Government of **Western Australia**
Department of **Water and Environmental Regulation**

Wellington Reservoir Modelling

Re-evaluating yield and salinity levels under a drying climate

Surface Water Hydrological series
HY 37
October 2018

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Re-evaluating the yield and salinity levels under a changing climate

Department of Water and Environmental Regulation

Surface water hydrology series

Report no. HY37

October 2018

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Cover photograph: Wellington Reservoir and dam wall.

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Summary

This report documents a project to re-evaluate the yield from Wellington Reservoir under a changing climate and various diversion and development scenarios. The project supports two business needs by:

- completing action 8 of the *Lower Collie surface water allocation plan* (Department of Water 2015a) to re-evaluate the yield of the Wellington Reservoir to reflect inflows to the reservoir under a drier future climate
- supporting investigations for the Myalup-Wellington Water for Food project proposing to reduce salinity in Wellington Reservoir by diverting saline water from the Collie River East Branch.

This project identified the need for a new allocation limit for Wellington Reservoir to provide a more reliable supply for the reservoir's water users and to maintain water for the downstream environment. The study's results indicate that the current allocation limit (85.1 GL/year) does not meet the target for reliability of supply (75 per cent) under a drier future climate and may also not support the winter release regime designed to provide water to the downstream environment.

Communicating with stakeholders about the extent and impacts of the projected climate change in the Collie region is key to successfully managing the water resource into the future. Stakeholders including Harvey Water, Collie Water and Synergy have been consulted on these findings. The Department of Water and Environmental Regulation is now taking steps to reduce the allocation limit from Wellington Reservoir to 68 GL/year. This volume matches the current entitlement from the reservoir, provides security to existing users and maintains flows for the downstream environment.

This report provides information on the water availability, the hydrological models used in the study and the results of scenario modelling considering climate, demand, water release and diversion options.

1 Introduction

This report documents a project to re-evaluate the yield from Wellington Reservoir under a changing climate and various diversion and development scenarios. There are two project tasks.

- **Project task 1** – Re-evaluate the yield from Wellington Reservoir

  The allocation limit from Wellington Reservoir was set at 85.1 GL/year in the *Upper Collie water allocation plan* in 2009 (Department of Water 2009). Since the release of the allocation plan, low rainfall years (2010 and 2015) combined with increased knowledge of the expected reducing rainfall trend over south-west Western Australia, have prompted the re-evaluation of the reservoir's yield. This work is an action of the *Lower Collie surface water allocation plan* (Department of Water 2015a).

- **Project task 2 –** Investigate the change in flow and salinity into Wellington Reservoir by diverting water in the Collie River East Branch.

  This work supports the Water for Food initiative – a Royalties for Regions funded program aiming to increase irrigated agriculture across Western Australia. The Myalup-Wellington Water for Food project is proposing to reduce salinity in Wellington Reservoir by diverting saline water from the Collie River East Branch to a mine void for desalinisation. Modelling of the Upper Collie catchment was completed in 2017 and this project now quantifies the changes to flow and salt loads into Wellington Reservoir.

Structure of the report

This report has six sections:

Section 1: Introduction and project tasks

Section 2: Overview of the water resources

Section 3: Details of the hydrological models

Section 4: Scenarios for assessment

Section 5: Results and interpretation

Section 6: Conclusions and recommendations

2 Overview of the water resources

2.1 Upper Collie catchment

Hydrology

The Upper Collie catchment is located in south-west Western Australia and covers an area of 2830 km^2. It has four main waterways: Collie River South Branch, Collie River East Branch, Harris River and Bingham River. Within the catchment are two large dams: Harris Dam located on Harris River (72 GL capacity, 15 GL/year allocation) and Wellington Reservoir (185 GL capacity, 85.1 GL/year allocation limit) located at the downstream end of the Upper Collie catchment (Figure 1).

Variability in the volume of streamflow within the catchment is mainly influenced by a decreasing rainfall gradient running west to east and the extent and density of native vegetation. Data from four streamflow gauging stations are presented in Table 1.

The lowest mean annual streamflow occurs at the Palmer monitoring location on the Bingham River, which is surrounded by forest. By contrast, the James Crossing site on the Collie River East Branch has a higher average streamflow than the Bingham River despite having a smaller catchment (less than half the size) and a lower average rainfall. This difference in streamflow is related to the significant difference in the percentage area of cleared native vegetation between the two catchments. The relatively high percentage of clearing within the James Crossing catchment results in it having the highest average runoff rate of the catchments in Table 1. Native vegetation coverage can also significantly influence the salinity level within the river. For instance, the largely forested Bingham River has vastly lower salinity than the other monitoring locations in the Upper Collie catchment.

Duderling Pool and Buckingham Bridge Pool are both located on the Collie River East Branch. A 1 ML/day supplementation is required upstream of Duderling Pool to maintain pool levels that are affected by mine dewatering (see inset Figure 1). This project assumes no additional dewatering is occurring above the minimum supplementation. The proposed diversion point on the Collie River East Branch is upstream from this supplementation point.

Table 1 Observed streamflow, salinity and rainfall data with catchment vegetation density

Gauging station, river name	Catchment area (km^2)	Native vegetation (per cent)[1]	Period of observed record (1991–2015)[2]				
			Average rainfall (mm/year)[3]	Average streamflow (GL/year)	Average runoff (mm/year)	Average salt load (tonnes/year)	Average annual salinity (mg/L)
Mungalup Tower, Collie	2456	76	696	82	33	96 164	1177
Coolangatta, Collie East Branch	1345	72	650	36	27	65 893	1845
Palmer, Bingham	366	93	670	5	13	1080	224
James Crossing, Collie East Branch	171	46	585	7	38	39 402	6048

[1] Calculated from GIS layer ‘Native vegetation – current extent DAFWA’

[2] Common time period for all gauges for both flow and salinity measurements

[3] Corresponds to the rainfall inputs to the Upper Collie LUCICAT model at the centroid of each subcatchment

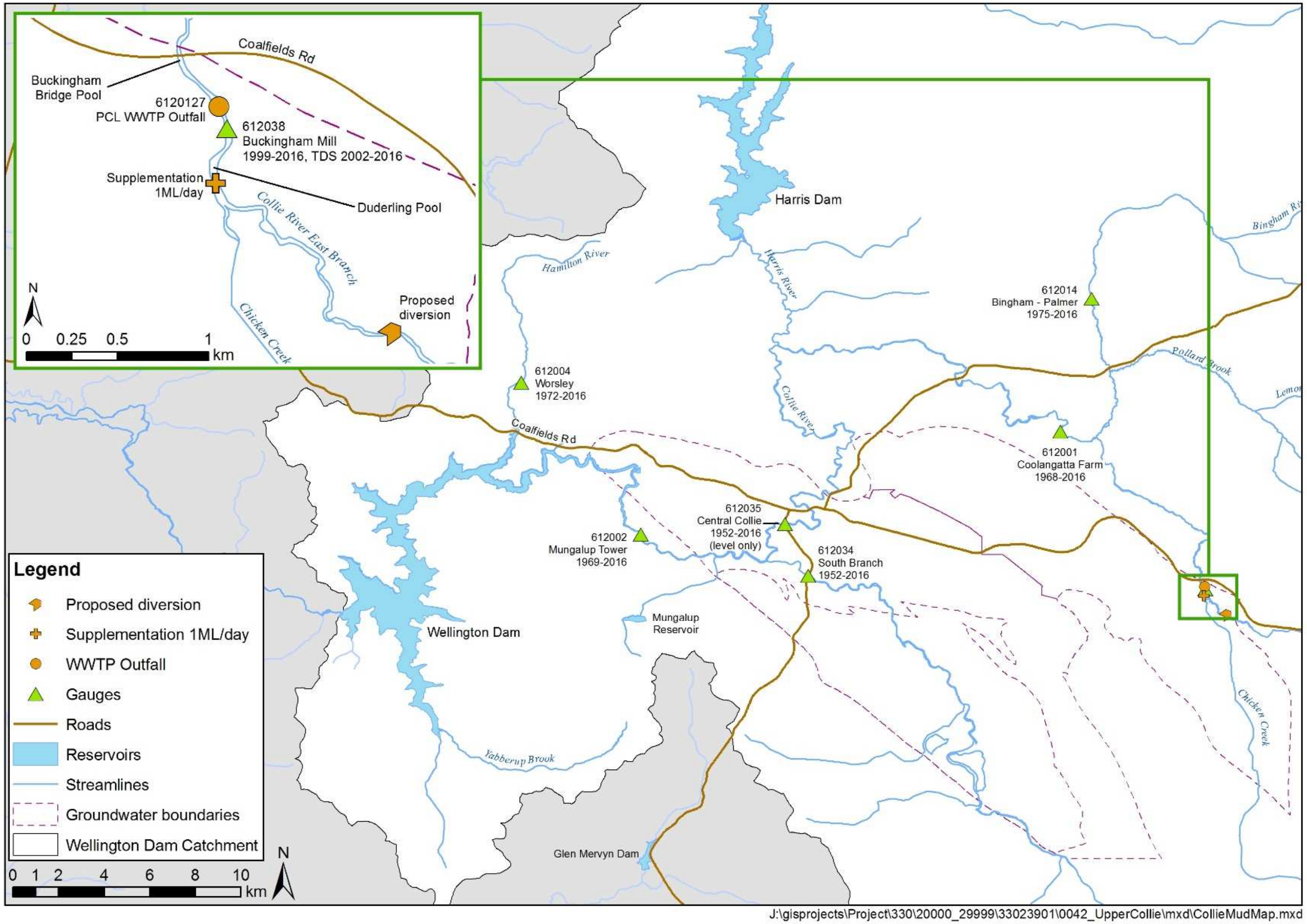

Figure 1 Overview map of Upper Collie catchment and Wellington Reservoir

2.2 Wellington Reservoir

Wellington Reservoir is located on the Collie River 15 km from the Collie townsite. The reservoir was built in 1933 and the dam wall raised to its current height in 1961. It supports an important irrigation industry, particularly the production of irrigated pasture for dairy and beef cattle (Bennett & Green 2011). Harvey Water holds a licence to divert up to 68 GL/year from the reservoir for irrigation. Water is released from Wellington Reservoir to Burekup Weir and then diverted through a series of open irrigation channels across the Collie River Irrigation District. The reservoir's characteristics are detailed in Table 2.

