Hydrological investigations to inform surface water use limits and generalised environmental water requirements for key ecological assets on Kangaroo Island

DEWNR Technical report 2015/07

Government of South Australia
Department of Environment, Water and Natural Resources

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February, 2015

DEWNR Technical Report 2015/07

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ISBN 978-1-922255-36-5

Preferred way to cite this publication

Whiting J. and Green D. 2015, *Hydrological investigations to inform surface water use limits and generalised environmental water requirements for key ecological assets on Kangaroo Island,* DEWNR Technical Report 2015/07, Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

Acknowledgements

The authors wish to acknowledge the following:

The Kangaroo Island Natural Resources Management Board and Kangaroo Island Water Resources Taskforce for providing funding assistance for this project, and reviewing this report.

Natural Resources Kangaroo Island regional staff:

- Jo Sullivan who provided operational spreadsheets and data, and valuable field knowledge
- Bill Haddrill and Martine Kinloch for providing feedback throughout the project

Department of Environment, Water and Natural Resources staff:

- Kumar Savadamuthu, Simon Sherriff and Jason Vanlaarhoven for their invaluable knowledge and assistance with the methodology, and for comments provided in reviewing this report
- Lieke van Roosmalen for providing project management and support
- Gabrielle Eckert and David Thompson for spatial analysis assistance

External peer reviews of this report were provided by:

- Dr Jai Vaze, Research Team Leader – Catchment Hydrology, CSIRO Land & Water
- Peter Goonan, Principal Scientific Officer (Aquatic Biology), South Australian Environment Protection Agency (SA EPA)

The financial support of the Commonwealth Government (under the Climate Change Adaptation Program – Stream 1) for this project is also gratefully acknowledged.

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Summary

This technical study was undertaken by the Science, Monitoring and Knowledge (SMK) Branch of the Department of Environment, Water and Natural Resources (DEWNR) in response to a request from the Kangaroo Island (KI) Natural Resources Management (NRM) Board ("the Board") to deliver a validated calculation methodology for helping to define Surface Water Use Limits (WULs) for KI NRM region. This report seeks to provide a suite of options to calculate revised WULs for KI at a subcatchment scale, but does not seek to recommend a particular approach to calculate WULs in any revised KI NRM Plan. It is acknowledged that any decision to alter WUL aspects of the KI NRM Plan is at the discretion of the Board. The WULs discussed in this report are limits for consumptive water use purposes only, and do not include the needs of water-dependent ecosystems, as encapsulated in environmental water requirements (EWRs). EWRs need to be defined and calculated for further determination of sustainable extraction limits (SELs) for KI.

The calculation of WULs requires the underlying rainfall and runoff generation processes on KI to be well understood, and for the meaning of "average catchment yield" to be clearly defined. This report reviews water resource information, and specifically gauged streamflow and gridded rainfall data, to characterise the hydrological processes of major catchments on KI in order to propose new WULs.

The Kangaroo Island Natural Resources Management Plan 2009 ("the 2009 Plan") defines limits on farm dams and watercourse extractions (which were termed *Sustainable Limits*, SLs) at a subcatchment scale for all water resource catchments outside National Park, Conservation Park and Wilderness Protection Areas. For this project, the Board has acknowledged the potential lack of clarity, in terms of the management of the water-dependent ecosystems of KI, presented with the phrase *Sustainable Limits*, and has sought to use the term *Water Use Limits* (WULs) instead to describe limits on farm dams and watercourse extractions in the non-prescribed KI NRM region. These limits currently apply to all new surface water use, including surface water capture and use from farm dams, watercourse diversions and extractions, and plantation forestry use, for which water-affecting activity permits are required. In the absence of long-term, high quality hydrological observations from KI, SLs in the 2009 Plan were derived from a rainfall-runoff relationship developed from a single series of reconstructed inflows to Middle River Reservoir (as a surrogate measure of streamflow) for 1970–92.

There are currently five series of daily streamflow records for KI, located in four distinct surface water catchments (Rocky River, Cygnet River, Timber Creek and Stunsail Boom River). The Stunsail Boom River gauging station was installed by DEWNR in February 2010 following the completion of the 2009 Plan.

This report identifies spatial variability in both annual rainfall and streamflow response across KI, with data from Cygnet River and Timber Creek indicating much higher catchment yields than either Rocky River or Stunsail Boom River. In addition, this report identifies temporal variability in rainfall-runoff relationships in both the Rocky River catchment on KI and various Mount Lofty Ranges (MLR) catchments, with the period since 1992 revealing lower catchment yields than for the 1970-1992 period that was used in the specification of SLs in the 2009 Plan.

This report provides estimates of catchment yields for KI using rainfall-runoff relationships developed in this study and average catchment rainfall, using all available hydrological data from KI. Streamflow data for the Cygnet River and Timber Creek catchments (for which streamflow records are available since 2003 and 2004, respectively) suggest that distinct rainfall-runoff curves can be developed for these catchments to estimate average annual yield, as distinct from the generalised KI-wide rainfall-runoff curve adopted for the 2009 Plan. Rainfall-runoff relationships are developed for "current conditions" on KI, with no adjustment made to gauged catchment yields to account for farm dam extractions. This approach was consistent with approach used to develop SLs in the 2009 Plan, and acknowledges that the hydrological modelling required to assess the impact of farm dams on KI, and to produce time series of "adjusted" catchment yields, was beyond the scope of this project.

Similar rainfall-flow relationships were developed at a daily scale, which is critical for the determination of conditions under which watercourse diversions may not occur. Distinct relationships between annual catchment rainfall and Unit Threshold Flow

Rates (UTFRs)[1] are provided as an option for Timber Creek and Cygnet River, as opposed to generalised KI-wide relationships that are used currently to implement the 2009 Plan.

Uncertainties inherent in short data sets, together with streamflow gauging uncertainty, make the provision of a confident validation of underlying rainfall-runoff relationships in KI watercourses difficult at this stage. With a continued commitment to hydrological monitoring and evaluation on KI that is guided by a robust risk management framework, this level of confidence in the underlying rainfall-runoff relationships should improve with time.

This report seeks to support a "stepping stone" approach by the Board towards water sharing policies that utilise KI-specific hydrological and ecological knowledge, to achieve a sustainable balance between the needs of the KI environment and the people who use the surface water of KI to make a living. As such, using the time and resources available, this project has taken the "first step" by using available KI hydrological and climate data to validate a standard hydrological methodology for estimating catchment yields. To further support this "first step", this project has also delivered a preliminary review of existing ecological data records. A survey was sent to landholders to obtain additional site-specific information regarding water-dependent flora and fauna. These tasks represent initial steps in the process of reviewing and potentially deriving new environmental water requirements for KI, after which Sustainable Extraction Limits (SELs) can be established.

This project provides the Board with the latest hydrological knowledge available which, when considered in parallel with the potential impacts of future climate scenarios, supports informed risk-based decision making in terms of formulating a revised NRM Plan for KI that is "climate ready". This report presents four options for the Board's consideration in the context of WUL and related policies that seek to consider the variability in streamflow responses across KI, as demonstrated through this project's analysis of hydrological data.

Option	WUL calculation basis and data sources	TFR calculation basis and data sources	Potential eco-hydrological advantages	Potential eco-hydrological disadvantages
A1 Abolish Zone A and await longer local data sets	• Ex-Zone B WULs are unchanged • Zone A replaced with "Method B" WULs with same basis as ex-Zone B, i.e. rainfall-runoff curve derived from Middle River Reservoir water balance inflows, with similarity to pre-1992 MLR hydrological relationships	• Regionalised MLR UTFR-rainfall curve (from 2009 Plan) retained for all zones	• Consistent calculation procedure for all KI catchments	• No eco-hydrological basis for yield calculations • No reference to KI streamflow gaugings • No consideration of changes in recent rainfall on hydrology since 1992
A2 Abolish Zone A and include latest rainfall data for Zone B	• "Generalised-extended" rainfall-runoff function used for all catchments, i.e. extend TanH function used in 2009 Plan to include latest rainfall data	• Regionalised MLR UTFR-rainfall curve (from 2009 Plan) retained for all zones	• Consistent calculation procedure for all KI catchments • Impacts of rainfall recorded since 1992 are included in yield estimation	• No eco-hydrological basis for yield calculations • No reference to KI streamflow gaugings

[1] UTFRs are defined as the rate of flow per unit catchment area (expressed as L/s/km^2), below which water must not be diverted or collected in farm dams. The 2009 Plan sets UTFRs as the rate of daily flow that would be exceeded or equalled for 10% of the time, divided by the area of the contributing catchment.

Option	WUL calculation basis and data sources	TFR calculation basis and data sources	Potential eco-hydrological advantages	Potential eco-hydrological disadvantages
B Abolish Zone A and use local data from most gauged catchments	• All available data from Cygnet River and Timber Creek gauges combined to derive a single "highly-developed area" rainfall-runoff function for Cygnet and Timber catchments • "Generalised-extended" rainfall-runoff function used for all other catchments, i.e. extend TanH function used in 2009 Plan to include latest rainfall data • Stunsail Boom River gauge data not used yet, due to insufficient data • Rocky River gauge data not used, as this is outside the Policy Area	• 10th percentile POE flows retained as UTFR • "Highly-developed area" UTFR-rainfall curve adopted for Cygnet River and Timber Creek catchments • Regionalised MLR UTFR-rainfall curve (from 2009 Plan) retained for other catchments	• Climatic impacts on hydrology since 1992 are included in yield and UTFR estimation • KI streamflow records included in yield and UTFR estimation • Some "highly-developed" but ungauged catchments may have yields and UTFRs under-estimated	• Some "less-developed" but ungauged catchments may have yields and UTFRs over-estimated (i.e. WULs will be greater than 25% of yield)
C Abolish Zone A and utilise local data across KI on a land use basis	• All available data from Cygnet River and Timber Creek gauges combined to derive a single rainfall-runoff function for <u>all</u> "highly-developed" catchments • "Generalised-extended" rainfall-runoff function used for all "less-developed" catchments (i.e. catchments with high proportions of uncleared land)	• 10th percentile POE flows retained as UTFR • "Highly-developed area" UTFR-rainfall curve adopted for all "highly-developed" catchments • Regionalised MLR UTFR-rainfall curve (from 2009 Plan) retained for all "less-developed" catchments	• Climatic impacts on hydrology since 1992 are included in yield and UTFR estimation • Yields and UTFRs of "highly developed" ungauged catchments consider increased runoff from cleared areas	• Some "less-developed" but ungauged catchments may have yields and UTFRs over-estimated (i.e. WULs will be greater than 25% of yield)

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PART 1 – Hydrological investigations to inform surface water use limits

1 Introduction

1.1 Overview

This technical study was undertaken by the Science, Monitoring and Knowledge (SMK) Branch of the Department of Environment, Water and Natural Resources (DEWNR) in response to a request from the Kangaroo Island (KI) Natural Resources Management (NRM) Board ("the Board") to deliver a validated calculation methodology to define Surface Water Use Limits (WULs). This report seeks to provide a suite of options to calculate revised WULs at a subcatchment scale, but does not seek to recommend a particular approach to calculate WULs in any revised KI NRM Plan. It is acknowledged that any decision to alter WUL aspects of the KI NRM Plan is at the discretion of the Board. The WULs discussed in this report are limits for consumptive water use purposes only, and do not include the needs of the water-dependent ecosystems, as encapsulated in environmental water requirements (EWRs). EWRs need to be defined and calculated for further determination of sustainable extraction limits (SELs) for KI.

1.2 Background of water use limits on KI

The 2009 Plan defines limits on farm dams and watercourse extractions (termed *Sustainable Limits*, SLs) at a subcatchment scale for all water resource catchments outside National Park, Conservation Park and Wilderness Protection Areas. The 2009 Plan separates KI into two hydrological zones ("A" and "B") on the basis of average annual rainfall, and presents separate methodologies ("Method A" and "Method B" respectively) to calculate SLs in these zones. The 2009 Plan postulated catchments on the lateritic plateau landform of KI with average annual rainfall of 600 mm or more as the basis for separating these zones.

For this project, the Board has acknowledged the potential lack of clarity, in terms of the management of the water-dependent ecosystems of KI, presented with the phrase *Sustainable Limits*, and has sought to use the term *Water Use Limits* (WULs) to describe limits on farm dams and watercourse extractions in the non-prescribed KI region.

The term *Sustainable Limits* is analogous to the term *Sustainable Use Limits* (or SULs) that has been used by the Board in recent years when describing the implementation of surface water management policies, and is consistent with strategic policy documents from the Government of South Australia, including the State NRM Plan 2006 (DWLBC, 2006). It should however be noted that these surface water extraction limits do not necessarily represent *ecologically* or *economically* sustainable extraction volumes and/or flow regimes. Rather, their definition enables the equitable sharing of surface water resources for consumptive (stock, domestic and irrigation) purposes. In its guidelines on water allocation and management, the State NRM Plan 2006 (DWLBC, 2006) Appendix 2 states the following:

> *Outside prescribed areas, and until there is additional information, 25% of median annual adjusted catchment yield should be used as an indicator of the sustainable limit of the catchment surface water and watercourse water use. 'Adjusted' is defined as the annual catchment discharge with the impact of dam storage removed.*

This "25% rule", to which it has been subsequently referred, was applied to the calculation of SLs in Zone "B" in the 2009 Plan (and termed Method "B"). This rule evolved from earlier policies in South Australia that required half the average runoff from any property to be permitted to pass to downstream users. As outlined in the Department of Water, Land and Biodiversity Conservation (DWLBC) *Fact Sheet 81: Sustainable limits of surface water use in South Australia* (DWLBC, n.d.):

The State NRM Plan's 25% rule evolved from the State Water Plan 2000 50% rule. To ensure that all surface water was equitably shared, the 50% rule required that half the average runoff from any property should pass to downstream users, leaving a maximum of 50% to be captured for use. Due to the lack of inflow during dry years, unharvestable spills occurring in large events and wet years, evaporation and seepage, experience has shown that only half of this volume can be reliably accessed from farm dams every year, giving rise to the 25% rule.

The 2009 Plan outlines the practical implementation of these surface water limits, noting the following provision:

Once a catchment's Sustainable Limit is reached the activity will become on-merit, and no further (water affecting activity) permits will be issued (in the specific catchment). Both dams and commercial forestry must fall within the Sustainable Limit.

In the 2009 Plan, Method "A" was predicated on an assumption that the yield characteristics of the gauged Rocky River catchment, an almost completely uncleared (native) catchment, represented the *desired* natural state runoff in neighbouring catchments (collectively Zone "A") that have varying degrees of land clearing for agricultural production. Streamflows in Rocky River catchment were therefore assumed to be "the minimum flow that must be protected from water resource development" (KINRMB, 2009) across Zone "A".

With a dearth of local hydrological data, the average yields of ungauged catchments in "Zone B" were calculated (for the purpose of the 2009 Plan) through a relationship that, while using KI rainfall data, relied heavily on hydrological information from gauged catchments in the Mt Lofty Ranges (MLR) to estimate catchment yields.

Across both Zone "A" and Zone "B", surface water volumes available for additional development were calculated as the difference between the catchment's SL and prior commitments, which include extractions for both farm dams and plantation forestry. The calculation of SLs therefore required a calculation of farm dam storage volumes, current extractions for plantation forestry and the calculation of median annual adjusted catchment yields across KI. This calculation was facilitated by spatial information regarding land-use changes (i.e. changes to forestry use) and farm dam volumes, and the use of rainfall-runoff relationships from gauged MLR watersheds to estimate median annual adjusted catchment yield. These MLR relationships were used as a result of a shortage of long-term streamflow data from KI.

To manage the risk of excessive watercourse diversion in dry years, the 2009 Plan also includes provisions to limit the rates of extraction, and stipulated threshold flow rates (TFRs) that would provide for low-flows to maintain aquatic and riparian ecosystems. At the time of preparing the 2009 Plan, longer-term daily streamflow records from MLR catchments (including the Fleurieu Peninsula) were used to calculate these TFRs. Hydrological information from the MLR has been adopted in other regions in South Australia where detailed Environmental Water Requirement (EWR) assessments had yet to be undertaken, in order to develop localised relationships between rainfall and streamflows.

1.3 Background of this project

The Board is currently reviewing the 2009 Plan in preparation for an imminent update. In 2013, the Board approached SMK of DEWNR to undertake scientific investigations into a revised method for determining WULs that would utilise hydrological data that was available from KI.

In finalising the 2009 Plan, a Water Resources Taskforce (WRTF) was established to, inter alia, review surface water policy set out in the 2009 Plan and the scientific basis of the policy. In May 2010, at the recommendation of the WRTF, the Board contracted CSIRO to conduct an independent scientific review of surface water resources management policies contained in the 2009 Plan. Through this review, Aryal (2011) concluded that (inter alia) there was little justification for the ongoing use of Method "A" (and its associated approach to SL calculation). The WRTF subsequently reviewed the CSIRO Report (Aryal, 2011), and made a suite of recommendations to the Board on how to proceed with water resources management policy on KI. These recommendations were released by the Board as a Public Communiqué in March 2012 titled "KI Water Resources Management Update" (KINRMB, 2012).

In response to the recommendations presented in this public communiqué, SMK presented an internal draft discussion paper to the WRTF in October 2012 that outlined a spectrum of eight options that could be used to determine WULs in future revisions of the 2009 Plan. The discussion paper and the associated presentation from SMK did not seek to advocate for one option or another, rather, it sought to inform discussion around the potential pros and cons of each option.

At the conclusion of the October 2012 meeting with SMK, the WRTF requested SMK to "...develop a project plan for the delivery of *Option 5 – Validated/refined Method B* and *Option 6 – Regionalisation using available data*, for the Board to consider." The basis for Option 5 was described in the draft discussion paper in the following manner:

> *Option 5: Validated/ refined Method B*
> *Validate/revise Method B (25% rule) and associated policies (e.g. maintenance of low flows) for different KI catchments using data that has become available since Method B was originally implemented for KI. This option would use all available data from KI, with the potential to use appropriate data from similar non-KI catchments also.*

Formal EWRs are yet to be developed across KI, and therefore a clear description of KI's water dependent ecosystems (WDEs) and the flow regimes required for maintaining the health of these ecosystems remains quantitatively limited. *Option 6* in the draft discussion paper was designed to address this through a complete review of the methodology for determining WULs based on KI-specific rainfall-streamflow relationships and new EWR data:

> *Option 6: Regionalisation using currently available non-KI and KI data*
> *Regionalise from available local rainfall & stream flow and catchment characteristics data (e.g. Middle River) to formulate new (water sharing) rules. Catchments/sub-catchments can be grouped into similar hydrological categories based on catchment characteristics prior to application of any methodology. Hydrological and ecological studies have occurred in similar environments to KI. It may be possible to extend findings from these areas to KI if regionalisation is possible. Using KI data where possible to validate hypotheses will increase confidence in findings.*

The Board subsequently requested SMK to undertake all work required to deliver *Option 5* from the draft discussion paper, taking into account the Board's commitment to complete *Option 6* at a later date. It was proposed that a revised/validated WUL methodology determined through *Option 5* would be applied to the whole of KI (outside national park, conservation park and wilderness protection areas), without the separation into hydrological Zones "A" and "B". This report represents SMK's response to the Board's request and provides a suite of options to calculate revised WULs at a subcatchment scale, and seeks to outline some progress towards *Option 6* and priorities for further works.

1.4 Project approach

The key objective of this project was to validate WULs across KI through the use of local hydrological information. To maintain consistency with State policy, the "25% rule" (as described in Section 1.2) was utilised to calculate WULs for both gauged and ungauged catchments. The use of this rule requires estimates for median adjusted annual catchment yields, and to be consistent with the methodology used for Zone "B" in the 2009 Plan (Method "B"), relationships between average catchment yield and average annual catchment rainfall were defined using the standard hydrological TanH function (Grayson *et al.*, 1996).

In the 2009 Plan, the parameters of the TanH function adopted for all Zone "B" catchments were estimated from a time series of reconstructed inflows to Middle River Reservoir, for the period 1970–92. As a consequence, existing WULs for KI were calculated under a range of modelling assumptions, including the relevance of the historical period used, the applicability of these data to represent yield in other catchments, and a purported close relationship to hydrological behaviours in MLR catchments.

Since the completion of the 2009 Plan, additional hydrological information has been obtained across KI through the installation of a streamflow gauging station on Stunsail Boom River, and ongoing operation of streamflow gauging stations on Cygnet River and Timber Creek. Although the gauging stations on these latter two watercourses pre-dated the 2009 Plan, the period of data available from these stations has now increased to a level that warranted investigations. The initial phase of this project involved analysis of hydrological data from KI and from selected MLR catchments, with a view to assessing the relevance of the assumptions made in the 2009 Plan. Recent streamflow records from KI were analysed against estimates of catchment-averaged rainfall (using gridded daily rainfall data from the SILO climate database to characterise rainfall-runoff relationships at both an annual scale and a daily scale. SILO is an enhanced climate data bank hosted by the Science Delivery Division of the Queensland Government Department of Science, Information Technology, Innovation and the Arts (DSITIA).

A range of options to calculate WULs in the various KI catchments using these rainfall-runoff relationships were then developed. In addition, rainfall-runoff relationships at a daily scale were explored in order to characterise threshold flow rates (TFRs), which can be used to manage surface water extractions on KI.

2 Hydrological data analysis

2.1 Background

Kangaroo Island has an area of 4370 km^2, measuring approximately 155 km east–west, and approximately 55 km north–south at its widest point. KI has 53 water resource catchments, and most watercourses are ephemeral providing flows mainly through the winter period. The majority of the watercourses drain the higher Gosse Ritchie plateau in the north-west of KI towards the coastline.

As with much of Southern Australia, KI has a temperate climate with dry warm summers and cool wet winters, with higher rainfall recorded in the western region of the island. Although a large proportion of KI has been cleared for agricultural production, significant areas of native vegetation remain. Plantation forestry expanded considerably in the early part of this century, and now covers around 230 km^2. The presence of plantation forestry plays an important role when defining the hydrological characteristics.

The Rocky River catchment is located in the Flinders Chase National Park in the south-west of KI, and is one of few catchments in South Australia still predominantly covered by native vegetation and not subject to land clearing (Banks 2010). The hydrological importance of a fully-vegetated natural catchment is recognised, with Rocky River having the longest operating streamflow-monitoring gauge on KI (installed in 1970). Although catchment yield from cleared agricultural land will be higher than from natural (uncleared) catchments, a shortage in streamflow monitoring stations across KI has prevented a thorough analysis in the past. There are currently five main streamflow gauging stations operating across KI, with locations of these stations shown in Figure 1. Two gauging stations located on the Cygnet River (which is the largest catchment on KI) and single gauging stations in the Timber Creek and Stunsail Boom River catchments have been established in the past 10 years, to complement the Rocky River gauge.

2.2 Previous hydrological analysis

The 2009 NRM Plan contains a suite of surface water management policies, including definitions of "Sustainable Limits" (SLs – refer to Part1, Section 1.2 for background) and actions for their implementation. Prior to the preparation of the 2009 Plan, a range of background studies had been completed to gain a better understanding of the quality and quantity of water resources of KI, and the management required to sustain natural ecosystems, primary industries, and human consumption needs, together with other urban and domestic uses (McMurray, 2007). Nilsen (2006) prepared a comprehensive report for the Board, as part of the *Rivers of Life* project that involved extensive on-ground investigations, which were a response to community concerns over deteriorating conditions of water resources. The report sought to provide a baseline technical background on the condition of surface water and groundwater resources, by focussing on seven main catchments.

As part of the same multi-agency study into the natural resources, McMurray (2007) developed a risk assessment approach to quantify the impact of farm dams on runoff and the potential threats to aquatic ecosystems through the use of a GIS-based model that incorporated simulated mean-annual runoff captured by farm dams. A rainfall-runoff equation based on the standard hydrological TanH equation was used for this assessment, the parameters of which were derived from annual rainfall and a yield analysis for the Middle River Reservoir catchment.

As previously indicated, the 2009 Plan specified SLs at a subcatchment scale. These SLs were derived from estimates of average catchment yields, which in turn were estimated (for ungauged catchments) from the rainfall-runoff relationship developed by McMurray (2007), derived from a time series of annual reconstructed inflows to Middle River Reservoir, the only major water supply storage on KI. Although SA Water developed a WaterCress water balance model (AWE, 2009) to assist the management of reservoir operations, this did not supply any additional information regarding streamflow responses in Middle River.

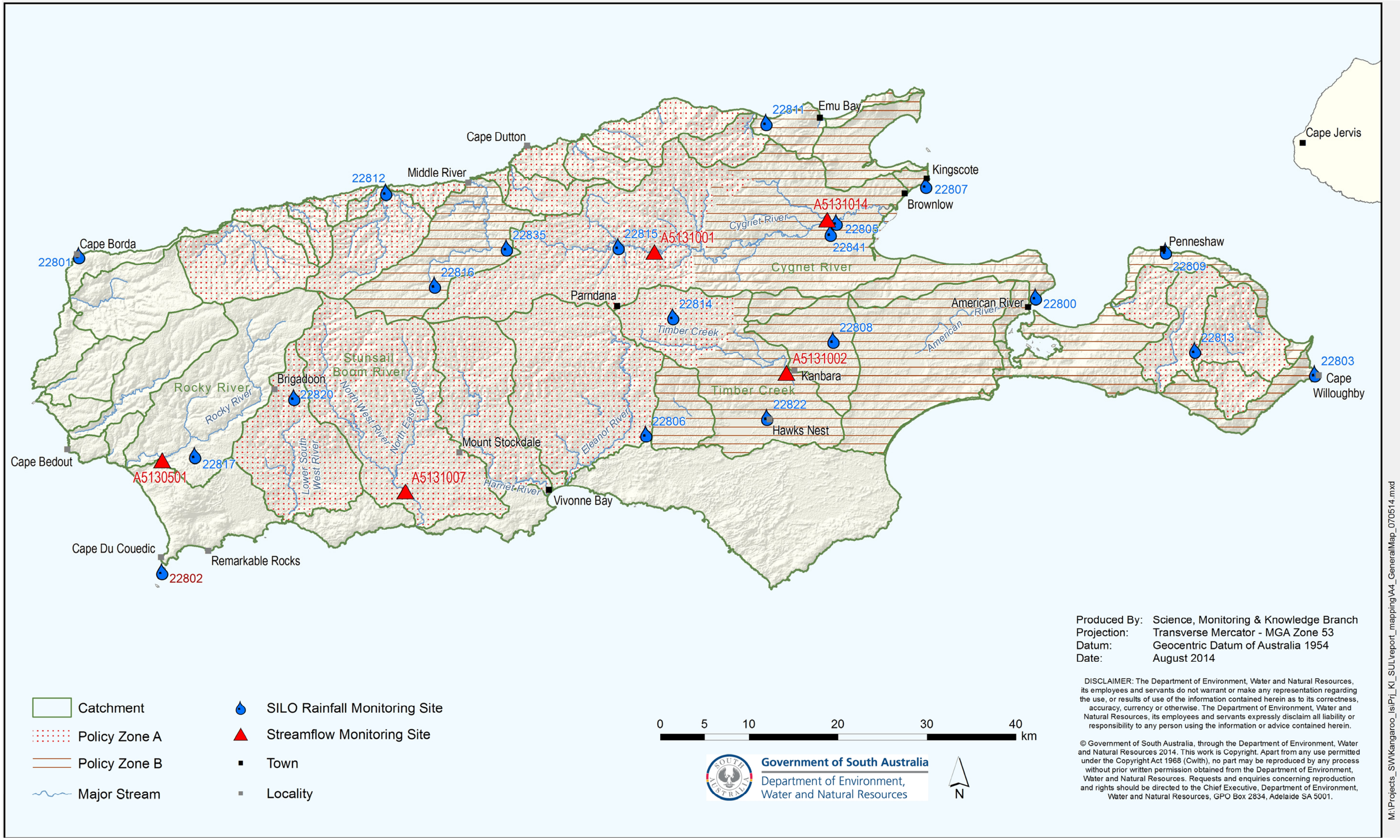


Figure 1 Locations of water resource catchments, streamflow gauging stations and rainfall gauging stations

2.3 Catchment characteristics

Land use plays a key role in catchment yield, with the clearing of native vegetation increasing yields and the development of plantation forestry significantly reducing yields. Greenwood and Cresswell (2007) indicated that the long-term reduction in runoff from forested catchments in the MLR approached 85% of pre-forest runoff. The assumption of plantation forestry having an 85% reduction in pre-forest runoff is now South Australian policy (Government of South Australia, 2009). To further explore the hydrological characteristics of KI, land use in catchments upstream of each gauging station were analysed using GIS tools.

The Australian Land Use Management (ALUM) Classification system (BRS, 2006) groups land uses under three classes, primary, secondary and tertiary, with each tertiary class being a sub–class of a secondary class and each secondary class being a sub–class of a primary class. Table 1 summarises the land use (under the primary land use classes (1 to 6) of the ALUM Classification) for the catchment areas upstream (u/s) of the gauging stations for the five gauged catchments and the entire area of the Middle River catchment. The data indicate that the primary land uses across KI are under the Conservation and Natural Environments class (Class 1) (which includes national parks, conservation parks, wilderness areas, and privately owned land that has not been cleared as sub-classes) and the Production and Dryland Agriculture and Plantations class (Class 3) (representing land cleared for agricultural and plantations). Plantation forestry is reported as a sub-class (Class 3.1) of Class 3, and since the area covered by this land use is significant across some of the catchments, values for this secondary class are also included in Table 1 and Figure 2.

Rocky River catchment is predominantly an uncleared area, with significant portions of uncleared land also present in the Stunsail Boom River catchment. In contrast, Timber Creek has a very high proportion of cleared land. Uncleared land appears to be distributed in a uniform manner through the Cygnet River catchment, with the area upstream of the Huxtable Forest gauge having a similar proportion to the larger catchment that is upstream of the Koala Lodge gauge. Plantation forestry in the Cygnet River catchment however is concentrated in the upstream end.

Table 1 Land use for the five KI streamflow gauging station catchments and the Middle River catchment

Australian Land Use Management (ALUM) Classification Class		Rocky River @ u/s Gorge Falls	Cygnet River @ Huxtable Forest	Timber Creek @ South Coast Road	Stunsail Boom River @ South Coast Road Bridge	Cygnet River @ u/s Koala Lodge	Middle River
1	Conservation and Natural Environments	186.02 (98.2%)	47.27 (21.8%)	23.58 (18.7%)	172.04 (63.7%)	101.72 (21.2%)	53.05 (36.4%)
2	Production from Relatively Natural Environments	0.00 (0.0%)	0.00 (0.0%)	0.00 (0.0%)	0.00 (0.0%)	0.00 (0.0%)	0.00 (0.0%)
3	Production from Dryland Agriculture and Plantations	0.60 (0.32%)	161.32 (74.5%)	98.59 (78.2%)	92.03 (34.1%)	364.54 (76.0%)	87.16 (59.8%)
3.1	*Plantation forestry*	*0.49 (0.26%)*	*39.07 (18.0%)*	*5.43 (4.3%)*	*41.29 (15.3%)*	*47.23 (9.8%)*	*26.16 (17.9%)*
4	Production from Irrigated Agriculture	0.00 (0.0%)	0.84 (0.4%)	0.56 (0.4%)	0.32 (0.1%)	1.19 (0.2%)	0.00 (0.0%)
5	Intensive Uses	1.21 (0.6%)	6.45 (3.0%)	2.88 (2.3%)	3.54 (1.3%)	10.94 (2.3%)	3.83 (1.3%)
6	Water	1.56 (0.8%)	0.68 (0.3%)	0.52 (0.4%)	2.14 (0.8%)	1.32 (1.3%)	1.69 (0.8%)
Total catchment area (km^2)		**189.39**	**216.56**	**126.12**	**270.07**	**479.72**	**145.74**

Figure 2 illustrates these land use areas in terms of proportions of total catchment area. Note that Plantation Forestry (Class 3.1) is sub-class of the Production from Dryland Agriculture and Plantation class (Class 3). These land use characteristics are explored later in this report in the analysis of rainfall-runoff relationships for KI. The distribution of land use types across the whole of KI are illustrated in Figure 3.

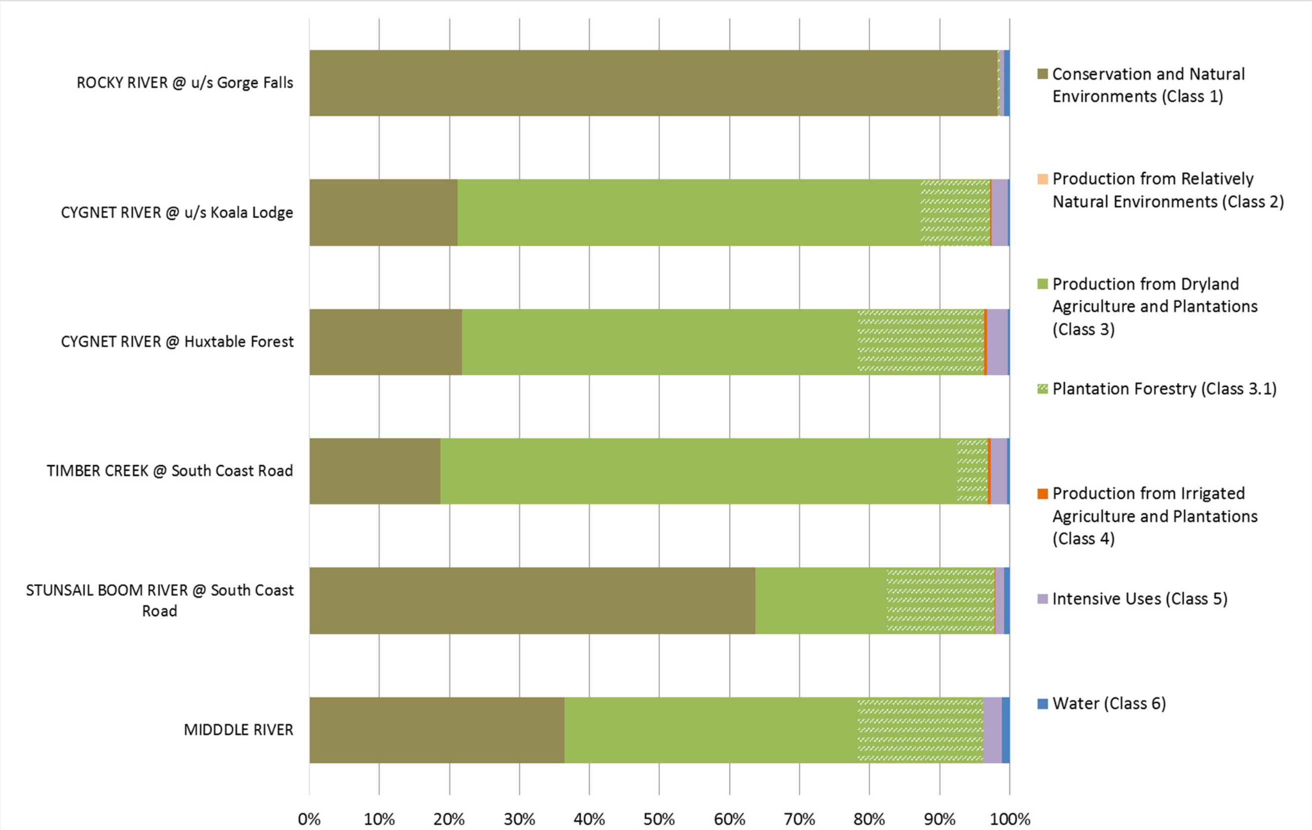


Figure 2 Land use proportions for the five KI streamflow gauging station catchments and Middle River catchment

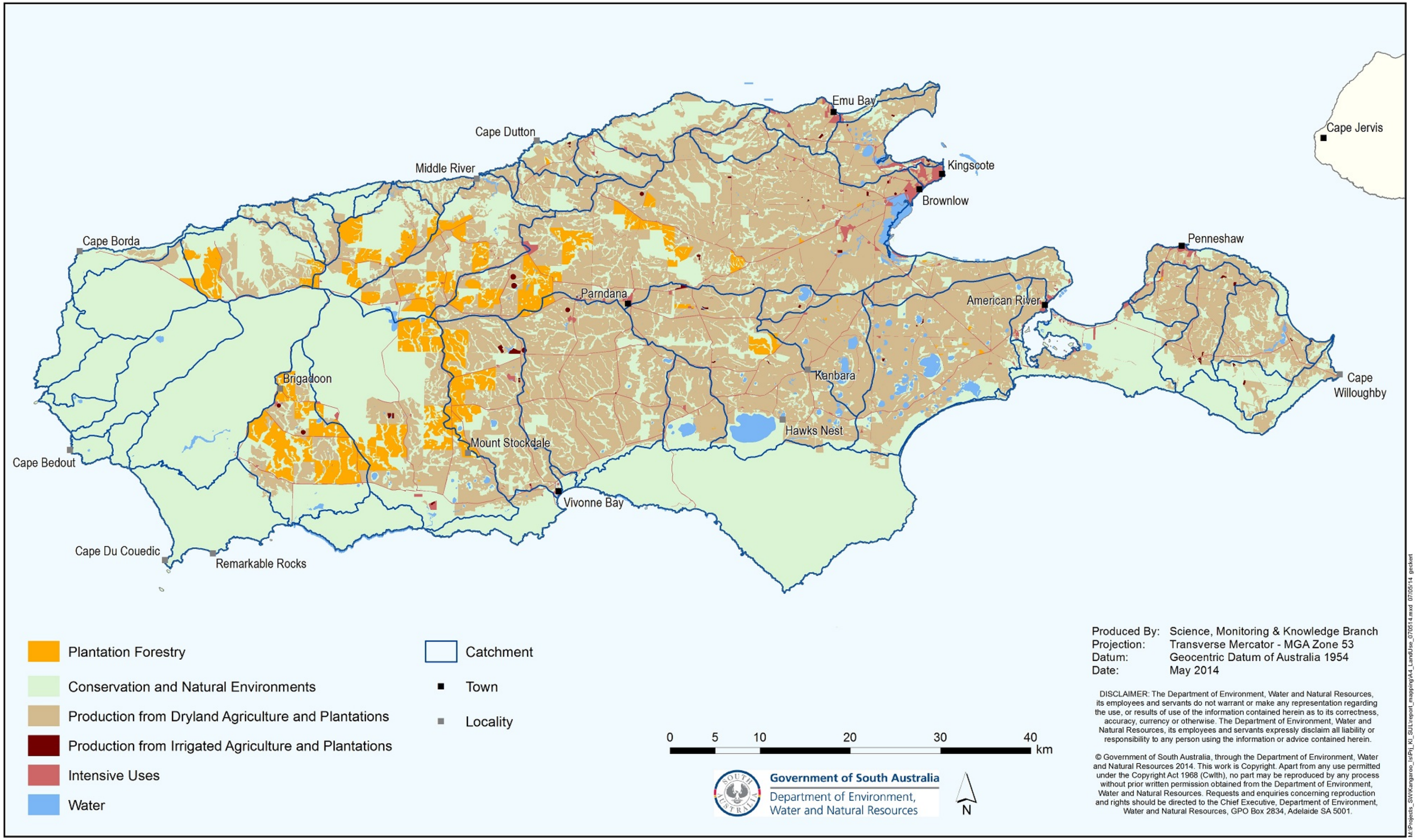


Figure 3 Distribution of land use types

2.4 Rainfall data

The spatial and temporal variability in historic rainfall across KI (and selected MLR catchment areas) was characterised from the SILO rainfall dataset in a GIS framework. These climate datasets, which include daily rainfall, are based on historical climate data provided by the Bureau of Meteorology (BoM).

The SILO Patched Point Dataset is a collection of daily climate data sets for BoM observation stations that extends original BoM measurements back to 1889 with interpolated values (Jeffrey et al., 2001). The annual rainfall records for two of these SILO stations 22816 (located in the upper catchment of Middle River on the Gosse Ritchie plateau) and 22841 (located at the downstream end of the Cygnet River catchment near the eastern coastline) are shown in Figure 4 and Figure 5 respectively. These two figures demonstrate the large spatial variability in rainfall across KI, with the former site having long-term mean annual rainfall of 799 mm (for 1889–2013) and the latter 474 mm.

The mean annual rainfall for each series was subtracted from each annual total to produce a series of annual "rainfall departure" values. These annual departures were then accumulated, with the resulting time series shown in Figure 4 and Figure 5 as the "cumulative departure from long-term mean". An extended period of negative cumulative departure values indicated an extended period of below-average rainfall. These cumulative departures highlight significant differences in the distribution of rainfall between these two stations. For example, 1975–91 was a period of consistently above-average rainfall at the inland station, but also a period of below-average rainfall at the coastal station. These observations indicate that the spatial variability in rainfall may have considerable impact upon hydrological responses across KI.

