Impacts of Farm Dams in Seven Catchments in Western Australia

- Final
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1. Introduction

1.1 Background
The Department of Water (DoW) is currently in the process of developing resource management plans for surface waters several catchments in the south west of Western Australia (WA). Irrigated agriculture in many areas of the south west of WA is characterised by self-supply from small to medium sized farm dams. Water from these dams is an important resource which contributes significantly to the regional and state economy. To support planning in the south west region, the DoW must weigh the economic benefits of water storage and use from farm dams against their environmental costs. There is also a need to quantify the proportion of the estimated sustainable yield currently captured by farm dams.

The interception of rainfall-runoff by farm dams has been shown to affect the flow regimes of river systems (as a function of farm density, volume and water use from the dams). A change to the regime and volume of flow has the potential to alter the ecology and natural values of the river systems.

1.2 Purpose of study
The purpose of this study was to investigate the impacts of farm dams on stream flow for seven selected catchments in south western WA. The impacts of farm dams were then characterised based on the climate in each catchment, and comparisons of impact can be made between different catchments.

As comparatively little investigation has been undertaken to date into farm dam impacts in WA, much of the derivation of model inputs and interpretation of results was based on comparison with similar studies previously undertaken in Victoria.
2. Method of Analysis

2.1 Modelling the impact of farm dams on stream flow

The modelling software package CHEAT (SKM, 2004a) was used to estimate the effect of farm dams on surface water flows. This software is specifically designed to estimate farm dam impacts on downstream flows, and works by performing a water balance on each farm dam in a catchment on a daily timestep. In this way, CHEAT is able to estimate the difference between flows into a farm dam and the flows out of a dam by taking into account dam storage level, rainfall, evaporation, and demands.

In order to run CHEAT, a range of inputs were required, including:

- gauged rainfall and evaporation data (available from the Bureau of Meteorology);
- demand data such as typical patterns of irrigation and stock and domestic demand (available from DoW); and
- the different sizes of farm dams in each catchment (available from DoW based on data previously collected by SKM).

Also, the gauged flow at the outlet of each catchment was required over a reasonable period of record (<20 years), so that model results were representative of long term conditions within each catchment.

2.2 Interpretation of results

In areas where many farm dams have been constructed, the impacts on downstream flows can be significant. Studies in Victoria have shown that farm dams can reduce the mean annual flow in catchments by typically up to 5%, although in some cases, annual flow reductions of over 30% have been estimated. However, in order to understand the effect of farm dams on stream flow and river health, annual flow reductions do not provide sufficient information. Flow regimes in streams vary between years, seasons, months, weeks, and days. The key components of this analysis include:

Flow exceedance

Flow exceedance percentiles have been determined for both the impacted and unimpacted flows. This helps to identify the relative proportions of the impacts for the full range of flows, indicating the extent to which high flows and low flows are being impacted.

Seasonal pattern
The seasonal variation in impacts can be important for downstream ecology as farm dams can affect summer freshes and early winter high flows, which help to maintain riparian habitat, pool water quality, and are sometimes used as breeding cues for some species.

Because farm dams often have highly variable impacts between seasons, the average monthly impacted and unimpacted flows were calculated. Impacts were typically very high during late summer and during early winter when dams are refilling. By late spring, impacts were typically very small.

**Summer spells**

Environmental stress can be caused by both increased frequency/duration of low flow spells, and decreased frequency/duration of high flow spells in summer. On this basis, both high flow and low flow spells were analysed, both in terms of their frequency and duration, for both the impacted and unimpacted flow scenarios.

**Compare impacts between years**

Impacts of farm dams will vary from year to year, depending on the level and timing of flows. The variability of farm dam impacts was assessed for high, medium, and low rainfall years, to gain an understanding of how climate factors influence annual dam impacts.

**Compare impacts between catchments**

Impacts of farm dams on stream flow have been compared between catchments, to attempt to gain some understanding of the key influences on the impacts. This has included comparison of impacts for high / low rainfall years; and comparison of impacts with farm dam development levels.
3. Selection of Catchments

Seven catchments have been used to investigate the effect of farm dams on flow around Western Australia that. These catchments are:

1) Lower Collie;
2) Capel River;
3) Chapman Brook (Hardy Estuary – Blackwood River);
4) Cowaramup Brook;
5) Lefroy Brook (Warren River);
6) Margaret River; and
7) Wilyabrup Brook.

A map showing the location of the seven catchments is shown in Figure 3-1.
Figure 3-1 Location of Catchments
4. Modelling farm dam impacts

The impact of farm dams was analysed using CHEAT (SKM 2004, Nathan et al. 2005). The CHEAT model uses information on the number and volume of farm dams to estimate impacts of farm dams based on a time series of stream flows. This is achieved by performing water balance calculations (inflow, spills, climate, demands) on each farm dam within a catchment for each day in the stream flow record. In this way, the model can determine the difference between the inflows to each dam and the outflows, which represents the farm dam impact.

The CHEAT model was originally created to test the assumptions made by its predecessor, TEDI. CHEAT is capable of performing more complex farm dam impact calculations than TEDI. Two features of CHEAT were particularly used during this project:

- CHEAT can perform farm dam water balance calculations on a daily time step (TEDI is limited to a monthly time step); and
- CHEAT allows the recorded set of farm dam surface areas to be used, rather than lumping dams into size distribution ranges.

The following sections detail the inputs required in CHEAT, the assumptions used, followed by the method used to derive farm dam impacts at each level of development (historic, current, and fully impacted). Much of the required data was already held by SKM and collated from the following projects:

- Farm dam distribution: mapping project for DoW.
- Stream flows: Recommendations for Sustainable Diversion Limits over Winterfill Periods in Unregulated South-West Western Australia Catchments, undertaken by SKM in 2007 for DoW.

4.1 Gauged data

The climate and flow data were collated for each catchment using the GIS data to determine the relevant rainfall, evaporation, and stream flow gauges. The annual rainfall distribution within each catchment was assessed using the Bureau of Meteorology gridded data, and this was used to ensure that the rain gauge chosen was representative of the catchment rainfall.

The model was run over the period 1 Jan 1975 to 30 April 2005. Where gauge data was not available from one gauge for the entire period, an extended record was created by combining and weighting the data from a nearby gauge, using a factor derived from correlating the cumulative rainfall/evaporation/flow. The gauges used are shown in Table 4-1.
Table 4-1: Gauges associated with each catchment

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Flow Gauge Name</th>
<th>Flow Gauge</th>
<th>Rain Gauge</th>
<th>Evaporation Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Collie</td>
<td>Cross Farm</td>
<td>612032</td>
<td>009513</td>
<td>009657</td>
</tr>
<tr>
<td>Capel River</td>
<td>Capel Railway Bridge</td>
<td>610010</td>
<td>009503</td>
<td>009842</td>
</tr>
<tr>
<td>Chapman Brook</td>
<td>White Elephant Bridge</td>
<td>609022</td>
<td>009547</td>
<td>009842</td>
</tr>
<tr>
<td>Cowaramup Brook</td>
<td>Gracetown</td>
<td>610029</td>
<td>009636</td>
<td>009842</td>
</tr>
<tr>
<td>Lefroy Brook</td>
<td>Cascades</td>
<td>607022</td>
<td>009592</td>
<td>009592</td>
</tr>
<tr>
<td>Margaret River</td>
<td>Willmots Farm</td>
<td>610001</td>
<td>009574</td>
<td>009842</td>
</tr>
<tr>
<td>Wilyabrup Brook</td>
<td>Woodlands</td>
<td>610006</td>
<td>009636</td>
<td>009842</td>
</tr>
</tbody>
</table>

The mean annual rainfall, evaporation, and flow for each catchment for the period 1975-2004 are summarised in Table 4-2.

