TECHNICAL NOTE 2011/02

Department for Water

Hydrological Modelling of the Eastern Mount Lofty Ranges: Demand and Low Flow Bypass scenarios

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February 2011

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ISBN 978-1-921923-02-9

Preferred way to cite this publication

Alcorn M. R., 2011, Hydrological Modelling of the Eastern Mount Lofty Ranges: Demand and Low Flow Bypass scenarios, DFW Technical Note 2011/02, Department for Water, Adelaide

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SUMMARY

The Science, Monitoring and Information (SMI) Division within the Department for Water (DFW) was engaged by the SA Murray-Darling Basin Natural Resources Management Board (SAMDBNRM) to undertake surface water demand modelling of the Eastern Mount Lofty Ranges (EMLR) Prescribed Water Resources Area (PWRA) for the scenarios where Low-Flow Bypass (LFB) occurs at:

- All irrigation dams; and
- All dams with a cease-to-flow storage volume of 5 megalitres (ML) or greater

This report also investigates the impact of various demand scenarios on the daily stream flow regime, as well as the effects on the annual water balance of the modelled catchments. It also details the modelling assumptions and methods employed to pass low flows around dams, vary demand from irrigation dams and set threshold flow rates for watercourse extractions. The outputs from this report, daily time step stream flow estimates at 63 test sites, have been delivered to the SAMDBNRMB. These outputs are intended to be analysed by the SAMDBNRMB with regard to meeting the environmental water requirements (EWR) metrics and targets through the adoption of any, or a combination of the scenarios presented. The outcome of the analysis is likely that the SAMDBNRMB will be able to establish Consumptive Use Limits (CUL) and Threshold Flow Rates (TFR) where flows will be required to be bypassed.

This report should be read in conjunction with the following, which have also been delivered to the SAMDBNRMB as part of this work:

- Environmental Water Requirements (EWR) spreadsheets (EWR_Scenarios2010.xlsm); and
- Data folders containing individual stream flow records for each EWR result spreadsheet for testing locations.

The results of this modelling indicate that providing low flows to the catchments downstream of selected irrigation and large stock and domestic dams would provide an overall increase in mean annual end of system flows of around 2%. There appears to be minimal difference in the total volume of flows (at the mean annual streamflow scale) delivered by either the “Irrigation Dam only” scenario or the scenario with “additional LFB on large (>= 5 ML) stock and domestic dams”. However, analysis of the daily flow regime suggest that there will be appreciable benefits to the low-flow regime, particularly during the low flow and transition seasons of January through to June, and in particular for the scenario of “LFB on large stock and domestic dams and all irrigation dams”.

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INTRODUCTION

AIM

The aim of this report is to summarise the work of the Science Monitoring and Information (SMI) Division within the Department for Water (DFW) in undertaking surface water modelling of the Eastern Mount Lofty Ranges (EMLR) Prescribed Surface Water Area (PSWA) for a range of water usage and Low Flow Bypass scenarios.

The scenarios where Low Flow Bypass (LFB) occurs at:

1. All irrigation dams; and
2. All irrigation dam and all stock and domestic dams with a cease-to-flow storage volume of 5 megalitres (ML) or greater, and for a range of water demands from dams and watercourses.

This work was requested by the SA Murray-Darling Basin Natural Resources Management Board (SAMDBNRMB), to provide input to the determination of Environmental Water Requirements (EWR) for the EMLR.

SCOPE

The intended scope of this report is to document the techniques and assumptions used to model the effect of low flow bypasses on farm dams, threshold flow rates on watercourse extractions and varying levels of water demand from the existing network of surface water development. The primary outcomes of this modelling are files containing modelled daily flow estimates for 63 testing sites over 4 catchment models within the EMLR.

Additional outputs of this study are:

- the automated generation of individual files describing the EWRs for each test site for each modelling scenario
- A collated spreadsheet containing summaries of all models and results for each site and scenario.

The daily hydrological models used in this study cover Bremer River (Alcorn, 2008), Angas River (Savadamuthu, 2006), Finniss River (Savadamuthu, 2003) and Currency Creek (Alcorn, M., 2006).

BACKGROUND

This work forms a part of the ongoing work by the DFW to provide science support to the process of Prescription in the Eastern Mount Lofty Ranges (EMLR) Prescribed Water Resources Area (PWRA). This is the third in a series of hydrological reports for the EMLR, and provides a range of water use and management options to the SAMDBNRMB, for the purpose of assessment of Environmental Water Requirements (EWRs) and eventually the Environmental Water Provisions (EWPs).

The first of these reports (Alcorn et al, 2008) sets out the basic framework for calculating the capacity of the surface water resource of the EMLR, with regard particularly to the impacts of farm dams on streamflow. The second report (Alcorn, 2010), revisited the existing hydrological models, updating farm dam data and climate data, and included the impact of existing watercourse extractions. It also provided the framework for estimating the average impacts of plantation forestry on the landscape as required through the Statewide Policy Framework (SA Government, 2009).

This report describes the scenario modelling requested by the SAMDBNRMB, and any changes made to the models since the estimates reported in DFW (2010). The outputs from this study are the modified daily time series at a series of test sites throughout the EMLR.

LOW FLOW RELEASE RATES

At the time of writing, it was likely that intended policy options for the EMLR Water Allocation Plan (WAP) will include the installation of some form of low-flow bypass device on licensable farm dams, and watercourse extractions, or the requirement to release low flows to the environment some other way. This report investigates the effect of including those releases. For licensable farm dams in the models flows are bypassed around the dam, and for watercourse extractions only water above the Unit Threshold Flow Rate (UTFR) may be extracted.

UNIT THRESHOLD FLOW RATES

The Unit Threshold Flow Rate (UTFR) is defined as the rate of flow per square kilometre of catchment at or below which water must not be diverted or collected by a dam, wall or other structure, and is expressed in litres/second/km^2. This rate was set to be equivalent to the rate of daily flow that is exceeded or equalled for 20% of the flowing period of the catchment. It is calculated by removing the zero flow days from the record and calculating the daily flow that is exceeded 20% of the time.

As calculating this value is not possible at the location of each and every dam or every watercourse extraction or diversion, a regional curve was constructed using streamflow data from all available gauging stations in the Mount Lofty Ranges and the corresponding rainfall in the catchment. This curve is shown in Figure 11 below. This allows a variable UTFR to be used for any location in the catchment, to be defined based upon the rainfall upstream of the dam or watercourse extraction in question.

The rationale for choosing this threshold was that it is approximately equivalent to the definition of a "T1 Fresh", in the Environmental Water Requirements flow metrics (Van Laarhoven and van der Wielen, 2009), and is relatively simple to calculate from measured streamflow data.

The UTFR for a dam (or a watercourse extraction) can be calculated by taking the mean annual rainfall upstream of the dam (or the watercourse) location and finding that point on the *x-axis* of the chart below, and finding the corresponding UTFR on the *y-axis.* Multiply the UTFR by the catchment area above the dam (or the watercourse extraction) to give the location specific Threshold Flow Rate (TFR) in litres per second.

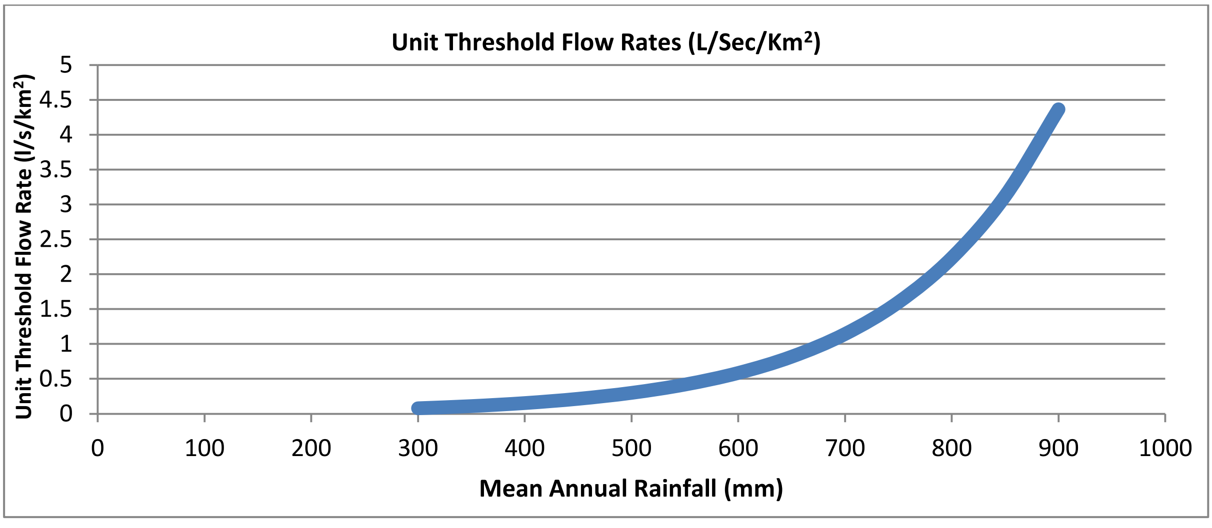

FIGURE 1. UNIT THRESHOLD FLOW RATES FOR THE EMLR

For all modelled catchments in this study, the relationship is defined as:

$$UFTR = 0.0105 \times e^{0.0067P}$$

Where:
UTFR = the unit threshold flow rate in units of $L/s/km^2$
P = the area weighted mean annual rainfall for the sub-catchment

SCENARIO MODELLING

Scenario modelling of water use from farm dams and watercourse extractions was undertaken considering the following assumptions and limitations:
Water use from farm dams identified as being for Stock and Domestic use remain fixed at an estimated 30% of the maximum capacity of the dam. This was a major assumption of the modelling and was bound by the absence of any management mechanisms relating to water use from this dam category (McMurray, 2004).
Demand scenarios were modelled for both irrigation dams and watercourse diversions so that a range of water consumption could be used to assess the impact on the flow regime and hence, on Environmental Water Requirements (EWRs).

SCENARIO DESCRIPTIONS

The scenarios that were modelled were:

1. “No dams or watercourse extractions” scenario: Often termed the “natural’ or “predevelopment flow”, this is the scenario against which all other scenarios are tested for EWRs.
2. “Current” or “Base” scenario: Includes current estimated use from farm dams and watercourse extractions, but does not model the impacts of plantation forestry.
3. “Varied usage on irrigation dams – no low-flow releases” scenario: A variation of Scenario 2, where all irrigation dams and watercourse extraction have the demand varied.
4. “Varied usage on irrigation dams – low flow releases on irrigation dams only” scenario: Similar to Scenario 3, but with the requirement to bypass low flows around irrigation dams and past watercourse extractions.
5. “Varied usage on irrigation dams – low flow releases on irrigation dams and dams with a capacity of 5 ML or greater” scenario: As Scenario 4, with the addition of low flow releases past large (>5 ML) Stock and Domestic dams.

Figure 2 shows the model domain for the four hydrological models used in this report, which include the Angas River, the Bremer River, Currency Creek, and the Finniss River. These are the only catchments in the EMLR Prescribed Water Resources Area (PWRA) that currently have daily rainfall-runoff models suitable for the purpose of EWR modelling. Although a similar daily hydrological model exists for the Tookayerta catchment (Savadamuthu, 2004), this was not included in the determination of the EWR of the EMLR due to the different nature of this catchment compared with other Mount Lofty Ranges catchments (VanLaarhoven, et al., 2009).

FIGURE 2. EMLR PRESCRIBED AREA SHOWING MODEL DOMAINS

SCENARIO 1: NO FARM DAMS OR WATERCOURSE EXTRACTIONS

The "No dams or watercourse extractions" scenario: Often termed the "natural' or "predevelopment flow", this is the scenario against which all other scenarios are tested for EWRs.

This scenario is modelled by removing all farm dams and watercourse extractions from the model. Note that modelled urban areas (Bremer and Angas models) are not removed as this modelling is focussed only on the impact of farm dams and watercourse extractions.

SCENARIO 2: CURRENT ESTIMATE OF DEMAND – WITHOUT LOW-FLOW RELEASES

The current or "Base" Case scenario includes current estimated use from farm dams and watercourse extractions, but does not model the impacts of plantation forestry. The results of this scenario are not discussed directly, but are considered as part of the range of results reported in Scenario 3, which encompass a broader range of demand estimates. Described in this section are the assumptions around farm dam water usage and extractions from streams.

WATER USE DATA

Water use across the modelled catchments in the EMLR is currently represented in the hydrological models by:

- farm dam extractions,
- watercourse diversions and extractions, and
- flood irrigation.