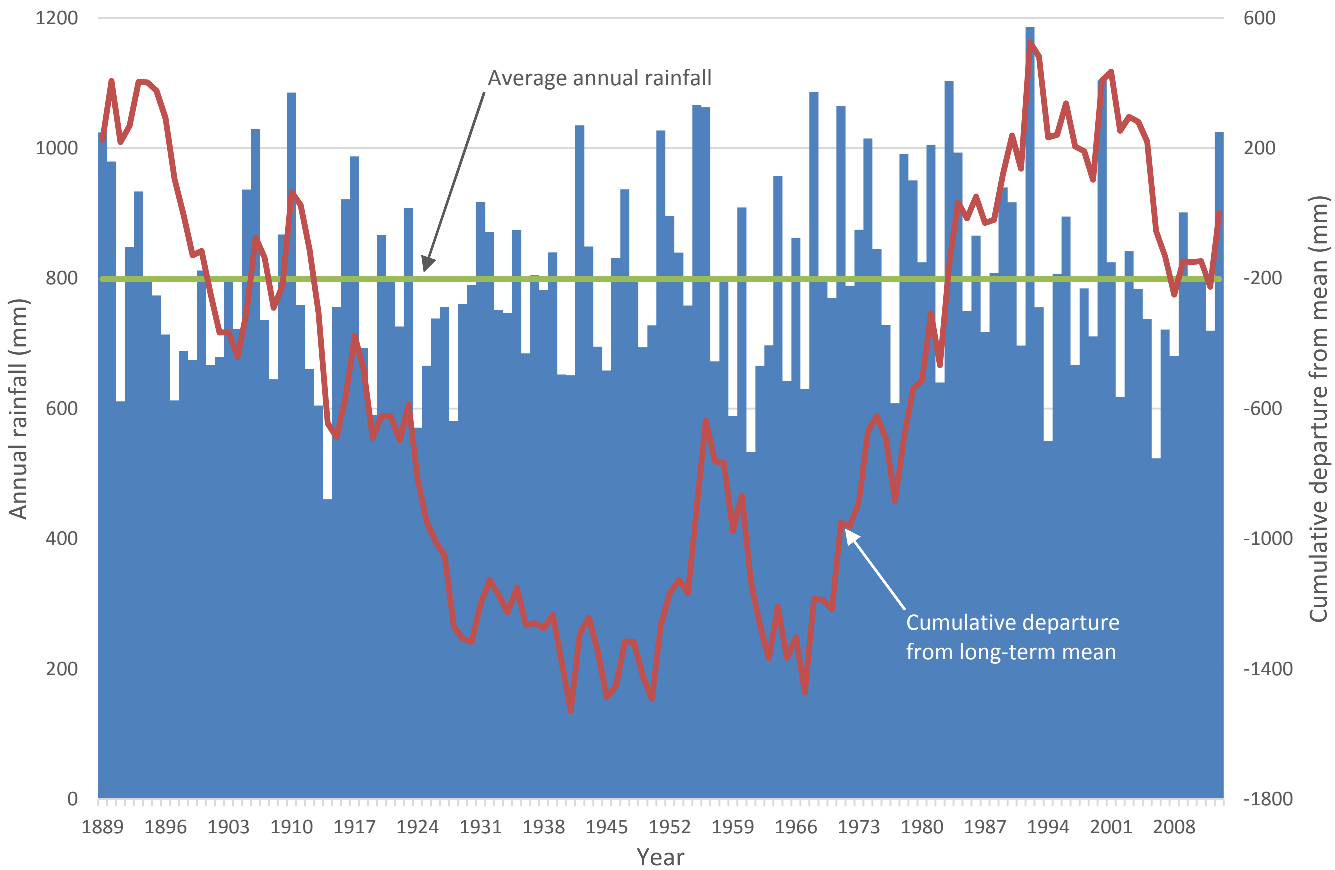


Figure 4 Annual rainfall for SILO station 22816 Parndana (Allandale)

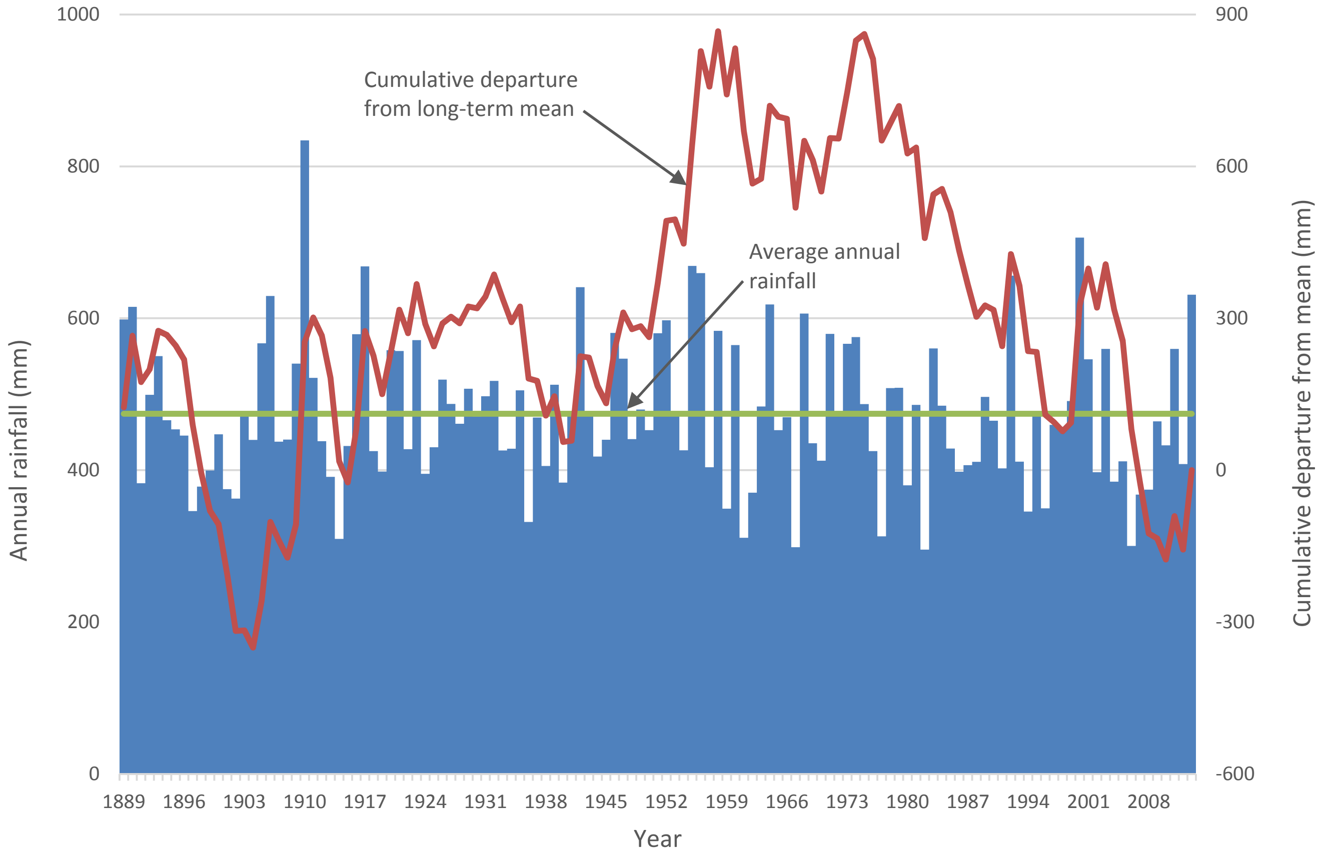


Figure 5 Annual rainfall for SILO station 22841 Kingscote Airport

The SILO Patched Point Dataset also includes daily records for a number of climate variables that have been interpolated between observation stations (through the use of splining and kriging techniques), and provided on a 0.05 degree grid (approximately every five kilometres) across Australia. These gridded data were available for the period 1900–2012, and although they are derived from measured data at discrete locations, they are entirely synthetic.

The SILO gridded rainfall data provided the most useful measurement of rainfall variability across KI, and were analysed via GIS to determine average daily rainfall across subcatchments. With many of these subcatchments being smaller than the 25 km^2 resolution provided in the original SILO gridded data, these data were resampled at a grid spacing of 0.005 degrees (approximately 0.5 km, realising a resolution of 0.25 km^2). Note that all 0.005 degree grids within a 0.05 degree grid have the same rainfall as that of the parent 0.05 degree grid. The resampled daily rainfall grids were aggregated from daily to annual totals, and were then analysed via GIS to calculate spatially averaged rainfall totals for areas including catchments upstream of gauging stations, and ungauged catchments at a subcatchment scale.

Figure 6 shows spatially-averaged annual rainfall totals for catchments upstream of the Rocky River and Timber Creek gauging stations for the period 1900–2012. These time series again highlight the variability in rainfall across KI, with the annual average rainfall across this period ranging from 705 mm for the Rocky River catchment to 540 mm for Timber Creek.

The spatial variability in annual rainfall across KI is illustrated in Figure 7 with annual spatially-averaged rainfall calculated from SILO gridded data (1900–2012) shown for each subcatchment area.

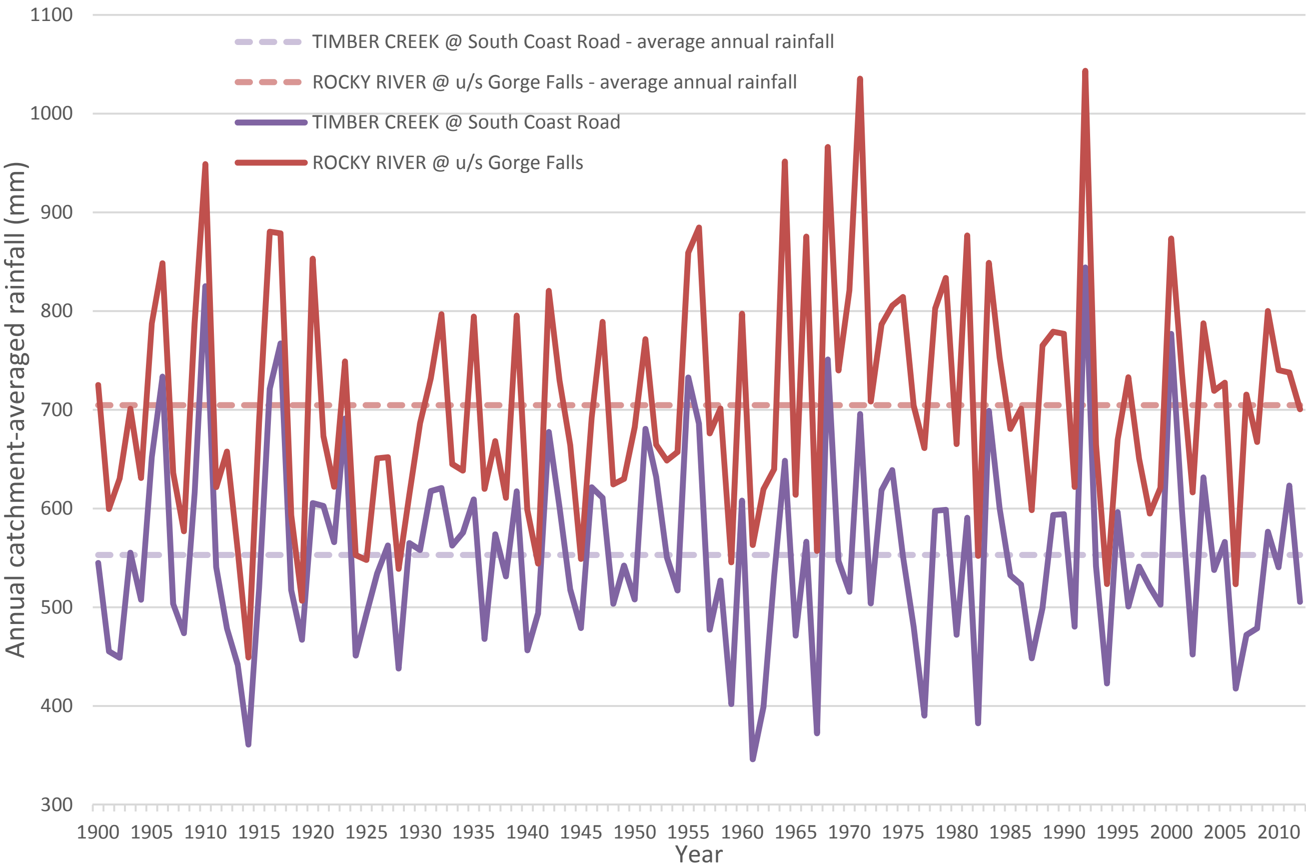


Figure 6 **Annual catchment-averaged rainfall associated with the Rocky River and Timber Creek streamflow gauging stations from SILO gridded data (1900–2012)**

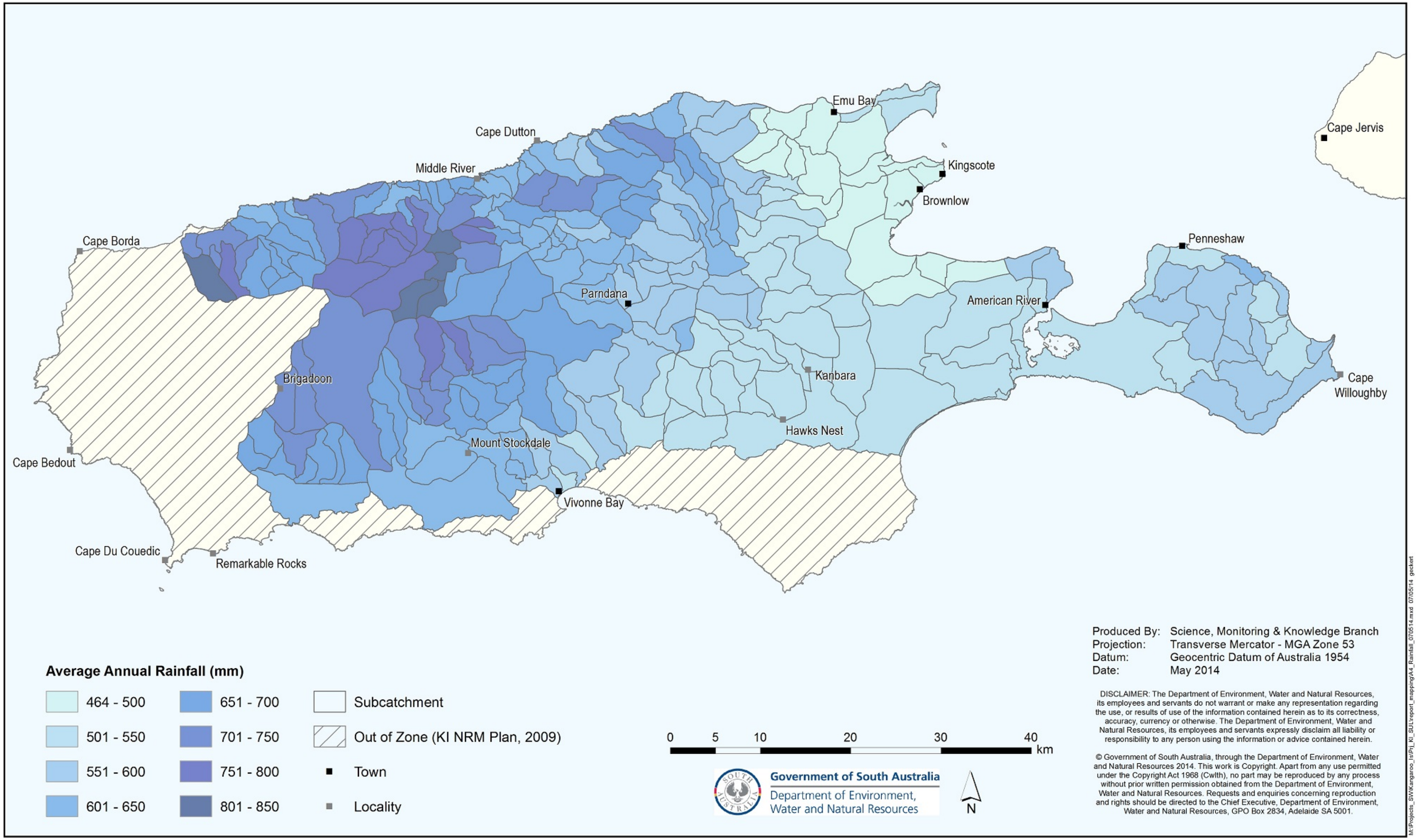


Figure 7 Average annual rainfall for subcatchments calculated from SILO gridded data (1900–2012)

At the time of preparing this report, SILO gridded data sets were not available for 2013, although daily rainfall at SILO stations (which are BoM observations stations) were available to 31 Dec 2013. Therefore to determine estimates of catchment-averaged rainfall for 2013, linear combinations of annual rainfalls at SILO stations located in (or adjacent to) the gauging station catchments were fitted to the spatially averaged series for 1900–2012. For each spatially averaged rainfall series, various combinations of point rainfall predictors were investigated with parameters fitted through minimising the residual sum of squares, and a parsimonious model structure chosen. The locations of the 21 SILO stations on KI are shown in Figure 1.

The linear model (M_t) chosen to describe average rainfall for the upstream catchment of the Timber Creek gauge was a combination of annual rainfall at sites 22814 (Parndana East Research Station) and 22822 (Murray Lagoon – Hawks Nest), i.e.:

$$M_t = 0.494 \times [22814]_t + 0.495 \times [22822]_t$$

The linear model for Timber Creek rainfall is shown alongside the spatially averaged gridded rainfall in Figure 8.

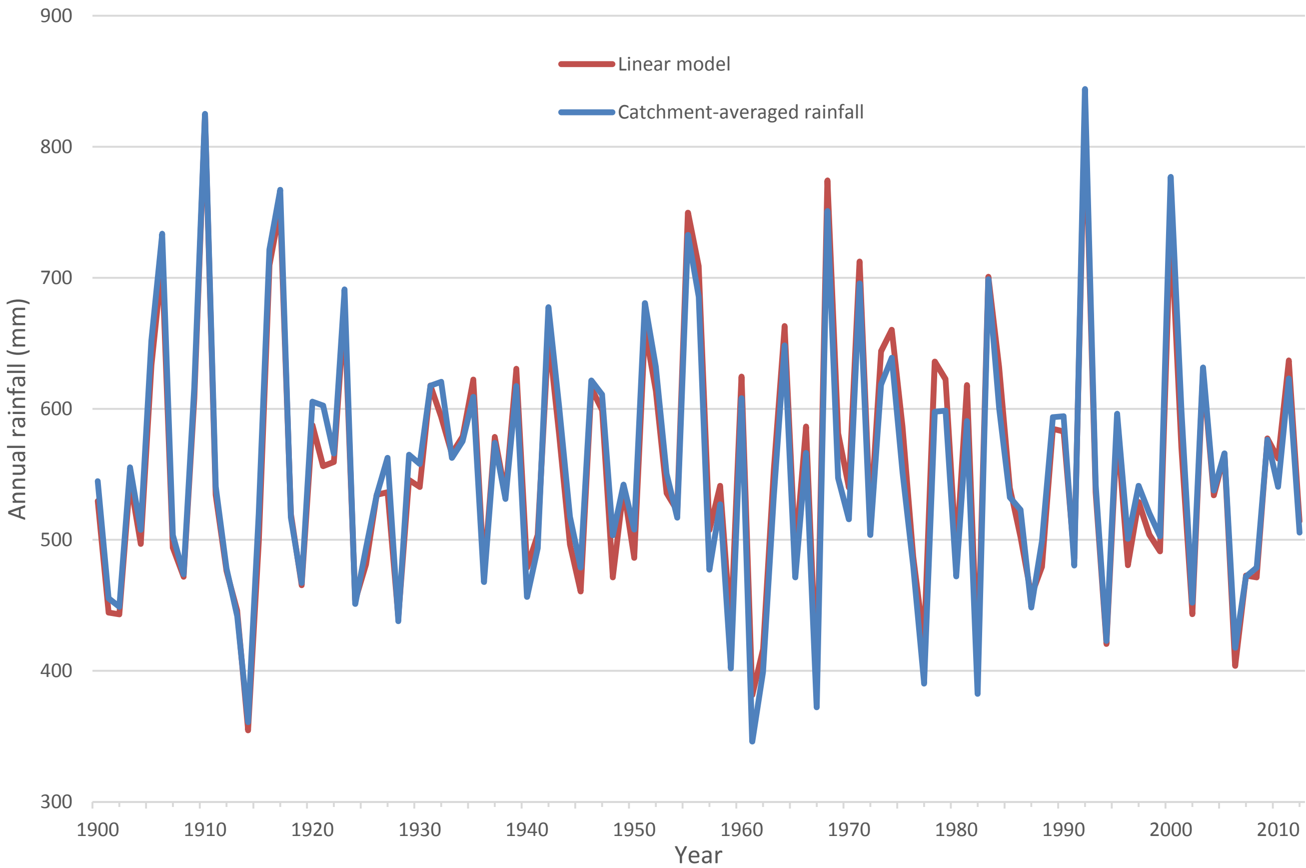


Figure 8 Catchment-averaged rainfall for the Timber Creek gauging station from SILO gridded data alongside a linear model of these data from SILO point rainfall

This model-fitting process was repeated for the catchment-averaged rainfall for each KI gauging station. Summary statistics for 1900–2012 for the linear combinations of point rainfall series are summarised in Table 2 alongside statistics for the catchment-averaged rainfall series.

The five linear combinations shown in Table 2 were then used to generate catchment-averaged rainfall associated with the five gauging stations for 2013, to enable analysis of the rainfall-runoff relationships for these streamflow gauges for 2013. The estimates for 2013 are shown in Figure 9 alongside the gridded rainfall totals for the period 1993–2012. These values were assumed to be the best estimates for catchment-wide rainfall in the absence of the SILO gridded daily rainfall data.

Table 2 Summary statistics for spatially averaged gridded rainfall and linear combinations of point rainfall series for the five KI gauging station catchments (1900–2012)

Streamflow gauging station catchment	Linear model	Annual average rainfall (mm)	Standard deviation (mm)	Annual maximum (mm)	Annual minimum (mm)	Linear correlation
Rocky River	n/a	704.72	115.45	1043.25	449.11	n/a
	0.706 x **22817** + 0.258 x **22816**	703.98	119.48	1040.65	441.87	0.991
Cygnet (Huxtable)	n/a	643.30	117.39	961.51	391.13	n/a
	0.376 x **22815** + 0.171 x **22835** + 0.349 x **22816**	639.05	116.68	928.38	391.20	0.991
Cygnet (Koala)	n/a	598.31	109.43	913.43	376.32	n/a
	0.215 x **22815** + 0.333 x **22816** + 0.408 x **22841**	598.27	108.81	928.96	374.26	0.992
Timber Creek	n/a	552.92	96.91	843.96	346.05	n/a
	0.494 x **22814** + 0.495 x **22822**	552.98	94.89	829.08	354.63	0.983
Stunsail Boom	n/a	696.20	117.31	1093.01	389.63	n/a
	0.486 x **22820** + 0.633 x **22806**	694.90	120.43	1115.00	427.30	0.962

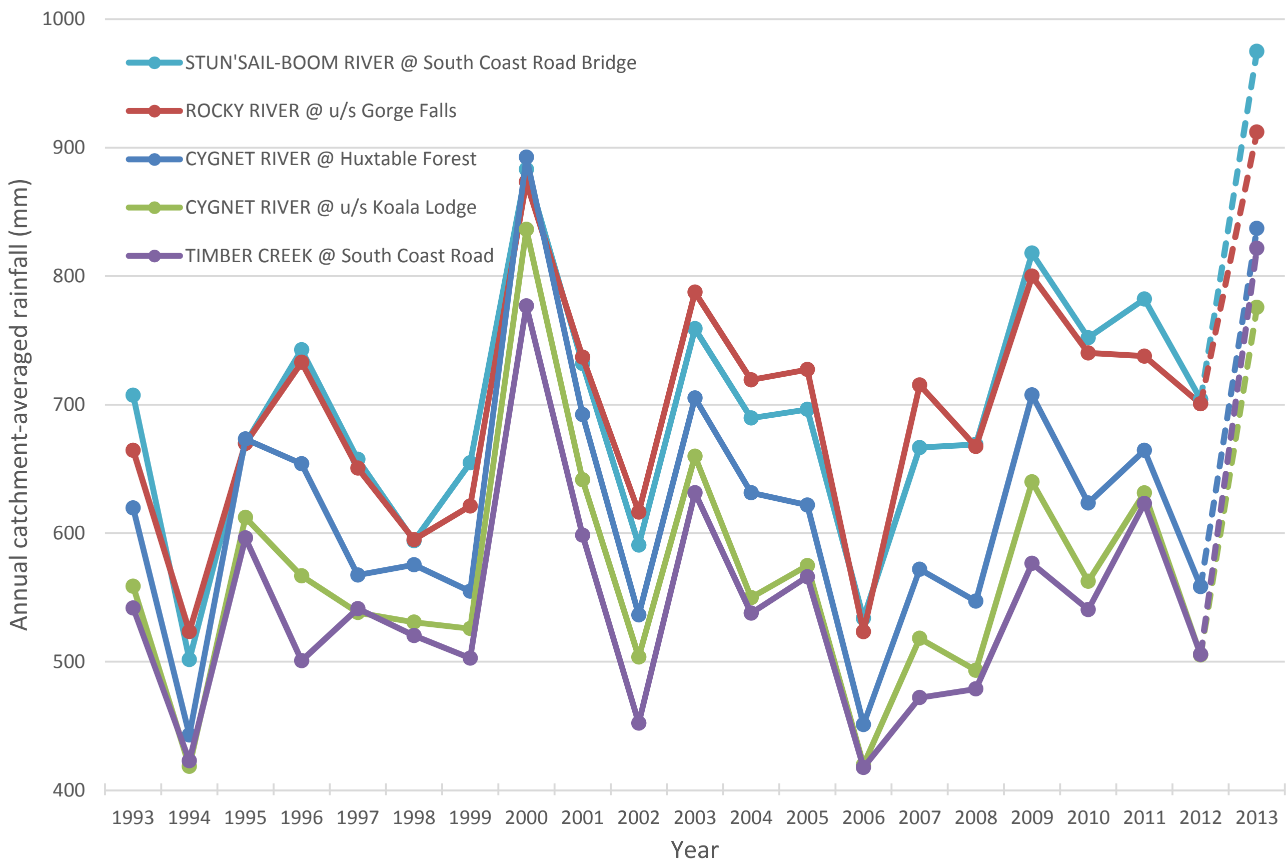


Figure 9 Annual catchment-averaged rainfall totals corresponding to the five KI streamflow gauging stations from SILO gridded data (1993–2013), with 2013 values estimated from linear models

2.5 Annual streamflow data

The five KI streamflow gauging stations that were used for this analysis (and the five stations currently operating on KI) are described in Table 3. The Rocky River gauging station was established in 1970, and has a mostly complete record of daily flows from 1974 onwards. However, there are long periods of missing flow data in the other four flow records, as shown in Figure 10 in terms of monthly record completion, with the percentage of days with non-missing data shown for each month from Jan 2003–Dec 2013.

Table 3 Summary information for KI streamflow gauging stations

Gauging station name	Station number	Area (km^2)	Start of flow record	Calendar years analysed
Rocky River @ u/s Gorge Falls	A5130501	189.4	28/08/1970	1974-2009, 2011-13 (39 years)
Cygnet River @ Huxtable Forest	A5131001	216.7	25/04/2004	2009-10, 2012-13 (4 years)
Cygnet River @ u/s Koala Lodge	A5131014	480.2	15/01/2003	2003-07, 2009-13 (10 years)
Timber Creek @ South Coast Road	A5131002	126.2	26/06/2004	2009-2013 (5 years)
Stunsail Boom River @ South Coast Rd Bridge	A5131007	270.1	18/02/2010	2012-2013 (2 years)

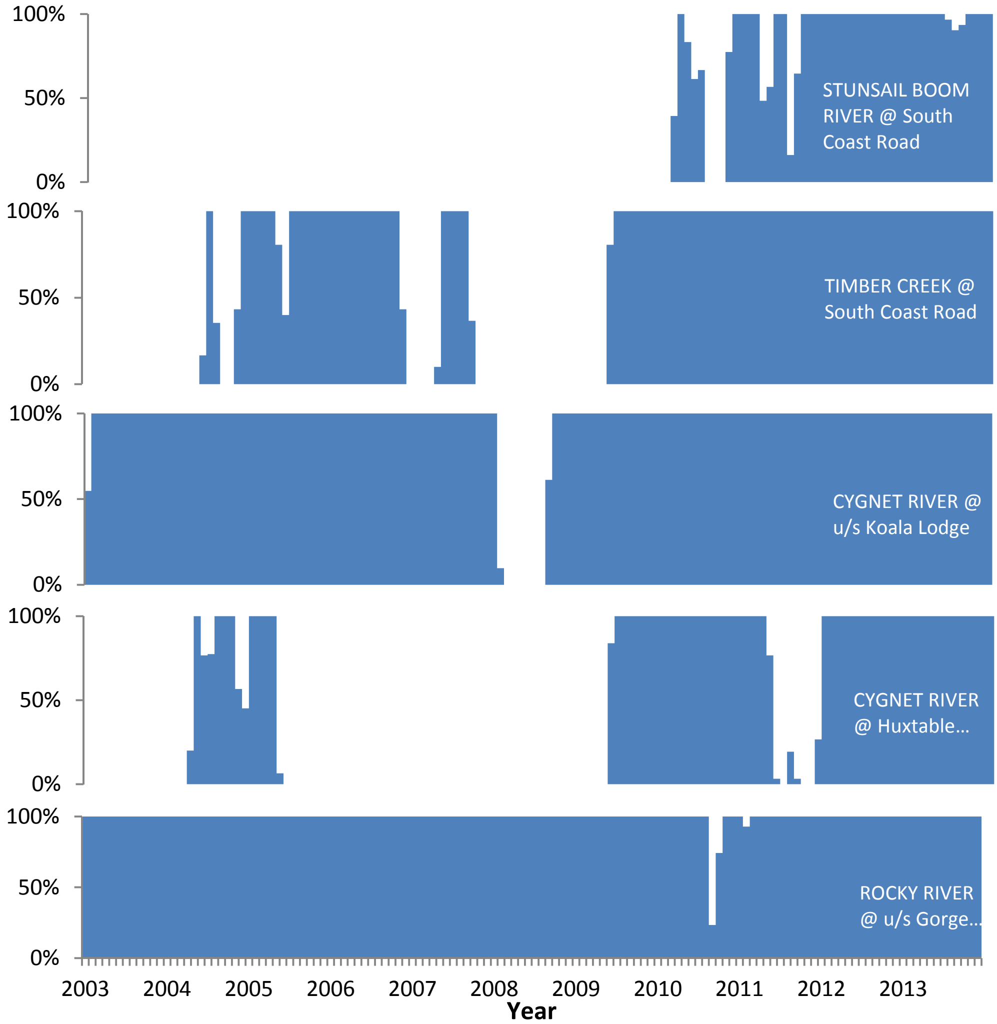


Figure 10 Monthly streamflow data availability for the five KI streamflow gauging stations

As a consequence of the periods of missing data across these daily streamflow records, the analysis of flow data (and hence catchment yield) for these KI gauges was undertaken only for the calendar years with non-missing flow data (or where missing data only occurred in low flow or likely zero-flow periods), as shown in Table 3. Annual flows recorded in these selected years are summarised in Table 4. Average rainfall-runoff relationships for these selected calendar years are described in Table 5.

Table 4 Summary of annual streamflow data for calendar years having non-missing data

Gauging station name	Mean annual flow (and std. dev.) for selected years (ML)	Maximum annual flow for selected years (ML)	Minimum annual flow for selected years (ML)
Rocky River @ u/s Gorge Falls	13,643 (9,400)	44,724	1,920
Cygnet River @ Huxtable Forest	28,977 (13,480)	42,096	14,389
Cygnet River @ u/s Koala Lodge	46,637 (38,389)	131,376	2,457
Timber Creek @ South Coast Road	19,342 (12,845)	41,978	11,179
Stunsail Boom River @ South Coast Rd Bridge	22,172 (10,529)	29,617	14,726

Table 5 Summary of rainfall-runoff relationships for calendar year having non-missing data

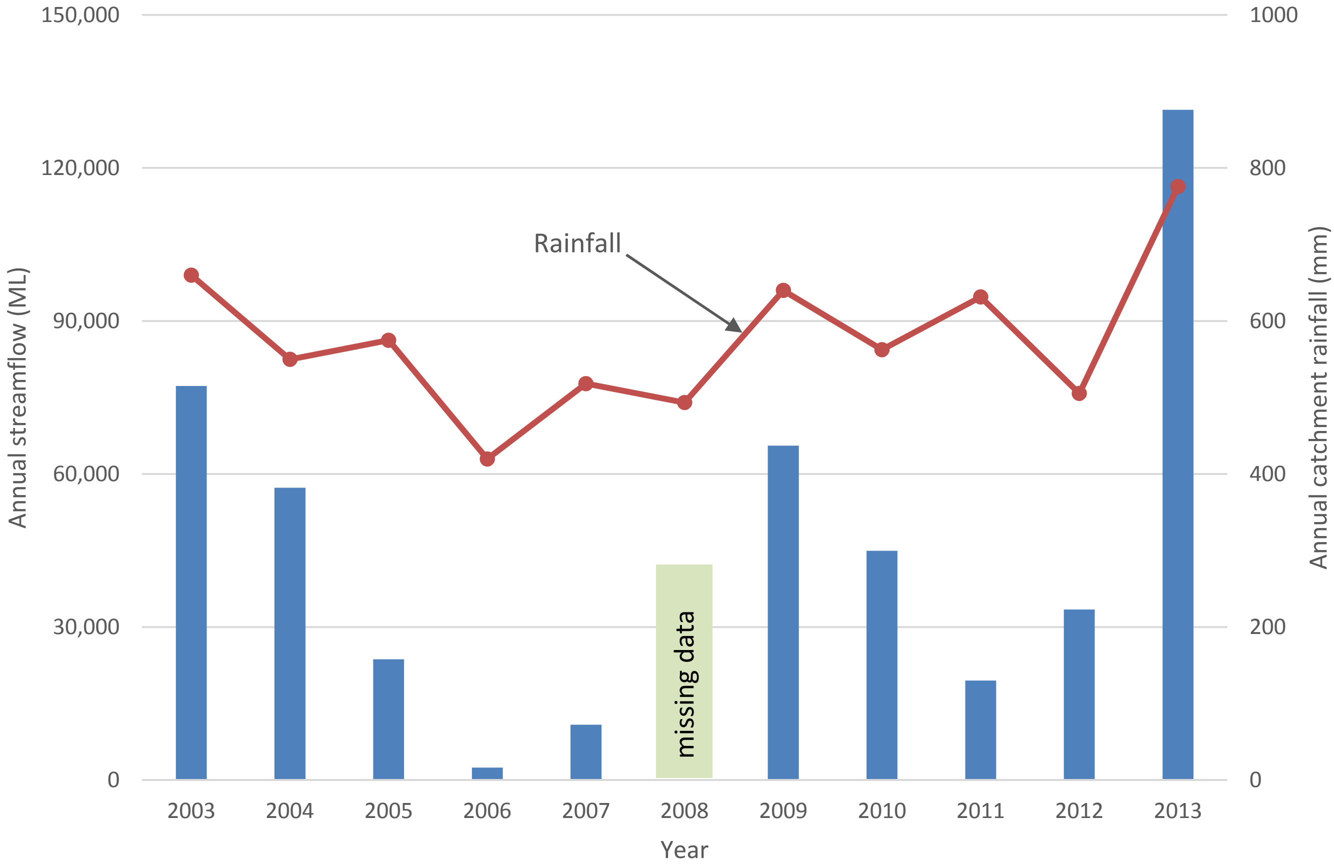
Gauging station name	Mean annual flow (ML)	Mean annual runoff (mm)	Mean annual rainfall (mm)	Runoff coefficient
Rocky River @ u/s Gorge Falls	13,643	72	725	10%
Cygnet River @ Huxtable Forest	28,977	134	682	20%
Cygnet River @ u/s Koala Lodge	46,637	97	575	17%
Timber Creek @ South Coast Road	19,342	153	613	25%
Stunsail Boom River @ South Coast Rd Bridge	22,172	82	840	10%

It is interesting to note in Table 5 that the runoff coefficient for the Huxtable Forest catchment of the Cygnet River was higher than for the downstream Koala Lodge gauge, where Figure 2 showed that the latter had a higher proportion of cleared land. However for short records, the period of analysis can have a large impact on deriving average annual characteristics. With the Huxtable Forest record being shorter (4 years) than the Koala Lodge record (10 years), it is necessary to also observe the average characteristics of the latter across the same period that is available for the former. Table 6 provides a comparison between rainfall-runoff relationships across this shorter 4 year sequence, showing that in these same years the downstream gauge has a much higher runoff coefficient.

The rainfall-runoff relationship for the Cygnet River catchment (as measured at the Koala Lodge gauge) is further analysed in Figure 11, with successively drier years (e.g. 2003–06) shown to have a cumulative impact of large reductions in streamflow.

Table 6 Summary of the impact of period of analysis on rainfall-runoff relationships in Cygnet River

Gauging station name	Period of analysis	Mean annual flow (ML)	Mean annual runoff (mm)	Mean annual rainfall (mm)	Runoff coefficient
Cygnet River @ Huxtable Forest	2009/10/12/13	28,977	134	682	20%
Cygnet River @ u/s Koala Lodge	2003-07,2009-13	46,637	97	575	17%
Cygnet River @ u/s Koala Lodge	2009/10/12/13	68,828	143	621	23%



[2]

Figure 11 Comparison of annual streamflow at the Koala Lodge gauging station on the Cygnet River with annual catchment rainfall for the upstream catchment

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[2] The green bar in Figure 11 does not represent the extent of missing data.

3 Annual rainfall-runoff relationships

The calculation of WULs for KI catchments with the "25% rule" requires a method to determine median annual adjusted catchment yield, as described in Part 1, Section 0. This is an important component of the WUL calculation process, both for gauged and ungauged catchments. As outlined in Part 1, Section 2.5, the Rocky River gauge is the only daily streamflow gauge on KI to provide long-term data. As a result, it was necessary to determine whether the hydrological data available from KI is sufficient to determine average catchment yields across both gauged and ungauged catchments.

As a means to validate WULs, it was necessary to first investigate the validity of key assumptions made to calculate WULs in the 2009 Plan, namely whether a single rainfall-runoff relationship is appropriate for the whole of KI, whether such a relationship(s) is consistent with hydrological relationships across the MLR, and whether the use of hydrological data for a period preceding 1993 is still appropriate.

Streamflow gauges that have been installed on KI since 1993 now provide some recent local hydrological data that enable such an investigation, with the five gauging records (although short in length) providing some insight to geographical influence on the hydrological characteristics of KI. If KI data were to reveal close hydrological relationships to MLR data, then the opportunity to utilise the longer MLR gauged records to better define rainfall-runoff relationships may be justified.

The rainfall-runoff relationship that was used to calculate WULs across KI for the 2009 Plan is a relationship between catchment rainfall and average catchment yield. No adjustment was made to these yields for farm dam extractions. To maintain consistency with the 2009 derivation of WULs, and to acknowledge that the hydrological modelling required to assess the impact of farm dams was beyond the scope of this project, this report followed the same approach. It should be acknowledged that this approach will result in lower estimates of average catchment yield than the 25% rule requires.

3.1 Background

The TanH hyperbolic relationship (Grayson *et al.*, 1996) is a standard model for relating annual rainfall to annual catchment yield, and is generally used for infilling annual runoff based on measured rainfall. This relationship estimates flow (Q) in terms of rainfall (P) and two parameters (L, F) in the following manner:

$$Q = (P - L) - F \times \tanh\frac{(P - L)}{F}$$

McMurray (2007) sought to define an annual rainfall-runoff relationship for KI. The only suitable runoff data at the time of the 2007 study was a series of modelled inflows to Middle River reservoir for the period 1970–92. This inflow series was derived from an annual water balance of Middle River Reservoir by Tomlinson (1996). As a consequence, these inflows were based on assumptions regarding the stage height to storage volume relationship of the Reservoir, and losses from storage due to evaporation and seepage and volumetric measurement of extractions. As a result, these data were unrepresentative of streamflows determined from a gauging station, and may have considerable uncertainty due to the many assumptions upon which they were based.

