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Tookayerta Creek Catchment

Source model build and scenario modelling

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Department for Environment and Water
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Acknowledgement of Country

We acknowledge and respect the Traditional Custodians whose ancestral lands we live and work upon and we pay our respects to their Elders past and present.

We acknowledge and respect their deep spiritual connection and the relationship that Aboriginal and Torres Strait Islanders people have to Country.

We also pay our respects to the cultural authority of Aboriginal and Torres Strait Islander people and their nations in South Australia, as well as those across Australia.

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1 Project overview

1.1 Introduction

The Department for Environment and Water (DEW) Water Science and Monitoring Unit (WSM) provides scientific services and advice to support and inform Government policy and regional delivery programs. In this capacity, WSM has developed catchment-scale hydrological models to help develop an understanding of catchment behaviour and surface water availability and simulate potential policy or initiatives.

Water Science support to the Flows for the Future program has included modelling and assessment for provision of low flows through priority catchments, with the aim of achieving environmental water provision and consumptive use limits, defined in the Eastern Mount Lofty Ranges Water Allocation Plan and Basin Plan.

A catchment model of the Tookayerta Creek was developed using WaterCress in 2004 (Savadamuthu 2004) with subsequent updates in 2010. The model structure was such that farm dams were lumped (that is, grouped to be treated as one large dam) within each model sub-watershed. The model was calibrated with community-collected water level (converted to flow) data. Quality assurance of the data and the rating relationship could not be undertaken to preferred DEW standards due to insufficient validations available at the time for pre-2000 streamflow conditions (i.e., prior to the Millennium drought).

This project has developed a new Tookayerta catchment model using eWater Source. Up-to-date modelling technology and best practice conceptualisation methods are important for ensuring reliable forecasts of demand, water availability, infrastructure capacity and cost-effective supply. Source is nationally recognised as the best-practice hydrological modelling platform. Transition of the existing Tookayerta catchment model to Source provided an opportunity to account for any changes to the catchment and its response and to construct the model in a way that is more flexible for future uses (that is, to have individual farm dams and watercourse extractions/diversions represented explicitly, along with representation of drains across the catchment). The model was calibrated using data from the, then, South Australian Murray–Darling Basin Natural Resources Management (SAMDB NRM) Board operated flow monitoring sites.

1.2 Modelling scope

The key output for this project is a calibrated rainfall–runoff model of the Tookayerta Creek catchment in the eWater Source modelling platform. As there are multiple uses for this model, it has been developed as a fully-distributed model where possible (that is, explicit representation of the spatial distribution of individual farm dams and watercourse extractions/diversions) to ensure the greatest flexibility in use.

In contrast to models built for other catchments, the Tookayerta Creek catchment is confounded by an extensive network of historical drains which may act as flow diversions from the watercourse or alter contributing catchments to a storage (for example, a dam). Reconnaissance and on-ground surveys of these features suggest that the data available does not always match what actually occurs on the ground, and that, in some instances, this may have policy implications (for example, in setting an accurate low-flow bypass rate). While effort was made to accurately represent these features in the model, it is noted that it is unlikely that all the relevant information was fully available/incorporated in the model.

Another key difference between Tookayerta Creek catchment and other catchments in the Eastern Mount Lofty Ranges (EMLR) is that the catchment has a very high proportion of baseflow (input from groundwater) throughout the year. This means the watercourses flow all year, supporting important water-dependent ecosystems. The perennial flow also leads to a higher proportion of water being taken from watercourses as needed for irrigation or other consumptive purposes rather than being captured in dams over the wetter seasons for later use in drier seasons as tends to occur in other EMLR catchments[1]. These factors mean that this modelling has paid particular attention to use of watercourse allocations during model calibration and behaviour of flow metrics representing key environmental water requirements.

The scope of the scenario modelling exercise was to identify the extent to which the Surface Water Management Zones (SWMZs) meet the Environmental Water Provision (EWP) targets under various *Current-use* and *Current-allocation* demand scenarios for the Tookayerta Creek catchment.

[1] For example, 81% of the standard allocation volume from surface water plus watercourses in the Tookayerta Creek catchment is taken from watercourses. This value is 23 to 39% for the hills component of the other major EMLR catchments (data taken from the Mount Lofty Ranges Assessment Dataset, version November 2022). These values are calculated excluding special allocation types such as lower Angas Bremer flood diversions and also excluding the substantial standard watercourse allocation volumes that are taken from the plains area of the Angas and Bremer Rivers, downstream of the major flow gauges used for model calibration.

2 Modelling domain and process

A new hydrological model for the Tookayerta Creek catchment (Figure 1) was constructed using the eWater Source modelling platform. The model is fully distributed in regard to relative spatial representation of all farm dams and watercourse extractions, with some exceptions, present at the time of model construction. A section of the catchment and its representation in the model is shown in Figure 2. A small number of water holding features were removed from the model, as they were identified as either turkey nest dams (which are elevated with negligible interception of surface water runoff) or are part of the Geographical Information System sub-watershed delineation process, where the delineated upstream areas resulted in diagonal pixels, indicating negligible catchment and runoff interception area.

Watercourse extractions

Watercourse extractions are typically located on third order or higher streams (fourth, fifth or sixth) with the majority of catchment flow generated from the upper section of the catchment. Given their location on main watercourses, most of them have large watershed areas with: (a) the majority of the catchment flows passing through them; and (b) their threshold flow (low-flow release) rates being higher in comparison to those for hill-side farm dams. Diversions and direct extractions from watercourses for irrigation purposes generally occur during late winter or from spring into the early summer months and this is reflected in the modelling where watercourse demand is extracted across the 6-month period from October to March each water year. This period is when flows in watercourses are receding; flows then mostly consist of base flow, which continues across this period, making Tookayerta Creek a perennial system. To achieve the overall program objective of passing low flows through the entire catchment, it is imperative that *only* flows above the threshold flow rate are extracted from watercourses. This approach is consistent with the threshold flow rate principles in the EMLR Water Allocation Plan (WAP) (SAMDB NRM Board 2019).

Drain diversion points

Tookayerta is unique when compared to other catchments across the Mount Lofty Ranges due to the presence and use of an extensive network of human-made drains (Figure 1). Construction of some drains date back more than a century and were primarily constructed to drain peatlands and other swampy or wetland areas to allow their use for agricultural purposes. The extensive drainage has reduced the extent of those wetland areas and substantially altered their hydrology with drains moving water out of wetlands more rapidly (Farrington et al. 2017). This means that these wetlands retain less water and it is possible that flow to downstream areas may be intermittent such as with flash flooding rather than a more consistent release from a large 'sponge' of hydrated peat or wetland soil.

The effects of wetland drainage on the flow pattern in the Tookayerta Creek catchment has not been explicitly represented in the model. Flow data are not available from pre-drainage conditions to support model calibration, and the EMLR WAP aims to work with current landscape conditions rather than seek a return to pre-European conditions.

Another effect of the drainage network is to divert flow from the main watercourses of Tookayerta and Nangkita Creek via gravity to off-stream locations across the catchment. This diversion affects the amount of flow available at watercourse diversions and dams and so it is useful to incorporate the major diversion features of the drainage network into the surface water model.

Field work was undertaken at key locations to estimate the flow split percentage at the junction of watercourses and drains. Work undertaken included surveys of watercourse and drain cross-section and slope. Flow velocity measurements at different locations were also taken along the watercourse and drains. This information was used to develop a theoretical rating of water level-to-flow at key locations to then parameterise 'splitter nodes' in the model, where a percentage of upstream flow is directed to a drain, while remaining flow continues down the watercourse.

The percentage flow split calculated and as used in the model at key locations are:

- Site 6 (upstream of trout farm), main watercourse 15%, drain 85%;
- Site 6a (downstream of trout farm), main watercourse 70%, drain 30%;
- Site 8, main watercourse 40%, drain 60%; and
- Site 9 (stop log weir – photograph on the cover page), main watercourse 90%, drain 10%.

