-catchment}} ) = water use from existing commercial forestry (ML/year)</td>
</tr>
<tr>
<td>( PFA_{\text{sub-catchment}} ) = area of existing commercial forestry in sub-catchment (ha)</td>
</tr>
<tr>
<td>( AAR_{\text{sub-catchment}} ) = average annual adjusted runoff for catchment (mm/year/ha)</td>
</tr>
</tbody>
</table>

Note: The Sustainable Use Limits and Available Water for subcatchments in Zone B are contained in the KI NRM Plan 2009.
3. Property scale

This assessment identifies if there is water available on the property for the proposed development.

Where properties cross more than one sub-catchment/management zone then each part of the property within each sub-catchment should be assessed separately to establish if the water required for the development is available at the property scale.

\[
\begin{align*}
AW_{\text{Property (SC 1-x)}} &= SUL_{\text{Property (SC 1-x)}} - FDU_{\text{Property (SC 1-x)}} - PFU_{\text{Property (SC 1-x)}} \\
FDU_{\text{Property (SC 1-x)}} &= FDC_{\text{Property (SC 1-x)}} \times 0.5 \\
PFU_{\text{property (SC 1-x)}} &= PFA_{\text{property (SC 1-x)}} \times AAR_{\text{property (SC 1-x)}} \times 0.85 \\
AND_{\text{property (SC 1-x)}} &= AW_{\text{Property (SC 1-x)}} \times 2 \\
ANF_{\text{property (SC 1-x)}} &= \frac{AW_{\text{Property (SC 1-x)}} \times 100}{(AAR \times 0.85)}
\end{align*}
\]

Terms:

- **AW property (SC 1-x)** = available water on the property within each sub-catchment (ML)
- **SUL property (SC 1-x)** = sustainable use limit on the property within each sub-catchment (ML/year)
- **FDU property (SC 1-x)** = water use from existing farm dams (ML/year)
- **FDC property (SC 1-x)** = total volume of existing farm dams on the property within each sub-catchment (ML)
- **PFU property (SC 1-x)** = water use from existing commercial forestry on the property within each sub-catchment (ML/year)
- **PFA property (SC 1-x)** = area of existing commercial forestry on the property within each sub-catchment (ha)
- **AAR property (SC 1-x)** = average annual adjusted runoff for each sub-catchment within the property (mm/year/ha)
- **AND property (SC 1-x)** = allowable new farm dam volume on property within sub-catchments 1 - X (ML)
- **ANF property (SC 1-x)** = allowable new forest area on property within sub-catchments 1 - X (ha)
APPENDIX C: TERMS OF REFERENCE

CSIRO will carry out an independent scientific review of the Kangaroo Island’s Water Resources Management Policy. The following individual issues will be addressed:

1. Review of the assumptions that underpin the policy frameworks applying to Zone A and Zone B including the appropriateness of runoff coefficients and the associated methods of calculating the Sustainable Diversion Limits including, but not limited to
   - Assumption that the 25% rule and Method A will meet the objectives of the policy.
   - Assumption that Method A is ‘better information’.
   - Assumption that the catchment characteristics for Rocky River is comparable to other catchments in Zone A.
   - Assumptions that separate Zone A from Zone B.

2. Review of the currency, validity and appropriateness of data used to support policy.

3. Review of methodologies being applied in other catchments at a state and national level and their relevance to Kangaroo Island.

4. Recommendations for future policy requirements if required

5. Recommendations for key data requirements, modelling and monitoring to improve development of water policies.