Table 4-2 Catchment Mean Annual Rainfall, Evaporation, and Flow (1975-2004)

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Mean Annual (1975-2004)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow (ML/yr)</td>
</tr>
<tr>
<td>Lower Collie</td>
<td>123,901</td>
</tr>
<tr>
<td>Capel River</td>
<td>44,401</td>
</tr>
<tr>
<td>Chapman Brook</td>
<td>54,686</td>
</tr>
<tr>
<td>Cowaramup Brook</td>
<td>3,356</td>
</tr>
<tr>
<td>Lefroy Brook</td>
<td>53,704</td>
</tr>
<tr>
<td>Margaret River</td>
<td>84,707</td>
</tr>
<tr>
<td>Wilyabrup Brook</td>
<td>23,632</td>
</tr>
</tbody>
</table>

Note that the Capel River gauge had a short record, only extending back to 1993. The period of record was increased by including modelled flows as provided by DoW. While these modelled flows provided reasonable estimates of annual flows and intra-year flow patterns, the summer low flows are considered to be less reliable.

4.2 Farm dams

The number and size of the farm dams within each catchment was obtained from data provided by DoW. The volume of each farm dam was calculated using the equation developed for Western Australian farm dams (DoW 2007):

\[ V = 0.0007 \times A^{1.0709} \]
where: \( V \) = storage capacity of a farm dam in ML
\( A \) = surface area of a dam in m\(^2\).

The farm dam density has been calculated for each catchment. Table 4-3 summarises the farm dam data for each catchment.

### Table 4-3 Catchment Farm Dams

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (km(^2))</th>
<th>Number of farm dams</th>
<th>Total dam volume (ML)</th>
<th>Farm dam density (ML/km(^2))</th>
<th>Mean Annual Historic Flow (ML/yr)</th>
<th>Mean Annual Historic Flow (ML/yr/km(^2))</th>
<th>Farm dam development (ML storage/ML Historic flow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Collie</td>
<td>528</td>
<td>564</td>
<td>970</td>
<td>1.8</td>
<td>123,901</td>
<td>234</td>
<td>1%</td>
</tr>
<tr>
<td>Capel River</td>
<td>635</td>
<td>911</td>
<td>3576</td>
<td>5.6</td>
<td>44,401</td>
<td>70</td>
<td>8%</td>
</tr>
<tr>
<td>Chapman Brook</td>
<td>184</td>
<td>434</td>
<td>1811</td>
<td>9.9</td>
<td>54,687</td>
<td>298</td>
<td>3%</td>
</tr>
<tr>
<td>Cowaramup Brook</td>
<td>24</td>
<td>90</td>
<td>225</td>
<td>9.5</td>
<td>3,356</td>
<td>143</td>
<td>7%</td>
</tr>
<tr>
<td>Lefroy Brook</td>
<td>358</td>
<td>665</td>
<td>8871</td>
<td>27.2</td>
<td>53,704</td>
<td>150</td>
<td>17%</td>
</tr>
<tr>
<td>Margaret River</td>
<td>477</td>
<td>738</td>
<td>1700</td>
<td>4.6</td>
<td>84,707</td>
<td>178</td>
<td>2%</td>
</tr>
<tr>
<td>Wilyabrup Brook</td>
<td>89</td>
<td>418</td>
<td>2221</td>
<td>24.9</td>
<td>23,632</td>
<td>265</td>
<td>9%</td>
</tr>
</tbody>
</table>

### 4.3 Dam Subcatchment Areas

The best estimates of catchment areas for farm dams are achieved using high detail digital elevation models to accurately delineate the boundary of each catchment. However this would be outside the scope of this project.

The relationship between the volume and catchment area of a typical farm dam is very complex. However, this relationship has been estimated for many different catchments around Victoria, and is generally represented as a linear relationship (Figure 4-1).
Since this study region in Western Australia is relatively flat compared to the catchments studied in Victoria, the dam subcatchment areas have been assumed to be at the higher end of the spectrum as shown by the bold line in Figure 4-1. The dam subcatchment areas are extrapolated based on the relationship that a 5ML dam has a catchment area of 1km$^2$ and a 100ML dam has a catchment area of 1.6km$^2$.

In some cases where there are very high levels of farm dam development, this relationship has resulted in the sum of all dam subcatchments being bigger than the total catchment itself. This is clearly not possible, and indicates that either:

- There are many cascading dams within these catchments; or
- There are many large dams in the catchment which have very small upstream areas compared to their volume. This may still be practical if rates of runoff are very high, otherwise there may not be enough flow to properly fill these dams each year.

On this basis, this relationship was adapted for the Lefroy and Wilyabrup catchments to 0.8 km$^2$ and 1.3 km$^2$, and 0.7 km$^2$ and 1.2 km$^2$ for 5ML and 100ML dams respectively.
4.4 Irrigation Demand

A study of over 500 dams in Victoria has shown that the typical threshold volume between irrigation dams and stock and domestic dams is 5ML (SKM 2004b). Based on similar data from DoW, this has been applied in all the catchments except for Chapman Brook and Lefroy Brook where it is 7 and 8 ML respectively. It is therefore assumed that all of the dams under these capacities are for stock and domestic purposes only. Dams greater than these thresholds are assumed to be irrigation dams.

The irrigation demand has been calculated based on crop type and water usage data. The annual demand as a fraction of the capacity of the dams was calculated by the DoW for each catchment, as given in Table 4-4. In addition, DoW have also estimated the average monthly pattern of demands for both irrigation and stock and domestic dams, as listed in Table 4-5 and Table 4-6, and shown graphically in Figure 4-2 and Figure 4-3.

