Impacts of Farm Dams on Streamflow

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- FINAL
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LIMITATION: The sole purpose of this report and the associated services performed by Sinclair Knight Merz (SKM) is assess the impact of farm dams on streamflows for seven catchments in south western WA in accordance with the scope of services set out in the contract between SKM and the West Australian Department of Water ('the Client'). That scope of services was defined by the request of the Client.

In preparing this report, SKM has relied upon and presumed accurate certain information (or absence thereof) provided by the Client. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information. The passage of time, manifestation of latent conditions or impacts of future events, such as the construction of new farm dams or the availability of more precise farm dam information, may require further exploration in the study catchments and subsequent data analysis, and re-evaluation of the findings, observations and conclusions expressed in this report.

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1. Introduction

1.1. Background

SKM has previously completed work to quantify the effect of farm dams on streamflows in the catchment of Lefroy Brook (SKM, 2007).

The current report builds upon this previous work. The modelling undertaken here differs from the 2007 work in the following ways:

- It focuses on a smaller sub-catchment within the Lefroy Catchment;
- Revised demands levels have been used, based on new data provided by DoW;
- 3 scenarios have been run (rather than only 1), each with a different level of demand;
- Various changes in the model have been implemented, improving estimation of impacts through more accurate representation of: (a) the stream network; (b) baseflow interactions; and (c) the catchment areas of individual dams; and
- The modelling period has been lengthened by a year to cover Jan 1975 – April 2006.

These points are discussed in more detail in the main body of this report.

1.2. Study Catchment

The catchment of the Channybearup Gauge (607002) is used in this modelling. This catchment has an area of 92 km^2 and has an average annual flow of 13 744 ML/year. Within this catchment there are 178 dams, with a total volume of 4203ML. This corresponds to a farm dam density of 45.7 ML/km^2.

Compared to previous modelling, this catchment is only a quarter of the size of the Lefroy catchment used in the 2007 report, and farm dam density is nearly twice as high. It is noted that, when compared to Victorian catchments, only 2% of Victorian catchments have a higher farm dam density.

1.3. Structure of this report

Section 2 below explains the improvements in modelling method that have been made in this project. The four main model inputs are described in Section 3, and then Section 4 explains the results for the scenario that uses the best estimate of demand. In Section 5, the results from the low demand and high demand scenarios are examined. Finally, conclusions and recommendations are given in Section 6.

2. Modelling improvements

As described above, the work undertaken for the current study builds upon previous work undertaken in 2007. The current work includes a number of improvements which should help to make the results more accurate:

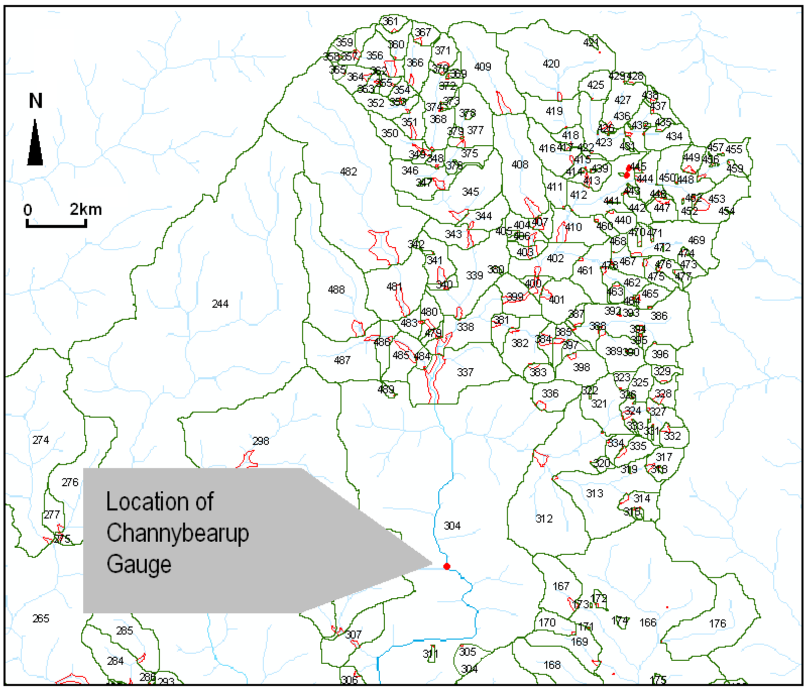
- Revised demands levels have been used, based on new data provided by DoW (see Section 3.4 below);
- 3 scenarios have been run (rather than only 1), each with a different level of demand. These three scenarios can be considered to represent the range of demands within the catchment, and as such, the results represent the upper and lower bound estimates of the impact of farm dams on the waterway (see Section 3.4 below);
- The modelling period has been lengthened by a year to cover Jan 1975 – April 2006. This additional representation of recent low flow conditions should help to provide more information regarding the impact of farm dams during dry seasons.

However, the most fundamental change since 2007 is the conceptual model representation of farm dams in the catchment. The three major differences are explained below.

2.1. The stream network

In the 2007 report, each dam was assumed to be operating independently of all the others. Under this system, when a dam overflows, the overflow is routed direct to the catchment outlet.

In the current modelling, the farm dams have been joined together into a network. This network identifies, for each dam, the dams that are downstream (see Figure 2-1 below). This allows representation of "cascading", where upstream dams affect flow into downstream dams. This information was provided by analysis of a Digital Elevation Model (DEM) in conjunction with aerial photos.



- **Figure 2-1: Excerpt from the GIS database for the Lefroy Brook Catchment, showing the areas upstream of the Channybearup Gauge, the locations of dams (red), their catchment areas (green) and the stream network joining them together (blue).**

Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\01_DerivingInputs\D01_kf_CHEAT_InputDerivation_Channybearup.xlsb

2.2. The catchment areas of individual dams

In the 2007 report, the model calculated subcatchment areas using a generic equation rather than using the actual subcatchment areas of farm dams. It assumed that large dams must have large subcatchment areas, while small dams must have small subcatchment areas. This works reasonably well in low development areas – individual dams may not have the correct subcatchment areas, but across the catchment as a whole this simplifying assumption makes little difference. However, in high development catchments this assumption can produce significant distortions in the results.

As shown in Figure 2-1, individual subcatchment area for each dam was available for the current study, and this data was developed by analysis of a Digital Elevation Model (DEM) in conjunction with aerial photos.

2.3. Baseflow interactions

In the 2007 report, the model assumed that the inflow to each dam was directly proportional to its subcatchment area. For example, if a farm dam has a subcatchment of 1km2 and the overall catchment area is 50km2, then the inflow to the dam will be 2% (1/50) of the total catchment inflow. Once again, this simplifying assumption is acceptable in low development catchments with relatively low impacts. However, in the Lefroy catchment the impact is likely to be high, and so the exact inflow into each dam is likely to be more important.

In the current study, the catchment flow has been separated into:

- "quickflow" representing direct runoff after rainfall events. The quickflow is distributed evenly between subcatchments, in proportion to catchment area; and
- "baseflow" representing the runoff slowly released over weeks and months from natural subsurface and groundwater storage. Baseflow is distributed to each subcatchment based on the average slope within the subcatchment.

This means that a farm dam in a steep slope area, most likely the upland areas at the top of the catchment, will harvest only quickflow. It would harvest relatively little subsurface groundwater flow. On the other hand, a farm dam in a very flat area is likely to be in the river floodplain at the bottom of the valley, and is likely to harvest both quickflow and baseflow.

These assumptions are based on an idealised catchment model as described in Kirkby (1975).

