Melbourne Water

Estimation of Impact of Farm Dams on Streamflows

Watts River

March 2002

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ESTIMATION OF IMPACTS OF FARM DAMS ON STREAMFLOWS

WATTS RIVER

Melbourne Water

March 2002

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EXECUTIVE SUMMARY

Background

Melbourne Water is required, under the State Environment Policy, to develop Streamflow Management Plans (SFMP) for unregulated catchments, which includes Watts River near Healesville in the Yarra Valley.

The primary objective of a Stream Flow Management Plan is to have agreed and equitable management of take-and-use licences, which considers all demands on the water resource and ensures there are sufficient flows to maintain the long-term environmental health of river systems. To assist in this process, Egis Consulting Australia was engaged by Melbourne Water to undertake a study into the impact of farm dams on streamflow in the Watts River catchment. The consideration of unlicensed diversions harvested by catchment dams in conjunction with licensed diversions provides a sound basis for development of the flow sharing rules required in a SFMP. The term “catchment dams” is used here to denote dams which harvest primarily rainfall runoff but which are not located on a waterway. The use of water from other types of dams (eg. off-stream and on-stream dams) are accounted for in the licensed diversions.

The effect of catchment dams on seasonal streamflow is not well understood, however it is considered that they can potentially have a significant impact. Several regions in Victoria, as well as further afield, are experiencing a rapid increase in high value intensive agricultural developments relying on new dams for their water supply. There is widespread concern over the impacts these new dams could be having on existing water entitlements and environmental flows, particularly in unregulated catchments, but there is little information available to inform catchment and water resource management agencies on how to respond to this trend.

Methodology

A modelling tool has been developed, known as the Tool for Estimating Dam Impacts (TEDI; SKM,2000; Neal et al., 2000; Nathan et al., 2000). This is a water balance simulation model specifically written to determine the impact of catchment dams. The model uses climate conditions (historical records of rainfall and evaporation) and data on known diversions to estimate natural streamflow conditions. In the case of Watts River, the natural streamflow can be calculated as

Natural Streamflow =	Gauged Streamflow
Plus	Licensed Diversions (incl. Melbourne Water urban diversions)
Plus	Farm Dam impact

This process allows the effect of each diversion type to be assessed individually.

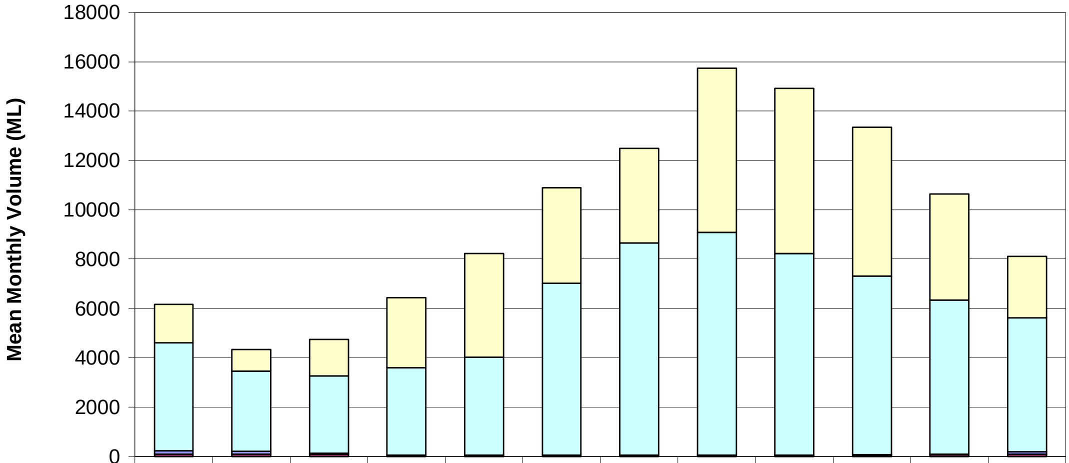
Results and Conclusions

Watts River (Entire Catchment)

Streamflow in the Watts River is affected by catchment dams, and will be further affected by additional catchment dams in future. Currently, approximately 0.7% of natural streamflows are being harvested by catchment dams.

- The current total volume of catchment dams in the Watts River catchment is 368 ML, which represents 0.3% of the natural mean annual flow (116,083 ML).
- The current total volume of licensed diversions is 450 ML, which represents 0.4% of the natural mean annual flow.
- Melbourne Water urban diversions are currently harvesting around 70,000 ML annually, which represents 60% of the natural mean annual flow.
- Current catchment dam development, assuming a dam usage factor of 2, has reduced the mean annual flow by approximately 0.7% (766 ML).
- Assuming a dam usage factor of 2, the current level of catchment dam development has reduced 10 percentile high flows by approximately 0.5% (767 ML/yr), median flows by 0.6% (766 ML/yr), and 90 percentile low flows by 1.0% (764 ML/yr).
- Assuming a dam usage factor of 2, for every 1 ML of additional catchment dam volume, the mean annual flow will reduce by 1.1 ML.
- Dry spells lasting longer, and are occurring earlier in the summer season than they would naturally.

The following chart shows that both catchment dams and licensed diversions within the Watts River catchment have an impact on streamflows throughout the year.



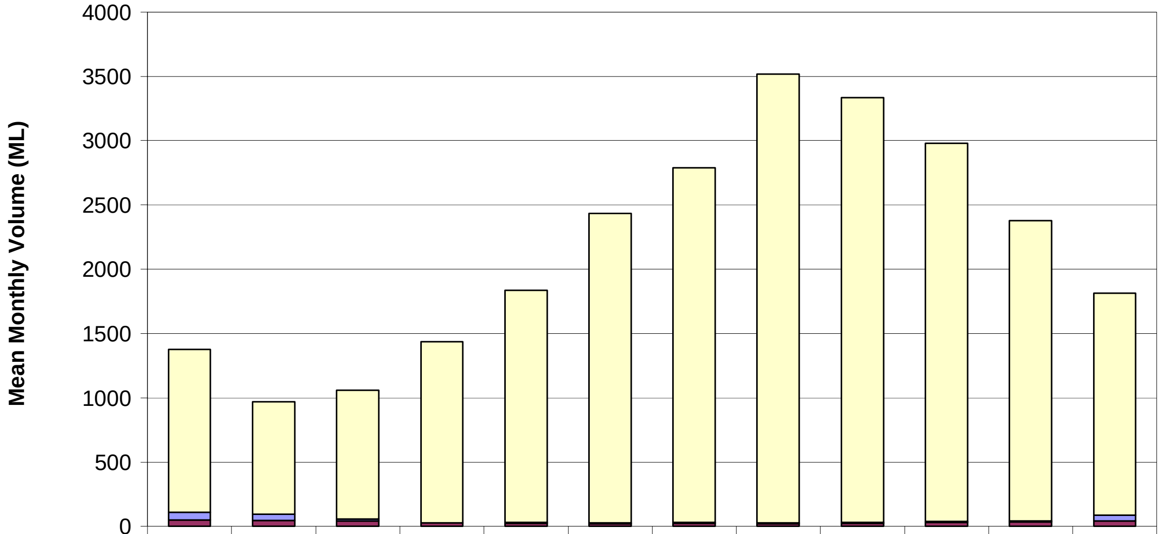
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	1556	865	1474	2835	4193	3886	3823	6659	6711	6014	4311	2500
MWC Diversions	4370	3270	3150	3540	3970	6960	8610	9030	8160	7250	6250	5440
Private Diversions	137	106	35	0	10	9	10	10	9	14	16	94
Catchment Dams	96	93	84	56	48	41	45	42	48	59	70	86

Chum Creek

Streamflow in Chum Creek is affected by catchment dams, and will be further affected by additional catchment dams in future. Currently, approximately 1.5% of natural streamflows are being harvested by catchment dams.