- **Table 4-4 Catchment Demand Factors for Stock and Domestic, and Irrigation**

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Maximum typical capacity of a Stock and Domestic Dam (ML)</th>
<th>Demand Factor</th>
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<tr>
<td></td>
<td></td>
<td>Stock and Domestic</td>
</tr>
<tr>
<td>Lower Collie</td>
<td>5</td>
<td>0.275</td>
</tr>
<tr>
<td>Capel River</td>
<td>5</td>
<td>0.285</td>
</tr>
<tr>
<td>Chapman Brook</td>
<td>7</td>
<td>0.245</td>
</tr>
<tr>
<td>Cowaramup Brook</td>
<td>5</td>
<td>0.276</td>
</tr>
<tr>
<td>Lefroy Brook</td>
<td>8</td>
<td>0.176</td>
</tr>
<tr>
<td>Margaret River</td>
<td>5</td>
<td>0.450</td>
</tr>
<tr>
<td>Wilyabrup Brook</td>
<td>5</td>
<td>0.276</td>
</tr>
</tbody>
</table>

- **Table 4-5 Catchment Stock and Domestic Demand Patterns (Fraction of Annual Demand)**

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Collie</td>
<td>0.105</td>
<td>0.100</td>
<td>0.095</td>
<td>0.086</td>
<td>0.071</td>
<td>0.063</td>
<td>0.063</td>
<td>0.063</td>
<td>0.070</td>
<td>0.087</td>
<td>0.095</td>
<td>0.103</td>
</tr>
<tr>
<td>Capel River</td>
<td>0.145</td>
<td>0.124</td>
<td>0.093</td>
<td>0.063</td>
<td>0.053</td>
<td>0.050</td>
<td>0.050</td>
<td>0.050</td>
<td>0.053</td>
<td>0.074</td>
<td>0.108</td>
<td>0.137</td>
</tr>
<tr>
<td>Chapman Brook</td>
<td>0.141</td>
<td>0.122</td>
<td>0.093</td>
<td>0.065</td>
<td>0.055</td>
<td>0.052</td>
<td>0.052</td>
<td>0.052</td>
<td>0.055</td>
<td>0.075</td>
<td>0.106</td>
<td>0.134</td>
</tr>
<tr>
<td>Cowaramup Brook</td>
<td>0.144</td>
<td>0.124</td>
<td>0.093</td>
<td>0.063</td>
<td>0.053</td>
<td>0.050</td>
<td>0.050</td>
<td>0.050</td>
<td>0.053</td>
<td>0.074</td>
<td>0.108</td>
<td>0.137</td>
</tr>
<tr>
<td>Lefroy Brook</td>
<td>0.140</td>
<td>0.124</td>
<td>0.107</td>
<td>0.076</td>
<td>0.053</td>
<td>0.048</td>
<td>0.048</td>
<td>0.048</td>
<td>0.051</td>
<td>0.072</td>
<td>0.101</td>
<td>0.131</td>
</tr>
<tr>
<td>Margaret River</td>
<td>0.151</td>
<td>0.128</td>
<td>0.093</td>
<td>0.060</td>
<td>0.050</td>
<td>0.048</td>
<td>0.048</td>
<td>0.048</td>
<td>0.050</td>
<td>0.073</td>
<td>0.110</td>
<td>0.142</td>
</tr>
<tr>
<td>Wilyabrup Brook</td>
<td>0.144</td>
<td>0.124</td>
<td>0.093</td>
<td>0.063</td>
<td>0.053</td>
<td>0.050</td>
<td>0.050</td>
<td>0.050</td>
<td>0.053</td>
<td>0.074</td>
<td>0.108</td>
<td>0.137</td>
</tr>
</tbody>
</table>

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Figure 4-2 Catchment Stock and Domestic Demand Patterns

Table 4-6 Catchment Irrigation Demand Patterns (Fraction of Annual Demand)

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Collie</td>
<td>0.218</td>
<td>0.180</td>
<td>0.131</td>
<td>0.058</td>
<td>0.010</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.068</td>
<td>0.137</td>
<td>0.198</td>
</tr>
<tr>
<td>Capel River</td>
<td>0.253</td>
<td>0.161</td>
<td>0.093</td>
<td>0.041</td>
<td>0.010</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.009</td>
<td>0.044</td>
<td>0.146</td>
<td>0.241</td>
</tr>
<tr>
<td>Chapman Brook</td>
<td>0.210</td>
<td>0.251</td>
<td>0.094</td>
<td>0.022</td>
<td>0.012</td>
<td>0.012</td>
<td>0.012</td>
<td>0.012</td>
<td>0.012</td>
<td>0.019</td>
<td>0.136</td>
<td>0.210</td>
</tr>
<tr>
<td>Cowaramup Brook</td>
<td>0.210</td>
<td>0.315</td>
<td>0.114</td>
<td>0.018</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.196</td>
</tr>
<tr>
<td>Lefroy Brook</td>
<td>0.234</td>
<td>0.205</td>
<td>0.121</td>
<td>0.047</td>
<td>0.006</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.006</td>
<td>0.036</td>
<td>0.129</td>
<td>0.216</td>
</tr>
<tr>
<td>Margaret River</td>
<td>0.206</td>
<td>0.198</td>
<td>0.066</td>
<td>0.010</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.006</td>
<td>0.053</td>
<td>0.232</td>
<td>0.227</td>
</tr>
<tr>
<td>Wilyabrup Brook</td>
<td>0.210</td>
<td>0.315</td>
<td>0.114</td>
<td>0.018</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.004</td>
<td>0.126</td>
<td>0.196</td>
</tr>
</tbody>
</table>
The irrigation demand is minimal in the winter months, rising in the summer months to a peak in February.

All farm dams were assumed to spill directly to the outlet, with no cascading effects. While this is known not to be the case, some high detail studies for the Avoca River and Woollen Creek catchments in Victoria (SKM 2004a) have shown that this effect is not significant unless farm dam development levels are extremely high.

Also it has been assumed that no bypass mechanisms are present in any farm dams.

The rainfall, evaporation, and dam distribution for each catchment are shown in Appendix A. In all catchments, it can be seen that rainfall and evaporation almost mirror each other with the result that winter rainfall exceeds evaporation and summer evaporation far exceeds rainfall, thus resulting in the need for irrigation dams which will fill in winter and be used during the summer.

The distribution of the farm dams and farm dam volume illustrates how the storage can be dominated by a few large dams within the catchment.
5. Impacts of farm dams on river flows

5.1 Flow exceedance – reduced flow at the catchment outlet
The reduction of flow at the catchment outlet was determined and plotted as exceedance percentiles. The flow duration curves show that lower flows are significantly reduced by farm dams, and the proportion of zero flow days can be significantly increased.

5.2 Seasonal Pattern – impact on early winter flows
The impact of farm dams on the timing and magnitude of winter freshes was also investigated by plotting the average monthly impacted and unimpacted flow. From these charts it is possible to compare the natural flow to the current flow, and so it is possible to see the effect of farm dams on the rivers, as well as the timing of when the dams typically fill and spill.

These impacts are then clearly shown by plotting the impact as daily average of the current flow as a percentage of natural flow. The impacts are typically very high during late summer (frequently up to 30% to 50% of natural flow) and during early winter when dams are refilling. By late winter, impacts are typically very small.

5.3 Summer spells analysis
Spells analyses on summer low flows and summer high flow were performed and the results are presented as Gantt charts indicating the change in the number and duration of spells. Note that in these Gantt charts, a coloured bar indicates when a spell is occurring.

Each spell is considered to be independent if they are more than 7-days apart and only the summer season (December to May) has been studied. A low flow spell is considered to be the flow below the 85th percentile natural summer flow. A high flow spell is considered to be the flow above the 15th percentile natural summer flow.

