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Avon Catchment Council

Report for Surface Water Management and Self-Sufficiency

Project – IWM006

Constructed Storage Analysis for the Avon Arc

December 2008

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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Executive Summary

An analysis was undertaken on the impact of farm dams on flows within the Avon River. This report is one of a series of investigations that consider potential impact of development within the Avon Arc on environmental flows within the Avon River.

It is estimated there are almost 14,000 dams within the 11,800 sq km study area of the Avon Arc. Dams typically ranged in size from 1.0 - 10 ML, with the average dam size estimated to be 3.3 ML. The largest artificial water storage found within the study area was approximately 76 ML.

Dam volume/area ratios varied throughout the study area ranging from a low of 1.5 - 1.6 ML /km^2 for the shires of Goomalling and Cunderdin to a high of 6.7 ML /km^2 for the Shire of Pingelly. Average landscape constructed storage was found to be approximately 3.28 ML/ km^2.

Run-off threshold modelling and adoption of previous Large Scale Catchment Modelling LASCAM) undertaken by CSIRO were applied, to assess the potential combined impact of additional farm dam construction and predicted climate change scenarios on flows within the Avon River.

LASCAM modelling (CSIRO 2008) was found to provide an adequate prediction of mean annual flow; however it under-predicted the variance in recorded flows over the calibration period. Rainfall threshold modelling used in predicting run-off in farm dam modelling provided mean and variance in flows similar to those of recorded flows for the calibration period.

LASCAM data used in the analysis enabled assessment of the potential influence of climate change over both the flows and salinity of rivers. Filtering of the LASCAM salinity data was undertaken to generate a salinity trace more reflective of recorded salinity (TDS) over the calibration period.

Modelling undertaken indicated dams currently capture and store approximately 14% of all run-off generated within the study area. Increases in dam storage within the study area are likely to be geographically restricted and associated with land use change and/or declining rainfall associated with climate change.

Modelling indicated declining rainfall associated with climate change represents the most significant potential driver for a reduction in flows within the Avon River. Alternative rainfall scenarios modelled included a 10% increase, the base case (no change), and 10% and 20% decline in rainfall over a 50 year period to 2056.

LASCAM modelling indicated changes in rainfall associated with climate change are likely to have a dramatic influence on the volume of flow within the Avon River. LASCAM modelling indicated a 10% increase in rainfall would result in a 60% increase in the average annual flow from 155 GL to 248 GL. The modelling also indicated 10% and 20% reductions in rainfall would result in 40% (155 GL to 95 GL) and 55% (155 GL to 55 GL) reductions in flow respectively. Changes in rainfall associated with climate change are predicted to have a mild influence over the frequency of flows within the Avon River, with

increases in the frequency of flow associated with increased rainfall and mild decreases in frequency of flows associated with reduced rainfall.

Changes in rainfall patterns are also likely to influence peak flows, with the one in 10 year flow at Northam Weir expected to increase from approximately 1.3 GL/day to 2.1 GL/day, assuming a 10% increase in rainfall. Conversely a 20% reduction in rainfall is expected to result in a reduction in the 1 in 10 year peak flow from approximately 1.3 GL/day to 0.5 GL/day at Northam Weir.

Modelling indicated reduced rainfall scenarios would have a significant influence over dam reliability within the study area. It is predicted that reliability of farm dams would decline from a current estimated 93% to 71% assuming a 10% reduction in rainfall. A 20% reduction in rainfall is predicted to result in a reduction in dam reliability from 93% to 52%, based on dams holding more than 5% of their available storage capacity based on a daily time step rainfall threshold run-off model.

Dam modelling indicated the addition of improved (roaded) catchments to farm dams would improve dam reliability and dramatically increase frequency of dam overflow. The inclusion of improved catchments increased the frequency of overflow of farm dams from approximately 1 overflow event every 3 years to approximately 5 overflow events per year. Additional flow generated by the development of improved catchments was found to be roughly equivalent to the volume of run-off captured by farm dams for all climate change scenarios. It was concluded that that the addition of improved catchments would largely nullify the negative influence of farm dams on river flows.

The addition of improved catchments is also likely to be an effective strategy for managing the potential impact of predicted reductions in rainfall on dam reliability. Modelling indicated the addition of a 3.5 ha improved catchment to a 3.3 ML dam would result in an increase in reliability from 93% to 99%, given current climatic conditions. Modelling also indicated the current average dam reliability (of 93% for a 3.3 ML dam) could be maintained through the addition of a 3.5 ha improved catchment, assuming a 10% reduction in rainfall.

Analysis indicated dam reliability is sensitive to the run-off threshold of improved catchments. Construction methods employed in the development of improved catchments and potential application of surface treatments are likely to be important factors in managing the potential impact of climate change on the future security of water resources within the study area.

The inclusion of improved catchments outperformed re-engineering (increasing dam size) for all rainfall scenarios tested. A 30% increase in storage volume (ie. increase dam size from 3.3 ha to 5.0 ha) resulted in an increase in dam reliability from 93% - 97% under current rainfall conditions, and from 71% - 86% assuming a 10% reduction in rainfall. Alternatively, the addition of an improved catchment was found to increase dam reliability from 93% - 99% and 71% - 93% for base case and 10% reduction in rainfall scenarios respectively.

A 30% increase in the volume per unit area of storage within the catchment would result in an increase in the proportion of run-off captured by farm dams from 14% (current conditions) to 22%, under the most severe climate change scenarios (20% reduction in rainfall). Increasing dam storage as a strategy for improving security of farm water supplies under reduced rainfall scenarios is unlikely to be effective and would exacerbate the impact of declining rainfall on environmental flows within the Avon River.

LASCAM modelling indicated that all rainfall scenarios are likely to result in increased salinity of flows at Northam Weir. Increases in salinity are predicted to be most severe assuming a 20% reduction in rainfall, with late season flows experiencing the greatest increase in salinity. Salinity of large flows appears to be relatively stable across all climate change scenarios. Low volume flows are predicted to be most affected by declining rainfall scenarios.

The addition of improved catchments is likely to result in an increasing magnitude and frequency of late season flows within the Avon River, providing beneficial downstream effects to environmental flows.

1. Introduction

1.1 Background

GHD were contracted by the Avon Catchment Council to deliver the 2005 - 2008 Investment Project: Water Management and Self-Sufficiency IWM006.

This project includes objectives associated with improving self-sufficiency for water supplies within the Avon River Basin and reducing reliance on the Water Corporation Water Supply Scheme (IWSS). The project also includes objectives associated with development of environmental flow requirements for the Avon River and adoption of planning provisions within the Avon Arc sensitive to environmental flow requirements.

In some instances there may be conflicts between these objectives, in that improved self-sufficiency for water supplies may be achieved by increasing water harvesting. However, it is imperative adequate stream flow is retained for environmental requirements.

This report is one of a series within the Water Management Self-Sufficiency Project dealing with issues surrounding environmental flows for the Avon River and associated planning recommendations. Other relevant reports include:

- *Preliminary Environmental Flow Analysis of the Avon River (GHD 2008 a); and*
- *Recommended Planning Provisions - Construction of New Storages within the Avon Arc (GHD 2008 b).*

This report focuses on the impact of constructed storages on environmental flows within the Avon Arc with consideration for hydrologic impact associated with potential increase in storages and climate change.

1.2 Relevant Management Action Target

The Management Action Target relevant to this project component is:

> ***W3 MAT 5.2.*** *Proposals for new dam construction within the Avon Arc are referred through provisions of the Town Planning Act 1928 for environmental assessment by 2009.*

1.3 Funding

The Water Management Self-Sufficiency Project is funded through the Avon Catchment Council (ACC) investment plan 2005 – 2008, with funds from the National Action Plan (NAP) for Salinity and Water Quality, a joint State and Commonwealth Government initiative.

2. Background

2.1 General

The project area associated with the assessment undertaken is restricted to the Avon Arc, a sub region of the Avon River Basin consisting of an area of 11,822 km^2, which includes areas contained within 10 local government authorities. The study area also contains the towns of Northam, Toodyay, York, Beverley and Brookton (Figure 1).

2.2 Climate

The climate within the region is Mediterranean, where summers are hot and dry, with approximately 80% of the annual rainfall falling within the months May – October. Rainfall throughout the Avon Arc is variable, with annual rainfall over the last 10 years ranging 327 – 398 mm from north to south and 457 – 349 mm from west to eastern bounds of the catchment respectively.

2.3 Vegetation

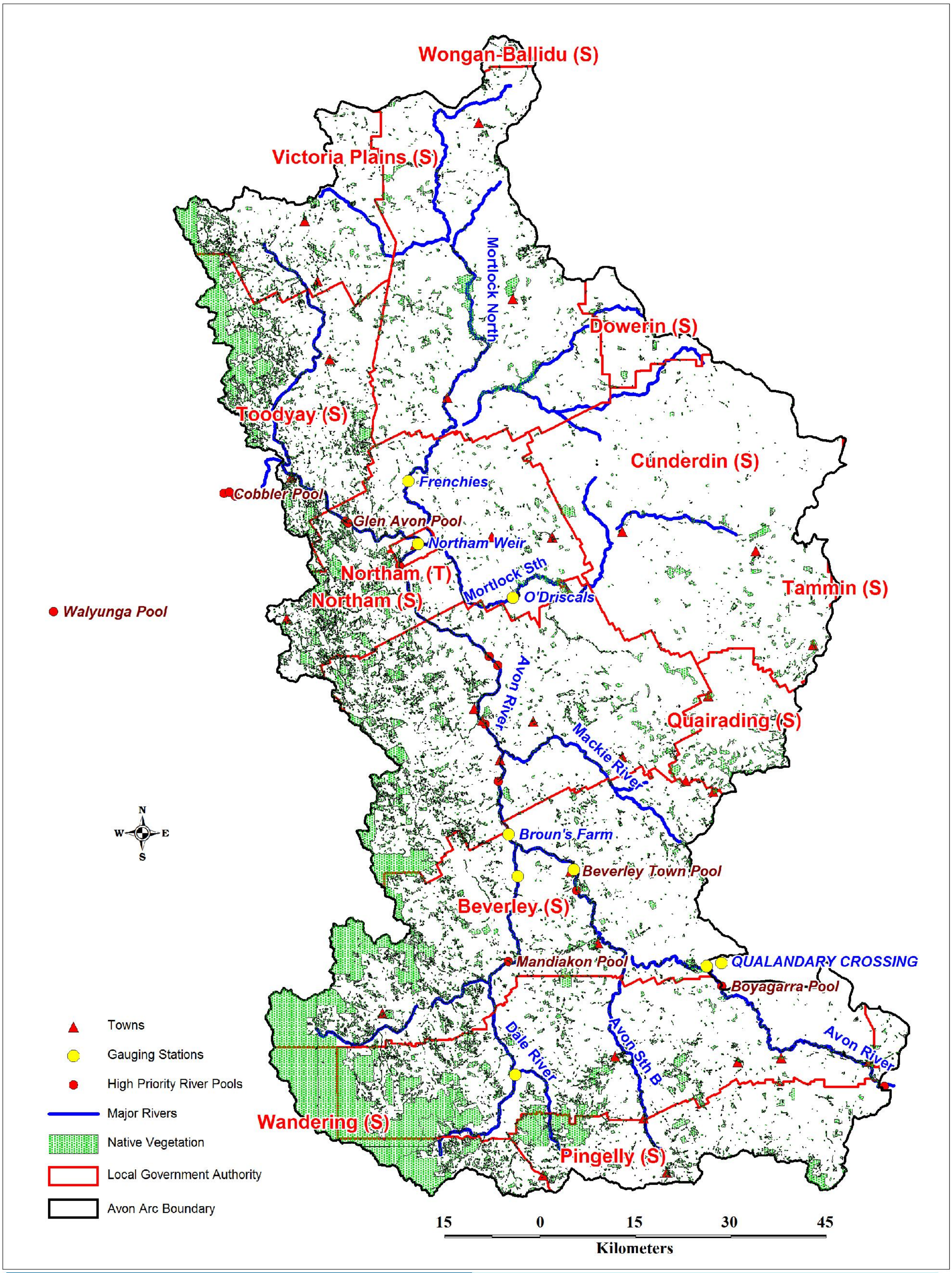
The western margin of the Avon Arc lies close to the Darling Scarp containing a high proportion of native Jarrah forests. Extensive clearing of land for mixed agriculture has occurred throughout the study area, increases towards the east of the catchment. The most significant areas of native vegetation remain within the Dale River catchment, which has a particular environmental significance due to its contribution of fresh flows to the Avon River (GHD 2008 b).