Table 2 Wellington Reservoir characteristics (Department of Water 2011a)

Characteristic	Value
Full supply level	166.56 m AHD
Wall height	34 m above ground level
Full supply storage capacity	185 GL
Surface area at full supply level	16.1 km^2
Crest length	367 m
Reservoir catchment area	2829 km^2 (including the 382 km^2 Harris Dam catchment)
Spillway type	Uncontrolled overflow section on dam
Spillway capacity	1430 m^3/s

Winter releases from Wellington Reservoir

Water is released from Wellington Reservoir during winter (May to October) to manage salinity in the reservoir and meet environmental water provisions downstream. The winter releases are made up of three components: daily releases, peak event releases and operator releases.

Optional operator releases are available during July, August and September to scour additional saline water from the reservoir. The combination of peak event and operator releases allows for a degree of operational flexibility to minimise the build-up of saline water at the base of the reservoir.

The monthly winter release volumes from the *Lower Collie surface water allocation plan* (Department of Water 2015a) are provided in Appendix A.

Water sharing arrangement from the Wellington Reservoir

The existing water sharing arrangement for consumptive use from Wellington Reservoir is based on the storage level on 1 October each year (Figure 2). This assumes the current full allocation is being used from the reservoir (85.1 GL/year). For a lower demand, the restriction rule varies according to Table 3. All water users have the same water sharing arrangement applied, aside from the 5.1 GL/year for power needs which is always unrestricted.

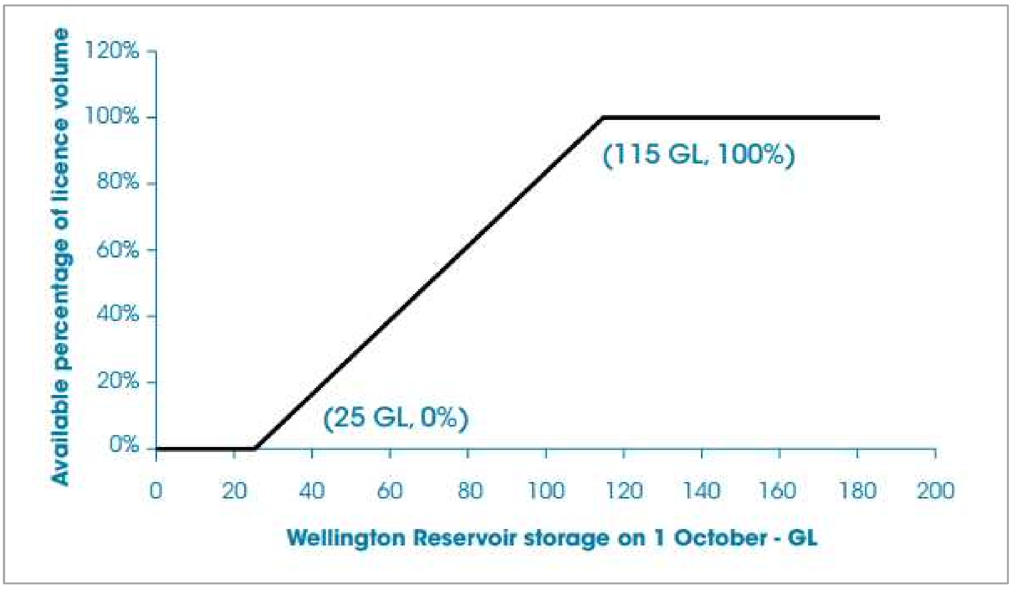

Figure 2 Wellington Reservoir storage on 1 October and associated restriction on irrigation and industrial entitlements (Department of Water 2015a)

Table 3 Water sharing rules for various demand volumes (Department of Water 2015a)

Water allocation	**Total volume of water entitlements (GL/year)**	**Reservoir storage levels that trigger restrictions (on October 1) GL**
Current irrigation entitlement	68	100
Current irrigation entitlement plus 12 GL/year of entitlements for new industry	80	106
Full allocation – current irrigation plus 12 GL/year for new industry plus 5.1 GL/year for power generation (unrestricted)	85.1	115

3 Hydrological models

This section describes the hydrological models used in the re-evaluation of the yield from Wellington Reservoir. Two hydrological models were used in this work:

- the Upper Collie LUCICAT model
- the Wellington Reservoir water balance model

3.1 Upper Collie LUCICAT model

The Land Use Change Incorporated CATchment (LUCICAT) model is a coupled salt and water balance model that represents stream salinity changes as a result of clearing (Bari & Smettem 2006). LUCICAT is a plug-in model to the eWater Source modelling platform. The LUCICAT model has been selected to represent the flow and salt balances for Upper Collie for numerous reasons, including:

- The conceptual and physical processes underlying the LUCICAT model were developed on forested and cleared research catchments in the Collie catchment (Bari & Smettem 2006).
- LUCICAT can represent the growth cycle of native forest, reforestation, pine and different types of annual and perennial pastures by taking input of leaf area index (LAI) maps at different times through a simulation (Bari et al. 2010).
- The LUCICAT model contains stores (which simpler empirical models do not): this means the model can attempt to predict the time it takes for salinity levels to recover or worsen after a land use change.

The Upper Collie LUCICAT model consists of 126 subcatchments (referred to as response units) with a total area of 2827 km^2 (Figure 3). Each subcatchment is divided into two functional units – forest and pasture – specified by percentage of total area (shown as green for forest and white for pasture in Figure 3). All links between nodes use straight-through routing to transfer water and salt downstream. Nodes are the location; flow and salinity are output from the model.

Extra confluence nodes were inserted in links to represent the location of gauging stations so that inflows to those nodes could be compared with observations. Nodes were also inserted for special functions (e.g. Harris Reservoir – storage node), external demands (e.g. water supply from Harris Reservoir – supply point node followed by water user node) and inflow from an external source (e.g. mine dewatering discharge – inflow node). Wellington Reservoir was not represented by a storage node as this model is used to generate total inflows and salt to the reservoir for input to a separate Wellington Reservoir water balance model.

Additional information about the model structure, input datasets and model performance can be found in the Department of Water (2017) internal report 'Upper Collie model: hydrological and constituent modelling for allocation planning and Water for Food'. This report has been externally reviewed and found suitable for assessing the impacts of diversions, future climate and vegetation changes on flow and salt into Wellington Reservoir. It was also found suitable for representing the catchment's hydrology and salinity responses to address the project's key objectives.

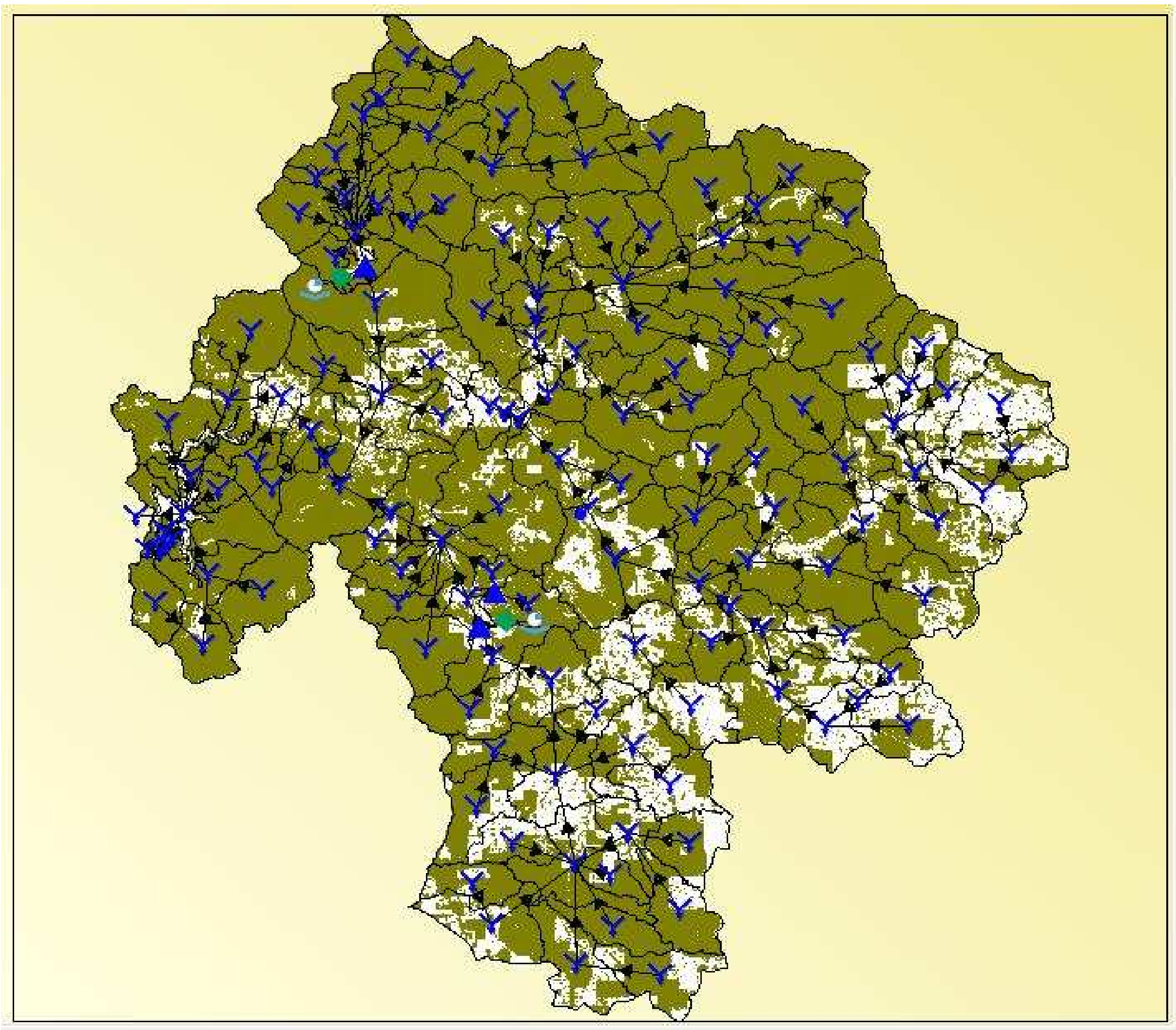

Figure 3 Upper Collie model in LUCICAT in eWater Source

3.2 Wellington Reservoir water balance model

The Wellington Reservoir model is a daily water and salt balance model that compares inputs (rainfall and inflow) against outputs (releases, spills and evaporation) to determine the remaining quantity and quality of water in storage. The model was developed as a management tool to assess the impact of demand scenarios and upstream land use change on supply reliabilities and salinity in the reservoir. See Figure 4 for a schematic of the Wellington Reservoir water balance model as created in eWater Source.

Further information about the development of the Wellington Reservoir water balance model can be found in eWater (2015) and Department of Water (2011a).

For this project, the model is now updated with revised climate and inflow data (an output from the Upper Collie catchment model).