3. Description of Model Inputs

3.1. Farm Dam Network

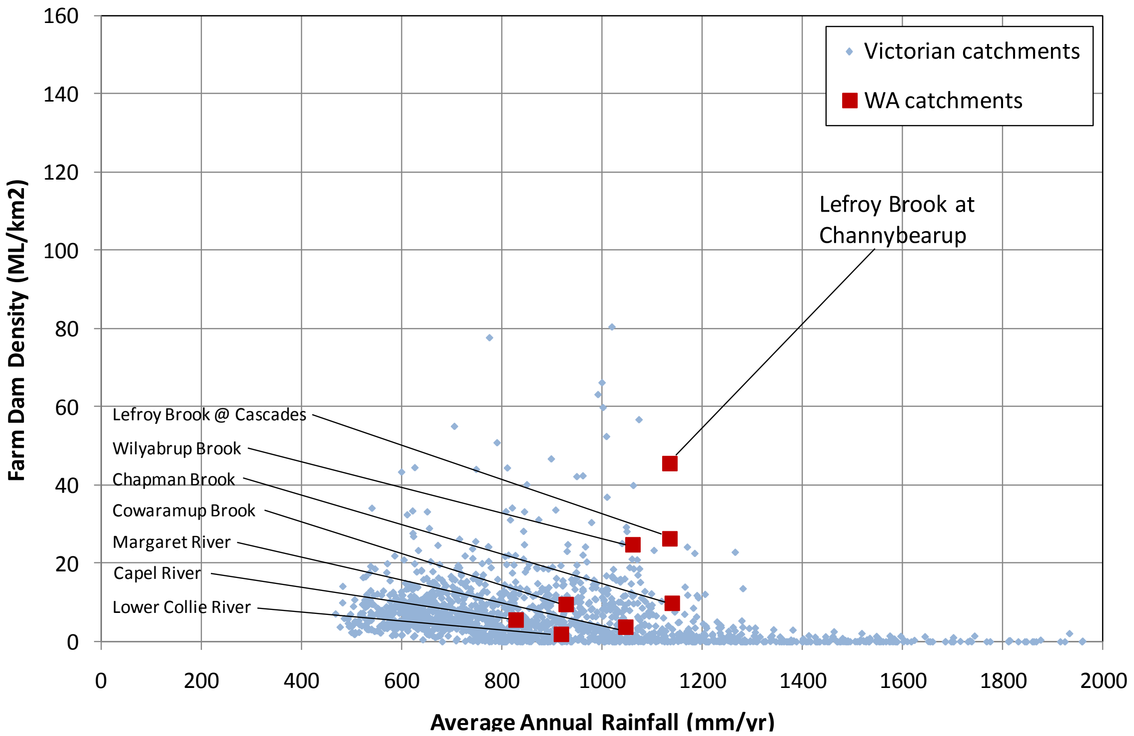
For this study, 179 dams were modelled within the study catchment. This set was composed of all dams identified as on-stream dams from the aerial photography. The photographs also provided dam surface areas. Using Equation 3-1, the same formula used in 2007 originally developed in DoW (2005), these areas were converted to volumes. Total dam volume for the study catchment was 4203 ML.

- **Equation 3-1** $\text{Volume (ML)} = 0.0007 \times \text{Area } (m^2)^{1.0709}$

Although this formula may not provide the correct volume for any individual dam, it is expected that the combined volume of all dams across a catchment will be estimated correctly.

As described in section 2, the representation of the network of farm dams in Lefroy Brook has been refined in the latest round of modelling. In the current modelling, the farm dams have been joined together into a network. This network identifies, for each dam, the dams that are downstream, allowing representation of "cascading", where upstream dams affect flow into downstream dams. This information was provided by analysis of a Digital Elevation Model (DEM) in conjunction with aerial photos. This process also provided the individual catchment area for each dam.

It is noted that the farm dam density in the study catchment is very high. The total dam volume of 4203ML, over the catchment area of $92km^2$, gives a farm dam density of $45.7ML/km^2$. Figure 3-1 below compares this density with Victorian catchments. It shows that only 2% of catchments in Victoria have a higher farm dam density.



- **Figure 3-1: Comparison of farm dam density between WA Catchments and Victorian Catchments, plotted against rainfall. The study catchment is in the top 2% of Victorian Catchments in terms of dam density.** Source: I:\VWES\Projects\VW04374\Technical\FarmDamDensities\D01_ram_comaprinf Vic and WA dam densities.xlsb

3.2. Streamflow

Streamflow was sourced from the Channybearup Gauge (607002). Records at this gauge cease at April 1999, so a method of infilling was required to bring the streamflow series up to April 2006. The method used was regression with a nearby gauge – 607013 (Lefroy @ Rainbow Trail). The regression equation was derived on a daily timestep, and is as follows:

- **Equation 3-2** $(Flow_{607002})^{0.5} = 0.6708 \times (Flow_{607013})^{0.5} - 0.9119$ $R^2 = 0.9594$

This equation was used to fill the years 1999-2006.

The mean annual flow for the modelling period (Jan 1975 – April 2006) was **13744 ML/year**.

3.3. Rainfall and Evaporation

Rainfall data and evaporation data were sourced from the Pemberton gauge (009592). Where gauge data was not available from a 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.

The average annual rainfall for the modelling period is 1133mm/year.

The average annual evaporation for the modelling period is 1136mm/year (coincidentally, almost identical to rainfall).

3.4. Demand information

This section describes the data made available to SKM and the resultant demand scenarios that have been constructed to represent different levels of demand in the CHEAT model.

Demand data was provided by DoW in April 2008. This data identifies 189 different properties in the Lefroy Brook Catchment. These properties:

- Have a combined storage capacity of 9,345 ML;
- Use 10,856 ML of water per year, of which:
    - 159 ML is stock and domestic use; and
    - 10,697 ML (98.5%) is irrigation use.
- The ratio of the total use to total capacity is 1.16 (this is the overall “Demand Factor”).

However, it is important to note that many properties use a very large amount of water compared to their storage capacity. For example, Property 1366920 has a total storage capacity of 5.9 ML, but annual usage is 72.0 ML. Therefore, it is reasonable to suggest that there is some alternative source of water being pumped into storage – either groundwater or river water (*Pers. Comms., K. Bennett, DoW, 2008*). The method adopted is to assume only 11.8 ML out of 72 ML (11.8 = 2×Dam Volume) is being sourced from the stream flowing into the dam. That is, *the usage for any property was limited to twice the storage size* for the purposes of calculating demands for on-stream dams.

When this limitation is included, the total usage reduces from 10856 ML to 7471 ML, and the demand factor reduces from 1.16 to 0.80.

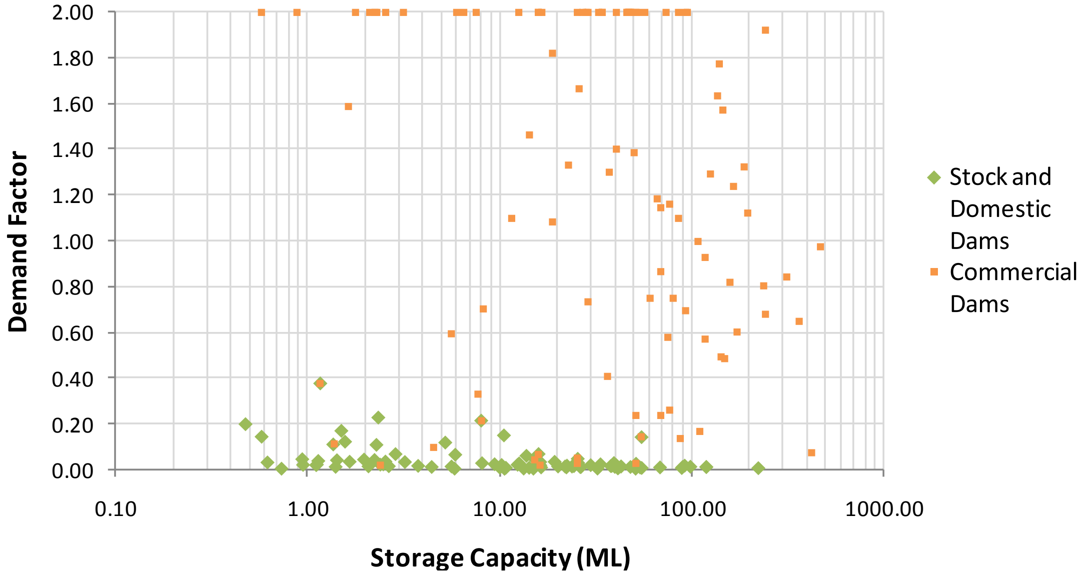
3.4.1. Threshold between Stock and Domestic dams and Irrigation dams

The next consideration is the distinction between irrigation dams and stock and domestic dams. It has been standard practice in CHEAT modelling to divide farm dams into two sets:

- *Stock and domestic dams*: smaller dams, typically with low overall demand spread fairly evenly throughout the year; and
- *Irrigation dams*: larger dams, typically with higher demand concentrated during summer irrigation seasons.

Also, it is important to note that all farm dams of a particular type must be given the same demand factor. This means that all stock and domestic dams must have the same demand factor, and all irrigation dams must have the same demand factor.

However, the data provided by DoW suggests that the farm dams in this catchment do not fit neatly into these typical categories. Figure 3-2 shows how the demand factor varies with dam volume. For example, the figure shows that there are many dams with a demand factor of 2.0, ranging in size from 0.6 ML up to 100 ML. These means the demand from these dams ranges from 1.2 ML/yr up to 200 ML/yr. Properties are marked as Irrigation if >90% of their overall demand is for irrigation, and marked S&D if >90% is S&D demand. Dams between 10% and 90% are marked as both.