FARM DAMS DATA

Farm dam water use is dominant in the highlands of the EMLR and is categorised within this report as either:

1. Irrigation: A dam from which water is used to irrigate land for commercial purposes. As this type of water use is controlled under the WAP, dam types in this category are also termed "licensed dams". The terms "Licensed dam(s)" and "irrigation dam(s)" are used interchangeably in this report.
2. Stock and Domestic: A dam from which water is taken to water stock or for domestic use. As this type of water use is not proposed to be controlled by the draft WAP, dam types in this category are also termed non-licensed dams. The terms "Stock and Domestic dam(s)" and "non-licensed dam(s)" are used interchangeably in this report.

Data describing farm dams in the EMLR is based on a combination of previously captured data and updated estimates of licensed dam capacities and locations. Licensed dam locations and cease to spill capacities of those dams were provided to this analysis by DFW's Water Planning and Management Division (WPMD) derived from detailed land and water use surveys carried out over the prescription period.

The remaining dams are categorised as Non-licensed dams. These dams were captured from high resolution aerial photography covering the period 2003-2005.

Farm dam capacity estimates are derived in the following way using the following methods in order of preference/accuracy:

1. Estimate from field survey or design calculations. Usually provided to the DFW as part of the land and water use survey, and this is considered the better of the dam capacity estimates. Many licensed dams are estimated using this method.

2. Estimated using field survey of dam wall height and surface area. The formula used derive volume using this method is:
   a. $Volume(kl) = 0.4Depth_{max}(m) \times SurfaceArea(m^2)$
3. Estimated using surface area derived from aerial photography using the following formula:
   a. $For\ A < 15000$
      i. $V = 0.0002A^{1.25}$
   b. For A >= 15 000
      i. V = 0.0022A

These formulas and their application are described in McMurray (2004).

Summary

Dams in the EMLR Prescribed Water Resources Area:

There are an estimated total of 7103 dams in the EMLR PWRA with a total capacity of 18.4 GL. Dams with a capacity of at least 5 ML account for around 10% of the total number dams (692) with a combined capacity accounting for 64% (11,828 ML) of the total volume.

TABLE 1. FARM DAM STATISTICS FOR THE EMLR

Dam Types	Count	Capacity
Licensed < 5 ML	307	559
Licensed > 5 ML	251	6115
Total Licensed	**558**	**6674**
SD < 5 ML	6104	5988
SD > 5 ML	441	5713
Total SD	**6545**	**11701**
Total Dams	**7103**	**18375**

Dams within the model domain in this report

Of the total 7103 dams inside the EMLR PWRA, 5546 (78%) fall within the model domain (Figure 2) of the 4 hydrological models. These dams represent a total of 14,930 ML of storage, which is 81% of the total storage. There are 472 licensed dams identified and 340 additional Stock and Domestic dams with a capacity of 5 ML or greater.
These two categories represent ~75% of the total modelled dam capacity within the four modelled catchments.
Table 2 below shows the dam statistics by modelled catchment.

TABLE 2. FARM DAM STATISTICS FOR THE FIVE MODELLED CATCHMENTS IN THE EMLR

Catchment	Angas River		Bremer River		Currency Creek		Finniss River		*Total (Model Domain)*	
Dam Type	**Count**	**Volume**	**Count**	**Volume**	**Count**	**Volume**	**Count**	**Volume**	***Count***	***Volume***
Irr < 5	32	63	75	142	36	69	106	213	249	488
Irr > 5	42	1035	66	1528	22	696	93	2108	223	5365
Tot Irr	***74***	***1098***	***141***	***1670***	***58***	***765***	***199***	***2321***	***472***	***5853***

SD < 5	890	939	1622	1677	472	431	1749	1717	4733	4763
SD > 5	88	1203	125	1499	15	203	112	1427	340	4331
Total SD	***978***	***2142***	***1747***	***3176***	***487***	***633***	***1861***	***3143***	***5073***	***9094***
Total	***1052***	***3239***	***1888***	***4834***	***545***	***1398***	***2061***	***5458***	***5546***	***14930***

WATER USE FROM FARM DAMS

In the WaterCRESS model, simulated water use from farm dams is defined by two settings; the internal annual use fraction and the monthly usage distribution.

Internal Annual Use Fraction

The internal usage fraction sets the proportion of a dams' maximum capacity that will be removed from the dam for external use, and is lost to the system.
Assumptions:

1. Stock and Domestic Dams (Non-licensed) demand a maximum 30% of the dam capacity in each year
2. Irrigation Dams (Licensed) demand a maximum 50% of the dam capacity in each year

The monthly usage distribution defines the proportion of the total demand from the dam that will be extracted in each month.
For modelled sub-catchments with a farm dam node which is lumped – that is, contains a representation of several dams – and that lumping comprises dams of different types, the initial usage fraction is calculated using the ratio of the total irrigation dam capacity to the total dam capacity. This is termed here, the irrigation proportion.
The irrigation proportion is defined as the total capacity of identified irrigation (licensed) dams divided by the total capacity of all dams for the modelled sub-catchment (Equation 1).
Thus the internal annual use fraction for a mixed use dam node will be between 30 and 50% with a 30% usage fraction for a sub-catchment denoting a lumped sub-catchment with only non-licensed dams. Likewise a 50% usage fraction for a sub-catchment would denote only licensed dam(s) are represented.

EQUATION 1. DEFINITION OF IRRIGATION PROPORTION (IP)

$$IP_n = \frac{\sum V_{irr}}{\sum V_{tot}}$$

Where:

$IP_n = \textit{Irrigation proportion at sub-catchment dam node } n$
$\sum V_{irr} = \textit{Sum of irrigation dam capacities in sub-catchment } n$
$\sum V_{tot} = \textit{Sum of all dam capacities in sub-catchment } n$

The IP is then used as the defining factor in assigning initial and variable demand from lumped farm dam nodes.

Definition of monthly usage distribution patterns

For irrigation dams, the monthly pattern is summer dominated with extraction only occurring during the months of October-March and defined by the Pattern Number 1, as assigned in the WaterCRESS model.

Stock and Domestic dams are assigned a distribution pattern (Pattern Number 0) that follows the evaporation distribution of the Mt Lofty Ranges area.

For lumped, mixed IRR and SD dam nodes, there are three more patterns given, based on the Irrigation Proportion. These can be seen in Table 3 and Figure 3.

TABLE 3. USAGE PATTERNS FOR IRRIGATION PROPORTION RANGES

	Irrigation Proportion Range				
	0 – 0.2	0.8 - 1.0	0.4 – 0.6	0.2 – 0.4	0.6 – 0.8
	Pattern Number				
	0 (S&D only)	1 (irrigation only)	2	3	4
Monthly Usage Proportion					
Jan	0.15	0.24	0.20	0.17	0.22
Feb	0.13	0.195	0.16	0.14	0.18
Mar	0.10	0.126	0.11	0.11	0.12
Apr	0.06	0	0.03	0.05	0.02
May	0.04	0	0.02	0.03	0.01
Jun	0.03	0	0.01	0.02	0.01
Jul	0.03	0	0.02	0.02	0.01
Aug	0.05	0	0.02	0.03	0.01
Sep	0.06	0	0.03	0.05	0.02
Oct	0.09	0.066	0.08	0.08	0.07
Nov	0.12	0.166	0.14	0.13	0.15
Dec	0.14	0.207	0.17	0.16	0.19

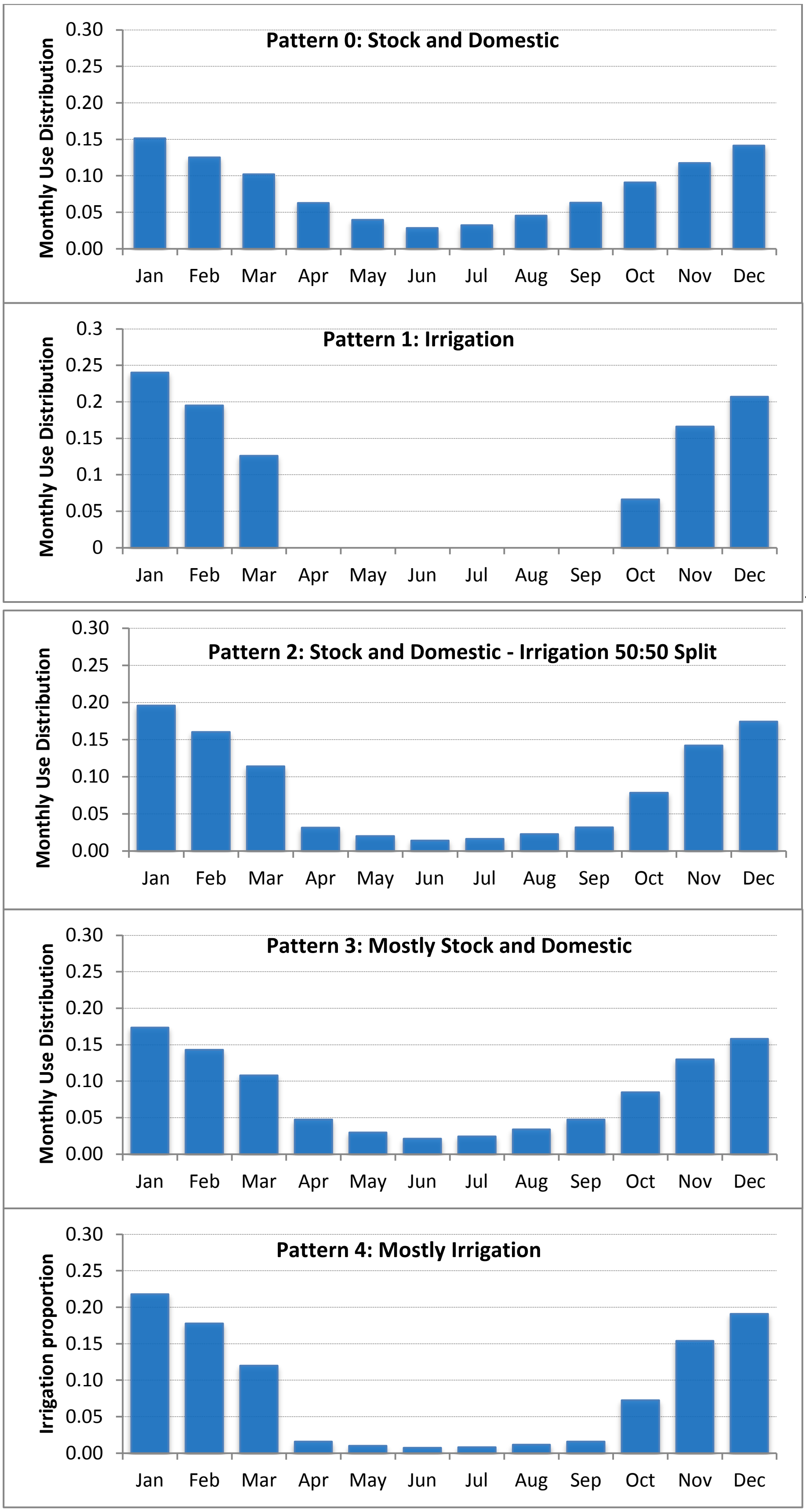

FIGURE 3. MONTHLY USAGE DISTRIBUTION PATTERNS

NET EVAPORATION FROM DAMS

The WaterCRESS model calculates both evaporation and rain falling from the dam surface. When combined, the difference between evaporation loss and rain on the water surface is termed the net evaporative loss.

At each time-step the WaterCRESS model calculates a water balance on the dam which is explained in the steps below:

1. Calculate the surface area from the volume at the previous time step

2. Calculate the evaporative loss, inflows, demand, and rainfall based on the surface area calculated at (1).

3. Calculate the change in storage, and if storage is greater than the full supply level, spill the remaining water downstream e.g.

$$S_t = S_{t-1} + (I - O - E + P - D)dt$$

Where:

S_t = storage to be calculated at current time step (m^3)

S_{t-1} = storage at previous time step (m^3)

I = inflow rate at current time step (m^3/s)

O = outflow rate at the end of the current time step (m^3/s)

E = evaporation loss at current time-step (m^3/s)

P = rain falling at current time-step (m^3/s)

D = water extraction rate (m^3/s)

dt = the model time step (s).

Terms E and P are calculated from the current estimate of surface area based on the storage volume at the previous time step.

Farm dams, as digitised from aerial photography of the region, are initially calculated a maximum surface area at the level at which the dam ceases to flow. This is usually at the point of the dam spillway. The surface area of the dam at less than full supply level is calculated using the estimate described by McMurray (2004)

$$A = A_{max}(\frac{V}{V_{max}})^{0.6}$$

Where:

A = Surface area (m^2) at volume V

A_{max} = surface area (m^2) at maximum volume

V = volume (ML)

V_{max} = Volume at maximum capacity.