2.4 Hydrology

The Avon River is comprised of several tributaries that form the Avon River which in turn forms the Swan River. The Avon River flows predominantly in a north – westerly direction, discharging from the study area near the town of Toodyay. Significant tributaries include the Mortlock North, Mortlock South, Mackie River, Dale River and the Avon South Branch (Figure 1).

A detailed description of the hydrology of the Avon River is contained within GHD 2008 b.

The Avon River contains many environmentally sensitive river pools supporting a high degree of biodiversity, including native fresh water fish species. Environmental values of the Avon River have previously been compromised as a result of the river training scheme and clearing of native vegetation resulting in salinisation, sedimentation, nutrient enrichment and increased frequency of fires (JDA, 1997). However, a number of river pools retain high conservation, social and, in some cases, economic values. A detailed description of environmental values of river pools is contained within GHD 2008 (b).



Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 50

Figure 1. Vegetation and River Pools Within the Avon Arc

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3. Methodology

An overview of the methods used in undertaking the analysis of the impact of dam storage on flows within the Avon River is presented in this section.

3.1 Project Scope

Activities undertaken within this project included:

- *Assessment of the extent of current constructed storage (including dams, reservoirs and artificial lakes) and assessment of the proportion of existing river flows represented;*
- *Assessment of the potential extent of increase in constructed storage within the Avon Arc (sensitivity analysis) and of the potential impact on existing flows; and*
- *Assessment of the potential impact of predicted climate change scenarios on constructed storage.*

3.1.1 Estimation of Current Storage

GHD assessed the number of dams, reservoirs and artificial lakes located within the Avon Arc catchment area.

The assessment included:

1. *Digitising dams within selected subcatchments of the Avon Arc;*
2. *Spatial analysis of digitised dams and comparison with existing GIS coverages (Department of Water); and*
3. *Estimation of the number, area and volume of artificial storages contained within subcatchment using outcomes of the spatial analysis undertaken in Step 2.*

Five subcatchments were selected to determine the natural variation of dam density across the catchment. These catchments were selected based on analysis of the existing DoW dam coverage, through assessing the current dam density over the study area.

The location and surface area of individual dams were digitised using scanned, rectified aerial photography, supplied by the Department of Water. This digitised dam coverage was compared statistically to a pre-existing dam coverage provided by the Department of Water.

Outcomes of the analysis were extrapolated to determine revised dam density for individual subcatchments within the study area. In addition, the spectrum of dam sizes existing throughout the Avon Arc was derived from the digitised dam coverage.

Dam volumes were extrapolated from digitised dam surface area using synthetic area - volume relationships.

Dam catchment areas were digitised for a representative sample of dams within the study area using digitised rectified aerial photography and a high-definition digital elevation model (40 m grid spacing).

3.1.2 Assessment of Impact of Changed Catchment Storage on Avon River Flows

An assessment of the impact of potential changes in constructed storage within the catchment was undertaken at nodes corresponding to the Northam Weir and Brouns Farm Gauging Stations, where measured data was available for comparison. The assessment included the development of a spreadsheet-based dam storage model to simulate the impact of increased catchment storage on current flows. The dam storage model included the following components:

- *Area and volume of storage at a subcatchment scale;*
- *Seepage and evaporative loss from catchment storages;*
- *Net daily usage (stock and domestic supply); and*
- *Provision for adding constructed improved catchments to catchment storages.*

The dam model included functionality to increase the number and size of discrete artificial catchment storages and improved catchments.

Existing and derived rainfall data was used within the model to assess the impact of potential increases in constructed catchment storage on environmental flows within the Avon Arc. The assessment was undertaken within the context of potential changes in flow associated with selected climate change scenarios. The main driving parameters within the model are:

- *Rainfall (daily);*
- *Dam Volume (ML);*
- *Dam Surface Area (m^2);*
- *Catchment Area (m^2);*
- *Catchment Runoff Threshold (mm);*
- *Runoff Coefficient; and*
- *Daily Losses.*

3.1.3 Assessment of Potential Climate Change

Climate change is increasingly accepted as a likely future reality. The south-west of Australia has been identified as 'severely affected' by changes in rainfall (EPA, 2007). Average winter rainfall has fallen 15% over the last 30 years, which has been projected to fall up to a further 60% by 2070 (Bureau of Meteorology, 2003).

Temperatures within the south-west of Western Australia are projected to increase by 1.5 – 2 degrees celsius by 2070. These predictions are likely to adversely affect hydrological processes occurring in catchments within the south west of Western Australia.

Rainfall datasets representing reduced rainfall conditions were developed by GHD to mimic CSIRO climate predictions as input to model catchment hydrology to 2050. CSIRO developed the Cubic Conformal Atmospheric Model 709 (CCAM), and published A2 and F2 future rainfall data output from CCAM prediction to 2065. This dataset has been used in the nearby Hotham Williams Murray catchment to model stream flow changes as a result of changing rainfall (Joyce, 2007). The data is considered a useful tool for assessing potential future rainfall change within the study area.

Analysis of the CCAMs rainfall datasets for the location of Northam was undertaken. Ten rainfall simulations were available for this period of assessment. Model climate change rainfall data (CCAM A2 C2) were compared to recorded rainfall for the period 1975 – 2005. Based on the mean annual rainfall for each period from the ten rainfall simulations, a 10% reduction in annual rainfall is predicted for the 60 year period from 1975 – 2005 to 2035 – 2065.

Results generated from the CSIRO CCAM data were used as a guide to extrapolate the current rainfall dataset to 2050 for the town of Northam. The rainfall dataset for the period 1975 – 2004 was replicated twice to extend the model rainfall dataset to 2065.

The replicated rainfall dataset was modified to depict a step change in rainfall to represent a linear depreciation in rainfall over the period 2005 - 2065. In achieving a 10% reduction in rainfall over the period 2005 - 2064, a stepped reduction of 5% and 10% was applied to the rainfall time sequences 2005 – 2034 and 2035 – 2064 respectively.

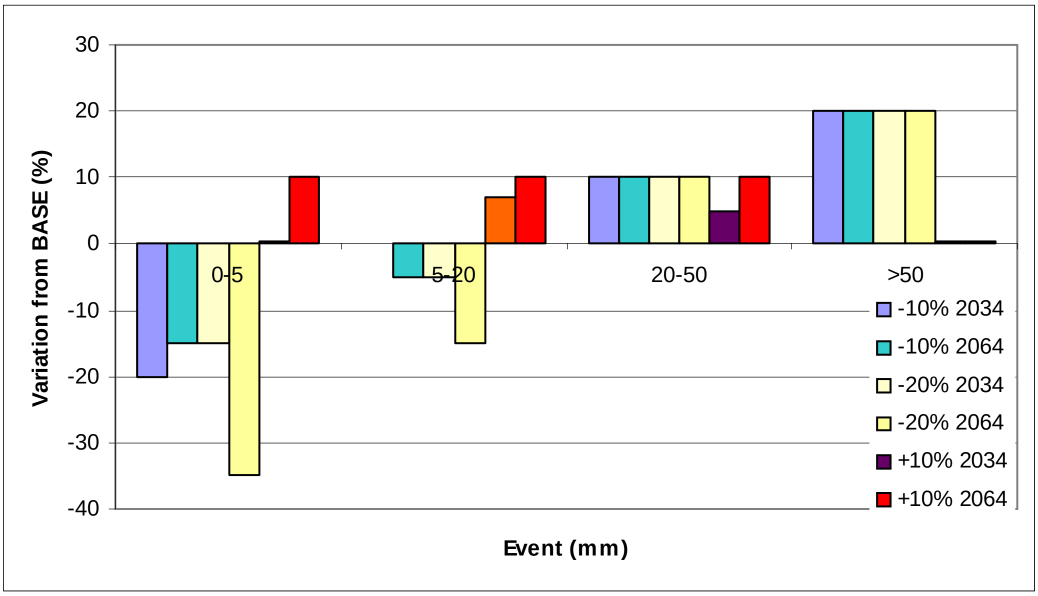
Event scaling was also undertaken to provide a more realistic predictive rainfall series. This included a reduction in the magnitude of smaller rainfall events and increased the magnitude of larger rainfall events (Figure 2).

The predicted rainfall datasets were adjusted to generate four climate change scenarios that matched Large-Scale Catchment Model (LASCAM) flow data generated from the same climate scenarios:

1. *Base Case (no change in rainfall patterns);*
2. *- 10 % mean reduction in rainfall;*
3. *- 20 % mean reduction in rainfall; and*
4. *+ 10% mean increase in rainfall.*

Figure 2 illustrates how each rainfall dataset was scaled from the base case rainfall scenario to generate the modified rainfall series. In each rainfall scenario, event scaling was broken down into two periods, 2005 – 2034 and 2035 – 2064. The bar chart illustrates the scaling factor as a percentage variation from the base case daily rainfall.

Figure 2. Event Scaling Used to Generate Future Rainfall Datasets for Northam.



3.2 Dam Model

A simple bucket spreadsheet model was developed to simulate paddock run-off and dam storage impact on flows within the Avon River. The model uses a daily time step to simulate rainfall - run-off utilising the principals of an initial and continuing loss model. The model simulates catchment discharge to storages, incorporating components of evaporation, seepage and water usage. Once storages are full they discharge to the river as outflow from the model.

A summary of the model is provided:

$$\sum O_{(n)} = I_{(n)} - (St_{(max)} - St_{(n-1)})$$

$$St_{(n)} = St_{(n-1)} - (Ev_{(n)} + Ex_{(n)} + Sp_{(n)}) + MI_{(n)}$$

***O**: Outflow from dam where $St(_{Max})$ is exceeded.*

***I**: Inflow*

***MI**: Modified inflow, (inflow limited by extent storage capacity)*

***St**: Dam Storage*

***$St_{(max)}$**: Maximum storage capacity*

***Ev**: Evaporation for dam surface*

***Ex**: Extraction*

***Sp**: Seepage fraction*

$$\sum I_{(n)} = ((R_{(n)} - T_{(Pad)}) \times A_{(Cat)} \times C_{(cat)}) + ((R_{(n)} - T_{IRd)}) \times A_{(Rd)} \times C_{(Rd)})$$

I: Inflow

R: Daily rainfall

$T_{(Pad)}$: Run-off threshold of paddock

$A_{(Cat)}$: area of paddock catchment.

$C_{(cat)}$: Run-off coefficient for paddock catchment

$T_{IRd)}$: Run-off threshold of improved catchment

$A_{(Rd)}$: Area of improved catchment.

$C_{(Rd)}$: Run-off coefficient for improved catchment

Average and dam size and dam density for individual subcatchments were used to simulate the distribution of volume storage throughout the study area.

Rainfall scenarios used in the model simulations included based case and predicted potential climate change scenarios of: -10%, -20% and +10% rainfall scenarios (Section 3.1.3).

4. Model Inputs

A detailed description of the analysis and outcome of investigations into dam distribution and density throughout the Avon Arc is presented in this section. The analysis undertaken provided input into the dam model described in detail in Section 6 of this report.

4.1 Dam Density

The size and distribution of constructed storages, including dams, throughout the study area is an important consideration in determining the impact of constructed storages on environmental flows within the river.

The Department of Water maintains GIS coverages of surface water hydrology features, including dams, artificial wetlands and reservoirs. The accuracy of the distribution and size of dams depicted within the Department of Water dataset was assessed through comparison with digital rectified aerial photography using GIS. The assessment revealed significant errors of both commission and omission in both the distribution and size of dams reported by Department of Water.