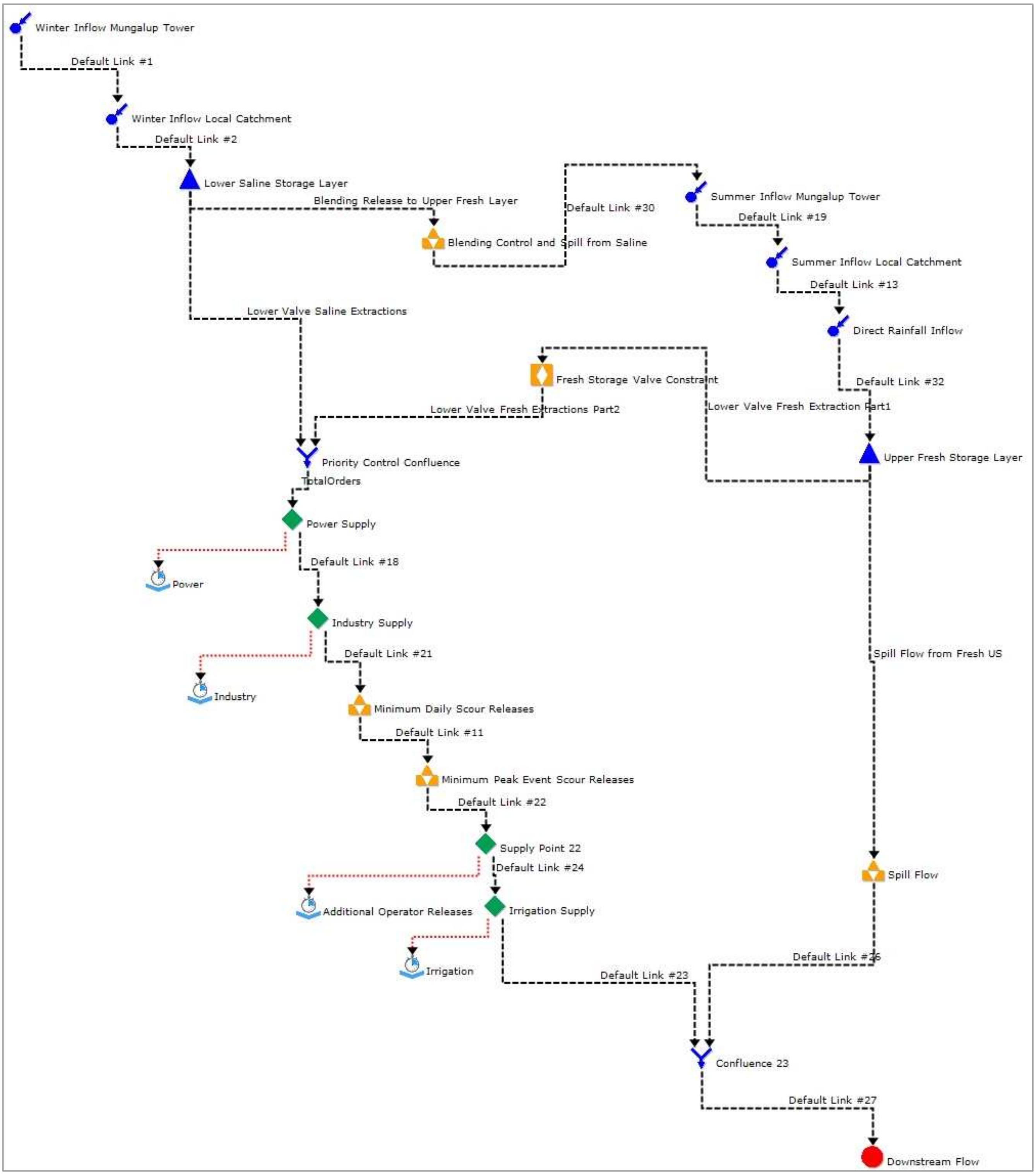

Figure 4 Wellington Reservoir schematic model in eWater Source

4 Scenario development

This section details the various Upper Collie and Wellington Reservoir scenarios that were modelled to see the potential impacts on reliability of supply and salinity of irrigation releases. This information supports decision-making for allocation planning and water licensing in the Upper Collie and Wellington Reservoir water resources.

4.1 Climate scenarios

The climate scenarios discussed here apply to both the Upper Collie and Wellington Reservoir models. As stated in the report *Selection of future climate projections for Western Australia* (Department of Water 2015b), increasing trends in temperature and decreasing trends in rainfall over south-west Western Australia since the 1970s make it inappropriate to use historical climate as an indicator of the future. It is thus recommended that climate projections be used for water resource management in south-west Western Australia.

Planning for a ‘dry 2030’ climate

Observed rainfall from 2009 to 2017 in the Collie catchment has fallen by 30 mm compared with the 1975 to 2008 average. The recent rainfall (post 2009) at Collie townsite aligns with the average rainfall projected under a ‘dry 2030’ future climate. Provided the current rainfall trend continues along the dry 2030 projection, the Department of Water and Environmental Regulation will base the allocation review on this projection. This will ensure security of supply is factored into our allocation decision-making, while meeting environmental requirements. Information relating to the ‘wet 2030’ and ‘median 2030’ future climates are reported occasionally throughout the report to indicate the possible range. Figure 5 shows the historical rainfall and the future average rainfall projections under three climate scenarios (wet, median and dry) at Collie rainfall station (BoM ref: 9628).

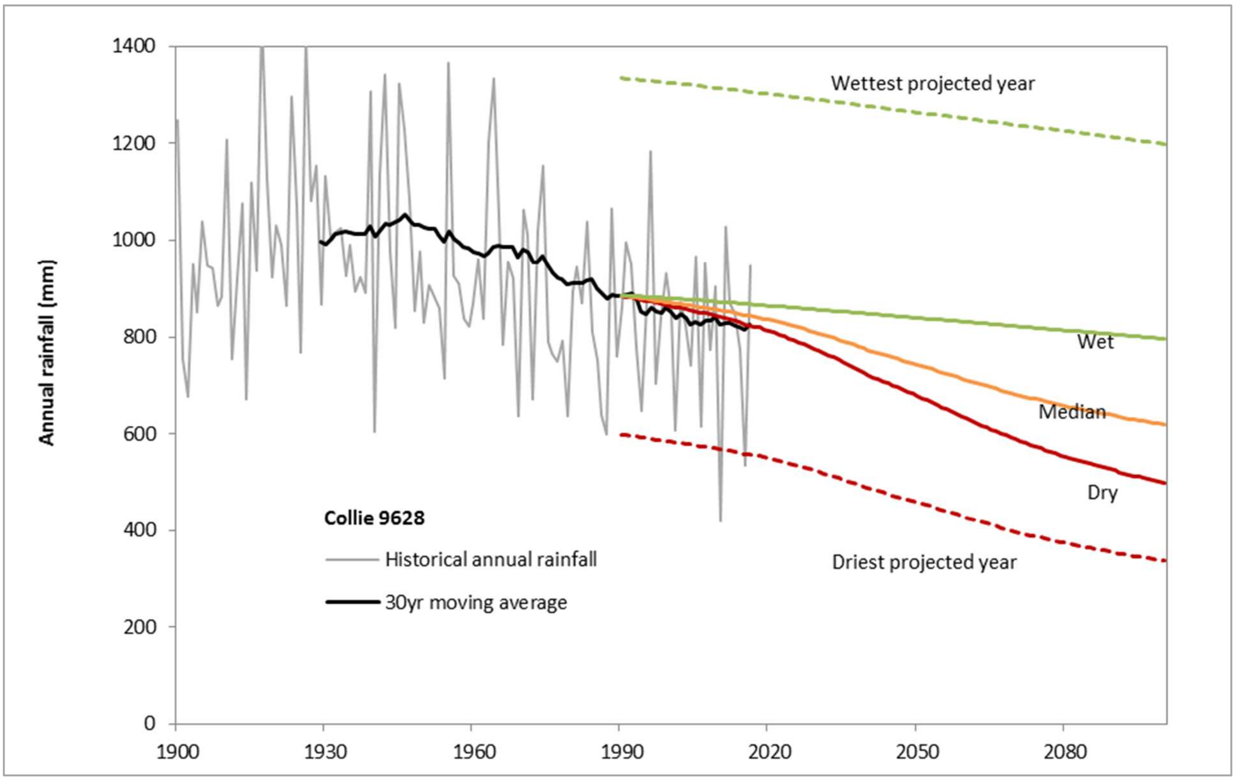

Figure 5 Future rainfall projections for Collie (BoM ref: 9628)

The Upper Collie model uses rainfall inputs from 28 rainfall sites across the Upper Collie and wider region (Figure 6). Future climate data have been determined for each rainfall location for a 2030 climate. See Figure 7 for the nominal 30-year dates used to model the future climate time period.