For example a 5 ML dam with a maximum surface area of 3300 m^2 the relationship of Volume (ML) to Surface area (m^2) would appear as below:

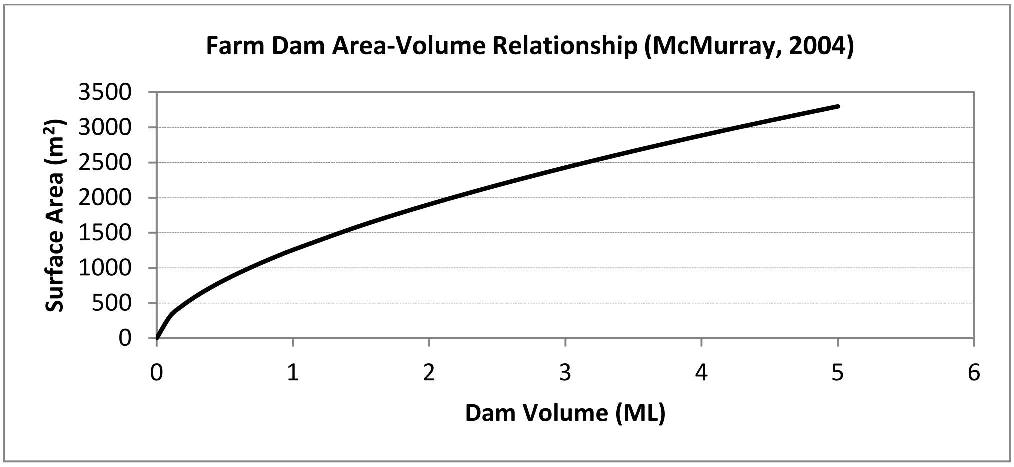

FIGURE 4. FARM DAM AREA-VOLUME RELATIONSHIP AT LESS THAN FULL SUPPLY LEVEL

For a selection of eight dams spread over the four models and split between wet and dry areas for each catchment, the range of exceedence values are displayed in Figure 4 above. Depending on the location of the dam, and hence the subsequent rainfall and evaporation regime it is exposed to, the volume of water in the dam will vary greatly.

TABLE 4. EVAPORATION DETAILS FOR SELECTED FARM DAMS

	Node	Dam Volume (ML)	Mean Annual Runoff (ML/a)	Dam Volume/ Runoff (%)	Mean Annual Rain (mm)	Mean Pan Evap (mm)	Net Evap Loss (ML)	Net Evap/Dam Volume (%)	Summer Evap/Dam Cap (%)
Angas Wet	77	8.83	185	5%	866	1444	0.65	7%	23%
Angas Dry	6	4.84	45.16	11%	537	1444	1.66	34%	40%
Finniss Wet	299	13.21	77	17%	851	1443	1.33	10%	30%
Finniss Dry	577	16.27	25	65%	670	1536	3.33	20%	26%
Currency Wet	11	248.86	567	44%	896	1371	5.73	2%	16%
Currency Dry	151	3.62	13.88	26%	519	1371	1.27	35%	41%
Bremer Wet	385	75.58	88.1	86%	806	1352	3.8	5%	14%
Bremer Dry	282	10.58	135	8%	558	1590	3.19	30%	33%

As shown in Figure 5, at the 50th percentile exceeded value (median), dams ranged from being full to only 56% of full supply. There are other factors involved in this dynamic including the rate and regime of water extraction from a farm dam, then amount of water diverted to the dam or bypassed around the dam, and the amount of runoff (in turn related to catchment area and runoff).

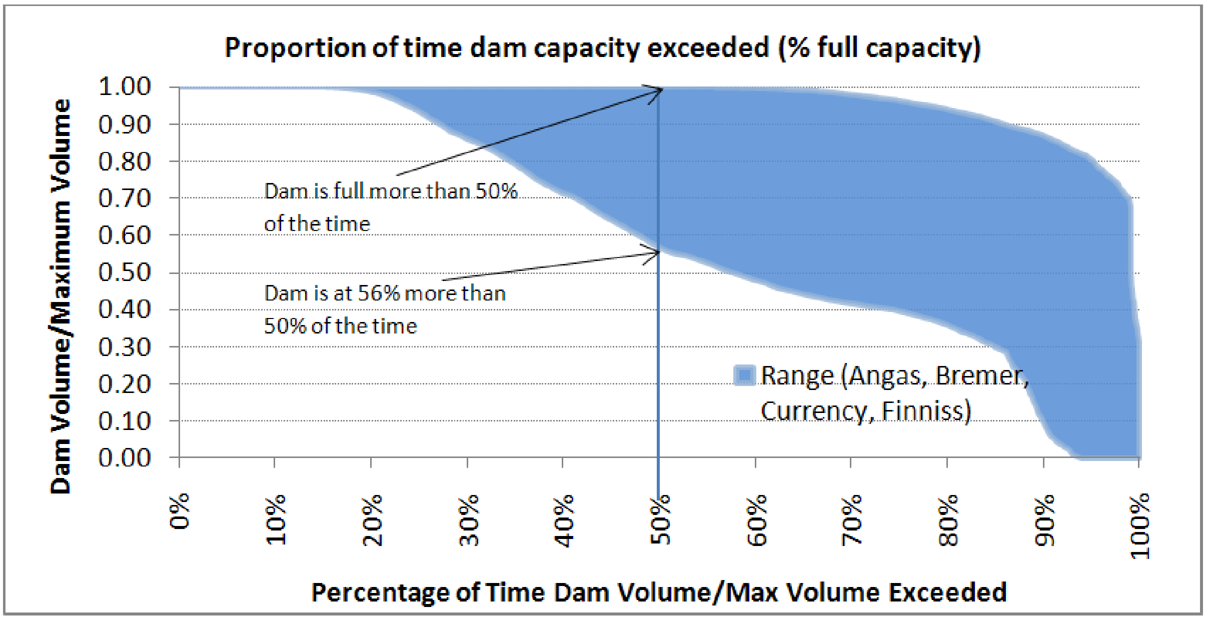

FIGURE 5. RANGE OF DAM VOLUME EXCEEDENCES

In order to gain an understanding of the overall water balances for these data, statistics have been calculated at the catchment scale with the WaterCRESS model being able to aggregate the calculations of each farm dam in the output file. This enables estimates to be made including; net evaporation loss, precipitation, dam volume, and extraction.

Results for these are given in the following section which includes an assessment of the seasonal estimate of net loss from farm dams for the months of November to May inclusive. These months cover those identified by Van Laarhoven et al (2009), as covering the critical flow seasons; Low Flow Season, Transition season 1 (Low to High), and Transition Season 2 (High to Low).

Figure 6 below shows the mean monthly storage volumes calculated in all dams, comprising a mixture of demands (refer to section on Water Use) highlighting the decreasing storage volume between November and April inclusive.

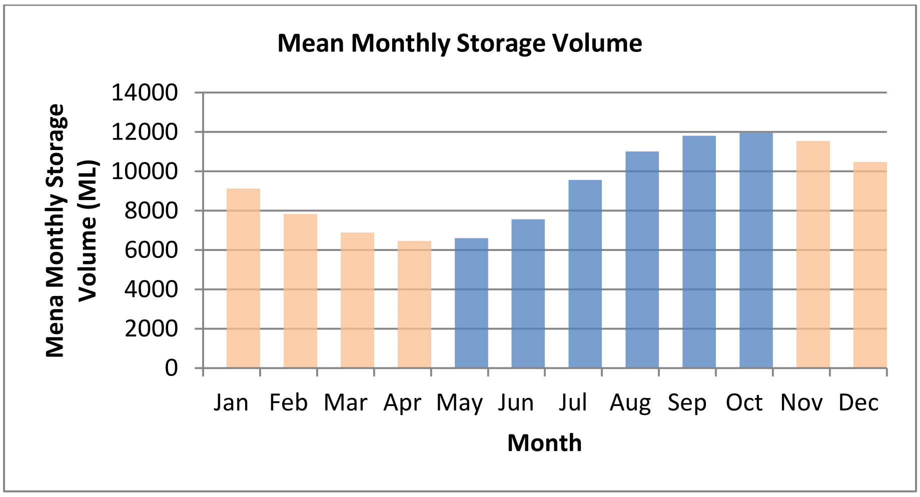

FIGURE 6. MEAN MONTHLY STORAGE VOLUME OF EMLR FARM DAMS

TABLE 5. ANNUAL DEMAND AND FLUX ESTIMATES

Component	Value	% of Dam Capacity
Evaporation	6087	38%
Extraction	5100	32%
Rainfall	4601	28%
Net Impact (ML)	6584	41%

TABLE 6. NOVEMBER–APRIL DEMAND AND FLUX ESTIMATES

Component	Value	% of Dam Capacity
Evaporation	2955	18%
Extraction	4117	26%
Rainfall	1560	10%
Net Impact (ML)	6702	42%

The figures in Table 5 highlight that when calculated over the entire year, the impact due to evaporation is apparently negated largely by the addition of rainfall to the dam surface resulting in a net evaporative loss of only 10% over the year (Total evaporation from the dam surface minus rain falling). However, since the impact of evaporation and extractions are summer dominant i.e., they are prevalent over the months of November-April (Transition and Low Flow seasons), and summer evaporation was considered to provide the highest disturbance to the flow regime. As such the evaporative impact over the period November-April is calculated to be approximately 18% of the dam capacity which is comparable to a figure of 20% suggested by McMurray (2004a). It is suggested that in order to account for this impact across the broadest range of situations across the EMLR, and noting that the majority of area modelled in this report covers the wetter regions of the EMLR, a figure of summer impact of 30% of dam capacity is suggested here. It is suggested that this be adopted as a precautionary estimate when assessing the impact of farm dams via evaporation over summer.

SCENARIO 3, SCENARIO 4 AND SCENARIO 5

Scenarios 3, 4, and 5 comprise the varied demand and LFB scenarios. The demand from farm dams and watercourse extractions is varied systematically within each scenario. Scenario 3 contains no bypass of low flows, Scenario 4 bypasses low flows from irrigation dams and watercourses only, while Scenario 5 bypasses low flows for irrigation dams, large stock and domestic dams (>= 5 ML) and watercourses.

DEMAND FROM FARM DAMS

This section describes the variation of water usage from different dam types – licensed and non-licensed – for the different usage scenarios. Water usage – via the internal annual use fraction in the WaterCRESS model - in is varied from zero to 100% of dam capacity for licensed dams only.

As many dams within the catchment are lumped in the modelling, it is necessary to vary the usage according to the proportion of licensed/non-licensed dams represented within the sub-catchment.

Variation of Usage from Lumped Dam Nodes where there is a combination of Licensed Irrigation Dams and Non-licensed Stock and Domestic dams

As some sub-catchments have a combination of licensed and non-licensed dams that may require LFB, there is a requirement to fix the level of usage from non-licensed 5 ML dams (and smaller SD dams) at 30% of the dam capacity (this is a major assumption of all modelling of SD dams to date) and vary the demand from irrigation dams and watercourse extractions.

For the demand scenarios i.e., varying demand from 0 to 100% for licensable dams it is necessary to separate out the total volume of irrigation dams from stock and domestic dams.

The irrigation proportion is defined as the total capacity of identified irrigation (licensed) dams divided by the total capacity of dams for the modelled sub-catchment.

EQUATION 2. VARIABLE DEMAND CALCULATION FOR MIXED SOURCE EXTRACTIONS

$$UF_n = (u_n \times IP) + (SDP \times SD_{30})$$

This simplifies to:

$UF_n = IP(u_n - SD_{30}) + SD_{30}$

Where:

u_n = variable demand fraction (n = 0, 0.1, 0.2....0.9, 1.0)

IP = irrigation proportion

SDP = Stock and Domestic Proportion (1 – IP)

SD_{30} = Fixed demand proportion for stock and domestic dams of 30%

UF_n = Combined use fraction at variable demand n

TABLE 7. EXAMPLE FOR A 50% IRRIGATION PROPORTION

Irrigation Proportion (*IP*)	0.5		
Stock and Domestic Proportion (*SDP*)	0.5		
Variable Irrigation Proportion (u_n)	**u_n times *IP***	**SDP times fixed 30% (SD_{30})**	**Total Demand Fraction (UF_n)**
0	0	0.15	0.15
0.1	0.05	0.15	0.2
0.2	0.1	0.15	0.25
0.3	0.15	0.15	0.3
0.4	0.2	0.15	0.35
0.5	0.25	0.15	0.4
0.6	0.3	0.15	0.45
0.7	0.35	0.15	0.5
0.8	0.4	0.15	0.55
0.9	0.45	0.15	0.6
1	0.5	0.15	0.65

VARIATION OF DEMAND FROM WATERCOURSE EXTRACTIONS AND LOW FLOW BYPASS CONDITIONS.