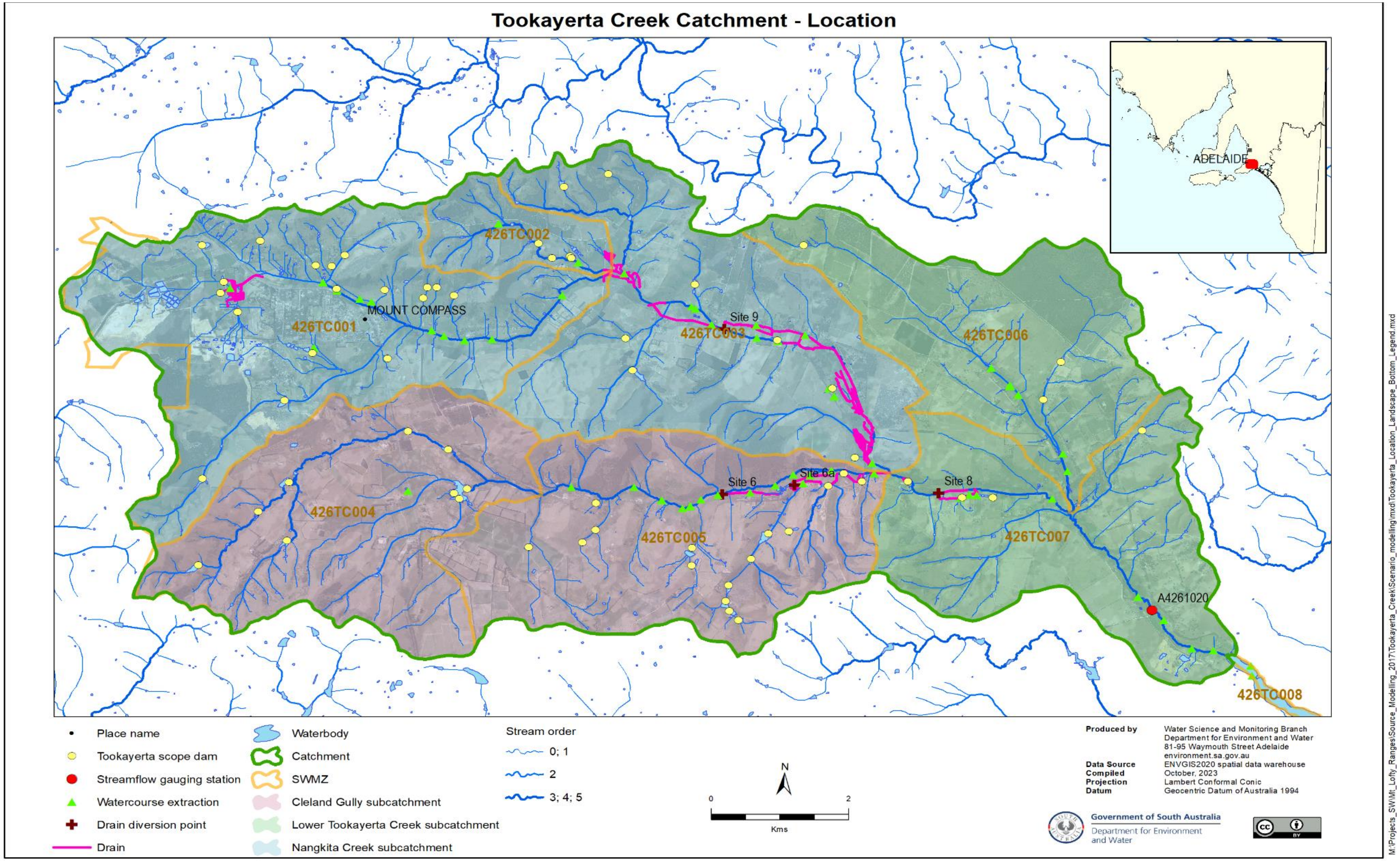

Figure 1. Tookayerta Creek catchment location and model drain diversion points

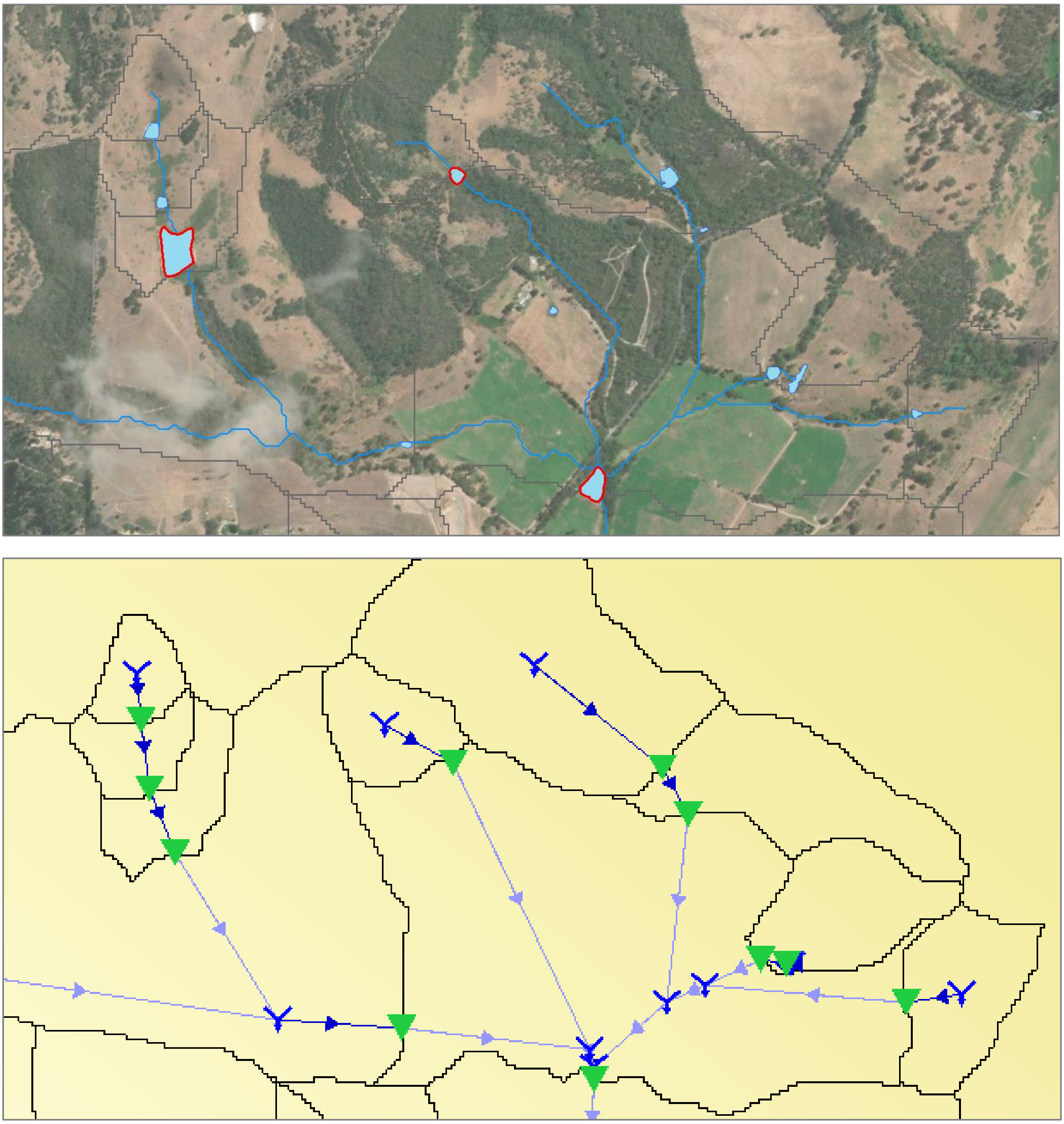

Figure 2. Tookayerta Creek model screenshot and corresponding satellite imagery

2.1 Model calibration

Functional units (FUs) are classified in Source to group spatial units with approximately similar hydrological responses. Model FUs for this study were defined as a raster by simplifying soil texture data sourced from ENVGIS 2020 and grouping them into one of 3 broad categories that affect rainfall–runoff response within the Tookayerta landscape: sand (S1); sandy loam (S2); and sandy clay loam (S3) (Figure 3). Dividing a catchment into discrete hydrologic units, coupled with the use of various climate data files, allows FUs to produce different runoff responses which is discussed further in Section 2.2. In areas where no gauged data are available, this approach allows a model to produce similar patterns of rainfall–runoff responses.

When calibrating the model, maximum water demand from dams and watercourse diversions were assumed to be as follows:

- non-licensed dams: 30% of dam capacity;
- licensed dams: 50% of dam capacity; and
- licensed watercourse extractions: 30% of allocated volume.

Non-licensed watercourse extractions are not included in the model.

These maximum water demand values were selected as being reasonable representations of current use to match up with the measured flow that occurred in response to actual climate, landscape and water use during the calibration period. The demand percentages for dams are the standard percentages used in models calibrated for other Mount Lofty Ranges catchments, based on McMurray (2004). The allocation-demand percentage for watercourse allocations is based on the average annual metered use of watercourse allocations as a percentage of allocated volume, calculated for the Tookayerta Creek catchment for 2017 to 2022.

Results indicate that the model calibrates well at the main gauging station Tookayerta Creek downstream Nangkita Creek (A4261020) for the calibration period 2013 to 2021 (Figure 4). This gauging station records 100% of streamflow generated from the 'hills' section of the catchment, just upstream from the outlet of Surface Water Management Zone (SWMZ) 426TC007. The daily flow duration curve demonstrates a very good fit between modelled and observed data with the difference in flow bands across low, medium, and high flows just 2%, 0% and 0% respectively. Overall bias difference across the calibration period is −0.5%.