McMurray (2007) noted that the TanH function (with L=140 and F=730) that was fitted through these Middle River data (when plotted against annual rainfall estimates for the Middle River catchment) plotted close to a rainfall-runoff curve (TanH function with L=200, F=650) that was derived from MLR flow data, in an unpublished DWLBC study for the period ending 1992. As noted by McMurray (2007), "the similarities (between the MLR and Middle River curves) provided a degree of confidence in the relevance of the equation derived from the Middle River". These two rainfall-runoff curves are shown in Figure 12. Streamflow gauging stations on KI have provided the local hydrological information from which KI catchment-specific rainfall-runoff relationships presented in this report can be derived.

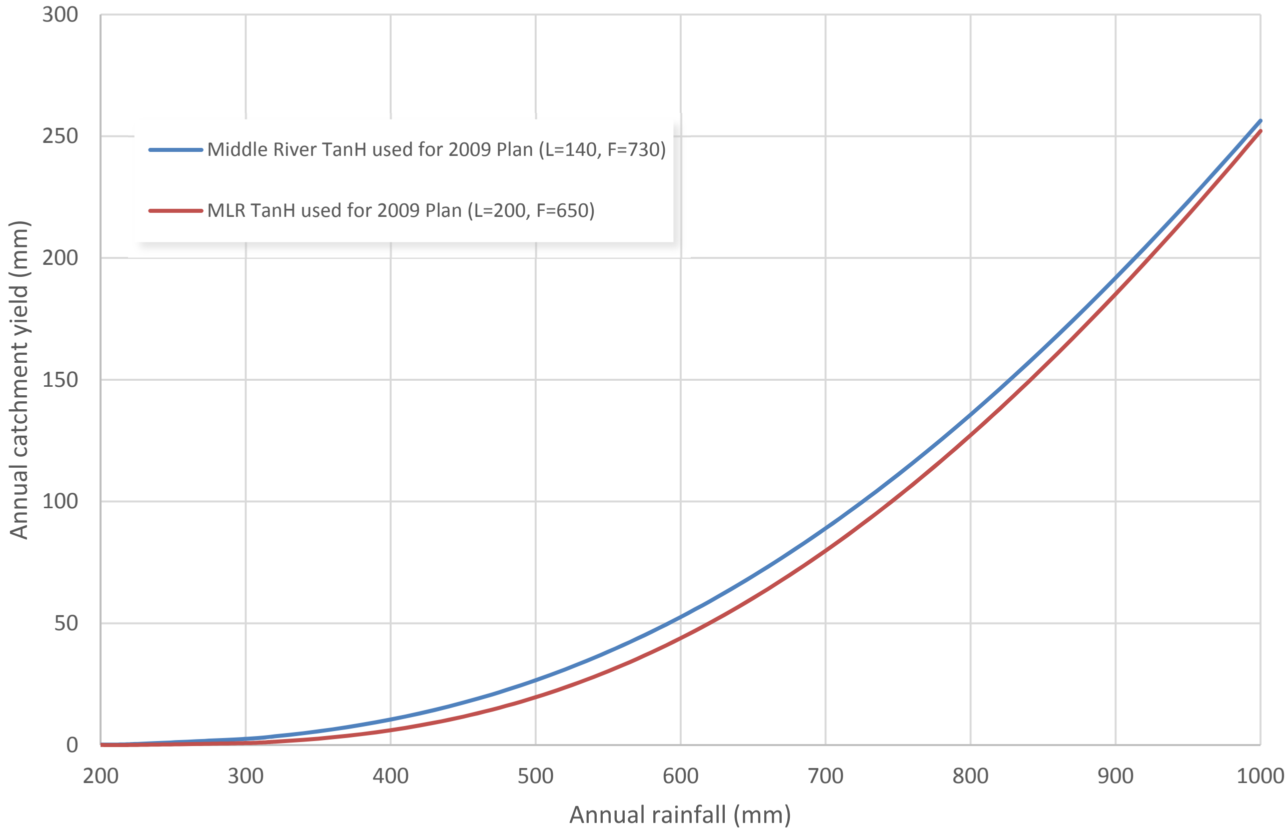

Figure 12 Rainfall-runoff curves for Middle River Reservoir inflow and MLR catchment runoff using TanH functions (McMurray, 2007)

3.2 Two-year analysis

The first aspect of this study was the investigation of rainfall-runoff relationships in KI across a common period for the five streamflow gauging stations. As noted in Part 1, Section 2.5, missing data in these five series presented some difficulties in establishing a continuous period at an annual scale with all five streamflow records available. The two-year period ending 31 Dec 2013 has only short periods of missing data in one gauge; a total of 6 missing days in the Stunsail Boom record across the months of June 2013 (1 day), July 2013 (3 days) and August 2013 (2 days), so while not ideal, this was seen as satisfactory. This 2-year period had the benefit of including both a close-to-average rainfall year (2012, as shown in Figure 6) and a wetter than average year (2013), with different hydrological responses expected in each year.

Daily streamflows at the five KI gauges were compared across this common 2-year period (1 Jan 2012 – 31 Dec 2013), with rainfall-runoff relationships evaluated using catchment-wide rainfall averages. Gridded rainfall data from the SILO climate database were re-sampled at 0.5 km x 0.5 km grids, and aggregated from a daily scale to annual totals across the catchment areas upstream of each gauging station. To investigate hydrological relationships between KI and across the MLR, as inferred by McMurray (2007), the rainfall-runoff relationships for these 5 gauges were compared to those for 19 gauged MLR catchments that each had continuous daily flow records for this two-year period. The various data series for 2012-13 used for this investigation are summarised in Table 7, and show that these MLR gauges cover a range of hydrological conditions, with varying rainfall conditions. The locations of these selected MLR streamflow gauges are shown in Figure 13. It should be noted that the streamflows in two of these watercourses, Dawesley Creek and the Onkaparinga River at Houlgraves, may be confounded by releases from the Bird-in-Hand Wastewater Treatment Plant (WWTP) and River Murray transfers through the Murray Bridge to Onkaparinga pipeline, respectively.

Table 7 Summary of annual streamflow and rainfall for 2012–13 for the KI and selected MLR gauges

Streamflow gauge	KI/ MLR	Station number	Area above gauge (km^2)	Mean annual flow (ML)	Mean annual runoff (mm)	Mean annual catchment rainfall (mm)	Runoff coeff.
ROCKY RIVER @ u/s Gorge Falls	KI	A5130501	189.4	11,923	63.1	806.3	7.8%
CYGNET RIVER @ Huxtable Forest	KI	A5131001	216.7	27,673	127.5	697.7	18.3%
CYGNET RIVER @ u/s Koala Lodge	KI	A5131014	480.2	80,987	168.7	640.4	26.3%
TIMBER CREEK @ South Coast Rd	KI	A5131002	126.2	27,159	215.6	663.5	32.5%
STUNSAIL BOOM @ South Coast Rd	KI	A5131007	270.1	21,047	78.0	839.5	9.3%
DAWESLEY CREEK @ Dawesley	MLR	A4260558	41.8	2,511	60.1	740.9	8.1%
MOUNT BARKER CREEK @ d/s Mt Barker	MLR	A4260557	85.9	9,207	107.2	803.2	13.3%
BREMER RIVER @ near Hartley	MLR	A4260533	473.4	22,998	48.6	465.9	10.4%
CURRENCY CREEK @ near Higgins	MLR	A4260530	57.1	7,117	124.6	868.6	14.4%
FINNISS RIVER @ 4km East of Yundi	MLR	A4260504	192.5	28,862	149.9	821.3	18.3%
INMAN RIVER @ u/s Victor Harbour STW	MLR	A5010503	164.3	13,040	79.4	865.6	9.2%
MYPONGA RIVER @ u/s Dam and Road Bridge	MLR	A5020502	75.5	8,186	108.4	876.0	12.4%
ALDGATE CREEK @ Aldgate Railway Station	MLR	A5030509	7.87	1,336	169.7	924.0	18.4%
SCOTT CREEK @ Scott Bottom	MLR	A5030502	26.6	3,292	123.8	746.3	16.6%
BAKER GULLY @ 4.5km WNW Kangarilla	MLR	A5030503	48.5	8,549	176.3	669.6	26.3%
BROWNHILL CREEK @ Scotch College	MLR	A5040901	18.1	2,509	138.6	797.0	17.4%
TORRENS RIVER @ Mt Pleasant	MLR	A5040512	26.1	2,797	107.2	625.8	17.1%
TANUNDA CREEK @ Bethany	MLR	A5050535	21.2	1,431	67.5	664.9	10.1%
ONKAPARINGA RIVER @ Houlgraves	MLR	A5030504	321.3	52,516	163.4	699.2	23.4%
NORTH PARA RIVER @ Yaldara	MLR	A5050502	375.8	6,643	17.7	430.6	4.1%
YANKALILLA RIVER @ d/s Blackfellows	MLR	A5011006	78	7,486	96.0	947.9	10.1%
ONKAPARINGA RIVER @ u/s Hahndorf Dis.	MLR	A5031001	227.3	18,248	80.3	639.6	12.6%
LITTLE PARA RIVER @u/s Fault	MLR	A5040503	89	1,002	11.3	527.1	2.1%
HINDMARSH RIVER @ Hind. Valley Resv. t/o Weir	MLR	A5010500	55.8	24,705	442.7	944.4	46.9%

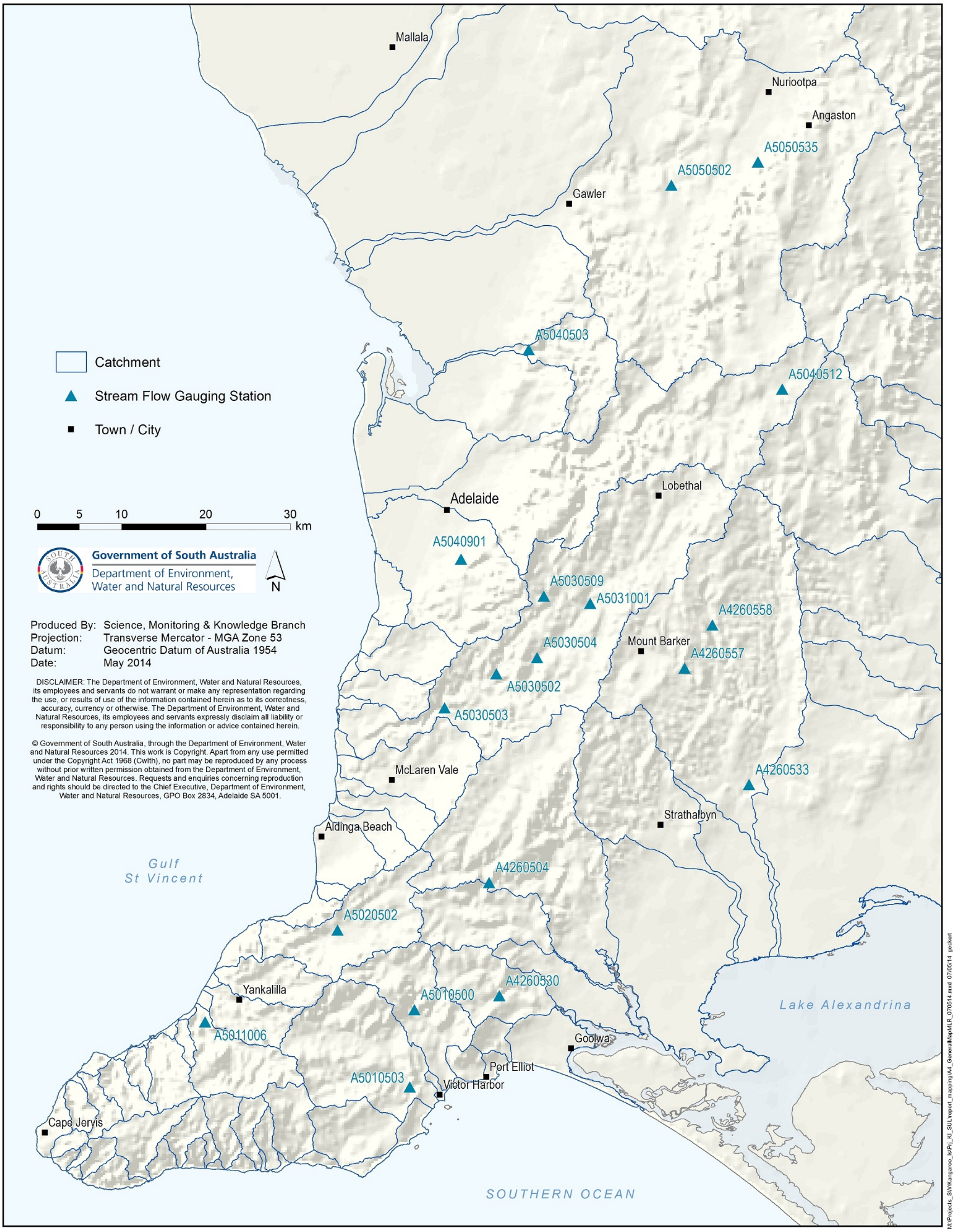

Figure 13 Locations of water resource catchments, and selected streamflow gauging stations in the MLR

The average annual catchment yield (for 2012-13) for each MLR gauge was plotted against its corresponding average annual catchment rainfall as shown in Figure 14, with a rainfall-runoff curve fitted to these data. The two parameters for the TanH function were fitted by minimising the residual sum of squares.

The use of a short time frame for comparative analyses such as Figure 14 provides the opportunity for short-term climatic events to mask the identification of any underlying hydroclimatic features. The Hindmarsh River gauge showed much higher runoff over the 2012–13 period than nearby MLR catchments (e.g. Myponga River and Yankalilla River) that have similar rainfall conditions. Longer period analysis together with catchment characterisation would be required to further clarify rainfall-runoff relationships in the Hindmarsh River catchment. The inclusion of this gauge in the suite of MLR data has the effect of increasing the slope of the rainfall-runoff curve shown in Figure 14. Although the runoff coefficient of the Hindmarsh River gauge (which approaches 50% for the 2012–13 period) is clearly higher than ratios for the other 18 MLR gauges over this period, additional information would be required to determine whether this gauge should be excluded from a comparison between the hydrological relationships across KI and MLR catchments.

Figure 14 illustrates large variability in rainfall-runoff relationships across these MLR gauges for the 2012-13 period, and shows some differences between the corresponding rainfall-runoff curve and the original rainfall-runoff curves presented by McMurray (2007) for reconstructed Middle River Reservoir inflows and MLR flows for 1970–92. The model-fitting process identified a zero value for the "L" parameter of the TanH function, which had the effect of giving this relationship a longer "tail", and hence higher catchment yields under lower rainfall conditions. It should also be noted that it is uncertain whether the TanH relationships in McMurray (2007) were fitted through a process of minimising residual sum of squares, as undertaken for this report, or whether the "L" parameter (termed "initial loss" by Grayson *et al.*, 1996) was fixed. This represents additional uncertainty regarding the use of this TanH function to derive average catchment yields in the "Zone B" catchments in the 2009 Plan.

In addition, these curves also suggest significant differences in rainfall-runoff relationships between the five KI gauges. For the 2012–13 period, Cygnet River and Timber Creek show higher runoff than many MLR gauges with similar rainfall, whereas Stunsail Boom River and Rocky River demonstrate lower runoff than was observed in many MLR gauges. These results are consistent with the land use differences shown in Figure 2, such that catchments with a higher proportion of cleared land recorded higher catchment yields, and conversely the Stunsail Boom River catchment, with a higher proportion of native vegetation, revealed much lower runoff.

From reviewing this two-year analysis, it was apparent that two of the gauged catchments on KI (Rocky River and Stunsail Boom River) had hydrological behaviours during this period that were quite different than the Cygnet River and Timber Creek catchments. Although the Rocky River catchment is outside the water policy zone for WULs, the Stunsail Boom River is within the zone, and therefore the use of a single rainfall-runoff relationship to calculate yield in these four catchments could lack precision. In addition, the TanH function fitted to the MLR data revealed differences from the original rainfall-runoff relationship of McMurray (2007), although it should be noted that the MLR gauges chosen for this analysis were different from the selection of gauges made by McMurray (2007) for this earlier assessment. Some of the records analysed by McMurray (2007) did not continue to 2013, and therefore could not be used in direct comparison with KI data.

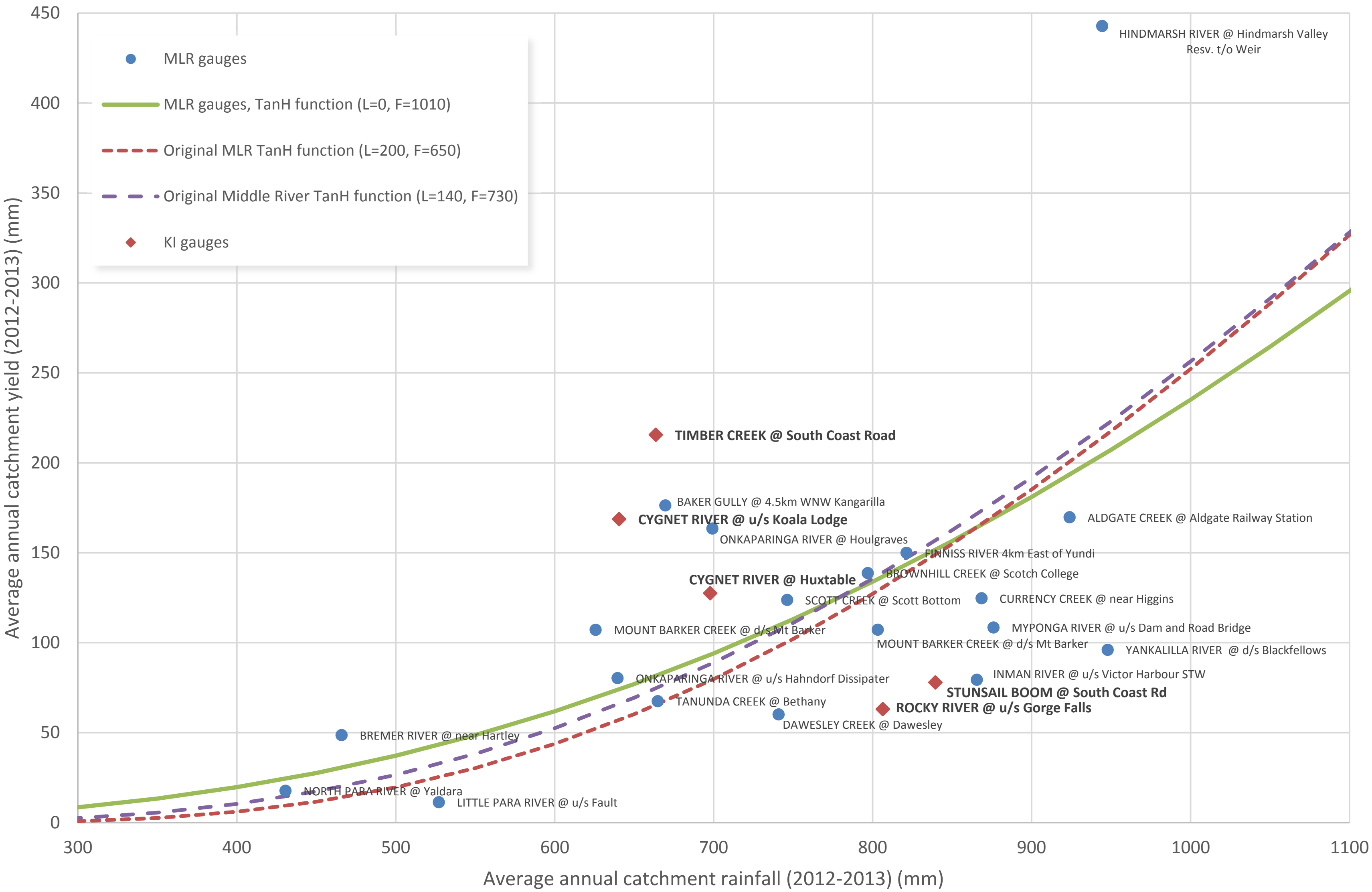

Figure 14 Rainfall-runoff relationships for five KI streamflow gauges and 19 streamflow MLR gauges for 2012–13

3.3 Longer-term analysis

While the two-year analysis of rainfall-runoff relationships in KI and selected MLR catchments shown in Figure 14 provided an opportunity for comparison between the five KI gauged records and a range of MLR data, this short timeframe also had the potential to be dominated by single climatic events. This analysis was then repeated using additional hydrological data to help identify longer-term characteristics across KI, and hydrological relationships with MLR data, and whether the pre-1993 data are representative of recent hydrological conditions.

It should be noted that for this investigation, it was not possible to use the same reconstructed Middle River Reservoir inflow series from McMurray (2007) for the period after 1992 to establish the impacts of post-1992 climate on KI hydrology, as the calculation process for the original series (Tomlinson, 1996) was unknown. Therefore, it was necessary to infer such effects through observing both the change in the hydrological responses of longer-term MLR records around 1992, and the relationship between these MLR data and KI data.

Average annual catchment yield for 1970–92 was determined for each of the 19 MLR gauges assessed in Part 1, Section 3.2 (or shorter periods if streamflow records didn't extend to 1970) and plotted against the average annual catchment rainfall for the same years. A TanH function was fitted to these points (with parameter values L=0, F=1030), and is shown in Figure 15 to plot slightly closer to the original rainfall-runoff curve of McMurray (2007) than was apparent with the 2012–13 data. This suggests that these selected MLR gauges are capturing a similar hydrological relationship to that previously identified.

This procedure was then replicated using average annual catchment rainfall and runoff associated with each gauge for 1993-2013. The rainfall-runoff relationship for this latter period (with parameter values L=0, F=1150) showed lower overall catchment yield for the MLR data than for the 1970–92 period that was used to calculate SLs in the 2009 Plan. Indeed, for annual rainfall in the range 550-750 mm (which corresponds to the range of average conditions across much of KI), these TanH functions suggests a reduction of approximately <u>18%</u> in average annual yield when compared to the 1970–92 period.

Analysis of data for the overall 1970–2013 period identified a TanH function (with parameter values L=0, F=1124) that plots between the two shorter-period curves, which was an expected result. However with only some of these MLR records extending back to 1970, information from 1992–2013 dominated the rainfall-runoff relationships for the longer 1970–2013 period, with the overall rainfall-runoff curve plotting much closer to the 1993–2013 curve. When the extended period (1970-2013) is compared against the earlier period (1970–92), an average yield reduction of approximately 14% is observed.

In addition to these MLR records, the average rainfall-runoff data for the five KI gauges are shown on Figure 15. Although flows for the Rocky River gauge are available from 1974 onwards, the 2003–13 period was chosen for this analysis as it corresponds to the record of the Koala Lodge gauge on the Cygnet River, the next longest KI record. This analysis of rainfall-runoff data from the KI gauged catchments for the 2003–13 period (or a shorter period where data does not extend back to 1970) indicated <u>higher</u> annual catchment yields for the Cygnet River and Timber Creek gauges in comparison to catchments in the MLR with similar rainfall and for the same period. In contrast, the Stunsail Boom River and Rocky River gauges showed <u>lower</u> yields than the generalised MLR relationship. These results are consistent with the general observations from the two-year analysis, and suggest a need to define different catchment yield relationships across KI, at a time when data availability facilitates an acceptable level of uncertainty.

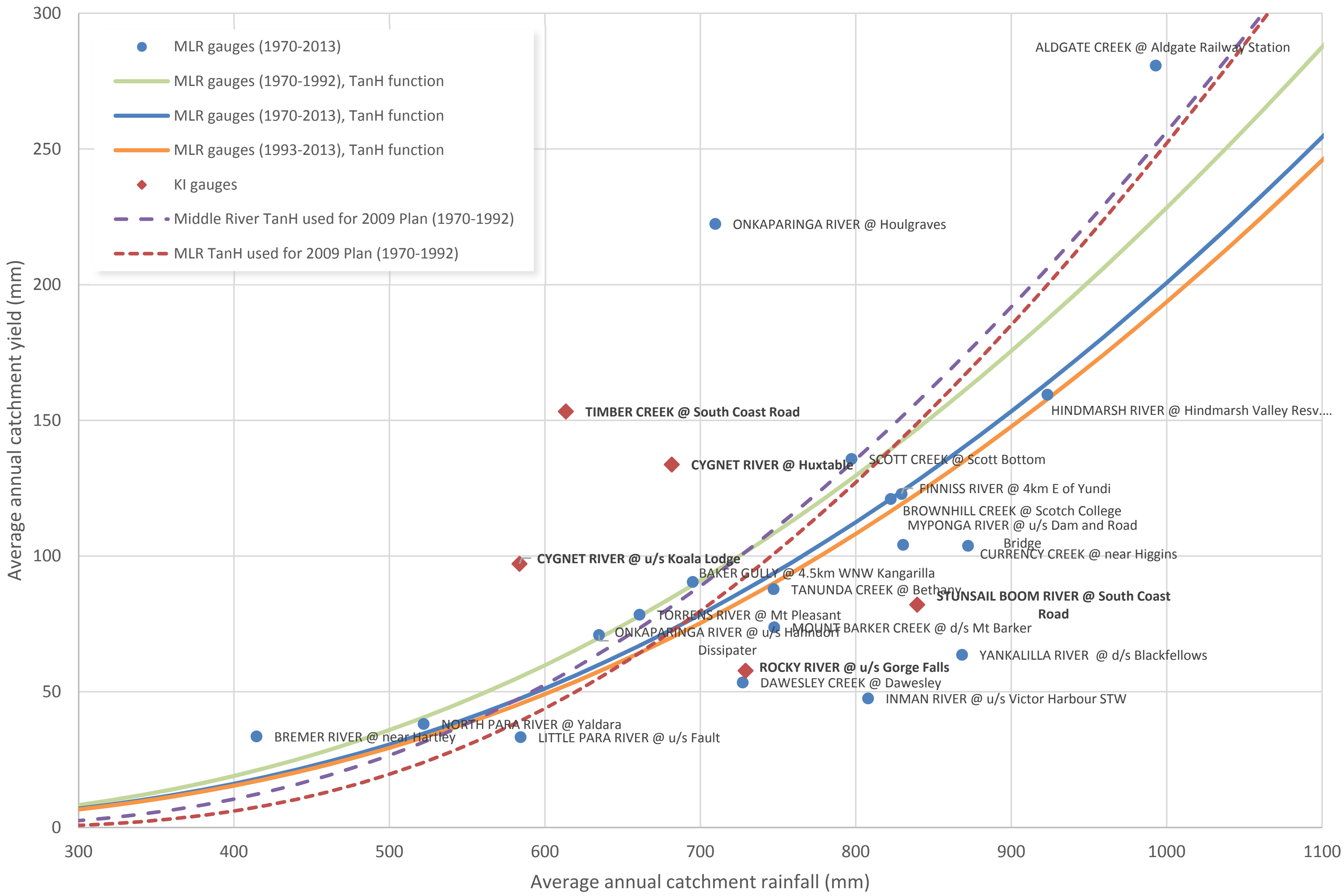

Figure 15 Rainfall-runoff relationships for five KI gauges and 19 MLR gauges for the 1970–2013 period

Figure 16 summarises the land use proportions of the catchments for the 19 selected MLR streamflow gauges. These characteristics demonstrate that there is no plantation forestry in these 19 MLR catchments, and that there is generally a high proportion of cleared agricultural land. Three catchments (Tanunda Creek, Scott Creek and Brownhill Creek) have "natural" (uncleared) land in over 40% of their area however, interestingly, these three gauges do not plot as low (in comparison to the other MLR gauges) in Figure 15 as the Stunsail Boom River and Rocky River do in comparison with the other KI gauges.

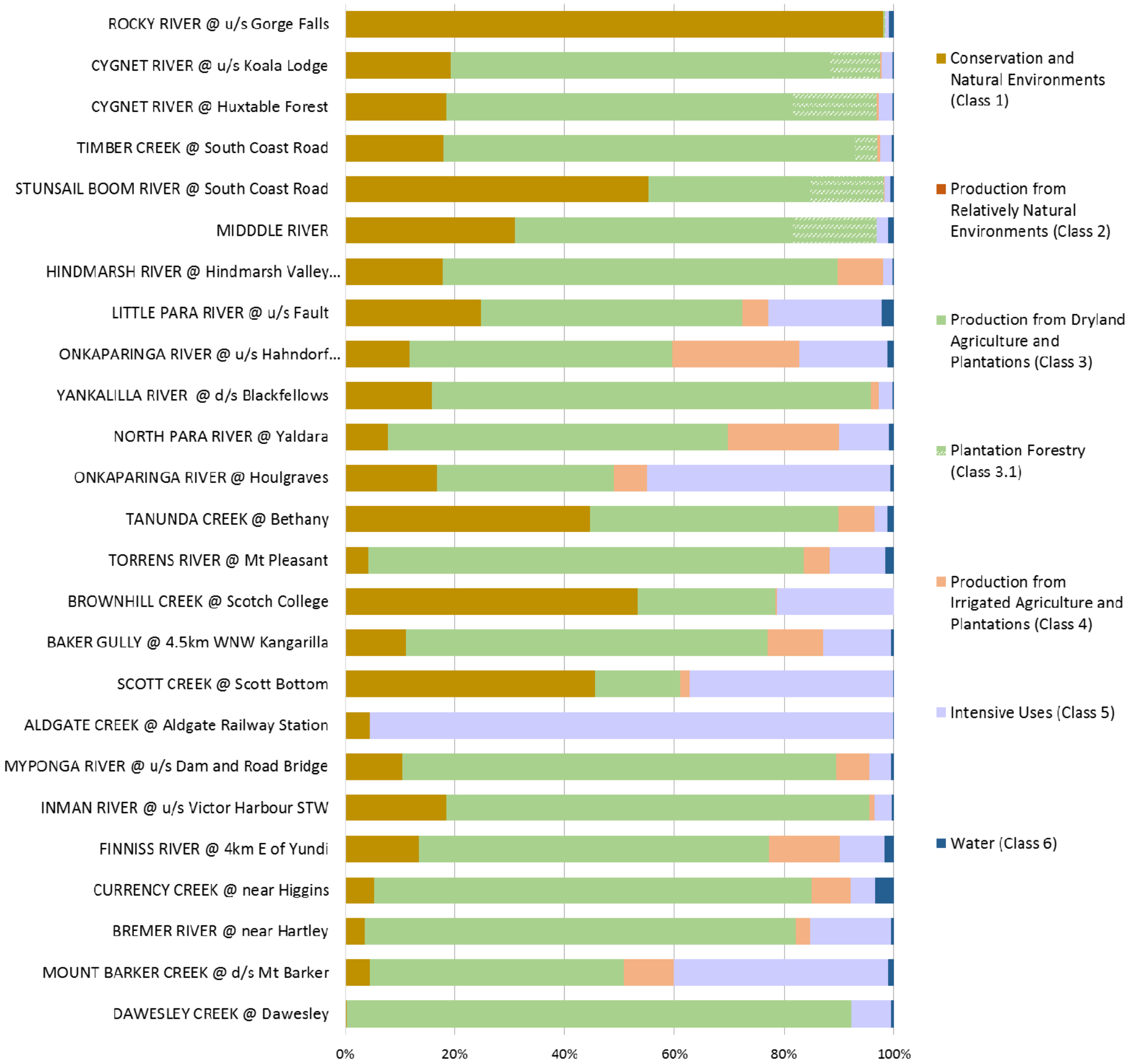

Figure 16 Land use proportions for the catchments of the five KI streamflow gauging stations and 19 selected MLR streamflow gauging stations

3.4 KI-specific relationships

3.4.1 Average KI relationships

Figure 17 explores further the variability in KI rainfall-runoff relationships, with catchment yields for the five KI gauges for the individual years (with no missing daily flow data) that were used to generate the average values in Figure 15 plotted against their corresponding annual catchment-averaged rainfall. 39 values are included for the Rocky River gauge, 10 for the Cygnet (Koala Lodge) gauge, 5 for Timber Creek, 4 for Cygnet (Huxtable Forest) and 2 data points shown for Stunsail Boom River.

TanH functions were then fitted to the series of annual rainfall-runoff values for the four longer records, and compared with the 2009 Plan Middle River TanH curve from McMurray (2007). These TanH functions are shown in Figure 17. A TanH function was not fitted to the Stunsail Boom data, as there were only two years of non-missing flow data (2012, 2013) from which rainfall-runoff information could be obtained. These data were insufficient information from which a rainfall-runoff relationship could be developed.

Figure 17 further suggests that although gauged data from KI is limited, there appears to be some difference in the rainfall-runoff relationships for the Cygnet River and Timber Creek catchments when compared to those that calculated SLs for the 2009 Plan.

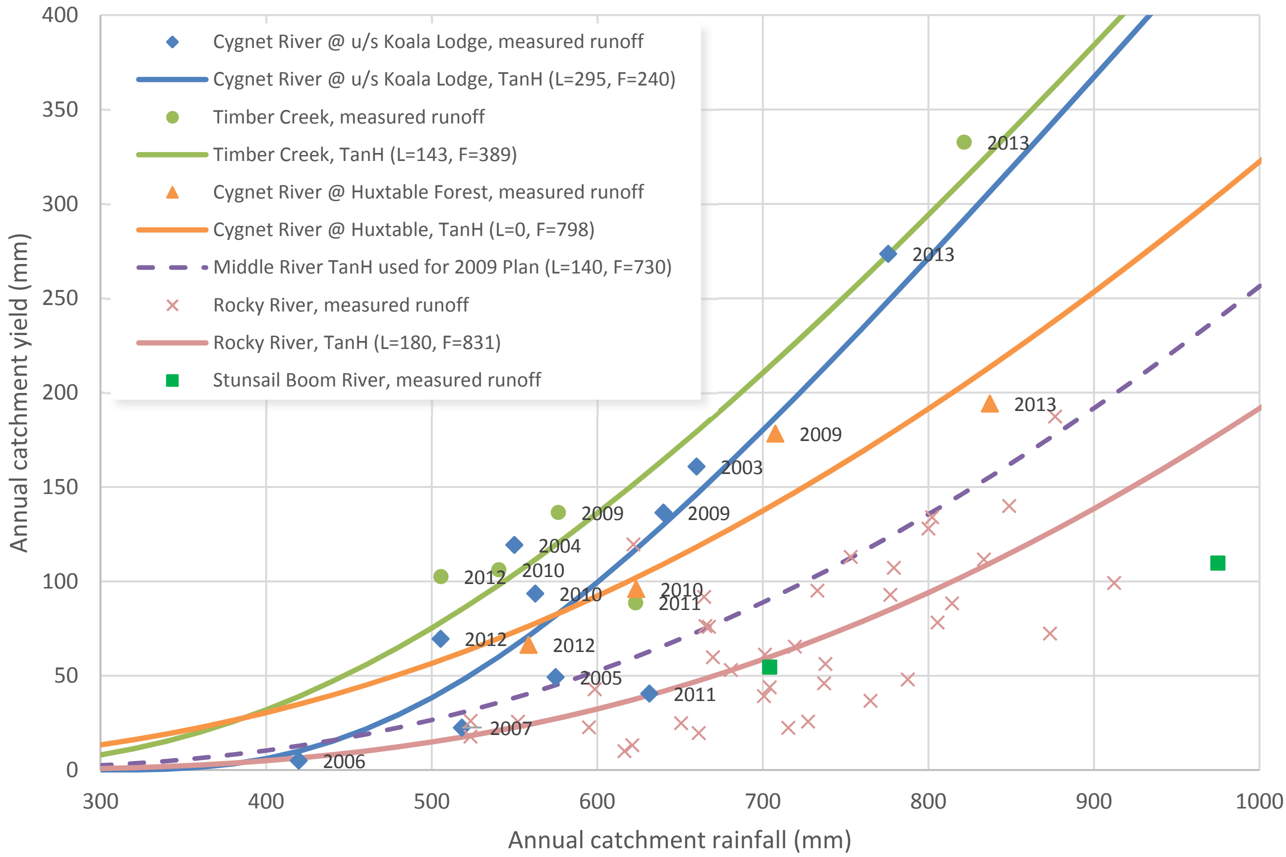

Figure 17 Annual rainfall-runoff relationships for KI streamflow gauges

Table 8 summarises the impact of these rainfall-runoff relationships on the generation of catchment yield. At an average annual catchment rainfall of 600 mm, the Middle River TanH relationship (used for the 2009 Plan) suggests catchment yield of 53 mm, whereas the rainfall-runoff curves associated with the Cygnet (Koala Lodge) and Timber Creek gauges produce yields of 99 mm and 136 mm, respectively. The use of rainfall-yield relationships such as these could clearly have the effect of increasing the WUL for Cygnet River and Timber Creek from the values that are currently presented in the 2009 Plan.

It is important to reiterate however that the TanH relationships for the Timber Creek, Huxtable and Koala gauges shown here are generated from only 5, 4 and 10 data points respectively. So although these flow records suggest higher yields in the Timber Creek and Cygnet River catchments from yields calculated using the Middle River rainfall-runoff relationship (from the 2009 Plan), there is significant uncertainty regarding the form of rainfall-runoff relationships for these areas.

Table 8 Comparison of catchment yields that are calculated using different rainfall runoff curves

TanH function	TanH "L" parameter	TanH "F" parameter	Yield at 500 mm rainfall	Yield at 600 mm rainfall	Yield at 700 mm rainfall
Timber Creek	143	389	75 mm	136 mm	211 mm
Cygnet River @ u/s Koala Lodge catchment	295	240	38 mm	99 mm	180 mm
Cygnet River @ Huxtable Forest catchment	0	798	57 mm	92 mm	137 mm
Middle River TanH function used for 2009 Plan	140	730	27 mm	53 mm	89 mm
Rocky River	180	831	15 mm	32 mm	59 mm

3.4.2 Temporal variability in Rocky River relationship

Figure 15 showed clear separation between the average rainfall-runoff relationships that corresponded to selected MLR gauge records for the periods 1970–92 and 1993–2013. From the available KI streamflow information, the Rocky River gauge provides the only source of continuous flow data for the period preceding 1993, and consequently it was possible to analyse differences in rainfall-runoff relationships either side of a 1993 breakpoint. This year was only chosen to correspond to the WUL calculation process in the 2009 NRM Plan, and there was no investigation undertaken into the most appropriate year for breakpoint analysis undertaken.

TanH functions were fitted to annual rainfall-runoff pairs for the Rocky River gauge the periods 1974–92 and 1993–2013, and shown in Figure 18. The latter period showed annual yield reduction of 17.5% at rainfall of 600 mm, 26.8% at 700 mm and 32.0% at 800 mm from the curve representing 1974–92 flows. A comparison between an extended period (1974–2013) rainfall-runoff curve and the earlier period curve suggests a reduction in average annual catchment yield of between 17% at 600mm rainfall to 10% at 900 mm rainfall. As a consequence, these rainfall-runoff curves suggest a reduction in Rocky River catchment yield since 1993. This result supports the generalised MLR observations that were shows in Figure 15, where average annual yield reduced by approximately 18% after 1992, and provides further support to the suggestion that pre-1993 data may not be the most appropriate description of recent hydrological responses in KI.

As previously noted, the 2009 Plan includes subcatchment SLs that are based on modelled hydrological data for the period 1970–92. Figure 15 and Figure 18 suggest that the use of relationships based on this earlier period may over-estimate catchment runoff in the period since 1992.