Water usage from watercourse extractions in the models was also varied between 0 and 100% of the original estimates[1].

To allow the bypassing of low-flows past watercourse extractions at the defined TFR, the original set-up of the model was required to be altered.

Previously watercourse extractions were enabled in the model by inserting a stream storage node, and extracting water from the node via a Text File Demand Node. This situation did not allow for the bypassing of low-flows as may be required under the proposed water allocation plan for the EMLR.

To allow this to happen, a weir node (Number 2 in Figure 7) was inserted above the stream storage node (Number 5 in Figure 7) and the diversion off-take (the pink line) was directed to the stream node. The main branch of the weir node is connected downstream in the direction of flow. The weir node allows a constant "base flow-to-pass" rate to be applied which is analogous to the Threshold Flow Rate. As for dams, the effect is to bypass flows along the main branch of the model. Refer to Figure 7 below for an example of how the model is constructed.

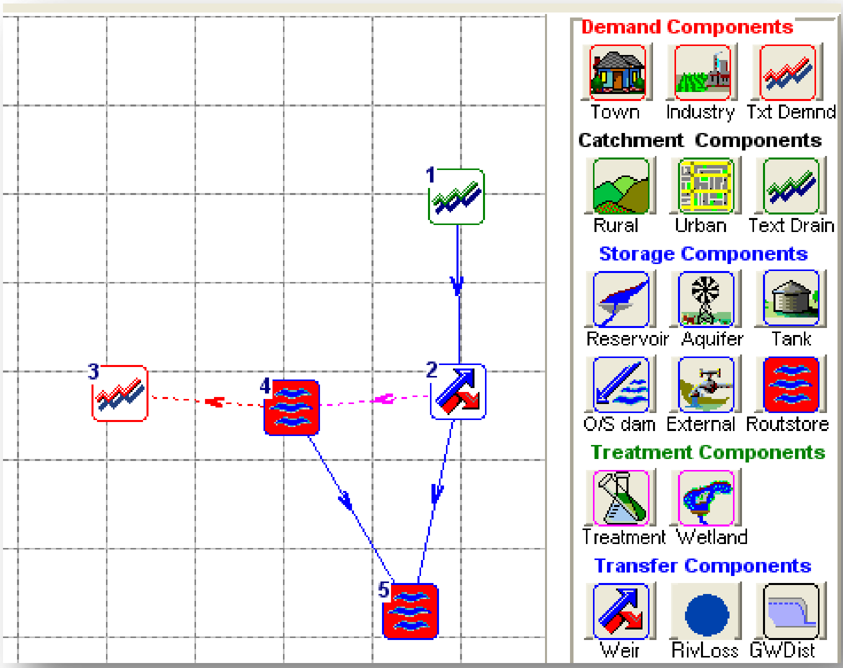

FIGURE 7. WATERCOURSE EXTRACTION SET-UP WATERCRESS MODEL

The "baseflow (or low flows) to pass" rate is calculated in the same manner as the TFR for dams. (Upstream area times UFTR)

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[1] Watercourse extraction estimates were supplied by Resource Allocation Division in May 2010 at the SWMZ scale

Watercourse extraction estimates: Catchment Scale

Watercourse demand estimates were supplied by the Water Planning and Management Division (WPMD) of DFW and are categorized by catchment total demand in Table 6 below. It should be noted that these figures are best estimates at the time of this report and could change as more information becomes available during the licensing process of the EMLR WAP.

TABLE 8. CATCHMENT-SCALE WATERCOURSE DEMAND ESTIMATES

Catchment	Watercourse Demand Estimate (ML/a)
Angas	873
Bremer	1856
Currency	290
Finniss	631

Selection of sub-catchments for low flow releases

The total number of modelled sub-catchments across the five catchments is 932.
Using the criteria of Stock and Domestic, Irrigation or Stock and Domestic larger than 5 ML, 382 of 932 model dam nodes have a LFB applied. The break down by catchment is in Table 9.

TABLE 9. SUB-CATCHMENTS SELECTED FOR LOW FLOW BYPASS

	Scenario 5*: Sub-cats. to Bypass Low Flows	Scenario 4**: Sub-cats. containing only Irrigation Dams	Sub-cats. containing at least one dam >= 5 ML
Angas	79	56	78
Bremer	137	94	136
Currency	28	33	23
Finniss	128	116	127
Total	372	299	364

*Varied demand on irrigation dams – low flow releases on irrigation dams and dams with a capacity of 5 ML or greater

**Varied demand on irrigation dams – low flow releases on irrigation dams only

Description of programs and data required to process inputs and outputs

Geographic Information System (GIS)

A GIS was used to identify the location of Farm Dams, model sub-catchments and water extractions. This information was used to determine the location of sub-catchments required to bypass low-flows, and also to determine the ratio of Stock and Domestic use to Irrigation use in each sub-catchment.

Excel Spreadsheets:

1. EWR_Scenarios2010.xlsm: Outputs and macros relating to base node information and EWR Metric result summaries
2. Use_Scenario.xlsm: Spreadsheet and macros used for running LFB and Demand Scenarios for Scenario 3
3. LFB_Use_ScenarioNewLFBIRR.xlsm: Spreadsheet and macros used for running LFB and Demand Scenarios for Scenario 4

4. LFB_Use_Scenario.xlsm: Spreadsheet and macros used for running LFB and Demand Scenarios for Scenario 5.

VBA programs

The analysis of these LFB and Demand scenarios, and the management of the output data sets relies on the use of several VBA (Visual Basic for Applications) scripts that allow for the processing of large numbers of scenario runs and output data. The table below describes:

1. The location (spreadsheet) in which the script resides
2. The order in which to run the scripts
3. Any other required data e.g. an open excel worksheet.

The full macro name is of the form:
[Spreadsheet Name]![Module Name].[Procedure Name]

TABLE 10. LIST OF SCRIPTS TO RUN EWR SCENARIO ANALYSIS

Step	Full Macro Name (includes base spreadsheet as the prefix)	Main Spreadsheet	Description
1	Use_Scenario.xlsm!NoDamsScenario. run_nodams_scenario()	Use_Scenario.xlsm	Sets all demands and dam volumes to zero, runs model and saves results.
2	Use_Scenario.xlsm!UseScenarios. usage_main()	Use_Scenario.xlsm	Runs through the demand scenarios for Scenario 3, and saves outputs.
3	LFB_Use_Scenario.xlsm!UpdateTFR. UpdateUTFR_Main()	LFB_Use_Scenario.xlsm	Sets the Threshold Flow rates for all applicable dams and extraction nodes.
3	LFB_Use_Scenario.xlsm!LFBUseMain.LFB_Use_Main()		Runs through the demand scenarios for Scenario 4 and 5, and saves outputs.
5	LFB_Use_Scenario.xlsm!SetTFRtoZero.ResetTFRtoZero_Main()	LFB_Use_Scenario.xlsm	Resets all Threshold Flow rates back to Zero.
6	EWR_Scenarios2010.xlsm!GetSummaryData.getdata_main()	EWR_Scenarios2010.xlsm	Collates model summary output files.
7	EWR_Scenarios2010.xlsm!update_output_node()	EWR_Scenarios2010.xlsm	Collates all node information from the model in this spreadsheet.

WaterCRESS Model Platform

These models are developed and run using the WaterCRESS model platform, which calculates water balances for catchments, storages and extractions on a daily time step.

The WaterCRESS model executables used in this report are:

1. Watercress.exe 4/02/2009 10:48 PM
2. wcmain2h.exe 10/12/2008 10:07 PM

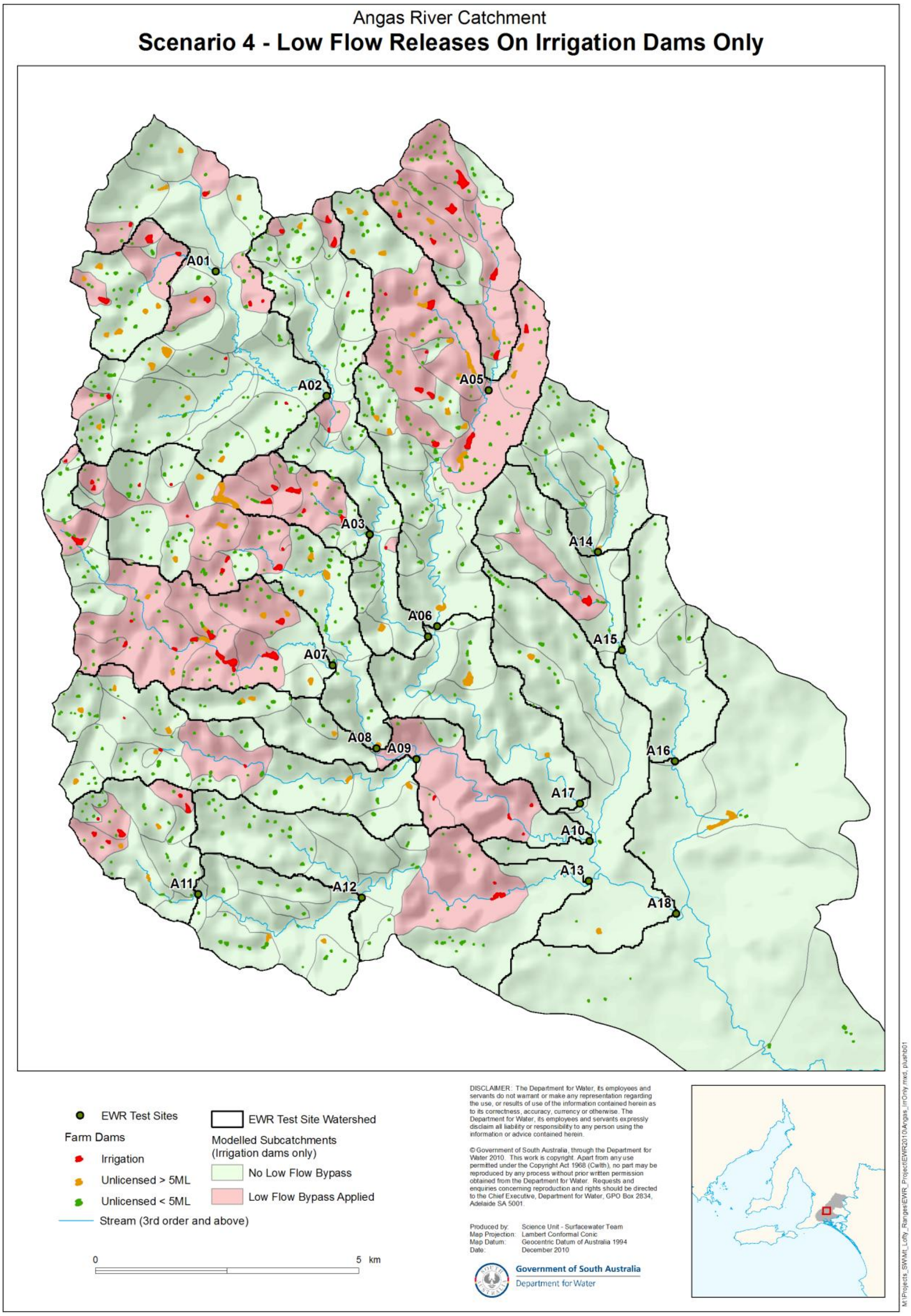

FIGURE 8. ANGAS RIVER TESTING SITES AND LFB SELECTION SCENARIO 4

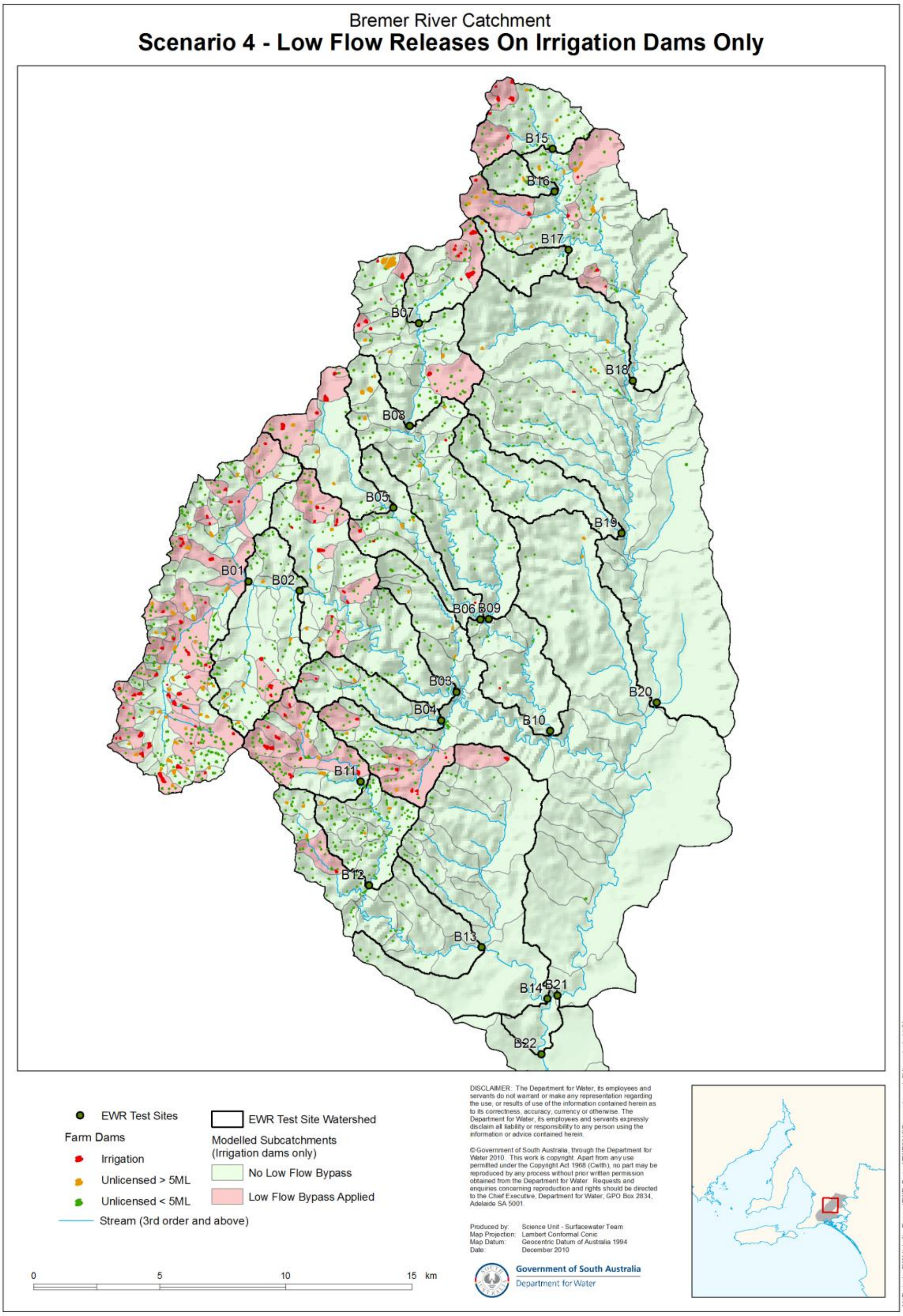

FIGURE 9. BREMER RIVER TESTING SITES AND LFB SELECTION SCENARIO 4

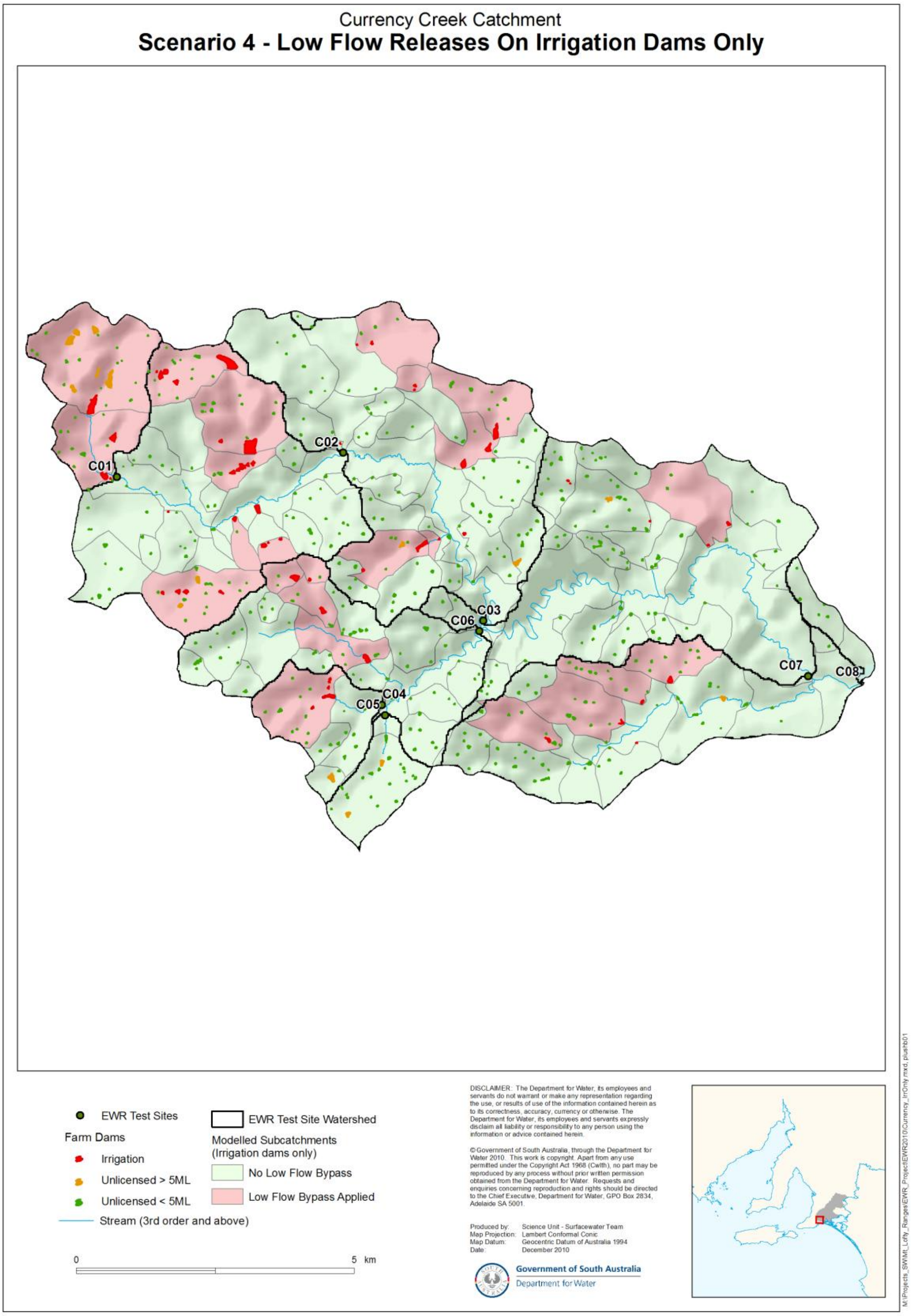

FIGURE 10. CURRENCY CREEK TESTING SITES AND LFB SELECTION SCENARIO 4

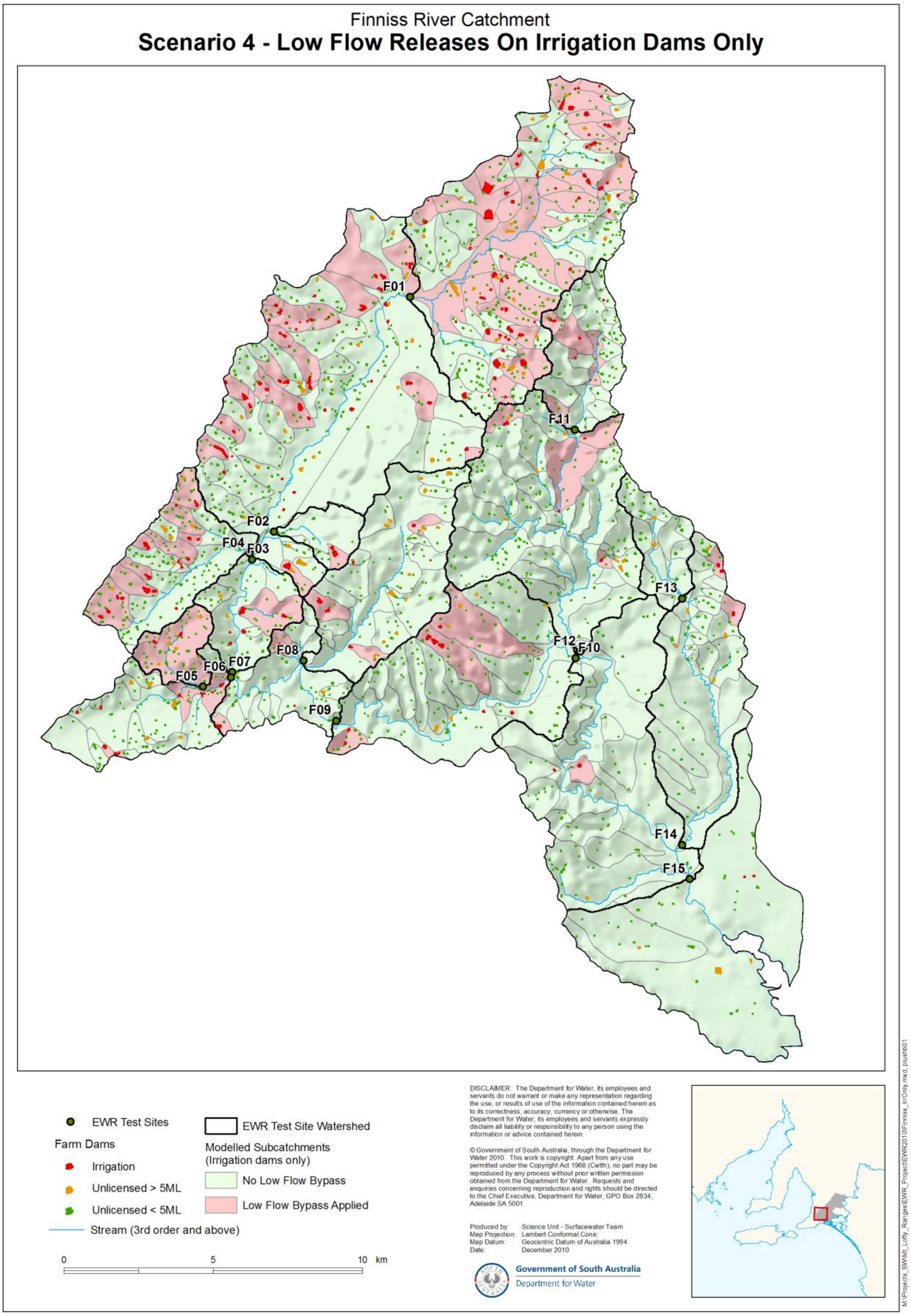

FIGURE 11. FINNISS RIVER TESTING SITES AND LFB SELECTION SCENARIO 4

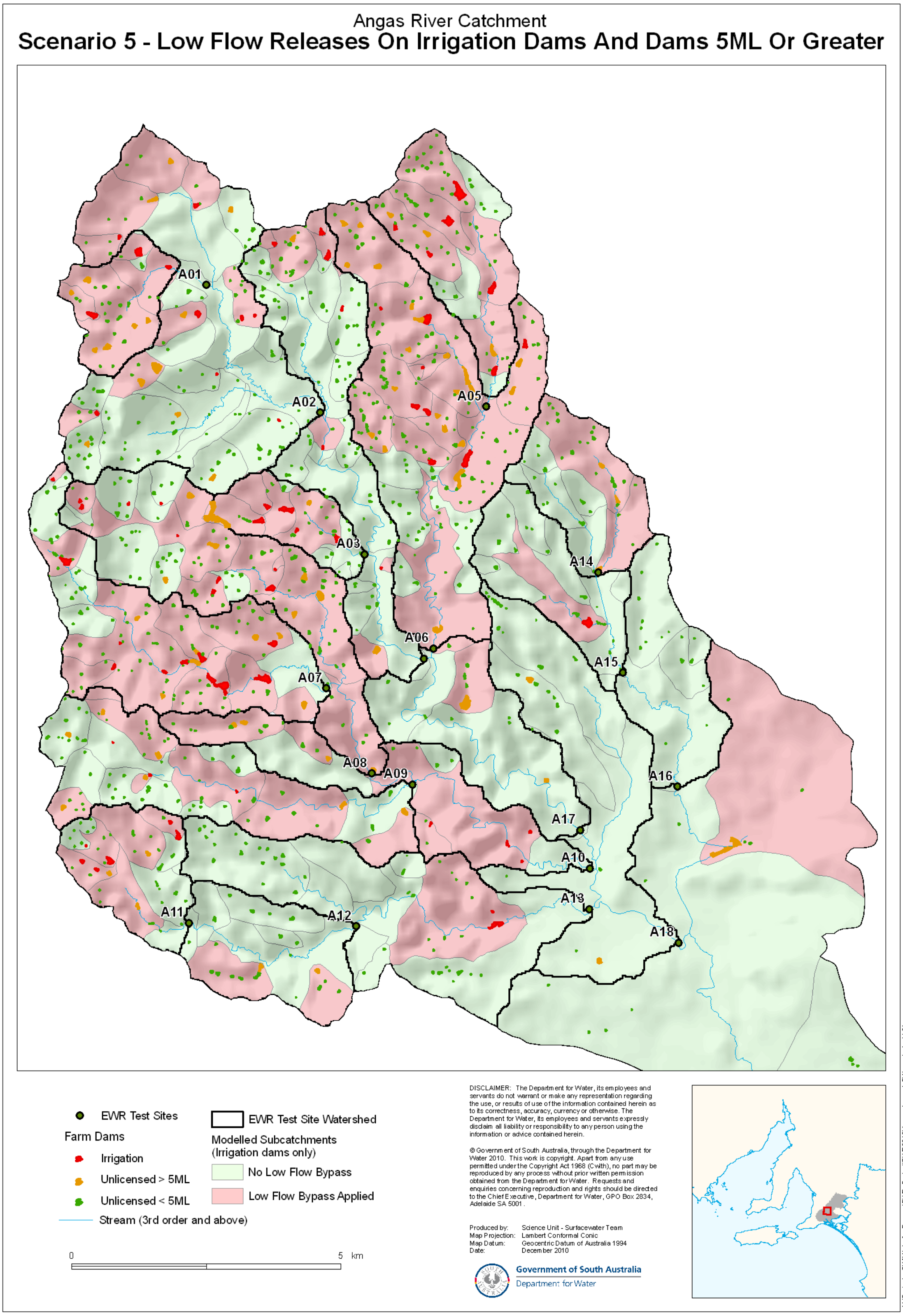

FIGURE 12. **ANGAS RIVER TESTING SITES AND LFB SELECTION SCENARIO 5**