- The current total volume of catchment dams in the Chum Creek catchment is 186 ML, which represents 0.7% of the natural mean annual flow (25,929 ML).
- The current total volume of licensed diversions is 219 ML, which represents 0.8% of the natural mean annual flow.
- Current catchment dam development, assuming a dam usage factor of 2, has reduced the mean annual flow by approximately 1.5% (388 ML).
- Assuming a dam usage factor of 2, the current level of catchment dam development has reduced 10 percentile high flows by approximately 1.2% (388 ML/yr), median flows by 1.5% (388 ML/yr), and 90 percentile low flows by 2.3% (386 ML/yr).
- Assuming a dam usage factor of 2, for every 1 ML of additional catchment dam volume, the mean annual flow will reduce by 1.1 ML.

The following chart shows that both catchment dams and licensed diversions within the Chum Creek catchment have an impact on streamflows throughout the year.



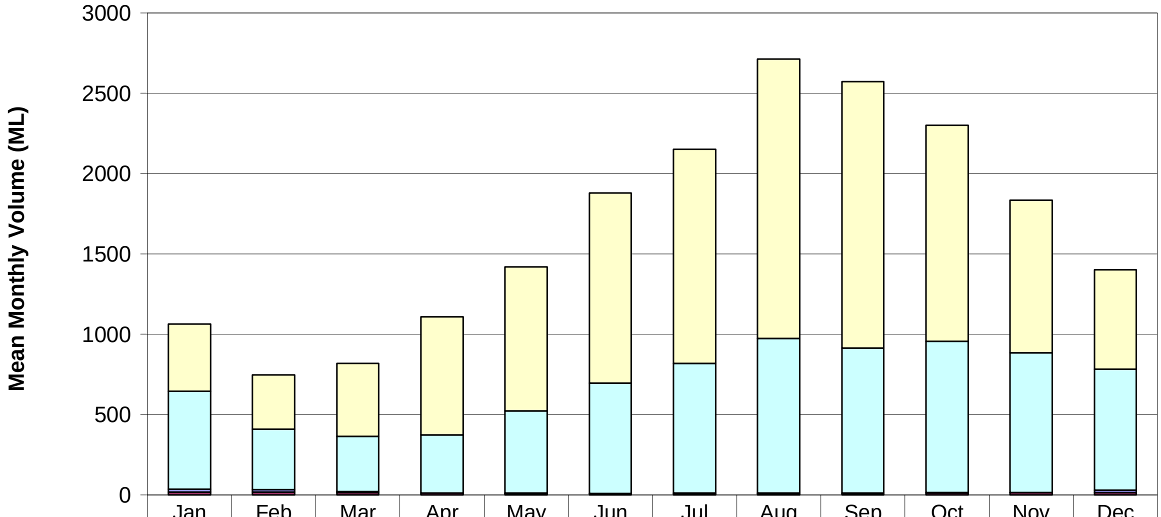
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	1266	874	1001	1408	1805	2406	2759	3487	3303	2940	2336	1728
Private Diversions	61	47	16	0	7	7	7	7	7	9	7	42
Catchment Dams	48	47	43	28	24	21	23	21	24	30	35	43

Grace Burn Creek

Streamflow in Grace Burn Creek is affected by catchment dams, and will be further affected by additional catchment dams in future. Currently, approximately 0.7% of natural streamflows are being harvested by catchment dams.

- The current total volume of catchment dams in the Grace Burn Creek catchment is 69 ML, which represents 0.3% of the natural mean annual flow (20,010 ML).
- The current total volume of licensed diversions is 66 ML, which represents 0.3% of the natural mean annual flow.
- Melbourne Water urban diversions are currently harvesting around 8125 ML annually, which represents 41% of the natural mean annual flow.
- Current catchment dam development, assuming a dam usage factor of 2, has reduced the mean annual flow by approximately 0.7% (143 ML).
- Assuming a dam usage factor of 2, the current level of catchment dam development has reduced 10 percentile high flows by approximately 0.6% (143 ML/yr), median flows by 0.7% (143 ML/yr), and 90 percentile low flows by 1.1% (143 ML/yr).
- Assuming a dam usage factor of 2, for every 1 ML of additional catchment dam volume, the mean annual flow will reduce by 1.1 ML.

The following chart shows that both catchment dams and licensed diversions within the Grace Burn Creek catchment have an impact on streamflows throughout the year.



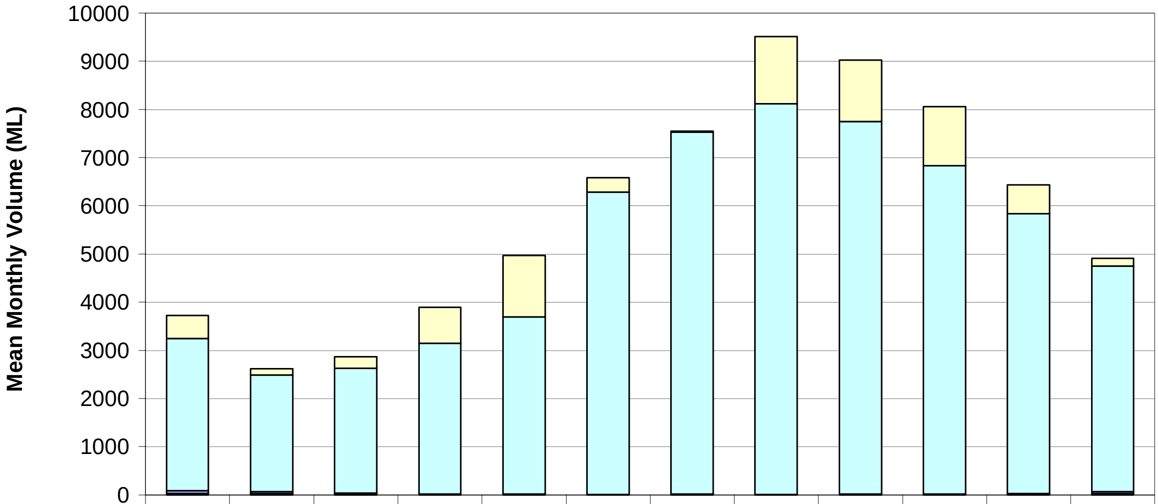
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	419	338	454	737	895	1182	1333	1740	1661	1343	953	617
MWC Diversions	607	378	343	362	511	686	808	963	901	942	867	754
Private Diversions	18	14	5	0	2	2	2	2	2	3	2	12
Catchment Dams	18	17	16	10	9	8	8	8	9	11	13	16

Watts River (Main Stream, excluding Chum and Grace Burn Creeks)

Streamflow in the main branch of the Watts River is affected by catchment dams, and will be further affected by additional catchment dams in future. Currently, approximately 0.3% of natural streamflows are being harvested by catchment dams.