- Figure 3-2: Storage capacity vs demand factor for Lefroy properties.

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This data shows that for the Channybearup catchment:

- The stock and domestic dams have a consistently low demand factor, but they are not typically small. They can vary from 0.5 ML up to 200 ML. This suggests that there are a large number of very big dams which are significantly under-utilised, being used only for stock and domestic purposes.
- The irrigation dams have a wide range of possible demand factors and volumes, ranging from a demand factor of 0.1 and a volume of 400 ML, up to a demand factor of 2.0 and a volume of 0.6 ML. This suggests that there are some large irrigation dams being significantly under-utilised, and some small dams being significantly over-utilised.

This presents a problem for CHEAT, because these characteristics do not fit in with the standard parameters applicable in most other catchments. Consider the ~100ML capacity in Figure 3-2. There are a few dams at Demand Factor = 0.0, a few at Demand Factor = 2.0 and then a range of dams between these two extremes. There is currently no way of representing this range of demands in CHEAT.

The proposed solution is to run multiple scenarios with different demands, as discussed below.

3.4.2. Demand scenarios

In order to provide an accurate assessment of the range of potential impacts that the assumed demand has on flow given the uncertainty regarding demand factors and dam volumes, the following three scenarios were run:

Low Demand Scenario

- This scenario represents the effect on streamflow if all dams were to use a very small percentage of their capacity each year.
- Demand Factor: 0.06 (corresponding to the 25th percentile of demand factors in the Lefroy Brook catchment).
- Monthly Demand pattern: Stock and domestic demand pattern (see below).

Moderate Demand Scenario (Best Estimate)

- Best estimate of impacts, using a single demand level derived by incorporating all available data.
- Demand Factor: 0.80 (ie. Total annual use*/Total dam capacity = 0.8)
- Monthly Demand pattern:
    - Stock and domestic demand pattern (see below) for dams with volume < 10ML.
    - Irrigation demand pattern (see below) for dams with volume > 10ML.

** Total annual use subject to the limitation that a property's use is limited to 2× storage capacity – see Section 3.4.1 for explanation.*

High Demand Scenario

- This scenario replicates the effect of streamflow if all dams were to have a high level of demand similar to the high-demand irrigation dams.
- Demand Factor: 1.4 (corresponding to the 75th percentile of demand factors in Lefroy Brook catchment)
- Monthly Demand Pattern: Irrigation demand pattern (see below).

3.4.3. Monthly Demand Patterns

The monthly demand patterns used in the modelling were provided by DoW based on the dataset mentioned above. The proportions of annual demand in each month are as shown in Table 3-1 below.

- **Table 3-1: Monthly demand pattern used in CHEAT modelling.**

Source: I:\VWES\Projects\VW04374\Technical\01_DetailedCHEAT\02_Demand Refinements\D01_kf_NewDemands_Lefroy.xlsb

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Stock & Domestic	0.13	0.12	0.10	0.08	0.06	0.05	0.05	0.05	0.06	0.08	0.10	0.12
Irrigation	0.23	0.20	0.12	0.05	0.01	0.00	0.00	0.00	0.01	0.04	0.13	0.22

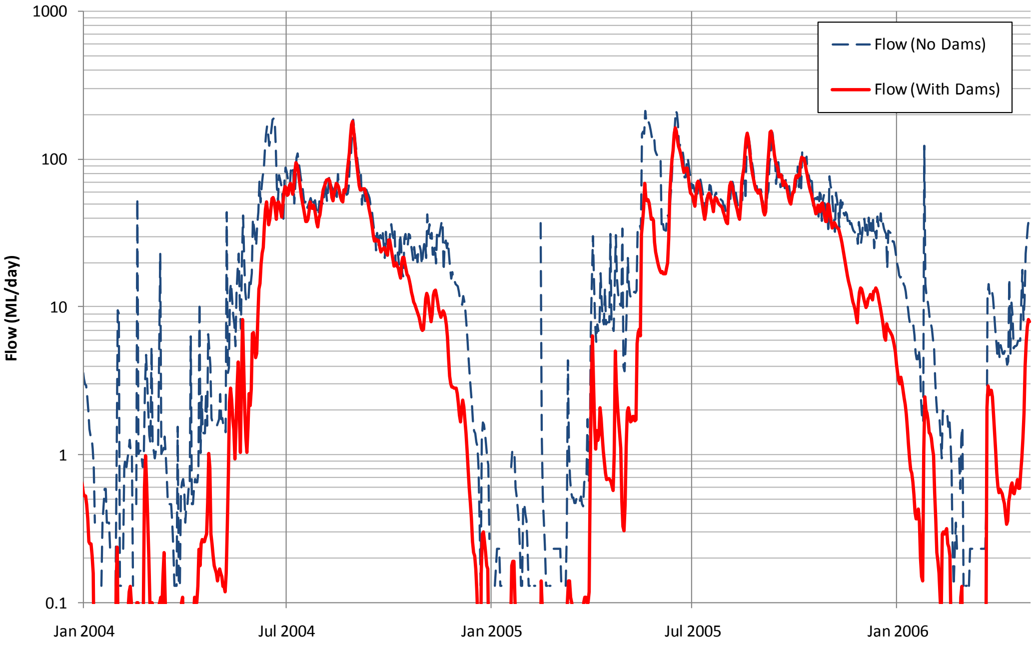
4. Results of moderate demand (best estimate) scenario

4.1. Daily streamflows and impacts

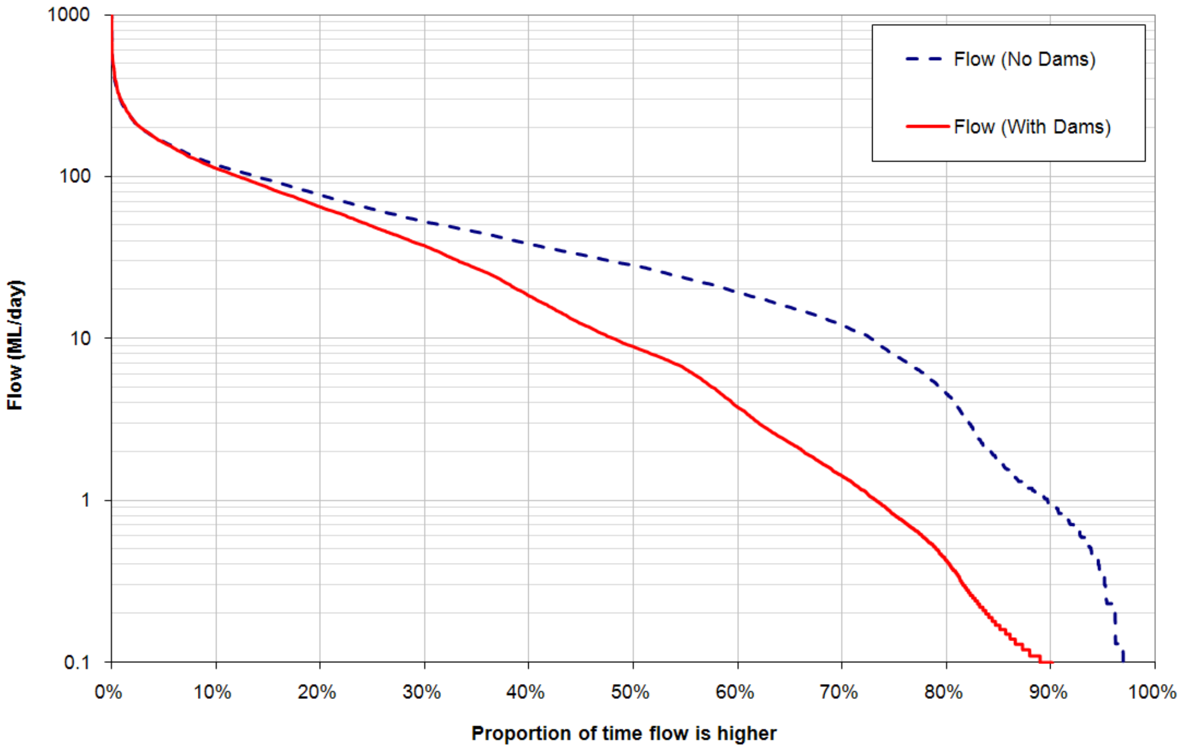
Figure 4-1 and Figure 4-2 show the recorded daily flows at Channybearup (shown as the "With Dams" case) and the estimated natural flow (shown as the "No Dams" case). The figures show both a sample of the daily streamflows at the site, as well as the flow exceedance curves (over 1975-2006).