Detailed analysis into the change in number and duration of summer high and low flow spells is shown in the box plots in Appendix B.

5.4 Annual variability
The variability of farm dam impacts has been assessed for varying rainfall years, to gain an understanding of how climate factors influence annual dam impacts. This variability has been plotted as current flow as a percentage of natural flow against annual rainfall.
5.5 Catchment Specific Impacts

5.5.1 Lower Collie

The impact of farm dams on flow at the catchment outlet is demonstrated in Figure 5-1.

- **Figure 5-1**: Impact of farm dam on flow at the Lower Collie outlet over the entire year

  The flow duration curves show that the impact on flows by the farm dams is minor with a slight decrease in the lower flows. The proportion of zero flows is unchanged.

  Figure 5-2 shows the average monthly impacted and unimpacted flow. It can be seen that farm dams in this catchment are not appreciably affecting the flow at any time of the year.

  Figure 5-3 shows that the average daily flow is only reduced down to 89% of the natural flow during late summer. In winter, the impacted flow is actually very slightly higher (maximum of 101.9% of the natural flow). This suggests that in late winter farm dams are actually increasing the flow in the catchment. While this may at first seem unlikely, it can occur in situations where farm dams are full and starting to spill. If high rainfall occurs, the catchment flow increases by an amount equal to the direct rainfall on the farm dam surface. In this way, the increase in flows is proportional to the surface area of the full dams.
• **Figure 5-2**: Average monthly flow for the Lower Collie

![Graph of Average Monthly Flow](image)

- Natural
- Current

• **Figure 5-3**: Difference in average daily flow due to farm dams (expressed as a percentage of natural flow) for the Lower Collie

![Graph of Current as a Percentage of Natural](image)

• **Figure 5-4** to **Figure 5-7** show the effect on the duration of low and high flow spells for natural and current flow respectively.
Distribution of Spells below 29.1 ML/d for Lower Collie Natural Flow

Figure 5-4: Spells distribution for the Lower Collie Natural summer low flows (i.e. flow lower than 29.1 ML/day)

Distribution of Spells below 29.1 ML/d for Lower Collie Current Flow

Figure 5-5: Spells distribution for the Lower Collie Current summer low flows (i.e. flow lower than 29.1 ML/day).
Figure 5-6: Spells distribution for the Lower Collie Natural summer high flows (i.e. flow greater than 115.4 ML/day).

Figure 5-7: Spells distribution for the Lower Collie Current summer high flows (i.e. flow greater than 115.4 ML/day).
As is expected, the farm dams result in more low flow events. However, the duration is not affected significantly. The number and duration of the high flow spells are not affected by farm dams.

During summer, 15% of unimpacted daily flows are less than 29.1 ML/d. Currently, 21% of daily flows are below this threshold.

During summer, 15% of unimpacted daily flows are greater than 115.4 ML/d. Currently, 12% of daily flows are above this threshold.

Figure 5-8 shows that the impact of farm dams is affected by the amount of annual rainfall with the greatest effect in drier years. There is little effect above an annual rainfall of approximately 1000mm.
5.5.2 Capel River

The impact of farm dams on flow at the catchment outlet is demonstrated in Figure 5-9.

- Figure 5-9: Impact of farm dam on flow at the Capel River outlet over the entire year

The flow duration curves show that at lower flows the flow is significantly reduced by farm dams.

Figure 5-10 shows the average monthly impacted and unimpacted flow. It can be seen that the pattern is very similar to that of natural with the magnitude being lowered for each scenario which has the effect of causing a lag in the first flush in early winter. The flows are decreased until spring, indicating that the storages do not spill frequently during winter.

Figure 5-11 shows that the average daily flow is reduced down to 50% of the natural flow during late summer. In late winter, the impacted flow is actually slightly higher (maximum of 102.9% of the natural flow); see Section 5.5.1 for explanation of increased flows.
**Figure 5-10: Average monthly flow for the Capel River**

**Figure 5-11: Difference in average daily flow due to farm dams (expressed as a percentage of natural flow) for the Capel River**

A spells analysis has not been performed for the Capel River since the current flow data did not have sufficient accuracy during summer low flows.
Figure 5-12 shows that the impact of farm dams is greatest in drier years and the effect plateaus at an annual rainfall of approximately 1000mm.

This figure shows a moderate degree of scatter in the results. The form of the line of best fit is based on clearer behaviour in the other catchments in this study.

- Figure 5-12 Variability of the impact of farm dams with annual rainfall for the Capel River
5.5.3 Chapman Brook
The impact of farm dams on flow at the catchment outlet is demonstrated in Figure 5-13.

- **Figure 5-13: Impact of farm dam on flow at the Chapman Brook outlet over the entire year**

The flow duration curves show that at lower flows the flow is significantly reduced by farm dams. The amount of time that zero flow occurs is increased by 5%.

Figure 5-14 shows the average monthly impacted and unimpacted flow. It can be seen that the magnitude of the flow changes slightly but there is no change in the timing of flows, and so no change in the timing of freshes over the winter period. Farm dams in this catchment are not appreciably affecting flow during winter, indicating that the storages must spill frequently during winter.

Figure 5-15 shows that the average daily flow is reduced down to 33% of the natural flow during late summer. In late winter, the impacted flow is actually slightly higher (maximum of 101.7% of the natural flow); see Section 5.5.1 for explanation of increased flows.
Figure 5-14: Average monthly flow for Chapman Brook

Figure 5-15: Difference in average daily flow due to farm dams (expressed as a percentage of natural flow) for Chapman Brook

Figure 5-16 to Figure 5-19 show the effect on the duration of low and high flow spells for natural and current flow respectively.
**Figure 5-16:** Spells distribution for Chapman Brook Natural summer low flows (i.e. flow lower than 0.03 ML/day).

**Figure 5-17:** Spells distribution for Chapman Brook Current summer low flows (i.e. flow lower than 0.03 ML/day).
Figure 5-18: Spells distribution for Chapman Brook Natural summer high flows (i.e. flow greater than 19.0 ML/day).

Figure 5-19: Spells distribution for Chapman Brook Current summer high flows (i.e. flow greater than 19.0 ML/day).
As is expected, the farm dams result in more events and longer durations for low flows. Conversely, for high flow conditions, the farm dams result in fewer events and shorter durations. The 85% percentile for summer low flows is very low (0.03ML/day). This spells analysis for summer low flows could therefore be considered a spells analysis for summer no flows.

During summer, 22% of unimpacted daily flows are less than 0.03 ML/d (this is the lowest non-zero flow on record). Currently, 31% of daily flows are below this threshold.

During summer, 15% of unimpacted daily flows are greater than 19.0 ML/d. Currently, 9% of daily flows are above this threshold.

Figure 5-20 shows that the impact of farm dams is greatest in drier years and the effect plateaus at an annual rainfall of approximately 1300mm.
5.5.4 Cowaramup Brook

The impact of farm dams on flow at the catchment outlet is demonstrated in Figure 5-21.