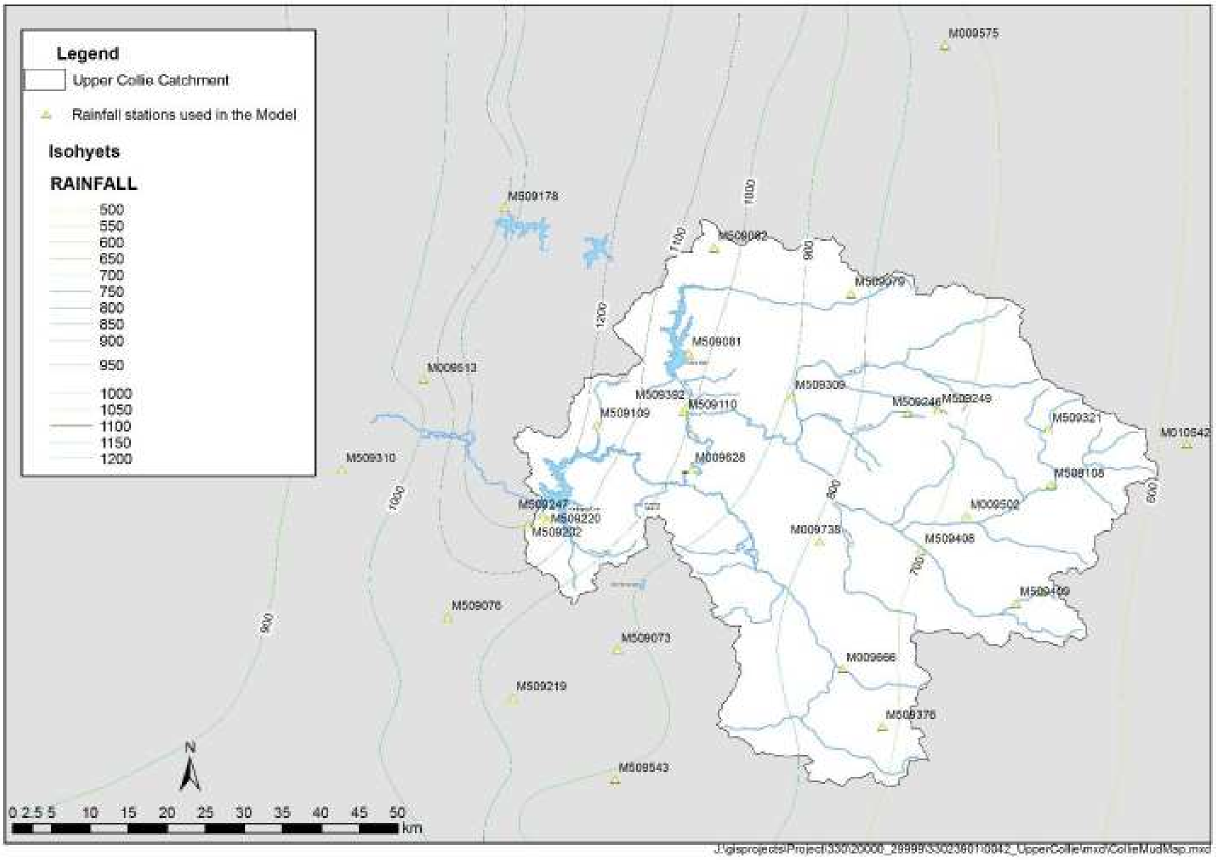

Figure 6 Location of rainfall sites used in the Upper Collie catchment model and Wellington Reservoir water balance model

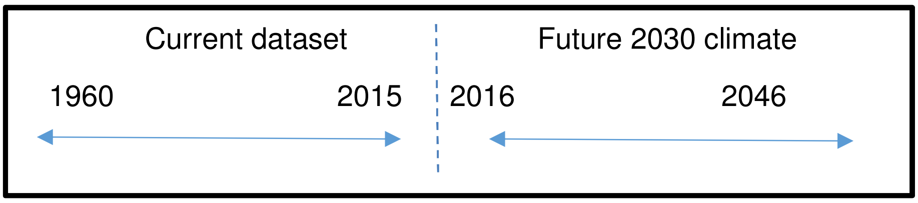

Figure 7 Implementation of future climate scenarios

The process of developing the future climate data is summarised in Figure 8. See the report *Selection of future climate projections for Western Australia* (Department of Water 2015b) for more information about the development of the future climate scenarios.

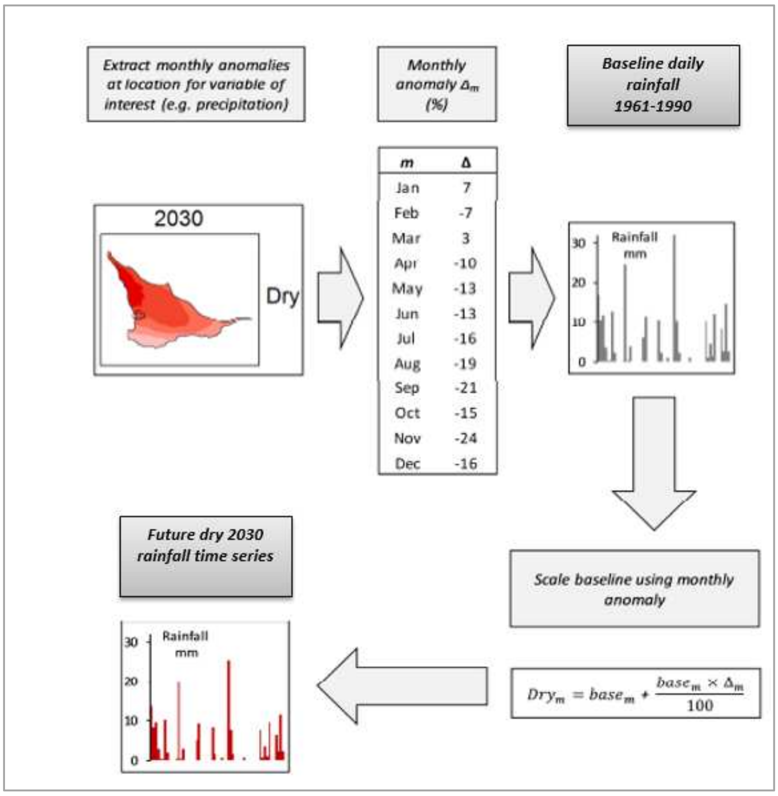

Figure 8 Flow diagram for the derivation of future rainfall data (Department of Water 2015b)

Figure 9 details the monthly anomalies for a dry 2030 climate projection. The anomalies indicate a reduction in monthly rainfall, particularly during winter when the majority of annual rainfall occurs over the Upper Collie catchment. The highest monthly reduction of 23 per cent is projected to occur at one rainfall station for November.

Interestingly, there is a projected increase in the January rainfall total of between 6 and 12 per cent compared with the 1961–1990 baseline. January rainfall is typically low and contributes little to streamflow. The projected increase in the monthly totals may be associated with the increase in summer storms predicted to occur alongside an increase in global temperature. However, studies such as CSIRO's South West Sustainable Yields (Charles et al. 2010) indicate the summer projections are more variable. In that study, eight global climate models (GCMs) projected decreases in rainfall and seven projected increases (Charles et al. 2010)

Projected monthly anomalies were similar across all rainfall sites used in the Upper Collie model (Figure 9).

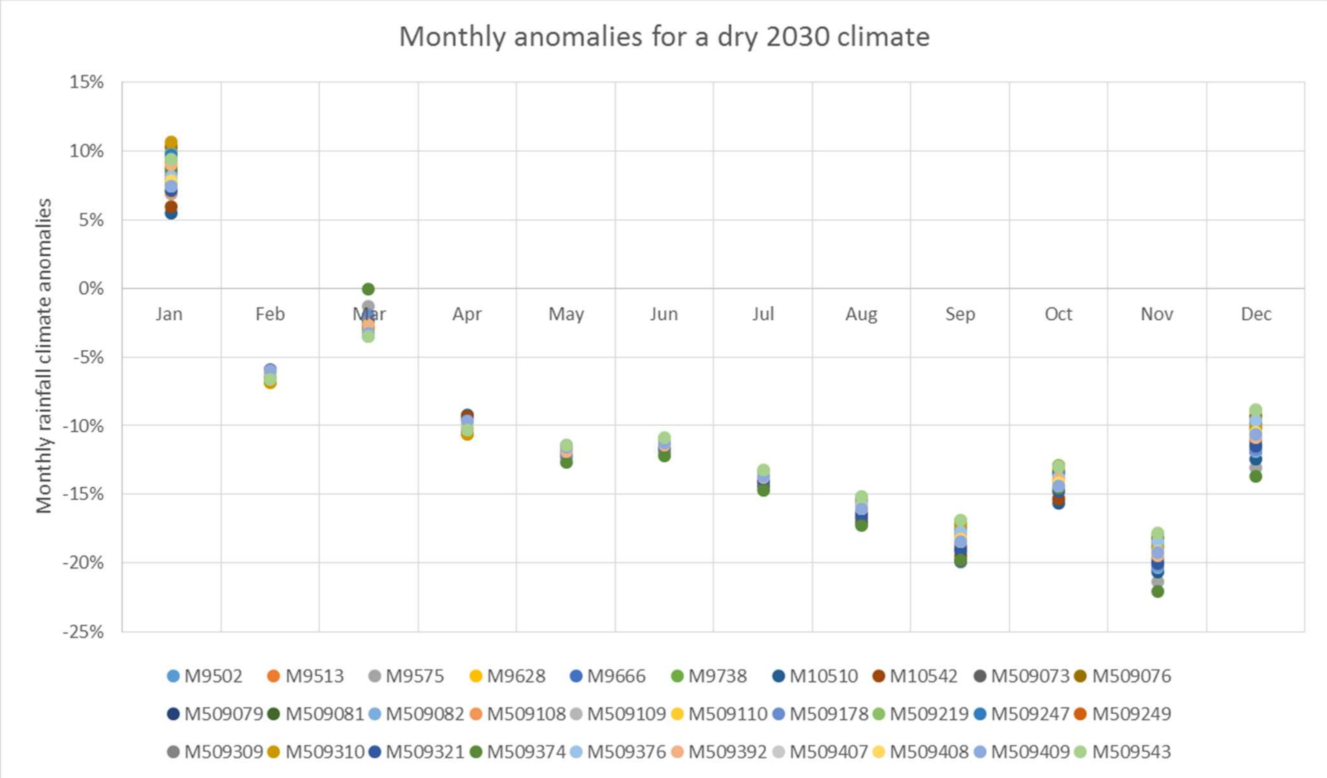

Figure 9 Monthly rainfall climate anomalies for a dry 2030 climate

4.2 Upper Collie model scenarios

Collie River East Branch diversion

Scenarios with and without the proposed Collie River East Branch diversion are run in the model. The diversion is represented as a loss node that removes flow above specified flow conditions. For our modelling purposes, the loss node has been configured based on the proposed licence conditions that flows above:

- 1 ML/day at the draw point can be removed from 1 November to 30 June
- 3.5 ML/day at the draw point can be removed from 1 July to 31 October.

This is outlined in a Department of Water internal report, 'Pumping to minimum seasonal flows at the Buckingham draw point'. The ecological assessments conducted at the site (used to develop the pumping rules outlined above) are also detailed in the report.

Additionally, a maximum daily pump of 400 ML/day was modelled based on engineering advice (GHD April 2017). The modelled streamflow for this project was provided to GHD for analysis. However, supply volumes and salinities may differ from the results presented due to infrastructure constraints, such as pipe capacity and mine void water balances.

Land use

In the model, land use in the Upper Collie has been kept at 2016 levels. Modelling of potential land use changes indicated limited effects on the volume and salinity objectives of the project. Clearing around the Collie River East Branch has a limited effect at the reservoir because the additional flow and salt generated is removed by the diversion and therefore does not make it downstream. A drying future climate has a greater effect on both the water removed by the diversion and the salinity at Wellington Reservoir than any of the land use changes modelled. These model results were presented to the Water for Food and Wellington technical advisory group on 22 August 2017.

4.3 Wellington Reservoir scenarios

Demand scenarios

The allocation limit (85.1 GL/year) from Wellington Reservoir is modelled as 68 GL/year for irrigation, 12 GL/year for industrial use and 5.1 GL/year for power supply. These demands are modelled by averaging the total annual volume across the number of days in the defined use period. For power and industry, the demand period is across the entire year, whereas the irrigation demand is concentrated over summer (October to April).