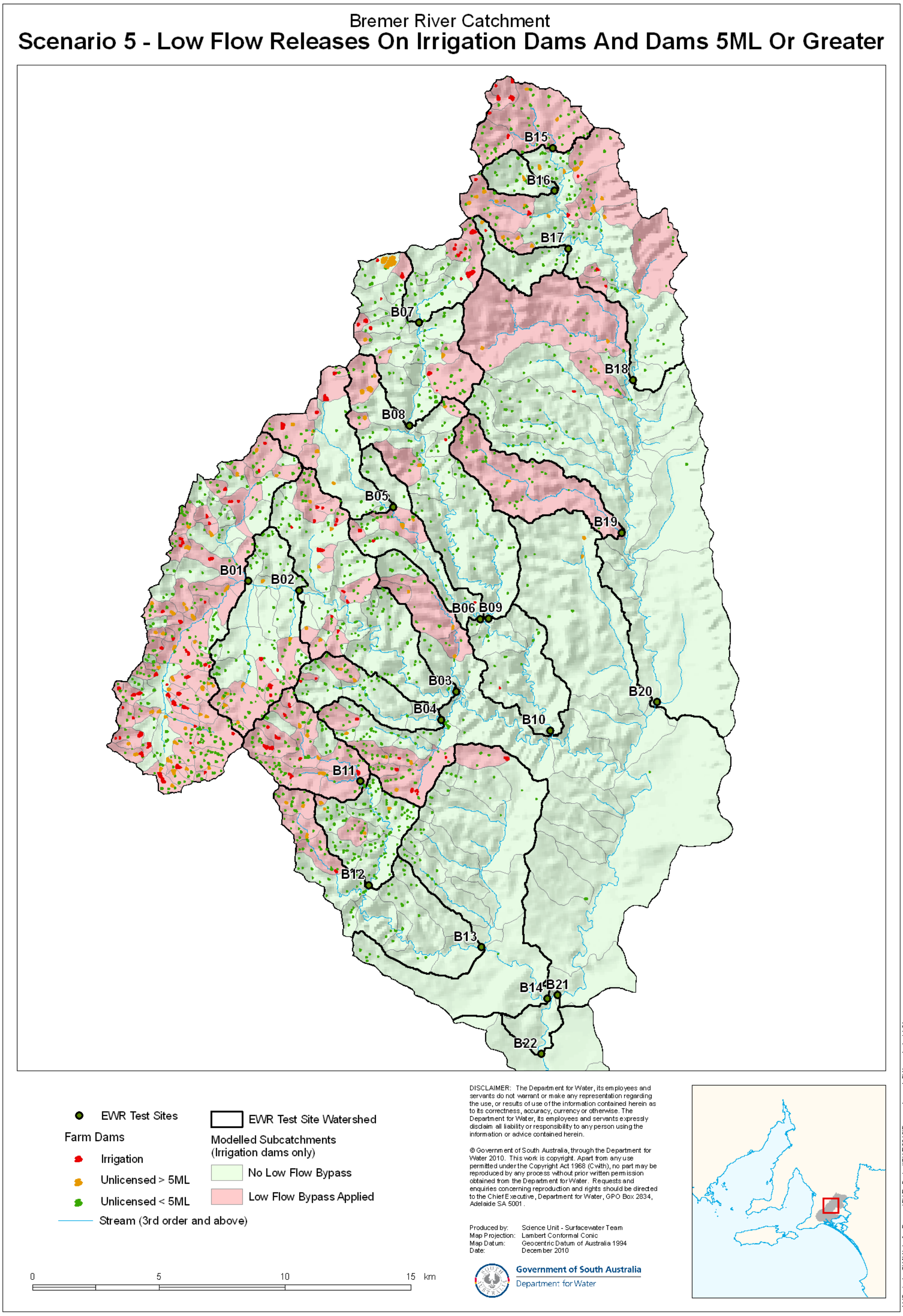

FIGURE 13. BREMER RIVER TESTING SITES AND LFB SELECTION SCENARIO 5

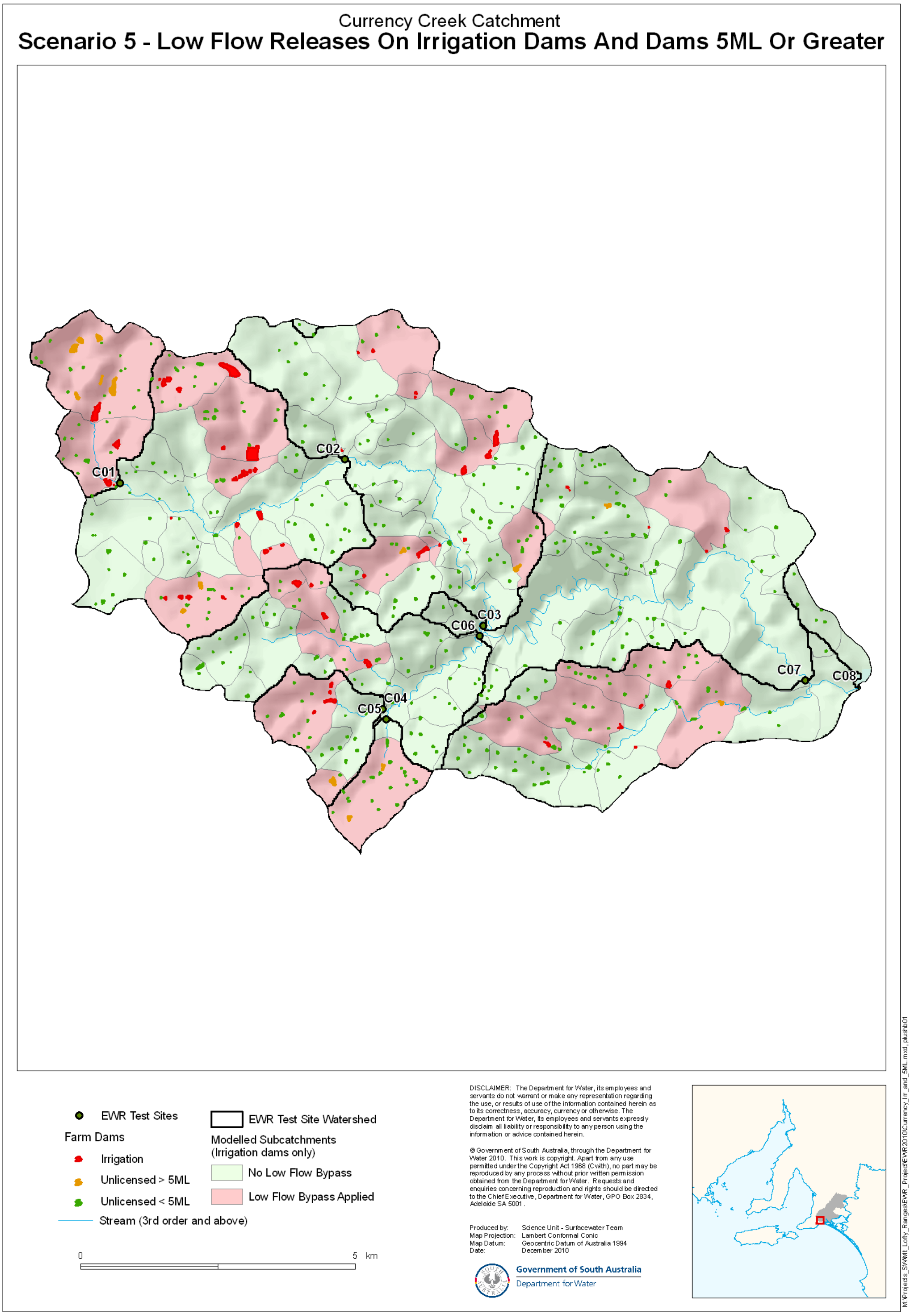

FIGURE 14. CURRENCY CREEK TESTING SITES AND LFB SELECTION SCENARIO 5

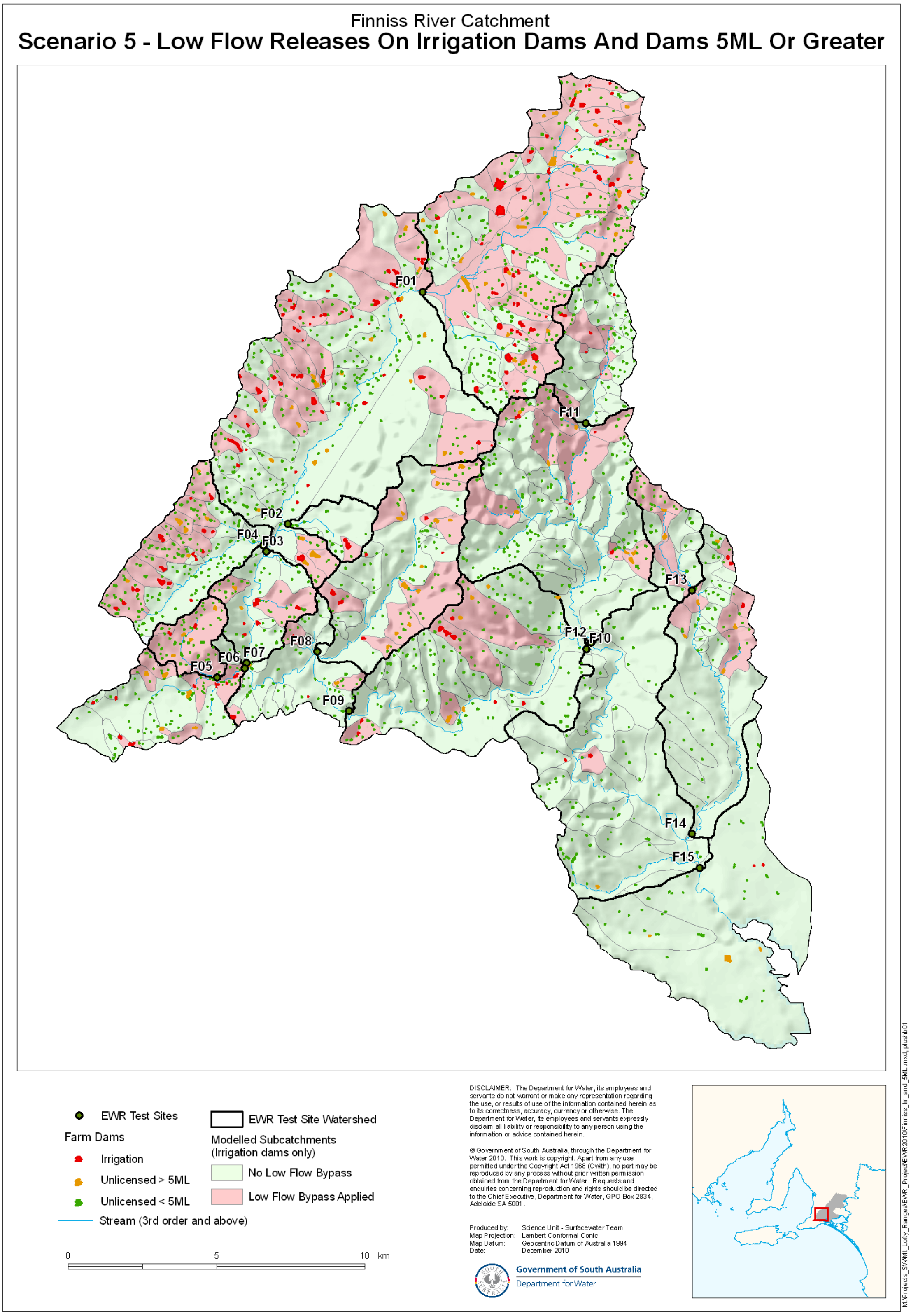

FIGURE 15. FINNISS RIVER TESTING SITES AND LFB SELECTION SCENARIO 5

RESULTS

FARM DAMS

There are a total of 7103 dams counted in the EMLR PWRA with a total estimated capacity of 18.4 GL. Dams with a capacity of at least 5 ML account for 10% (692) of the total number dams with a combined capacity accounting for 64% (11.8 GL) of the total capacity.