- The current total volume of catchment dams in the Watts River subcatchment is 113 ML, which represents 0.2% of the natural mean annual flow (70,145 ML).
- The current total volume of licensed diversions is 165 ML, which represents 0.2% of the natural mean annual flow.
- Melbourne Water urban diversions are currently harvesting around 61,875 ML annually, which represents 88% of the natural mean annual flow.
- Current catchment dam development, assuming a dam usage factor of 2, has reduced the mean annual flow by approximately 0.3% (235 ML).
- Assuming a dam usage factor of 2, the current level of catchment dam development has reduced 10 percentile high flows by approximately 0.3% (235 ML/yr), median flows by 0.3% (235 ML/yr), and 90 percentile low flows by 0.5% (235 ML/yr).
- Assuming a dam usage factor of 2, for every 1 ML of additional catchment dam volume, the mean annual flow will reduce by 1.1 ML.

The following chart shows that both catchment dams and licensed diversions within the Watts River subcatchment have an impact on streamflows throughout the year.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	480	133	233	744	1277	303	13	1392	1271	1233	601	163
MWC Diversions	3156	2413	2593	3125	3675	6268	7518	8106	7735	6806	5804	4678
Private Diversions	57	44	15	0.3	0.3	0.3	0.3	0.3	0.3	1.9	6.8	39
Catchment Dams	29	28	26	17	15	12	14	13	15	18	22	26

1. INTRODUCTION

1.1 CATCHMENT DESCRIPTION

The Watts River rises to the east of Healesville in the Yarra Ranges. The stream flows north west for approximately 15 km, then turns south west, flowing through Maroondah reservoir and Healesville township. Watts River joins the Yarra River approximately 3 km downstream of Healesville, near Tarrawarra.

The total catchment area of the Watts River is approximately 222 km^2. The main tributaries include Chum Creek, Myers Creek, and Donnellys Creek to the north of the catchment, and Grace Burn Creek to the south. These four tributaries combined contribute approximately 49% of the total catchment area.

The climate is typically cool and wet in the catchment, with an average annual rainfall of over 1600 mm at Black Spur, and over 1100 mm at Maroondah reservoir. The current mean annual streamflow at the catchment outlet is approximately 116,000 ML.

Much of the upstream parts of the catchment are heavily forested, with logging occurring in some areas. Along Chum and Myers Creeks, there are areas of cleared land, used predominantly for vegetable crops and cattle grazing. The lower reaches of Grace Burn Creek have been extensively cleared for agriculture and urban development, with vegetable crops, viticulture and cattle grazing occurring in the area. Some irrigation of recreational facilities occurs near Healesville, including several ovals on Grace Burn Creek, and the Healesville Racecourse on Watts River.

As with the rest of the Yarra Valley, an increasing number of properties in the Watts River catchment are being used for irrigation intensive crops, such as viticulture and vegetables. This is expected to produce an increase in farm dam development and an increase in the total water demand for the catchment as a whole.

Maroondah reservoir is a major urban water storage operated by Melbourne Water. With a full capacity of 22,000 ML, the reservoir is currently drawing an average of 70,000 ML of water per year from the Watts River. Diversions are in place on Grace Burn Creek and Corranderk Creek, which divert water from these streams to Maroondah reservoir. In the past, these diversions have also been used to divert water to Silvan reservoir. Note that Corranderk Creek is outside the Watts River catchment.

1.2 PURPOSE OF THE STUDY

The SEPP Waters of Victoria, Schedule F7 Waters of the Yarra Catchment requires that Stream Flow Management Plans (SFMP's) be developed for all tributaries in the Yarra Basin where there are greater than 100 ML of diversion licenses. The SFMP's include rules governing the sharing of water and water harvesting within the catchment.

Although the effect of farm dams upon catchment streamflows is difficult to quantify, it is clear that extensive farm dam development will have a significant impact on streamflows. As described above, the Watts River catchment has significant farm dam development, especially large dams for orchards, vegetable crops, and tree plantations. There is some concern that excessive development of dams within the catchment could substantially affect existing water entitlements and environmental flows.

Egis Consulting Australia (Egis) has been engaged by Melbourne Water to study the effect of existing and future farm dam development on streamflows within the Watts River catchment. The results of this study will assist the SFMP working group in making sound decisions for sustainable water use in the catchment.

1.3 TERMINOLOGY

Catchment Dam

A dam which predominantly harvests water from rainfall runoff events from other than a defined waterway in accordance with the Water Act.

On-Stream and Off-stream Storage

A dam which predominantly harvests water from a defined waterway.

The filling of off-stream or on-stream dams from a defined waterway requires a diversion licence. Diversion licences are issued in accordance with the Water Act 1989 and allow the taking and use of water under specific conditions. Typically, the filling of on-stream and off-stream storages is licensed to occur during the months of May to October inclusive, with a requirement that all flows outside of this period are passed.

Direct Licence

A licence to draw water from a waterway at any time of year for immediate use.

Direct licences have an upper limiting volume which the licensee is allowed to draw. Stock, domestic, commercial, and industrial licenses generally draw water on a constant basis throughout the year, whereas irrigation licenses tend to draw most water during summer months. These seasonal demands are reflected in the monthly demand patterns in Section 3.3.2.

Winterfill Licence

A licence to draw water from a waterway during the months May to October, usually to store in an on or off stream storage for later use.

Winterfill licenses have an upper limiting volume which the licensee is allowed to draw, typically the full volume of the storage dam. An on stream storage is usually required to pass all flows outside of the licence period.

Natural Flow

The flow that would occur in the catchment if no catchment dams, licensed diversions, or licensed discharges were present. For the purposes of this study, the natural flow assumes the current catchment conditions apply, including land uses, urban development levels, and impervious areas (roads, roofs, paved areas).

Note that natural flow, within this report, **does not** refer to pre-European flow conditions.

2. MODELLING APPROACH

2.1 TEDI

The central tool used in the study of farm dams in the Watts River catchment was TEDI (Tool for Estimating Dam Impacts). This computer based model was developed by Sinclair Knight Merz for the Murray Darling Basin Commission with the specific intention of modelling the impacts of catchment dams.