The initial calibration annual NSE[2] statistic, which compares modelled to observed annual flow, was observed to be quite poor at 0.26 NSE. The confidence levels of the observed rainfall and streamflow data used as model inputs during this period could be the contributing factors. Two periods from May to September 2015 and July to December 2016 were identified as having a large impact on results and can be clearly seen in the monthly and annual flow charts in Figure 4. May to September 2015 showed much larger observed streamflow than modelled, while the opposite was observed from July to December 2016 with observed streamflow being much smaller than modelled. To confirm the 2 periods were impacting calibration results, data for this period ('suspect data') were removed and results analysed (Figure 5). Total monthly and annual flow charts show a much better fit and this is observed in the statistics where monthly and annual R values improved from 0.85 to 0.90 and 0.83 to 0.94 respectively, while monthly and annual NSE values improved from 0.71 to 0.81 and 0.26 to 0.86 respectively. Daily

[2] The Nash-Sutcliffe efficiency (NSE) is a normalised statistic that determines the relative magnitude of the residual variance compared to measured data variance and calculated as one minus the ratio of the error variance of the modeled time-series divided by the variance of the observed time-series. A perfect model with estimation error variance equal to zero results in an NSE = 1. Conversely, a model that produces an estimation error variance equal to the variance of the observed time-series results in an NSE = 0.

statistics were observed to be slightly lower as a result, while the difference observed in the high flow band became slightly larger.

It should be noted that rating accuracy at this gauging station is considered ±10% for water level up to approximately 3.0m (around 335 ML/d) and ±50% for water levels above 3.0 m when the road is overtopped, indicating less confidence in higher flows. Rainfall–runoff parameters adopted in the final model and presented in Table 1 are from calibration including the periods of suspect observed data.

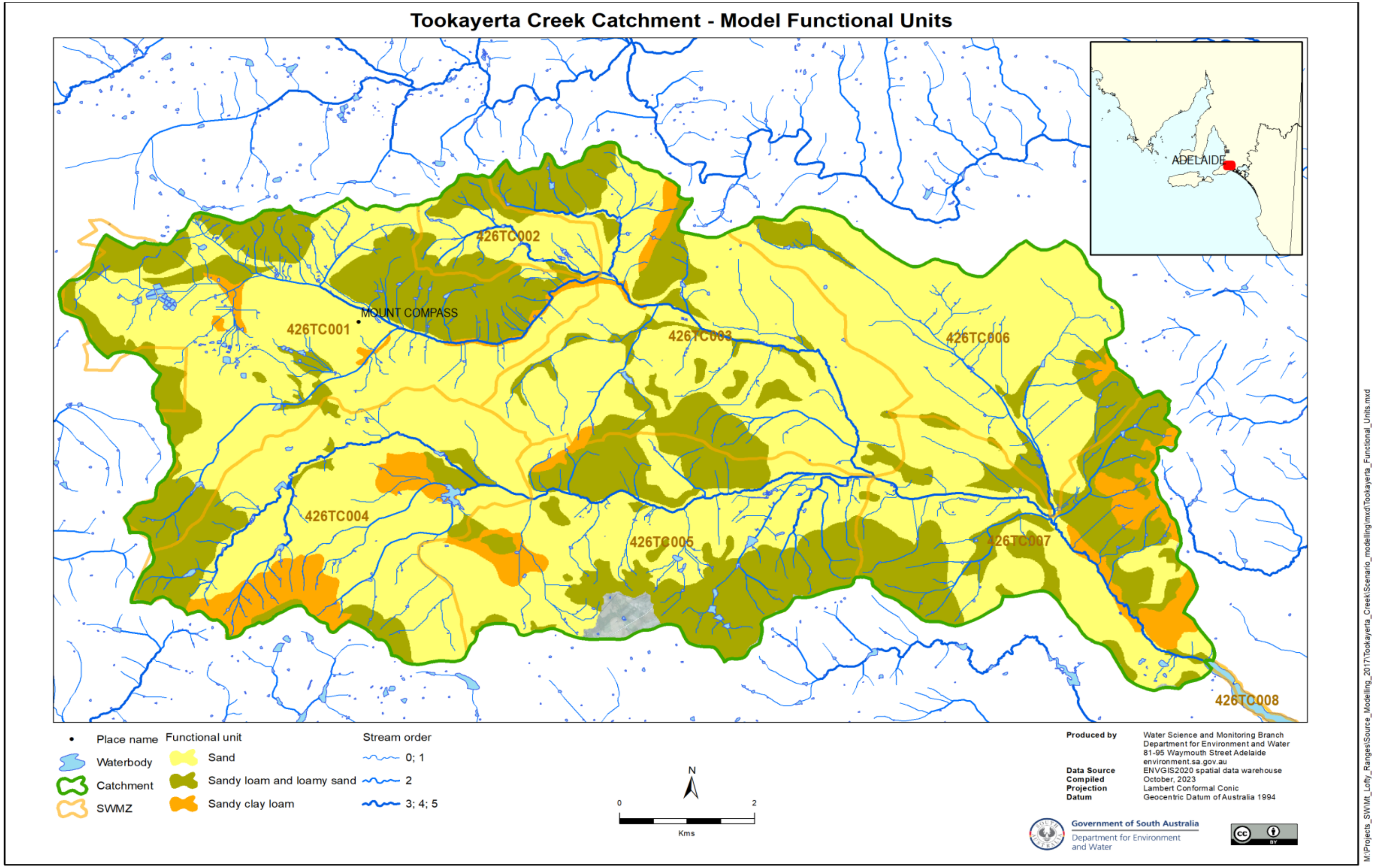

Figure 3. **Model functional units**

2.1.1 Gauging station A4261020: Tookayerta Creek d/s Nangkita Creek

Statistic	Daily	Monthly	Annual	Percentile exceedance	Daily observed flow (ML)	Daily modelled flow (ML)	Difference %	Difference Q band
r	0.75	0.85	0.83	90th	4.0	4.1	2%	Low
				80th	7.0	7.2		
NSE	0.57	0.71	0.26	70th	9.5	9.9	0%	Med
				60th	12.3	13.8		
				50th	17.3	18.0		
				40th	23.9	23.9		
				30th	32.8	30.4		
Bias	−0.5%	−0.5%	−0.5%	20th	45.6	42.0	0%	High
				10th	72.3	76.4		

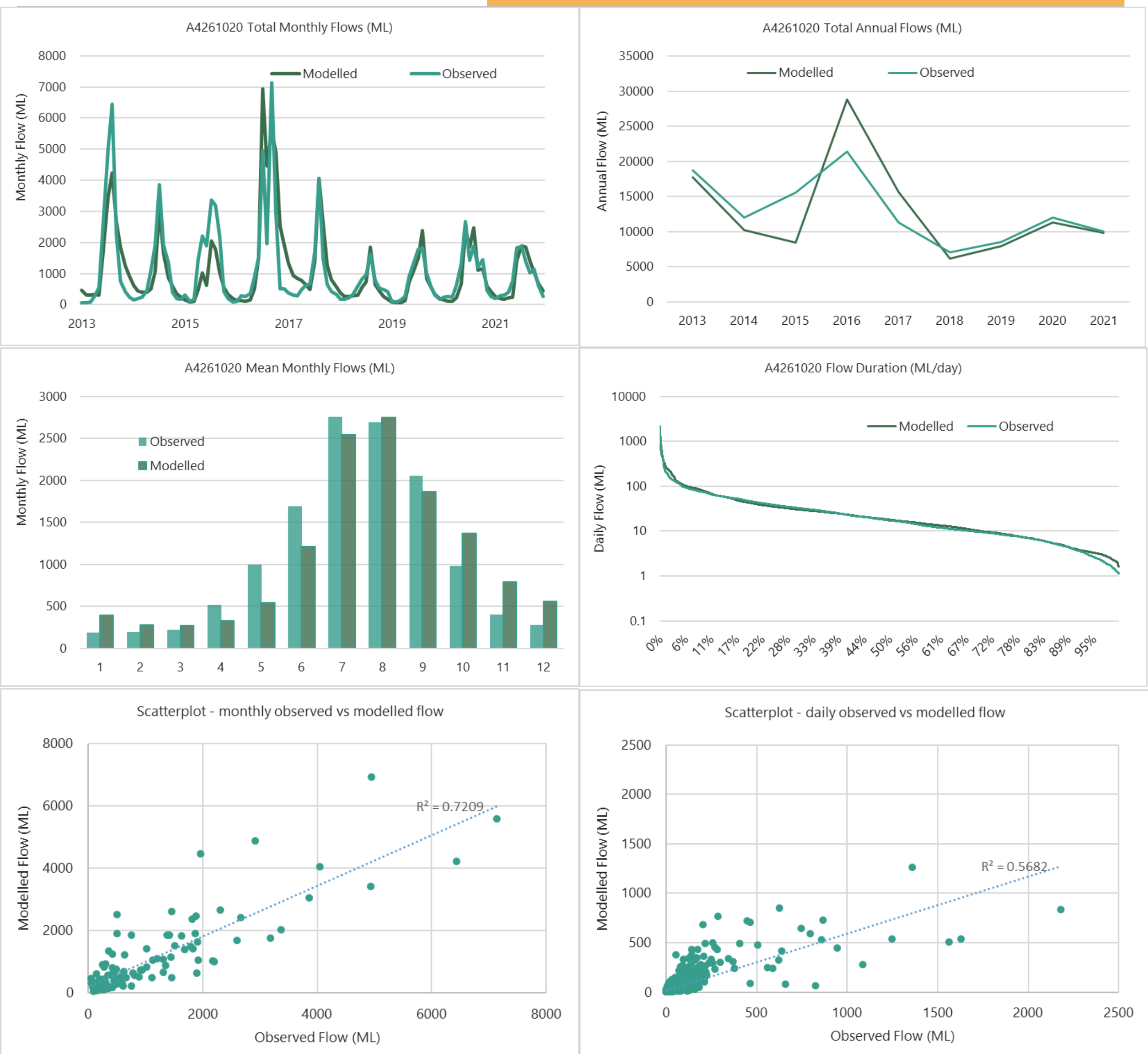

Figure 4. Calibration results for gauging station A4261020 (2013 to 2021)