Licensed dams:

There were a total of 558 licensed dams identified for this report, comprising an estimated capacity of 6674 ML. Of these 558 dams, 251 are at least 5 ML in capacity.

Non-licensed dams:

A total of 6545 non-licensed dams were identified in this report comprising an estimated capacity of 11,701ML. Of these dams, 441 are at least 5 ML in capacity.

Dams within the model domain:

Of the total 7103 dams inside the EMLR PWRA, 5546 fall within the model domain (Figure 1) of the 4 hydrological models. These dams represent a total of 14,930 ML of storage, which is 81% of the total. There are 472 licensed dams identified and 340 additional Stock and Domestic dams with a capacity of 5 ML or greater. These two categories represent ~75% of the total modelled dam capacity within the five modelled catchments.

MODEL SUB-CATCHMENTS

For the scenario where only Irrigation Dams are required to bypass low flows, 299 of a total 857 model sub-catchments are selected for LFB.

For the scenario where large stock and domestic dams (=> 5 ML) are also required to bypass low flows, 364 of 857 model sub-catchments are selected for LFB.

TABLE 11. MODEL SUB-CATCHMENTS SELECTED FOR LFB

	Scenario 5*: Sub-cats to Bypass Low Flows	Scenario 4**: Sub-cats containing only irrigation dams	Sub-cats containing at least one dam >= 5 ML
Angas	79	56	78
Bremer	137	94	136
Currency	28	33	23
Finniss	128	116	127
Total	372	299	364

*Varied demand on irrigation dams – low flow releases on irrigation dams and dams with a capacity of 5 ML or greater

** Varied demand on irrigation dams – low flow releases on irrigation dams only

WATER USE ESTIMATES FOR DEMAND SCENARIOS

Water use, expressed as a percentage of total runoff (not including stream losses) is reported in Table 12 below. Base case – that is, the current estimate of water usage is highest in the Angas River catchment at

15% of the runoff generated over the catchment, whilst the Finniss River records the lowest overall percentage of usage at 7%.

It should be noted that these figure are reported at a whole of catchment scale, and water usage will be higher at smaller scales within the catchment.

TABLE 12. WATER USAGE AS PERCENT OF TOTAL CATCHMENT RUNOFF FOR VARIOUS DEMAND SCENARIOS

Demand Scenario	Angas			Bremer			Currency			Finniss			Tookayerta		
	No LFB	LFB Irr. Dams Only	LFB Irr. and >= 5 ML	No LFB	LFB Irr. Dams Only	LFB Irr. and >= 5 ML	No LFB	LFB Irr. Dams Only	LFB Irr. and >= 5 ML	No LFB	LFB Irr. Dams Only	LFB Irr. and >= 5 ML	No LFB	LFB Irr. Dams Only	LFB Irr. and >= 5 ML
Base	15	13	13	12	11	11	10	8	8	7	5	5	12	12	12
Use 0	6	5	5	5	5	5	2	2	2	2	2	2	1	1	1
Use 10	7	7	7	7	7	7	4	4	4	3	3	3	2	2	2
Use 20	9	9	9	8	8	8	5	5	5	4	3	3	3	3	3
Use 30	10	10	10	9	8	8	6	6	6	4	4	4	5	5	5
Use 40	12	11	11	10	9	9	7	7	7	5	5	5	6	6	6
Use 50	13	12	12	11	10	10	9	8	8	6	5	5	7	7	7
Use 60	15	13	13	12	10	10	10	8	8	7	6	6	8	8	8
Use 70	16	14	14	12	11	11	11	9	9	7	6	6	10	9	9
Use 80	17	15	15	13	11	11	12	10	10	8	7	7	11	10	11
Use 90	18	15	15	14	12	12	13	11	11	8	7	7	12	12	12
Use 100	19	16	16	14	12	12	14	11	11	9	7	7	13	13	13

CATCHMENT WATER BALANCES

Mean Annual Catchment water balances are estimated here for each catchment for the following scenarios:

1. Scenario 1: No Dams or extractions
2. Scenario 2: Base (Current) – use scenario with no LFB
3. Scenario 4: Base (Current) – use with LFB on Irrigation Dam sub-catchments only
4. Scenario 5: Base (Current) – use with LFB on Irrigation Dam and Large SD Dam sub-catchments.

These data represent the mean annual water balance for the period 1971-2006.

TABLE 13. ANGAS RIVER CATCHMENT WATER BALANCE

Angas River Catchment Water Balance					
		No Dams	**Base**	**LFB Irr.**	**LFB GT 5 ML**
Inflows	Catchment Inflows	10417	10417	10417	10417
	Urban Inflows	238	238	238	238
	Txt In	0	0	0	0
Losses	Farm Dam Losses	0	418	389	371
	Stream Losses/Gains	2315	1682	1994	2071
Supply	Farm Dam Water Supply	0	1133	1097	1086
	Watercourse Water Supply	0	444	273	272
Outflow	End-of System Flow	8335	6964	6897	6854

TABLE 14. BREMER RIVER CATCHMENT WATER BALANCE

Bremer River Catchment Water Balance					
		No Dams	**Base**	**LFB Irr.**	**LFB GT 5 ML**
Inflows	Catchment Inflows	17423	17423	17423	17423
	Urban Inflows	945	945	945	945
	Txt In	439	439	439	439
Losses	Farm Dam Losses	0	611	593	579
	Stream Losses/Gains	2768	2037	2111	2185
Supply	Farm Dam Water Supply	0	1630	1565	1553
	Watercourse Water Supply	0	557	323	325
	Floodplain Diversion/loss	245	4589	3882	3835
	Floodplain Returns	0	1533	1183	1155
Outflow	End-of System Flow	15690	9483	10373	10377

TABLE 15. CURRENCY CREEK CATCHMENT WATER BALANCE

Currency Creek Catchment Water Balance					
		No Dams	**Base**	**LFB Irr.**	**LFB GT 5 ML**
Inflows	Catchment Inflows	8048	8048	8048	8048
	Urban Inflows	0	0	0	0
	Txt In	0	0	0	0
Losses	Farm Dam Losses	0	120	108	106
	Stream Losses/Gains	0	-6	-5	-5
Supply	Farm Dam Water Supply	0	560	545	545
	Watercourse Water Supply	0	229	104	105
Outflow	End-of System Flow	8047	7139	7293	7295

TABLE 16. FINNISS RIVER CATCHMENT WATER BALANCE

Finniss River Catchment Water Balance					
		No Dams	**Base**	**LFB Irr.**	**LFB GT 5 ML**
Inflows	Catchment Inflows	38195	38195	38195	38195
	Urban Inflows	0	0	0	0
	Txt In	0	0	0	0
Losses	Farm Dam Losses	0	486	447	430
	Stream Losses/Gains	-42	-56	-46	-44
Supply	Farm Dam Water Supply	0	1950	1918	1916
	Watercourse Water Supply	0	567	115	114
Outflow	End-of System Flow	38235	35224	35749	35771

Based on the catchment water balances presented in Tables 12 to 16, there would be a total of 2% increase to end of system flows for both Scenarios 4 and 5 as opposed to Scenario 3 (Current). There appears to be little difference in the overall end-of-system flows between the two LFB scenarios. Whilst this may suggest there is little benefit in applying Scenario 5 over Scenario 4 in terms of mean annual water balances, it should be noted that the determination of Environmental Water Requirements uses a more detailed set of criteria to assess this against. These criteria are not discussed further in this report as they are the subject of a previous report on the determination of the EWR of the MLR (VanLaarhoven, et al., 2009).

In the Angas River catchment, there appears to be a negative difference in the end of system flow with the Low Flow Bypass scenarios when compared with Scenario 3. This can be largely attributed to the method employed to simulate stream losses in the lower reaches of the model which use a linear relationship to model loss. In the event that low flow releases enable flow to travel through to the Angas Plains section of the model, some of this low-flow is simulated as being lost to the stream bed. This flow would be in addition to any losses currently occurring in the model if the flow occurs at a time in which the stream did not previously flow.

EFFECT OF LFB AND DEMAND SCENARIOS ON DAILY FLOW

Results in this section are presented for two testing sites – B18 and F15. These results are intended to demonstrate the effect on the daily flow regime of bypassing low flows from farm dams and setting threshold flow levels on watercourse extractions for the two bypass scenarios in catchments with different flow regimes ranging from dry (B18) to wet (F15).

Site B18 Results

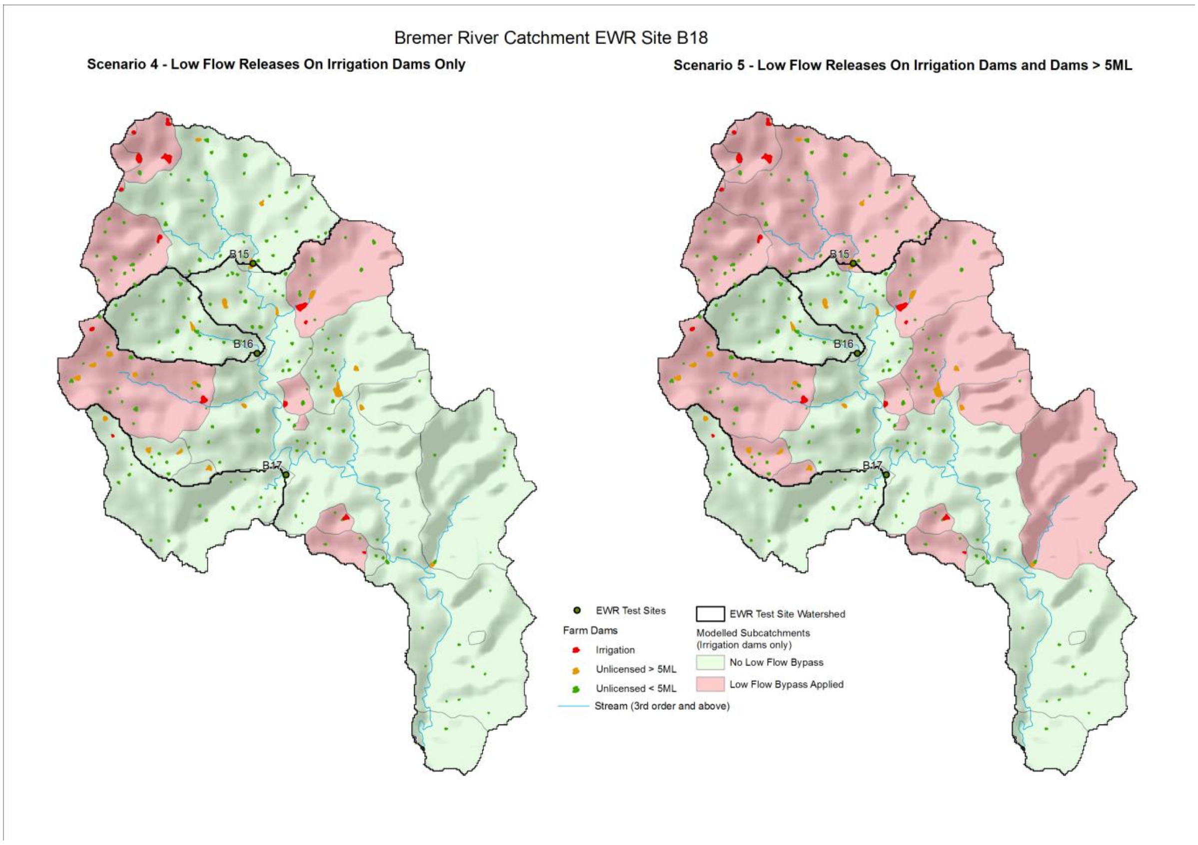

FIGURE 16. MODEL LAYOUT COMPARISON OF SCENARIOS 4 AND 5 FOR EWR SITE B18 IN THE UPPER BREMER RIVER

TABLE 17. EWR SITE DETAILS FOR B18 IN THE UPPER BREMER RIVER

Catchment	**Bremer River**
Zone NAME	B18
Upstream Adjusted Runoff (KL)	2736557
Upstream Dam Farm Dam Capacity (KL)	645341
Dam Capacity /Upstream Runoff	24%
Dam Density (ML/km^2)	11.2
Reach Type	Wet Upper Pool Riffle