The daily flow patterns show that high flows during the middle of each winter season are impacted little, whereas medium and low flows are impacted considerably. For example:

- the median flow is reduced by the farm dam network from 28ML/d to 9ML/d.
- the flow dropped below 10ML/day 28% of the time under natural conditions, whereas the farm dam network has increased this to 52% of the time.
- the stream ceased to flow 4% of the time under natural flow conditions, whereas this increased to 10% of the time with the dam network.
- Numerous summer freshes are present in the "natural" flow series (see Figure 4-1), but the dam network has evidently captured these flows before they reach the outlet.



- **Figure 4-1: Sample of daily flows with dams (ie. recorded flow), and estimated flow without dams.** Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\Channybearup_2\kf_RunBest_OutputInterpretation_daily_v6b_31yrVersion.xlsb

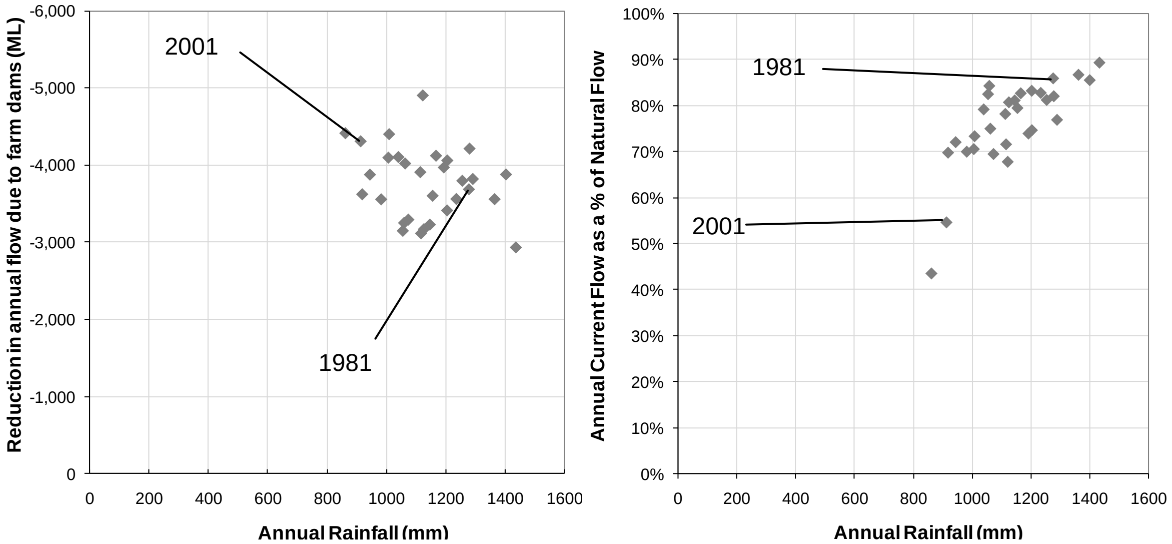


- **Figure 4-2: Flow exceedance curves for estimated flows with and without dams over the period 1975-06.** Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\Channybearup_2\kf_RunBest_OutputInterpretation_daily_v6b_31yrVersion.xlsb

4.2. Annual streamflows and impacts

The observed average annual flow over 1975-2006 at Channybearup was **13, 744 ML/year**. The results indicate that the flow that would have occurred if the dam network was absent (the “natural” flow) is **17, 514 ML/year**. Therefore, the modelling indicates that the dams are causing a **22% reduction** each year, on average.

Figure 4-3a below shows that there is very little correlation between annual rainfall and the volumetric reduction caused by farm dams. The annual flow reduction is generally around 3-4GL, regardless of how wet or dry the year is. Therefore, in percentage terms, the impact is much greater in drier years. This is because the 3-4GL taken by dams, accounts for a greater proportion of streamflow in dry years. This is shown below in Figure 4-3b below.



- **Figure 4-3: Reductions in annual flow due to farm dams, expressed as volumes (left) and as percentages of natural flow (right). Plotted against annual rainfall in mm.**

Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\Channybearup_2\kf_RunBest_OutputInterpretation_daily_v6b_31yrVersion.xlsb

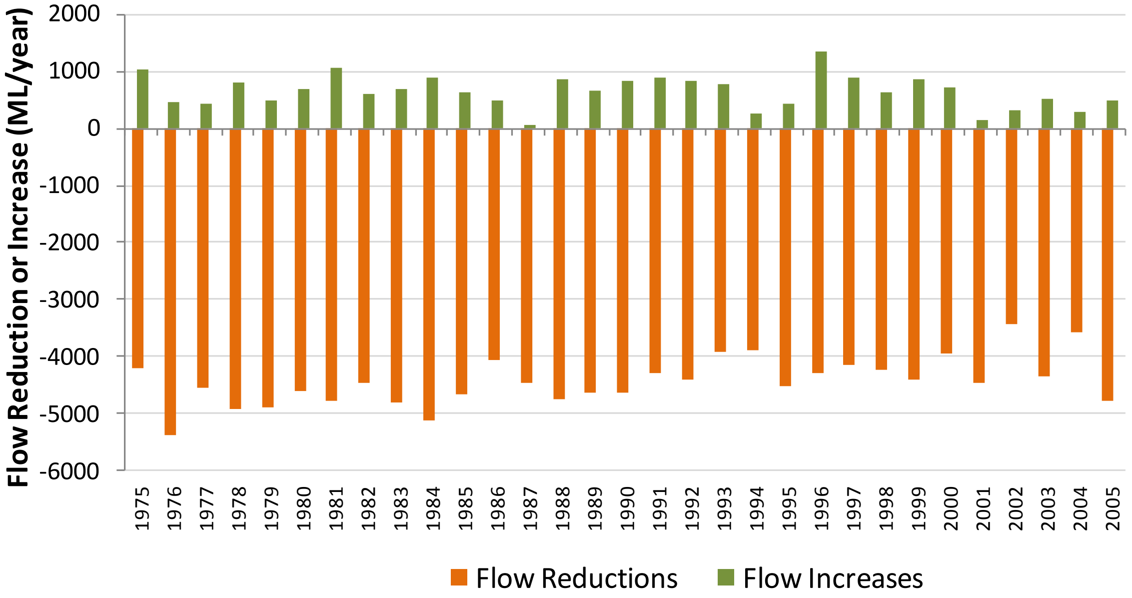
To give a few examples from Figure 4-3:

- in 1981, the estimated reduction due to farm dams was 3.7GL, but since this was a wet year (rainfall = 1278mm, annual flow = 26.2GL), the reduction was equivalent to 14% of flow.
- In 2001, the reduction was slightly more (4.3GL), but since this was a dry year (rainfall = 915mm, annual flow = 9.3GL), this reduction accounted for 45.4% of flow.

4.3. Seasonal impacts of farm dams

As explained above, the net effect on flow was around 3-4GL per year. However, this net effect is composed of flow reductions in summer and flow increases in winter. This is because dams are frequently full to overflowing during the winter months, leading to rainfall being directly converted to stream flow, thus increasing the flow. This process offsets flow decreases in summer/autumn. For example, in the year 1981, the net reduction was 3.7GL, but this was composed of flow increases of 1.1GL over winter and flow reductions of 4.8GL over non-winter months. See Figure 4-4 below for the breakdown for each year.

Figure 4-5 shows the average monthly variation in flows, with each monthly value being the average over the 31 year modelling period. The biggest difference is between April and June, when dams are often harvesting early winter flows. Flow reductions of >20ML/day are common during these months.