Figure 10 shows the difference between the modelled demand and observed demand (monitored releases from the Mount Lennards gauging station – 612006). The monitored data fluctuates daily based on a varied daily demand for water. This study does not attempt to replicate the fluctuations in daily demand – further research and mapping of the area’s crop demand factors would be needed to refine the water demand estimation. However, this is unlikely to affect the seasonal or annual reliability of the supply numbers presented in this report.

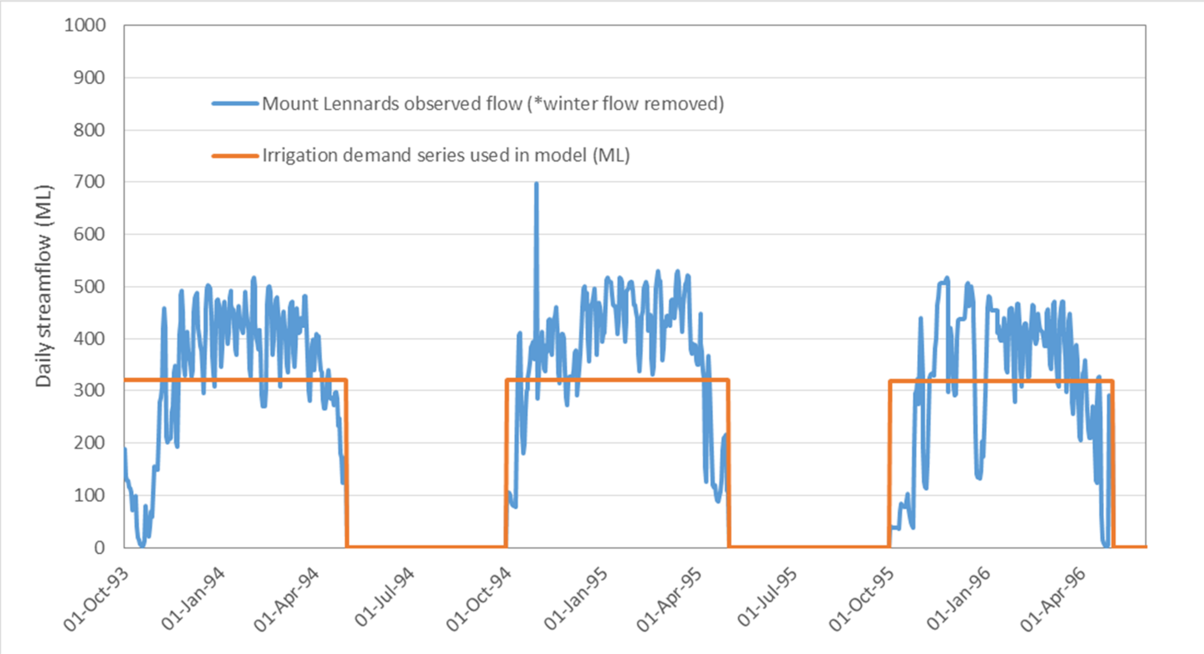

Figure 10 Summer irrigation demand from Wellington Reservoir, modelled and observed

No operator releases with Collie River East Branch diversion

The dam operators may release additional water during winter to improve water quality in the reservoir. These releases are only permitted when specific storage volumes exist (outlined in Appendix A). For all Upper Collie catchment scenarios that include the Collie River East Branch diversion, the corresponding Wellington Reservoir model runs do not include the operator releases. This assumption is based on the diversion improving the quality of the water flowing into the reservoir, which removes the need to release further water from the reservoir. However, in scenarios that do not include the Collie River East Branch diversion, the operator releases are assumed always to be implemented given the need to improve water quality in the reservoir.

5 Results

This section describes the Upper Collie and Wellington Reservoir model outputs. Estimations of water availability, reliability of supply and salinity levels are provided to show how water management decisions influence the performance of the water resource.

The historical scenarios are run from 1960 to 2015 with results reported for the historical period of 1975 to 2015. Future climate scenarios are reported from 2016 to 2045.

Modelling results from the Upper Collie model are presented in Section 5.1. These address the objectives of project task 2 – the change in flow and salinity into Wellington Reservoir due to the diversion of water from the Collie River East Branch. Results show the water availability at the diversion point and volume of salt removed, as well as the effects on flow and salt into Wellington Reservoir.

Salinity and reliability of supply estimates from the Wellington Reservoir model are presented in Section 5.2. These address the objectives of project task 1 – re-evaluating the yield of Wellington Reservoir.

5.1 Upper Collie modelling results – project task 2

Collie River East Branch diversion

The Water for Food Myalup-Wellington project aims to divert up to 15 GL/year of saline water in the Collie River East Branch, preventing between 60 000 and 110 000 tonnes of salt entering Wellington Reservoir.

Based on the Upper Collie model results presented in Table 4, the average volume diverted from the Collie River East Branch ranges from 6 GL/year under a dry 2030 climate to 11 GL/year under a wet 2030 climate.

The volume removed at the diversion site varies annually, with the maximum annual diverted volume estimated at 31 GL under a wet 2030 climate and 24 GL under a dry 2030 climate. It is estimated that in some years, little to no water would be available for extraction at the diversion site, due to limited flows above the thresholds.

The average salt removed ranges from 37 000 to 53 000 tonnes under the four climate scenarios assessed (Table 4). Similarly, annual variability arises within these results – aligning with the variability in annual flow. Under a dry 2030 climate the annual average is estimated at 37 000 tonnes; however, in some years removal of up to 81 000 tonnes may be possible.

Table 4 Volume of diversion and salt load removed under various climate scenarios

	Average diverted volume from the Collie River East Branch[1] (GL/year)	Maximum annual volume diverted (GL/year)	Minimum annual volume diverted (GL/year)	Average salt load removed (tonnes)
Historical 1975–2015	10	28	0.2	53 000
Wet 2030	11	31	0.02	52 000
Med 2030	8	27	0	46 000
Dry 2030	6	24	0	37 000

[1] Provided water can be extracted according to the specifications outlined in Section 4. Engineering constraints may restrict the volume of water that can be extracted.

Wellington Reservoir inflows under climate and diversion scenarios

Rainfall has been declining in south-west Western Australia since the mid-1970s and all future climate models indicate the trend is likely to continue. This has translated into a reduction in inflows which has been reported in previous work such as the South West Sustainable Yields project (Charles et al. 2010). Inflow projections using the Department of Water and Environmental Regulation's climate guidelines (Department of Water 2015b) are shown in Table 5. Results indicate the average annual inflow into Wellington Reservoir could range from 141 GL/year (wet 2030 scenario) to 80 GL/year (dry 2030 scenario). The upstream removal of flow from the Collie River East Branch under the diversion proposal results in a further reduction in average annual inflow. No change to the minimum annual inflow occurs with the diversion because flows remain below the thresholds set for diversion.

Table 5 Inflow and salinity into Wellington Reservoir including comparison with the Collie River East Branch diversion under various climate scenarios

	Mean annual inflow (GL)	Average annual inflow salinity (mg/L)	Minimum annual inflow (GL)
Historical,1975–2015 (Historical with diversion)	124 (114)	1103 (667)	13
Wet 2030 (Wet 2030 with diversion)	141 (130)	1120 (675)	16
Med 2030 (Med 2030 with diversion)	104 (96)	1256 (761)	11
Dry 2030 (Dry 2030 with diversion)	80 (74)	1297 (834)	8

5.2 Wellington Reservoir modelling results – project task 1

This section documents the results from the Wellington Reservoir water balance modelling.

Reliability of supply

Reliability of supply for the current allocation limit (85.1 GL/year) and current demands (power, irrigation and industry) is set to maintain 100 per cent reliability of supply for power under all climate and diversion scenarios. However, the reliability of supply for irrigation and industry reduces from 73 per cent under a historical climate to 70 per cent under a wet 2030 climate, 40 per cent under a median 2030 climate and 37 per cent under a dry 2030 climate (Table 6).

This potential decline in reliability of supply was identified in the *Lower Collie surface water allocation plan* where 'under a median drying climate scenario, inflow would result in the allocation limit being available in 10 out of 30 years' (Department of Water 2015b).

The minimum annual supply volume indicates a large shortfall of supply in dry years. Under a dry 2030 climate in the lowest supply year almost no water (only 1 GL) is supplied for irrigation.

Salinity

The range of average annual irrigation salinities is shown as box-plots in Figure 11 for historical climate and the dry 2030 climate with the current allocation limit (85.1 GL/year).

The Collie River East Branch diversion is effective at reducing salinity levels in most years. The average salinity may reduce by 41 per cent (1038 to 611 mg/L) under an historical climate (Table 6).

The effectiveness of the Collie River East Branch diversion is partially offset by the increase in salinity expected to occur under a drying climate. The average salinity may increase by 30 per cent (611 to 793 mg/L).

Without the diversion, the average salinity may increase by 25 per cent (1038 mg/L to 1300 mg/L). This level is considered brackish according to Mayer & Ruprecht (2005), who advise to 'irrigate with caution' at these salinity levels.

Table 6 Key metrics from all demand and climate scenarios assessed. Power, irrigation and industry statistics are reported for the October to September water year.