TABLE 18. DAILY FLOW STATISTICS FOR EWR SITE B18 IN THE UPPER BREMER RIVER

Daily Flow Statistic (ML/day)	Scenario 1	Scenario 2	Scenario 4	Scenario 5
Mean	7.85	6.96	7.00	7.00
10th Percentile	0.00	0.00	0.00	0.00
20th Percentile	0.00	0.00	0.00	0.00
30th Percentile	0.00	0.00	0.00	0.00
40th Percentile	0.00	0.00	0.00	0.00
50th Percentile	0.05	0.00	0.00	0.00
60th Percentile	0.23	0.00	0.00	0.00
70th Percentile	0.73	0.00	0.01	0.19
80th Percentile	2.05	0.76	1.17	1.42
90th Percentile	6.65	4.61	4.91	5.03

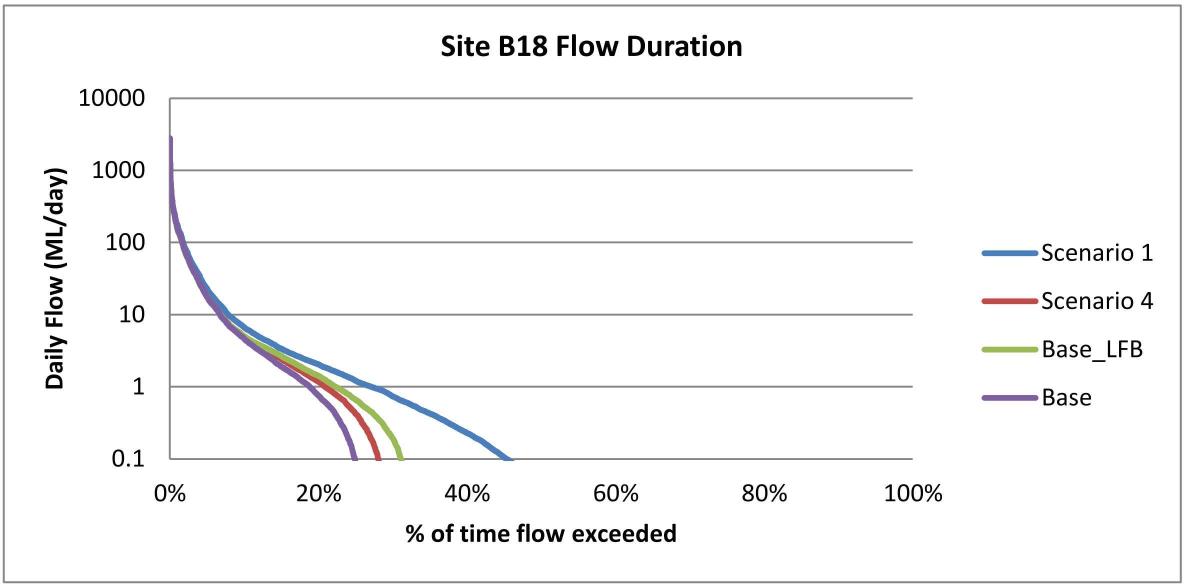

FIGURE 17. FLOW DURATION CURVES FOR EWR SITE B18 IN THE UPPER BREMER RIVER

Comprising the upper reaches of the Bremer River with rainfall of around 500mm, EWR zone B18 under the pre-development scenario would flow for less than 50% of the year. Under the current-use scenario, flow is reduced in this reach to around 20% of the time during an average year.

Figure 17 shows an improvement in both Scenarios 4 and 5 with daily flows in both scenarios increasing by around 10 percent in duration. The improvement in flows below 1ML/day is considerable for both scenarios in relative terms showing a 21% improvement in the 80th Percentile Flow (Table 17).

Note that modelling of very low flows in dry ephemeral catchments generally entails a high level of uncertainty, and as such the results should be taken as an indicative response for a low rainfall ephemeral stream reach. For calibration details of the Bremer River model please refer to the modelling report for that catchment. (Alcorn, 2008)

Site F15 Results

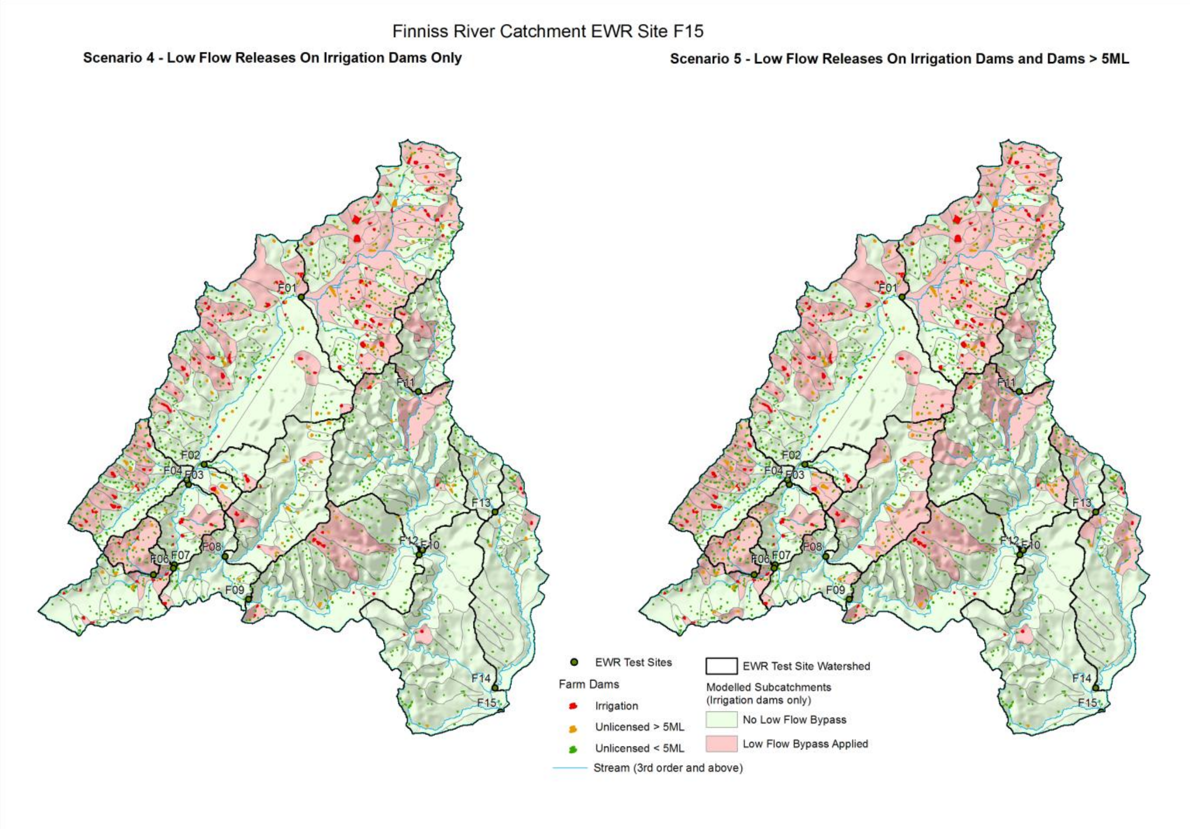

FIGURE 18. MODEL LAYOUT COMPARISON OF SCENARIOS 4 AND 5 FOR EWR SITE F15 IN THE LOWER FINNISS RIVER

TABLE 19. EWR SITE DETAILS FOR F15 IN THE LOWER FINNISS RIVER

Catchment	Bremer River
Zone NAME	F15
Upstream Adjusted Runoff (KL)	38,194,644
Upstream Dam Farm Dam Capacity (KL)	5,006,231
Dam Capacity /Upstream Runoff	13%
Dam Density (ML/km^2)	13.3
Reach Type	Lowland with Floodplain

TABLE 20. DAILY FLOW STATISTICS FOR EWR SITE F15 IN THE LOWER FINNISS RIVER

Daily Flow Statistic (ML/day)	Scenario 1	Scenario 2	Scenario 4	Scenario 5
Mean	100.94	92.84	94.26	94.31
10th Percentile	2.99	0.00	1.51	1.88
20th Percentile	6.05	0.67	3.14	3.77
30th Percentile	9.91	2.73	5.95	6.86
40th Percentile	16.22	7.14	10.21	11.35
50th Percentile	26.48	15.33	18.22	19.41
60th Percentile	42.58	31.69	31.48	32.67

Daily Flow Statistic (ML/day)	Scenario 1	Scenario 2	Scenario 4	Scenario 5
70th Percentile	66.76	55.74	53.43	53.57
80th Percentile	117.19	107.63	96.04	95.15
90th Percentile	264.16	251.10	247.33	245.11

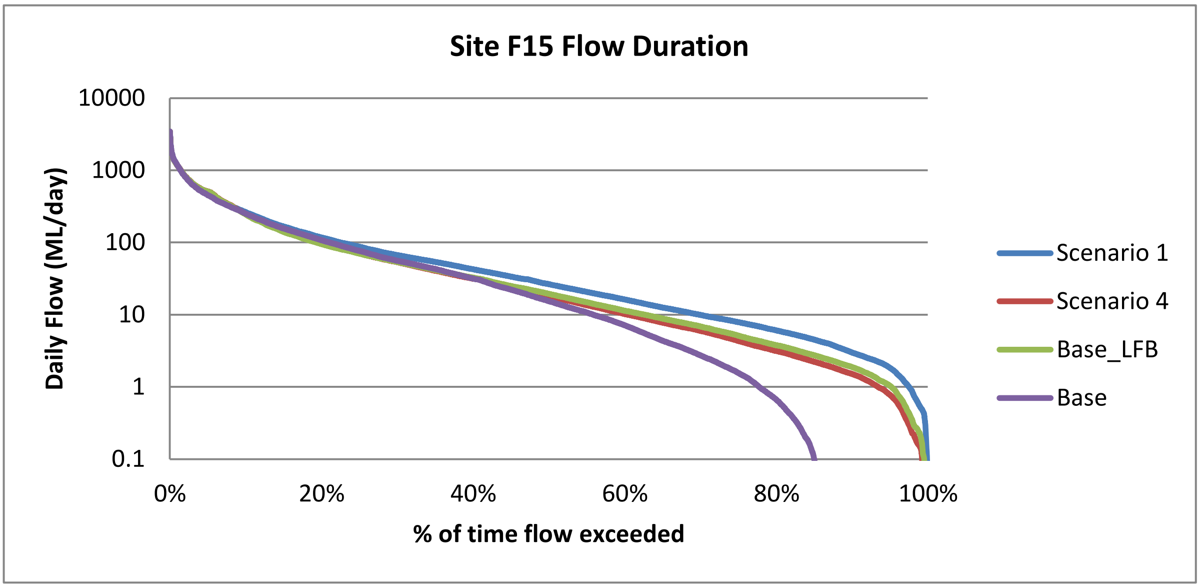

FIGURE 19. FLOW DURATION CURVES FOR EWR SITE F15 IN THE LOWER FINNISS RIVER

Site F15 drains almost the entire Finniss River catchment and so shows the full catchment scale impact of bypassing low flows from farm dams and watercourse extractions. The flow duration indicates that under current conditions, the Lower Finniss flows for just over 80% of the year, whilst under adjusted conditions it may flow for the entire year. The bypassing of low flows would greatly improve the duration of flows up to around 10 ML/day.

Interestingly, bypassing low flows would have the effect of actually decreasing some high flows in the range of 100 ML/day or greater. The cause of this effect is that allowing low flows to bypass the system early in the season can delay the fill of the dam to its maximum capacity. In doing so, the spill of water is effectively spread over a longer period, thereby reducing the size of some peak flows.

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