2.1.2 Gauging station A4261020: Tookayerta Creek d/s Nangkita Creek – suspect data removed

Statistic	Daily	Monthly	Annual	Percentile exceedance	Daily observed flow (ML)	Daily modelled flow (ML)	Difference %	Q band
				90th	3.7	3.9	2%	Low
r	0.73	0.90	0.94	80th	6.5	6.6		
				70th	8.8	9.2	1%	Medium
				60th	11.1	12.3		
NSE	0.54	0.81	0.86	50th	15.4	15.9		
				40th	20.5	20.6		
				30th	28.6	27.4		
Bias	−3%	−3%	−3%	20th	38.5	35.1	-8%	High
				10th	59.4	55.3		

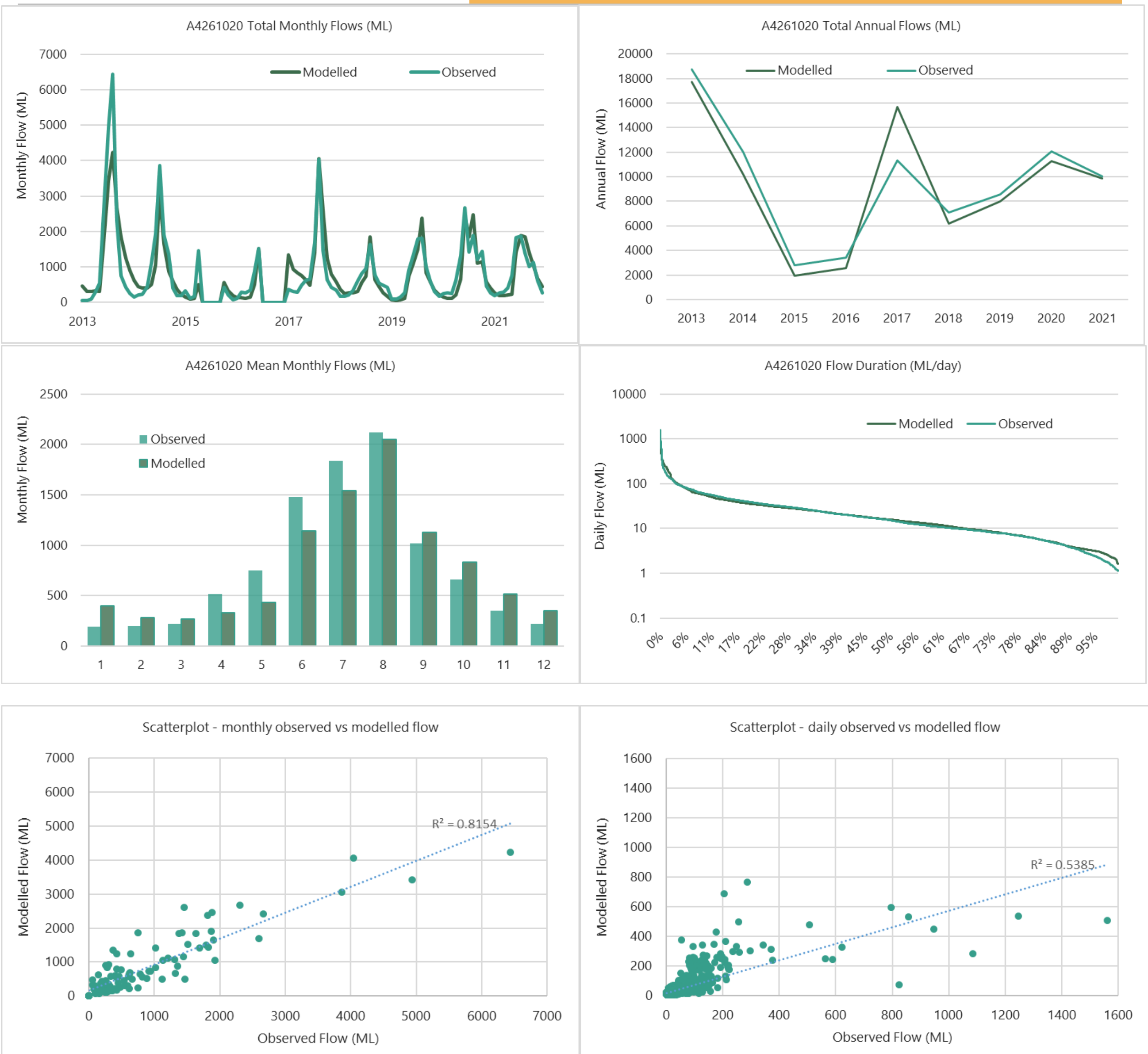

Figure 5. Calibration results for gauging station A4261020 (2013 to 2021) – suspect data removed.

Table 1. Calibrated AWBM parameters of the Tookayerta Creek catchment model

AWBM model parameter	A1	A2	C1 (mm)	C2 (mm)	C3 (mm)	BFI	KBase	KSurf
Description	Partial area of surface store 1	Partial area of surface store 2	Capacity surface store 1	Capacity surface store 2	Capacity surface store 3	Baseflow index	Baseflow recession constant	Surface flow recession constant
Calibrated model parameters for Tookayerta Creek								
FU S1	0.328	0.144	38.000	220.000	266.404	0.892	0.992	0.977
FU S2	0.182	0.182	39.485	102.386	203.533	1.000	0.200	0.628
FU S3	0.278	0.000	0.505	33.622	221.006	0.101	0.200	0.999

2.2 Rainfall–runoff relationship

Rainfall–runoff is the relationship between annual rainfall and runoff, that is, total annual flow (expressed as runoff depth in millimetres) generated from a catchment area for a total annual rainfall (in millimetres). Plotting the annual time-series of rainfall against runoff and fitting a curve using a Tanh function, the annual rainfall–runoff relationship for the calibration period (2013 to 2021) for the Tookayerta catchment is shown in Figure 6. The runoff coefficient is derived by dividing the average annual runoff depth (in mm) of an area by the average annual rainfall. Results are summarised by model functional unit in each subcatchment in Table 2. For example, the runoff coefficient for the S1 functional unit (sand) in the Nangkita Creek subcatchment is 0.22, or in simpler terms, on an annual basis, an average of 22 mm of runoff is generated from the S1 functional unit in this subcatchment for every 100 mm of rainfall. The coefficient was derived from modelled mean annual runoff (151 mm) and mean annual rainfall (702 mm) for the model calibration period 2013 to 2021. As expected, the S1 (sand) functional unit runoff coefficient in each subcatchment is consistently lower than the S2 (sandy loam) functional unit. The S3 (sandy clay loam) functional unit has the highest runoff coefficient across each subcatchment. The Tookayerta Creek catchment as a whole has an area-averaged runoff coefficient of 0.24 for the calibration period 2013 to 2021.