The TEDI model is able to simulate catchment dam development levels and provide details of:

- the effect of the existing level of catchment dam development on streamflows within the catchment (including an estimate of the 'natural' streamflow);
- the effect of future catchment dam development on streamflows within the catchment.

The TEDI model is essentially a water balance, using a monthly timestep. Each month, all of the various inputs and outputs to the system are calculated. Inputs include rainfall and runoff, and spillage from full dams. Outputs include evaporation, water usage for stock, domestic use, irrigation, and streamflow leaving the catchment. The difference between the total inputs and total outputs is equal to the change in dam storage during that month.

Calculating the Effect of Existing Dams

In order to determine the effect of existing catchment dams, the model firstly assumes that the existing level of dam development is doubled. That is, the existing level of development is added to the existing streamflow to determine its effect. This effect is then subtracted from the existing streamflow to provide the natural streamflow.

For example, let us assume that a catchment has 50 farm dams, and streamflows are typically about 100 ML per month. If development is doubled to 100 farm dams, the model may find that streamflow is reduced by around 20 ML per month.

It is logical to assume that if the extra 50 dams reduced flow by 20 ML per month, then the first 50 dams would also reduce flows by 20 ML per month. Thus, the 'natural' streamflow (without any dams) is around 120 ML per month.

Calculating the Effect of Future Dams

In order to determine the effect of future development, the model recalculates the streamflow many times, each time with a few more dams. In this way, the progressive impact of dams upon the catchment streamflow can be seen.

2.2 DATA REQUIRED FOR TEDI

The TEDI model requires a range of data before it can accurately model the catchment. The data can be broadly categorised as Catchment Data, Demand Data, Storage Data, and Climate Data, and is summarised below.

Catchment Data

- **A time series of streamflows from the catchment.** The streamflows must be stationary so that there is no observable trend in the data.
- **Total catchment area.**
- **Catchment area corresponding to a 5 ML and 100 ML dam.** Typically, larger dams have a larger catchment area than smaller dams, because they need to collect more runoff to fill up. TEDI simplifies modelling by assuming a linear relationship between dam volume and catchment area, defined by the catchment areas of a 5 ML and a 100 ML dam.
- **Total volume of existing catchment dams.**
- **Total volume of potential future catchment dams.**
- **Number of additional catchment dams to be modelled at a time.** TEDI models future dam development by adding a few dams at a time and calculating the streamflow.

Demand Data

- **Volume threshold between larger irrigation dams and smaller stock / domestic dams.** Typically, irrigation dams tend to be larger to accommodate the volumes of water required for intensive irrigation. Stock and domestic dams are usually smaller. TEDI requires that a volume threshold be set, above which all dams are assumed to be for irrigation.

- **Average monthly pattern of irrigation water demands.** Irrigation dams usually have seasonal variation in water demands, which need to be specified. Stock and domestic dams are assumed to have constant demand throughout the year.

- **Volume of water used as a proportion of dam volume.** Some dams may be used frequently, and the water constantly replenished, whereas other dams may not be used at all. This proportion is the average usage factor for all catchment dams.

Storage Data

- **The distribution of existing and future catchment dam volumes.** Dams come in a range of volumes, and this range needs to be specified. This is done using average volumes and the proportion of dams which are near that average volume.

- **Parameters for relating dam surface area and volume.** TEDI calculates the surface area of dams (A) from the volume (V) using a relationship of the form $A = aV^b$. The values of a and b need to be specified.

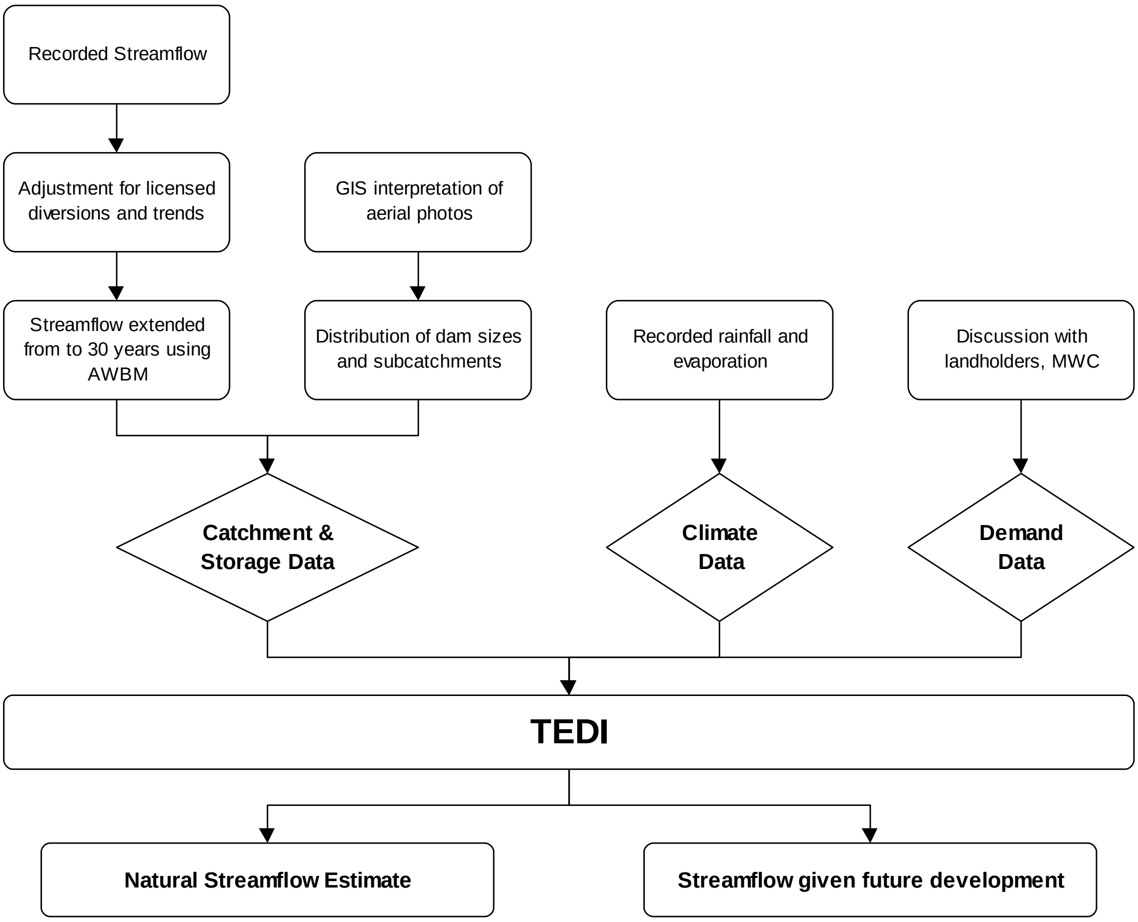
Climate Data

- **Average monthly rainfall and evaporation.**

2.3 MODELLING METHODOLOGY

The methodology used to analyse and model the Watts River catchment is shown in Figure 2.1 below.