	Climate	Mean annual inflow[1] (GL/year)	Average annual inflow salinity[1] (mg/L)	Minimum annual inflow[1] (GL)	Power	Irrigation			Industry			
					Per cent reliability of supply (out of 30 years)	Per cent reliability of supply (out of 30 years)	Average supply salinity (mg/L)	Minimum annual volume supplied (GL)	Per cent reliability of supply (out of 30 years)	Average supply salinity (mg/L)	Minimum annual volume supplied (GL)	Median volume of winter releases (does not include spills from the reservoir) (GL)[1]
85.1 GL demand with operator releases	Historical (1975–2015)	124	1103	13	100	73	1038	14	73	1139	2	12
	Wet 2030	141	1 20	16	100	60	1014	10	60	1109	2	12
	Med 2030	104	1256	11	100	40	1157	4	40	1241	1	8
	Dry 2030	80	1297	8	100	37	1268	1	37	1334	0.2	6
85.1 GL demand with Collie River East Branch diversion and no operator releases	Historical (1975–2015)	114	667	13	100	68	611	14	68	698	2	11
	Wet 2030	130	675	16	100	60	601	9	60	687	2	9
	Med 2030	96	761	11	100	40	689	4	40	765	1	5
	Dry 2030	74	834	8	100	37	793	1	37	847	0.2	3

[1] Statistics reported for the annual year, January to December

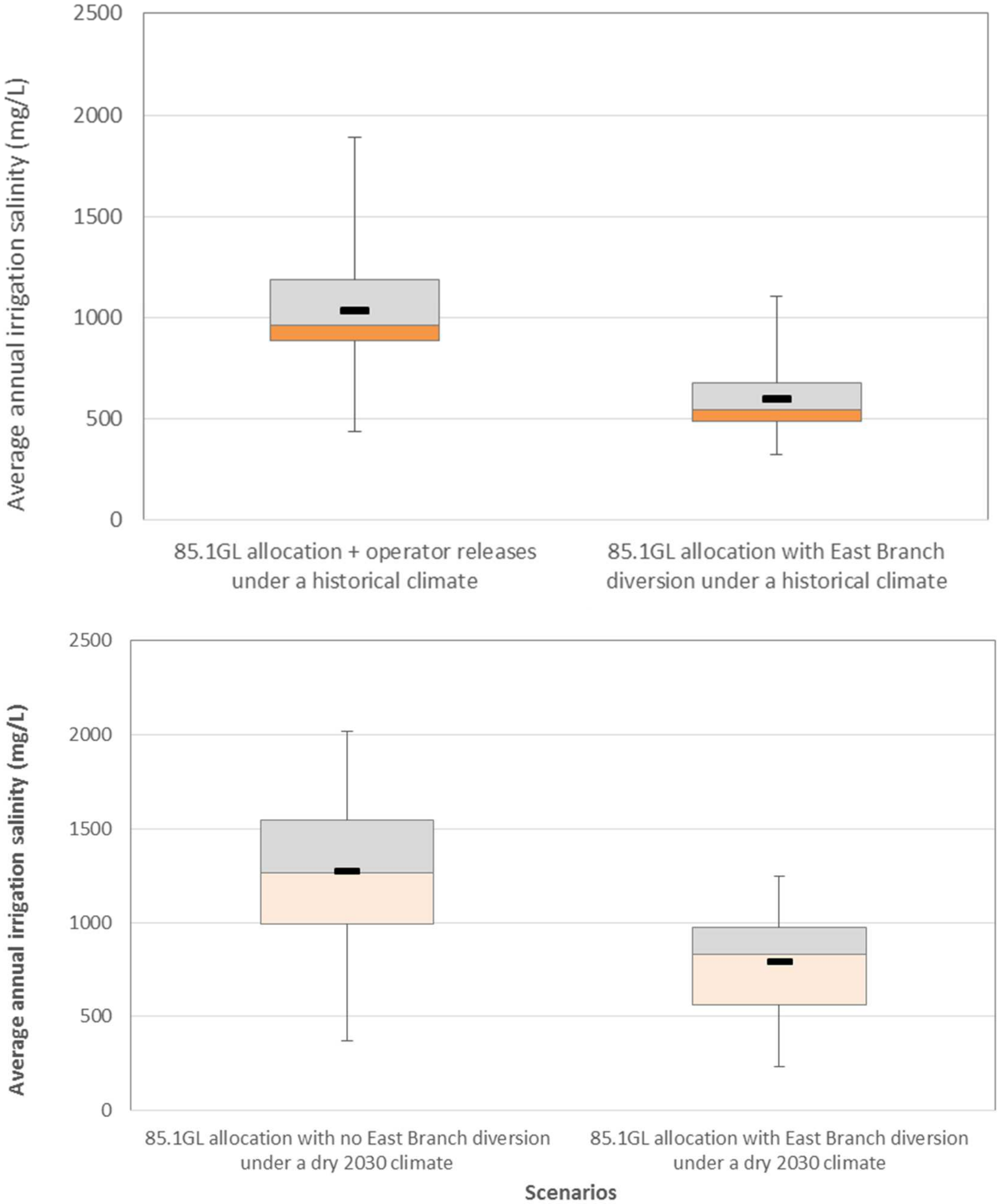

Figure 11 Average annual irrigation salinity under historical (top) and dry 2030 climate (bottom)

Winter environmental release

The importance of environmental water downstream of Wellington Reservoir is documented in Bennett and Green (2011) and WRM (2009).

Despite the fact that Wellington Reservoir has modified the natural system, the reach between the reservoir and Burekup Weir still supports ecological values such as populations of native fish, crayfish, macroinvertebrates and riparian vegetation. The reach also supports Indigenous values, as well as social values such as camping, fishing, swimming and canoeing (Bennett & Green 2011).

Change in environmental release volume due to climate change

The median annual volume of water delivered as a winter environmental release reduced by half from 12 GL/year under a historical climate to 6 GL/year under a dry 2030 climate (Table 6). This reflects the reduction in inflow volume and consequent reduction in storage levels and the corresponding winter release requirements. The impact of this reduction on maintaining and meeting the frequency of key ecological thresholds is highlighted in monthly flow duration curves (figures 12, 13 and 14).

The winter releases under a historical climate (yellow dashed line in figures 12 and 13) for May, June and July maintain a minimum daily flow of 15 ML/day (100 per cent exceedence). In comparison, the winter releases for the same months under a dry 2030 climate without the diversion (green dashed lines in figures 12 and 13) do not maintain a minimum of 15 ML/day (exceedence 77 to 80 per cent in May, 80 per cent in June and 93 per cent in July). This suggests that maintaining the current allocation limit and reservoir operating rules under a dry 2030 climate may result in approximately 20 per cent of days where the minimum flow of 15 ML/day is not maintained in May, June and July in the downstream reach from Wellington Reservoir to Burekup Weir. This is also demonstrated in the spells analysis for period of flow above 15 ML/day (Figure 15), which shows extended periods under the dry 2030 climate where the threshold is not met. The risk to the ecology and environment in this reach of the Collie River will be assessed in the allocation planning process.

For August, September and October the winter release regimes visually follow the same distribution as the inflows (dashed black, dashed blue and solid grey lines in figures 12, 13 and 14), although release volumes and durations are reduced.

Change in environmental release volume due to Collie River East Branch diversion

Comparison between the winter release volume and regimes under a dry 2030 climate with and without the Collie River East Branch diversion show a reduction in the water released downstream for environmental purposes (difference between green and orange dashed lines in figures 12, 13 and 14). This change in winter release volume from the diversion is less than the reduction in winter release volume due to climate change. For example, in May the number of days below 10 ML/day is reduced by 4 per cent as a result of diversion and by 20 per cent as a result of a drying climate.

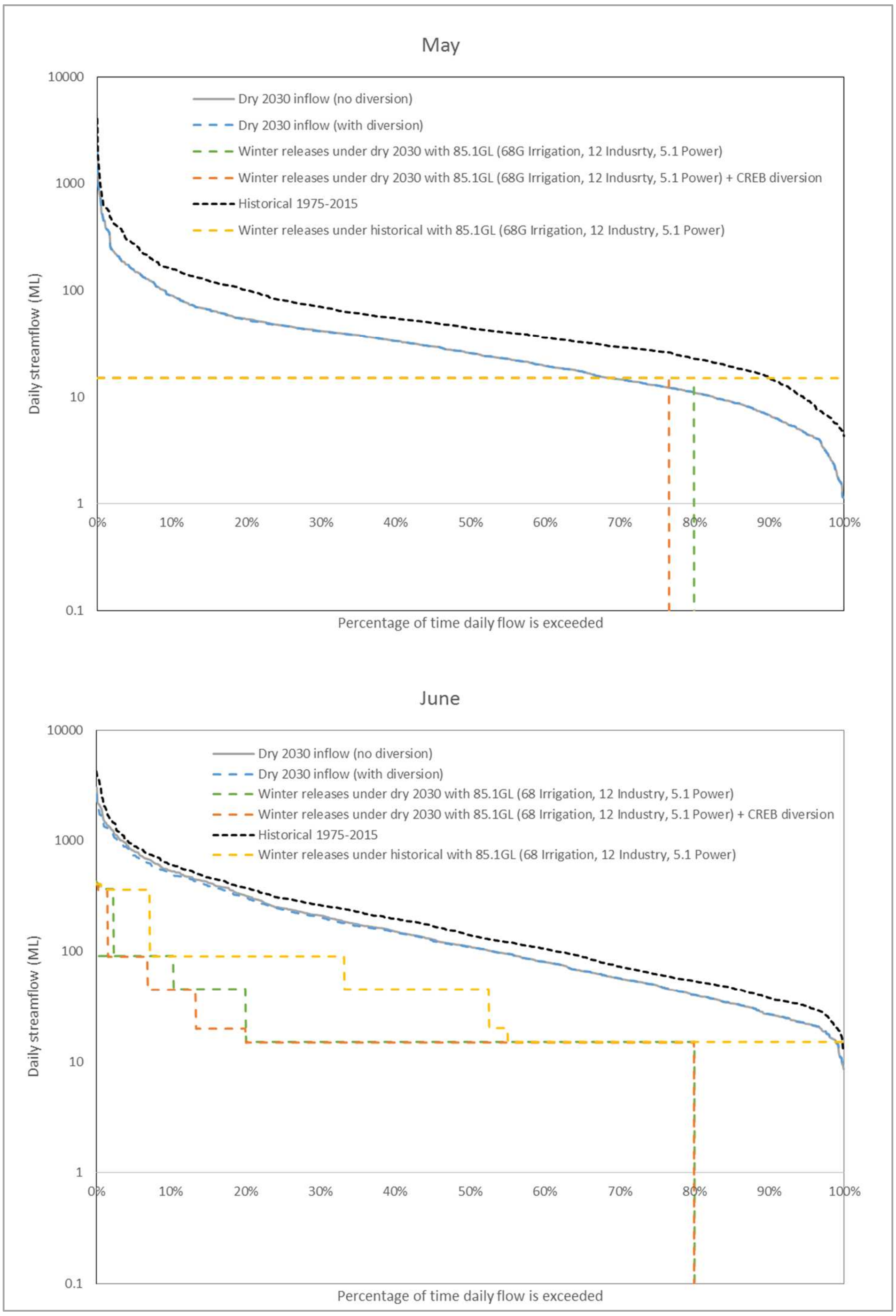

Figure 12 May (top) and June (bottom) daily inflow and winter release flow duration curves with 85.1 GL/year demand and historical and dry 2030 climate scenarios