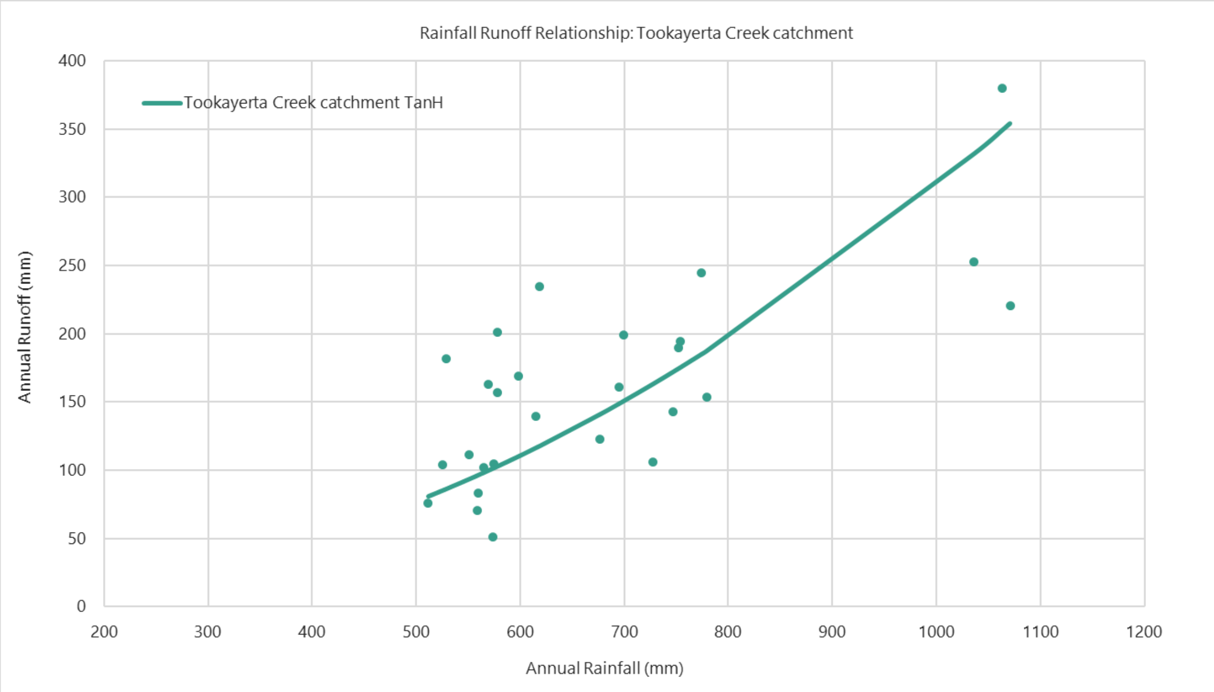

Figure 6. Rainfall–runoff relationship, Tookayerta Creek catchment

Table 2. Runoff coefficients for subcatchments of the Tookayerta Creek catchment

Subcatchment	Period of record*	Functional unit	Mean annual rainfall (mm)	Mean annual runoff (mm)	Runoff coefficient
Nangkita Creek	2013 to 2021	S1	702	151	0.22
		S2	713	180	0.25
		S3	712	203	0.28
Cleland Gully	2013 to 2021	S1	719	162	0.23
		S2	702	172	0.25
		S3	747	226	0.30
Lower Tookayerta Creek	2013 to 2021	S1	574	84	0.15
		S2	604	107	0.18
		S3	583	127	0.22
Total catchment	2013 to 2021	S1, S2, S3	677	160	0.24

*Denotes model simulation period

2.3 Model assumptions and limitations

The Tookayerta Source model is primarily set up to estimate catchment rainfall–runoff and for use as a farm dam and water allocation impact tool. Calibration was limited to observed streamflow data for the period 2013 to 2021. The coverage of farm dams and watercourse extractions used in the model were assumed current as at the start of the model build process.

Other limitations include:

- watercourse extractions are limited to the months of October to March only, to mimic reduction in rainfall;
- possible temporal changes in physical characteristics of the catchment, such as soil or land use change or change in surface water–groundwater interaction, are not included. No change in these above factors over the modelling period is assumed which means these modelling inputs are held constant;
- a focus on calibration for the more recent period (post-Millennium drought) to align with available daily observed streamflow data;
- observed data from gauging station A4261020 containing a number of daily high flow events, which the model has trouble simulating, which is common with conceptual rainfall–runoff models;
- that only licensed watercourse extractions are used in the model. Watercourse extractions for non-licensed (stock and domestic) purposes have not been mapped. This is consistent with the approach in other EMLR catchments, where watercourse extractions for non-licensed purposes are generally assumed to be minor and/or the data are unavailable; and
- that the Tookayerta Creek catchment model does not incorporate the effects of commercial forestry on runoff. This approach is consistent with other EMLR models. Fourteen per cent of the total catchment area is in the 'Forestry/Protected Area' land use classification. Commercial forestry is assumed to reduce average annual adjusted runoff by 85% in the EMLR WAP.

3 Scenario modelling

Scenario modelled for the Tookayerta Creek catchment are described below and in Table 3.

The *No-dams* scenario removes the impact of farm dams and watercourse extractions from the model to mimic 'pre-development' conditions.

The *Current-use* scenario includes the impact of farm dams and watercourse extractions on water resources to mimic current on ground conditions. Demand is set to 30% or 50% of dam capacity for non-licensed and licensed farm dams, respectively. Demand from watercourse extractions is set to 30% of allocation and is based on average actual use from 2017 to 2022 when compared to total allocations.

The *Current- allocation* scenario includes current estimated use from farm dams, as per the *Current-use* scenario. However, demand from watercourse extractions is set to 100% of allocation.

Scenarios modelled in addition to each of *Current-use* and *Current-allocation* scenarios include *BaseWAP* and *WCE LFR only*. The *BaseWAP* scenario incorporates low flow release (LFR) implementation to all scope dams[3] and watercourse extractions present in the model. The *WCE LFR* only scenario incorporates LFR implementation to watercourse extractions only.

Table 3. Scenarios modelled

Scenario name	Scenario definition in model
No-dams	Impact of farm dams and watercourse extractions removed.
Current-use	Current impact of farm dams and 30% of allocation demand for current watercourse.
Full Allocation	Current impact of farm dams and 100% of allocation demand for current watercourse extractions.
Current-use BaseWAP	*Current-use* scenario with LFR applied to all scope dams and watercourse extractions present in the model.
Current-use WCE LFR only	*Current-use* scenario with LFR applied to watercourse extractions only present in the model.
Current-allocation BaseWAP	*Current-allocation* scenario with LFR applied to all scope dams and watercourse extractions present in the model.
Current-allocation WCE LFR only	*Current-allocation* scenario with LFR applied to watercourse extractions only present in the model.

The next stages of modelling if required, which are beyond the scope of this exercise, include:

1. Strategic Low Flow Release (SLFR) scenario modelling to optimise LFR implementation by identifying the minimal combination(s) and/or groups(s) of scope sites required to meet the EWP targets defined in the Water Allocation Plan for the Eastern Mount Lofty Ranges. Dams and/or watercourse extractions that constitute the minimum subset of scope sites required to meet the EWP targets are referred to as Tier 1 sites. Scope sites not required to pass low flows to meet EWP targets are referred to as Tier 2 or Tier 3 sites; and

2. Simulating a fully allocated catchment. Current total water demand from surface water + watercourses in the Tookayerta Creek catchment is 72% of the evaporation and consumptive use limit (data from the

[3] Scope dams: (i) Dams used for licenced purposes – any size and (ii) dams used for non-licensed purposes ≥ 5 ML.

MLR WAP assessment dataset, version November 2022) with an additional 1,294 ML available for consumptive use (and evaporation from dams) within the limit. Further development up to the limits will affect the flow regime, near stream groundwater levels, and the existing and future scope sites that need to pass low flows to meet the EWP target may be different to those required under the current level of development. See section 4 Recommendations.

3.1 Scenario modelling additional flow volume results

The Tookayerta hydrological model was used to model the scenarios described in Table 3. Each scenario was run for a 36-year period, from 1971 to 2006 (WAP model run period), incorporating a 3-year model 'warm up' from 1971 to 1973. Daily flow was output at the outlet of each Surface Water Management Zone (SWMZ) in the modelling domain. Daily flow outputs from each model scenario were then compared to flow from the *Current-use* scenario to determine the volume of additional water available to the system. Additional flow volume results from the scenario modelling are presented in Appendix A.

The total number of scope sites across the Tookayerta catchment is 125, comprising 62 farm dams and 63 watercourse extractions. The threshold flow rate applied to each for scenario modelling was calculated as:

Threshold flow rate (L/s) = Unit Threshold Flow Rate (L/s/sq.km) x total upstream area (sq.km)

The Unit Threshold Flow Rate is 1 L/s/sq.km for each site, as per the EMLR Water Allocation Plan.

Under the *Current-use* scenario with no LFR, the mean annual flow available at the end of the system is estimated to be 16,243 ML. The end of the system is the outlet of SWMZ 426TC009; however, the majority of catchment runoff is generated in the hills zone upstream of SWMZ 426TC007. The *Current-use BaseWAP* scenario, where low flow releases are applied to all 125 scope sites, results in 171 ML of additional flow at the end of system. When applying LFR to watercourse extractions only, the *Current-use WCE LFR only* scenario results in 166 ML of additional flow at the end of system. The small 5 ML difference in additional flow between *Current-use BaseWAP* and *Current-use WCE LFR only* scenarios highlights that the 62 scope dam LFR across the catchment contribute negligible additional flow with the majority of additional flow being achieved via LFR from the 63 watercourse extractions.

End of system mean annual flows under the *Current-allocation* scenario is 15,164 ML, around 1,079 ML less than the *Current-use* scenario. As expected under the *Current-allocation* scenario, mean annual flow is consistently lower across all SWMZ compared to *Current-use* scenario flow. Applying LFR to all scope sites under full allocation conditions, the *Current-allocation BaseWAP* scenario results in 520 ML of additional flow at the end of the system compared to the *Current-allocation* scenario and 559 ML less than the *Current-use* scenario. Additional flow at the end of the system under the *Current-allocation WCE LFR only* scenario is 523 ML when compared to the *Current-allocation* scenario.