Figure 2.1 – Schematic Of Modelling Methodology



A streamflow gauge exists on Watts River, at the Healesville - Kinglake Rd bridge. However, this gauge only records flow remaining after the urban water diversions for Melbourne Water. Therefore, the effects of Melbourne Water urban diversions and private diversions had to be taken into account. The effects of Melbourne Water urban diversions was calculated using information on the Grace Burn Creek diversion, Watts River streamflow into Maroondah reservoir, and the spill from the reservoir.

Details of the existing catchment dams were obtained by interpreting aerial photos of the catchment to determine the distribution of dam sizes, the number of existing dams, and typical catchment areas for dams.

Details of private licensed diversions within the catchment were provided by Melbourne Water. This allowed the licensed storages to be identified, and removed from all further analysis.

The aerial photos were also used to determine areas within the catchment where irrigation takes place, such as vineyards, orchards, and vegetable crops. Dams which were present in these areas were assumed to be used for irrigation, thus enabling an estimate of the typical volumes of irrigation dams and stock / domestic dams.

Rainfall and evaporation data was obtained from the Bureau of Meteorology.

All of this information was entered into the TEDI model. The model results included a natural streamflow estimate, and estimates of flow given the level of future dam development. These monthly flow series are shown in Appendix A.

Because only one streamflow record could be estimated at the outlet of the catchment, only one analysis was carried out for the entire catchment. All input data was collected for the catchment as a whole.

Also, a dry spell analysis of the existing streamflow record and the stationary streamflow record was undertaken. This provided estimates of the likely length and frequency of dry spells within the catchment.

3. MODEL INPUTS

All of the inputs the TEDI model requires to simulate catchment dams and streamflows are listed in Section 2.2. The derivation of these inputs is described in the following sections.

3.1 STREAMFLOW DATA

There are some general requirements for the streamflow data:

- Melbourne Water require the analysis to cover 30 years of streamflow. If the recorded data for the catchment is not long enough, it must be synthetically extended.
- The TEDI model requires that the streamflow series contains no significant long term trends. This requirement can be checked using statistical methods.
- Also, the TEDI model requires that the level of catchment dam development present in the streamflow record does not change. This level of development must be explicitly entered into the model.

For these reasons, the recorded data available for the catchment is not appropriate for direct use in the model. It is necessary to adjust the recorded data to account for the above factors before it can be used.

The adjustment process involves the following steps:

1. Compile a streamflow series representing flows at the catchment outlet;
2. Adjustment of flows for licensed diversions;
3. Analysis and removal of long term trends within the data;
4. Extend the data to 30 years record length (1970 to 2000).

These steps, as applied to the Watts River catchment, are described below.

3.1.1 Recorded Streamflow Data

The only streamflow gauge within the catchment is **229144 Watts River at Kinglake Rd**.

This gauge is located near the outlet of the stream, with the catchment area downstream of the gauge representing only 2% of the total catchment area. Most of this downstream area consists of floodplain, and therefore the contribution of this area to the overall streamflows is not likely to be significant. Thus, it has been assumed, for the purposes of this study, that the streamflow recorded at this gauge is representative of streamflow for the catchment outlet.

Also, the gauge is located far enough from the outlet that it is unlikely to be significantly affected by flooding in the Yarra River floodplain.

Daily streamflow data for this gauge was available from April 1987 through to June 1998. An informal inspection of the data was undertaken, and it was found to be acceptable, with only minor gaps and inconsistencies evident. These were not considered significant, as they were fairly short.

However, it was found that the gauge does not provide accurate flow estimates during low flow conditions. Periods of low flow usually coincided with high harvest volumes from the Melbourne Water urban diversions, so the poor gauge readings only accounted a small proportion of the total catchment flow at these times.

3.1.2 Adjustment of Flows for Melbourne Water Urban Diversions

The system of Melbourne Water urban diversions within the catchment make the accurate estimation of catchment runoff difficult.

The schematic in Figure 3.1 shows how these diversions generally operate.

The streamflow gauge does not measure the real catchment runoff. What it actually measures can be given as:

Gauge Flows = Chum Ck Flows + Grace Burn Flows (after diversion) + reservoir spill

If there were no Melbourne Water urban diversions, the gauge would be measuring **real flows** as follows:

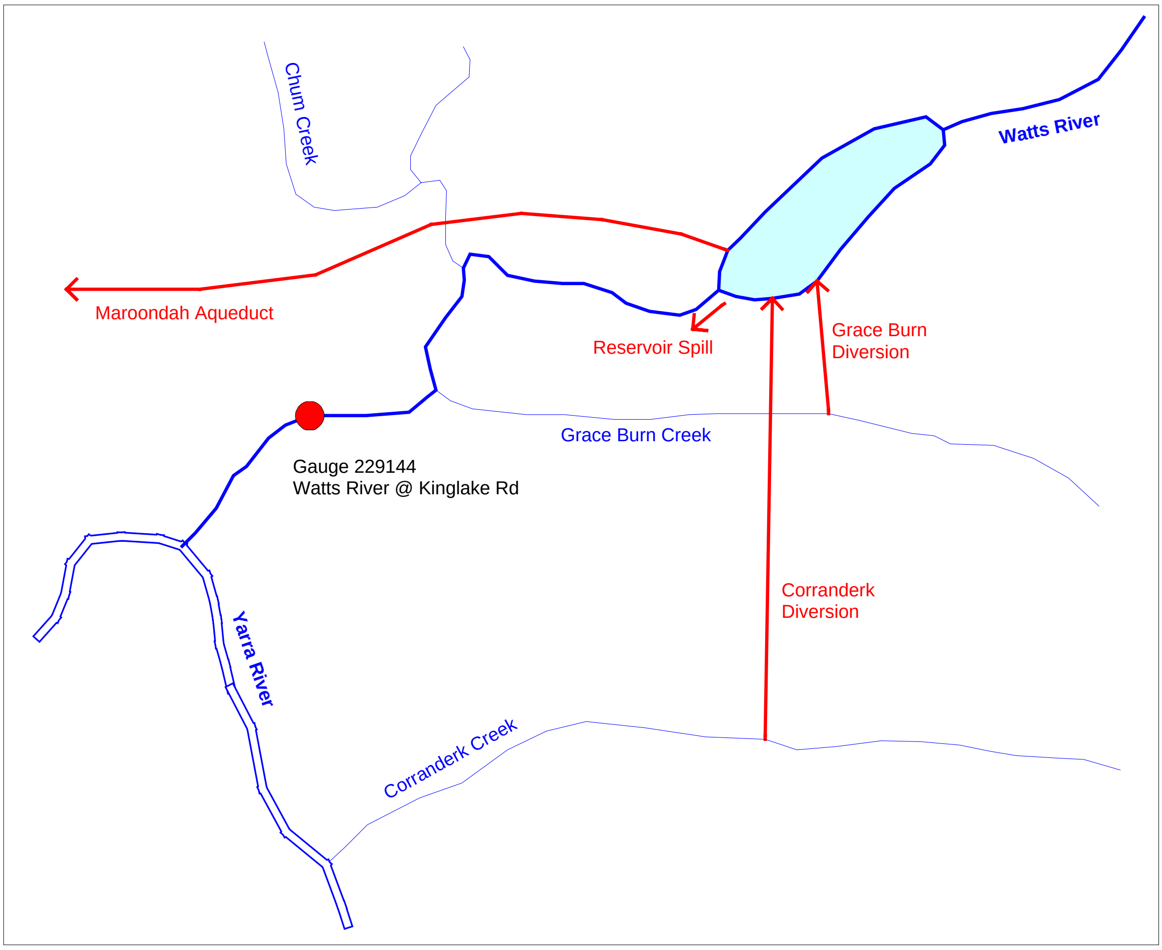
Real Flows = Chum Ck Flows + Grace Burn Flows (all) + Watts River Flows (into reservoir)