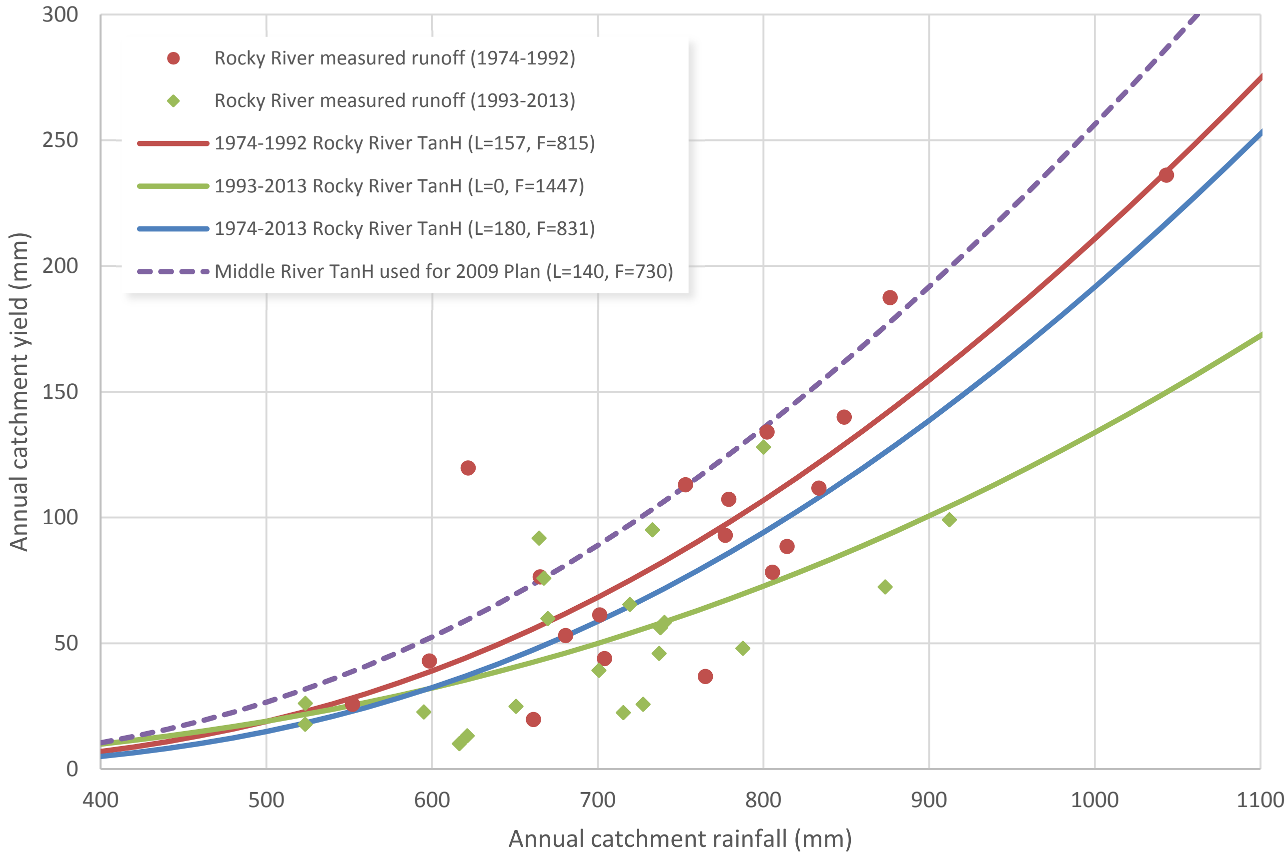

Figure 18 Rainfall-runoff curves for Rocky River, with TanH functions fitted to pre-1993 and post-1993 data

3.4.3 Influence of individual years on average relationships

The analysis of short-term hydrological information at an annual scale, such as the streamflow records from KI, reduces the number of data points from which generalised relationships can be derived. The consequence of this is that such relationships can be influenced by low-frequency observations that occur in the period of record. For both the Timber Creek and Cygnet River (Koala Lodge) gauges, data points corresponding to 2011 observations plot significantly below the rainfall-runoff curves that were developed from all available data (including these 2011 values). Figure 17 shows that 2009 and 2003 provided similar rainfall conditions to 2011 for the Cygnet River (Koala Lodge) catchment, however the streamflow gauge showed much higher catchment yields in these years. Similarly for the Timber Creek gauge, the annual catchment rainfall for 2009, 2010 and 2012 were all lower than for 2011, yet annual runoff in these years were significantly higher. The Cygnet River (Huxtable Forest) gauge had a large amount of missing daily flow data in 2011.

Table 9 shows the runoff coefficients for individual years for the Timber Creek and Cygnet River gauges, and highlights that hydrological conditions in 2011 were different from the years either side.

Table 9 Runoff coefficients for individual calendar years

Streamflow gauge	2009	2010	2011	2012	2013
Timber Creek	23.7%	19.6%	14.2%	20.3%	40.5%
Cygnet River @ u/s Koala Lodge	21.3%	16.6%	6.4%	13.8%	35.3%
Cygnet River @ Huxtable Forest	25.2%	15.4%	N/A	11.9%	23.2%

To further illustrate the variation in streamflow response in the Cygnet River across the period of flow record, Figure 19 provides a comparison between daily flows at the Cygnet River (Koala Lodge) gauge for the three-year period 2011–2013. This flow series shows the first major flow event of 2011 occurred on 22 March 2011 (approx. 2800 ML/day), much earlier than break-of-season flows that were observed during late June in 2013 and late August in 2012. The significance of this March 2011 flow event is further illustrated by the fact that it represented a significant proportion (close to 20%) of the total annual flow for 2011.

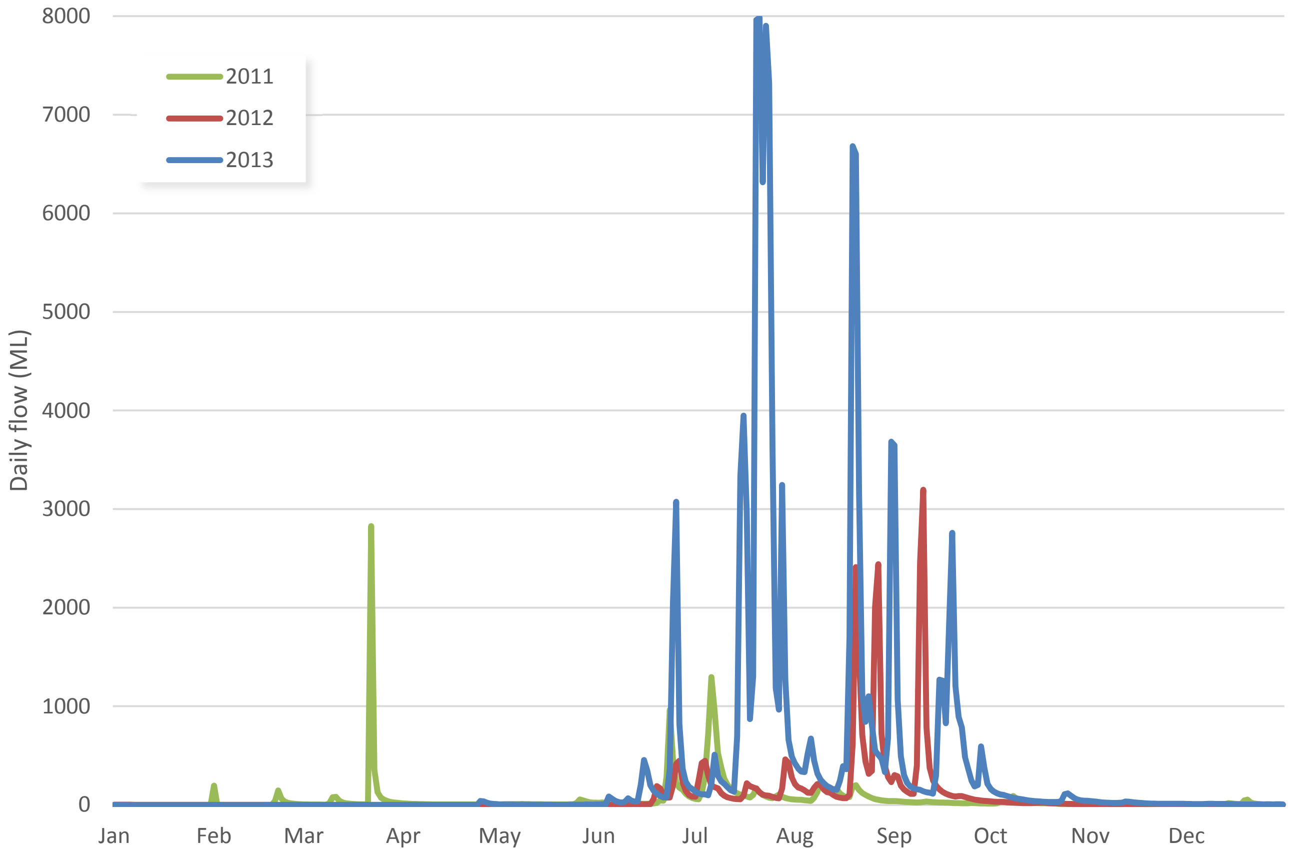

Figure 19 Time series of daily flows for the Cygnet River (Koala Lodge) gauge for 2011, 2012 and 2013

In terms of catchment hydrology, streamflow response is influenced by both the timing and magnitude of rainfall events. A clearer picture of the impact of the 22 March 2011 flow event, in terms of the overall rainfall-runoff relationship for 2011, is obtained through analysis of daily rainfall records. Figure 20 shows the daily SILO rainfall record for the three years 2011–13 recorded at the Kingscote Aero station (22841), which is close to the Cygnet River (Koala Lodge) streamflow gauge. This time series shows that the large flow event on 22 March 2011 followed a large rainfall event (110 mm) on the preceding day, although two large rainfall events (75 mm on 19 February 2011 and 46 mm on 8 March 2011) would have wetted the catchment in order for the 21 March rainfall event to produce high runoff volumes.

Rainfall recorded at this station during February/ March 2011 were historically significant. For 1900–2012, the SILO PPD series for station 22841 has an average March rainfall of 17.8 mm, 3.8% of the annual average rainfall of 474 mm for this period. In March 2011, 161 mm rainfall was recorded at this station, approximately 29% of the 559 mm total for 2011. Therefore, the wet month of March 2011 had a very low probability of exceedance. The spatial variability of rainfall across KI can be illustrated by the daily PPD series for station 22835 (location shown in Figure 1) upstream of the Cygnet River (Huxtable Forest) gauge, which showed that rainfall in March 2011 was less extreme than at site 22841, with a total March 2011 rainfall represented only 11.9% of the annual total.

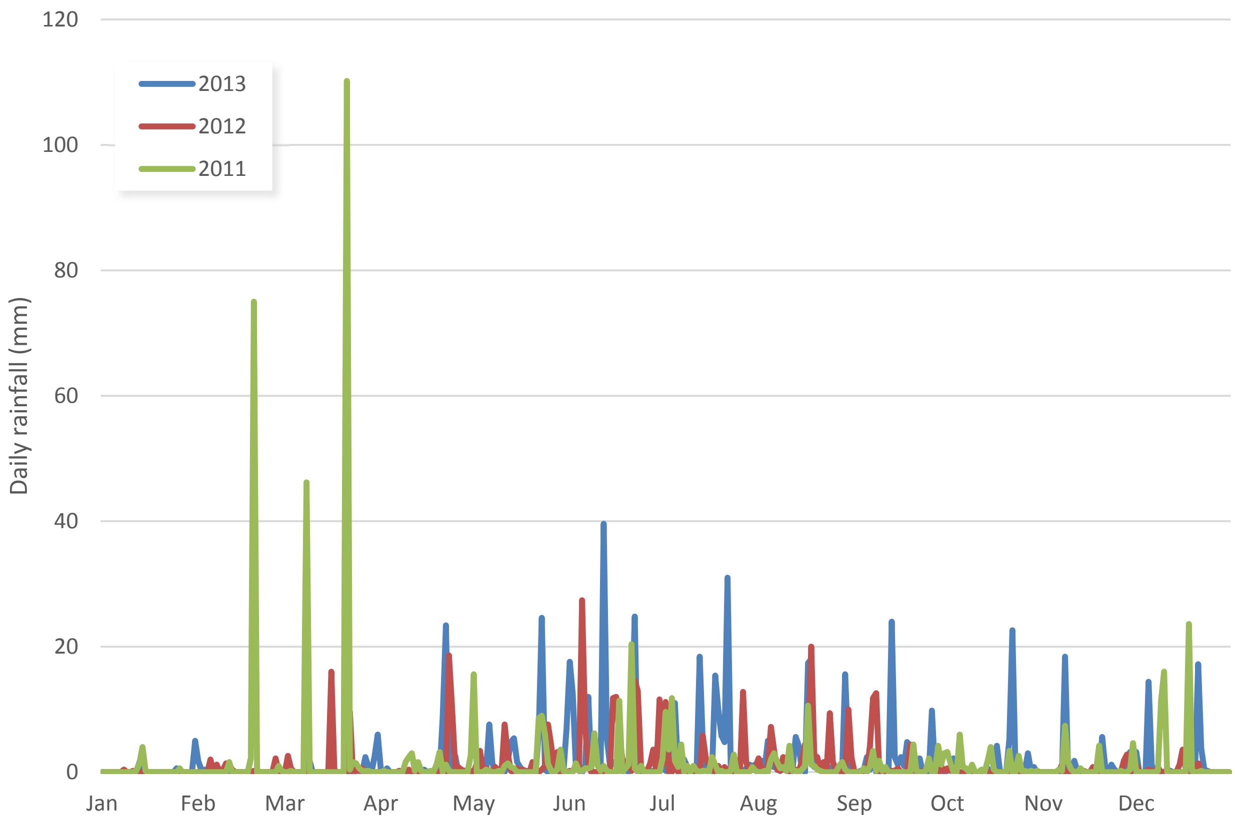

Figure 20 Daily SILO rainfall for BoM observation station 22841 (Kingscote Aero) for 2011–13

The important role of catchment soil moisture levels on surface runoff is also illustrated in the flow series from 2013. The first major flow event in 2013, which peaked at approximately 3000 ML/day in late June, was produced from a rainfall event of 25 mm on 22 June 2013, and a number of other preceding rainfall events (including 40 mm on 12 June 2013). The effect of a wet catchment in generating higher runoff volumes is then observed in flow record from the following month. A sequence of wet days in July 2013, which included 31 mm of rainfall on 22 July 2013, produced a flow event that peaked at approximately 8000 ML/day, much larger than flows in June 2013.

The temporal distribution of rainfall events in 2011, with high rainfall depths occurring over a short period in February and March at a time of high temperatures and dry catchments (resulting in high losses through seepage), produced different hydrological outcomes (i.e. lower runoff volumes) than would occur if a similar volume of rain fell on wetter catchments during Winter months.

The lower runoff coefficients for 2011 causes slopes of the rainfall-runoff curves for the Cygnet River (Koala Lodge) and Timber Creek gauges (as shown in Figure 17) to be lower, representing lower catchment yield for a certain annual rainfall, than if these data were absent. However, the inclusion of the 2011 data highlights risks involved in deriving long-term relationships from short records, and demonstrates the high impact that localised low-frequency climate events can have on such records.

4 Catchment yield calculations

The various rainfall-runoff relationships described in Part 1, Section 3 present a range of potential approaches to calculate catchment yields for KI, and consequently a range of options from which to calculate WULs. The rainfall-runoff comparisons in Part 1, Section 3.4 showed that separate relationships between catchment yield and catchment rainfall (described by TanH functions) can be developed for the Timber Creek and Cygnet River catchments, rather than a single relationship being described for all KI catchments.

4.1 Generalised KI relationships

The impetus for this study was the recognition that the SL/ WUL calculation process for KI in the 2009 Plan was contingent upon a times series of reconstructed inflows to Middle River (and informed by hydrological observations from the MLR), and was not informed by local hydrological observations. In the period since the completion of the 2009 Plan, a number of streamflow gauging stations have been installed from which data have been used to observe rainfall-runoff interaction across KI, and potentially to inform revision to the WUL calculation process.

With 40 water resource catchments in the project area (excluding the 13 catchments of high conservation value), there are still 37 of these without gauged streamflow data. As a result, the estimation of WULs across KI requires a mechanism (such as a "generalised" KI rainfall-runoff relationship) to calculate WULs in these ungauged catchments. In the 2009 Plan, the original Middle River rainfall-runoff curve (representing the period 1970–92) was used as a "generalised" rainfall-runoff relationship for Zone B. The validation of the WUL calculation process with local hydrological data encompasses a review of the form of this "generalised" KI rainfall-runoff relationship.

The existing "generalised" KI TanH function (in the 2009 Plan) does not account for rainfall recorded in the period 1993–2013. The rainfall-runoff analysis in Part 1, Section 3 showed that selected streamflow gauges have shown variable rainfall-runoff relationships in the period following 1992. Figure 15 suggested an average yield reduction of 18% across the 19 selected MLR gauges for the period after 1992 and Figure 18 showed even higher yield reductions in Rocky River flows. However a possible interpretation of the rainfall-runoff analysis presented in Part 1, Section 3 may conclude that at this point there are insufficient data to propose a new form of the "generalised" KI rainfall-runoff relationship, and that this existing rainfall-runoff relationship is still appropriate as a method to calculate WULs. On the other hand, the rainfall-runoff analysis in Part 1, Section 3 could also be interpreted to suggest a modified form of the "generalised" KI relationship (a "generalised-extended" KI TanH function) is appropriate to account for an extended period of analysis to 2013.

This latter interpretation of Figure 15 and Figure 18 could include proposing a "generalised-extended" KI rainfall-runoff curve that reduces average yield by approximately 10% compared with yield calculated via the Middle River rainfall-runoff curve from the 2009 Plan. To this end, a TanH function corresponding to a 10% reduction in the TanH function from the 2009 Plan was fitted to ensure both an average reduction in yield of 10% across a 400 mm-800 mm range of annual rainfall, and a 10% reduction at annual rainfall of 600 mm. Table 10 summarises the variation in yield reduction for this new TanH function (defined by parameters L=142, F=770), compared to the function used for the 2009 Plan. Figure 21 illustrates this proposed "generalised-extended" rainfall-runoff relationship, which is a potential alternative to the Middle River rainfall-runoff curve (2009 Plan) to calculate average catchment (and subcatchment) yield. The application of this "generalised-extended" rainfall-runoff curve would reduce WULs from values calculated using the existing "generalised" KI function (2009 Plan).

Table 10 Summary of "Generalised" KI rainfall-runoff function and a proposed "Generalised-extended" KI rainfall-runoff function representing a 10% yield reduction at annual rainfall of 600 mm

TanH function	TanH "L" parameter	TanH "F" parameter	Yield at 400 mm rainfall	Yield at 600 mm rainfall	Yield at 800 mm rainfall
"Generalised" KI (2009 Plan)	140	730	10.5 mm	52.6 mm	135.6 mm
"Generalised-extended" KI	142	770	9.2 mm	47.3 mm	124.1 mm
Yield reduction			11.7 %	10.0 %	8.5 %

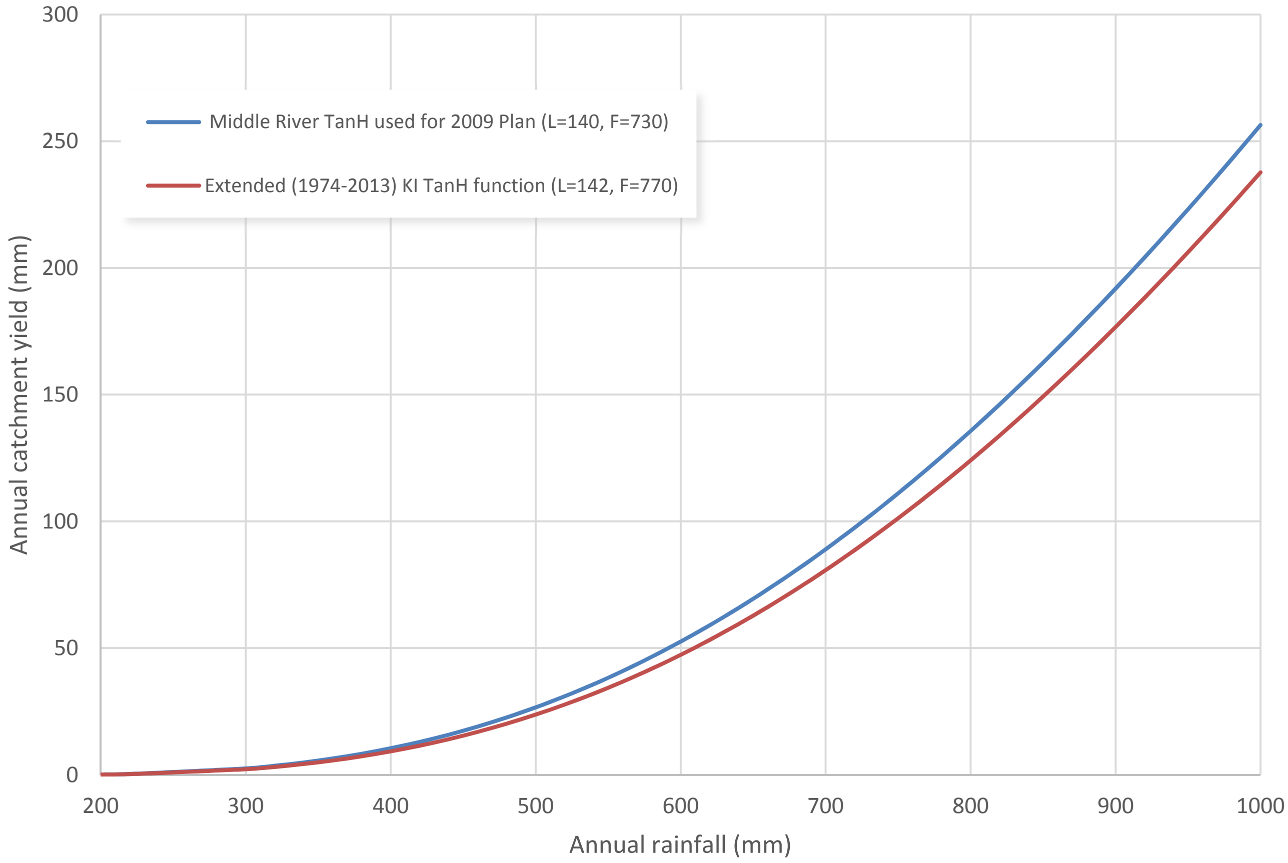

Figure 21 Proposed "generalised-extended" KI rainfall-runoff curve, compared with Middle River rainfall-runoff curve used for the 2009 Plan

4.2 Cygnet River catchment

The annual rainfall-runoff relationships described in Figure 17 suggested that rainfall-runoff relationships for the Huxtable Forest and Koala Lodge gauges on the Cygnet River could be described by different rainfall-runoff relationships, although these curves were identified through only small datasets. The rainfall-runoff curve for the upstream catchment was fitted through four data points, with the downstream catchment TanH function using 10 points. These small datasets likely contribute to the results of these two rainfall-runoff curves having quite different shapes, with the Koala Lodge dataset including one dry year (2006) that is absent from the Huxtable Forest record. The two rainfall-runoff curves cross at rainfall of approximately 577 mm, with the Koala Lodge rainfall-runoff curve producing higher yield than the Huxtable Forest curve for rainfall exceeding 577 mm, and catchment rainfalls lower than this producing the opposite effect. Above an annual rainfall of 444 mm, the Koala Lodge relationship will produce higher catchment yield than the Middle River rainfall-runoff curve used for the 2009 Plan, whereas the Huxtable Forest curve produces higher yields than the Middle River rainfall-runoff curve for all rainfalls.

The analysis of rainfall-runoff relationships for the two Cygnet River gauges reveals a number of options for calculating yields (and hence WULs) of the Cygnet River subcatchments. One approach would be to use the Huxtable Forest rainfall-runoff curve and the Koala Lodge rainfall-runoff curve as detailed in Figure 17, with the former defining yield for all subcatchments draining upstream of the Huxtable Forest gauge, and the latter for all other Cygnet River subcatchments. Whilst this approach utilises all available Cygnet River observations, it would create a situation where subcatchments that drain to the Huxtable gauge, yet border subcatchments that drain downstream of this gauge, have their annual yield calculated via an approach that differs from these adjacent subcatchments. Hence the WULs calculated via these differing approaches might be quite different, even though average rainfall may be similar. Also, with the Huxtable Forest record having fewer data points than the Koala Lodge record, there will be less confidence in the definition of the rainfall-yield relationship for the former.

An alternative approach would be to define a new "Combined Cygnet" rainfall-runoff curve using all 14 data points from the Huxtable Forest and Koala Lodge gauges. By using both the 10 data points from the Koala Lodge record and the 4 data points from the Huxtable Forest record, a new rainfall-runoff curve is shown in Figure 22. This new curve fits between the two other Cygnet River curves, and may represent a more appropriate description of catchment-wide rainfall-yield relationships for all subcatchments of the Cygnet River.

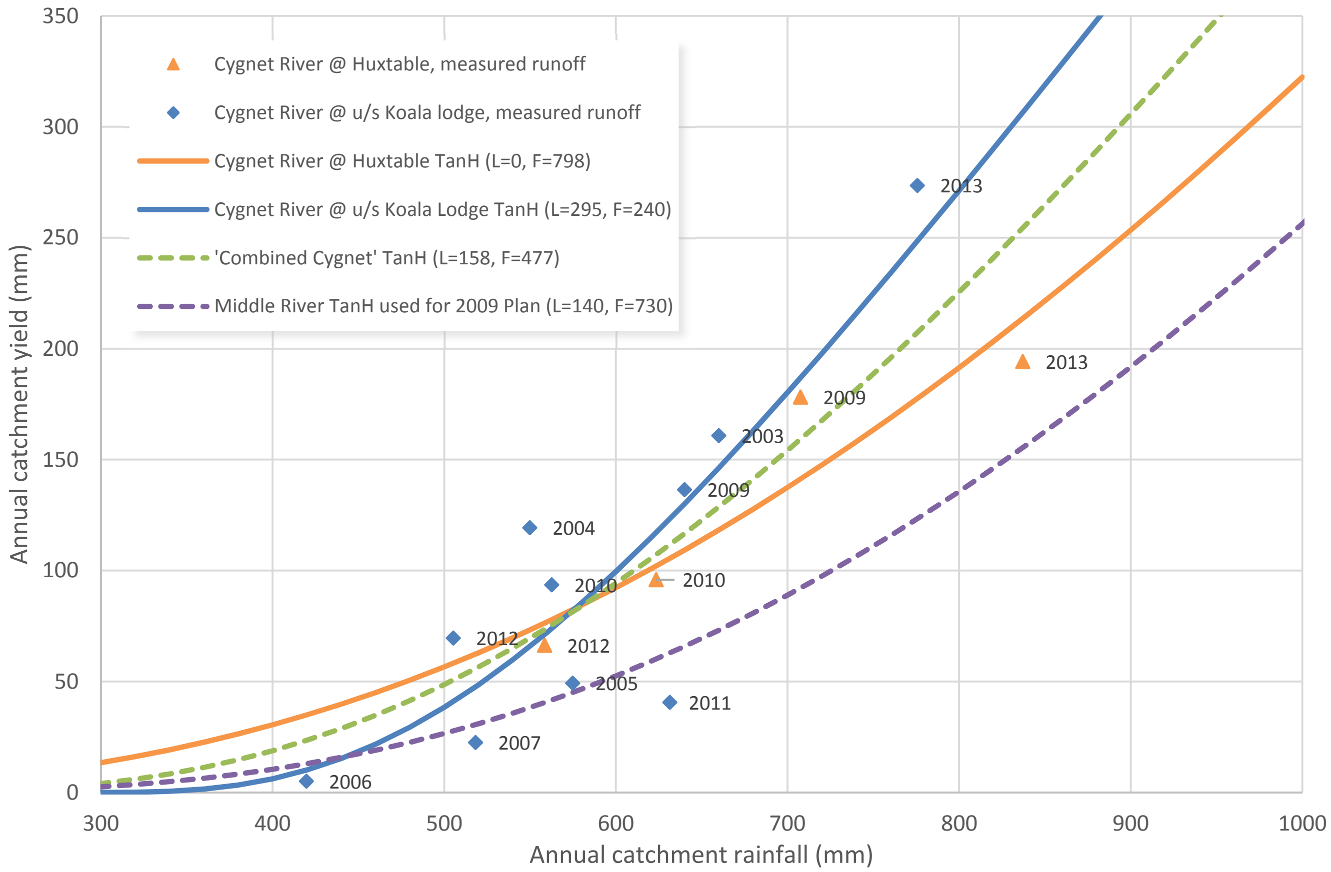

Figure 22 Annual rainfall-runoff relationships for the two Cygnet River gauges, showing a TanH function that was derived from combining these two data series

Even though the "combined Cygnet" rainfall-runoff curve shown in Figure 22 may represent a more appropriate catchment-wide description of rainfall-runoff interaction, it is still based on only 14 data points. As such it could be argued that this is an insufficient number of data points, and that the ongoing use of a generalised KI rainfall-runoff curve for the entire Cygnet River catchment remains suitable, until such time as sufficient data to represent the temporal variability in rainfall has been collected. Analysis of the rainfall records from existing long–term rainfall stations in the different catchments in KI would provide data that represent average, wetter–than–average and drier–than–average rainfall periods. These data sets could then be used to develop a representation of the temporal variability of rainfall.

The three potential Cygnet River data-derived rainfall-runoff relationships are compared against the "generalised" KI and "generalised-extended" KI curves in Table 11. These relationships indicate that for annual rainfalls across the range 500-700 mm, each Cygnet River data-derived curve calculates higher catchment yields than the Middle River rainfall-runoff curve (2009 Plan). As a result, the adoption of any of these three relationships would produce WULs that are higher (for a given estimate of average rainfall) than the existing SLs (in the 2009 Plan).

Table 11 Summary of annual rainfall-runoff curves for Cygnet River

TanH function	TanH "L" parameter	TanH "F" parameter	Yield at 500 mm rainfall	Yield at 600 mm rainfall	Yield at 700 mm rainfall
Cygnet River @ Huxtable Forest catchment	0	798	57 mm	92 mm	137 mm
Cygnet River @ u/s Koala Lodge catchment	295	241	38 mm	99 mm	180 mm
Combined Cygnet River	158	477	48 mm	94 mm	154 mm
"Generalised" KI (2009 Plan)	140	730	27 mm	53 mm	89 mm
"Generalised-extended" KI (refer Part 1, Section 4.1)	142	770	24 mm	47 mm	81 mm

4.3 Timber Creek catchment

The rainfall-runoff curve shown in Figure 17 for the Timber Creek gauge was generated from five data points, and shows higher catchment yields than the Cygnet River (Koala Lodge) curve for a given annual rainfall. If this relationship was adopted for calculating average annual yields in the Timber Creek subcatchments, higher yields (hence higher WULs) than the values presented in the 2009 Plan will be calculated for given annual rainfall.

An alternative to the adoption of a new Timber Creek data-derived rainfall-runoff relationship would be the conclusion that five data points are insufficient information from which to define a long-term rainfall-yield relationship in the Timber Creek catchment, and a generalised KI curve should continue to be used until additional gauged yield data is obtained. Alternatively, the option of combining Timber Creek data with that from the other largely-cleared catchments should be explored (see Part 1, Section 4.4).

The Timber Creek data-derived TanH function is compared with the generalised KI and "generalised-extended" KI rainfall-runoff curves in Table 12.

Table 12 Summary of annual rainfall-runoff curves for Timber Creek

TanH function	TanH "L" parameter	TanH "F" parameter	Yield at 500 mm rainfall	Yield at 600 mm rainfall	Yield at 700 mm rainfall
Timber Creek	143	389	68 mm	132 mm	211 mm
"Generalised" KI (2009 Plan)	140	730	27 mm	53 mm	89 mm
"Generalised-extended" KI (refer Part 1, Section 4.1)	142	770	24 mm	47 mm	81 mm

4.4 Highly-developed catchments

A further alternative to defining separate rainfall-runoff curves to calculate yield in the Cygnet River and Timber Creek catchments is to firstly acknowledge the impact of land use on catchment yield in these two areas of high agricultural development, and generate a single "highly-developed area" TanH function through combining observations at all three gauges. The calibration of a single rainfall-runoff curve (TanH function with parameters L=162, F=438) to these 19 data points produces a new rainfall-runoff relationships that is still significantly different from the Middle River ("generalised" KI) rainfall-runoff relationship used for the 2009 Plan.

The annual yield estimated from this "developed area" rainfall-runoff curve is compared in Table 13 to the other functions that have been previously introduced. This new rainfall-runoff curve is shown in Figure 23 alongside the parameters of the TanH function used for the 2009 Plan.

Table 13 Comparison of "highly-developed area" rainfall-runoff curve with other potential curves

TanH function	TanH "L" parameter	TanH "F" parameter	Yield at 500 mm rainfall	Yield at 600 mm rainfall	Yield at 700 mm rainfall
Timber Creek	143	389	68 mm	132 mm	211 mm
Cygnet River @ u/s Koala Lodge catchment	295	241	38 mm	99 mm	180 mm
Cygnet River @ Huxtable Forest catchment	0	798	57 mm	92 mm	137 mm
"Highly-developed area"	162	438	54 mm	105 mm	170 mm
"Generalised" KI (2009 Plan)	140	730	27 mm	53 mm	89 mm
"Generalised-extended" KI (refer Part 1, Section 4.1)	142	770	24 mm	47 mm	81 mm

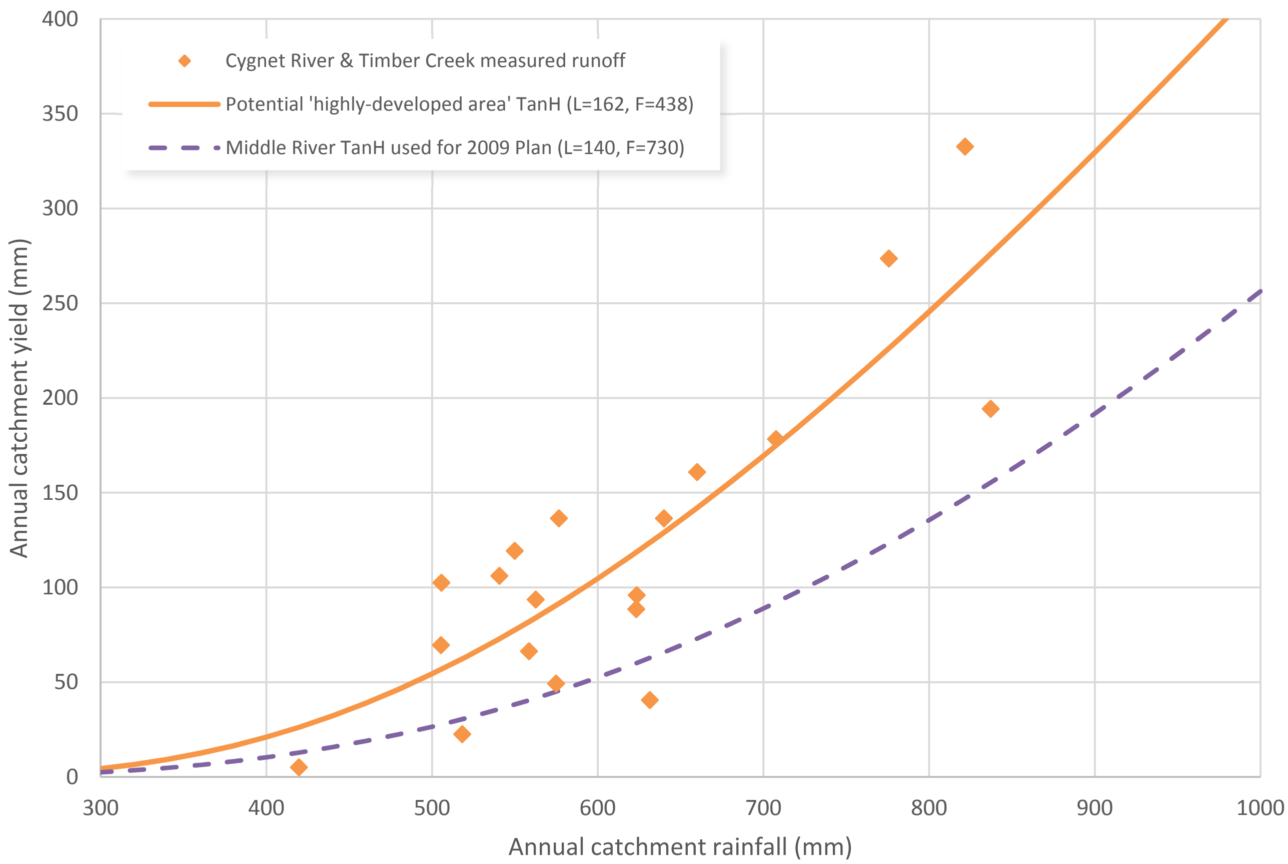

Figure 23 Annual rainfall-runoff relationships for two Cygnet River gauges and the Timber Creek gauge, showing a potential "highly-developed area" rainfall-runoff curve that was derived from combining these three data series

4.5 Less-developed catchments

It was shown previously that the Stunsail Boom River streamflow gauge provides only two years of flow data from which rainfall-yield relationship could be developed. Although this is insufficient to reliably define a long-term rainfall-runoff curve, Figure 17 shows that flows in these two years plot below the Middle River TanH curve used for the 2009 Plan, and close to the rainfall-runoff curve associated with the Rocky River catchment for the period 1974–2013.

As a result, one approach to calculate WULs for the Stunsail Boom River catchment could be to use the rainfall-runoff relationship defined for the Rocky River catchment (parameters L=12, F=1267), even though the Rocky River catchment remains outside the policy zone for WULs. This approach would highlight the role played by the significant areas of natural vegetation in the Stunsail Boom catchment (approximately 64% of the total catchment area) upon the rainfall-runoff processes, and would result in lower catchment yield estimates relative to a generalised KI rainfall-runoff curve (refer Table 14).

Table 14 Summary of potential annual rainfall-runoff curves for Stunsail Boom River

TanH function	TanH "L" parameter	TanH "F" parameter	Yield at 500 mm rainfall	Yield at 600 mm rainfall	Yield at 700 mm rainfall
"Less-developed area"/ Rocky River	180	831	15 mm	32 mm	59 mm
"Generalised" KI (2009 Plan)	140	730	27 mm	53 mm	89 mm
"Generalised-extended" KI (refer Part 1, Section 4.1)	142	770	24 mm	47 mm	81 mm

An alternative approach to estimating catchment yield in less-developed catchments (for the purpose of defining WULs) could be to focus only upon the area of the catchment that has been cleared for agricultural production or plantation forestry, and the contribution these areas provide to overall catchment runoff. The existing calculation methodology for WULs (described in Part 1, Section 4.7) relies upon an assumption that plantation forestry represents an average reduction in catchment runoff of 85% from cleared land (Government of South Australia, 2009), and that the runoff from natural vegetation was 45% of the runoff from cleared land. The Stunsail Boom River gauge recorded total annual flows of 14,726 ML in 2012 and 29,617 ML in 2013, corresponding to average runoff values of 54.5 mm and 109.7 mm from the catchment upstream of the gauging point. By analysing the catchment areas corresponding to different land use types (Table 1) and these afore-mentioned assumptions regarding runoff from each land type, the runoff from the cleared portion of the Stunsail Boom catchment is calculated as approximately 105 mm in 2012 and 211 mm in 2013 for respective annual rainfall of 704 mm and 975 mm.

By comparing these annual values in Figure 24, it is possible that the cleared parts of the Stunsail Boom River catchment could have runoff characteristics more closely aligned to other cleared catchments, and that the uncleared parts of the catchment could have runoff characteristics more closely aligned to the uncleared Rocky River catchment. As a result, there is a greater degree of uncertainty with the overall runoff characteristics of the Stunsail Boom River catchment, and a precautionary approach should be adopted to this catchment. Until additional hydrological observations are obtained for less-developed catchments (such as the Stunsail Boom River catchment), WULs could continue to be calculated from a generalised KI rainfall-runoff relationship.