Errors of commission typically included:

- *Bare areas of land and small trenches recorded as dams;*
- *Single dams digitised with multi-polygons; and*
- *Standard polygon size used to depict dams that had no relationship to the actual area of the dam.*

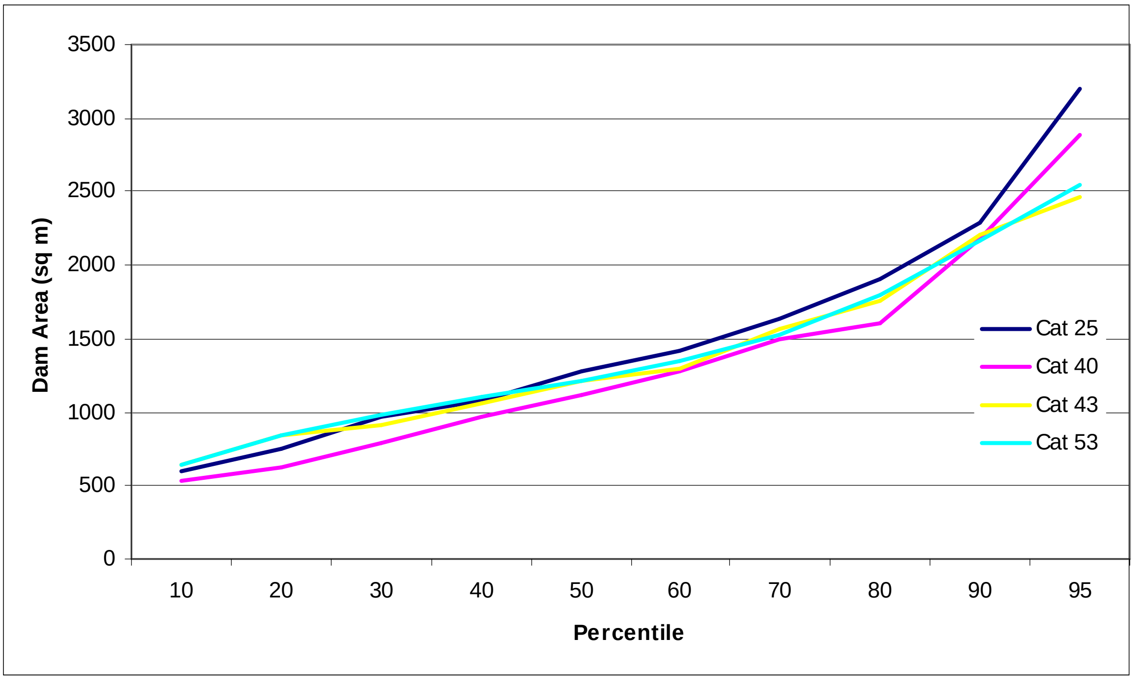
Errors of commission typically led to an overestimation of the number and size of dams throughout the study area. However a strong correlation was found to exist between the number of DoW dams and the number of actual dams. A total of 1037 dams within six selected subcatchments were digitised from aerial photographs. The six subcatchments selected were evenly distributed throughout the study area, providing a representative sample of different landscapes. The investigation concluded that 812 (or 78%) of the 1037 dams reported by Department of Water surface hydrology dataset were found to exist.

The extent of overestimation of distribution throughout the study area was found to be relatively consistent and a standard scaling of 0.78 was used to derive the number of dams within the study area from the Department of Water surface hydrology dataset. The analysis was further refined by calculating the arable area of each subcatchment excluding areas of native vegetation. The resulting derived dam density describes the number of dams per unit area (of arable land) within individual subcatchments, excluding areas of native vegetation.

The relative distribution of dam sizes throughout the Avon Arc was also an important input into dam modelling undertaken within the project.

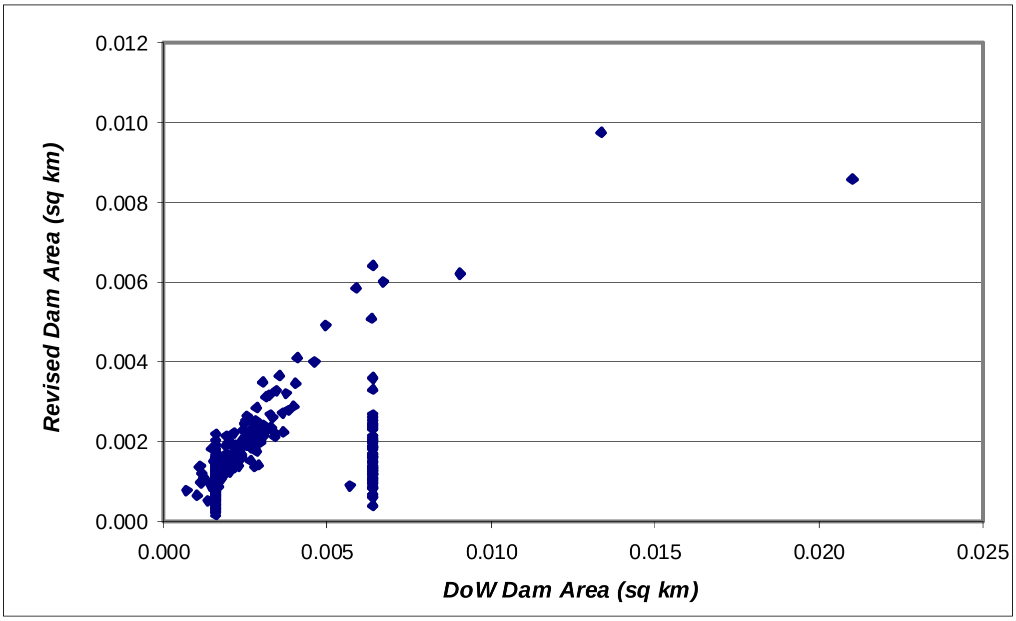
The distribution of digitised dam areas within four separate catchments is plotted in Figure 3. The four subcatchments were distributed throughout the study area and were selected to represent different landscapes and land uses. The analysis indicated the distribution of dam sizes across each of the four subcatchments investigated is relatively uniform. As a result, a standard distribution of dam sizes was applied to all subcatchments within the study area, based on the average dam area for the four subcatchments plotted in Figure 3.

Figure 3. Percentile Rank of Dam Area Within Four Catchments



Digitised dam sizes were compared with dam sizes reported within the Department of Water surface hydrology dataset and are presented in Figure 4. The analysis indicated a basic correlation between digitised dam sizes and those reported by Department of Water. However, the correlation was compromised by the application of standard polygons to describe dams within the Department of Water dataset. Clusters of dams within the Department of Water dataset have been digitised using two standard polygon sizes of 0.0016 km^2 and 0.0064 km^2, evident within Figure 4.

Figure 4. Digitised Dam Area vs DoW Dam Area.



It was concluded the number and distribution of dams throughout the study area could be derived from applying a 0.78% scaling factor to dams reported within the Department of Water surface hydrology dataset. It was also concluded a standard distribution of dam sizes could be applied throughout the study area. The distribution of dam sizes adopted was an average distribution across four selected subcatchments shown in Figure 3.

A summary comparing statistics of dam areas reported by the Department of Water surface hydrology dataset and digitised dam data is presented in Table 1.

Table 1. Summary of Department of Water and Digitised Dam Coverages

Dams Dataset	Mean Surface Area (sq m)	St Dev Surface Area (sq m)	Maximum Surface Area (sq m)	Minimum Surface Area (sq m)
Department of Water (surface hydrology)	2,540	2,390	36,047	696
Digitised Dams	1366	942	9,745	176

4.2 Dam Volume

Two methods for inferring dam volume from dam surface area were considered: the Turner method and the Good and McMurray (1997) method. Outcomes of the analysis are presented in Table 2.

Table 2. Comparison of Dam Volume (ML) Estimation Methods for the Digitised Dam Coverage Using the Revised Dam Coverage Dataset

Estimation of Dam Volume (ML)	Mean	St Deviation	Max	Min
Turner (1998)	3.29	5.4	76.2	0.17
Good & McMurray (1997)	1.2	1.39	16.9	0.06

The two methods provided very different estimations of dam volumes within the study area. The Turner method was determined to be the most applicable to the Avon Arc, based on comparison with standard dam construction methods generally adopted within the southwest of Western Australia, with the summary analysis presented in Table 2.

The Turner method is based on a square dam design with a fall of less than one metre across the dam site. The method considers storage capacity (ML) as a function of the surface area of the dam water body (m^2), depth (m) and bottom area (m^2).

Standard dam construction criteria were used to determine a relationship between the volume and surface area of the dam water body, presented in Figure 5.

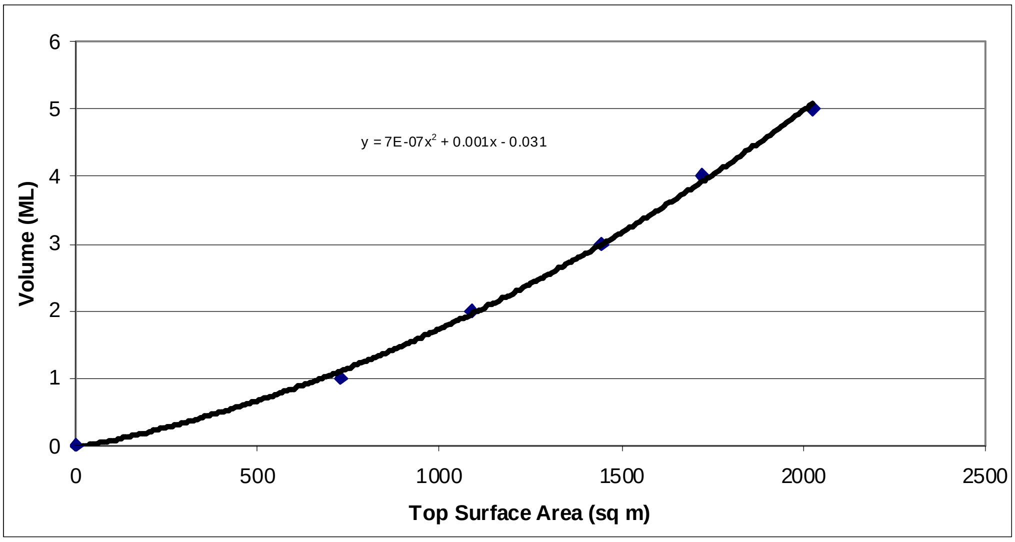
The volume (ML) and top surface area (m^2) values were analysed to generate an equation used to calculate dam volume based on surface area.

$$Vol = 7E\text{-}07 \times (A)^2 + 0.001 \times A - 0.031$$

***Vol**: Derived dam volume (ML)*

***A**: Surface area of dam water body (m^2)*

Figure 5. Turner Methods Displaying the Relationship Between Dam Volume and Surface Area



A summary of the dam density and storage volume ratios for the 16 shires located within the Avon Arc is presented in Table 3 and Figure 6. Note the figures presented are calculated from the area of each shire located within the Avon Arc boundary.