Combining these two relationships, we find that:

Real flows = Gauge Flows + Grace Burn Diversion + Watts River Flows (into reservoir) - reservoir spill

Although this relationship is only an approximation, it does take into account all runoff produced downstream of the reservoir and Grace Burn diversion.

Figure 3.1 - Schematic Layout of MW Urban Diversions



Historical flow information on Watts River above the reservoir, reservoir spill, and Grace Burn diversions was provided by Melbourne Water.

3.1.3 Adjustment of Flows for Private Licensed Diversions

For all of the 30 year period, licensed diversions were removing water from the streams in the catchment. This effect was taken into account by calculating how much water had been removed each day, and adding that back into the streamflow.

The usage rates for each licence were calculated by assuming that each licence used its maximum permitted volume annually from the year the licence was first issued. This is due to the fact that no diverter usage survey had been undertaken at the time of this study.

Winterfill Licences

> The daily volume for these licences was modelled as a regular daily volume extracted over the winter season, from May to October. The sum of these daily extractions was the total annual winterfill licence volume.

Direct Licenses

> The daily volume of these licenses was modelled as a regular daily volume, varying each month. The sum of these daily extractions was the total annual direct licence volume. The monthly usage pattern was assumed to be the same as the monthly irrigation pattern given in Section 3.3.2, with irrigation licenses varying monthly, and stock / domestic, commercial, and industrial licenses remaining constant throughout the year.

3.1.4 Adjustment of Flows for Long Term Trends

A statistical analysis shows that the data contains no statistically significant long term trend. Details of the statistical analysis are given in the remainder of this section.

A statistical trend analysis of the streamflow data was undertaken to check for any long term trends in the data. Such trends may be caused by gradual changes in land use or agricultural practices within the catchment, or by changes in the level of farm dam development.

The analysis was performed by creating a statistical model of the streamflow, based on a number of factors including rainfall, season, and the number of months since the start of the record. If the model was found to change over time, the degree of change could be statistically tested to determine if it was significant.

The statistical model was of the form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_n x_n$$

where y = dependent variable
x_n = independent variables
β_n = calibrated coefficients

For this analysis, the model was created on a monthly timestep. This was to ensure that daily variations in flow and lag effects between rainfall and flow were insignificant.

The dependent variable was streamflow (ML/month), and the independent variables were rainfall (mm/month), months since the start of the record, season, and the streamflow for the previous month. The season was modelled sinusoidally throughout each year, so that the regular seasonal variation present in the recorded data could be accurately measured.

Thus, the model used to simulate streamflows was:

$$Q = \beta_0 + \beta_1 t + \beta_2 R + \beta_3 \sin\left(\frac{2\pi i}{12}\right) + \beta_4 \cos\left(\frac{2\pi i}{12}\right) + \beta_5 Q_{t-1}$$

where Q = streamflow (ML/month)
t = months since start of record
Q_{t-1} = streamflow for the previous month
R = rainfall (mm/month)
i = month of the year
β_n = calibrated coefficients

The streamflow for the previous month was included because the data is serially correlated, with each streamflow value affecting the streamflow in the next month.

This model was calibrated using the method of least squares. The graph shown in Figure 3.2 below shows the actual flows with the modelled flows. The line through the centre is the long term trend, given by the β_1**t** term in the above equation.

Figure 3.2 – Modelled Flows, Actual Flows, and Long Term Trend

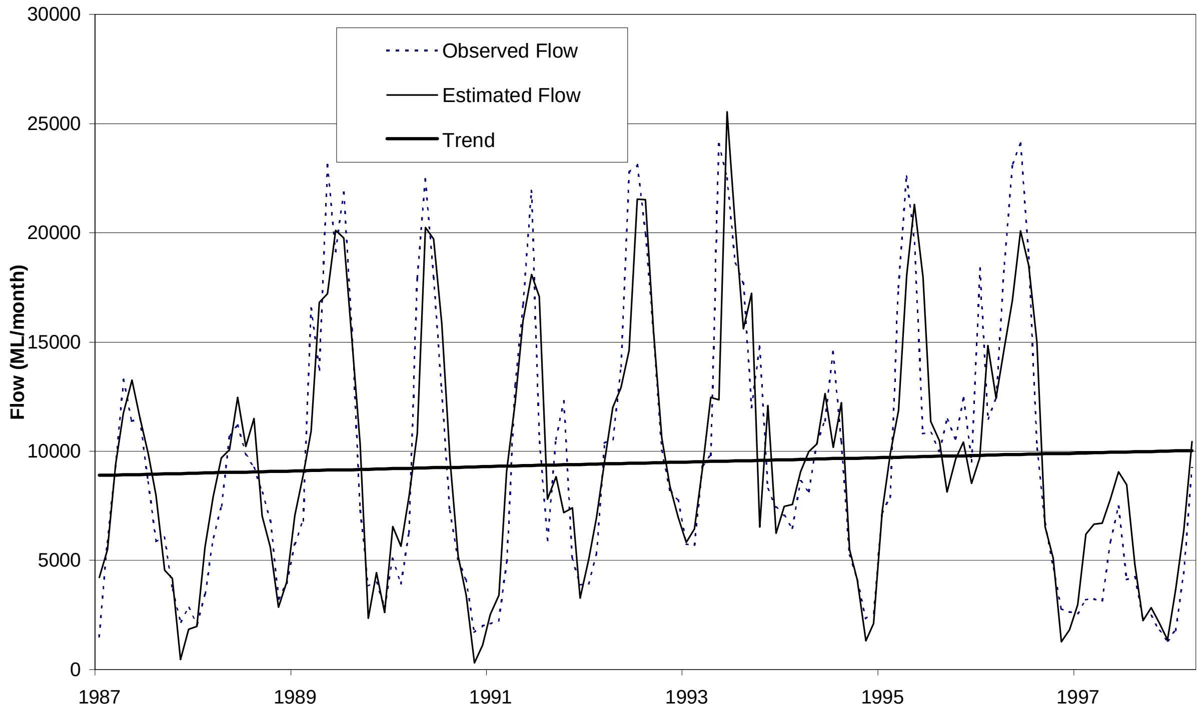


Table 3.1 – Calibrated Coefficients

Independent Variable	Coefficient	Coefficient Value
	β_0	-585
t	β_1	8.5
R	β_2	31
sin(2πi/12)	β_3	-1599
cos(2πi/12)	β_4	-2039
Q_{t-1}	β_5	0.66

Using Table 3.1, the long term trend in the data can be calculated. Over the period of record, the month parameter **t** reaches a maximum of 134 months. Therefore, the long term trend over 11 years is an increase in the average monthly flow of 1139 ML, or about 13%.