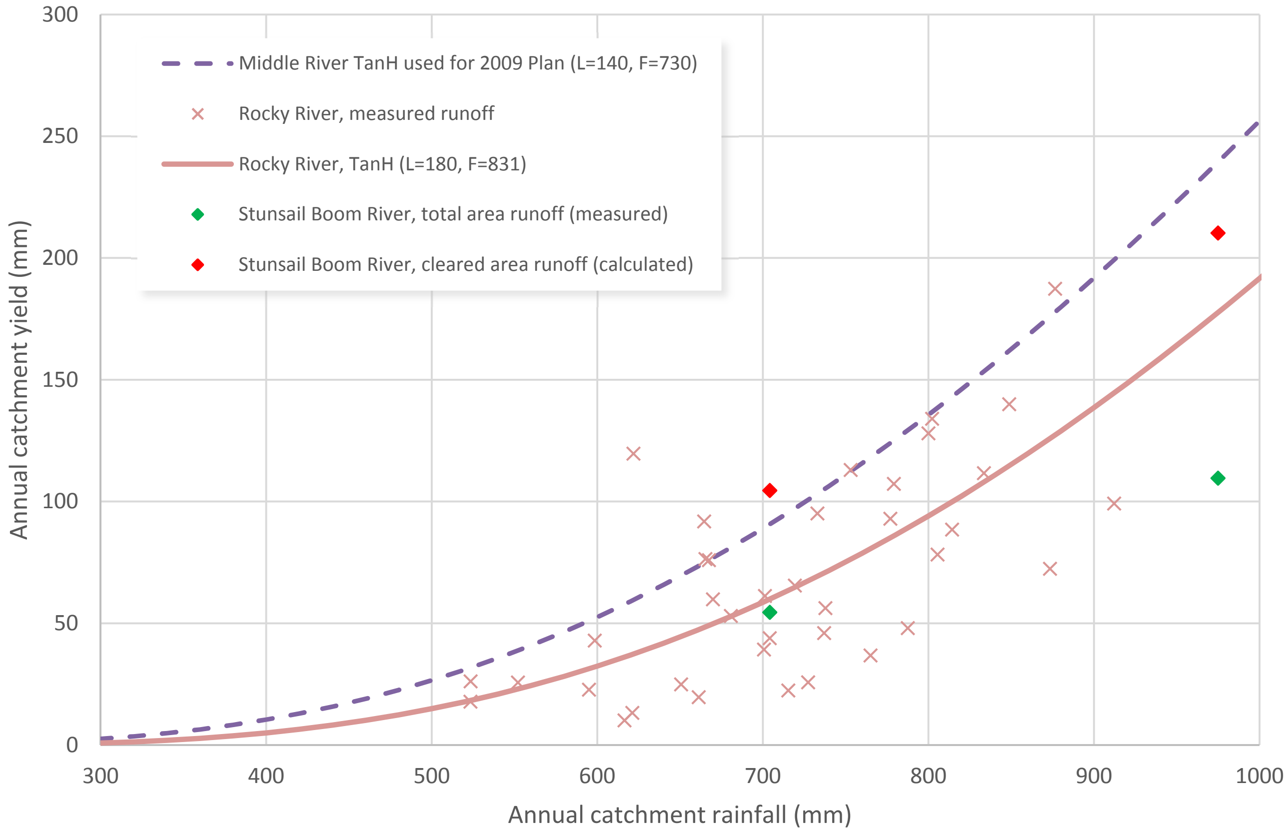

Figure 24 Annual rainfall-runoff relationships for Stunsail Boom River gauge, showing comparison between measured runoff for the total catchment area and the calculated runoff from the cleared portion of the catchment

4.6 Regionalisation for catchment analysis

As noted in Part 1, Section 1.3, this report represents SMK's response to the Board's request to deliver "Option 5", as a stepping stone towards the completion of "Option 6" at a later date. This "Option 6", as defined in Part 1, Section 1.3, involves the regionalisation of non-KI and KI data to formulate new water sharing rules in ungauged catchments. One approach to determining rainfall-runoff relationships in ungauged catchments on KI would be to first use all gauged data from KI to produce a "regionally-applicable" rainfall-runoff model, although this model-averaging approach is only suitable if the ungauged catchments were hydrologically similar to the gauged catchments. Additionally, if this approach was followed, rainfall-runoff relationships would need to adequately account for the entire flow regimes of ungauged catchments, not only total annual runoff – with components such as threshold flow rates important for the implementation of water sharing rules.

Alternatively, this regionalisation could involve the grouping of KI catchments/ subcatchments into categories on the basis of catchment characteristics. More specifically, it would be based on a selection of gauged catchments that have a degree of "similarity" to specific ungauged catchments. Whilst being outside the scope of this project, some initial investigations have been undertaken into defining appropriate regionalisation approaches for KI. The generalised KI and "generalised-extended" KI rainfall-runoff relationships (refer Part 1, Section 4.1) provide "default" methods for calculating catchment yield in ungauged catchments in KI in terms of the catchment-averaged annual rainfall. However in the absence of recorded streamflow data, catchment descriptors can be used to identify similarities between gauged and ungauged catchments, with optimised flow-related parameters then applied across catchments with similar characteristics.

There are at least four categories of catchment descriptors that can be analysed for this purpose: climatic descriptors (including mean and seasonal distributions of rainfall and evaporation), catchment morphology descriptors (including slope and altitude range among others), landscape descriptors and land cover descriptors. Land Use type was previously introduced (see Part 1, Section 2.3) as a land cover attribute that affects the rainfall-runoff process. Potential landscape attributes that could be used to identify hydrological similarity of catchments include surface waterholding capacity (a spatial measure of surface soil depth and texture), surface soil texture (a spatial measure of clay content in surface soil), depth to groundwater and susceptibility to waterlogging, which is a series of landscape map classes that describe the degree of surface and sub-surface drainage, among others. These four descriptors are all examples of landscape features that impact the rainfall-runoff processes, and therefore surface water yields, at a catchment scale.

An initial classification of gauged catchments on KI and in the MLR, on the basis of these landscape-based characteristics, was undertaken via GIS during this study. These catchment classifications were then related to streamflow records to investigate the strongest predictors of flow. A more rigorous approach to the identification of hydrological similarity of catchments on KI and surrounding areas (e.g. MLR) may involve the use of multivariate statistical techniques such as cluster analysis to relate a large number of catchment descriptors to gauged streamflow records. There have been a large number of studies into the development of regionalisation approaches for ungauged catchments (e.g. Merz & Bloschl, 2004), and it is envisaged that "Option 6" will include a detailed assessment of the most appropriate technique for KI.

4.7 WUL calculation procedure

4.7.1 Methodology used for Zone B in the 2009 Plan

The Sustainable Limits described in the 2009 NRM plan were calculated at a subcatchment scale in a spreadsheet format (J Sullivan [DEWNR] 2014, pers comm, 10 February). The methodology that was used to calculate annual limits for subcatchments in Zone B can be described in the following manner:

a) Calculate the total subcatchment area (A_T)

b) For the subcatchment of interest, calculate the area of natural vegetation (A_N) and the area of plantation forestry (A_F)

c) The area of cleared land (A_C) calculated as $A_C=(A_T-A_N-A_F)$

d) Calculate average annual rainfall for subcatchment (P)

e) Using the Middle River rainfall-runoff relationship from the 2009 Plan (TanH function with parameters L=140, F=730), calculate average annual runoff for the subcatchment (R_A)

f) Calculate runoff from the cleared area of subcatchment, $R_C=1.2 \times R_A$ (i.e. a 20% increase from average yield is assumed, to account for greater runoff from cleared land)

g) Calculate runoff from natural area, $R_N=0.45 \times R_C$

h) Calculate total subcatchment yield, $Y_T = (A_C R_C + A_N R_N)$ and WUL = $0.25 \times Y_T$

i) Determine farm dam capacity (FDC) in subcatchment

j) Calculate losses through farm dam use and plantation forestry interception, i.e. $L_T = 0.5 \times \text{FDC} + (0.85 \times R_C)$

k) Volume available for additional development, $V_{AD} = \text{WUL} - L_T$

l) If $V_{AD} < 0$, then the WUL is exceeded, and activity will become on-merit, with additional water affecting activity permits may not be issued.

4.7.2 Assumptions in the 2009 Plan methodology for calculating SLs

The methodology outlined in Part 1, Section 4.7.1 includes a number of assumptions:

a) Firstly, the methodology assumes that the subcatchment portions with different land use are each exposed to the same rainfall conditions. An alternative (but more time consuming) approach would be to aggregate gridded rainfall across the cleared and uncleared areas of the subcatchments separately.

b) The methodology also assumes that runoff from natural areas is a constant 45% of the runoff generated from cleared land. No reference to this assumption can be found in documentation relating to the 2009 Plan. The suitability of this assumption has not been analysed as part of this study, as the adoption of rainfall-runoff curves derived from gauged data from KI (as introduced in this report) would not require the separate calculation of runoff from natural areas. However it should be noted that the locations within catchments of both native vegetation and plantation forestry will play a major role in their impact on surface water runoff. Plantations close to the catchment outlet can tap much higher volumes of water, and will therefore show much larger reduction in runoff at the outlet compared with plantations in upper reaches of the catchment.

c) The losses from plantation forests were assumed to be a constant 85% of the runoff from cleared land (i.e. runoff from plantation forests assumed to be 15% of runoff from cleared land). This assumption was consistent with South Australian state policy (Government of South Australia, 2009), and therefore the suitability of this assumption was not investigated.

d) On average, 50% of the total volume of farm dams was assumed to meet the total annual extractions and losses from watercourses, which is consistent with the Sustainable Limit policy on KI (2009 Plan). The total farm dam volume was estimated from GIS information, using surface area-volume relationships calculated from MLR investigation, and no review of these numbers was undertaken as part of this study.

e) The operational spreadsheets that were provided for this study (J Sullivan [DEWNR] 2014, pers comm, 10 February) contain no reference to the observation period or calculation approach used to generate average annual rainfall totals for each KI subcatchment. When compared to average annual totals calculated using the SILO gridded data (1900-2012) in this study, there are some marked differences between the assumed average rainfall totals that underpin the calculation of current WULs in certain subcatchments, and the average rainfall estimated in this study. As noted previously, the period of historical record from which average rainfall is calculated will impact the estimation of average catchment yield, and therefore the calculation of average WULs.

4.7.3 Impact of applying Method B to former "Zone A" catchments

As previously noted, the 2009 Plan outlined an alternative "Method A" for calculating SLs in the higher-rainfall "Zone A" catchments. The subsequent CSIRO review of the 2009 Plan (Aryal, 2011) raised questions about the basis for this Method A, and its ongoing use.

Under "Method A", the flow conditions in Rocky River were assumed to represent the "desired natural state runoff" (KI NRMB, 2009c) for the catchments of "Zone A", and therefore became the minimum flow that must be protected from water resource development.

The calculation methodology for Zone A catchments (J Sullivan [DEWNR] 2014, pers comm, 10 February) firstly calculates average yield in each subcatchment using the original Middle River rainfall-runoff curve (treating cleared and natural parts separately, as per the 2009 Plan's application of "Method B"), then subtracts from this yield the corresponding yield from a Rocky River rainfall-runoff curve, to produce an annual volume available for use. The effect of this is that the WUL produced is generally higher than the volume that would be calculated using Method B (i.e. taking 25% of the total yield).

The application of Method B (the 25% rule) to calculate WULs in all ex-"Zone A" catchments (should this approach be adopted by the Board) would result in a reduction in WULs from values listed in the 2009 Plan, even before post-2009 changes in average rainfall, farm dam volumes and land use types are factored in.

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5 Daily rainfall-runoff relationships

5.1 Background

The characterisation of WULs on KI requires the specification of annual rainfall-runoff relationships for both gauged and ungauged catchments. In addition, the current Plan (2009) seeks to manage the timing and conditions of extraction from watercourses via the definition of daily threshold flow rates (TFRs). The implementation of these TFRs seeks to maintain flows to downstream users, and to protect surface water dependent ecosystems during drier periods. As such, TFRs represent a "surrogate measure" for low flows, in the absence of detailed environmental water requirements (EWRs) across KI.

The Unit Threshold Flow Rate (UTFR) is defined as the rate of flow per unit catchment area (expressed as $L/s/km^2$), below which water must not be diverted or collected in farm dams. The 2009 Plan defines location-specific TFRs (or low flow bypass rates) as the product of the UTFR and the catchment area draining to (a) the point of capture (for farm dams) or (b) the point of diversion. The 2009 Plan sets the UTFR as the rate of daily flow that would be exceeded or equalled for 10% of the time, divided by the catchment area. During the preparation of the 2009 Plan, there was very limited daily flow information for KI watercourses from which to calculate these flow rates, and therefore UTFRs were informed by hydrological observations from other gauges in South Australia, via the adoption of a regionalised curve (relating UTFR to average annual rainfall) from MLR gauges. With streamflow observations now available for gauging stations on KI, it is possible to analyse whether daily flows can inform the specification of UTFRs that better reflect local conditions.

5.2 Daily streamflow data

The daily streamflow observations for the selected calendar years having non-missing data (as presented in Part 1, Section 2.5) are summarised in Table 15.

Table 15 Summary of daily streamflows for KI gauging sites for selected calendar years (with non-missing data)

Gauging station name	Max. daily flow (ML)	Mean daily flow (Std Dev) (ML)	Median daily flow (ML)	Total no. days	% days missing	% days zero flow
Rocky River @ u/s Gorge Falls	2,235	**37.4** (96.5)	8.2	14,245	<0.1%	20.2%
Cygnet River @ Huxtable Forest	4,817	**86.8** (305.4)	2.8	1,461	8.6%	30.5%
Cygnet River @ u/s Koala Lodge	10,440	**128.2** (570.0)	4.0	3,652	0.4%	37.2%
Timber Creek @ South Coast Road	2,288	**56.9** (201.1)	3.5	1,826	4.2%	6.9%
Stunsail Boom River @ South Coast Rd Bridge	1,755	**61.2** (158.7)	6.2	731	0.8%	27.9%

The daily streamflow data for the five KI gauges for the selected calendar years (with non-missing data) are compared through flow duration curves in Figure 25. These curves are cumulative frequency curves showing the percent of time during which daily flows were equalled or exceeded during the select years.

The shape of flow duration curves provide a cumulative impact of the various factors that influence runoff, such as climate, topography, land use and soil condition. As such, a comparison of the shapes of these five curves provides some insight into the hydrological characteristics of these catchments. The two flow durations curves for the Cygnet River plot close together, which is expected, as the contributing catchment of the Koala Lodge station incorporates the Huxtable Forest gauge catchment. The flatter slope at the lower end of the Timber Creek duration curve suggests a greater amount of perennial storage in that catchment, indicating a higher baseflow persistence in comparison to the other catchments.

The flatter slope throughout the Rocky River curve indicates that it has a less variable flow pattern than the other streams, with its flow equalised to a greater degree, possibly due to surface or groundwater storage. This curve is also the smoothest curve, as it represents the longest streamflow time series from KI.

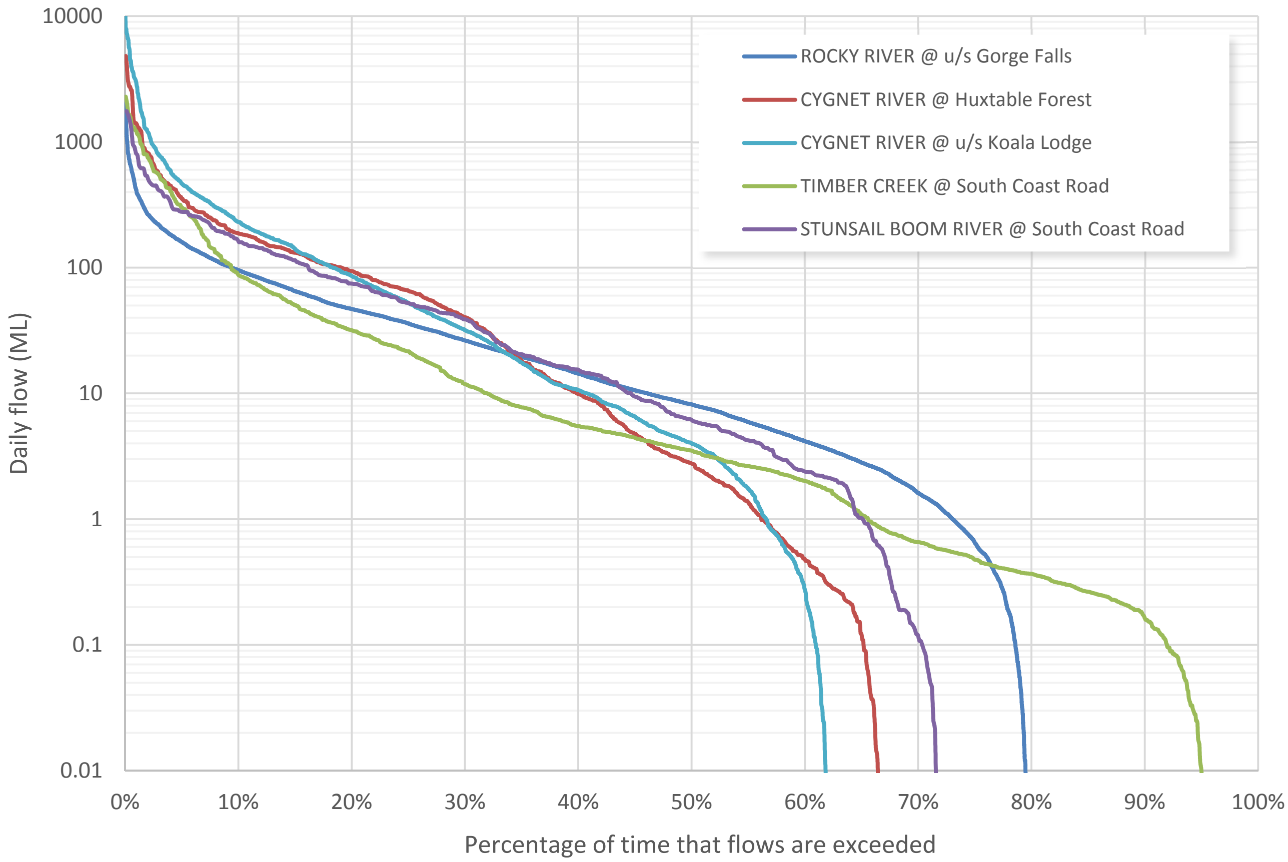

Figure 25 Daily flow duration curves for selected calendar years (non-missing data) at each KI streamflow gauge

The daily flow rates for the five KI gauges having various probabilities of exceedance (POE), as shown in the historical flow duration curves of Figure 25, are summarised in Table 16.

Table 16 Summary of historical daily flows (ML) for the five KI gauges for selected calendar years

Percentage of time flow exceeded	ROCKY RIVER @ u/s Gorge Falls	CYGNET RIVER @ Huxtable Forest	CYGNET RIVER @ u/s Koala Lodge	TIMBER CREEK @ South Coast Road	STUNSAIL BOOM RIVER @ South Coast Road
10th %ile POE flow	95.4	186.3	231.0	86.7	159.5
20th %ile POE flow	46.9	93.7	85.8	31.7	74.5
30th %ile POE flow	26.3	40.3	31.7	11.8	38.7
40th %ile POE flow	14.4	9.9	10.6	5.5	15.3
50th %ile POE flow	8.2	2.8	4.0	3.5	6.2
60th %ile POE flow	4.2	0.5	0.3	2.0	2.4
70th %ile POE flow	1.6	0	0	0.7	0.1
80th %ile POE flow	0	0	0	0.4	0
90th %ile POE flow	0	0	0	0.2	0

5.3 Flow duration curve variation

Figure 25 illustrated flow duration curves for the five KI gauges, using all available data from calendar years selected for analysis of rainfall-runoff relationships. To analyse the inter-annual variability in the daily flow records of these gauges, flow duration curves for 2012 and 2013 are presented in Figure 26 and Figure 27 respectively, alongside flow duration curves from a selection of gauges in the MLR. This comparison with MLR data seeks to explore the validity of applying a UTFR-rainfall relationship from MLR gauges to KI catchments.

Through comparing Figure 26 with Figure 27, it appears that drier conditions in 2012 revealed a higher proportion of zero flows in the KI catchments (apart from Timber Creek), and flow duration curves having steeper slopes, which suggest more variable flow conditions. The magnitude of medium-size flows (nominally between 10% and 50% exceedance) in 2013 are consistently higher than in 2012 for the KI gauges. The characteristics of the flow-duration curves for selected MLR gauges appear significantly different from the KI gauges; firstly the MLR gauges show considerably more baseflow than the KI gauges, with a flatter slope at the lower end of these curves for both years indicating more perennial storage, and secondly even though total flows during 2013 were slightly higher than 2012 for each of the four MLR gauges shown, the medium-sized flows were generally smaller during 2013. These characteristics further suggest that the hydrological processes in these MLR catchments are slightly different from those underlying the KI catchments. This is an important observation when viewed against the existing use of a general UTFR-rainfall relationship from the MLR to manage watercourse extractions on KI.

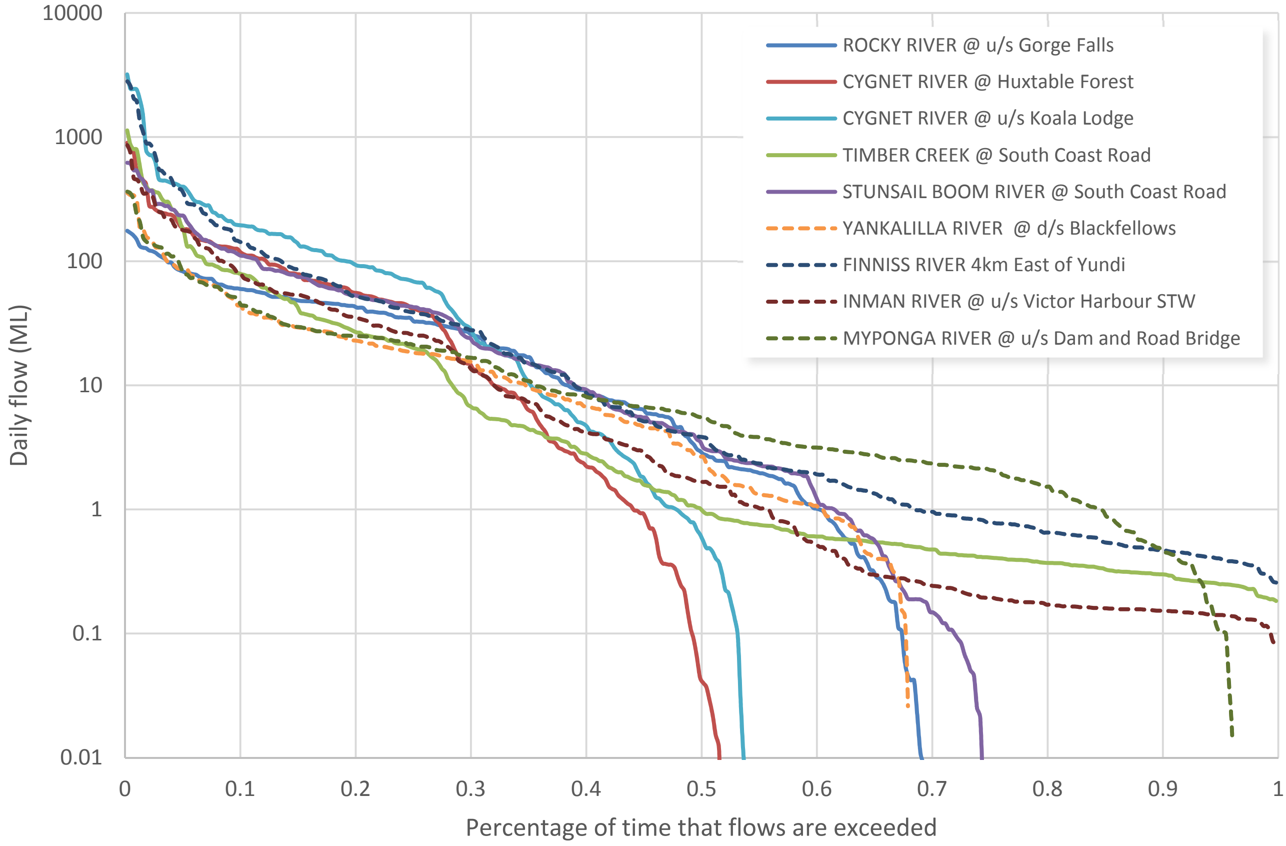

Figure 26 Flow duration curves for 2012 for KI gauges (solid lines) and selected MLR gauges (dashed lines)

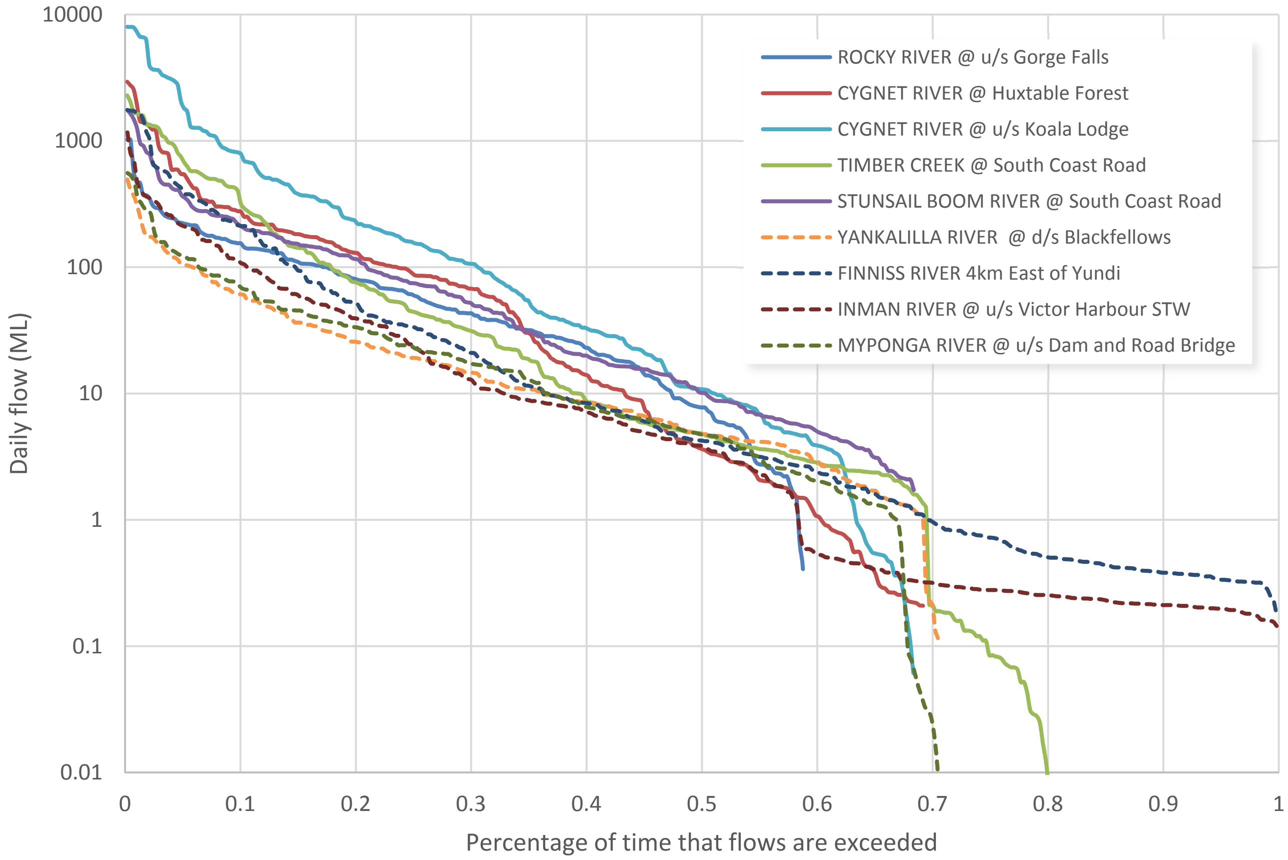

Figure 27 Flow duration curves for 2013 for KI gauges (solid lines) and selected MLR gauges (dashed lines)

This inter-annual variability in the daily flow records is explored further in Table 17, with the 10th percentile POE flow rates shown for each calendar year that was used in the annual rainfall-runoff analysis. These annual flows show that the flow volumes preserved for downstream use will vary dramatically between years.

Table 17 Summary of annual 10th percentile POE flows (ML/day) for the five KI streamflow gauges

Year	ROCKY RIVER @ u/s Gorge Falls	CYGNET RIVER @ Huxtable Forest	CYGNET RIVER @ u/s Koala Lodge	TIMBER CREEK @ South Coast Road	STUNSAIL BOOM RIVER @ South Coast Road
2003	74.0	n/a	474.1	n/a	n/a
2004	84.3	n/a	317.2	n/a	n/a
2005	29.5	n/a	183.2	n/a	n/a
2006	19.2	n/a	17.6	n/a	n/a
2007	32.6	n/a	79.8	n/a	n/a
2008	128.9	n/a	n/a	n/a	n/a
2009	179.3	128.9	387.4	169.4	n/a
2010	61.6	133.0	161.8	45.6	n/a
2011	69.7	n/a	114.4	48.9	n/a
2012	59.5	115.9	194.1	78.3	110.5
2013	150.0	265.4	750.0	307.2	208.1

5.4 Flow volumes

Figure 28 and Figure 29 show daily streamflows recorded at the Koala Lodge gauge on the Cygnet River during 2012 and 2013 respectively. In addition, these plots also show the 10th percentile POE flow rate for each year, and highlight the portion of the hydrograph passing the Koala Lodge gauging point that exceed the 10th percentile POE flow rate. These time series indicate large inter-annual variability in both catchment yield and the total volume of water that could be available for extraction in these two years, assuming that the 10th percentile POE daily flow rate is maintained. For information, the 20th percentile POE non-zero flow rates for 2012 and 2013 are also included in Figure 28 and Figure 29 respectively. The 20th percentile non-zero flow rate was identified as a suitable UTFR descriptor through Water Allocation Plan modelling for the Eastern MLR Prescribed Water Resources Area (PWRA) (Alcorn, 2011), and Western MLR PWRA (VanLaarhoven, 2012). Figure 28 shows that this latter flow rate is very similar to the 10th percentile POE flow rate for 2012, although Figure 29 shows that this is significantly lower for 2013.

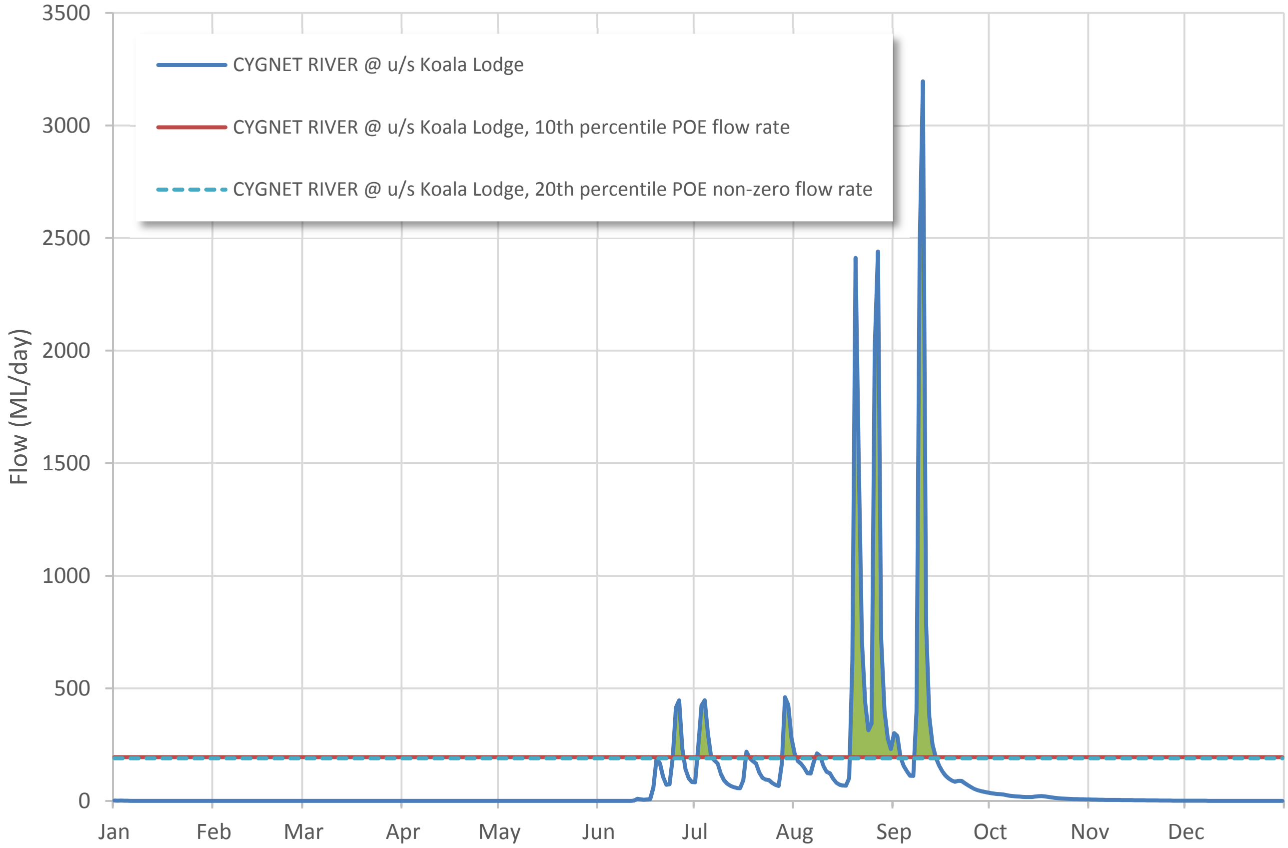

Figure 28 Daily flows for 2012 for Cygnet River (Koala Lodge) gauge, with flows above the 10th percentile POE flow rate for 2012 shaded

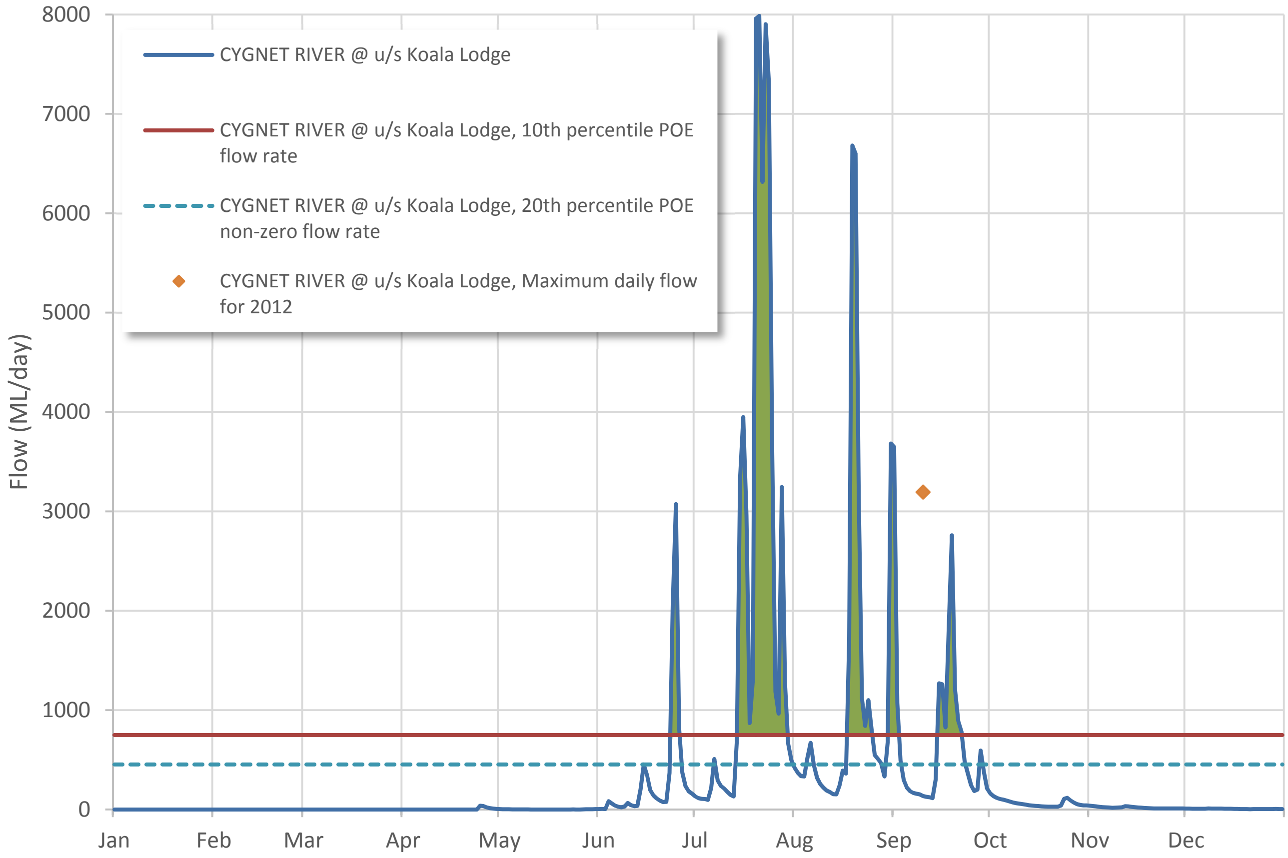

Figure 29 Daily flows for 2013 for Cygnet River (Koala Lodge) gauge, with flows above the 10th percentile POE flow rate for 2013 shaded

Table 18 summarises the variability in the total volumes of flows above the 10th percentile POE rate that would potentially be available for extraction, in terms of both the total annual volumes that occur above this threshold flow rate, and the proportion of the total annual flow recorded at each gauge. These results indicate that the Stunsail Boom River and Rocky River gauges have a higher proportion of their total flows being above the 10th percentile POE rate, highlighting the increased surface interception by the natural vegetation in the catchments.

Table 18 Volume available (in ML) for extraction (above 10th percentile POE flow rates) and percentages of total annual flows for each calendar year for the five KI streamflow gauges

	ROCKY RIVER @ u/s Gorge Falls	CYGNET RIVER @ Huxtable Forest	CYGNET RIVER @ u/s Koala Lodge	TIMBER CREEK @ South Coast Road	STUNSAIL BOOM RIVER @ South Coast Road
2003	4,452 (48.9%)	n/a	54,479 (70.5%)	n/a	n/a
2004	7,618 (61.4%)	n/a	45,342 (79.1%)	n/a	n/a
2005	2,540 (52.0%)	n/a	13,699 (57.8%)	n/a	n/a
2006	2,152 (63.7%)	n/a	1,551 (63.1%)	n/a	n/a
2007	2,219 (52.2%)	n/a	6,240 (57.6%)	n/a	n/a
2008	8,527 (59.3%)	n/a	n/a	n/a	n/a
2009	14,049 (57.9%)	29,208 (75.6%)	51,429 (78.5%)	14,760 (85.7%)	n/a
2010	7,606 (68.9%)	17,344 (83.4%)	41,465 (92.2%)	11,919 (89.0%)	n/a
2011	5,291 (49.7%)	n/a	13,391 (68.6%)	8,716 (78.0%)	n/a
2012	3,529 (47.4%)	9,829 (68.3%)	25,449 (76.1%)	10,315 (79.7%)	9,648 (65.5%)
2013	10,769 (57.3%)	30,551 (72.6%)	107,604 (81.9%)	33,590 (80.0%)	19,476 (65.8%)

5.5 UTFR-rainfall relationships

As previously indicated, UTFRs are currently defined for KI catchments in the 2009 Plan by a relationship between UTFR and annual catchment rainfall, which was developed from MLR records, and defined by a TanH function with parameters L=250 and F=2750. This relationship is applied to all catchments on KI to determine the relative UTFR, and hence the TFR at each watercourse diversion or on-stream dam capture location. Using the daily flow observations from five KI streamflow gauges, separate TanH functions describing rainfall-UTFR relationships can be generated. This reflects the annual rainfall runoff relationships described in Part 1, Section 3.3. The 10th percentile POE flow rates for each KI gauge were divided by the gauging catchment area to produce annual UTFRs (in L/s/km^2), and these were plotted against the corresponding annual catchment-averaged rainfall in Figure 30. Rainfall-runoff curves were then fitted to each series by minimising the residual sum of squares.

In a similar outcome to annual rainfall-runoff relationship in Figure 17, the rainfall-runoff curves corresponding to the Timber Creek gauge and the two Cygnet River gauges plot separately from the existing MLR TanH function. These results suggest higher threshold flow rates for these three KI catchments in comparison to MLR catchments with similar rainfall, further suggesting that a relationship between UTFR and catchment rainfall for Cygnet River and Timber Creek (represented by a TanH curve) may differ from the relationship currently adopted by the 2009 Plan. A TanH function developed as a “combined” Cygnet River relationship, using data from both Cygnet River gauges, plots very close to the rainfall-runoff curve of the shorter Cygnet River (Huxtable Forest) gauge, but still significantly higher than the existing MLR curve. A potential “highly-developed area” rainfall-runoff curve was also fitted to the combined set of observations from the two Cygnet River gauges and the Timber Creek gauge.

With only two years of flow data, there is insufficient data to develop a UTFR-rainfall relationship for the Stunsail Boom River catchment. However as these two data points plot either side of the existing MLR curve, there is also insufficient evidence to suggest that the existing MLR-derived rainfall-runoff curve is inappropriate for this catchment.

These results suggest that although there may be higher annual yield in the Cygnet River and Timber Creek catchments than suggested using the existing “generalised” KI rainfall-runoff relationship (2009 Plan), higher daily flows would need to remain in-stream, when compared with the values published in the 2009 Plan.