This analysis indicated that the Shires of Beverley and Pingelly have the highest dam storage volume-to-area ratios within the study area of 5.72 ML/km^2 and 6.7 ML/km^2 respectively. The Shires of Corrigin and Goomalling the lowest dam storage volume-to-area ratio within the study area of 2.8 ML/km^2 and 1.5 ML/km^2 respectively

Table 3. Summary of Dam Density and Storage Volume/Area Ratio - Local Government Authorities

Shire	Estimated Number of Dams	Shire Area (km^2)	Storage Volume / Area Ratio (ML/km^2)
Wandering	191	272	2.32
Toodyay	1034	756	4.51
York	2583	1611	5.29
Wongan-Ballidu	5	29	0.61
Tammin	2	4	1.14
Beverley	2995	1703	5.72
Northam	1506	1105	4.49
Victoria Plains	393	540	2.40
Dowerin	115	163	2.34
Pingelly	1250	615	6.70
Brookton	2032	1500	4.47
Northam Town	30	26	3.86
Goomalling	681	1492	1.51
Cunderdin	827	1677	1.63
Corrigin	27	42	2.08
Quairading	299	283	3.48
Total	***13,970***	***11,818***	***3.28***

4.3 Dam Catchment Area Estimation

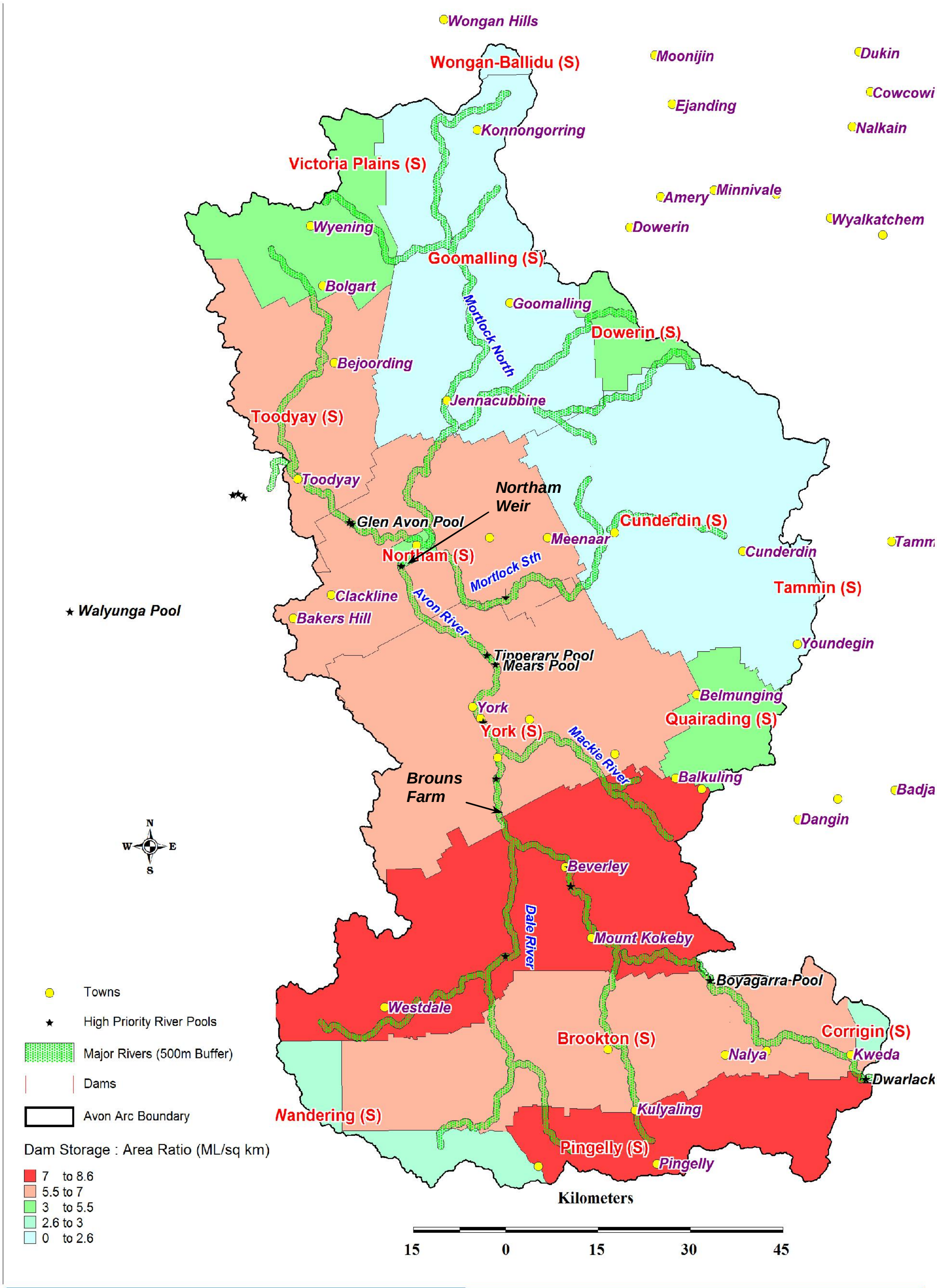
The mean contributing dam catchment area was an important input into modelling. Dam catchment areas provide an indication of the total study area subject to water catchment for dam storage and are important in assessing the potential for increase in dam storage within the study area.

Dam catchment areas were digitised for 272 dams across four evenly distributed subcatchments within the Avon Arc.

The mean catchment size was found to be 14.6 ha. When considered in association with dam densities, dam catchment areas represent approximately 24% of the landscape contributing flows into the Avon River upstream of the Northam Weir pool (Table 4).

Table 4. Proportion of Catchment Subject to Dam Catchments - Brouns Farm and Northam Weir.

Gauging Station	Catchment Area (sq km)	Dam Catchment Area (sq km)	Proportion of Catchment Subject to Dam Catchments
Brouns Farm	472,739	107,111	23%
Northam Weir	635,304	152,348	24%



Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 50

Figure 6 Avon Arc LGA Storage / Area Ratio

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5. Previous Modelling (LASCAM)

5.1 Modelling (LASCAM)

Previously, salinity and flow modelling was undertaken within the Avon River basin by CSIRO under contract to the Department of Water. The project involved the development of the LASCAM (LArge Sale CAtchment Model) for the Avon River basin to assess a range of regional drainage options for managing salinity throughout the region. The analysis also included a series of climate change scenarios.

LASCAM model data provided by CSIRO included:

- *Rainfall Scenarios – Base Case, -10%, -20%, +10%;*
- *Year (1965 – 2050);*
- *Discharge (ML;*
- *Salt Load (t); and*
- *Mean Flow Weighted Salinity (g/L).*

An evaluation of LASCAM outputs was undertaken to determine their potential application to this project, including calibrating flow outputs generated from the dam model for future flow scenarios.

The data generated from the LASCAM base case scenario was compared to recorded flow data at Northam Weir and Brouns Farm Gauging Stations over the period of measured data (Table 5).

Table 5. Period of Recording at Northam Weir and Brouns Farm

Gauging Station	Flow (ML/day)	TDS (mg/L)	TDS Load (t/day)
Northam Weir	1978 - 2006	1996 – 2002	1996 – 2002
Brouns Farm	1976 - 2001	1993 – 2000	1993 - 2000

5.2 LASCAM Flow and Salinity Assessment

Simple catchment wetness index modelling was undertaken as an additional means of determining the potential impact of predicted climate change scenarios on peak and annual flows within the Avon River basin. The details of catchment wetness index modelling undertaken are contained within GHD 2008 a. Simple threshold modelling was also undertaken to predict runoff within the *Dam Model*, involving application of a rainfall threshold and continuing loss for the catchment.

Presented in Table 6 are gross comparisons of annual and peak flows, salinity and salt loads for the various modelling techniques applied.

The analysis indicated LASCAM accurately predicts average annual flow (to 98%), however grossly under-predicts the extent of variation (reported as standard deviation)in annual flow (by 33%). Catchment wetness modelling accurately predicts average annual flow and provides consistency in the variation of flow occurring between individual years. Modelled flow using a catchment wetness index provides a correlation of 0.87 (r^2 value) for both annual and peak flows, indicating a relatively simple relationship between catchment wetness and flow. Simple threshold modelling also effectively predicts the volume and variation of annual flow, however is less reliable in predicting flow in individual years, with a poor correlation ($r^2 \sim 0.19$) between actual and modelled flow.

Table 6. Comparison of Flow Modelling Output with Recorded Flows for Broun's Farm

Flow criteria	Method	Average	St dev
Annual Flow GL	Monitored	105.6	99.1
	LASCAM	108.1	66.4
	Wetness Model	109.0	94.0
	Threshold Model	110.0	95.0
Peak Flows (cumecs)	Monitored	74.1	53.1
	LASCAM	65.0	43.0
	Wetness Model	73.2	48.7
Salinity (mg/L)	Monitored	7,467	2,126
	LASCAM	25,040	11,819
Salt load (t)	Monitored	864	795
	LASCAM	943	761

LASCAM appears to provide a reasonable simulation of flows and salt loads throughout the year, as described by monthly average modelled and recorded flows for Northam Weir and Broun's farm (Figure 7 to Figure 10). However, LASCAM appears to slightly underestimate intensity and salinity of flows occurring as a result of summer storm events. LASCAM also appears to slightly overestimate flow and therefore salt load for the winter – spring period.