A statistical analysis shows that the long term trend apparent in the data is not statistically significant. A p-test on the β_1 parameter gave a p value of 0.1. This indicates that, assuming the streamflow data contains no long term trend, then the chances of obtaining a value for β_1 of 8.5 or more is about 1 in 10. Generally, a statistic is significant only if the p value is 0.05 or less.

Because the trend is not statistically significant, no further trend analysis is required.

3.1.5 Extending the Length of Flow Record to 30 Years

The estimated streamflow data for the Watts River catchment outlet covers the period from April 1987 to June 1998, only 11 years. Melbourne Water requires that the model be run over 30 years so that the results of the TEDI model could be more representative of long term average conditions. Therefore, the streamflow data had to be artificially extended to cover the 30 year period starting from January 1970.

Extending the streamflow record was done using the Australian Water Balance Model (AWBM). This computer based modelling package is able to model daily runoff from a catchment by applying rainfall and evaporation to a series of three hypothetical storages covering the entire catchment. When a storage overflows, direct runoff is produced. Some of this direct runoff enters the main waterway and becomes streamflow (wet weather surges), the rest empties into groundwater stores, which slowly releases the water to the stream as baseflow (dry weather flows). In a small catchment such as Olinda Creek, the results can be very accurate.

The parameters used for the AWBM models are defined below. The actual values of parameters used for each catchment are shown in Table 3.2.

- Each hypothetical storage is defined in terms of its depth '**d**' (mm), and the proportion of the catchment that it covers '**a**'.
- When a storage overflows, the proportion of the overflow which becomes groundwater is '**B**'.
- The rate at which groundwater is fed into streams depends on the baseflow recession constant 'K_b'.
- The length of time required for water in a stream to reach the catchment outlet depends on the surface recession constant 'K_s'.

Table 3.2 – AWBM Parameters Used

Storage 1		Storage 2		Storage 3		B	Kb	Ks
a	d	a	d	a	d			
0. 4	0	0.1	10	0.5	130	0.4	0.4	0.97

3.1.6 Final Input into TEDI

The streamflow series, having been adjusted for Melbourne Water urban diversions, private licensed diversions, and found to contain no long term trends, was converted to a monthly series for use in the TEDI model.

3.2 CATCHMENT DATA

3.2.1 Streamflows

The derivation of a stationary, 30 year streamflow series for the Watts River is discussed in Section 3.1.

3.2.2 Total Catchment Areas

The catchment boundaries were determined from interpretation of 10 metre topographic contours. The resulting catchment areas are as follows:

Watts River (downstream of streamflow gauge)	4.8 km^2
Watts River (upstream of streamflow gauge)	129.1 km^2
Grace Burn Creek	38.2 km^2
Chum and Myers Creeks	49.5 km^2
TOTAL	**221.8 km^2**

A map of the Watts River catchment is shown in Appendix B.

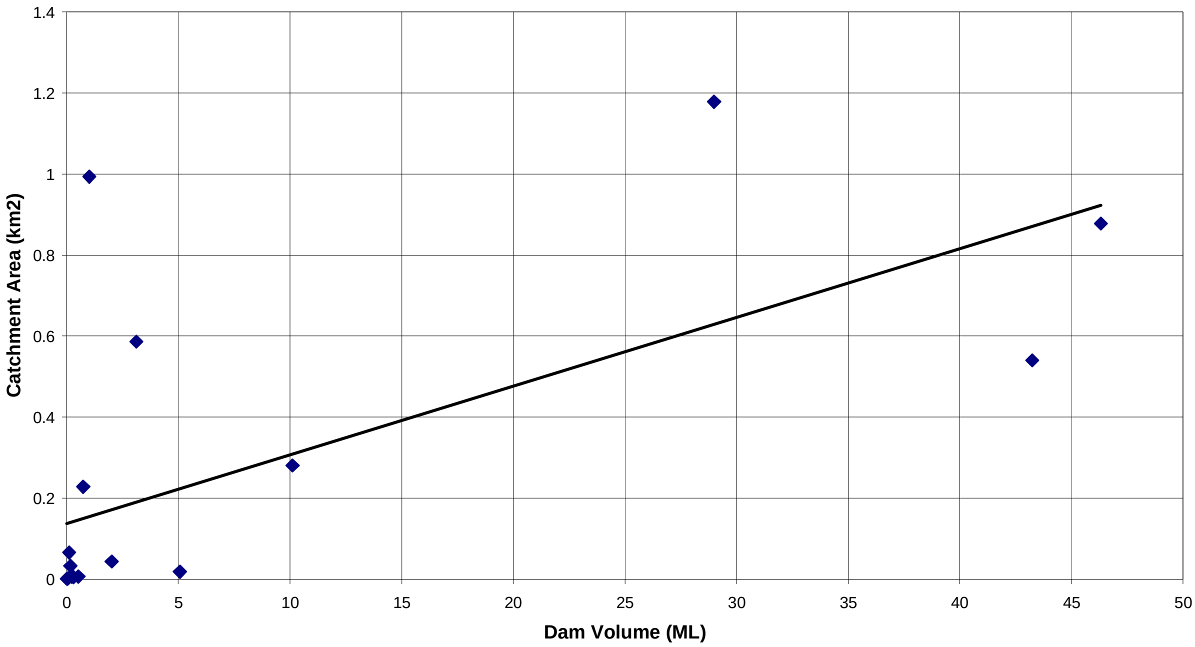
3.2.3 Subcatchment Areas for a 5 ML and 100 ML Dam

The TEDI model assumes a linear relationship between the volume of a dam and its catchment area. This relationship is defined using the catchment areas for both a 5 ML dam and a 100 ML dam.

In order to determine this relationship, the catchment areas of 18 randomly selected dams were calculated. The dam volumes and catchment areas were plotted, and a line of best fit was selected. From this line, the 5 ML and 100 ML catchment areas were determined to be 0.22 km^2 and 1.84 km^2 respectively.

Figure 3.3 shows the relationship between catchment areas and dam volumes.