3.2 Assessment of environmental water requirements

3.2.1 Background on environmental water provision target and metrics

The EMLR WAP and the existing user licensing process for the area use the same volumetric limits on the amount of water available for consumptive use, plus associated rules requiring flows up to the threshold flow rate to be returned at sufficient sites (SAMDB NRM Board 2019; VanLaarhoven and van der Wielen 2012). These limits and rules have been set to provide adequate environmental water provisions to maintain water-dependent ecosystems at an acceptable level of risk, while balancing social and economic requirements. Specifically, these limits and rules have been set to meet the EWP target of failing no more than 15% of the environmental water requirements (EWR) flow metrics for the majority of cases.

The EWR metrics are described in VanLaarhoven and van der Wielen (2012) and in Chapter 2 of the EMLR WAP. In summary, the EWR metrics are flow statistics chosen to represent key components of the flow regime that are important for supporting environmental processes, such as magnitude, duration, and frequency of different flow components in different flow seasons. Flow components include flows of different sizes such as zero flows, low flows, bankfull (high) flows and freshes (short pulse flows after rainfall). The flow seasons in Tookayerta are described as low flow season (January to April), high flow season (July to October), transition from low to high (T1, May to June) and transition from high to low (T2, November to December). Watercourses have been mapped into different reach types, where a reach type is an area of similar aquatic habitat. Different subsets of the EWR metrics apply to different reach types.

For each EWR metric, a target has been set as the maximum allowable deviation from the metric's value under the 'No dams' scenario. If the value for an EWR metric for a given flow scenario is outside that allowable range, then the metric is considered to 'fail'. For a given site and flow scenario, all the relevant EWR metrics are assessed and the proportion of EWR metrics that fail are calculated. A scenario at a site is considered to fail the EWP target if 15% or more of the EWR metrics fail.

For the purposes of scenario modelling, the EWR metrics are calculated and assessed using the modelled flow at the downstream end of each SWMZ. In addition, if the most downstream SWMZ in a catchment fails (426TC009 for Tookayerta Creek), then the entire catchment is considered to fail.

3.2.2 Calculation of environmental water requirement metrics in Tookayerta Creek catchment

The flow data and EWR metrics results are reviewed to check whether the results seem reasonable and to interpret the outcomes. Through this review, it was noticed that the standard method for identifying the occurrence of freshes, or short pulse flows after rainfall events was not reasonably representing this type of flow event in the modelled flow data and that some of the associated EWR metrics were failing as a result.

In the standard EWR metric calculations, a fresh flow event occurs when the modelled flow rate is higher than the fresh threshold rate for a flow season, where the fresh threshold rate is calculated as twice the median non-zero daily flow rate for the season for the *No-dams* scenario. In the Tookayerta Creek catchment, the modelled baseflow can be quite high in the T2 transitional flow season from high to low and even into the low flow season, particularly in wet years. This baseflow can be high enough that it exceeds the fresh threshold rate in some years and so is identified as a fresh under the standard EWR metric calculations, even though there has not been recent rainfall. For many scenarios, flow extraction reduces the length of time that this baseflow is above the fresh threshold rate compared to the *No-dams* scenario and is often reduced to the extent that some of the EWR metrics for freshes fail.

However, these cases of large and long-duration baseflow are not actually freshes from a hydro-ecological perspective (that is, not shorter pulse flows following rainfall events). Thus, the standard method of identifying freshes for these seasons in the Tookayerta Creek catchment is not working as intended and is mis-identifying some flow events as freshes. This seems to be a problem particular to the Tookayerta Creek catchment because of the very high baseflow compared to other EMLR catchments.

Figure 7 provides an example. This graph shows rainfall (blue columns) and modelled daily flow for the T2 (high to low) flow season for 1992 in SWMZ 426TC005 for the *No-dams* (green solid line) and *Current-allocation* (orange solid line) scenarios. The fresh threshold rate is shown as a grey dashed horizontal line and any day with flow above this threshold is considered to be a fresh under the standard EWR metric calculations. Days that meet this standard fresh rule are shown with a triangle at the top of the graph (green for the No-dams scenario and orange for the *Current-allocation* scenario) with contiguous fresh days joined with a dotted line to show the duration of the fresh event.

It can be seen that for the *No-dams* scenario, a fresh event occurs from 1 November through to 6 December, primarily due to baseflow being above the fresh threshold rate, rather than in response to recent rain. The fresh event from 18 to 21 December occurs in response to rain, so is a true fresh event. For the *Current-allocation* scenario, a fresh event occurs from 1 November to 11 November, again primarily due to baseflow being above the threshold flow rate (although the last 3 days of this event is due to rainfall response). This baseflow-driven fresh is much shorter than the one that starts at the same time in the *No-dams* scenario as baseflow for the *Current-allocation* scenario is reduced by extraction and so is above the fresh threshold rate for a shorter time. As a result, the metric for fresh duration for this season is more likely to fail for the *Current-allocation* scenario.

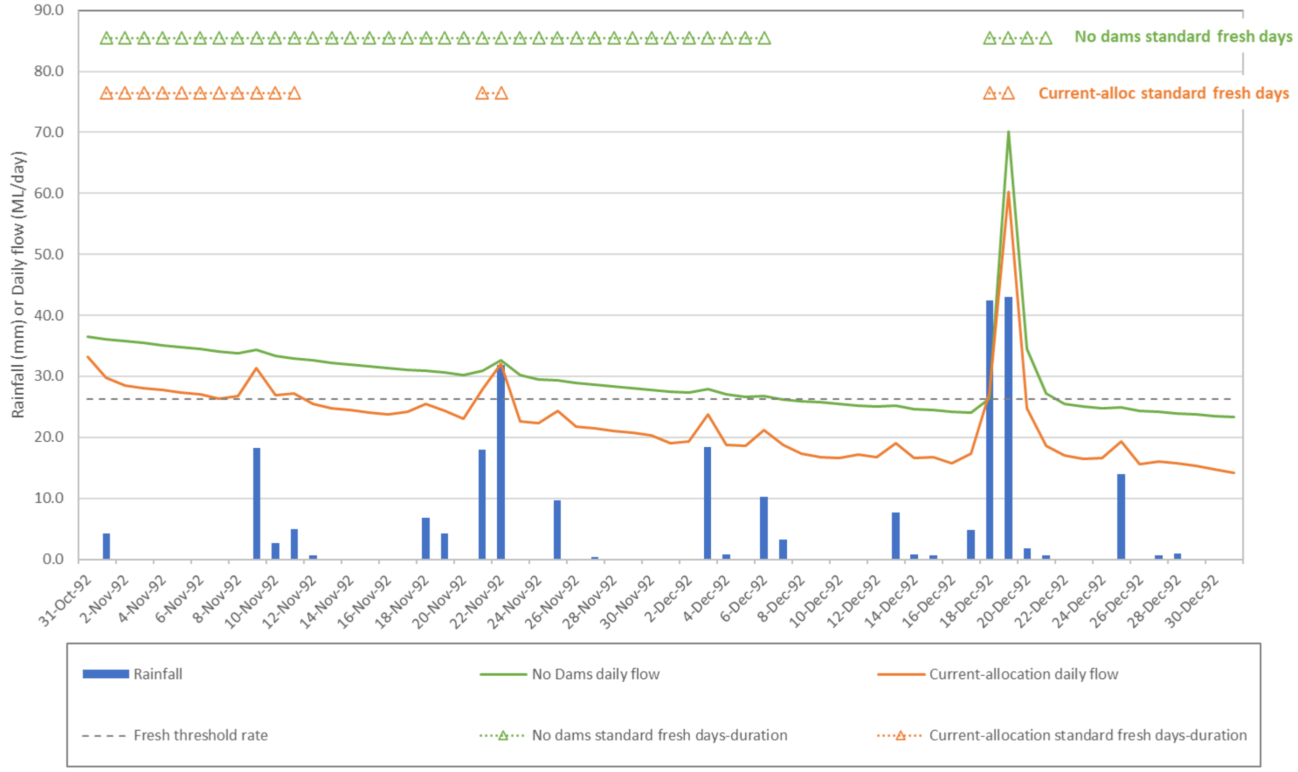

Figure 7. Rainfall, modelled daily flow and duration of standard fresh events for Tookayerta zone 426TC005, for *No-dams* and *Current-allocation* (no LFR) scenarios, for T2 (transition high to low) flow season for 1992

As a result, a revised method was developed for identifying when a fresh event is occurring, for the T2 transitional flow season and low flow season, for use in the Tookayerta Creek catchment. The rules for this revised method, as well as the standard EWR metric calculations are given in Table 4. Note that the fresh threshold rate is calculated in the same way for both methods.

Table 4. Rules for identifying when a fresh event starts and finishes, for the standard EWR metrics calculations, and for the revised method for freshes in T2 and low flow season in Tookayerta Creek catchment

	A fresh event starts* when:	A fresh event finishes** when:
Standard EWR metrics	Daily flow rate is higher than the fresh threshold.	Daily flow rate is less than the fresh threshold.
Revised EWR metrics for freshes in T2 and low flow seasons for Tookayerta Creek catchment	All of these conditions are met. a) Daily flow rate is higher than the fresh threshold. b) There has been rainfall today or yesterday. c) The flow rate today is higher than yesterday.	Either: a) daily flow rate is less than the fresh threshold; or b) daily flow rate is below the flow rate from the day before the fresh event started.