- **Figure 5-21: Impact of farm dam on flow at the Cowaramup Brook outlet over the entire year**

  The flow duration curves show that at lower flows the flow is significantly reduced by farm dams. There is no flow for much of the time for both natural and current flow, but this figure shows that the proportion of zero flow days will increase from about 40% of days to nearly 50% of days.

  Figure 5-22 shows the average monthly impacted and unimpacted flow. It can be seen that the current flow pattern is very similar to that of the natural flow with the magnitude being lowered in the autumn/early winter months which has the effect of causing a lag in the first flush. Farm dams in this catchment are not appreciably affecting flow during late winter/spring, indicating that the storages must spill frequently during winter.

  Figure 5-23 shows that the average daily flow is reduced down to less than 10% of the natural flow during late summer. In late winter, the impacted flow is actually slightly higher (maximum of 102.8% of the natural flow); see Section 5.5.1 for explanation of increased flows.
- **Figure 5-22**: Average monthly flow for Cowaramup Brook

- **Figure 5-23**: Difference in average daily flow due to farm dams (expressed as a percentage of natural flow) for Cowaramup Brook

Figure 5-24 to Figure 5-27 show the effect on the duration of low and high flow spells for natural and current flow respectively.
Figure 5-24: Spells distribution for Cowaramup Brook Natural summer low flows (i.e. flow lower than 0.11 ML/day).

Figure 5-25: Spells distribution for Cowaramup Brook Current summer low flows (i.e. flow lower than 0.11 ML/day).
- Figure 5-26: Spells distribution for Cowaramup Brook Natural summer high flows (i.e. flow greater than 0.56 ML/day).

- Figure 5-27: Spells distribution for Cowaramup Brook Current summer high flows (i.e. flow greater than 0.56 ML/day).
As is expected, the farm dams result in more events and significantly longer durations for low flows. The 85% percentile for summer low flows is very low (0.11ML/day). This spells analysis for summer low flows could therefore be considered a spells analysis for summer no flows. Conversely for high flow conditions, the farm dams result in fewer events and shorter durations.

During summer, 60% of unimpacted daily flows are less than 0.11 ML/d (this is the lowest non-zero flow on record). Currently, 89% of daily flows are below this threshold.

During summer, 15% of unimpacted daily flows are greater than 0.56 ML/d. Currently, 5% of daily flows are above this threshold.

Figure 5-28 shows that the impact of farm dams is strongly affected by the amount of annual rainfall with the effect being greatest in drier years. The degree of impact only appears to begin to lessen at an annual rainfall above approximately 1150mm.
5.5.5 Lefroy Brook

The impact of farm dams on flow at the catchment outlet is demonstrated in Figure 5-29.

- Figure 5-29: Impact of farm dam on flow at the Lefroy Brook outlet over the entire year

The flow duration curves show that most flows (~ 80%) are significantly reduced by farm dams.

Figure 5-30 shows the average monthly impacted and unimpacted flow. It can be seen that the current flow pattern is similar to that of the natural flow with the magnitude being significantly lowered all year round except for late winter. This has the effect of causing a definite lag in the timing of early winter freshes.

Figure 5-31 shows that the average daily flow is reduced down to 24% of the natural flow during February. In late winter, the impacted flow is actually slightly higher (maximum of 109.4% of the natural flow); see Section 5.5.1 for explanation of increased flows.
Impacts of Farm Dams in Seven Catchments in Western Australia

Figure 5-30: Average monthly flow for the Lefroy Brook

Figure 5-31: Difference in average daily flow due to farm dams (expressed as a percentage of natural flow) for the Lefroy Brook

Figure 5-32 to Figure 5-35 show the effect on the duration of low and high flow spells for natural and current flow respectively.

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**Impacts of Farm Dams in Seven Catchments in Western Australia**

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**Figure 5-32**: Spells distribution for Lefroy Brook Natural summer low flows (i.e. flow lower than 17.99 ML/day)

**Figure 5-33**: Spells distribution for Lefroy Brook Current summer low flows (i.e. flow lower than 17.99 ML/day).
- Figure 5-34: Spells distribution for Lefroy Brook Natural summer high flows (i.e. flow greater than 86.29 ML/day).

- Figure 5-35: Spells distribution for Lefroy Brook Current summer high flows (i.e. flow greater than 86.29 ML/day).
The farm dams actually have the effect of reducing the number of low flow spells but this is because they merge to last for a significantly longer duration. For high flow conditions, the farm dams result in fewer events and shorter durations, as expected.

During summer, 15% of unimpacted daily flows are less than 17.99 ML/d. Currently, 65% of daily flows are below this threshold.

During summer, 15% of unimpacted daily flows are greater than 86.3 ML/d. Currently, 3% of daily flows are above this threshold.

Figure 5-36 shows that the degree of impact of farm dams is significantly affected by the amount of annual rainfall with the effect being greatest in drier years. The degree of impact only appears to begin to lessen at an annual rainfall above approximately 1300mm.

- Figure 5-36 Variability of the impact of farm dams with annual rainfall for the Lefroy Brook
5.5.6 Margaret River

The impact of farm dams on flow at the catchment outlet is demonstrated in Figure 5-37.

- Figure 5-37: Impact of farm dam on flow at the Margaret River outlet over the entire year

The flow duration curves show that at lower flows the flow is reduced by farm dams. There is no flow for much of the time (20%) for both natural and current flow.

Figure 5-38 shows the average monthly impacted and unimpacted flow. It can be seen that the magnitude of the flow changes very slightly but there is no change in the timing of flows, and so no change in the timing of freshes over the winter period. Farm dams in this catchment are not appreciably affecting flow during winter, indicating that the storages must spill frequently during winter.

Figure 5-39 shows that the average daily flow is reduced down to 70% of the natural flow during late summer. In late winter, the impacted flow is actually very slightly higher (maximum of 100.7% of the natural flow); see Section 5.5.1 for explanation of increased flows.
Figure 5-38: Average monthly flow for Margaret River

Figure 5-39: Difference in average daily flow due to farm dams (expressed as a percentage of natural flow) for Margaret River

Figure 5-40 to Figure 5-43 show the effect on the duration of low and high flow spells for natural and current flow respectively.

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• **Figure 5-40**: Spells distribution for Margaret River Natural summer low flows (i.e. flow lower than 0.01 ML/day).

• **Figure 5-41**: Spells distribution for Margaret River Current summer low flows (i.e. flow lower than 0.01 ML/day).
Figure 5-42: Spells distribution for Margaret River Natural summer high flows (i.e. flow greater than 21.64 ML/day).

Figure 5-43: Spells distribution for Margaret River Current summer high flows (i.e. flow greater than 21.64 ML/day).
These charts show that the farm dams do not affect the number or duration of low flows. The number and duration of summer high flows is slightly reduced by the presence of farm dams.

During summer, 19% of unimpacted daily flows are less than 0.01 ML/d (this is the lowest non-zero flow on record). Currently, 19% of daily flows are below this threshold, the same as for the unimpacted flows.