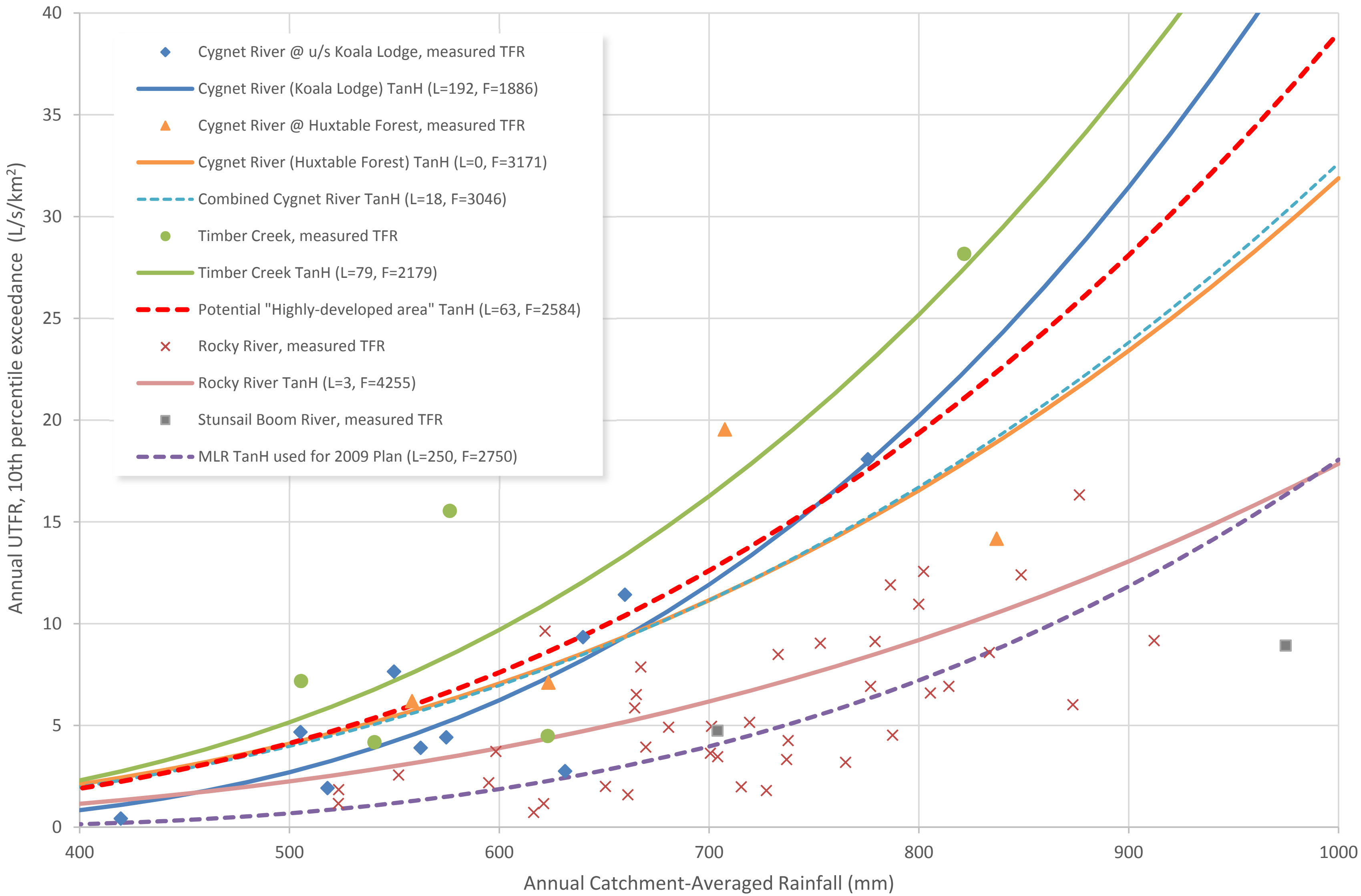

Figure 30 Unit threshold flow rates for individual years for the five KI streamflow gauges

6 Flow measurement uncertainty

The estimation of flow rates at streamflow gauges is a source of uncertainty in the characterisation of rainfall-runoff relationships in all hydrological studies such as this, not only KI. The degree of uncertainty here is determined by a number of factors, as explored below in the context of this KI project.

Estimates of flow rate at a gauging station are interpreted from stage height (water level) measurements through the use of rating tables. At low flows the relationships between water depth (stage) and flow rate are generally very accurate, due to the well-defined weir structures at the gauges, across which the behaviour of streamflows are understood with high certainty. When flows overtop these structures, stage-flow relationships need to be estimated from theoretical rating curves, the form of which are influenced by site characteristics such as topography and surface roughness.

When streamflow gauges are established in South Australia, an estimate of confidence in the theoretical stage-flow relationship (above the gauging structure) is made by hydrographic staff. Spot gaugings, involving the in-situ measurement of stage heights and flows, then seek to refine the rating curve, and reduce the uncertainty around the estimates of higher flow rates.

The five KI streamflow gauges analysed in this study are managed by DEWNR, whose hydrographic staff are generally based in Adelaide. Given the generally swift rainfall-runoff response times for higher flows in KI streams, the travel time between Adelaide and KI (for hydrographic staff) makes spot gauging the less frequent, over-weir structure flows a challenging proposition, which is further compounded by budget limitations. As such, the rating curves for some of the KI streams have only a few gaugings above the height of the weir structures.

Figure 31 shows the rating curve (accessed through South Australia's Hydstra surface water database) that is currently used to estimate flows at the Timber Creek streamflow gauge, together with the confidence bounds around the theoretical relationship. The highest gauging at this site (shown as "23/08/2005") was at a stage height of 1.401 m, whereas the highest recorded daily flow across the 2009–14 period was 2.846 m.

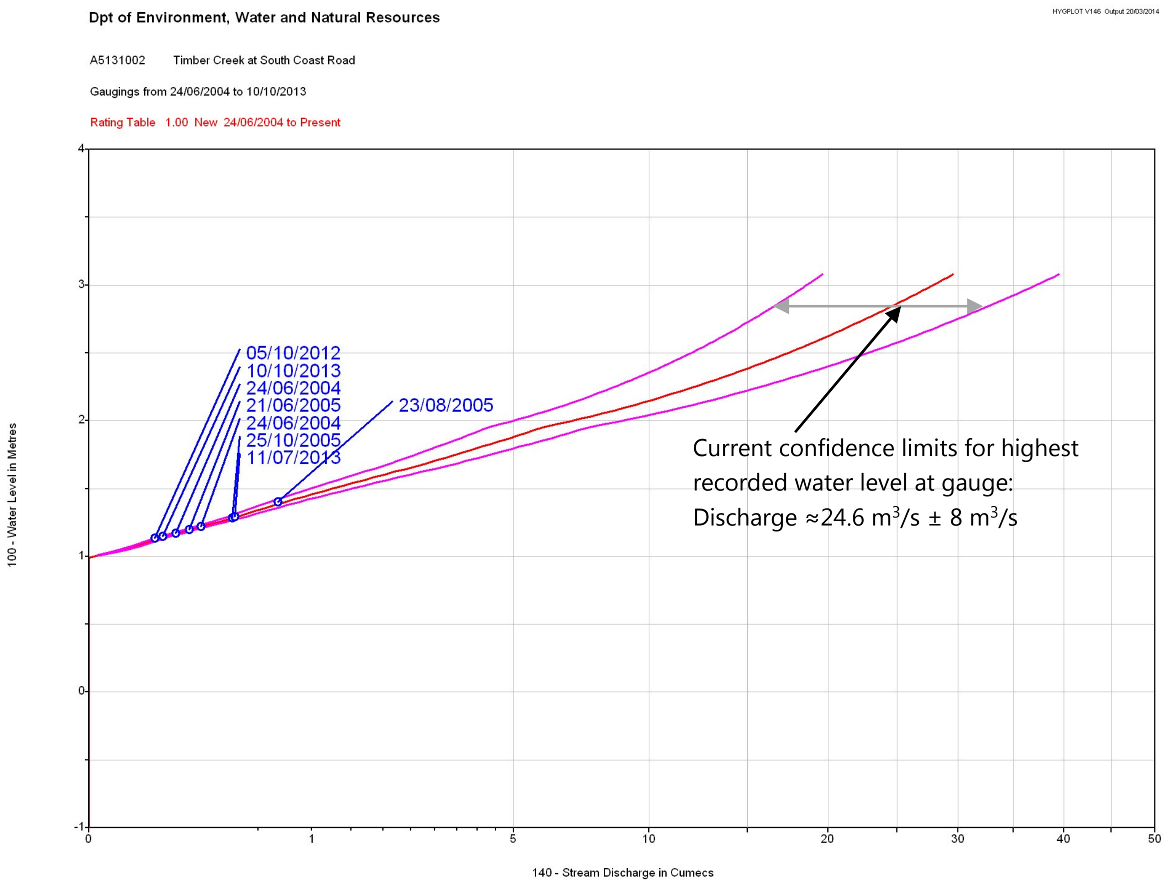

Figure 31 Rating table (with confidence limits) used to describe flows passing the Timber Creek streamflow gauge (site A5131002) as at May 2014, with individual gaugings shown

While the Timber Creek streamflow gauge shows a large proportion of the potential flow range above the stage height that has been gauged by DEWNR staff, Rocky River has a well-defined gauging station that has had over 90 flow gaugings made, primarily due to the fact that the Rocky River gauge has been in place 30 years longer than Timber Creek. Table 19 shows the proportion of time in each flow sequence in which the mean daily recorded stage height exceeds the highest recorded gauging. Additionally, the proportion of total flow volume which flows on these days is shown, indicating that the days in which flows are above the highest gauging correspond to periods of high flow, and represent significant proportions of the total annual flow. It is evident that uncertainties with measuring these high flows needs to be considered when using data from these gauging stations to derive rainfall-runoff relationships, especially at an annual time scale.

Table 19 Uncertainties in flows rates estimated from streamflow rating tables

Gauging station name	% of days with stream heights exceeding highest recorded gauging	% of total flow volume
Rocky River @ u/s Gorge Falls	< 0.1%	< 1%
Cygnet River @ Huxtable Forest	11%	77%
Timber Creek @ South Coast Road	10%	85%
Stunsail Boom River @ South Coast Rd Bridge	5%	54%
Cygnet River @ u/s Koala Lodge	1%	45%

To further illustrate the impact of uncertainty in gauging these high flows, Figure 32 shows the daily hydrograph for Timber Creek in 2013. The solid line represents the theoretical flow rate at the highest recorded gauging height (1.401 m, discharge 57 ML/d), and the area shaded represents the total flow volume passing the gauge on days with stage heights higher than this.

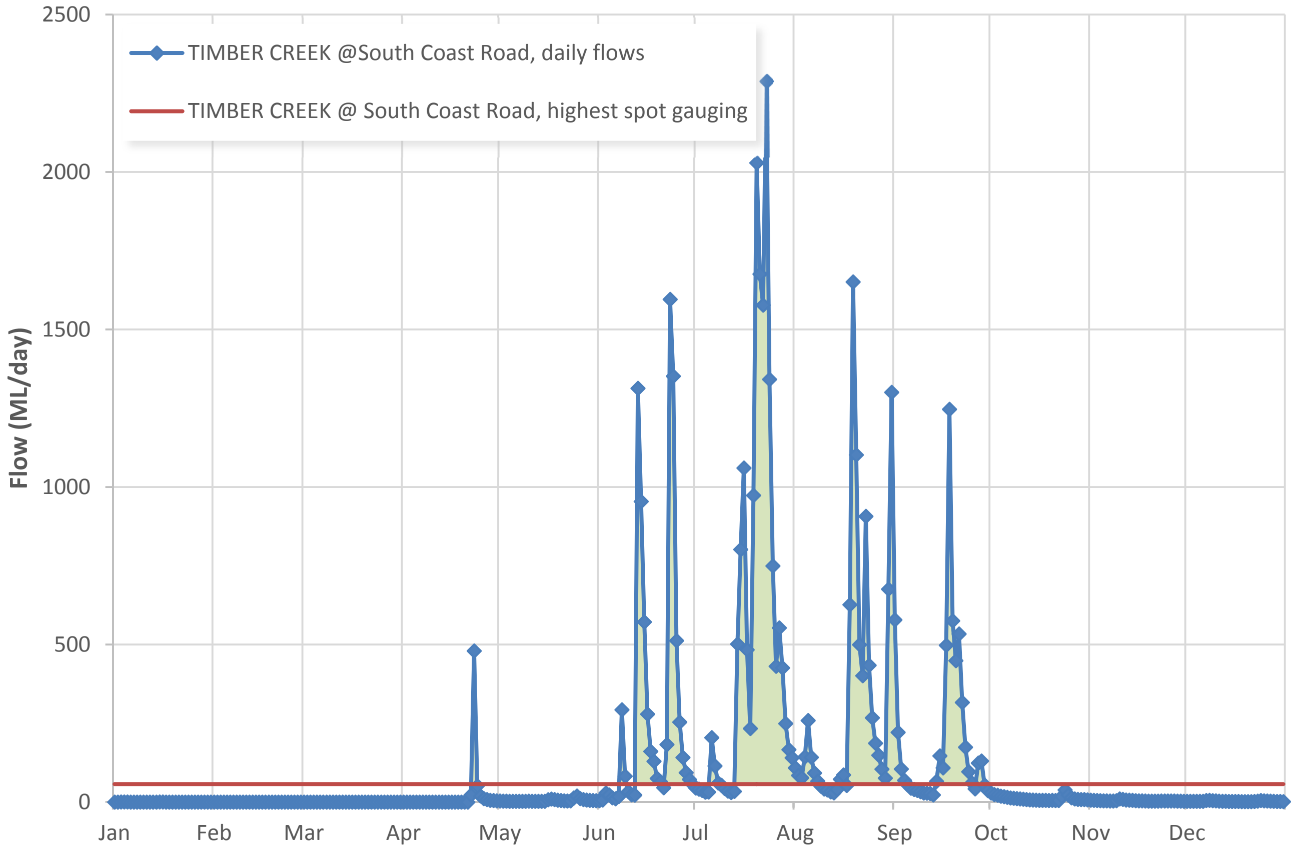

Figure 32 Daily streamflow recorded in 2013 at the Timber Creek gauge, with portion of record during which stage height exceeded the highest spot gauged stage height

The confidence intervals around the theoretical rating curve in Figure 31 were estimated at the installation of the gauging station. For the Timber Creek gauge, these confidence bounds range from approximately 18.6% at the highest recorded gauging (1.401 m) to 33% at a stage height of 3 m, as shown in Figure 33.

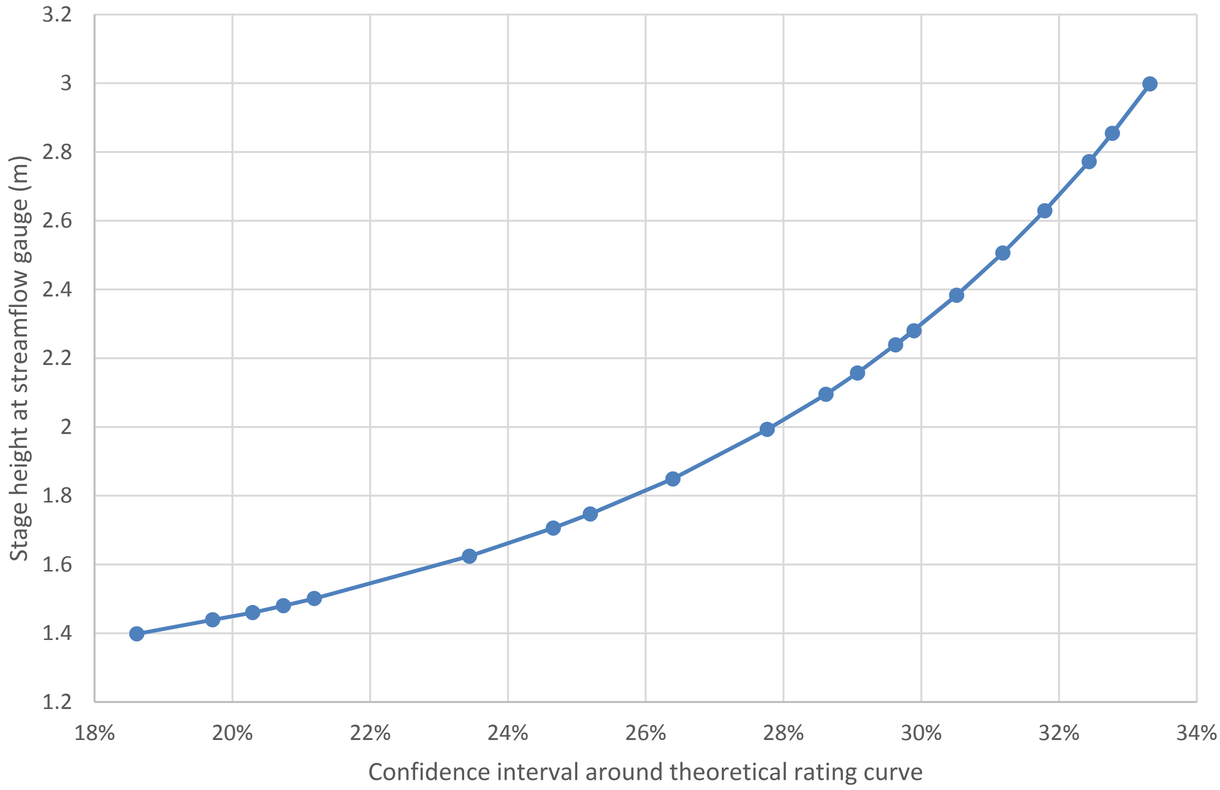

Figure 33 Variation in confidence interval around theoretical rating curve for the Timber Creek streamflow gauge

The impact of uncertainties in stage-flow relationships for Timber Creek were explored further, with the time series of daily flow heights for the five-year period 2009–13 modified using the confidence intervals around the theoretical flow estimates (taken from the middle line on the rating curve). For each day with mean stage height greater than 1.401 m, the confidence interval in flow estimate at that height was interpolated from the relationship in Figure 33. Flow estimates were then modified to produce an "upper" and "lower" daily flow estimate (i.e. theoretical flow rate ± confidence interval). These daily sequences were then aggregated to annual totals, and these "upper" and "lower" annual totals then related to annual rainfall values as in Part 1, Section 3. Rainfall-runoff curves were then fitted to the three sequences of five annual rainfall-runoff pairs, as shown in Figure 34, with the middle curve representing the Timber Creek curve that was originally shown in Figure 17, and the upper and lower curves representing the cumulative impact of the uncertainty interval around flow estimates.

This result demonstrates that the uncertainty in flow data that is inherent with the estimation of high flows, a feature that is not unique to KI, will impact the derivation of annual runoff characteristics – particularly for short sequences. However it should be noted that the lower TanH curve in Figure 34, which corresponds to a reduction in estimated catchment yield of up to 25% from the theoretical TanH curve, still estimates yields that are up to twice the yields estimated from the Middle River TanH function (2009 Plan). This further highlights that, even in light of uncertainties involved in measuring flows in Timber Creek, there is a strong indication that there are significantly higher yields in the Timber Creek catchment (for a given annual rainfall) than estimated from the generalised KI approach of the 2009 Plan.

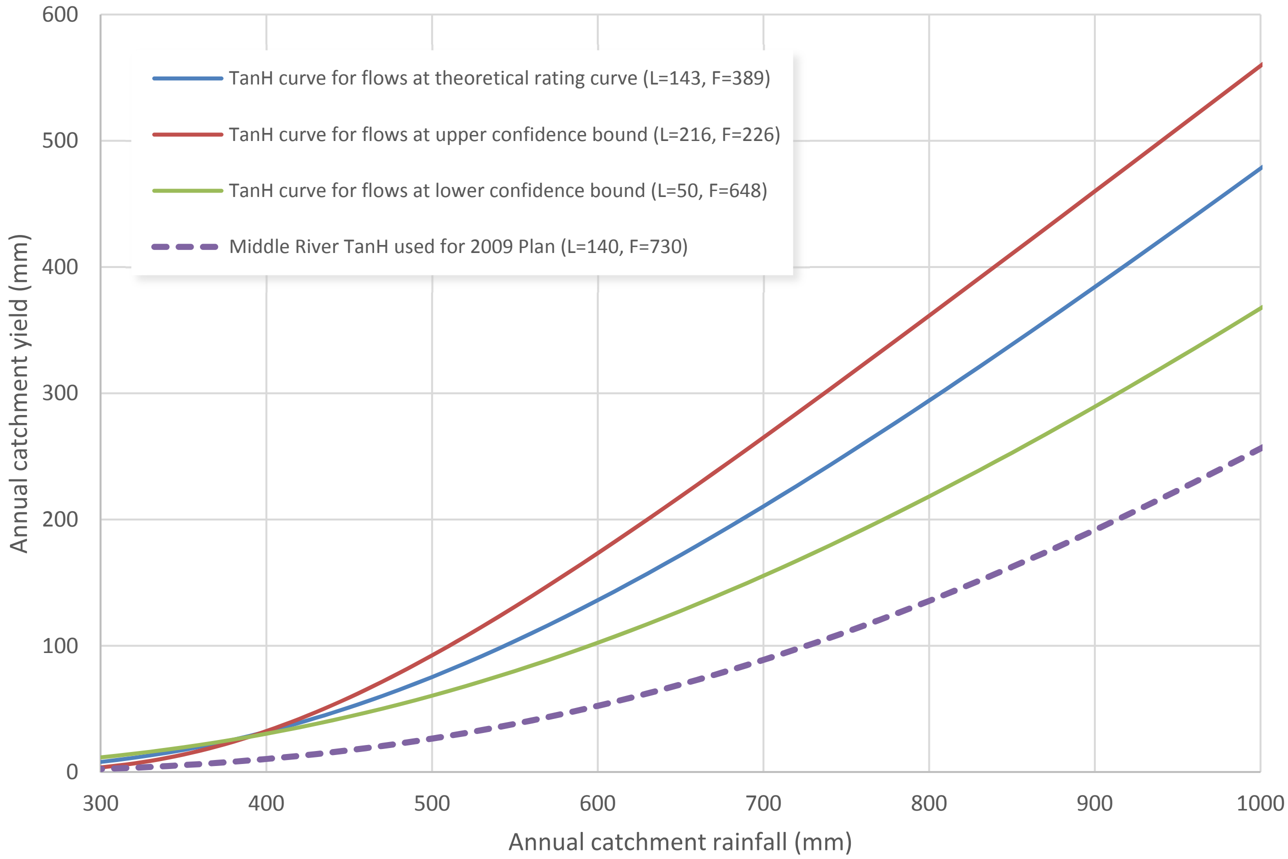

Figure 34 Annual rainfall-runoff relationships for the Timber Creek gauge, showing rainfall-runoff curves fitted to flow rates calculated from the theoretical rating curve, and at upper and lower confidence bounds around the theoretical curve

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7 Conclusions

This report has characterised catchment yield relationships across KI using streamflow gauging records at five locations across four catchments for the period up to 2013. While ostensibly being a validation of WULs using local hydrological data, this study has offered an exploration of the underlying rainfall-runoff relationships that are used to estimate catchment yield in the 2009 Plan. To this end, the report has focused on the question of whether the local hydrological data are sufficient to refine existing hydrological relationships that calculate both average annual yield, and hence annual WULs at a subcatchment scale.

For the imminent review of the KI NRM Plan, the intention of the KI NRM Board is to define WULs across KI using a locally-validated "25% rule", a statewide policy position that aims to equitably share surface water resources in areas with only limited hydrological data, and consistent with "Method B" that was defined in the 2009 Plan. The application of this method requires a mechanism to calculate average yield in ungauged catchments, with the existing 2009 Plan using a single rainfall-runoff relationship (termed a "generalised" KI relationship) to estimate average subcatchment yield across KI. In the absence of long-term streamflow data from developed areas of KI, this relationship was derived from a time series of estimated annual inflows to Middle River Reservoir for 1970–92.

The analysis of recent streamflow gauge observations suggest that catchment yield in two of the more developed catchments on KI, Timber Creek and Cygnet River, may be considerably higher than is suggested by the "generalised" KI relationship that underpins the WULs in the 2009 Plan. Higher catchment yields would then equate to higher annual WULs, for given rainfall conditions. These two catchments are highly developed, with large proportions of land (over 70% of the Timber Creek catchment) being cleared since European settlement for dryland agriculture.

Conversely, the analysis of the streamflow gauge observations in the Stunsail Boom River and Rocky River, two catchments with high proportions of "natural" (uncleared) land, suggest a tendency for yield to be lower than would be estimated using the 2009 Plan "generalised" KI rainfall-runoff relationship. This variability in relationships between catchment yield and spatially-averaged rainfall across five streamflow gauges raises questions as to the appropriateness of using only a single rainfall-runoff relationship to calculate catchment yield across KI, and suggests a key role of land use type in determining total catchment yield.

The Rocky River streamflow gauge is the only long-term gauge on KI, with an almost complete record of daily flows available from 1974 onwards (almost 40 years of record). The next longest record of streamflow observations is from the Koala Lodge gauge at the downstream end of the Cygnet River, with a little over 10 years of flow data available since 2003. The Rocky River daily flow record was analysed alongside the flow records of 19 streamflow gauges in the Mt Lofty Ranges (some of which were longer than the Rocky River gauge) to determine the temporal variability in their catchment-specific rainfall-runoff relationships. With the 2009 Plan WULs having been calculated with reservoir inflow estimates for the period 1970–92, the impact of rainfall-runoff relationships for the period commencing 1993 was evaluated. This analysis showed that both the Rocky River and MLR records reflected a tendency towards lower yields in the period 1993–2013 than for periods ending 1992. An estimation of Rocky River rainfall-runoff relationships over the period 1974–2013 showed average annual yields were at least 10% lower, for given rainfall, than yields estimated for the period 1974–92. Generalised relationships for the MLR showed average yield reductions of approximately 14% when the period of analysis was extended from 1992 to 2013, although it should be noted that not all these flow records have the same record period.

It should be acknowledged that the most recent 20-year period has revealed generally lower catchment yields in both the Rocky River catchment in western KI and in streamflow catchments across the MLR. If WULs were re-calculated using a single generalised rainfall-runoff relationship for the period 1970–2013 (rather than 1970–92 as in the 2009 Plan), it is likely that lower WULs would be calculated across KI than values shown in the 2009 Plan.

Data validation is a process that considers some key characteristics of data series including fitness, accuracy and consistency. Although this study had the objective to validate WULs with local hydrological data, the short records of streamflow gauge observations from KI proves to be a limiting factor in confidently validating the rainfall-runoff relationships that calculate catchment yields at a subcatchment scale. It is clearly a benefit to hydrological analyses on KI for local streamflow data to be available for demonstrating the variability in streamflow generation processes. However the 4 years of good data at the Huxtable Forest gauge in the Cygnet River, and five years of record at the Timber Creek, are likely to be not long enough to sufficiently capture the expected variability in climatic influences on catchment yields. Flow records collected for a period that sufficiently represent the observed rainfall variability i.e. average, drier–than–average and wetter–than–average rainfall is required to adequately represent the climate influenced variability of catchment yields.

The short record of flows in the Timber Creek gauge do suggest much higher yields than would be estimated from rainfall-runoff relationships derived from the 2009 Plan Middle River Reservoir inflow sequence. However the derivation of a validated rainfall-runoff relationship for this catchment is difficult to provide with confidence, when using only 5 years of data. In an attempt to reduce the uncertainty in such relationships that are produced from short records, the rainfall-runoff observations at the two Cygnet River gauges were pooled with the Timber Creek observations to develop a combined relationship from which average catchment yield in these "developed" areas of KI could be calculated. This relationship was estimated from 19 data points, rather than the five available for Timber Creek alone, and suggested yields that were approximately twice the yield that would be calculated from the 2009 Plan generalised KI relationship. In this context, the use of the existing "generalised" KI relationship to calculate WULs in these catchments would be a conservative decision, as it may be defining less than 25% of the average yield in these catchments for watercourse extraction, although this would allow for uncertainties in the exact form of the rainfall-runoff relationship for these areas.

Another major area of uncertainty in the estimation of average yield in the gauged catchments on KI are those related to flow measurement. The refinement of stage-height relationships for streamflow gauges can only happen over a period of time, and for the Cygnet River and Timber Creek gauges, there is a real need for additional gaugings at medium-high flow rates to increase confidence in the estimates of flow rates. This is particularly relevant when attempting to define rainfall-runoff relationships for the calculation of average catchment yield and WULs. However in light of this, it should be noted that even if the theoretical rating curve for Timber Creek was over-estimating flow rates by 30%, the resulting yield estimates for this catchment would still be significantly higher than yields calculated from the existing "generalised" KI relationship.

In summary, this project presents the following options (Table 20) for the Board's consideration in the context of WULs and TFR policies in an imminent review of the KI NRM Plan. The resultant zone-by-zone WUL/TFR tables for potential inclusion in a revised NRM Plan can be developed when preferred options are clear. It should be emphasised here that other variations on the options presented below are also available, and can be explored in more detail at the Board's request.

Table 20 Summary of options for the calculation of WULs and TFRs on KI

Option	WUL calculation basis and data sources	TFR calculation basis and data sources	Potential eco-hydrological advantages	Potential eco-hydrological disadvantages
A Abolish Zone A and await longer local data sets	• Ex-Zone B WULs are unchanged • Zone A replaced with "Method B" WULs with same basis as ex-Zone B, i.e. rainfall-runoff curve derived from Middle River Reservoir water balance inflows, with similarity to pre-1992 MLR hydrological relationships	• Regionalised MLR UTFR-rainfall curve (from 2009 Plan) retained for all zones	• Consistent calculation procedure for all KI catchments	• No eco-hydrological basis for yield calculations • No reference to KI streamflow gaugings • No consideration of changes in recent rainfall on hydrology since 1992
A2 Abolish Zone A and include latest rainfall data for Zone B	• "Generalised-extended" rainfall-runoff function used for all catchments, i.e. extend TanH function used in 2009 Plan to include latest rainfall data	• Regionalised MLR UTFR-rainfall curve (from 2009 Plan) retained for all zones	• Consistent calculation procedure for all KI catchments • Impacts of rainfall recorded since 1992 are included in yield estimation	• No eco-hydrological basis for yield calculations • No reference to KI streamflow gaugings
B Abolish Zone A and use local data from most gauged catchments	• All available data from Cygnet River and Timber Creek gauges combined to derive a single "highly-developed area" rainfall-runoff function for Cygnet and Timber catchments • "Generalised-extended" rainfall-runoff function used for all other catchments, i.e. extend TanH function used in 2009 Plan to include latest rainfall data • Stunsail Boom River gauge data not used yet, due to insufficient data • Rocky River gauge data not used, as this is outside the Policy Area	• 10th percentile POE flows retained as UTFR • "Highly-developed area" UTFR-rainfall curve adopted for Cygnet River and Timber Creek catchments • Regionalised MLR UTFR-rainfall curve (from 2009 Plan) retained for other catchments	• Impacts of rainfall recorded since 1992 are included in yield and UTFR estimation • KI streamflow records included in yield and UTFR estimation • Some "highly-developed" but ungauged catchments will have yields and UTFRs under-estimated	• Some "less-developed" but ungauged catchments may have yields and UTFRs over-estimated (i.e. WULs may be greater than 25% of yield)
C Abolish Zone A and utilise local data across KI on a land use basis	• All available data from Cygnet River and Timber Creek gauges combined to derive a single rainfall-runoff function for <u>all</u> "highly-developed" catchments • "Generalised-extended" rainfall-runoff function used for all "less-developed" catchments (i.e. catchments with high proportions of uncleared land)	• 10th percentile POE flows retained as UTFR • "Highly-developed area" UTFR-rainfall curve adopted for all "highly-developed" catchments • Regionalised MLR UTFR-rainfall curve (from 2009 Plan) retained for all "less-developed" catchments	• Impacts of rainfall recorded since 1992 are included in yield and UTFR estimation • Yields and UTFRs of "highly developed" ungauged catchments consider increased runoff from cleared areas	• Some "less-developed" but ungauged catchments may have yields and UTFRs over-estimated (i.e. WULs will be greater than 25% of yield)

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PART 2 – Generalised environmental water requirements for key ecological assets

1 Introduction

A number of investigations of the aquatic ecology of KI have been undertaken previously, including macroinvertebrate monitoring, fish sampling and vegetation surveys. The objective of Part 2 of this report was to summarise the current knowledge of inland aquatic ecosystems of Kangaroo Island, and to provide qualitative environmental water requirements (EWRs) for the major functional biotic groups that are present. A number of databases were examined, including records from the South Australian Museum (SAM), South Australian Environment Protection Agency (EPA), and the South Australian Research and Development Institute (SARDI), amongst others (Table 21).

Table 21 Summary of the major ecological assessments that were analysed for this report

Study	Date	Author(s)	Organisation	Data collected	Data location
Fish Action Plan	2009	M. Hammer, S. Wedderburn, J. van Weenen	Aquasave/ DEH (incorporating SAM records)	Fish presence	Stored on DEWNR servers
Middle River fish survey	2009	D. McNeil, S. Fredburg	SARDI	Fish Presence/Length Data	SARDI Database
Rivers of Life	2006	T. Nilsen	KI NRM Board, DEH, DWLBC	Aerial Videography and Photography	Stored on DEWNR servers
AusRivAS	1994-2009	P. Goonan	EPA	Macroinvertebrate presence and abundance/ Water Quality and Habitat Data	EPA
Wetland Inventory Kangaroo Island	2002	R. Seaman	DEH	Wetland Information including Zooplankton and Fish	Unknown
Aquatic Ecosystem Condition	2008,2013	P. Goonan	EPA	Macroinvertebrate presence and ranked abundance/Water Quality and Habitat data	EPA servers
Community Ecological Survey	2014	D. Green	DEWNR	Presence of ecological assets	DEWNR/ Natural Resources KI

The largest datasets analysed as part of this study were those housed in the EPA macroinvertebrate sampling database and the Fish Action Plan's collection of fish data from SARDI, Aquasave and SAM records. Additional data sets were obtained from the DEWNR Fauna "supertables" of the Biological Databases of South Australia. These datasets were combined with results from a questionnaire sent to KI landholders as part of this project in April 2014, which sought site-specific information from landholders on KI regarding the identification and location of aquatic ecological assets. In addition, previously acquired aerial videography and aerial photography (Nilsen. 2006) were reviewed to identify areas of permanent water in some of the catchments. All data sets analysed in this study were consolidated into a single geodatabase and a series of layer files for spatial analysis of the ecological assets of KI.

Environmental water requirements (EWRs) may be described as the "water regime needed to sustain the ecological values of ecosystems, including their processes and biological diversity, at a low level of risk" (DWLBC, 2006). The functional output of this definition is generally a threshold attached to a hydrological metric for a given species or functional group. EWRs have been developed for a range of areas across South Australia by relevant experts who hypothesised critical hydrological thresholds beyond which the ecosystem would probably experience degradation. While area- and fauna-specific EWRs are desired for risk assessment purposes, generalised functional group EWRs from across South Australia provide a starting point for examining risks from water extractions and allocations to the aquatic ecological assets of KI.

2 Summary of assets

This section provides a general summary of the aquatic vegetation, fish and macroinvertebrates that have previously been identified. In addition to these assets, KI also supports other water dependent fauna, including six species of frog that occur in catchments with low to moderate salinity levels (Nilsen, 2006). There is also a self-sustaining population of Platypus (*Ornithorhynchus anatinus*) that were introduced from Tasmania in the past and are found in the western rivers of the island, most notably in Rocky River (Nilsen, 2006).

2.1 Fish

2.1.1 Summary of avaliable data

There are two major sources of information about inland fish. The Fish Action Plan (Hammer *et al.*, 2009) provides a summary of all fish data collected from KI up to the mid-2000s, including SAM records and data from surveys undertaken by Aquasave and by M. Hammer with community groups. In addition, fish data from a 2009 survey of the Middle River Catchment undertaken by SARDI was reviewed.

2.1.2 Assessment of data quality

Previous fish surveys have provided wide spatial coverage of KI, with each of the major catchments being surveyed on multiple occasions (Figure 35). Data collected for the Fish Action Plan (Hammer *et al.*, 2009) is limited to species presence only, with no information about numbers or size of fish caught. These data are very spatially representative, with species considered to have been identified accurately, with the exception of some of SAM records (e.g. the presence of Mountain Galaxias and River Blackfish have been questioned by the author [M. Hammer, pers. comm.]). The trapping methods employed for these surveys were not recorded, although these were assumed to be a combination of seine netting, bait trapping and electro-fishing. This means that fish presence is the only information that can be used from these survey data.

The 2009 SARDI survey was limited to the Middle River catchment, however this survey provided more detailed information that included accurate species identification, fish count and length data. This additional information is useful for species population analyses and fish community health assessments. The sampling methods employed for this survey were standard comprehensive SARDI methods that included the use of fyke nets set over 24-hour periods.

Survey questionnaires sent to the public as part of this project provided some high-level information that was generally limited to the presence of fish, with some responses including species identification that often cited common names (e.g. "Muddies", which were assumed to be Climbing Galaxias). Several records of alien species (e.g. Rainbow Trout) were also provided that are probably accurate but require further field verification to confirm their presence in various subcatchments.

2.1.3 Summary of ecological community

A total of 15 species of fish have been recorded from rivers and estuaries of KI (Table 22). Historical fish data identified two dominant species, the Common Galaxias (*Galaxias maculatus*) and Climbing Galaxias (*Galaxias brevipinnis*), with both found in all major surface water catchments on the island with the exception of Timber Creek (SARDI Data, Hammer *et al.*, 1999). Both fish species are diadromous (migratory between fresh and salt water) and therefore their absence from Timber Creek, which drains into Murray Lagoon, is probably due to its lack of connection to the ocean (McNeil and Hammer, 2007). The widespread distribution of these species indicates that there are limited barriers to upstream dispersal, with the Climbing Galaxias being able to reach the plateau on the western side of KI. The Common Galaxias has inferior climbing ability and is limited to higher order watercourses below the plateau.

The Climbing Galaxias population in Middle River shows that this species can persist in some locations without a seaward connection, presumably using the Middle River Reservoir as a surrogate for the ocean (McNeil and Fredberd, 2010).

The Western Blue Spot Goby (*Pseudogobius olorum*) is another freshwater species that is relatively widespread across KI. This species is generally restricted to the areas near river mouths (McNeil and Hammer, 2007) but can be found further upstream in high numbers. On KI, it is restricted to the higher order streams closer to estuarine environments with the exception of the more saline Cygnet and Wilson Rivers where it is found further upstream.

Smaller numbers of other fish species are present across the estuaries of KI. These estuaries harbour some of the most diverse fish communities in South Australia, in contrast with other estuarine areas of the State that are affected by habitat degradation and reduced water level fluctuations, characteristics that McNeil and Hammer (2007) suggested were important for supporting estuarine fish. Species of fish previously found in estuaries of KI include the Lagoon Goby (*Tasmanogobius lasti*), Smallmouth Hardyhead (*Atherinosoma microstoma*), Southern Black Bream (*Acanthopagrus butcheri*), Tamar Goby (*Afuragobius tamarensis*), Bridled Goby (*Arenigobius bifrenatus*), Australian Herring (*Arripis georgianus*) and juvenile Mullet (Family: *Mugilidae*). Baker (2004) identified several marine species in the estuaries and lagoons of KI, including Eel Blenny (*Peronedys anguillaris*) and King George Whiting (*Sillagnodes punctata*). The Short Finned Eel (*Anguilla australis*) has also been found in limited numbers, mostly around the coast and in the lower reaches of the larger rivers, most recently captured in the Lower South West River and Stunsail Boom River (data supporting Hammer *et al.*, 2009).

The South Australian Museum has records of Pouched Lamprey (*Geotria australis*) and Mountain Galaxias (*Galaxias olidus*) on KI. It is probable that Pouched Lamprey could use KI watercourses for the freshwater portion of their life cycle, however this species is currently very rare in South Australia and has not been captured in any recent sampling on KI in the past few decades. The Mountain Galaxias is a relatively robust species that lives its entire lifecycle in headwater streams (McNeil and Hammer, 2007). Although there are habitats on KI that may be suitable to support Mountain Galaxias, a lack of records or confirmed observations in recent years, indicates that this South Australian Museum record was probably a misidentified Climbing Galaxias.

There are only limited number of records of introduced fish species on KI; all were records of Rainbow Trout (*Oncorhynchus mykiss*) that appears to be limited to the Middle River catchment. Community survey responses suggested that Rainbow Trout have also been introduced to De Mole and possibly the Cygnet River catchments. Rainbow Trout are known to predate heavily on Galaxias species (Lintermans, 2000) so ongoing monitoring and management of Rainbow Trout populations should be carried out to minimise the impact of this species upon native fish populations on KI.