* *That is, day 1 of a fresh event is the day that all of these conditions are first met.*

** That is, it is no longer a fresh event on the day these conditions are first met, and the last day of the fresh event is the previous day.

The effect of the revised method is to identify the same fresh events as the standard method but exclude those where it has not rained recently, and/or where the flow rate has not increased after rain.

As per Table 4, once a fresh has started, it ends when the daily flow drops: (a) below the fresh threshold; or (b) below the daily flow rate from the day before the fresh event started, whichever occurs first. Part (b) was included to force freshes to end for cases where the baseflow was already higher than the fresh threshold when the fresh event started. Otherwise, the fresh would continue until the baseflow drops below the fresh threshold which may represent an extended period. However, from a hydro-ecological perspective, it seems reasonable to consider that the rainfall-driven flow pulse ends when daily flow is back to what it was before the pulse started.

Figure 8 shows the same example data as Figure 7 but also includes fresh days that meet the revised fresh rules as crosses above the graph (green for *No-dams* scenario, orange for *Current-allocation* scenario). Comparing the triangles (standard fresh days) and crosses (revised fresh days) within a scenario shows that the revised method still includes freshes where flow increases after rain and is above the fresh threshold rate (for example, 9 November for *No-dams* scenario and 9 to 11 November for *Current-allocation* scenario). However, the revised method excludes the fresh days where daily flow is above the fresh threshold rate, but it has not rained recently and/or where the flow rate has not increased after rain – for example:

- 1 to 2 November for both scenarios are not considered fresh days under the revised rules, as the daily flow has not increased compared to the previous day despite rainfall on 1 November; and
- 3 to 8 November for both scenarios are not considered fresh days under the revised rules, as it has not rained on those days or the previous day.

Figure 8. Rainfall, modelled daily flow and duration of standard and revised fresh events for Tookayerta zone 426TC005, for *No-dams* and *Current-allocation* (*no LFR*) scenarios, for T2 (transition high to low) flow season for 1992

The reduction in daily flow in scenario *Current-allocation* (compared to *No-dams*) apparent in Figure 7 and Figure 8 is captured in the EWR metrics for magnitude of low flows and average daily seasonal flow.

This revised method for identifying when a fresh event is occurring in T2 and low flow seasons was incorporated into the EWR metrics calculation spreadsheet and used to calculate the EWR metric results for each modelled flow scenario, for each SWMZ.

3.3 Environmental water requirement metric results for modelled scenarios

Table 5 shows the percentage of EWR metrics failed for each modelled flow scenario, for each SWMZ in the Tookayerta Creek catchment. Scenarios that have failed the EWP target for a zone are shown in bold font (i.e. failed 15% or more of the EWR metrics for the scenario for the zone).

The results for the *Current-use* scenarios are included for information on the impact of current use on achievement of the EWP target at a SWMZ scale. However, the *Current-use* scenarios should not be used for decision-making on implementation of low flows policy. Licensees are legally permitted to use up to their full allocation and could do so in future. Decision-making should be based on what is permitted to occur, not current use. The primary purpose of developing the *Current-use* scenario was for model calibration purposes, as outlined in Section 2.1.

The *Current-allocation* scenarios represent what is permitted to occur based on the current level of allocation and so provide a first step to support decision-making on implementation of low flows policy. However, before proceeding with implementation of low flow policy in the Tookayerta Creek catchment, scenarios need to be run that simulate a fully allocated catchment, where model water demand equals the volumetric limit on consumptive water use set in the EMLR WAP (see section 4 Recommendations).

Table 5. Percentage of EWR metrics failing for each Tookayerta Creek catchment SWMZ, for different flow scenarios.

SWMZ	% EWR metrics failed for different flow scenarios					
	Current-use (no LFR)	Current-use BaseWAP	Current-use WCE LFR only	Current-allocation (no LFR)	Current-allocation BaseWAP	Current-allocation WCE LFR only
426TC001	5%	2%	5%	5%	2%	5%
426TC002	5%	5%	5%	7%	7%	7%
426TC003	5%	2%	5%	7%	2%	5%
426TC004	5%	5%	5%	5%	5%	5%
426TC005	5%	5%	5%	**17%**	14.6%	10%
426TC006	2%	0%	0%	5%	2%	2%
426TC007	5%	5%	5%	8%	13%	8%
426TC008	5%	5%	5%	**16%**	11%	11%
426TC009	5%	5%	5%	**16%**	11%	11%

Key results for the *Current-use* scenarios.

- All the *Current-use* scenarios pass the EWP target, even those *Current-use* scenarios that do not pass low flows.
- The metrics that are failing are the magnitude of low flows in low flow season and T2 (high to low) flow season. Passing low flows raises the low flow rate enough for these metrics to pass in some cases (for example, zones 426TC001, 003 and 006 fail fewer metrics for BaseWAP scenario, compared to *Current-use* scenario with no LFR).
- Examining the detail within the EWR metric results shows that passing low flows for the *Current-use* scenario often gives a better environmental flow pattern for cases when the percentage of metrics failed does not change. For example, the seasonal low flow rates are usually higher if low flows are passed but this increase is not enough to cause failing low flow metrics to pass for some zones.

Key results for the *Current-allocation* scenarios.

- The higher levels of water use in the *Current-allocation* scenarios are associated with a higher percentage of the EWR metrics failing, compared with the *Current-use* scenarios.
- Three SWMZs fail the EWP target for the *Current-allocation* scenario with no LFR (426TC005, 008 and 009). This includes the most downstream SWMZ, so the overall catchment is also considered to fail the EWP target for this scenario.
- Both scenarios that pass low flows result in all SWMZs passing the EWP target (i.e., *Current-allocation* BaseWAP and *Current-allocation* WCE LFR only).
- For the current level of allocation, passing low flows at only scope watercourse diversions would be sufficient to pass the EWP target for all zones in the Tookayerta catchment. However, the catchment is not yet fully allocated. As outlined in section 4 Recommendations, more work is needed to determine if the EWP target

would still be met for all zones once the catchment becomes fully developed, if low flows are passed at scope watercourse diversions only.

- In some cases, the best result (lowest percentage failed) is achieved with the *Current-allocation* BaseWAP scenario which passes low flows at all scope dams and scope watercourse diversions (that is,426TC001 and 003).
- In some cases, the best result is achieved with the *Current-allocation* WCE LFR only scenario which passes low flows at scope watercourse diversions only (for example, 426TC005 and 007). In this case, passing low flows for the BaseWAP scenario results in an improvement in the low flow metrics in the low flow season but causes some of the fresh metrics to fail in the low flow season giving a higher percentage of metrics failed for the BaseWAP scenario compared to the WCE LFR only scenario. This pattern of improving low flows but worsening freshes has occasionally been seen in other EMLR catchments and is thought to occur because dams that are passing low flows fill more slowly, compared to dams that do not pass low flows. Therefore, dams passing low flows are more likely to capture the beginning of larger flow events, and so freshes may be shorter, or pulse events may be reduced in size to below the fresh threshold rate (that is, the pulse still occurs but may be smaller than what is defined as a fresh for the EWR metrics). This pattern is more likely to occur when the threshold flow rate (passed for the low flow policy) is smaller than the fresh threshold rate, which is particularly the case for the Tookayerta catchment, where the threshold flow rates have been set to be lower than for other EMLR catchments with similar rainfall[4]. For the *Current-allocation* WCE LFR only scenario, the scope dams are not passing low flows, so this potential impact on fresh metrics does not occur.
- Note that the EWR metric values for low flow and seasonal flow in the low flow season are better for the BaseWAP scenario than the WCE LFR only scenario in this case but not enough to change whether those metrics pass or fail. That is, the BaseWAP scenario is generally better than the WCE LFR only scenario for addressing impacts on low flows but can have a small negative impact on freshes in the low flow season, in some cases.
- Interpreting the behaviour of freshes and their metrics is complex in the Tookayerta Creek catchment due to a range of issues that can mask each other. This includes the issues already noted (influence of high baseflow, and interception of early flow events by dams passing low flows), as well as an occasional stronger pulse response to rainfall events for the scenarios with water resource development, compared to the *No-dams* scenario (for example, in Figure 8, the fresh peaks are larger for the *Current-allocation* scenario than they are for the *No-dams* scenario). In some cases, a fresh event occurs after rain in the developed scenarios but not in the *No-dams* scenario. This modelled response may be due to higher runoff from the effectively impervious surface of dams for the scenarios with water resource development, compared to the lower runoff from those surface areas as land for the *No-dams* scenario. This complexity means that assessing results based on percentage of metrics passed or failed only may not give a full picture of flow responses to potential management actions.