- **Figure 4-4: Changes in flow due to dams, for each year in the modelling period.**

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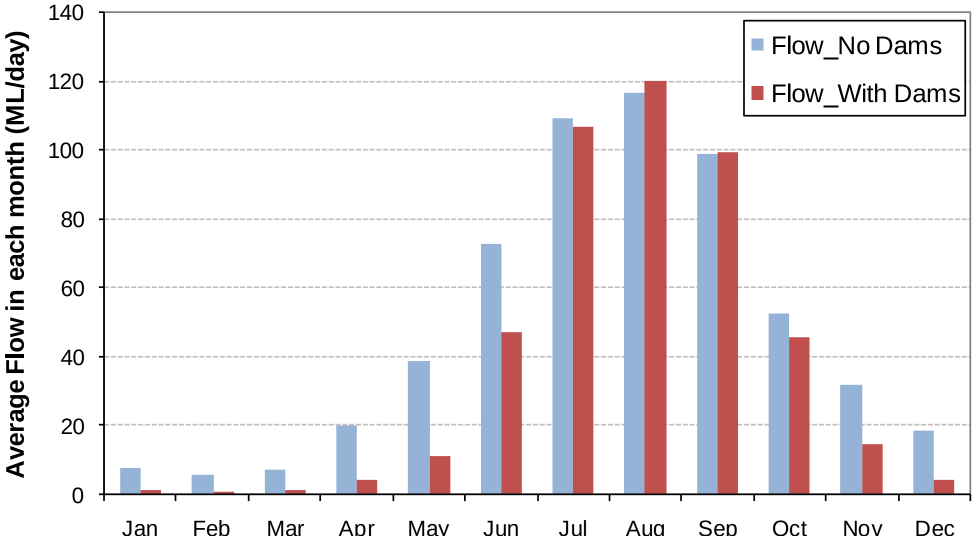

- **Figure 4-5: Average daily flow in each month, with and without dams.**

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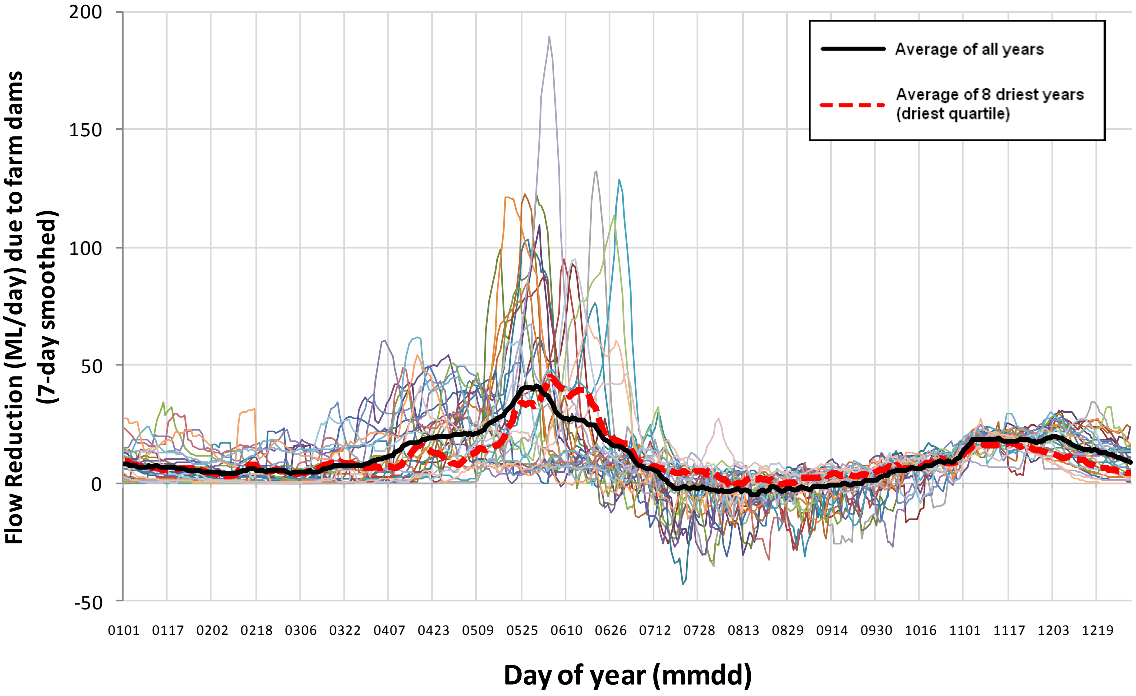
The monthly averages shown in Figure 4-5 above do not capture the variability in the system. There is considerable variation from year to year in the timing and magnitude of reductions in flow, as shown in Figure 4-5. This shows reductions in flow throughout the year, with each line representing a single year between 1975 and 2006.



- **Figure 4-6: Day to day variation in flow impacts. Each of the 31 years are plotted, along with overall average (black) & average of driest quartile of years (red dashed).**

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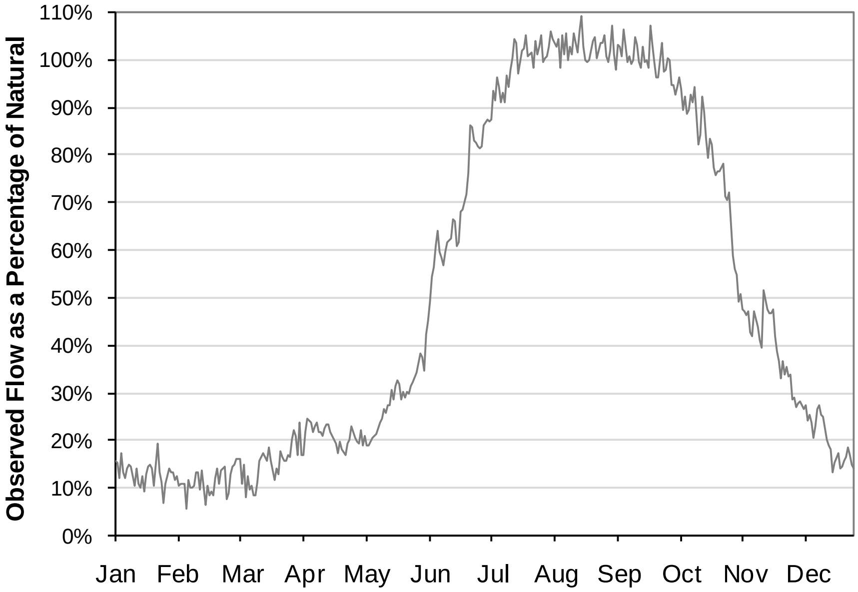
The following points are noted:

- The greatest impact on flow generally occurs around the 1st June. At this time, the average flow impacts were around 40 ML/day. However, as shown in Figure 4-6 above, in some years the impacts were many times greater than 40 ML/day.
- In some years, significant impacts occurred earlier in the year – for example, in 1982, most (~60%) of flow reductions occurred before 31st May.
- Generally, in drier years, the impacts were delayed by around 1-2 weeks, as shown by the thick dashed red line in Figure 4-6.
- During late July, August and September, flow was generally increased rather than decreased by the presence of farm dams. As discussed earlier, this is due to direct rainfall on dams.
- There is a second, smaller peak in flow impact during late October, November and early December. It is suggested the reasons for this are:
  - At earlier times (eg. September), the flow is high but the demand is negligible, so the dams are still full; and
  - At later times (eg. January), the demand is high but the flow is too low for large volumes of flow to be diverted.



- **Figure 4-7: Observed flow as a percentage of natural flow, throughout the year (average for all years of the modelling period).** Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\Channybearup_2\kf_RunBest_OutputInterpretation_daily_v6b_31yrVersion.xlsb

Figure 4-7 above shows that the summer months are the most impacted by farm dams, if judged by *percentage reduction* in flows. Nearly all (~85%) of the summer flows are diverted by the farm dam network.

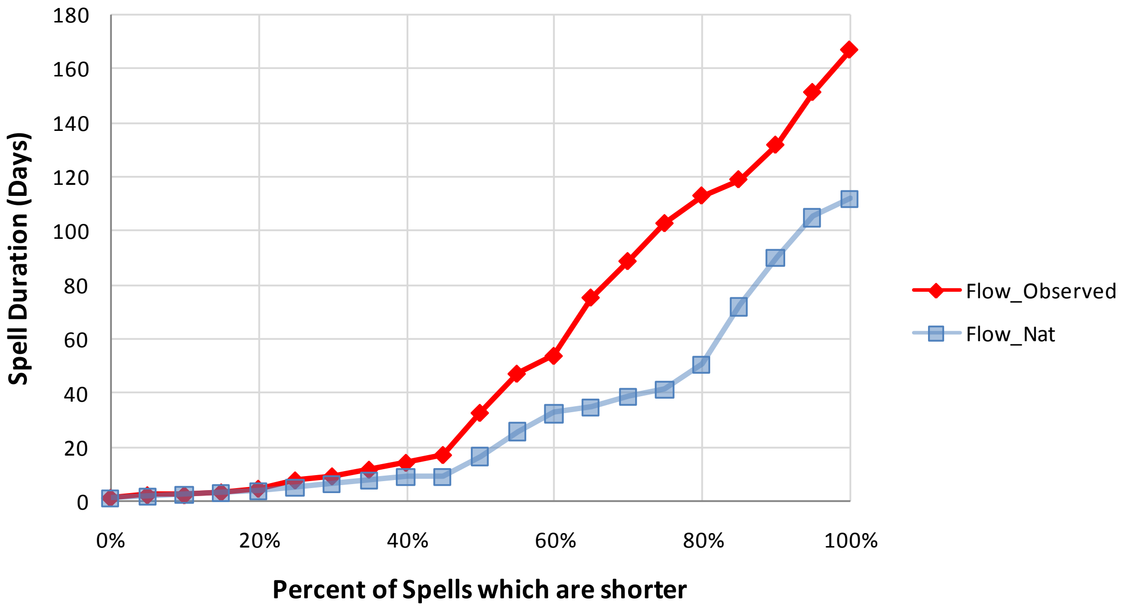
4.4. Low flow spells

Figure 4-8 and Figure 4-9 below show the distribution and timing of spells under a threshold flow of **0.58 ML/day**. This flow was chosen because it is exceeded 85% of the time during summer in the natural flow series. In terms of spells under this threshold, the impact of dams is as follows:

- **Natural flow series**: 753 days under the threshold, occurring in 27 separate spells*. Average spell length: 28 days.
- **Observed flow series**: 2447 days under the threshold, occurring in 45 separate spells*. Average spell length: 54 days.