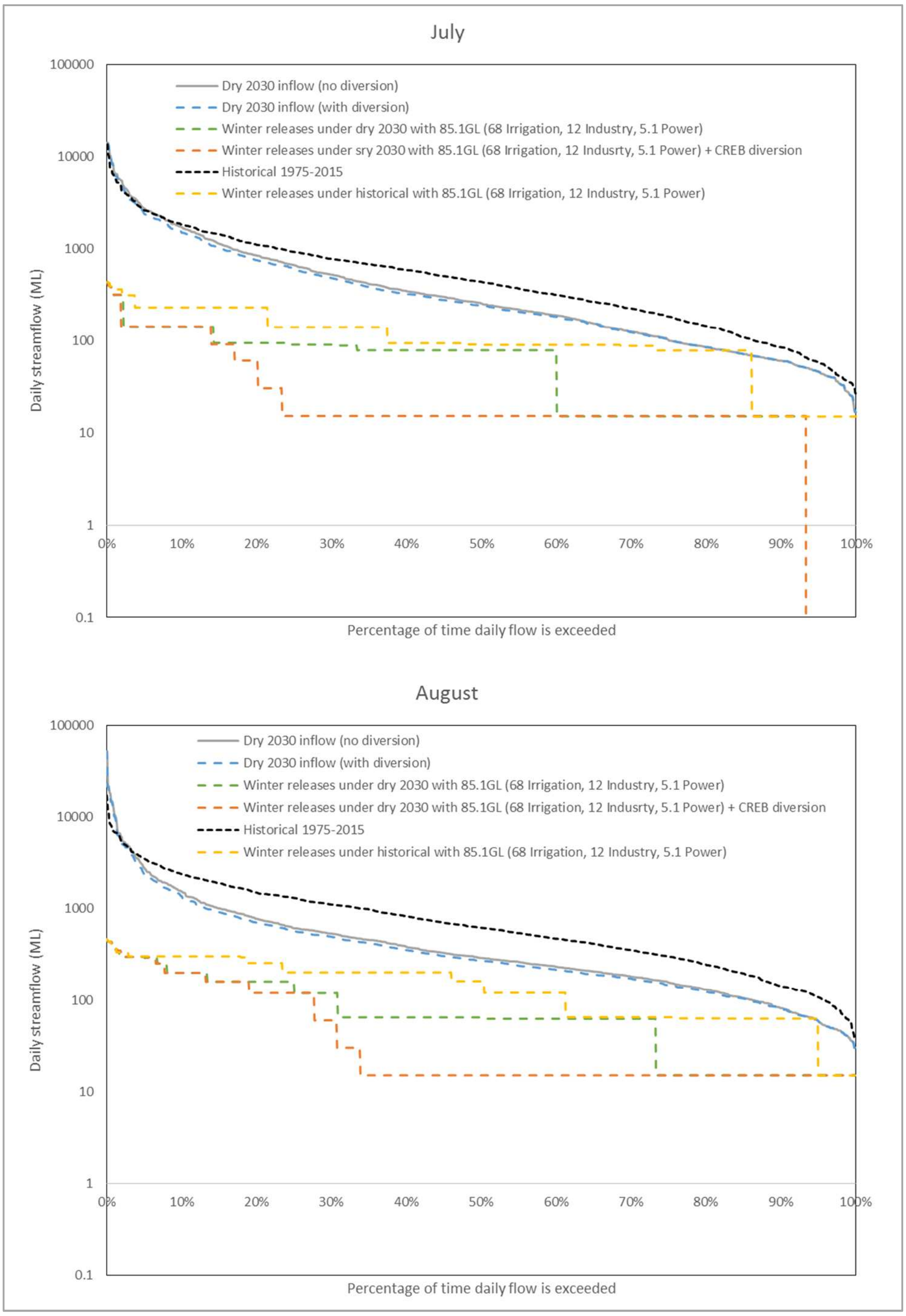

Figure 13 July (top) and August (bottom) daily inflow and winter release flow duration curves with 85.1 GL/year demand and historical and dry 2030 climate scenarios

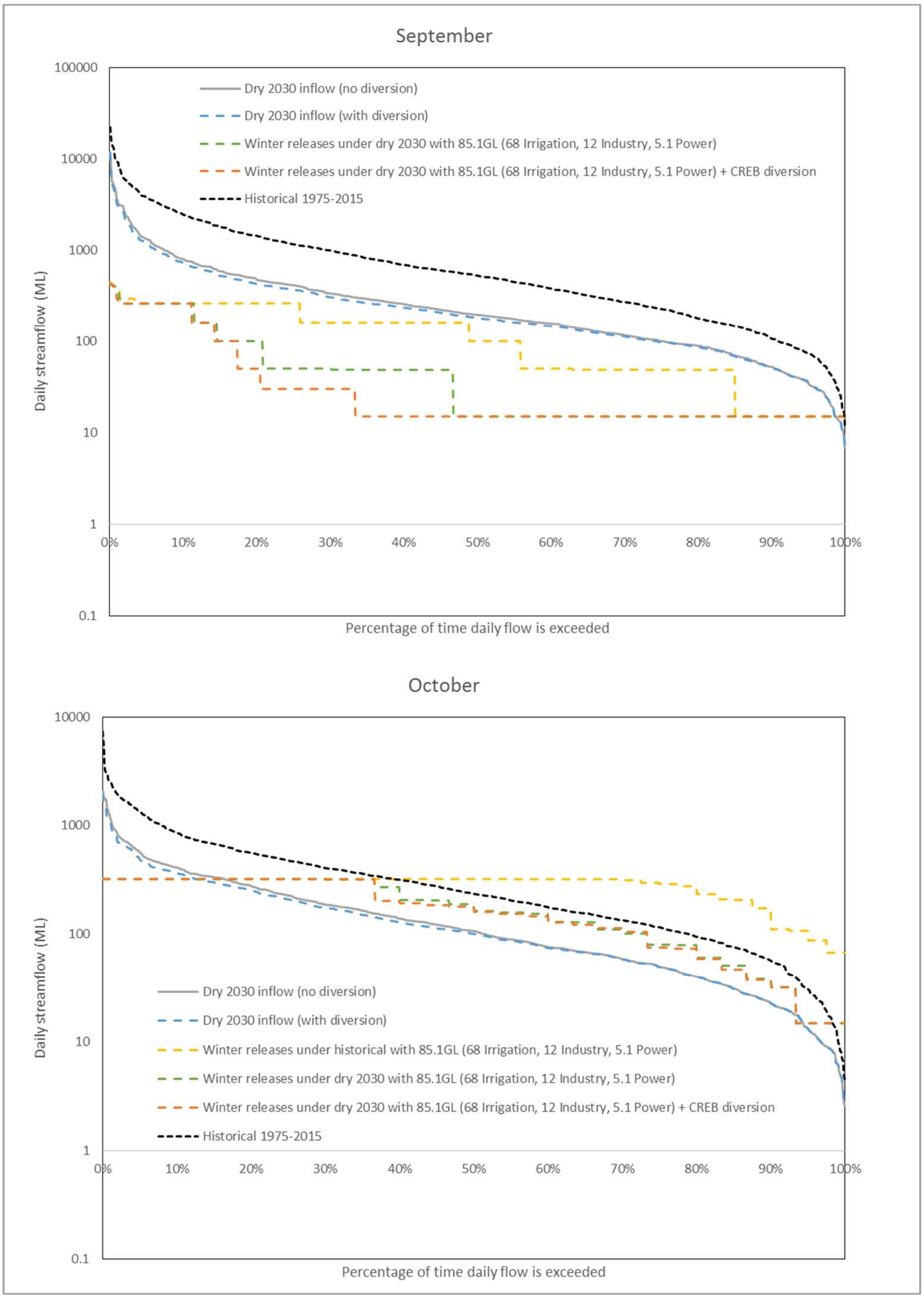

Figure 14 September (top) and October (bottom) daily inflow and winter release flow duration curves with 85.1 GL/year demand and historical and dry 2030 climate scenarios

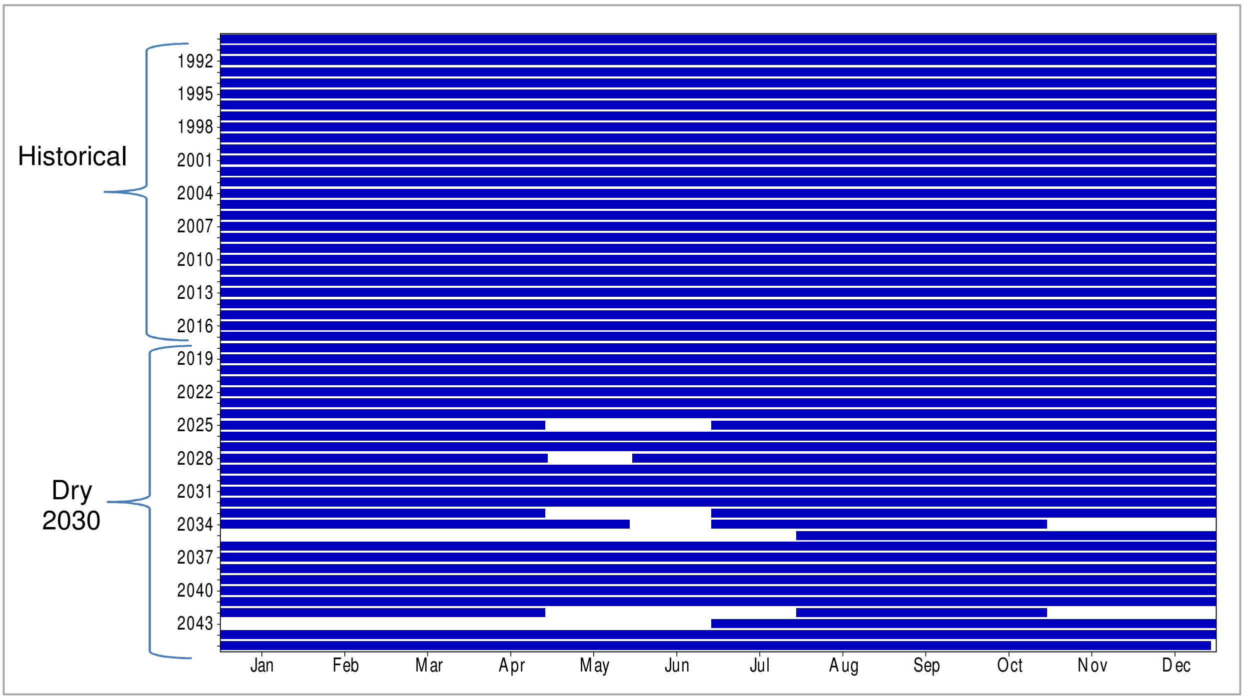

Figure 15 Period of flow equal to or above 15 ML/day downstream of Wellington Reservoir

5.3 Allocation planning and climate change

Water from the Wellington Reservoir is classified as having a high climate risk: this is due to the high demand compared with the modelled availability under future climate projections (demand exceeds reliable availability).