3.3.1 EWR metric results and current condition of water-dependent ecosystems

The EWP target is being met under modelled current conditions without low flows being passed (i.e. *Current-use* scenario). However, many water-dependent ecosystems in the area are under stress – for example, the overall condition of native fish populations for the Tookayerta catchment is rated as poor to moderate for monitoring

[4] In most cases, the threshold flow rates have been set to pass low flows throughout the year, and freshes in the low T1 and T2 flow seasons, for the majority of cases. For the Tookayerta catchment, the threshold flow rate has been set based on the approximate summer baseflow. For more information, see EMLR WAP section 2.4.2.3, subsection 'Managing volume of licensed use together with diversion rules – threshold flow rates' and subsection 'Determination of environmental water provisions – Modifications to the evaporation and consumptives use limit and taking rules – Tookayerta Creek catchment'.

data collected from 2009 to 2017 (Whiterod 2018). Some possible reasons for this apparent mismatch between the EWP target and ecological condition are noted below.

- The surface water model, and the EWR metrics, do not account for the effects of wetland drainage on the flow regime, other than the effect of water in drains being diverted to other locations in the catchment for key locations (as per section 2). Wetland drainage will have substantially changed the hydrology and ecological condition of the wetlands and, potentially, altered the pattern of flow from the wetland to downstream habitats.
- As noted in section 2, the effects of wetland drainage on the flow pattern in the Tookayerta Creek catchment has not been incorporated into the surface water model. Flow data are not available from pre-drainage conditions to support model calibration and the EMLR WAP aims to work with current landscape conditions, rather than seek a return to pre-European conditions.
- It would be useful to consider an integrated approach to water regime management for the Tookayerta Creek catchment, including measures that can be implemented through water allocation planning and licensing (for example, passing low flows at dams and watercourse diversions to keep water in flow paths and watercourses), as well as complementary measures to keep natural wetlands sufficiently wet by reducing the effects of wetland drainage for example, see Bachmann and Farrington (2017).
- The surface water model, and the EWR metrics, do not account for the effects of plantation forestry on runoff or flow regime. Larger areas of forestry (for example, in the upper reaches of SWMZ 426TC006) may be reducing downstream runoff and associated environmental condition but this is not reflected in the EWR metrics.
- The condition of water-dependent ecosystems may also be affected by negative impacts from other factors in addition to water regime, such as physical habitat degradation, physical barriers to movement, impacts from introduced species (for example, weeds and feral fish) and water quality issues.

4 Recommendations

Primary recommendation: Run scenarios for a fully developed catchment.

For the *current level of allocation*, passing low flows at only scope watercourse diversions would be sufficient to pass the EWP target for all zones in the Tookayerta catchment. However, the catchment is not yet fully allocated. Before proceeding with implementation of low flow policy in the Tookayerta Creek catchment, scenarios need to be run that simulate a fully allocated catchment, where model water demand equals the volumetric limit on consumptive water use set in the EMLR WAP.

Comparison of the EWR metric results from the *Current-use* and *Current-allocation* scenarios shows that increasing the volume of water taken can substantially increase the number of EWR metrics that fail.

The current volume of water demand is about 72% of the catchment-scale limit on consumptive use and evaporation. Once the current reservation on further development is lifted, then an extra ≈1,300 ML could be allocated (up to the limit of 4,620 ML). Under the EMLR WAP, all new dams and licensed watercourse diversions would need to pass low flows (including those transferring in water). The impact on groundwater would also need to be considered.

When the catchment becomes fully developed and low flows are passed at existing watercourse diversions and future watercourse diversions and dam, but not at existing scope dams, it is not currently know if this will be enough to meet the EWP target.

Testing the effects of a fully developed scenario has not been carried out when testing strategic low flow scenarios for other EMLR catchments that are not fully developed (for example, Currency and Finniss catchments). Testing a fully developed scenario with limited implementation of passing low flows at existing sites is particularly relevant for the Tookayerta Creek catchment, compared to other catchments that are not fully developed. This is because:

- the threshold flow rate is low for the Tookayerta catchment compared to other areas with similar rainfall, so the potential for negative environmental outcomes is higher;
- the scale of reduction of the number of scope sites that would not need to pass low flows is particularly high for Tookayerta, if passing low flows at watercourse diversions only is contemplated; and
- the Tookayerta Creek catchment supports particularly high value environmental assets, including the majority of the EMLR's Fleurieu swamps (a critically endangered community under the *Environment Protection and Biodiversity Conservation Act 1999*).

That is, there is much more scope in the Tookayerta catchment to not do enough to treat existing infrastructure, and so not meet environmental water provisions for some important habitats, if the effects of the current level of development is only considered.

Other considerations

The updated Tookayerta model has somewhat different flow characteristics to the 2010 model used for WAP development. Consideration could be given to exploring how the threshold flow rate will affect the ability of users to access water in the light of improved understanding of flow behaviour and the likely drier climate since the WAP was developed.

The lower threshold flow rate in the Tookayerta catchment was set at approximately the rate of summer baseflow, as a way of balancing environmental provisions with the ability for water users to continue their current practices of directly accessing water from the permanently flowing watercourses as needed, rather than capturing runoff in a dam over winter and using it in summer.

The summer baseflow and associated threshold flow rate was set based on the best available data at the time. Since then, more flow data have been collected and understanding of the flow behaviour has improved. It may be worth considering how the threshold flow rate will affect the ability of users to access water in the light of improved understanding of flow behaviour, and the likely drier climate since the WAP was developed.

5 Appendices

A Scenario modelling additional flow summary

Summary of Results: Additional* flows# available to the system with low flows being released, Tookayerta Catchment

Modelled mean annual flows
* Additional = With low flows being released MINUS low flows not being released

Total number of scope sites in the Tookayerta catchment:	125
Total number of TIER 1 scope sites in the Tookayerta catchment:	0

Scenario name	Description	No.
Current	Current impact of farm dams and 30% of allocation demand for watercourse extractions	0
Current - BaseWAP	Low flow release (LFR) applied to all scope sites in model	125
Current - WCE LFR only	LFR applied to watercourse extractions only	63
Full allocation	Current impact of farm dams and 100% of allocation demand for watercourse extractions	0
Full allocation - BaseWAP	Low flow release (LFR) applied to all scope sites in model	125
Full allocation - WCE LFR only	LFR applied to watercourse extractions only	63

	Scope site data								Modelled mean annual flows (ML)							Additional flows (ML) available to the system				Additional flows (%) available to the system			
	Number of Scope dams				Number of WCEs																		
	Current - BaseWAP	Current - WCE LFR only	Full allocation - BaseWAP	Full allocation - WCE LFR only	Current - BaseWAP	Current - WCE LFR only	Full allocation - BaseWAP	Full allocation - WCE LFR only	No dams	Current	Current - BaseWAP	Current - WCE LFR only	Full allocation	Full allocation - BaseWAP	Full allocation - WCE LFR only	Current - BaseWAP	Current - WCE LFR only	Full allocation - BaseWAP	Full allocation - WCE LFR only	Current - BaseWAP	Current - WCE LFR only	Full allocation - BaseWAP	Full allocation - WCE LFR only
Total Tookayerta *(EOS - U/S of 426TC009)*	**62**	**0**	**62**	**0**	**63**	**63**	**63**	**63**	**17595**	**16243**	**16413**	**16408**	**15164**	**15684**	**15687**	**171**	**166**	**520**	**523**	**1.05%**	**1.02%**	**3.43%**	**3.45%**
Tookayerta - Management zones																							
426TC001	18	-	18	-	11	11	11	11	4463	4193	4202	4201	4093	4124	4125	9.4	8.4	30.8	31.3	0.22%	0.20%	0.75%	0.77%
426TC002	4	-	4	-	2	2	2	2	479	448	451	450	435	442	441	2.6	2.2	7.0	6.5	0.58%	0.48%	1.60%	1.50%
426TC003	8	-	8	-	12	12	12	12	7798	7283	7342	7340	6952	7125	7126	58.5	56.1	173.1	173.8	0.80%	0.77%	2.49%	2.50%
426TC004	9	-	9	-	1	1	1	1	3598	3381	3384	3382	3359	3367	3365	3.1	1.2	7.3	5.5	0.09%	0.04%	0.22%	0.16%
426TC005	16	-	16	-	18	18	18	18	6205	5564	5644	5641	5081	5305	5304	79.5	76.8	223.3	222.7	1.43%	1.38%	4.39%	4.38%
426TC006	3	-	3	-	6	6	6	6	1471	1428	1432	1432	1399	1411	1410	3.5	3.1	11.6	11.4	0.24%	0.22%	0.83%	0.81%
426TC007	4	-	4	-	8	8	8	8	17277	15993	16148	16142	15056	15516	15517	155.2	149.3	460.3	460.9	0.97%	0.93%	3.06%	3.06%
426TC008	-	-	-	-	4	4	4	4	17460	16107	16278	16273	15030	15550	15552	170.5	165.5	519.7	522.2	1.06%	1.03%	3.46%	3.47%
426TC009	-	-	-	-	1	1	1	1	17595	16243	16413	16408	15164	15684	15687	170.6	165.6	520.3	522.8	1.05%	1.02%	3.43%	3.45%

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