Figure 7. LASCAM and Measured Flow at Brouns Farm

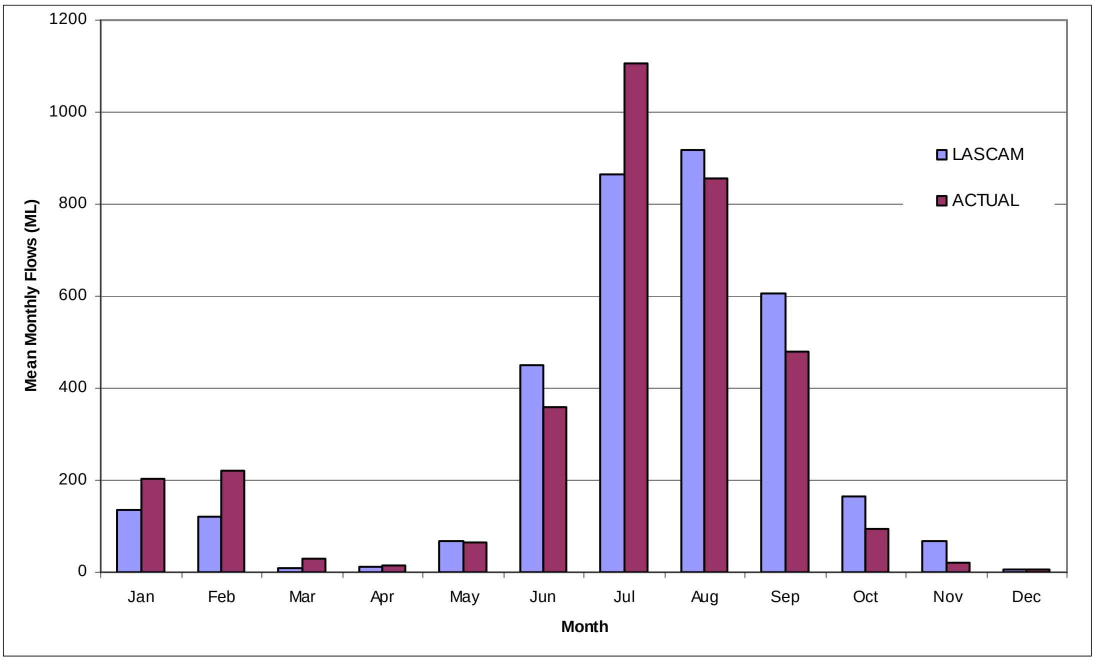


Figure 8. LASCAM and Measured TDS Load at Brouns Farm

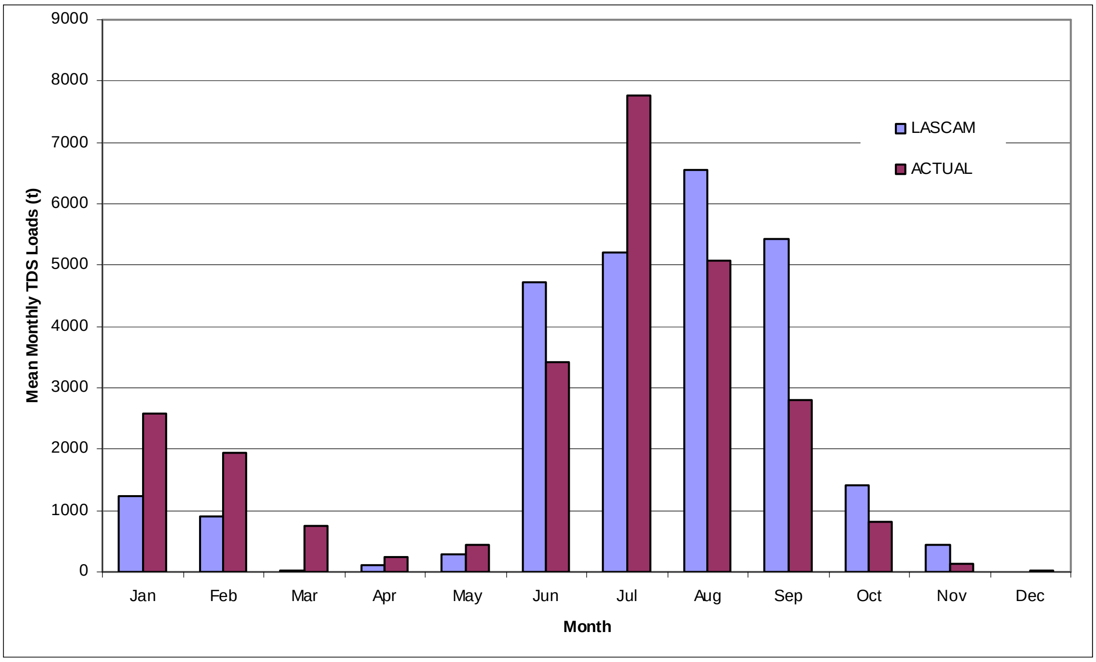


Figure 9. LASCAM and Measured Flow at Northam Weir

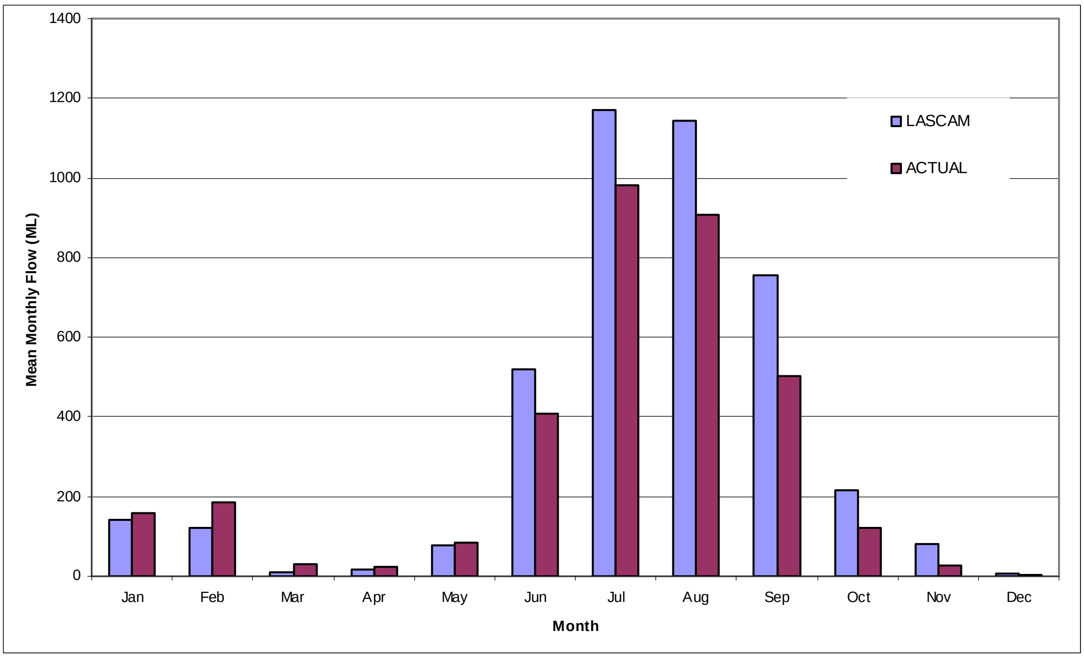
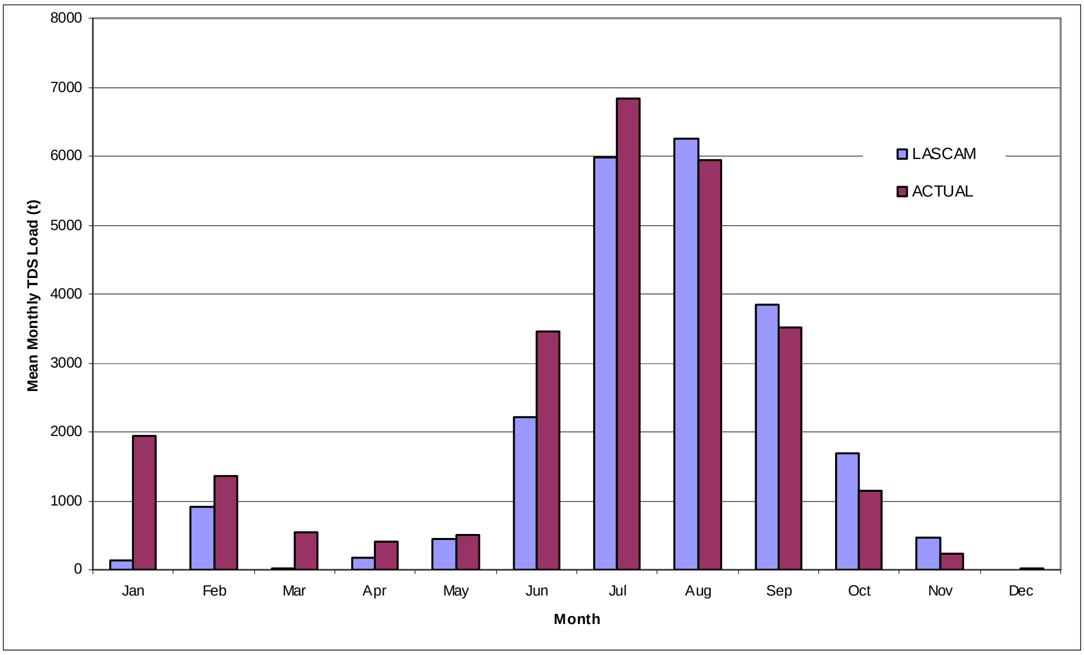


Figure 10. LASCAM and Measured TDS Load at Northam Weir



5.3 LASCAM and Measured TDS Concentration Comparison

Simple catchment wetness index and threshold modelling are not sophisticated enough to provide modelling for salinity or salt load.

LASCAM is calibrated for flow and salt load for major nodes where sufficient data is available for the calibration sequence to occur. LASCAM is well calibrated for salt load to within 9% and 5% for average annual and standard deviation in salt load respectively for the period 1976 - 2005 at Broun's Farm. Whilst this is considered a reasonable calibration, particularly for longer term assessment of total salt load, environmental flow analysis requires an assessment of the variation in salinity (TDS).

LASCAM is not calibrated for salinity per se. Calibration sequences are undertaken for flow and salt load only, with the model providing unrealistic fluctuations in salinity as indicated in Table 6. Variance in salinity (TDS) appears to be a result of a series of extreme values contained within the 90th percentile range, with values as high as 13,000,000 mg/L reported by LASCAM.

Filtering LASCAM salinity (TDS) data was undertaken to improve the correlation between modelled output and recorded flow. Filtering data involved the removal of salinity values of greater than 15,000 mg/L, and less than 10 mg/L. The resulting data set contained data values within the 20th and 90th percentile of ranges. The result was a significant improvement in the distribution of salinity data reported by LASCAM (Figure 11 and Figure 12).

Figure 11. LASCAM and Recorded Salinity (TDS) data for Brouns Farm

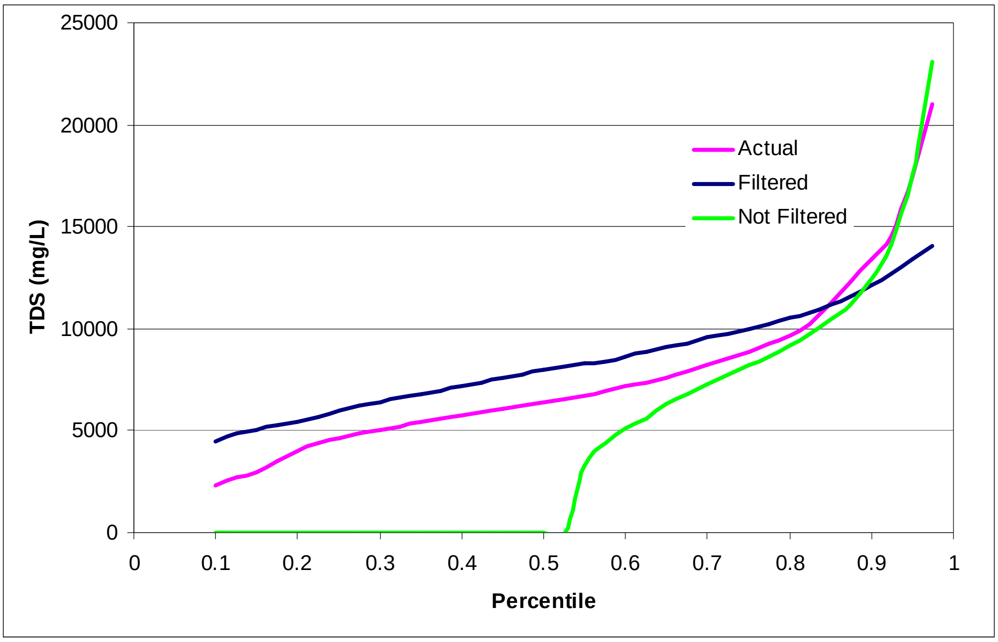
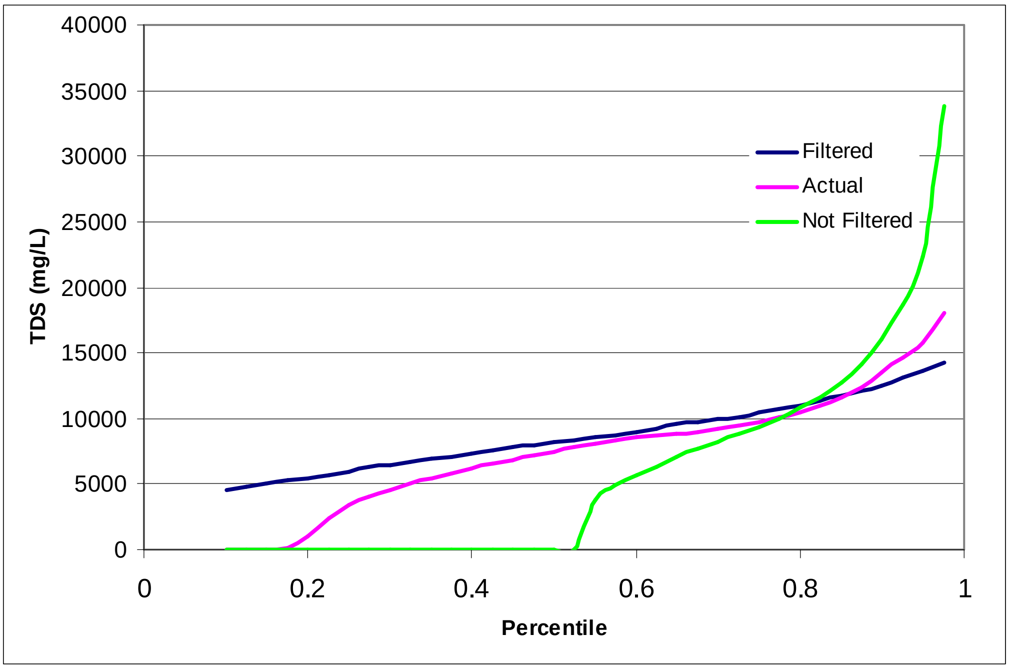


Figure 12. LASCAM and Recorded Salinity (TDS) data for Broun's Farm



Filtered LASCAM salinity data provides a reasonable estimation of the distribution of salinity for Broun's Farm and Northam Weir, however a consequence of filtering salinity data is the removal of high and low salinity values. The result is that filtered LASCAM salinity (TDS) data does not necessarily match monthly measured TDS concentration averages over the recorded period. The filtered LASCAM dataset was compared to measured TDS concentrations at Brouns Farm and Northam Weir (Figure 13 and Figure 14).