During summer, 15% of unimpacted daily flows are greater than 21.64 ML/d. Currently, 12% of daily flows are above this threshold.

Figure 5-44 shows that the impact of farm dams is greatest in drier years and the effect plateaus at an annual rainfall of approximately 1100mm.

- Figure 5-44 Variability of the impact of farm dams with annual rainfall for Margaret River
5.5.7 Wilyabrup Brook

The impact of farm dams on flow at the catchment outlet is demonstrated in Figure 5-45.

- Figure 5-45: Impact of farm dam on flow at the Wilyabrup Brook outlet over the entire year

The flow duration curves show that at lower flows the flow is significantly reduced by farm dams. Also, the proportion of zero flows is strongly affected by farm dams, increasing from only 20% of days naturally to 40% of days currently. Having twice as many zero flow days as occurred naturally is expected to have a significant impact on the waterway environment.

Figure 5-46 shows the average monthly impacted and unimpacted flow. It can be seen that the magnitude of the flow is reduced slightly but there is no change in the timing of flows, and so no change in the timing of freshes over the winter period. The peak winter flows are also reduced, however, the farm dams are not appreciably affecting flow during late winter.

Figure 5-47 shows that the average daily flow is significantly reduced down to 7% of the natural flow during late summer. In late winter, the impacted flow is actually slightly higher (maximum of 104.6% of the natural flow); see Section 5.5.1 for explanation of increased flows.
Figure 5-46: Average monthly flow for Wilyabrup Brook

Figure 5-47: Difference in average daily flow due to farm dams (expressed as a percentage of natural flow) for Wilyabrup Brook

Figure 5-48 to Figure 5-51 show the effect on the duration of low and high flow spells for natural and current flow respectively.

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- Figure 5-48: Spells distribution for Wilyabrup Brook Natural summer low flows (i.e. flow lower than 0.15 ML/day).

- Figure 5-49: Spells distribution for Wilyabrup Brook Current summer low flows (i.e. flow lower than 0.15 ML/day).
**Figure 5-50**: Spells distribution for Natural summer high flows (i.e. flow greater than 3.84 ML/day).

**Figure 5-51**: Spells distribution for Wilyabrup Brook Current summer high flows (i.e. flow greater than 3.84 ML/day).
The farm dams actually have the effect of reducing the number of low flow spells but it is because they merge to last for a significantly longer duration. The 85% percentile for summer low flows is very low (0.15ML/day). This spells analysis for summer low flows could therefore be considered a spells analysis for summer no flows. The significant increase in duration of no flow events could have serious ramifications for the riverine ecology. For high flow conditions, the farm dams result in fewer events of shorter duration, as is expected.

During summer, 31% of unimpacted daily flows are less than 0.15 ML/d (this is the lowest non-zero flow on record). Currently, 80% of daily flows are below this threshold.

During summer, 15% of unimpacted daily flows are greater than 3.84 ML/d. Currently, 5% of daily flows are above this threshold.

Figure 5-52 shows that the impact of farm dams is greatest in drier years and the effect appears to start to plateaus at an annual rainfall of approximately 1300mm.

- **Figure 5-52 Variability of the impact of farm dams with annual rainfall for Wilyabrup Brook**
6. **Comparison of impacts between catchments**

In order to attempt to gain some understanding of the key influences on the impacts of farm dams on stream flow, the impacts have been compared between catchments. Following on from the assessment of the variability of farm dam impacts with annual rainfall, the same data has been plotted for all catchments for high, medium, and low rainfall years (10\textsuperscript{th}, 50\textsuperscript{th}, and 90\textsuperscript{th} percentiles), see Figure 6-1. It can be seen that Lefroy Brook has by far the most impacted flow, and that this impact is accentuated in low rainfall years.

![Comparison of impacts between catchments]

- **Figure 6-1 Inter-catchment variability of the impact of farm dams with annual rainfall**

This figure shows that high impact years are strongly correlated with years of low rainfall, and that while low impact years can occur at any time, they are correlated with high rainfall years.

In order to determine the key indicators of farm dam impact on stream flow, various potential indicators were listed, see Table 6-1.
Table 6-1 Farm dam development and the impact on stream flow

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Total farm dam storage (ML)</th>
<th>Farm dam development (ML storage / ML natural flow)</th>
<th>Annual Rainfall (mm)</th>
<th>Current mean annual flow (ML/yr)</th>
<th>Natural mean annual flow (ML/yr)</th>
<th>Impact of farm dams (ML/yr)</th>
<th>Percent reduction of natural flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Collie</td>
<td>970</td>
<td>1%</td>
<td>919</td>
<td>123,540</td>
<td>124,346</td>
<td>806</td>
<td>1%</td>
</tr>
<tr>
<td>Capel River</td>
<td>3576</td>
<td>7%</td>
<td>829</td>
<td>44,401</td>
<td>47,970</td>
<td>3,569</td>
<td>7%</td>
</tr>
<tr>
<td>Chapman Brook</td>
<td>1811</td>
<td>3%</td>
<td>1,140</td>
<td>54,687</td>
<td>56,191</td>
<td>1,504</td>
<td>3%</td>
</tr>
<tr>
<td>Cowaramup Brook</td>
<td>225</td>
<td>6%</td>
<td>927</td>
<td>3,356</td>
<td>3,527</td>
<td>171</td>
<td>5%</td>
</tr>
<tr>
<td>Lefroy Brook</td>
<td>8871</td>
<td>14%</td>
<td>1,136</td>
<td>53,704</td>
<td>62,991</td>
<td>9,287</td>
<td>15%</td>
</tr>
<tr>
<td>Margaret River</td>
<td>1700</td>
<td>2%</td>
<td>1,048</td>
<td>84,707</td>
<td>86,368</td>
<td>1,661</td>
<td>2%</td>
</tr>
<tr>
<td>Wilyabrup Brook</td>
<td>2221</td>
<td>9%</td>
<td>1,062</td>
<td>23,632</td>
<td>25,196</td>
<td>1,564</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 6-1 shows that Lefroy Brook has the most dam development (14%) as a percentage of natural flow, and it also has the highest impact on natural flow (15%). Similarly for Lower Collie River, has the least dam development (1%) as a percentage of natural flow, and also has the lowest impact on natural flow (1%). Closer examination of this table shows that there is an approximate 1:1 relationship between farm dam storage and the annual impact on streamflows, see Figure 6-2 and Table 6-2.