* Spells were deemed independent if they were separated by 7 or more days.

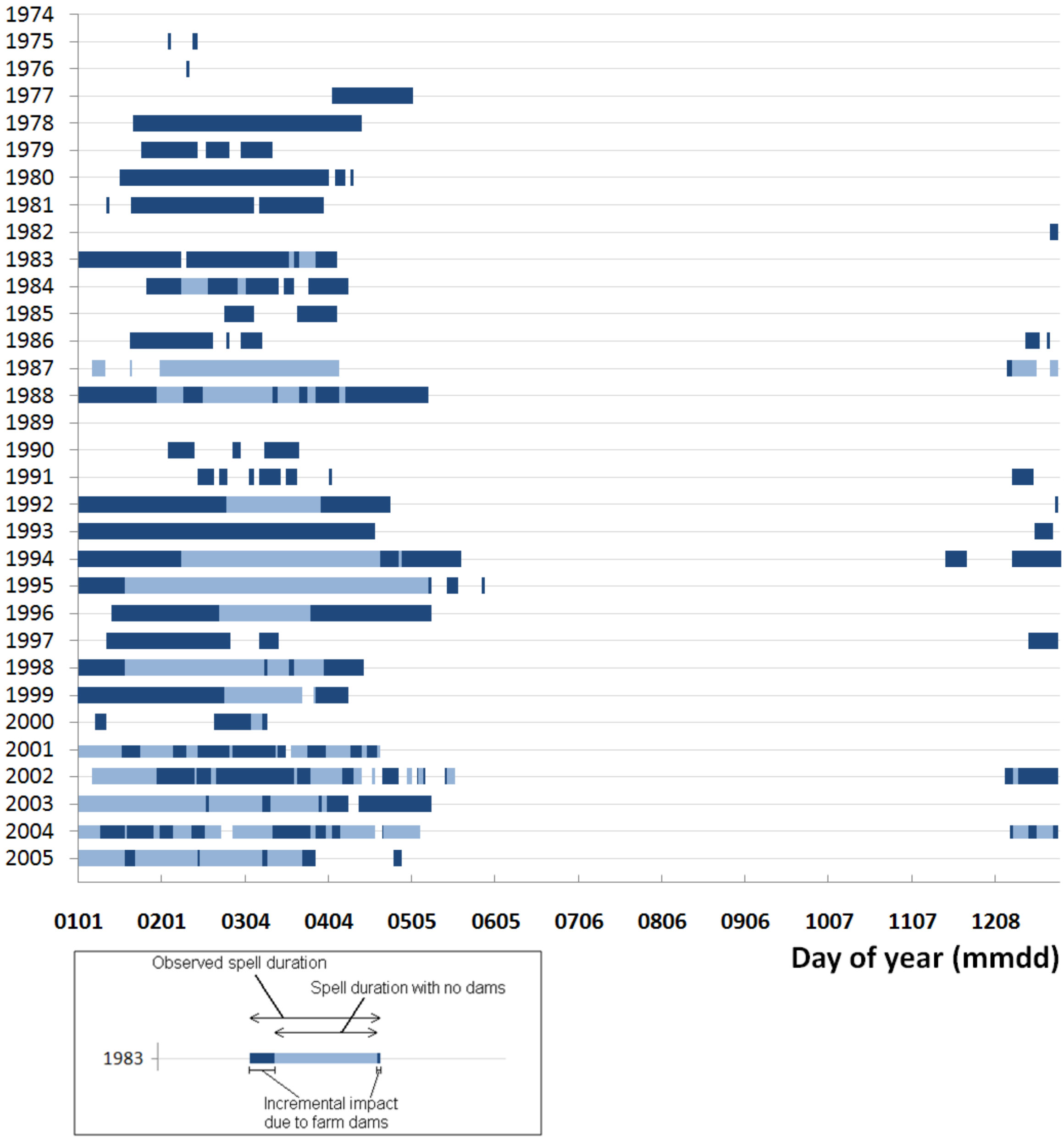
The above results suggest that the farm dams cause spells under the threshold to be longer and more numerous. The distribution of length of spells is displayed graphically in Figure 4-8 below, showing that spells of all lengths become more common because of farm dams - particularly spells of longer duration. For example, under natural conditions, a spell of 100 days would have been in the top 10% in terms of spell duration. However, in the observed series, spells of 100 days or more are more common - 25% of spells are longer than 100 days.



- **Figure 4-8: Distribution of spell lengths for spells under 0.58ML/day.**

Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\Channybearup_2\kf_RunBest_OutputInterpretation_daily_v6b_31yrVersion.xlsb

Figure 4-9 below shows the actual timing of individual spells in each of the years of the modelling period. Darker shades indicate the portions of the spells that were created/lengthened by the impact of the farm dam network.



- **Figure 4-9: Spells under 0.58ML/day, for each year in the modelling period. The darker shades refer to parts of the spell that are caused by farm dams.**

Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\Channybearup_2\kf_RunBest_OutputInterpretation_daily_v6b_31yrVersion.xlsb

5. Results of other scenarios (low impact/high impact)

The previous section dealt with the results of the best estimate of impacts due to farm dams in Lefroy Brook upstream of Channybearup. However there are a number of uncertainties surrounding the levels of demand in the catchment, and some particular aspects of demand are difficult to represent in the CHEAT model. For this reason, the high and low demand scenarios have been modelled representing the extreme upper and lower bound estimates.

Results of these scenarios are given in this section.

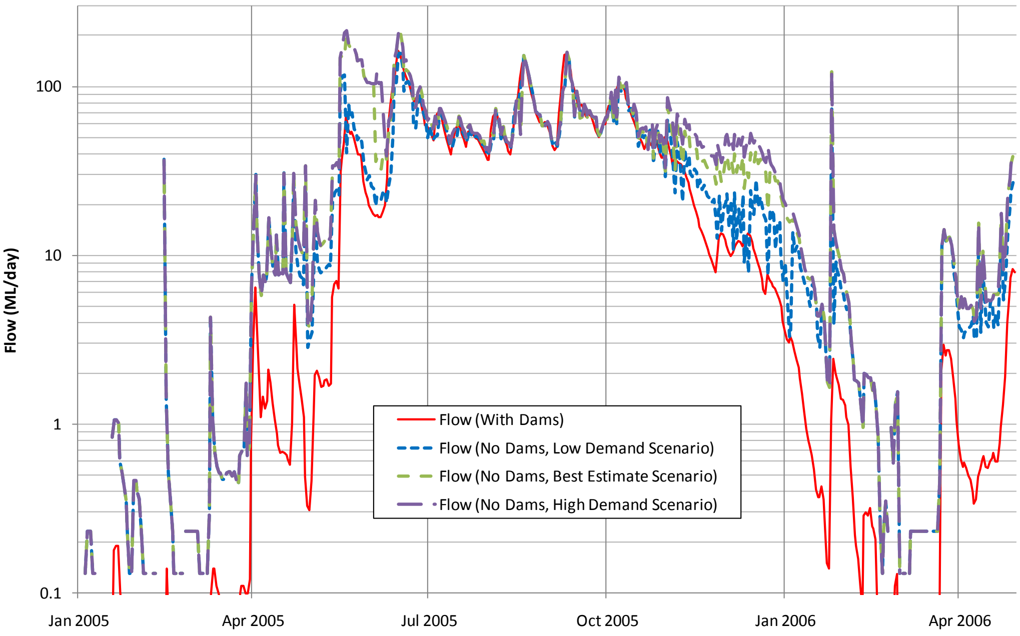
NOTE – All model runs presented in this report are based on observed flows at Channybearup. Each model run attempts to estimate the "no dams" flow in the catchment, the flow that would have been recorded if no dams were present. This "no dams" flow varies depending on what demand level has been assumed. For each model run, the "with dams" flow is the actual recorded flow, and does not vary between runs.