LASCAM appears to over-predict average monthly salinity at Northam Weir (typically by 25%), except for June where LASCAM appears to slightly under-predict salinity. At Broun's Farm LASCAM appears to under-predict salinity in the early part of winter and over-predict salinity in late winter and spring. However, LASCAM appears to provide a reasonable prediction of overall patterns of salinity fluctuations throughout the year.

Figure 13. Monthly Filtered LASCAM and Recorded Salinity (TDS) - Brouns Farm

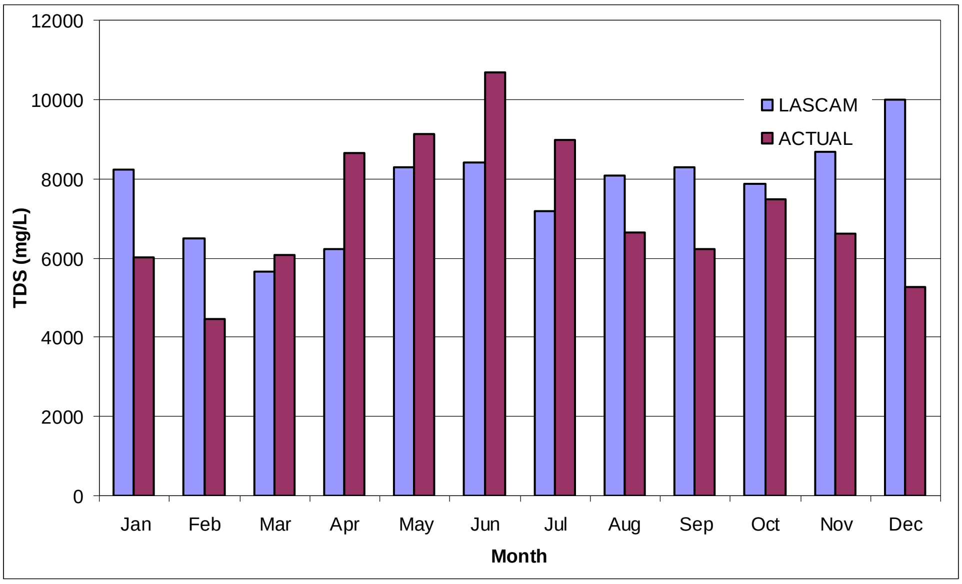
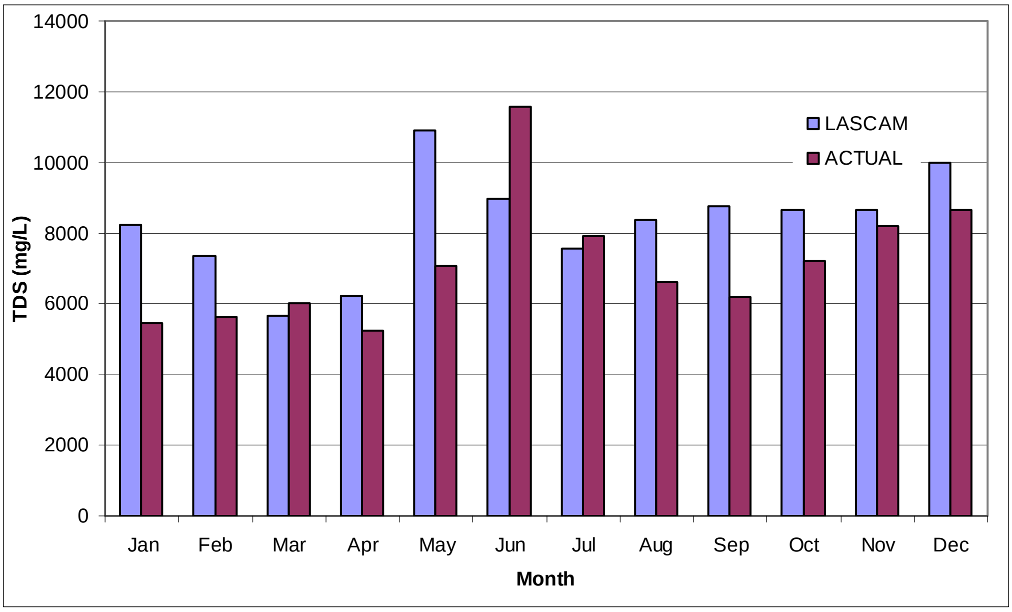


Figure 14. Monthly Filtered LASCAM and Recorded Salinity (TDS) - Northam Weir



5.4 Summary

LASCAM predictions for flow in the Avon River provide good correlation with recorded flow when averaged over a relatively long time period. However LASCAM does not effectively mimic recorded variation in flow within the Avon River.

Both catchment wetness index and flow threshold models provide average and standard deviations of annual flows similar to recorded flows. The flow threshold model has a low correlation with recorded flows for individual years resulting from the relative simplicity of the model, which does not take into account catchment wetness when determining potential runoff associated with individual rainfall events. However, due to the effectiveness of the flow threshold model in correctly predicting average and standard deviation of flows, it was considered adequate for determining flow input to the dam model.

The LASCAM model provides the only mechanism for predicting influence of potential climate change scenarios over the salinity of flows within the Avon River. Filtering LASCAM salinity data was required to provide a salinity distribution similar to that recorded for the Avon River at Northam Weir. Filtered LASCAM salinity data was considered to provide a reasonable indication of the potential impact of predicted climate change scenarios on the salinity of the Avon River.

6. Dam Modelling

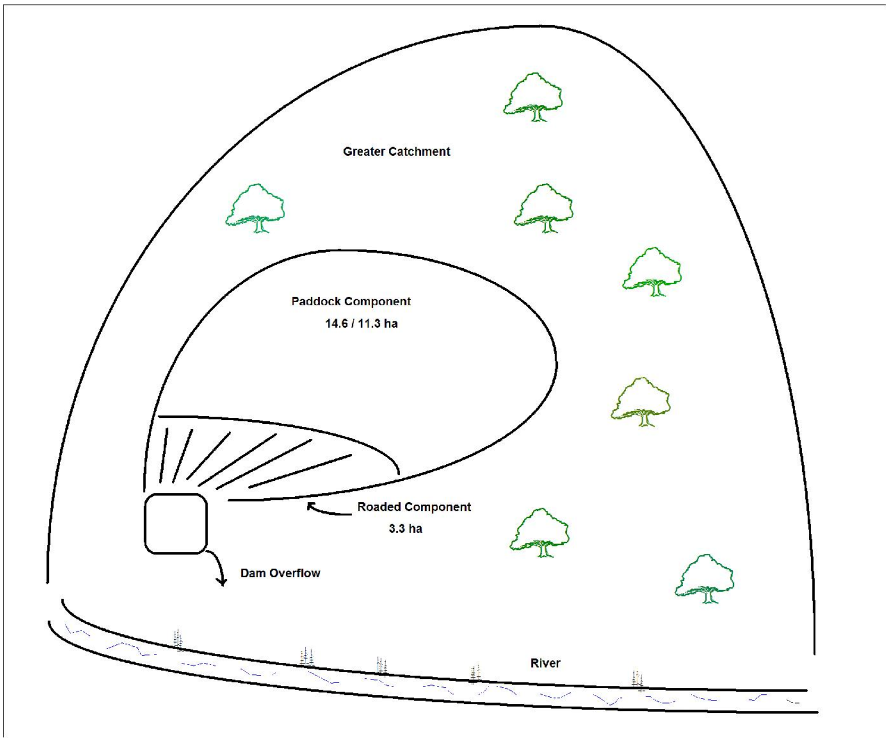
6.1 Paddock and Roaded Dams

The dam model incorporated dams with both paddock and improved (roaded) catchments. The size of paddock catchments was assessed and found to have a mean size of 14.6 ha, discussed in more detail in section 4.3. Approximately 24% of the greater study area is subject to dam catchments.

Improved catchments refer to the inclusion of a constructed "roaded" or compacted catchment, typically with a lower threshold to runoff than paddock catchments. It was estimated approximately 1 ha of improved catchment is required for 1 ML storage, making 3.3 ha the average improved catchment for the study area.

The analysis undertaken indicated improved (roaded) dam catchments are relatively rare throughout the study area, with less than 1% of dams investigated through aerial photography analysis connected to improved catchments. The model was developed to simulate the use of improved catchments to test improved management options for managing flows within the study area. A schematic diagram of improved catchments is presented in Figure 15.

Figure 15. Conceptual Diagram of a Roaded Dam and its Upstream Catchment.



6.2 Dam Model Calibration

Threshold and coefficient run-off parameters were adjusted to achieve calibration with modelled annual flow output from the LASCAM model at Northam Weir for the period of prediction, 2006 - 2050. Calibration with LASCAM was undertaken to ensure consistency of modelling, as the LASCAM outputs were used for determining the potential impact of climate change on river flows and salinity (TDS).

Run-off threshold and coefficients remained unchanged throughout modelling of future base case and predicted climate change scenarios.

Runoff thresholds and coefficients adopted for the dam model are presented in Table 7.

Table 7. Runoff and Thresholds and Coefficients Adopted for Dam Model

	Runoff Threshold (mm)	Run-off coefficient
Paddock catchment	18.5	0.75
Improved catchment	8	0.8

6.3 Dam Runoff Capture Efficiency

The analysis indicated given current climate conditions and dam density, between 55% and 58% of runoff generated from paddock catchments was being held within farm dams, for Brouns Farm and Northam Weir respectively. The remaining runoff is dam overflow, which discharges downstream and contributes to river flow. In contrast, dams with improved catchments capture between 40% and 41% of total flow generated within paddock areas subject to dam flow capture. The minor variations in catchment runoff capture efficiency between dams upstream of Brouns Farm and Northam Weir are due to variations in dam density within the catchment upstream of each gauging station.

Approximately 24% of the land area within the Avon Arc is subject to dam catchments (refer section 4.3). This translates to between 13% - 14% of all runoff generated within the study area currently being captured by dams.

6.3.1 Impact of Improved Catchments

The addition of improved catchments within the model significantly reduces the percentage volume of base surface water flow captured by farm dams. The advantage of improved catchments it that they generate additional runoff, due to a lower rainfall - runoff threshold of the constructed “roaded” catchment, compensating for paddock runoff captured within farm dams.

Analysis undertaken indicated the addition of improved catchments to farm dams largely negated the negative influence of farm dams withholding runoff to the river. Output from the dam model describing impact of improved catchments or total and river flow for both paddock and improved catchments, for the range of climate change scenarios, is presented in Table 8. The analysis undertaken assumed either all dams relied entirely on paddock catchments to provide runoff, or alternatively all dams had the addition of improved catchments, resulting in additional runoff.

Table 8. Dam Model Analysis of Impact of Improved Catchments of Flow

	Catchment Type	Total Runoff (GL/yr)	River Flow (GL/yr)
Base case	Paddock	**181**	156
	Improved	213	**182**
+ 10% Rainfall Scenario	Paddock	**222**	195
	Improved	258	**227**
- 10% Rainfall Scenario	Paddock	**172**	147
	Improved	203	**172**
- 20% Rainfall Scenario	Paddock	**141**	118
	Improved	168	**138**

River flows are represented as total runoff minus flows captured within farm dams. The dam model analysis indicated that in all rainfall scenarios modelled the addition of improved catchments to dams effectively negated the influence of farm dam storage over river flows. Volumes are presented as annual average flow reported as GL/year.

The addition of improved catchments negated the impact of farm dams on river flow by increasing the frequency and volume of runoff. Presented in Table 9 is the modelled increase in dam capture volumes resulting from the addition of improved catchments. Volumes reported for improved catchments in Table 9 include both flows generated for the paddock catchment and the improved catchment, representing total flow available for water storage.