Table 22 Native fish species recorded from rivers and estuaries

Record	Common name	Species	Functional group	Source
Recent	Climbing Galaxias	*Galaxias brevipinnis*	Diadromous	SARDI, Hammer *et al.* 1999
	Common Galaxias	*Galaxias maculatus*	Diadromous	SARDI, Hammer *et al.* 1999
	Smallmouth Hardyhead	*Atherinosoma microstoma*	Estuarine	SARDI, Hammer *et al.* 1999
	Southern Black Bream	*Acanthopagrus butcheri*	Estuarine	SARDI, Hammer *et al.* 1999
	Lagoon Goby	*Tasmanogobius lasti*	Estuarine	SARDI, Hammer *et al.* 1999
	Tamar Goby	*Afuragobius tamarensis*	Estuarine	SARDI, Hammer *et al.* 1999
	Bridled Goby	*Arenigobius bifrenatus*	Estuarine	SARDI, Hammer *et al.* 1999
	Western Blue Spot Goby	*Pseudogobius olorum*	Wetland specialised/ Estuarine	SARDI, Hammer *et al.* 1999
	Australian Herring	*Arripis georgianus*	Estuarine	SARDI, Hammer *et al.* 1999
	Juvenile Mullet	*Family: Mugilidae*	Estuarine	SARDI, Hammer *et al.* 1999
	Ellblenny	*Peronedys anguillaris*	Marine	Baker 2004
	King George Whiting	*Sillagnodes punctata*	Marine	Baker 2004
	Short Finned Eel	*Anguilla australis*	Diadromous	SA Museum
Historic	Pouched Lamprey	*Geotria australis*	Diadromous	SA Museum
	Mountain Galaxias*	*Galaxias olidus*	Stream specialised	SA Museum

*Suspect record of this species on the island

2.1.4 Gaps and knowledge deficiencies

There are knowledge gaps associated with three types of fish information for KI. The first of these concerns data acquisition, including both count and length data, as provided in the SARDI survey for the Middle River catchment. This data provides a clearer picture of the community health (e.g. recruitment levels and trophic interactions) than presence-only data but is currently limited to the Middle River catchment.

The second knowledge gap concerns a lack of quantitative fish data in proximity to streamflow gauging and water quality monitoring stations. Current trends in EWR development involves a move away from setting expert-derived thresholds towards developing empirical response models, however, this requires fish, streamflow and water quality data collected from the same general location on targeted streams.

The third main knowledge gap concerns establishing relationships between flow regimes and the ecology of the estuarine areas of KI. These areas are known to maintain a high diversity of fish (14 species of fish have been documented), however, the potential impacts on estuarine communities of changes to the flow regimes of KI watercourses area is currently unknown. A better understanding of the relationship between ecological communities and flow regimes of estuaries is consequently required.

Finally, the presence, distribution and population structure of some of the rarer fish species on KI are currently unknown. For example, Pouched Lamprey, Short finned Eel and River Blackfish have all been recorded on KI, either anecdotally or as part of a sampling program. Knowledge gaps relating to the presence of these fish presents a risk to water management on KI.

2.1.5 Future investment opportunities

In order to address knowledge gaps with respect to fish species on KI, it is proposed that the first priority for any future fish monitoring on mainland KI would be the development of a time series dataset linked to flow records at key locations, for the purpose of assessing temporal variability in populations in response to flow changes. These data are absent across much of South Australia and are vital for linking the response behaviour of fish to the hydrological environment.

The second priority would be to investigate the distribution of some of the rarer fish species on KI such as the Short Finned Eel and the Pouched Lamprey. This would involve targeted sampling during a specific time of the year in order to catch fish migrating upstream, rather than opportunistic catching in the inland area of KI. Targeted sampling to establish the presence and distribution of these rarer fish should enable a better understanding of the risk profile of these fish communities.

Finally, an investigation into the ecology of the KI estuaries, and their responses to changes in flow regimes would inform the quantification of risks to these systems.

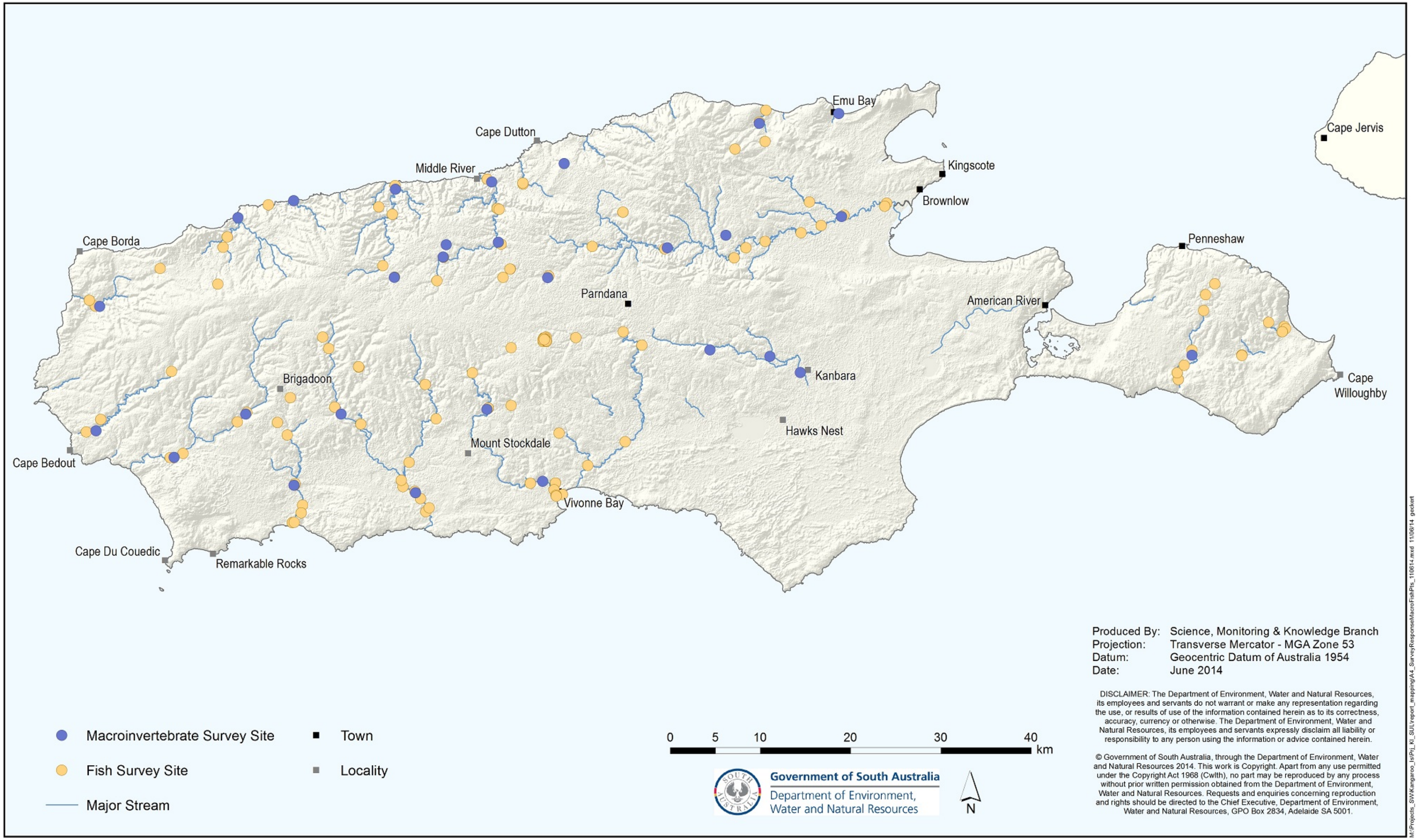

Figure 35 Previous fish and macroinvertebrate survey sites

2.2 Macroinvertebrates

2.2.1 Summary of avaliable data

There are three main sources of macroinvertebrate data relating to KI. The first source of data is the AusRivAS sampling that was undertaken as part of the statewide AusRivAS program from 1994–2007. A selection of sites were made across the island from 1994–95, and again from 1997 to 2007; samples were generally taken in autumn and spring of just the one year sampled, although several sites were sampled repeatedly. Following the completion of the AusRivAS program, the EPA's aquatic ecosystem monitoring program has twice included KI (2008 and 2013). In addition to these data, a separate study of KI wetlands was undertaken in 2002 (Seaman, 2002), focusing on 14 lagoons and wetlands near the Timber Creek Catchment. All previous macroinvertebrate sampling sites are shown in Figure 35 (excluding wetland and lagoon sites as these were not these locations were not recorded) and summarised in Table 23.

2.2.2 Assessment of data quality

Both the AusRivAS and aquatic ecosystem monitoring data include species identification wherever possible and either laboratory estimated counts in the earlier work and ranked abundance estimates from the most recent field based assessments at all survey sites. The species identification is considered to be accurate, and although the count data include subsampled and categorical estimates, these are also considered to be adequate.

Seaman (2002) provides only limited information with regards to sampling methodology, or identification of samples taken during the 2002 survey of KI wetlands, although specimens were identified to either genus or species, where applicable. This study suggested the use of a condition rating system that was based on number of families present and trophic levels. This proposed rating system differs from other commonly-used macroinvertebrate rating systems and likely overestimate the health of these systems, although many rating systems are designed for rivers rather than wetlands.

2.2.3 Summary of ecological community

Macroinvertebrate surveys of watercourses have identified tolerant, generalist species from nutrient enriched streams and rare and sensitive species from more natural streams from the western end of the island. Surveys undertaken since 2007 have used the EPA's aquatic ecosystem condition reporting methods (http://www.epa.sa.gov.au/reports_water/ki_creeks-ecosystem-2008, EPA, 2014). A diverse range of macroinvertebrate species have been sampled with the most abundant being chironomids (*Chironomidae*), Water Scud (*Austrochiltonia*), and water beetles. There are also records of several sensitive and/or rare species, including scorpionfly larvae (*Nannochorista*), stoneflies (*Newmanoperla thoreyi, Austrocerca tasmanica, Illiesoperla mayi, Riekoperla naso*), mayflies (*Centroptilum elongatum, Atalophlebia, Thraulophlebia inconspicua, Nousia fuscula*), caddisflies (*Apsilochorema gisbum, Tasimia*, *Orthotrichia bishopi, Oxyethira columba, Lingora, Atriplectides dubius*), uncommon chironomids (*Stempellina* and *Podonomopsis*) and riffle beetle larvae (*Kingolus*).

Sampling of six watercourses in 2008 identified high nutrient levels at each location, an expected result for catchments with agricultural development, but not expected for Breakneck River, which lies entirely within Flinders Chase National Park. Elevated nutrient levels at this site were thought to have resulted from a recent bushfire that occurred in the catchment. The western part of KI has higher rainfall and is less affected by surface water salinity, and as noted above, supports a more diverse suite of macroinvertebrate species. Many rivers on the eastern side of KI were assigned "poor" ratings in the EPA's aquatic ecosystem condition reports due to increased nutrient levels and higher salinity.

Sampling results from 2013 were similar to those from 2008, with many sites showing high nutrient levels and higher than expected salinity. The 2013 survey included 31 sites on KI that were visited in both autumn and spring. A majority of these sites had been previously sampled for macroinvertebrates, and only one site was dry in both seasons. The EPA results show that most sites have maintained a generally "fair" or "poor" rating, which is unsurprising given the ecological condition of a majority of KI rivers has remained unchanged. Only a few streams (20% of sites) from the well vegetated western end of the island were assigned "very good" or "good" ratings.

Recent sampling results have shown a continuing prevalence of introduced macroinvertebrates. The introduced Marron (*Cherax tenuimanus*) has colonised all major catchments across KI apart from the more saline streams such as Timber Creek (Nielsen, 2006). The interactions of Marron with the native macroinvertebrate and aquatic plant food web are not well understood, therefore the implications of its ongoing presence on the island are unknown. Marron are thought to compete with other large crustaceans such as the native Yabby (*Cherax destructor*), and have high fecundity and can reach very high densities under ideal conditions (Beatty, 2006). The New Zealand Pond Snail (*Potamopyrgus antipodarum*) is another introduced species that has been found across KI. This small bodied snail also has the ability to reproduce quickly and reach large numbers, particularly in flowing brackish and saline habitats, but it is unclear whether it competes with other native snails.

Wetlands on KI include freshwater and saline swamp and lake habitats (Seaman 2002), and each supports distinctive communities of zooplankton and macroinvertebrates. The species that were identified in the 2002 survey were all relatively common species on the island and southern parts of the State (c.f. appendix in Seaman (2002)).

2.2.4 Gaps and knowledge deficiencies

Previous macroinvertebrate sampling at benchmark locations revealed little change in the abundance and presence of macroinvertebrates over time, although there is only limited understanding about the macroinvertebrate health outside these sites. The EPA has recently revised their sampling approach to focus on different sites every five years as a means to increase the spatial distribution of ecological condition assessments on the island. The EPA also plans to continue to sample a small number of fixed sites and incorporate randomly selected sites in order to be able to extrapolate the results throughout the island in the future.

2.2.5 Future investment opportunities

Where possible, future macroinvertebrate data should be paired with additional data, particularly flow observations to assist the process of characterising EWRs across KI. The EPA sampling currently includes water quality and another approximately 250 habitat, vegetation and sediment metrics, and estimated flow metrics with each survey carried out providing time and site specific information. For the development of response models, links to longer term flow and water quality data are required.

The characterisation of thresholds in flow, water quality (salinity in particular) and other abiotic factors is probably going to be the most effective means to identify key management actions for the maintenance and protection of significant macroinvertebrate communities and the ecological processes that support them. To assist this process, investigations could be targeted at specific groups of taxa (e.g. flow dependent mayflies, stoneflies, caddisflies and some dipterans) and involve more regular sampling programs and testing specific hypotheses about key taxa.

Table 23 Previous macroinvertebrate sampling sites

Sampling site ID	Location	Sampling year	Agency
West Bay Rd	Breakneck River	2008	EPA
11.5 km NW from NPWS Hdqters	Breakneck River	2013	EPA
E from 'Woodleigh'	Chapman River	2013	EPA
U/s estuary	Chapman River	2013	EPA
SW from Lashmar Lagoon	Chapman River	2013	EPA
Bhutt Creek Rd	Cygnet River	1994-2007	EPA
Streaky Bay Rd	Cygnet River	1994-2008	EPA
W from Parndana	Cygnet River	2013	EPA
Koala Lodge Flow Gauging Station	Cygnet River	2013	EPA
Huxtable Forest GS	Cygnet River	2013	EPA
U/s estuary in lower catchment	De Mole River	2013	EPA
South Coast Rd	Eleanor River	2008	EPA
U/s estuary in lower catchment	Emu Bay Creek	2013	EPA
E-W Hwy	Harriet River	2008	EPA
W from 'Vivonne Heights'	Harriet River	2013	EPA
NE from Mount Taylor	Harriet River	2013	EPA
Ncoast Rd	King George Creek	2008	EPA
N from Murray Lagoon	Little Timber Creek	2013	EPA
Playford Hwy	Middle River	1994-2009	EPA
U/s Lagoon Flat	Middle River	2013	EPA
NNW from Gosse	Middle River	2013	EPA
N from 'Bangor'	Middle River	2013	EPA
U/s from Middle River Dam	Middle River	2013	EPA
N from Karatta	North West River	2013	EPA
S from Cape Borda	Ravine des Casoars	2013	EPA
Snake Lagoon Trk	Rocky River	1994-2009	EPA
3km west from NPWS Hdqters	Rocky River	2013	EPA
E branch, Flinders Chase	Rocky River	2013	EPA
SW from Smith Beach	Smith Creek	2013	EPA
U/s estuary in lower catchment	Snug Cove Creek	2013	EPA
W from Kelly Lodge	South West River	2013	EPA
SW from Stokes Bay	Springy Water Creek	2013	EPA
South Coast Rd	Stunsail Boom River	2008	EPA
Stunsail Boom GS	Stunsail Boom River	2013	EPA
South Coast Rd	Timber Creek	2008	EPA
Timber Creek GS	Timber Creek	2013	EPA
SE from Parndana	Timber Creek	2013	EPA
NE Pardarna Consv Park	Tributary of Cygnet River	2013	EPA
N from 'Bangor'	Tributary of Middle River	2013	EPA
U/s estuary	Western River	2013	EPA
W from 'Woodleigh'	Wilson River	2013	EPA
WilsonR Rd	Wilson River	1994-2009	EPA
Wetland	Breakneck River	2002	DEH
Lagoon	Discovery Lagoon	2002	DEH
Lagoon	Six Mile Lagoon	2002	DEH
Lagoon	Six Mile Lagoon 2	2002	DEH
Lagoon	Salt Lagoon	2002	DEH

Sampling site ID	Location	Sampling year	Agency
Lagoon	Rush Lagoon	2002	DEH
Lagoon	Grassdale Lagoon	2002	DEH
Lagoon	Duck Lagoon	2002	DEH
Lagoon	Cygnet River Lagoon	2002	DEH
Lagoon	Big While Salt Lagoon	2002	DEH
Lagoon	Greenfields Lagoon	2002	DEH
Swamp	Emanual Swamp	2002	DEH
Lagoon	Lashmar Lagoon	2002	DEH
Lake	Salt Lake	2002	DEH
Lagoon	White Lagoon 1	2002	DEH
Lagoon	Nepean Bay Lagoon	2002	DEH
Lake	Milky's Lake	2002	DEH
Swamp	Destree Swamp	2002	DEH
Lagoon	Wangara Lagoon	2002	DEH
Lake	Salt Lake 2	2002	DEH
Lagoon	Murrays Lagoon	2002	DEH
Lagoon	White Lagoon	2002	DEH
Lagoon	White Lagoon	2002	DEH
Swamp	Halls Road Swamp	2002	DEH
Lagoon	Birchmore Lagoon	2002	DEH

2.3 Aquatic and riparian vegetation

2.3.1 Summary of avaliable data

The most comprehensive survey of riparian vegetation on KI was undertaken as part of the Rivers of Life project (Nilsen, 2006). This report used aerial videography and photography taken in 2005 and 2006 to examine the extent and condition of the riparian vegetation across six of the major catchments on KI: Rocky River, Cygnet River, Middle River, Harriet River, Timber Creek and Wilson River. These data were also used to characterise flow regimes and in-stream structures, with vegetation species identified through site visits.

Site specific data from the EPA Condition Assessments (EPA 2014) also provide information on major species present as well as the presence of any weeds.

2.3.2 Assessment of data quality

Vegetation data provided in Nilsen (2006) is extensive, covering most 3rd- and higher-order rivers on KI, however there is only limited information provided on flow regimes and in-stream structures, predominantly due to shading provided by the vegetation overstorey. Although Nilsen (2006) did not identify vegetation species, it is assumed that most of the wider section of riparian vegetation included relatively intact remnant vegetation.

The EPA condition assessments provide site specific information for sites used in their condition assessments. These reports detail major plant groups present (percentage cover) and the presence of weeds. While not specifically intended as vegetation surveys, they allow for limited interpretation of the vegetation community.

2.3.3 Summary of ecological community

Vegetation surveys for the Rivers of Life project (Nilsen, 2006) assessed riparian vegetation as being in relatively good condition, with at least half the surveyed watercourse length having more than 15 m width of riparian vegetation and less than

10% of the watercourse length being totally bare banked. The survey attempted to document the presence of in-stream vegetation and sedges, however this was hampered by large trees obscuring the understory vegetation.

A majority of remnant riparian vegetation are woodland trees dominated by large eucalypts, including River Red Gums (*Eucalyptus camaldulensis*) and Sugar Gums (*Eucalyptus cladocalyx*). There are also sections of watercourse, particularly in the western and southern parts of KI that pass through Mallee. Understory vegetation varies considerably across KI with both rainfall and topography; watercourses on the eastern side of KI generally have sedges (*Cyperus sp*.), rushes (*Juncus sp*.) and reeds (*Typha sp*.), with pockets of ferns generally found in the higher rainfall areas, while the riparian understory of the western catchments is more commonly dominated by ferns, with sedges, rushes and reeds less common. Coral fern (*Gleichenia sp*.) and Bracken (*Pteridium sp*.) often form dense stands, particularly in the higher rainfall areas. In-stream vegetation is typically dominated by Water Ribbon (*Triglochin sp*.) with limited growths of other species. The exception is the Cygnet River, in which no submerged aquatic vegetation was observed during the last survey.

Historical survey data suggest a distinct change in the level of remnant vegetation (particularly riparian vegetation) between the east and west sides of KI (Nilsen, 2006), which corresponds to patterns in macroinvertebrate and water quality data collected by the EPA (EPA, 2014). In addition, historical survey data does not suggest a presence of weeds of national significance or species of conservation concern across KI, though these ratings are subject to review.

2.3.4 Gaps and knowledge deficiencies

The extent of the riparian vegetation is well understood across the major surface water catchments on KI, and this level of understanding compares well to other areas of South Australia. Outside the major catchments, however, there is only a limited understanding of both the health and structural diversity of riparian vegetation, and the distribution of introduced plant species, which represents a significant knowledge gap. This information is routinely collected by the EPA in the condition assessments; however, the spatial scale of this collection is very limited.

2.3.5 Future investment opportunities

The development of vegetation response models, and ultimately the characterisation of environmental water requirements (EWRs) on KI would be assisted through additional vegetation surveys undertaken at selected sites across KI. Future surveys should target information including relationships between vegetation functional group/species and water depth, periods of inundation and cease-to-flow points in KI watercourses. In addition, this information would enable an assessment of the movement of plant communities in response to changes in flow regime. Auble *et al.* (1994) describe a method using inundation periods and functional groups to model vegetation responses that is suitable for developing response models, and is therefore applicable to KI.

Targeted investigations are also required to develop an improved conceptual understanding of the drivers of poor water quality, in order to define the role of riparian vegetation buffer zones, which are present across many catchments (Nilsen, 2006), to improve surface water quality.

2.4 Water quality

2.4.1 Summary of avaliable data

Water quality data for KI is provided through a number of different sources. The primary source of this information is streamflow monitoring data (that includes salinity) from five streamflow monitoring sites across KI (the Timber Creek, Stunsail Boom River, Cygnet River-Koala Lodge and Cygnet River-Huxtable Forest gauging stations, and Harriet River). The second source of water quality data is the EPA's aquatic ecosystem monitoring database, with point samples of water quality taken alongside macroinvertebrate samples. Water quality measurements from individual projects (e.g. Nilsen, 2006 and Seaman, 2002) are also available for analysis.

2.4.2 Assessment of data quality

In-stream salinity measurements at streamflow gauging stations across KI are considered to be good quality, and suitable for understanding trends in salinity over time. The time series of daily mean corrected EC (see Figure 36, Figure 37 and Figure 38) have significant periods of missing data, many of which correspond to periods of low or zero flow in these watercourses. The EPA point sampling data is considered a reliable indicator of trends in watercourse salinity and water quality, though care needs to be taken that localised, site specific readings are reflecting overall trends to ensure validity of data.

2.4.3 Historical water quality

Water quality measurements show the monitored watercourses on KI are more saline than many watercourses in the Mt Lofty Ranges, and also demonstrate a pattern of salinity increasing from West to East across KI. Figure 36 shows a time series of corrected EC for Stunsail Boom River (A5131007) for the period 2010–13, which shows a distinct seasonal pattern in salinity that reduces in the high-flow periods, with average corrected EC (for non-missing data) of 2,654 µS/cm. Water quality data recorded at the Koala Lodge gauge (A5131014) on the Cygnet River also reveals a seasonal pattern of salinity (Figure 37), however the average corrected EC value for this period (for non-missing data) is considerably higher (6,701 µS/cm) than Stunsail Boom River. There is less missing data in the Koala Lodge record, which may indicate that the measuring equipment at this gauge has been more reliable than at the Stunsail Boom River gauge. Figure 38 shows a time series of mean daily corrected EC for Timber Creek, which although shows a similar seasonal pattern, also shows the highest average daily salinity for these streams (13,470 µS/cm).

While there is no daily corrected EC data for Rocky River, the EPA's point sample records suggests that this has some of the freshest surface water on KI with EC levels recorded around 500 µS/cm.

Watercourse salinity levels shown in Figure 36, Figure 37 and Figure 38 are high enough to preclude many freshwater species, and may explain an absence of obligate freshwater fish from surveys on KI.

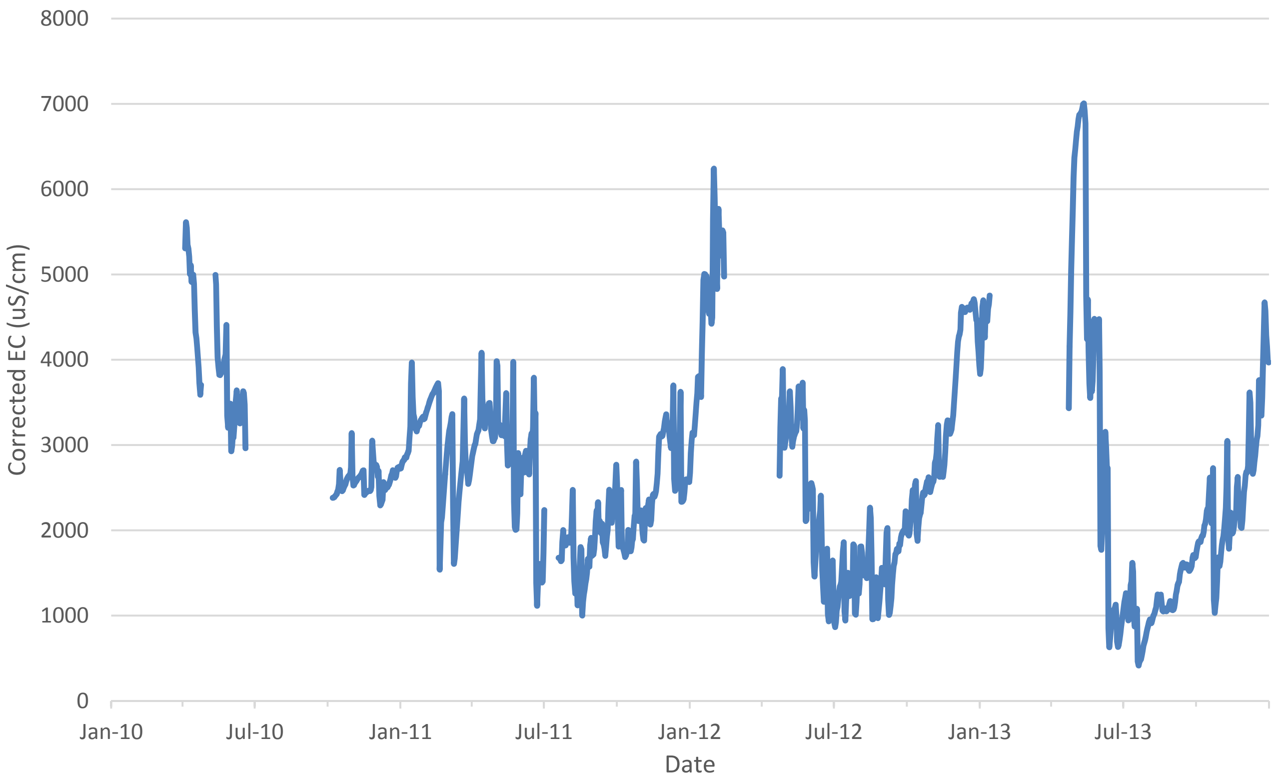

Figure 36 Daily mean corrected EC for Stunsail Boom River (A5131007) for 2010–13

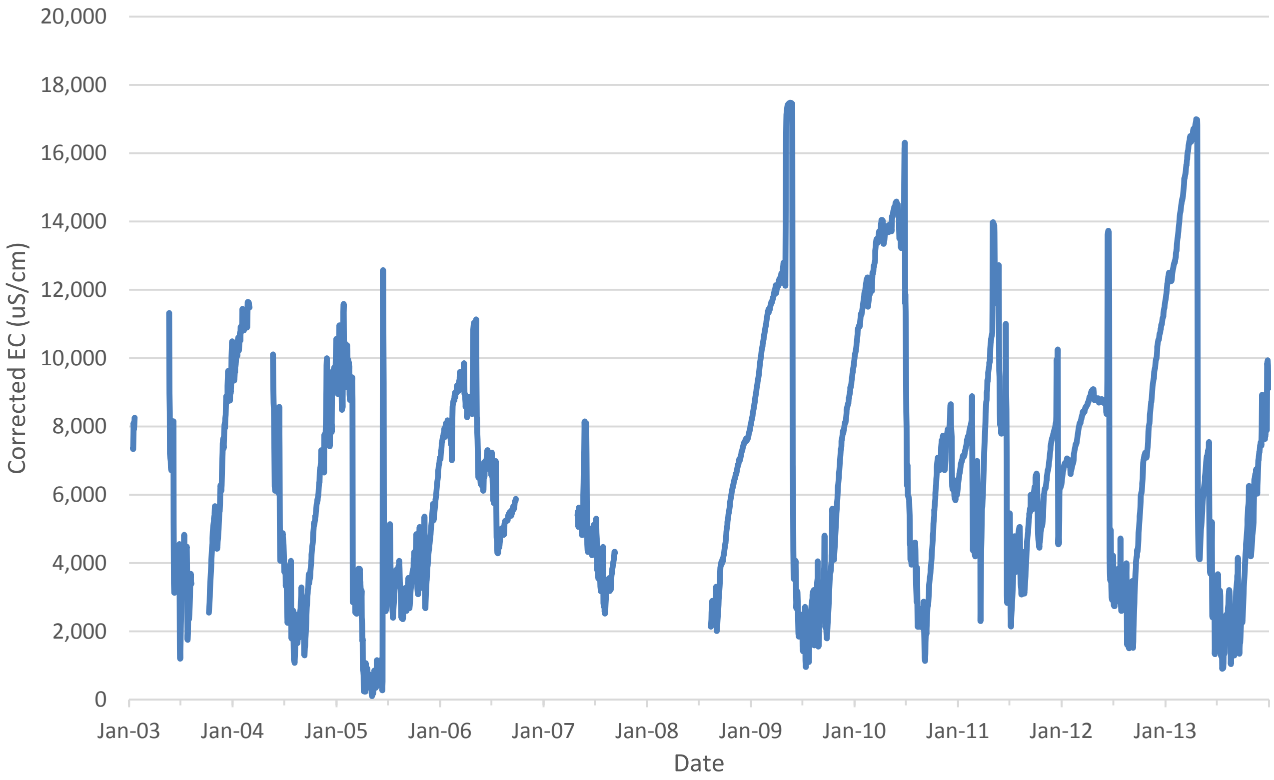

Figure 37 Daily mean corrected EC for the Koala Lodge streamflow gauging station on Cygnet River (A5131014) for 2003–13

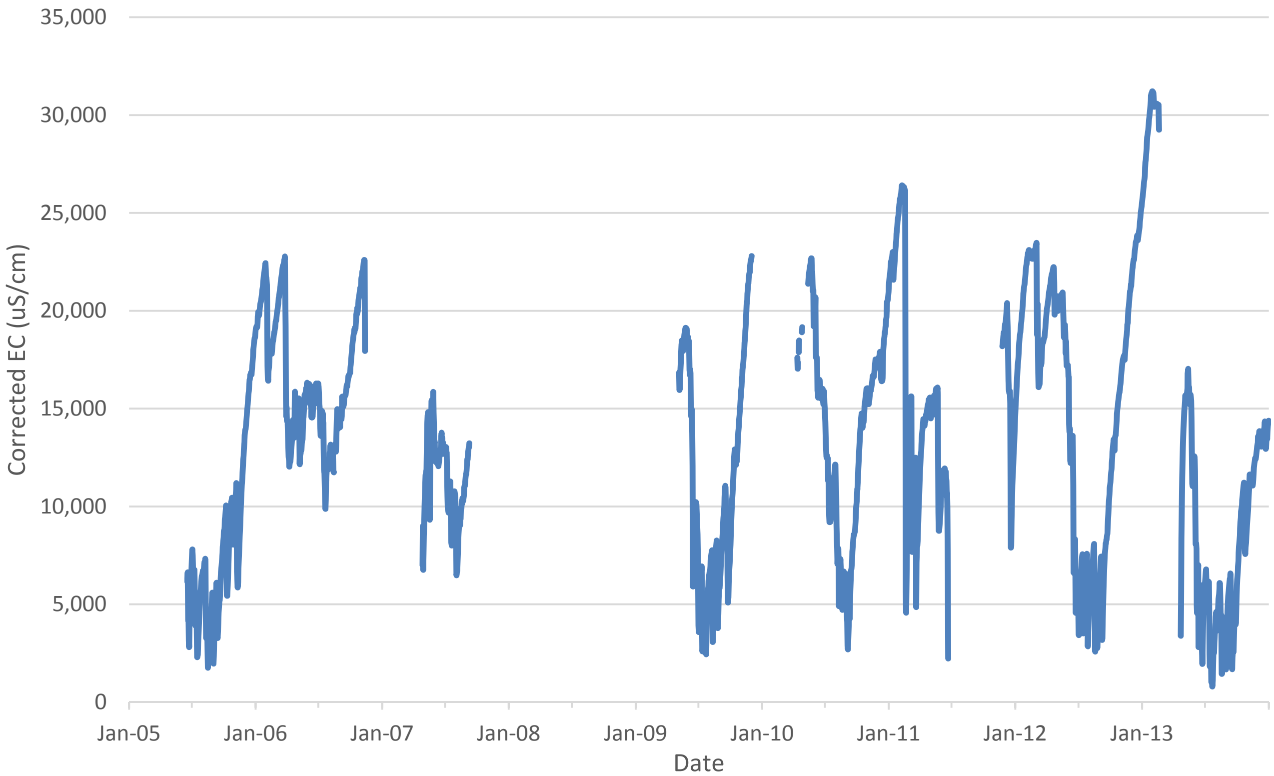

Figure 38 Daily mean corrected EC for the Timber Creek streamflow gauging station (A5131002) for 2005–13

2.4.4 Gaps and knowledge deficiencies

There is only limited understanding about the historical salinity levels of KI watercourses, with Nilsen (2006) noting that natural surface water salinity may have been exacerbated by land clearing since European settlement. Although water quality monitoring at streamflow gauging stations have provided good records of daily changes in surface water salinities of these monitored watercourses, there is very little information regarding salinity levels of other KI watercourses. It is very difficult to interpolate salinity and water quality levels across catchments. While there may be sufficient data to develop preliminary relationships between ecological response and water quality, there is little to compare these relationships to in many cases.

2.4.5 Future investment opportunities

Water quality data from DEWNR streamflow monitoring stations, together with EPA reporting has provided a useful description of in-stream salinity across KI. However the acquisition of salinty data for additional watercourses on KI would further assist the process of relating the health and diversity of water-dependent ecosystems to changes in salinity. As noted in Part 2, Section 2.3.5, additional salinity data is also vital to determine the role of riparian vegetation buffer zones in improving salinity, and overall water quality.

3 Generalised environmental water requirements (EWRs)

Environmental water requirements (EWRs) are defined as the water regime needed to sustain the ecological values of ecosystems, including their processes and biological diversity, at a low level of risk (DWLBC, 2006). The functional output of this definition is generally a threshold that is attached to a flow band (water depth) for a given species or functional group. Figure 39 (after Favier *et al.*, 2004) provides a schematic representation of the key flow bands and typical functions in relation to a cross-section of a watercourse.

An investigation in 2010 into the EWRs for fish in Middle River (McNeil and Fredberd, 2010) is the only study into EWRs of native fauna on KI. The outcomes of this 2010 report were used in conjunction with EWR reports from other South Australian regions to hypothesise some broad EWRs that may be relevant for vegetation, fish and macroinvertebrates that occur on KI. The application of site-specific EWRs to a particular catchment, sub-catchment or management zone will ultimately be dictated by the presence of specific functional groups (for fish and vegetation), or the presence of specific habitat types (for macroinvertebrates) in that area. EWRs for frogs and platypus have yet to be documented (including in Tasmania), however EWRs for vegetation, fish and macroinvertebrate functional groups may also cover the EWRs for frogs and platypus. However given that platypus is an introduced species to KI, with a range that is limited to National Park areas, EWRs for this species may not be applicable.

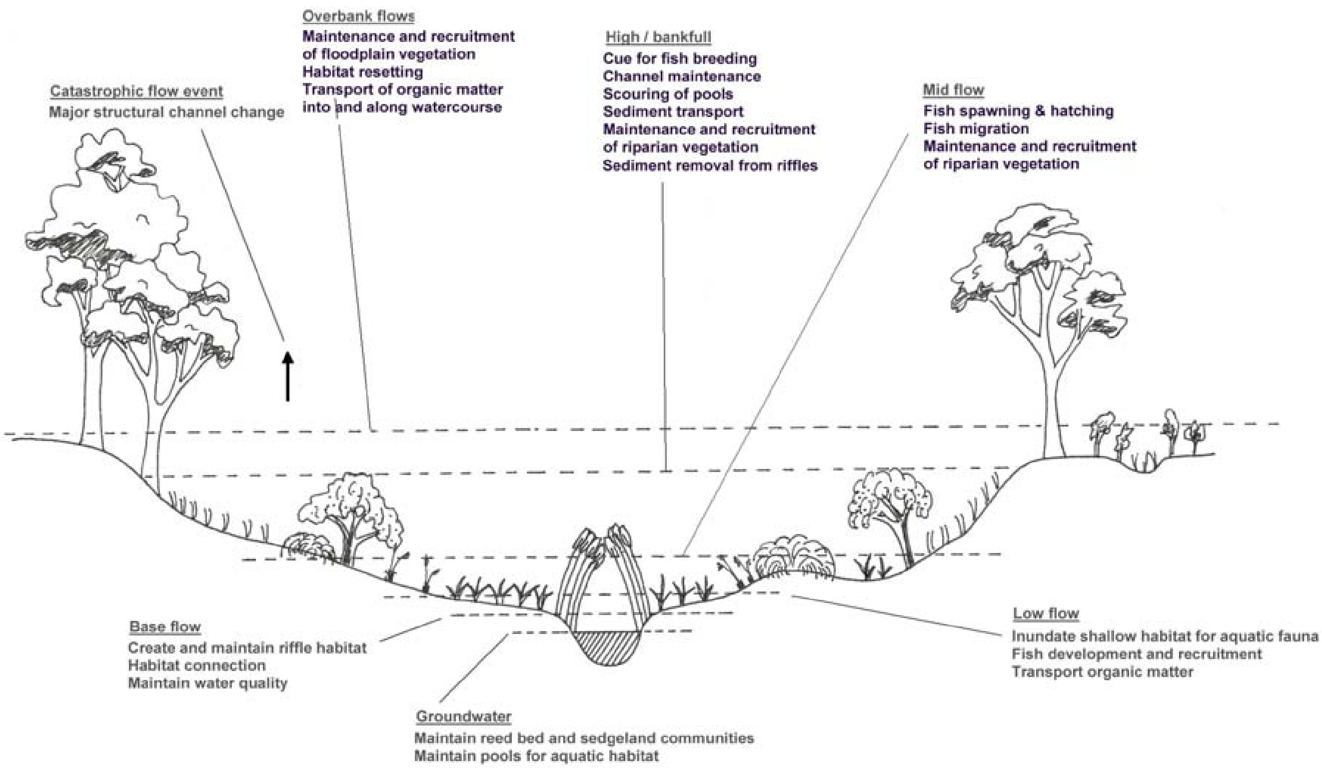

Figure 39 Common environmental water requirement processes linked to flow magnitudes (after Favier *et al.*, 2004)

The EWRs presented in this section are generalised EWRs that have been developed through previous investigations, and not specific to KI. These EWRs are generally based on expert opinion and are not validated to KI conditions, although targeted site investigations can reduce the inherent uncertainty through the development of ecological response models. These EWRs are designed around thresholds that deliver a "pass/fail" result, rather than reflecting a changing risk profile for ecological systems in response to changes in water regimes that is provided by ecological response models. Although some thresholds do exist in ecology, they are not generally identified and described using a pass/fail assessment (e.g. Groffman *et al.*, 2006).

The generalised EWRs presented in this section mostly relate to a particular flow regime during a particular season for a given time. These metrics are a simple representation of a complex interaction between flow and ecology, but do not cover all aspects of maintaining a viable ecological community. As such, these generalised EWRs should be viewed as a first step towards a more in-depth assessment of water dependent ecosystem requirements. It should be noted that the generalised EWRs are presented for fish, macroinvertebrates and vegetation separately, and therefore there may be conflicting results across biotic groups.

3.1 Fish

There are three functional groups of fish on KI; diadromous migratory species (Climbing Galaxias, Common Galaxias, Short Finned Eel and Pouched Lamprey), wetland specialised species (Western Blue Spot Goby) and obligate freshwater species (exotic Rainbow Trout). Diadromous species need to migrate from the ocean to riverine environments for reproduction, wetland specialised species require fluctuating water levels and flow for migration and stream specialised species require variable flow regimes for reproduction and dispersal.