5.1. Daily streamflows and impacts

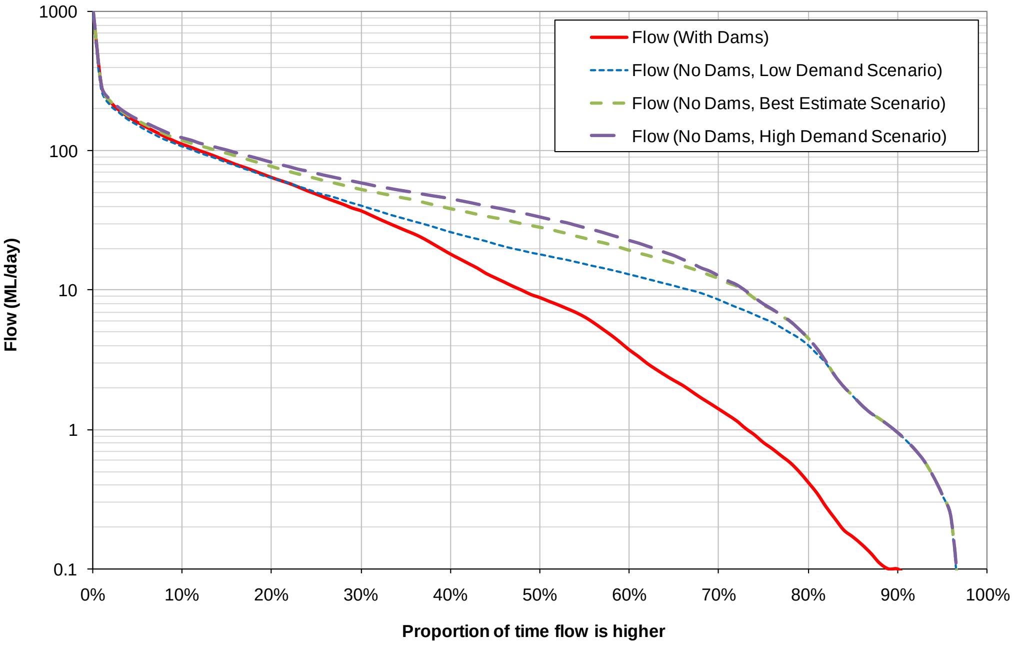
The following figures show the recorded daily flows at Channybearup over 1975-2006 (shown as the "With Dams" case) and the estimated natural flows for the high and low demand scenarios (shown as the "No Dams" cases). The figures show both a sample of the daily streamflows at the site, as well as the flow exceedance curves.

These figures demonstrate that there is not a large difference between the "high" demand scenario and the "best estimate" scenario. For the low flows as well as the mid and high flows, the flow durations curves and time-series were fairly similar for these two scenarios. The demand factor in the high scenario was 1.4 compared to 0.8 for the "best estimate" scenario, but the effect of this on actual impacts was not large, with the two scenarios tracking each other to (generally) within 20%.

For the low demand scenario, the results indicated that flows above ~50ML/day were practically unchanged by the dam network. This may be because these flows occur mainly in mid-late winter and by this time the dams are generally full in this scenario. However, for flows below 50ML/day the impacts are more significant, and for flows below 3 ML/day the impacts for all three scenarios are identical, according to the flow duration curves in Figure 5-2. These low flows generally occur during mid-late summer, and the results suggest that there is sufficient airspace in the dams to absorb incoming flows at this time, regardless of the demand. It is likely that even if the demand was zero, evaporation from dam surfaces would replenish airspace enough to absorb these low summer flows. This will be discussed further below.



- **Figure 5-1: Sample of daily estimated flows with and without dams.** Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\D01_ChannybearupComparison_1,2,3.xlsb



- **Figure 5-2: Flow exceedance curves for estimated flows with and without dams over the period 1975-2006.** Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\D01_ChannybearupComparison_1,2,3.xlsb

5.2. Annual streamflows and impacts

The observed average annual flow over 1975-2006 at Channybearup was **13, 744 ML/year**. The high and low demand results indicate that the flow that would have occurred if the dam network was absent is between approximately **14,500 ML/year** and **18,700 ML/yr**, respectivly**.** Therefore, the modelling indicates that the dams are causing a reduction in streamflow of between 7% and 27% each year, on average, depending on the level of demand that is assumed. These figures are summarised in the table below.

- **Table 5-1: Comparison of mean annual flows at Channybearup with and without dams**

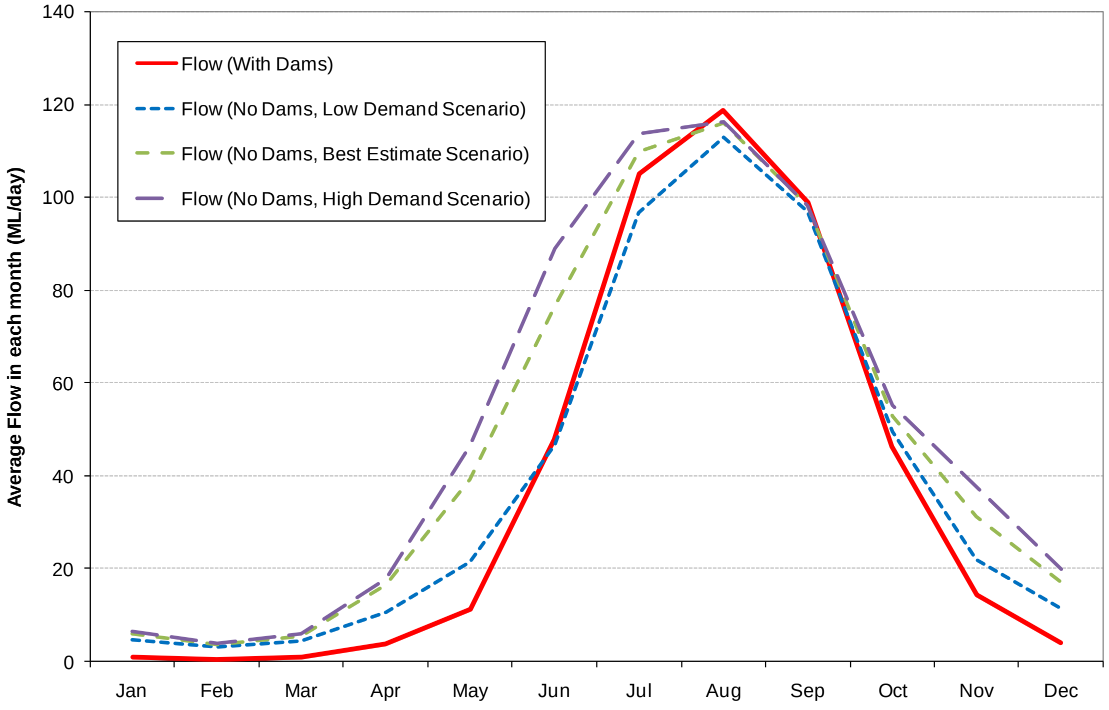
Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\D01_ChannybearupComparison_1,2,3.xlsb

Heading	With dams (current observed flows)	No dams (low demand scenario)	No dams (best estimate)	No dams (high demand scenario)
Mean annual flow (ML/yr)	13,744	14,721	17,514	18,773
Reduction in mean annual flow from observed (ML/yr)	-	977	3,770	5,029
Reduction in mean annual flow from observed (%)	-	7%	22%	27%

5.3. Seasonal impacts of farm dams

Figure 4-5 shows the average monthly variation in flows, with each monthly value being the average over the 31 year modelling period. The observed flow is significantly less than the estimated natural flow throughout late spring, summer, and autumn. During May and June, the low demand natural flow is much lower than the other demand scenarios. This is to be expected, as it indicates that for the higher demand scenarios, the dams empty out more during the year, and take longer to fill in early winter. In this case, the impact of dams filling is still present through May, June and July.

As noted above, each model run attempts to estimate the “no dams” flow in the catchment, the flow that would have been recorded if no dams were present. This “no dams” flow varies depending on what demand level has been assumed. This is why three different estimates of the natural “no dams” flow appear in Figure 5-3, and in other figures further down (eg. Figure 5-5 expresses recorded flow as a percentage of “natural”).