Table 9. Mean Annual Volume of Runoff Captured Per Dam (2004 – 2050)

Rainfall Scenario	Paddock Catchment Runoff (ML/y)	Improved Catchment Volume (ML/y)	Percent Increase
Base Case	1.77	2.99	69%
-10%	1.71	2.97	74%
-20%	1.45	2.89	99%
+10%	2.04	3.00	48%

The analysis indicated for all rainfall scenarios, significant increases in the volume of flow is likely to be generated as a result of the implementation of improved catchments. The most significant increase in flow resulting from the implementation of improved catchments is likely to occur under the lowest rainfall scenario, a 20% reduction in rainfall over the period 2005 – 2050, highlighting the enhanced runoff benefits of an improved catchment.

The implementation of improved catchments also increases the frequency of discharge from farm dams, improving the reliability of dam storages. Presented in Table 10 is the modelled frequency of overflow of farm dams with and without improved catchments. The analysis indicated a 10% reduction in rainfall would result in the frequency of overflow from farm dams declining from 0.34 (approximately 1 in 3 years) to 0.23 (approximately 1 in 4 years).

Most significantly the 20% reduction average annual rainfall over the period 2005 - 2050 is likely to result in a reduction in the frequency of overflow of dams to 1 in 10 years. Not only would this have a significant influence over environmental flows within the Avon River, it would result in relatively poor reliability of farm dams.

Table 10. Frequency of Dam Overflow Events (2004 – 2050)

Rainfall Scenario	Paddock Catchment Dam Frequency / yr	Improved Catchment Dam Frequency / yr
Base Case	0.34	5.64
- 10%	0.23	5.25
- 20%	0.082	3.94
+ 10%	0.62	8.02

The addition of improved catchments to farm dams increases the frequency of discharge from approximately 1 in 3 years to between 5 and 10 overflow events per annum. This would result in greatly improved reliability of farm dams.

An increase in the number of farm dams has the potential to influence the proportion of runoff extracted for farm dam storage. The proportion of runoff captured within farm dams for a 15% and 30% increase in the number of dams for different rainfall for scenarios is presented in Table 11.

Table 11. Proportion of Runoff Extracted for Farm Dams (2005 - 2050)

	No increase in farm dams	15% increase in farm dams	30% increase in farm dams
BASE	14%	16%	18%
- 10% Rainfall scenario	15%	17%	19%
- 20% Rainfall scenario	16%	19%	22%
+10% Rainfall scenario	12%	14%	15%

The dam model indicated a moderate increase (2% - 4%) in the proportion of run-off contained within farm dams is likely to occur as a result of 15% - 30% increase in the number of farm dams, given no change in rainfall over the period 2005 – 2050. However, a 20% reduction in rainfall combined with a 30% increase the number of dams would probably result in an increase in the volume of runoff contained within dams from 14% to 22%. This scenario represents a very significant influence over environmental flows when considering that LASCAM predicts a 20% reduction in rainfall would result in a reduction in river flow from 155 to 55 GL/year in average annual flow.

The analysis presented in Table 10 indicated a 20% reduction in rainfall would result in many farm dams becoming unreliable, with overflow frequency falling to 1 in 10. This projected reduction in dam reliability may lead to an increase in the overall storage capacity (size of dams) or an increase in the number of dams in an attempt by landholders to “offset” the impact of reduced dam reliability. The outcome of this would be a significant reduction in river flows, with potentially severe environmental impact.

6.3.2 Dam Reliability

An assessment of dam reliability was undertaken using the dam model. The analysis included potential climate change scenarios and management options including increasing dam storage and the application of improved (roaded) catchments.

The predictive rainfall sequence used in undertaking the analysis was based on the 32 year time sequence between 1975 and 2006 and was derived from recorded rainfall for the centre of Brookton. Run-off modelling assumed 18.5 and 8 mm rainfall thresholds and runoff coefficients of 0.75 and 0.8 for paddock and improved catchments respectively. The paddock catchment size used in the analysis was 20 ha.

The dam size adopted for the analysis was 3.3 ML (calculated mean dam volume for the study area). The analysis assumed 500 sheep stock over 365 days, that a standard volume depth relationship existed (refer section 4.2) and average daily evaporation rates would derive from monthly averages sourced from the Bureau of Meteorology.

In undertaking the analysis, the dam was considered as having failed when the volume of storage within the dam fell below 5% of storage capacity. Results of the analysis are presented in Table 12.

Table 12. Summary of Dam Reliability – Management of Climate Change

Dam reliability – proportion of day > 5% capacity	Base Case	+10% Rainfall	-10% Rainfall	-20% Rainfall
Paddock Runoff (Standard Dam (3.3 ML)	93%	98%	71%	52%
Increase Dam Storage (5 ML)	97%	100%	86%	65%
Improved Catchment (3.5 ha)	99%	100%	93%	75%
Improved Catchment (5 ha)	100%	100%	97%	83%
Increased Dam Storage (5 ML) and Improved Catchment (5 ha)	100%	100%	99%	93%

The analysis indicated the average size dam (3.3 ML), receiving runoff from a paddock catchment, given the current climatic conditions (base case) has a reliability of approximately 93% (i.e. the volume of water stored within the dam was greater than 5% of its capacity, 93% of the time). The addition of an improved catchment (3.5 ha) increased the reliability of the dams to 99%, whereas increasing dam volume to 5 ML only resulted in a 97% reliability.

It was estimated a 10% increase in rainfall, resulting from climate change, would result in an increase in dam reliability from 93% to 98% for the base case scenario.

Assuming a 10% and 20% decrease in rainfall, dam reliability is predicted to fall to 71% and 52% respectively, assuming no increase in size of storage and continued reliance on paddock catchments.

Modelling indicated increasing the dam storage volume from 3.3 ML to 5.0 ML would result in a 14% - 15% increase in dam reliability assuming 10% and 20% reductions in rainfall respectively, whereas the addition of an improved catchment would result in a 22% - 23% increase in dam reliability.

Assuming a 10% reduction in rainfall as a result of climate change, the addition of a 3.3 ha improved catchment would maintain dam reliability at current levels (assuming no improved catchment is currently employed). A 20% reduction in rainfall would require the addition of a 5 ha improved catchment and an increase in dam storage from 3.3 ML to 5 ML to maintain the current reliability of a dam receiving paddock runoff. However if the runoff threshold of the improved catchment is reduced from 8 mm to 6 mm, then a 3.3ML catchment with a 5 ha improved (roaded) catchment is estimated to be 95% reliable.

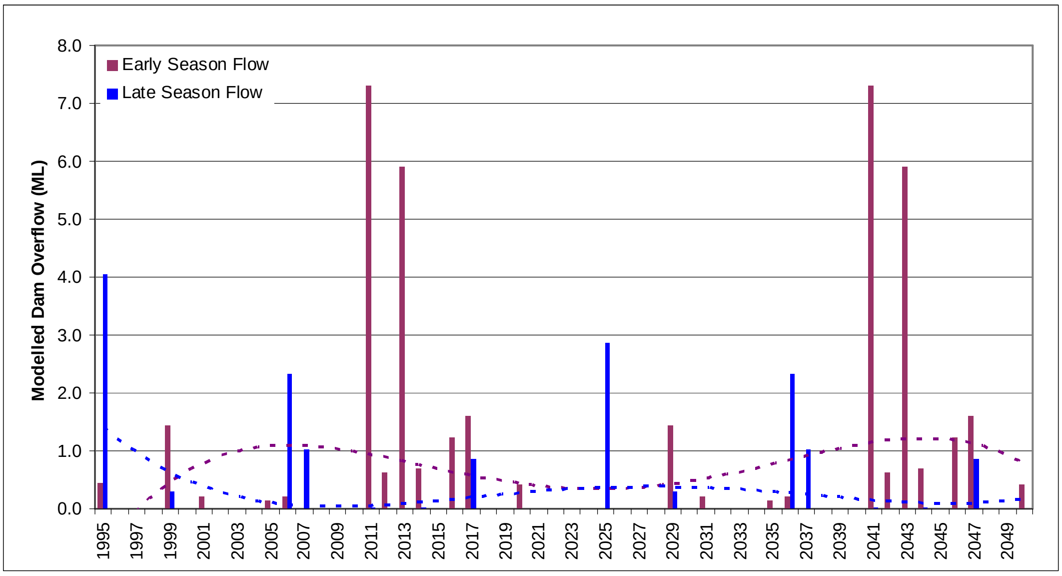
In general, the addition of an improved catchment outperformed re-engineering (increasing the size of the dam storage), for all reduced rainfall scenarios. The analysis is sensitive to the runoff threshold applied to the improved catchment, suggesting that the design and maintenance of improved catchments would be critical to maintaining dam reliability under climate change scenarios associated with reduced rainfall. The application of artificial polymers and other potential management techniques that reduce runoff thresholds for improved catchments are likely to be very important in maintaining dam reliability in the future.

6.3.3 Timing of Flows

The importance of late season flows has been acknowledged as a key factor in maintaining the ecological health of river pools within the Avon River. The timing and magnitude of dam overflow events was investigated for both paddock and improved catchments in early (May – Jul) and late (Aug – Oct) season winter flows.

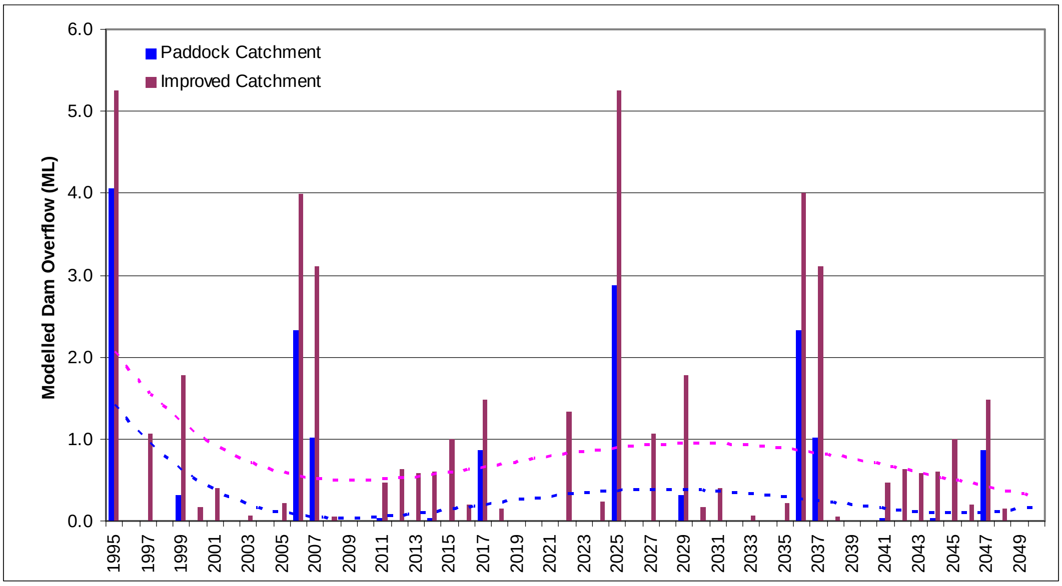
The comparison of overflow events of early and late season flows for a typical dam is presented in Figure 16. The analysis displays infrequent overflow, with quite considerable variation between the frequency of overflow events over the modelled period. The modelled period also indicated early-season overflow events are more frequent and potentially have a higher magnitude than late season overflow events. However, this may be an anomaly resulting from the relatively short rainfall period used in the analysis. Note that the rainfall sequence for the period 2000 – 2024 is repeated to provide the Rainfall period from 2025 - 2050.

Figure 16. Comparison of Overflow Events for Early and Late Season Rainfall Events



A comparison of late season overflow events for paddock and improved catchments for a typical dam is presented in Figure 17. The analysis indicated considerable variation between the frequency and magnitude of rainfall events over the modelled period. However, modelling indicated the application of improved catchments significantly increases the frequency and magnitude of overflow events, particularly for low to moderate rainfall events.

Figure 17. Comparison of Late Season Overflow Events for Paddock and Improved Catchments



The modelling undertaken indicated the adoption of improved catchments on farm dams is likely to have a positive influence over the frequency and magnitude of late season flows. This may present beneficial downstream effects in the context of environmental flows, creating an environment more likely to include fresher late season flows within the Avon River.