Table 24, Table 25 and Table 26 summarise generalised EWRs for these three functional groups that have been previously documented in southern Australia through over 20 separate EWR investigations. Several of these reports are detailed from investigations undertaken on KI and represent the highest confidence for EWRs, particularly those for the diadromous fish. These EWRs from outside KI will need to be verified, and possibly adjusted, for their application to KI, through the use of local knowledge and expert opinion. There are also a number of estuarine species present on KI for which EWRs have yet to be documented. It should be noted that the EWRs for the exotic Rainbow Trout relate to their exclusion, not for their preservation.

Table 24 Generalised EWRs for diadromous migratory fish species

Flow season	Minimum permanent depth	Depth required during flows	Flow requirements	Timing of flow events	Duration of flow events
Low flow season	20 cm depth for smaller fish, 30 cm for larger fish				Zero flows for no more than 100 days At least one fresh per month
Transition 1			Flows to flush spawning sites (fresh to bankfull depending on substrate)	Flushing flows leading into spring	Flushing flows for about 2 days
High flow season		10-30 cm across 25% of the wetted channel for smaller fish Fresh flows to maintain pool water quality	Connecting flows to mouth Over mid-flows to inundate eggs	1 in 2-5 years for connecting flows Extended flows between June and December	July-November for connecting flows for 1-12 weeks

Table 25 Generalised EWRs for wetland specialised fish species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	20 cm depth for smaller fish	Low flows Low flow season fresh			Zero flows for no more that 100 days At least one fresh per month
Transition 1			Flows to flush spawning sites (fresh to bankfull depending on substrate)	Flushing flows leading into spring	Flushing flows for about 2 days
High Flow Season		10-30 cm across 25% of the wetted channel for smaller fish Fresh flows to maintain pool water quality	Inundation of macrophyte beds for spawning Overbank flows for migration	Annual for connecting and mid flows Overbank flows 1 in 1-3 years	Connecting flow for 3 months Mid flows for 1-3 weeks minimum for breeding events

Table 26 Generalised EWRs for exotic fish species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season			No Flows*	If no flows occur naturally 1 in 1	No longer than 100 days

*This is an EWR designed to select against Trout.

3.2 Macroinvertebrates

Hydrologically-defined habitats present across KI include flowing water (riffle), still water (persistent ponds and pools), still water (lowland streams), still water (temporary pools) and still water (floodplain wetlands). These represent all of the habitats for which EWRs have been described. It was hypothesised during previous workshops that EWRs for fish will probably cover the EWRs for most macroinvertebrates that are present in the same areas.

Table 27 Generalised EWRs for flowing water (cascade) macroinvertebrate species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	Larvae not well adapted to dry, can survive brief periods at cease to flow 0.1 m depth	10 cm, 75% of the low flow Channel Inundated 0.1m depth		Year Round	
Transition 1		10 cm, 75% of the low flow Channel Inundated		Break in season no later than April	
High Flow Season			Flows through Reed beds to Overbank flows for large recruitment events	Mid flow to overbank flow 1 in 1-2 years, 1 in 2-3 years sustaining 1-3 weeks optimal, 1 week sustaining	
Transition 2		10 cm, 75% of the low flow Channel Inundated			

Table 28 Generalised EWRs for flowing water (riffle) macroinvertebrate species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	Larvae not well adapted to dry, can survive brief periods at cease to flow 0.1 m depth	10 cm, 75% of the low flow Channel Inundated 0.1 m depth		Year round	
Transition 1		10 cm, 75% of the low flow Channel Inundated		Break in season no later than April	
High Flow Season			Flows through Reed beds to Overbank flows for large recruitment events	Mid flow to overbank flows 1 in 1-2 years, 1 in 2-3 years sustaining	Min. 30 days (Middle River EWRs) 1-3 weeks, sustaining 1 week (Broughton EWRs) Stoneflies Require water for 5-6 months
Transition 2		10 cm, 75% of the low flow Channel Inundated			

Table 29 Generalised EWRs for macroinvertebrates specialised for still water, persistent ponds and pools

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	0.1 m depth	0.1 m depth	Fresh (>2 time median non-zero flow)	Fresh >1 per month	Zero flows for no more than 100 days
Transition 1				Break of season no later than April	
High Flow Season			Mid flows to overbank flows	Mid flow to overbank flows 1 in 1-2 years, 1 in 2-3 years sustaining	1-3 weeks, sustaining 1 week (Broughton EWRs) Stoneflies Require water for 5-6 months

Note: Hypothesised that fish parameters will provide for Macroinvertebrates as well (Middle River EWRs)

Table 30 Generalised EWRs for macroinvertebrates specialised for still water and lowland streams

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	0.1 m depth	Fresh (>2 times median non-zero flow) 0.1m Pool Depth	LFS 80th percent exceedence flow to maintain pool condition	Fresh > 1 per month	Zero flows for no longer than 100 days
High Flow Season			Flows through Reed banks to overbank flows	Mid flow to overbank flows 1 in 2 years, 1 in 2-3 years sustaining	1-3 weeks, 1 week sustaining Stoneflies require water from 5-6 months

Note: Hypothesised that fish parameters will provide for Macroinvertebrates as well (Middle River EWRs)

Table 31 Generalised EWRs for macroinvertebrates specialised for still water and temporary pools

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
High Flow Season (or when created)		0.1 m depth	Flows through reed beds to overbank flows to create habitat		Time to complete lifecycle

Table 32 Generalised EWRs for macroinvertebrate species specialised for still water floodplain wetlands

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	0.1 m depth	0.1 m depth			Permanent
High Flow Season			Flows through reed beds to overbank	Mid flow to overbank flows 1 in 2 years, 1 in 2-3 years sustaining	Time to complete lifecycle Min 1-3 weeks, sustaining 1 week

3.3 Aquatic and Riparian Vegetation

The vegetation functional groups on KI include emergent, terrestrial dry/damp, amphibious fluctuation tolerator (low growing), amphibious fluctuation tolerator (emergent), amphibious fluctuation tolerator (large woody) and amphibious fluctuation tolerator (plastic) (Cassanova, 2011). For many vegetation groups with requirements for permanent water it was assumed that EWRs for fish will be sufficient, however this assumption needs to be considered when managing sites with no fish but with vegetation that requires permanent water.

Table 33 Generalised EWRs for terrestrial dry/damp vegetation species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
High Flow Season			Bank full flows to prevent encroachment		

Note: Flows not needed to sustain

Table 34 Generalised EWRs for amphibious fluctuation tolerator (low growing) vegetation species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	Damp Soils Needs to be exposed for reproduction			Damp soils through growing period (Sept/Oct through April/May)	
High Flow Season		Shallow flooding	Bank full flows to move propagules	Shallow flooding in spring	3 months

Table 35 Generalised EWRs for amphibious fluctuation tolerator (emergent) vegetation species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	Damp to water logged soils			Through growing period (Sept/Oct through April/May)	Dry time during autumn
High Flow Season		Lower bank sections inundated to prevent encroachment In channel benches inundated	Bank full flows to move propagules HFS freshes	Lower banks inundated every 1 in 2 years	Lower banks inundated for 2-8 months Inundated 8-10 months

Table 36 Generalised EWRs for amphibious fluctuation tolerator (Large Woody) vegetation species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
High Flow Season		Mid to high flows		Mid to high flows June – December Overbank flows Spring – summer	Mid to high flows 1 in 3.3-4 years + successive Over bank flows 1 in 1-20 years for 1-6 weeks*

Note: Large variations in flow requirements and durations from different EWR reports.

Table 37 Generalised EWRs for amphibious fluctuation responder (plastic) vegetation species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	Standing water			Permanent	
High Flow Season		Shallow inundation of benches and low banks	Bank full flows for propagules movement	Low flows needed 1 in 2 years provided permanent pools available in the interim	6-12 months

Table 38 Generalised EWRs for amphibious fluctuation responder (emergent) vegetation species

Flow Season	Minimum Permanent Depth	Depth Required During Flows	Flow Requirements	Timing of Flow Events	Duration of Flow Events
Low Flow Season	Constant water up to 50 cm		Lowest bars and banks inundated Low flows required for recruitment	Low flows Permanent Pools	9-12 months for low flows Year round presence of permanent water
High Flow Season			Flows to prevent choking Bank full flows for movement of propagules		
Transition 2			Low flows		

Note: It is assumed that criteria for fish will cover for submerged plants

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4 Community ecological survey

4.1 Methods

To assist the identification of aquatic ecosystem assets on KI outside previously surveyed areas, the project team communicated directly with landholders to obtain site-specific information regarding aquatic flora and fauna assets on their properties. A community survey was considered the most efficient mode of communication given the large number of landholders on KI with watercourses on their properties. This survey, presented in Appendix A, was sent in April 2014 to each landholder with a property size of at least 50 hectares which intersected a 2nd order or higher stream. As a result, the community survey was sent to 470 landholders, and covered almost all subcatchments of the project area outside National Park, Wilderness and Conservation Areas.

The survey comprised of two sections, the first identified assets on their land, and the second asked for the landholder's thoughts about water management on KI, and solicited their values regarding the aquatic environments of KI. This latter section was not specific to the particular project, but was opportunistically collected at the Board's request to further inform broader water management considerations by the Board. As such, this latter survey section is not reported here, other than the provision of a general summary. Each landholder was sent a copy of a map with their property outlined on an aerial photograph, which they were asked to mark-up with locations of any known water dependent flora or fauna. They were also asked to identify the flow regime of the rivers on their properties, wherever possible.

Ecological information gathered from this survey was collated in a spatial database, and aggregated at a subcatchment scale. Information was recorded as "presence only" information of:

- aquatic macroinvertebrates
- fish
- submerged vegetation
- aquatic vegetation
- permanent pools (not including dams)

The survey also asked if the landholder was able to be more specific about the ecological assets present. They were asked about the presence of:

- non-native fish
- native fish
- yabbies
- marron
- riparian trees
- aquatic sedges
- frogs

This information was combined with the data collected from previous survey work to provide a more complete description of the presence of aquatic assets on KI.

4.2 Survey results

A total of 122 surveys were returned from 81 individual landholders spanning 93 subcatchments. The spatial distributions of these responses are shown in Figure 40. All major surface water catchments were represented by at least one survey response, although there are large sections of some catchments that were not represented. For example, the North East River (the eastern branch of Stunsail Boom River) had no survey coverage, and there were large gaps on the northern subcatchments of the Cygnet River and in the headwaters of Middle River. Smaller catchments that flow north were also poorly represented.

A majority of survey responses (78%) identified healthy riparian vegetation along watercourses, which corresponds with results of the Rivers of Life Project (Nilsen, 2006). There was also a significant proportion of responses (58%) that indicated the presence of aquatic macroinvertebrates, (Figure 41), while only 28% of responses indicated the presence of fish (Figure 42).

A more detailed examination of responses to the ecological questions in the survey suggests that Yabbies are more common than Marron, where they were believed to occur in 38 and 24 subcatchments, respectively. There were 19 subcatchments where both Marron and Yabbies were identified together. The survey responses showed no apparent patterns in the spatial distribution of macroinvertebrates.

Native fish were recorded in 16 subcatchments and included mainly Climbing Galaxias, which are often referred to as "Muddies" or "Mud Fish", or simply Galaxias KI. Five subcatchments had non-native trout and White Lagoon had translocated Silver Perch in a farm dam). This represents an expansion of the range of trout from that identified in the formal fish survey results presented in Part 2, Section 2.1. One survey response identified River Blackfish (*Gadopsis marmoratus*); this is a relatively rare species that is present in isolated areas of both the Eastern and Western Mt Lofty Ranges (McNeil and Hammer, 2007), and has only been identified once on KI (SAM record) though there are limited details about its origin. The habitats of KI are suitable for River Blackfish, however it is also possible that this was a misidentification of a large specimen of Climbing Galaxias.

The survey responses indicated a variable distribution of the presence of permanent water across KI (Figure 43). The presence of permanent pools was correlated with the presence of fish, with most subcatchments with permanent water also having at least one species of fish present, although nine subcatchments with fish did not have any clearly identify permanent pools present. Permanent flow was identified in five of these nine subcatchments, with the remaining four subcatchments being most likely representative of the movement of migratory fish during times of high flow. Given that both species of native fish found in high abundances on KI are diadromous, observations of migration events are likely to be conspicuous when they occur (e.g. McNeil and Hammer, 2007).

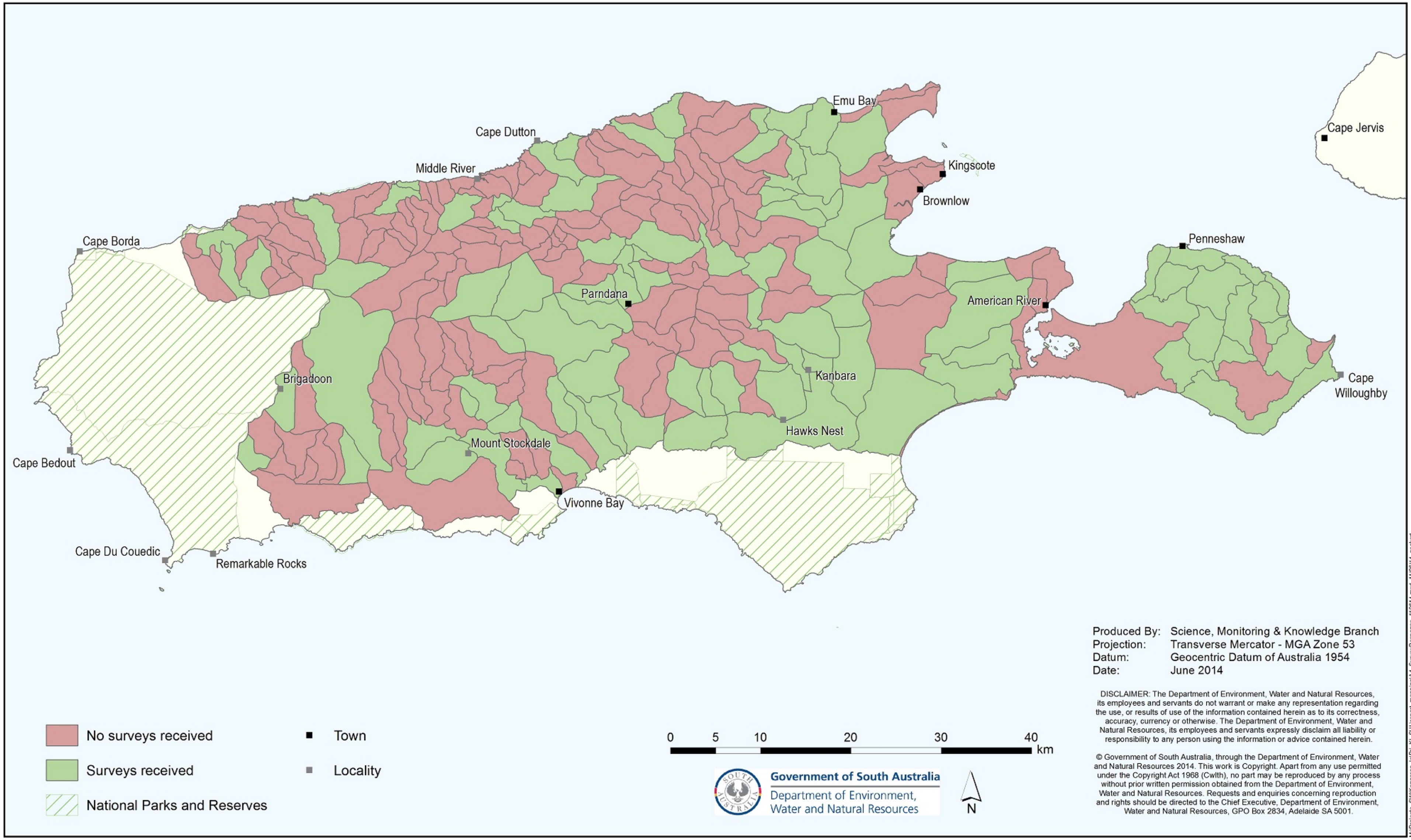

Figure 40 Subcatchments where survey responses with useful information were received

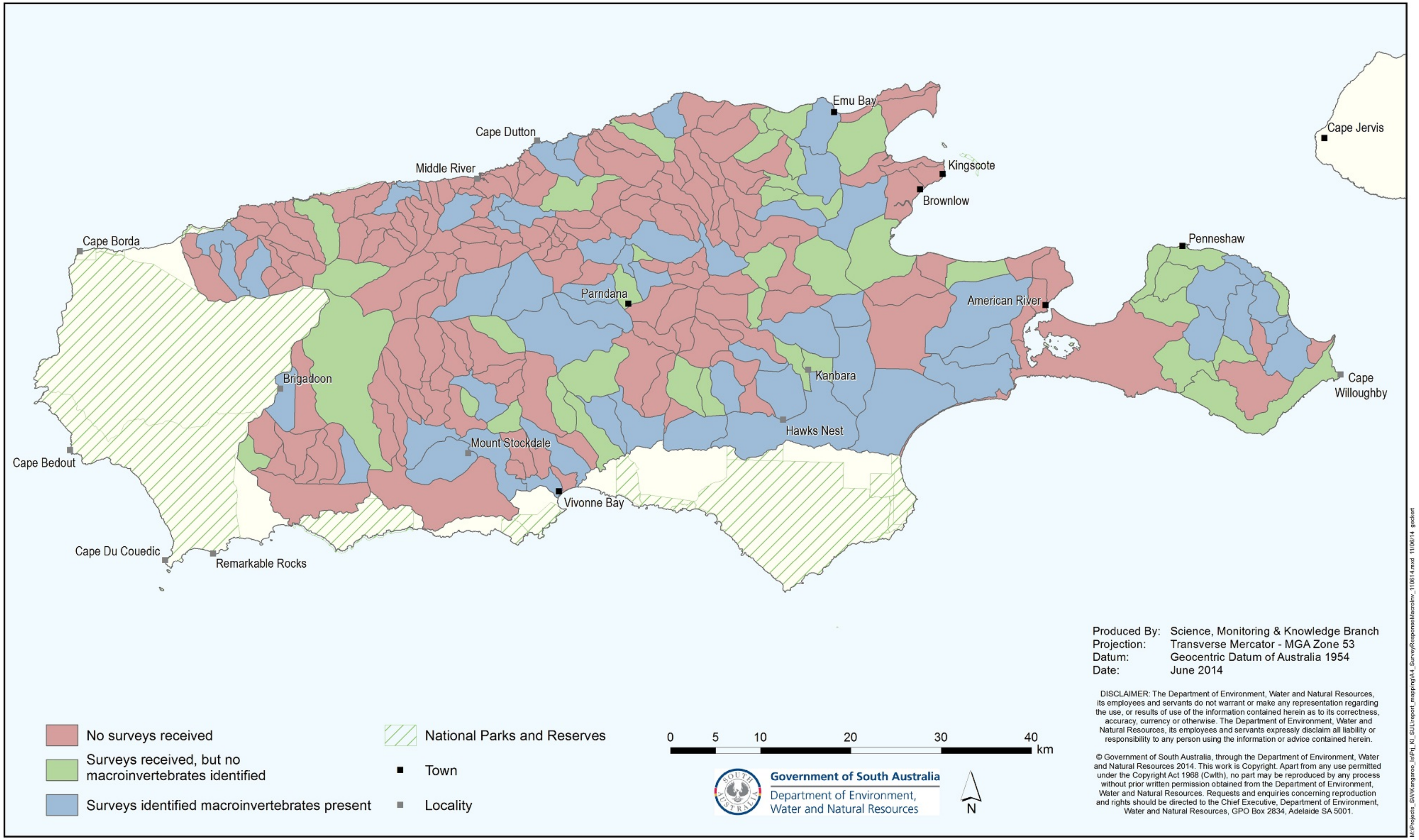

Figure 41 Subcatchments with survey responses that identified macroinvertebrates

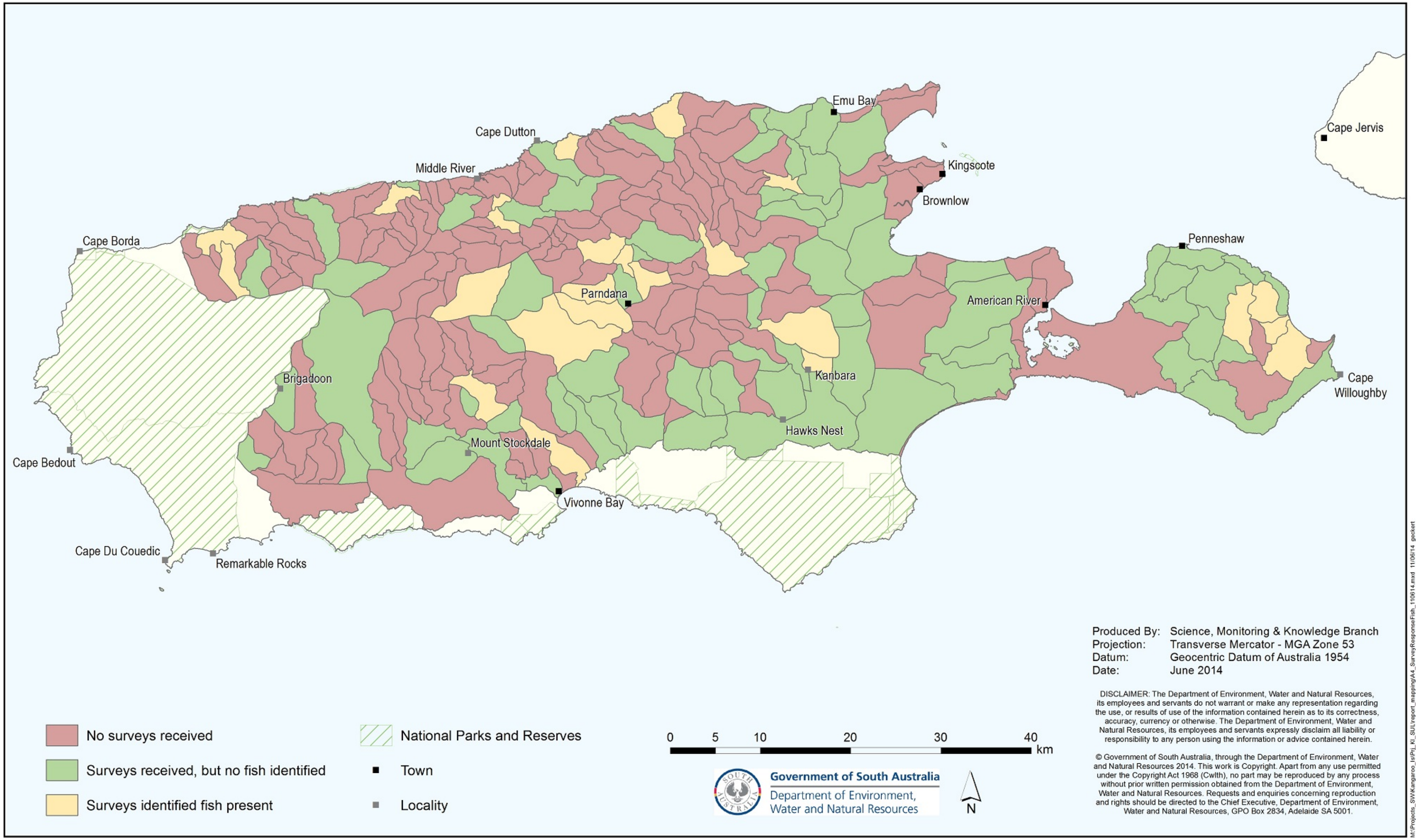

Figure 42 Subcatchments with survey responses that identified fish

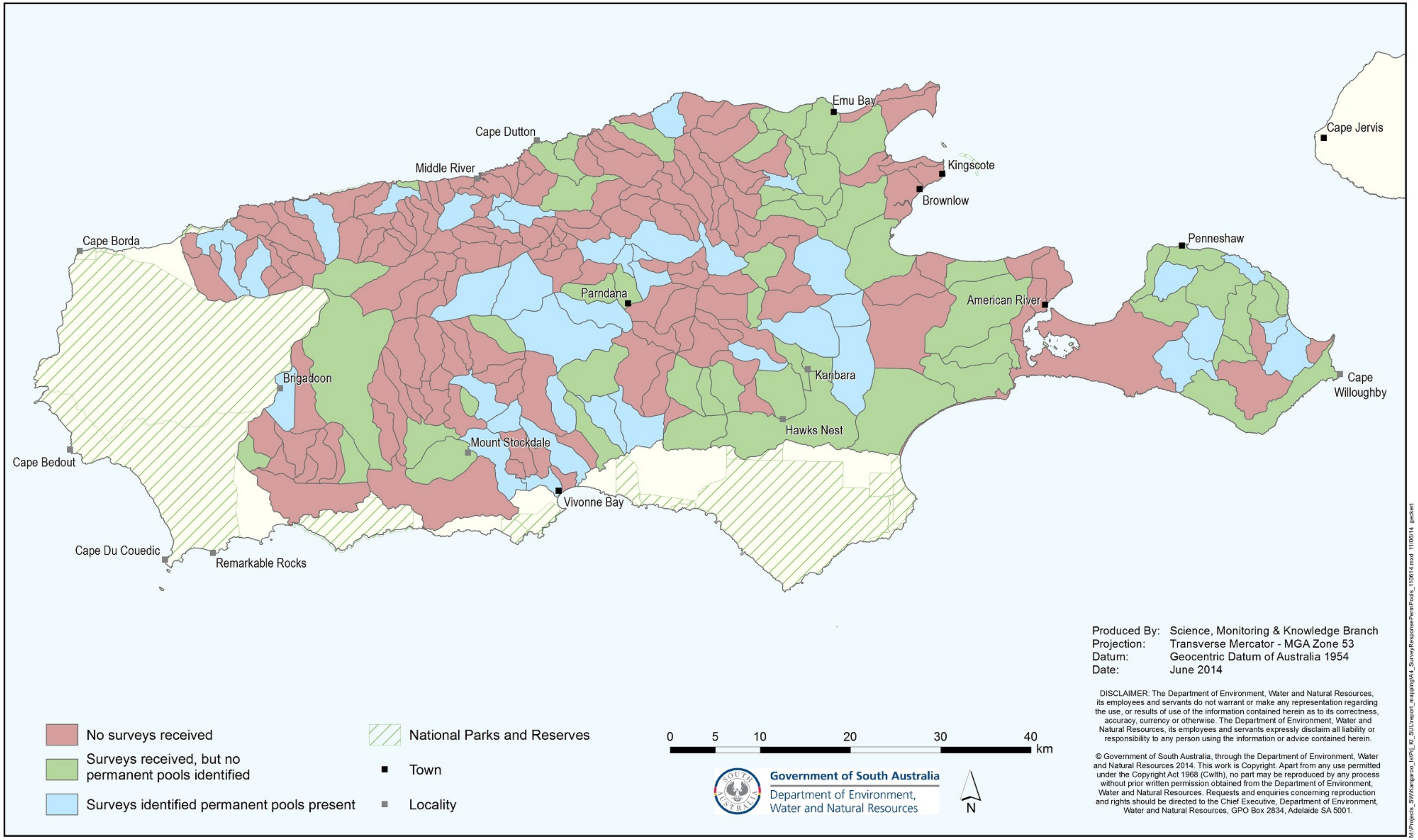

Figure 43 KI subcatchments with survey responses that identified permanent pools

5 Summary

Previous ecological surveys have provided insight into the current state of aquatic ecological assets across much of KI, with most of the major surface water catchments having aerial videography and photography surveys to identify the extent of riparian vegetation, which complements the existing data from on-ground surveys of fish and macroinvertebrates. Historical fish surveys show only limited populations of native fish in the inland areas of KI, with two species of diadromous fish dominating the inland rivers. Estuarine areas of KI show much higher diversity, with multiple fish species being sampled, including diadromous species, estuarine species and marine species. Macroinvertebrate communities that have been collected across KI are generally in very good to poor condition based on the EPA's assessment protocols. The most recent macroinvertebrate sampling included a number of sites that had not been sampled in the last 10 years, which greatly improved the spatial coverage of macroinvertebrate knowledge. The condition of riparian vegetation is not well understood, although its presence and width from the watercourse is well documented across major surface water catchments.

The environmental implications of water management decisions would be better understood by establishing a connection between biological sampling and surface water flow observations. Current trends in the development of EWRs include a preference towards response modelling, at the expense of hydrologically metric-driven approaches. The collection of KI-specific data should enable surface water management decisions to be driven by KI-specific conditions. These data should both validate existing ecological response models and ultimately enable KI-specific response models to be developed. Additional streamflow gauges on currently ungauged watercourses would not only assist the understanding of catchment yields, but also provide additional data for ecological response modelling and empirically-derived EWRs in these catchments.

The lagoon areas on the eastern side of KI are areas with only limited understanding of ecological assets, and investigations into the communities that are present in these systems should assist in the development of targeted management strategies. The estuarine areas of KI support a diverse range of fish species, and further sampling of these areas will expand current understanding of the role of freshwater inflows to these areas, which in turn has implications on management strategies of the surface water resources on KI.

The community survey sent as part of this project successfully obtained some high-level ecological data from many different areas of KI, and these survey responses have complemented existing sampling data to characterise ecological assets. This site-specific information will greatly enhance the development of surface water management strategies to meet ecological objectives.

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PART 3 – Future steps

This study was undertaken with a primary objective of validating surface water use limits across KI with local hydrological data. This report therefore represents a "stepping stone" to the characterisation and provision of an environmentally sustainable water regime in KI that supports social and economic needs for water. The KI NRM Board has committed to undertaking "Option 6" (as described in Part 1, Section 1.3 of this report), which will involve the development of new water sharing rules for KI, at a later date. The timing of the Board undertaking this future work, and the form that it will take, will depend on funding and personnel availability.

The 2009 NRM Plan defines limits on surface water use in a manner to ensure water supplies for downstream users, and the environment, in the absence of additional information regarding eco-hydrological relationships. The path towards defining new water sharing rules to replace existing WULs will ideally lead to the characterisation of sustainable extraction limits (SELs) for KI, and the definition of new rules around the taking of water from KI watercourses. SELs represent a collective response to the varying environmental, social and economic demands on surface water resources. It is clear that in order to specify these, additional monitoring and site investigations of the surface water resources across KI will be required. It is acknowledged however that the process to obtain the necessary local knowledge (of KI's hydrology, ecology and geomorphology) will require significant expenditure, and the input of experienced staff members. As such, the Board has not committed to a set timeframe for the completion of "Option 6".

The development of SELs across KI requires a continued expansion of the level of understanding of eco-hydrological relationships. The development of Environmental Water Requirements (EWRs) in areas of South Australia that have been prescribed under the state's *Natural Resources Management Act (2004)* represents a goal in this context towards which the Board can work. For prescribed areas, the Act requires the development of Water Allocation Plans, which are to include an assessment of the quantity and quality of water required by water dependent ecosystems. The prescription of KI's surface water resources may not be a necessary step in order for the Board to develop and implement water-sharing rules, however much of the learning from the EWR process in areas of South Australia that have been prescribed (including the Eastern and Western Mt Lofty Ranges) could be applied to KI, if time and budget permit.

The ultimate definition of SELs across KI will require a greater understanding of KI's total resource capacity (representing the total water available across KI). This current study has shown progress in this regard, and has highlighted the importance of local gauged streamflow records for accurately estimating catchment yields. Additional monitoring sites in the southern parts of KI that have significant agricultural development, including the Eleanor and Harriet Rivers, together with longer records at existing sites to capture the impacts of climatic variability will greatly assist the definition of the resource capacity. In addition, the collection of fish and biotic data at the same locations as flow monitoring is undertaken will greatly benefit the development of ecosystem response models. Associated with this would be an emphasis on additional spot gaugings at existing streamflow gauges wherever possible, in order to reduce the uncertainties associated with medium-high flow estimation.

In addition to the definition of total resource capacity on KI, the characterisation of SELs requires the specification of KI-specific environmental water requirements (EWRs), which represent the water regimes required to maintain (at a low level of risk) the ecological values of water dependent ecosystems. Environmental Water Provisions (EWPs) represent those parts of the EWRs that can be met at any given time. These are determined by identifying a water regime that maintains the environment at an *acceptable* level of risk, and therefore represent modifications to EWRs in response to social and economic demands on surface water resources. They require an assessment of the risk level that society is willing to place on the ongoing health of KI ecosystems. The interaction between EWRs, EWPs and SELs is represented in Figure 44.

The determination of EWRs for water-dependent fauna and flora on KI should be guided by local knowledge, and as shown in Part 2 of this report, there are still many gaps in the spatial distribution of ecological observations for KI. EWRs are generally described in terms of measureable hydrologic "metrics" that correspond to key, ecologically relevant parts of the flow regime including flow season, frequency, duration and magnitude (Savadamuthu *et al*., 2011), although recent trends in EWR development have shown a move toward ecological response models. A firm understanding of local hydrology, ecology and geomorphology is therefore required to understand the impact of varying flow conditions on aquatic ecosystems. With only a small number of surface water flow monitoring gauges currently installed across KI, in the first instance eco-hydrological modelling to inform EWRs will need to be directed towards monitored zones.

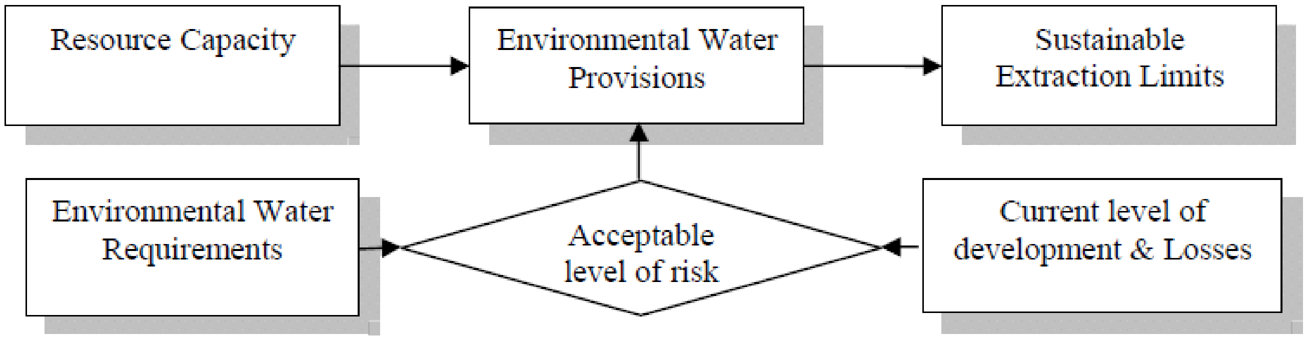

Figure 44 Description of the interaction between EWRs, EWPs and SELs (after Savadamuthu *et al.*, 2011)

A coordinated ongoing monitoring programme that builds upon the historical ecological datasets (as described in Part 2) will be vital for the Board to continue to move towards a deeper understanding of the ecological assets of KI. The community survey has benefited this process with a large number of responses complementing historical monitoring results and providing the Board (and DEWNR) with additional information regarding ecological assets. An initial follow-up to these responses will be advantageous, in order to "ground truth" observations captured in the survey responses such as the presence of permanent pools, and aquatic vegetation. With KI covering such a large area, it will be imperative for ongoing field investigations of KI catchment areas to be prioritised. This prioritisation will be a matter for the Board to consider, which may involve a pragmatic approach guided by risk management and knowledge gaps.

The description of "Option 6", as provided in Part 1, Section 1.3 of this report, emphasised the role of regionalisation using currently available non-KI and KI data to inform the development of new water sharing rules. In this manner, it is proposed that by grouping catchment/ subcatchments into similar categories, hydrological and ecological knowledge in areas of similarity outside of KI can be extended to KI. Therefore the lack of detailed eco-hydrological knowledge in parts of KI could be alleviated somewhat. A detailed process of regionalisation was beyond the scope of this current study, although the classification of land use types in each KI gauged catchment (and the selected MLR catchments) gave some insight into this approach (refer Part 1, Sections 2.3 and 3.3). A rigorous regionalisation process, using characteristics such as those described in Part 1, Section 4.6 of this report could identify a group of reference catchments in the MLR and other locations that have more extensive ecological and hydrological information than their corresponding KI catchments. Given ongoing limitations in funding and resources, such scientifically defensible transfers of existing eco-hydrological knowledge could provide the Board with options to ultimately define eco-hydrological relationships for KI, sooner than would otherwise be the case.

In the short term, this report has tabled a number of WUL and TFR calculation options for the Board's consideration in revising the 2009 KI NRM Plan. In addition, this report has characterised a range of assumptions used in the calculation of WULs in the 2009 Plan that could be reviewed as an outcome of this project. At a subcatchment scale, surface yield was calculated separately for the cleared and uncleared components of the ungauged catchments. This approach, along with the assumption that runoff from uncleared components is 45% of runoff from cleared areas, and assumptions regarding the calculation of average annual rainfall at a subcatchment scale, may need to be reviewed. Moreover, it should be noted that the application of the "25% rule" (as "Method B") in the 2009 Plan did not attempt to adjust median annual catchment yields for farm dam extractions. The development of catchment scale rainfall-runoff models, together with the associated data collection, that would be required to calculate the hydrological impacts of farm dams on KI will require significant resources. The Board may need to consider whether this is a necessary action for the ongoing use of the "25% rule" across KI.

As such, it is now envisaged that the Board, via the KI WRTF, will partner with DEWNR to inform decision-making on the water management policies to be adopted in the imminent revised KI NRM Plan.

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Appendix

A. Community survey

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Government of South Australia
Kangaroo Island Natural Resources Management Board

Community Survey

Kangaroo Island Surface Water Use Limits Policy Revision

The Kangaroo Island Natural Resources Management (KI NRM) Board is currently undertaking a project in collaboration with the Department of Environment, Water and Natural Resources (DEWNR) to review water resource policies on KI. This project is gathering information to give the Board a better understanding of the Island's water resources at a catchment scale.

A key source of information for this project is the KI community, so this short questionnaire seeks to capture your knowledge of local water resources and obtain a better understanding of the value you place on them.

All landholders who complete and return the survey will be in the running to win a two-night accommodation package at one of KI's heritage cottages.[3]

Please take a few minutes to answer the questions about the sections of creeks, rivers or wetlands on your property. In particular, we want to identify areas that have permanent water in them, either flowing or pooled, and find out how often and for how long the rivers and creeks on your property flow.

We are also interested in knowing if there is any aquatic life inhabiting the creeks, rivers and wetlands on your property, including fish, invertebrates (e.g. marron) and vegetation.

Information gathered from this survey will be published only in an aggregated form. Individual people and properties will not be identified, unless specific written permission is obtained.

We have provided a map of your property to help your response, together with an example map to illustrate how your property map can be used to respond to questions 1–5. Please return your marked-up map and this form in the enclosed **prepaid** envelope no later than **Thursday, 10 April 2014.**

Please direct any enquiries to:

Joseph Sullivan

NRM Officer – Water, Natural Resources Kangaroo Island

Joseph.Sullivan@sa.gov.au | (08) 8553 4438

[3] Landowners who are members of the KI NRM Board or employees of Natural Resources Kangaroo Island are encouraged to complete the survey but are excluded from entering the draw for the accommodation prize

The following questions concern the creeks, rivers and wetlands on your property:

1. On the map provided, please identify the locations of:
   a. permanently flowing creeks and rivers
   b. creeks and rivers that flow during winter/spring
   c. creeks and rivers that flow only after moderate/large rainfall events
   d. permanent pools located in creeks and rivers
   e. wetlands.
2. Have you ever seen or caught fish on your property? YES / NO (circle one)
   If yes, please mark locations on map and record which species of fish (if known).
3. Do you know if there are any frogs or yabbies/marron or other large aquatic invertebrates present? YES / NO (circle one)
   If yes, please mark locations on map and record which species (if known). (Invertebrates such as yabbies and marron can indicate the quality of water present.)
4. Is there any submerged vegetation in the creeks, rivers or wetlands on your property? YES / NO (circle one)
   If yes, please mark locations on map.
5. Is there any larger vegetation (trees/shrubs/sedges) around the creeks, rivers or wetlands? YES / NO (circle one)
   If yes, please mark locations on map and record approximate width of vegetation, and note whether larger vegetation is native or non-native.

We would also appreciate your general thoughts about water resources on KI. Feel free to provide any information in response to the following questions:

6. What do you value about rivers, creeks and wetlands on KI?

7. What concerns do you have about water use on KI?

8. Do you have any suggestions about how to improve the management of water on KI?

9. How do you think climate change will affect water and its use on KI?

10. Is there any other information that you think would assist this project?

The Board thanks you for taking the time to share this information and for working with us to improve water resource management on KI for the sake of future generations.

If you are happy for the KI NRM Board to contact you to follow-up your responses if required, please provide your details below.

Email: ....

Phone: ....

Government of South Australia

Department of Environment,
Water and Natural Resources