![Graph showing relationship between total dam storage and difference in mean annual flow]

Figure 6-2 Relationship between the catchment total dam storage volume and the difference in mean annual flow
Table 6-2 Farm dam storage capacity and the annual impact on stream flow

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Total farm dam storage capacity (ML)</th>
<th>Impact of farm dams on mean annual flow (ML/yr)</th>
<th>Impact (ML) as a proportion of dam capacity (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lefroy Brook</td>
<td>8871</td>
<td>9,287</td>
<td>1.05</td>
</tr>
<tr>
<td>Capel River</td>
<td>3576</td>
<td>3,569</td>
<td>1.00</td>
</tr>
<tr>
<td>Margaret River</td>
<td>1700</td>
<td>1,661</td>
<td>0.98</td>
</tr>
<tr>
<td>Lower Collie</td>
<td>970</td>
<td>806</td>
<td>0.83</td>
</tr>
<tr>
<td>Chapman Brook</td>
<td>1811</td>
<td>1,504</td>
<td>0.83</td>
</tr>
<tr>
<td>Cowaramup Brook</td>
<td>225</td>
<td>171</td>
<td>0.76</td>
</tr>
<tr>
<td>Wilyabrup Brook</td>
<td>2221</td>
<td>1,564</td>
<td>0.70</td>
</tr>
</tbody>
</table>

This table shows that the impact of farm dams is generally between 0.7 and 1.05 ML of mean annual flow per ML of farm dam volume. This figure varies according to differences within each catchment, including net evaporation, typical demands patterns, and the typical volume and catchment area of farm dams. However, the four catchments with the lowest impact as a proportion of dam capacity are notable because:

- Cowaramup Brook and Wilyabrup Brook are very small ephemeral catchments, with flows which are heavily rainfall dependant. This reduce the proportion of time each year in which farm dams could potentially affect flows, and will therefore affect the impact as a proportion of flow.
- Lower Collie River, Chapman Brook, and Wilyabrup Brook have very high catchment yield, each over 200 ML/yr/km². The high yield may provide some buffer against high impacts due to farm dams.

The range of farm dam impacts also varies linearly according to the volume of farm dams within a catchment. Figure 6-3 below shows the relationship between streamflow impact and farm dam volume for the median impact year, and 10th and 90th percentile low impact year.
This figure shows that the impact of farm dams on streamflow is typically equal to 100% of the volume of farm dams, but can vary from year to year from 114% to 90% of the volume of farm dams.

The two outliers shown in this figure (around 2000 ML farm dam volume) are Wilyabrup Brook and Chapman Brook, which have reduced impacts due to farm dams possibly as a result of high catchment yields and/or ephemeral flows, as described previously.

This allows some approximate estimations to be made for other catchments not included in this study. Figure 6-3 shows that the median impact is approximately 100% of the volume of farm dams, but can vary from year to year from 115% to 90% of the volume of farm dams. Also, Figure 6-1 shows that high impact years are strongly correlated with years of low rainfall, and that low impact years can occur at any time, but are sometimes associated with high rainfall years.

It should be noted that these figures can only approximate the impact of farm dams on streamflow approximately, and that the figures are only applicable to catchments which are located near or are hydrologically similar to those in this study.
7. Conclusions

The purpose of this report is to show the effect of different farm dam on river flows. It has been shown that:

- Effect on the total flow at the catchment outlet varies seasonally with the greatest impact occurring in late summer.
- Effect on the duration and frequency of summer high and low flow spells is generally to increase the number and duration of low flow spells and decrease the number and duration of high flow spells.
- In the most impacted catchments (Lefroy, Wilyabrup, and Cowaramup), the timing of early winter freshes is delayed. It is expected that this is also the case in the Capel catchment; however, spells analysis was unable to be undertaken.
- The degree of impact is dependent on the annual rainfall with the impact being greater in drier years.
- Inter-catchment variability is dependent upon the ratio of farm dam development to the mean annual unimpacted stream flow. Typically, for every 1 ML of farm dams in a catchment, the mean annual flow is reduced by approximately 1 ML, although this can vary year by year from 1.15 ML to 0.9 ML. Some exceptions were noted, with significantly lower impacts in some catchments possibly due to very high catchment runoff and/or ephemeral catchment flows.
8. Further Work

This study has shown the level of impacts of farm dams on stream flows for a range of catchments. However, this analysis was based on a range of inputs. In order to improve the quality of the estimates of farm dam impacts, some additional work could be undertaken as described below.

More detailed CHEAT analysis
The Lefroy catchment showed an extremely high level of farm dam development. As a comparison, the average farm dam development in Victoria is 5 to 7 ML/km$^2$, but the Lefroy catchment had development levels over 25 ML/km$^2$. This high level of development may result in a reduction in the accuracy of the results in this study.

To improve the estimates of farm dam impacts in the Lefroy catchment, a more detailed CHEAT analysis could be undertaken. This analysis may involve:

- Digitising farm dams in the catchment using the latest orthophotography or satellite imagery;
- Determining the connectivity between dams, identifying which dams cascade into others;
- Using a digital elevation model (DEM) of the catchment, if available, to estimate the subcatchment area and subcatchment slope for each farm dam, which assist in determining differences in farm dam harvest characteristics as a result of groundwater interaction;
- Using more detailed demand information from DoW, if available, with some dam specific demand data either based on metered extractions or local knowledge of irrigation practices;
- Using the Surface Energy Balance Algorithm for Land (SEBAL) which uses remote sensing to accurately determine evapotranspiration rates on a very fine scale. This technique can provide more accurate assessments of likely crop water demand, and can assist in verifying and improving irrigation demand estimates.

In this way, the impacts of farm dams could be estimated more accurately. This is justified for the Lefroy catchment, and perhaps for the Wilyabrup and Cowaramup catchments also, because the level of farm dam impacts is so high, with the potential to affect the waterway environment downstream.

Effect of additional dams
The intention of the current investigations into farm dams in WA is to assist DoW in developing policy on farm dam construction. However, different types of farm dams have different impacts on stream flows. For example, a large ornamental dam (no demands) will have some impact on stream flow as it still causes significant evaporation losses, while a small irrigation dam may have a different level of impact because it will have lower losses, but increased extractions.
On this basis, some work could be undertaken to determine the expected impact of future additional dams in a catchment, with results given as ML of farm dam impact per ML of farm dam volume. These results could be provided for different types of dams with different volumes and patterns of demand.

In addition, these results could also be presented to represent the expected impact during the SDL winter fill season, allowing relatively simple accounting of existing and future farm dam impacts as compared to the available SDL.

**Bypasses**

Farm dams bypasses are a simple way of reducing the impact of farm dams on low flows. If DoW is considering the use of bypasses on farm dams, some investigation could be undertaken to demonstrate the likely effect of installing bypasses on farm dams, and to provide some guidance on various construction methods available.

Some of this work has already been undertaken for Victorian catchments, however it is expected that methods of construction may differ in WA, and the effect of bypasses may be different for the typical hydrological characteristics of catchments in WA.