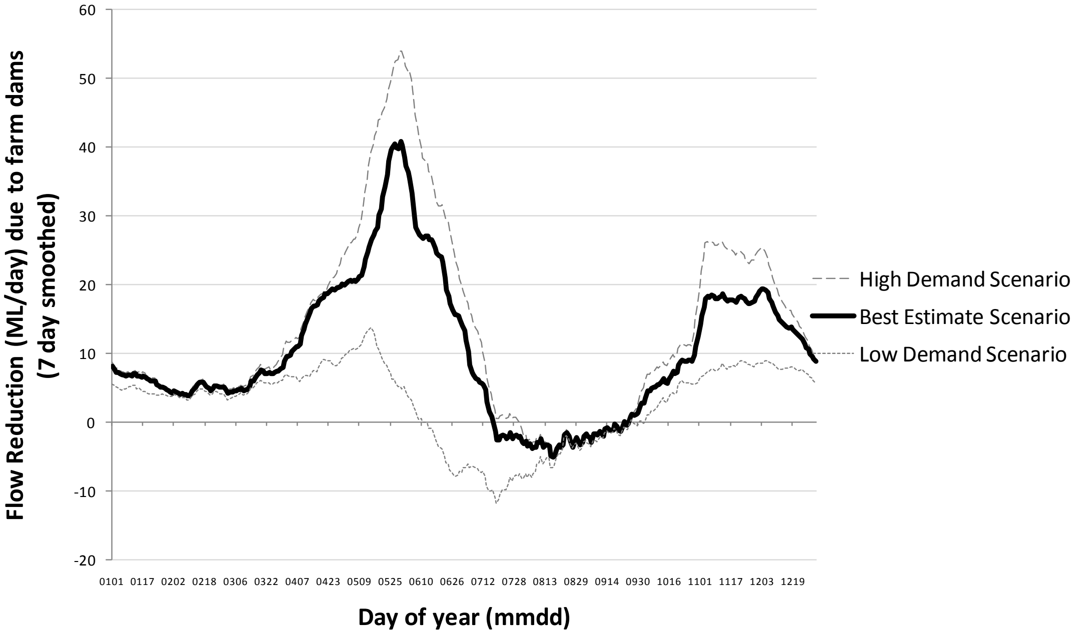


- **Figure 5-3: Average flow in each month (ML per day), with and without dams.**

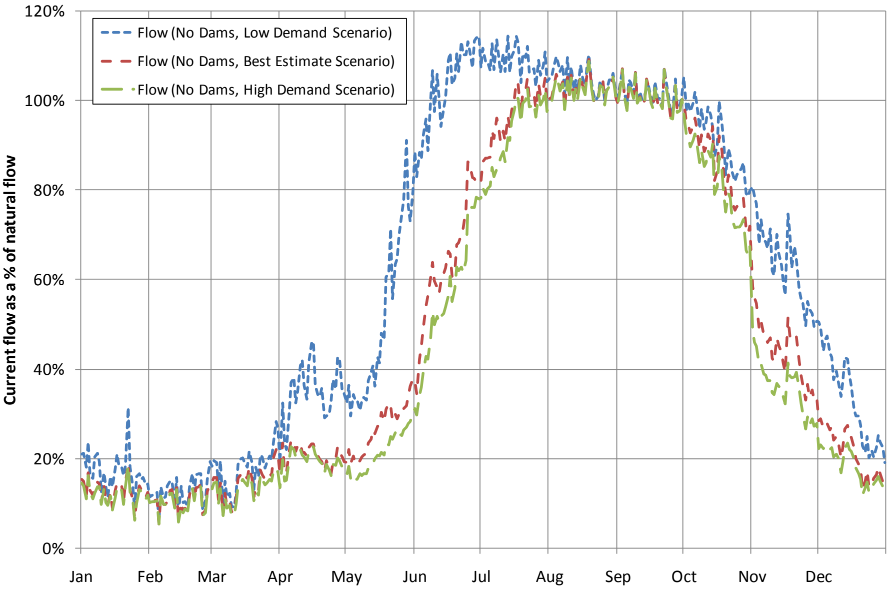
Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\D01_ChannybearupComparison_1,2,3.xlsb

As explained previously for the best estimate scenario, there is considerable variation from year to year in the timing and magnitude of reductions in flow. The average pattern of impacts on streamflow throughout the year for the three scenarios are shown in Figure 5-4. This demonstrates that the low demand scenario tends to produce a peak in farm dam impacts earlier in the year than the other scenarios, and that the high demand scenarios tend to produce farm dam impacts that last longer through the winter season.

Similarly, Figure 5-5 shows the average pattern of flows throughout the year, showing the current observed flow as a percentage of the estimated natural. For all three scenarios, the summer flow is only 20% of the estimated natural flow, suggesting that farm dams are harvesting 80% of summer flow. The actual magnitude of this flow is small, but at this time of year the waterway environment is usually under stress through lack of flow, causing reduction in available habitat, and reducing water quality and water availability for vegetation. Any reduction in flow at this time of year will have significant implications for the waterway environment.



- **Figure 5-4: Day to day variation in flow impacts for the three scenarios (average over the 31-year modelling period).** Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\D01_ChannybearupComparison_1,2,3.xlsb



- **Figure 5-5: Day to day variation in recorded flow for the three scenarios, expressed as % of natural flow.** Source: I:\VWES\Projects\VW04374\Technical\03_ChannybearupModelling\02_CHEAT Modelling\D01_ChannybearupComparison_1,2,3.xlsb

5.4. Low flow spells

Investigating spells for the high and low demand scenarios has shown that the frequency and duration of low flow events below 0.58 ML/d is exactly the same as for the best estimate scenario. The flow exceedance curve shown in Figure 5-2 confirms this result, showing that for flows below approximately 3 ML/d, the three scenarios are identical.

This suggests that during low flow events, the farm dams are having exactly the same effect on flows regardless of demand. In this situation, there are no dams in the catchment at full capacity, and therefore all of the flows in the catchment originating upstream of farm dams are being intercepted.

If the presence of dams in the catchment is affecting low flows in this way regardless of on-farm demands, then limiting on-farm demand will not affect summer low flows. The only options for increasing summer low flows in the catchment is to either:

- reduce the number of dams in the catchment and thereby reduce the proportion of the catchment upstream of the dams, or
- to install low flow bypasses on selected dams. A low flow bypass would allow low flows to divert around the dam and continue downstream, but higher flows would still be harvested by the dam.

6. Conclusion and Recommendations

The Lefroy Brook Catchment has an exceptionally high level of farm dam development, even if compared to states outside Western Australia. Only 2% of catchments in Victoria have a higher farm dam density than the catchment of the Channybearup Gauge (610002).

This study has confirmed that the farm dams in the Lefroy Brook Catchment are significantly affecting Lefroy Brook streamflow at the Channybearup Gauge. Using the "Best Estimate" of demand levels, the following results were obtained:

- Annual flow was reduced by 22%, on average;
- The largest volumetric reductions occur during the months of April, May and June. For example, in April, $\text{Flow}_{\text{Observed}}$ = 4ML/d, but $\text{Flow}_{\text{Simulated Natural}}$ = 20ML/d, on average. In May, $\text{Flow}_{\text{Observed}}$ = 11 ML/d, but $\text{Flow}_{\text{Simulated Natural}}$ = 39ML/d, on average.
- The dams intercepted nearly all (~85%) of summer flows. Sensitivity testing of demand levels indicated that the demand level makes little difference to this result.
- Analysis of spells below 0.58ML/d indicated that, under natural conditions, only 24 days each year would be spent under this threshold, compared to the observed 79 days each year. Typically, spells were nearly twice as long and 50% more frequent due to farm dams. Demand level made no difference to this result.

These last two points indicate that it is the presence of the dams themselves, rather than the demands on the dam, that are causing impacts during summer. The only ways to lessen the effect would be to remove some dams or to install low flow bypasses on some dams. Therefore, further study is recommended to examine strategies for implementation of low flow bypasses, to ensure that the right dams are targeted and the maximum benefit is derived in terms of flow impacts.

7. References

Kirkby, M.J. (1975): “Hydrograph modelling strategies”. In R. Peel, M. Chisholm and P. Haggett (eds) “Process in Physical and Human Geography”, Heinemann; 69-90.

Nathan R, Jordan P, Morden R (2005): “Assessing the Impact of Farm Dams on Streamflows, Part I: Development of Simulation Tools”. *Aust J Water Resour* 9(1), 1-12.

Sinclair Knight Merz (2007): “Impact of Farm Dams in Seven Catchments in Western Australia”. Report prepared for Western Australian Department of Water, November 2007.

Department of Water (2007): “Farm Dam Capture Project – Part 1 – Wilyabrup Brook Catchment – development and case study application”. Internal report prepared for Department of Water (WA) Water Resource Management Division.