The Department of Water and Environmental Regulation uses the allocation planning model to make the best-possible water allocation decisions (Figure 16).

There is a consistent scientific understanding that rainfall is likely to reduce in south-west Western Australia. Current practice is to annually evaluate the Upper Collie and Lower Collie water allocation plans to track and assess how the water resource is performing against their objectives (Figure 16). Through the evaluation process, the department can adaptively manage water resources by updating existing management frameworks in light of new information.

The model results presented in Section 5 identify that the current full allocation for Wellington Reservoir may only be available in a limited number of years in the short-term, with the reliability of supplying that allocation reducing further in the future.

The following section documents the reliability of supply for different volumes from Wellington Reservoir under current reservoir management. The environmental flows downstream are also assessed to determine potential trade-offs between allocating water for consumptive use and the environment.

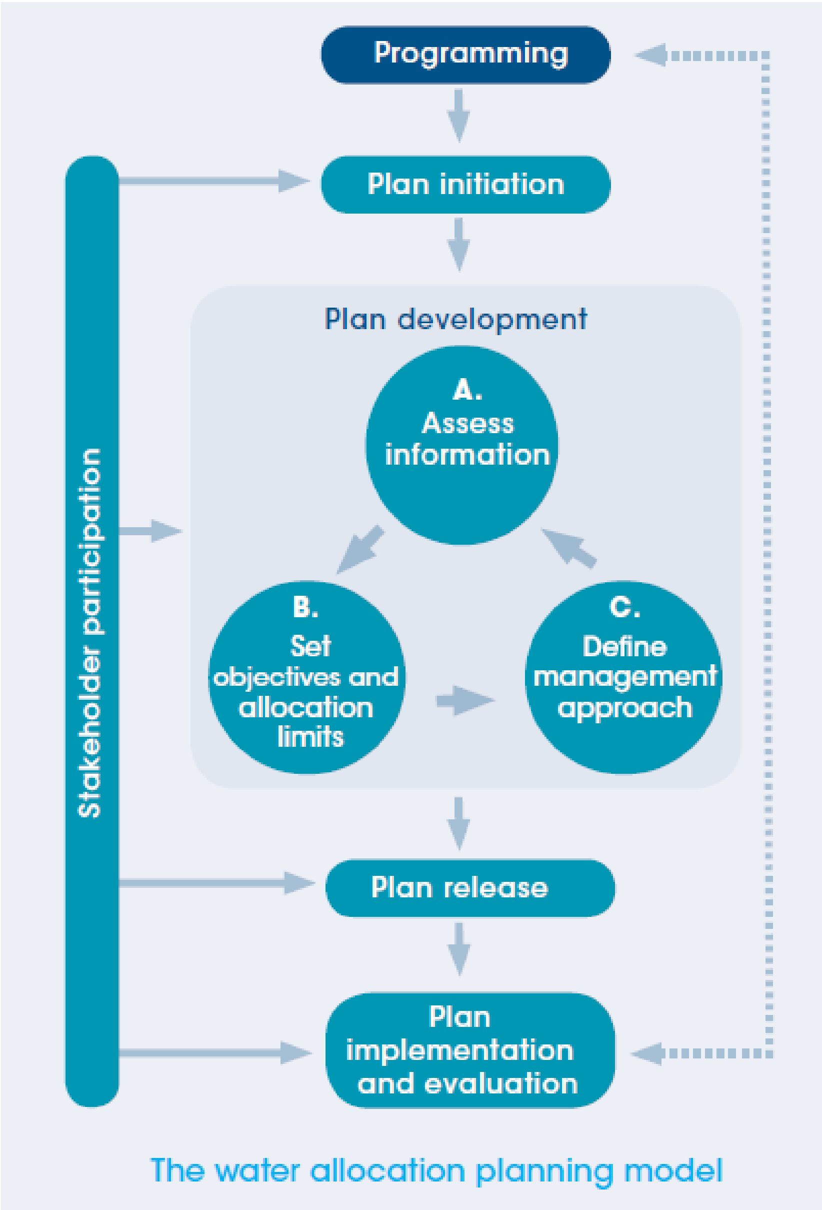

Figure 16 Water allocation planning model in Western Australia (Department of Water 2011b)

5.4 Options for allocation planning

Under a drying future climate, the trade-off between water for consumptive use (irrigation) and water for the downstream environment needs to be balanced to ensure the needs of both are met or any shortfall is shared. This aligns with the objectives in the *Lower Collie surface water allocation plan* that highlights the importance of the water resource downstream of Wellington Reservoir to agriculture, industry and the environment. The intent of the department's management is to provide '…a flow regime that supplies authorised use in most years and meets minimum and key ecological and social requirements' (Department of Water 2015a).

Table 7 summarises a range of different Wellington Reservoir model runs varying the allocation limit (68, 53 and 50 GL/year) and the storage volumes that restriction of irrigation demand start at (100, 79 and 76 GL and unrestricted). The results indicate:

- Lowering the allocation limit increases reliability of supply for irrigation.
- Lowering the storage volume at which supply is restricted increases the reliability of supply for irrigation.
- The restriction rules influence the minimum volume obtained for irrigation, by maintaining storage in the reservoir for the following year.
- Lowering the storage volume at which supply is restricted increases the percentage of cease-to-flow days downstream from Wellington Reservoir.
- Twenty to 26 per cent of the annual inflow is released under the winter release regime for environmental requirements.
- Average annual irrigation salinity does not vary significantly with varying allocation limit volume.
- While having a no-restriction rule (unrestricted irrigation) increases the water supplied to irrigators, it greatly reduces the volume supplied for the environment during winter (36–40 per cent of cease-to-flow days).

Table 7 Allocation planning options for Wellington Reservoir under a dry 2030 climate

Potential management decision					Winter release regime		
Allocation (GL/year) + diversion or operator releases	**Restriction rule, storage volume on 1 October (GL)**	**Reliability of supply (per cent of years)**	**Minimum volume obtained (GL/year)**	**Average annual salinity of water supplied (mg/L)**	**Median volume supplied May–Oct only**	**Percentage of inflow released from May–Oct**	**Percentage of days recording cease-to-flow between May & Oct**
68 + operator releases	100	45	5	1260	16	23	2
68 + CREB diversion	100	45	5	790	10	20	3
68 + operator releases	79	59	0.4	1240	15	22	18
68 + CREB diversion	79	52	0.9	792	12	21	35
68 + operator releases	unrestricted	66	7	1240	14	24	36
68 + CREB diversion	unrestricted	59	7	792	11	23	40
53 + operator releases	100	57	11	1240	17	26	0
53 + CREB diversion	100	57	11	753	15	25	0
53 + operator releases	79	69	4	1230	17	26	4
53 + CREB diversion	79	62	4	754	14	25	4
50 + operator releases	76	72	6	1230	17	26	3
50 + CREB diversion	76	72	6	750	17	25	3

6 Conclusions and recommendations

This project's results support two business needs for the Department of Water and Environmental Regulation:

- Project task 1 completes action 8 of the *Lower Collie surface water allocation plan* (Department of Water 2015a), which is to re-evaluate the yield of the Wellington Reservoir to reflect inflows to the reservoir under a drier future climate.
- Project task 2 supports investigations for the Myalup-Wellington Water for Food project which proposes to reduce salinity in Wellington Reservoir by diverting up to 15 GL/year of saline water in the Collie River East Branch to a mine void for desalinisation.

As a result of re-evaluating the yield of Wellington Reservoir, a change to the current allocation limit is recommended. The current 85.1 GL/year allocation limit will not be reliable under a dry 2030 climate and may also not support the winter release regime designed to provide water to the downstream environment. The department is working towards reducing the allocation limit to Harvey Water's current licensed entitlement of 68 GL/year and issuing no further licences for additional water.

Harvey Water, Synergy and Collie Water have been consulted on the two recommended allocation options. The department is now working to finalise the review of the allocation limit. Further work to investigate changes to restriction triggers and rules will also be explored in the near future.

Appendices

Appendix A – Components of the winter releases from Wellington Reservoir

(Department of Water 2015a)

Volume of daily and peak event releases from Wellington Reservoir

Storage (1st day of month) GL	Total monthly release ML/month					
	May	June	July	August	September	October[1]
≤ 25	0	0	0	0	0	0
> 25 ≤ 40	465	450	465	465	450	465
> 40 ≤ 55	465	450	465	465	450	465
> 55 ≤ 70	465	450	1400	950	450	465
> 70 ≤ 85	465	450	2300	1870	450	465
> 85 ≤ 100	465	600	2740	3180	450	465
> 100 ≤ 115	465	1805	3610	5240	1370	465
> 115 ≤ 130	465	5160	5420	6320	2400	465
> 130 ≤ 145	465	5160	7940	7700	3800	775
> 145 ≤ 160	465	5160	8750	8000	5480	1240
> 160 ≤ 175	465	5160	8750	8000	5820	1240
> 175 ≤ 185	465	5160	9020	10 700	9240	4020
> 185	465	5160	9020	10 700	9240	4020

[1] If irrigation releases are required during October and are higher than the daily release no additional water needs to be released.

Volume of operator releases from Wellington Reservoir

Storage (1st day of month) GL	Maximum operator release ML/month					
	May	June	July	August	September	October
< 25	-	-	-	-	-	-
≥ 25 ≤ 40	-	-	-	-	-	-
> 40 ≤ 55	-	-	2425	1940	-	-
> 55 ≤ 70	-	-	2820	1940	1455	-
> 70 ≤ 85	-	-	2640	1880	1455	-
> 85 ≤ 100	-	-	2640	1760	1455	-
> 100 ≤ 115	-	-	2460	380	1410	-
> 115 ≤ 130	-	-	3600	340	1350	-
> 130 ≤ 145	-	-	3780	300	1200	-
> 145 ≤ 160	-	-	3780	300	1020	-
> 160 ≤ 175	-	-	3780	3600	1020	-
> 175 ≤ 185	-	-	3780	2400	5760	-
> 185	-	-	6480	4800	5760	-

Shortened forms

EWP	environmental water provision
EWR	ecological water requirements
LUCICAT	Land Use Change Incorporated Catchment
CREB	Collie River East Branch
LAI	leaf area index
GCM	global climate model
GL	gigalitres
mg/L	milligrams per litre

Glossary

Climate change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.
LUCICAT	The Land Use Change Incorporated Catchment (LUCICAT) model is a dynamic water balance model that simulates daily streamflow and salt load for given rainfall, evaporation and land use.
Reliability of supply	The frequency with which a specified water volume is supplied in full.

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