The analysis was restricted to an assessment of a typical dam, because modelling undertaken was not sophisticated enough to include routing of catchment flows through multiple dam storages. This is principally due to the large number of dam storages within the catchment.

6.4 Climate Change – Impact on Flow

Analysis of potential climate change impact on flows within the Avon River was previously undertaken using the LASCAM model (CSIRO 2008).

LASCAM modelled flows and salinity for the Avon River basin for the period 1965 – 2100. The model applied actual rainfall data for the period 1965 – 2003 and replicated this 40 year sequence twice to form a predictive rainfall series to 2100.

Daily rainfall was scaled to provide rainfall input sequences for climate change modelling scenarios within LASCAM. For each scenario, the daily rainfall for the period after 2003 was scaled according to three rainfall scenarios. To achieve rainfall input for the –10% rainfall scenario (i.e. 10% reduction in rainfall) the daily rainfall sequence for the period 1965 – 2003 was reduced by 10% and applied to the period 2004 to 2050. The four rainfall scenarios used to generate the LASCAM data were the same as those used as input data into the dam model:

- *Base Case;*
- *–10%;*
- *–20%; and*
- *+10%.*

6.4.1 Flow

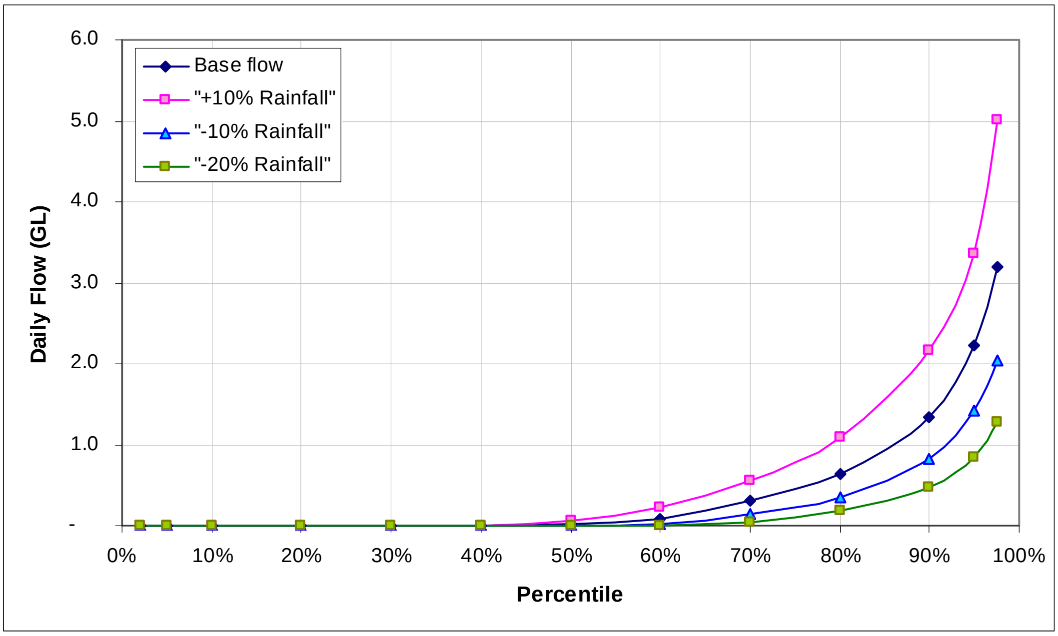
Outcome of the LASCAM modelling previously undertaken by CSIRO (2008) assessing potential climate change scenarios for river flows at Northam Weir is presented in Table 13. The analysis indicated river flows are sensitive to changes in rainfall, with a 10% increase in rainfall likely to result in 60% increase in average annual flow at Northam Weir. Modelling also indicated that 40% and 60% reductions in flow would probably result from 10% and 20% reductions in rainfall respectively.

Table 13. Impact of Climate Change Scenario on River Flows - LASCAM (CSIRO 2008)

	Base case	+10% Rainfall	-10% Rainfall	-20% Rainfall
Mean annual flow (GL/year)	155	248	95	55
Standard deviation annual flow (GL/year)	95	167	56	35

Model rainfall scenarios previously undertaken using LASCAM (CSIRO 2008) indicated changing rainfall associated with climate change is likely to have a significant influence over flow intensity and frequency for the Avon River at Northam Weir. Outcomes of the analysis are presented in Figure 18.

Figure 18. Model the Influence of Climate Change Scenarios over daily flow – Avon River at Northam Weir – LASCAM (CSIRO 2008)



LASCAM predicts a 10% increase in rainfall would result in flow frequency increasing from 50 days in 100 days to 60 days in 100 at Northam Weir. A 20% reduction in rainfall would result in a fall in the frequency of flow from 50 days in 100 to 40 days in 100.

LASCAM predicts potential climate change rainfall scenarios would exert significant influence over flow intensity at Northam Weir (Figure 18). The analysis indicated the 1 in 10 year flow (90 percentile) would increase from approximately 1.3 GL/day to 2.05 GL/day. Conversely a 20% reduction in rainfall would cause a reduction in flow from 1.3 GL /day to 0.5 GL/day at Northam Weir.

6.4.2 Salinity (TDS)

Filtered LASCAM salinity data was used to determine potential impact of climate change on the salinity of flows at Northam Weir for the period 2025 - 2050. Climate change scenarios of +10%, -10% and -20% were compared against the base case scenario to determine potential influence of predicted climate change scenarios. LASCAM salinity data was filtered, removing flows from the base case scenario where predicted flows are greater than 15,000 mg/L or less than 100 mg/L, consistent with discussions within section 5.3 of this report. Outcomes of comparative analysis are presented in Figure 19 and Figure 20.

LASCAM predicts -10% and + 10% rainfall scenarios would have a relatively minor influence over average salinity of the Avon River at Northam Weir up to approximately the 70 percentile. Modelling indicated that a 10% increase in rainfall would result in a significant increase in salinity of river flows above the 70 percentile flow. The modelled increase in salinity predicted for a 10% increase in rainfall is assumed to result from a higher rate of groundwater recharge, caused by additional groundwater discharge to the Avon River resulting in higher salinities.

LASCAM predicts a 20% reduction in rainfall would result in an increase in the overall salinity of flows within the Avon River. The increase in salinity appears to result from reduced dilution (refer Section 6.3).

Figure 19. LASCAM Predicted Salinity for Flow at Northam Weir 2025 – 2050 – (Apr – Jun) Climate Change Scenarios

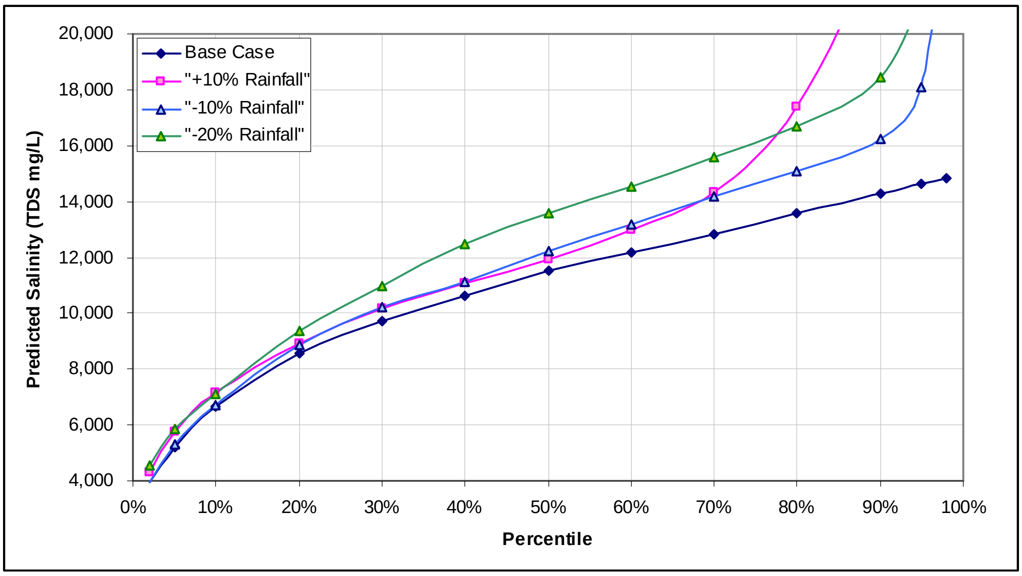
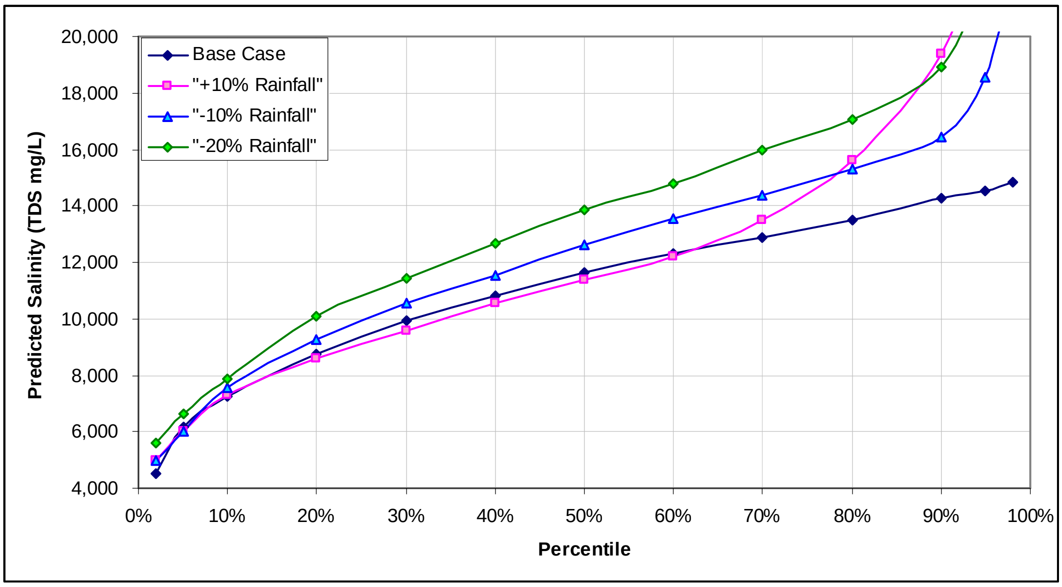


Figure 20. LASCAM Predicted Salinity for Flow at Northam Weir 2025 – 2050 (July – Sept) – Climate Change Scenarios



In summary, LASCAM indicated all rainfall scenarios would result in higher salinity flows within the Avon River at Northam Weir resulting from a change in catchment hydrology. The most significant influence is likely to occur as a result of the reduced rainfall scenarios, however the +10% rainfall scenario is predicted to result in an increase in salinity during high flow periods, resulting from an assumed increased in groundwater discharge into the Avon River. LASCAM predicts higher salinities of late season flows compared to early season flows, contrary to recorded flows at Northam Weir.

7. Conclusions

Farm dams currently account for approximately 14% of runoff.

Climate change appears to represent the most significant hazard to reducing flows and increasing salinity of the Avon River.

Reduced rainfall climate change scenarios are likely to result in a very significant reduction in the reliability of farm dams. An increase in the volume of landscape storage, as a result of increasing the size of farm dams, or increasing the number of farm dams, is unlikely to be an effective strategy for managing the impacts of climate change on dam reliability. Increasing the volume of landscape storage does however represents a significant hazard to environmental flows within the Avon River. Both reduced run-off associated with potential decline in rainfall resulting from climate change and an increase in catchment dam storage are both likely to have a detrimental impact on the quality of late season river flows.

Modelling undertaken indicates that the construction of improved (roaded) catchments is the most effective strategy for increasing farm dam reliability assuming reduced rainfall scenarios associated with climate change.

Construction of improved catchments is also likely to result in an increase in late season flow to the Avon River, largely offsetting the influence of construct dam storages on river flow.

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