**Effect of climate change on farm dam impacts**

Climate change is an extremely important consideration across Australia, and especially in the south west of WA where reductions in surface runoff in recent years have been significant. To further understand the likely effect of climate change on farm dam impacts, the farm dam model inputs can be adjusted – streamflows can be reduced, evaporation and rainfall can be modified, and farm dam demands can be changed to reflect the likely impact of climate change.
9. References


Appendix A  Rainfall, evaporation, and dam distribution

A.1  Lower Collie

- Figure A.9-1 Lower Collie Average Monthly Rainfall and Evaporation (1975-2004)

- Figure A.9-2 Lower Collie Farm Dam Distribution
A.2 Capel River

- Figure A.9-4 Capel River Average Monthly Rainfall and Evaporation (1975-2004)

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Figure A.9-5 Capel River Farm Dam Distribution

Figure A.9-6 Capel River Farm Dam Volume
A.3 Chapman Brook

- Figure A.9-7 Chapman Brook Average Monthly Rainfall and Evaporation (1975-2004)

- Figure A.9-8 Chapman Brook Farm Dam Distribution
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Figure A.9-9 Chapman Brook Farm Dam Volume

A.4 Cowaramup Brook

Figure A.9-10 Cowaramup Brook Average Monthly Rainfall and Evaporation (1975-2004)
**Figure A.9-11 Cowaramup Brook Farm Dam Distribution**

**Figure A.9-12 Cowaramup Brook Farm Dam Volume**
A.5 Lefroy Brook

- Figure A.9-13 Lefroy Brook Average Monthly Rainfall and Evaporation (1975-2004)

- Figure A.9-14 Lefroy Brook Farm Dam Distribution
A.6 Margaret River

- Figure A.9-15 Lefroy Brook Farm Dam Volume

- Figure A.9-16 Margaret River Average Monthly Rainfall and Evaporation (1975-2004)
Impact of Farm Dams in Seven Catchments in Western Australia

**Figure A.9-17 Margaret River Farm Dam Distribution**

**Figure A.9-18 Margaret River Farm Dam Volume**
A.7 Wilyabrup Brook

- Figure A.9-19 Wilyabrup Brook Average Monthly Rainfall and Evaporation (1975-2004)

- Figure A.9-20 Wilyabrup Brook Farm Dam Distribution
In all catchments, it can be seen that rainfall and evaporation almost mirror each other with the result that winter rainfall exceeds evaporation and summer evaporation far exceeds rainfall, thus resulting in the need for irrigation dams which will fill in winter and be used during the summer.

The distribution of the farm dams and farm dam volume illustrates how the storage can be dominated by a few large dams within the catchment.

- **Figure A.9-21 Wilyabrup Brook Farm Dam Volume**
Appendix B  Spells Analysis

B.1  Lower Collie
The impact on the number of low and high flow spells is shown in Figure B.1. Figures B.2 and B.3 show the effect on the duration of low and high flow spells respectively (error bars show the 5th and 95th percentiles). As is expected, the farm dams result in more low flow events. However, the duration is not affected significantly. The number and duration of the high flow spells are not affected by farm dams.

- Figure B.1: Spells analysis results (number) for the Lower Collie for summer low and high flows
Figure B.2: Spells analysis results (duration) for the Lower Collie for summer low flows (i.e. flow lower than 29.1 ML/day).

Figure B.3: Spells analysis results (duration) for the Lower Collie for summer high flows (i.e. flow greater than 115.4 ML/day).
B.2 Capel River
A spells analysis has not been performed for the Capel River since the current flow data did not have sufficient accuracy during summer low flows.

B.3 Chapman Brook
The impact on the number of low and high flow spells is shown in Figure B.4. Figures B.5 and B.6 show the effect on the duration of low and high flow spells respectively. As is expected, the farm dams result in more events of longer duration for low flows. Conversely, for high flow conditions, the farm dams result in fewer events of shorter duration. The 85% percentile for summer low flows is very low (0.03ML/day). This spells analysis for summer low flows could therefore be considered a spells analysis for summer no flows. The increase in number and duration of no flow events could have serious ramifications for the riverine ecology.

- Figure B.4: Spells analysis results (number) for Chapman Brook for summer low and high flows
Figure B.5: Spells analysis results (duration) for Chapman Brook for summer low flows (i.e. flow lower than 0.03 ML/day).

Figure B.6: Spells analysis results (duration) for Chapman Brook for summer high flows (i.e. flow greater than 19.5 ML/day).
B.4 Cowaramup Brook

The impact on the number of low and high flow spells is shown in Figure B.7. Figures B.8 and B.9 show the effect on the duration of low and high flow spells respectively. As is expected, the farm dams result in more events of a significantly longer duration for low flows. The 85% percentile for summer low flows is very low (0.11ML/day). This spells analysis for summer low flows could therefore be considered a spells analysis for summer no flows. The increase in number and duration of no flow events could have serious ramifications for the riverine ecology. Conversely for high flow conditions, the farm dams result in fewer events of shorter duration.

- Figure B.7: Spells analysis results (number) for Cowaramup Brook for summer low and high flows
Figure B.8: Spells analysis results (duration) for Cowaramup Brook for summer low flows (i.e. flow lower than 0.11 ML/day).

Figure B.9: Spells analysis results (duration) for Cowaramup Brook for summer high flows (i.e. flow greater than 0.56 ML/day).
B.5  Lefroy Brook
The impact on the number of low and high flow spells is shown in Figure B.10. Figures B.11 and B.12 show the effect on the duration of low and high flow spells respectively. The farm dams actually have the effect of reducing the number of low flow spells but they last for a significantly longer duration. For high flow conditions, the farm dams result in fewer events of shorter duration, as is expected.

- Figure B.10: Spells analysis results (number) for the Lefroy Brook for summer low and high flows
- Figure B.11: Spells analysis results (duration) for the Lefroy Brook for summer low flows (i.e. flow lower than 17.99 ML/day).

- Figure B.12: Spells analysis results (duration) for the Lefroy Brook for summer high flows (i.e. flow greater than 86.29 ML/day).
B.6  Margaret River

The impact on the number of low and high flow spells is shown in Figure B.13. Figures B.14 and B.15 show the effect on the duration of low and high flow spells respectively. These charts show that the farm dams do not affect the number or duration of low flows. The number and duration of summer high flows is slightly reduced by the presence of farm dams.

- Figure B.13: Spells analysis results (number) for Margaret River for summer low and high flows
**Figure B.14**: Spells analysis results (duration) for Margaret River for summer low flows (i.e. flow lower than 0.01 ML/day).

**Figure B.15**: Spells analysis results (duration) for Margaret River for summer high flows (i.e. flow greater than 21.64 ML/day).
B.7 Wilyabrup Brook
The impact on the number of low and high flow spells is shown in Figure B.16. Figures B.17 and B.18 show the effect on the duration of low and high flow spells respectively. The farm dams actually have the effect of reducing the number of low flow spells but they last for a significantly longer duration. The 85% percentile for summer low flows is very low (0.15ML/day). This spells analysis for summer low flows could therefore be considered a spells analysis for summer no flows. The significant increase in duration of no flow events could have serious ramifications for the riverine ecology. For high flow conditions, the farm dams result in fewer events of shorter duration, as is expected.

- Figure B.16: Spells analysis results (number) for Wilyabrup Brook for summer low and high flows
Figure B.17: Spells analysis results (duration) for Wilyabrup Brook for summer low flows (i.e. flow lower than 0.15 ML/day).

Figure B.18: Spells analysis results (duration) for Wilyabrup Brook for summer high flows (i.e. flow greater than 3.84 ML/day).