Figure 3.3 – Catchment Area vs Dam Volume



3.2.4 Total Volume of Existing Catchment Dams

The total volume of existing unlicensed catchment dams within the Watts River catchment was found to be 368 ML. This volume was determined by:

- defining dam surface areas using aerial photography;
- ignoring all dams identified as being licensed; then
- calculating volumes for each dam using the relationships in Section 3.4.2.

It should be noted that, due to heavy forest in some parts of the catchment, smaller dams in these areas may not be visible in aerial photographs and therefore have not been counted.

Also, the available aerial photography did not cover the entire catchment, as shown in Appendix B. As a result, dams outside of the photographic coverage were not counted. However, the areas not covered are predominantly state forest, where few dams are expected.

The volumes within each catchment are as follows:

Watts River (downstream of streamflow gauge)	16 ML
Watts River (upstream of streamflow gauge)	97 ML
Grace Burn Creek	69 ML
Chum and Myers Creeks	186 ML
TOTAL	**368 ML**

It should be noted that the above volumes do not include the Maroondah reservoir, because the effect of this reservoir has been taken into account during the streamflow analysis.

Dams downstream of the streamflow gauge were included in the analysis, as described in Section 3.1.

3.2.5 Total Volume Of Potential Future Catchment Dams

After discussion with Melbourne Water, it was decided that the assumed volume of potential future dams should be the volume of recent dams only. This includes all dams which have been proposed or constructed since the aerial photographs were taken, from February 2000 to December 2001. This is due to a lack of information available to estimate future dam development within the catchment.

3.2.6 Number Of Additional Dams To Be Modelled At A Time

Additional dams were modelled one at a time.

3.3 DEMAND DATA

3.3.1 Volume Threshold Between Irrigation and Stock/Domestic Dams

Because irrigation requires substantially more water than other less intensive agricultural practices eg. stock and domestic use, the dams required to hold the water are larger. The TEDI model requires that a threshold volume be set, above which all dams are assumed to be for irrigation purposes, and **use monthly irrigation demand patterns**. Below this threshold, all dams are assumed to be for stock or domestic purposes, **with constant demand throughout the year**.

In order to determine this threshold, aerial photographs were examined to define areas within the catchments where irrigation is occurring, including orchards, viticulture, tree plantations, and vegetable crops. These areas are shown in Appendix B.

Once the irrigation areas were identified, it was assumed that all unlicensed dams inside these areas (identified using aerial photography) were used for irrigation, and all unlicensed dams outside were used for stock or domestic purposes. A comparison was then made between the volumes of these irrigation dams and stock/domestic dams.

- The total volume of all irrigation dams in the catchment is 113 ML (31%).
- The total volume of all stock dams in the catchment is 255 ML (69%).

The most appropriate threshold for stock/domestic and irrigation dams is one which maintains the above total volumes in the catchments. This is so that the correct volume of water is apportioned to the correct usage pattern in the model**. In this case, the threshold is 32 ML.**

This threshold is not intended to be a literal description of dams within the catchment. The true relationship between the size of a dam and its usage is complex, but TEDI simplifies this relationship by assuming an arbitrary threshold.

3.3.2 Monthly Irrigation Demands

The TEDI model assumes that all dams larger than a specified level are used for irrigation. Irrigation is typically seasonal, thus water usage rates are modelled with a set of average monthly demand factors.

All smaller dams are assumed to be used for stock or domestic purposes, and are modelled using a constant demand throughout the year.

The monthly demand pattern adopted for the Watts River catchment was based on the pattern used for a previous study for Hoddles Creek. The Hoddles Creek catchment is immediately to the west of Watts River, with similar climate and similar irrigation types including vegetables and viticulture.

Table 3.3 – Monthly Demand Patterns for Irrigation and Stock/Domestic Dams

Pattern	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irrigation	35%	27%	9%	0	0	0	0	0	0	1%	4%	24%
Stock/domestic	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%

3.3.3 Proportion of Dam Volume Used

Usage of dams varies, with annual usage of some irrigation dams totalling several times the dam's capacities. Usage of some irrigation dams may be much lower, with only a small proportion of each dam being used annually.

After discussion with Melbourne Water staff, it was decided that a factor of 2 would be appropriate. That is, the annual usage of each irrigation dam is typically 2 times its capacity. However, to cater for some uncertainty in this factor, the difference in results if the usage factor was set to 1 has also been investigated.

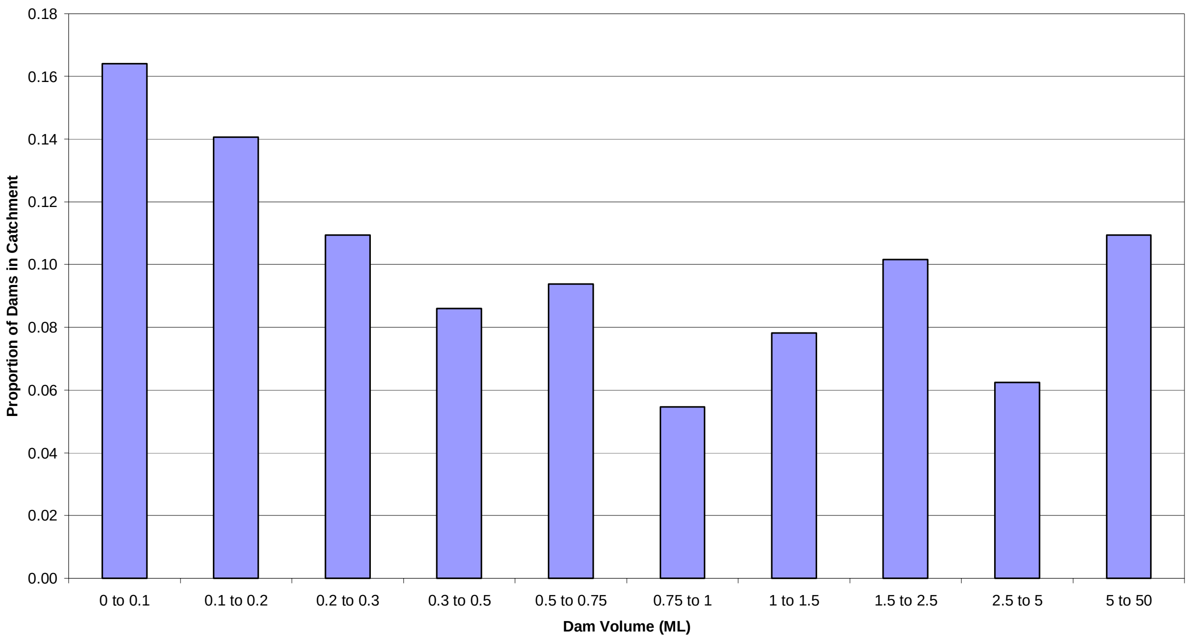
This factor applies only to irrigation dams. Stock / domestic dams always have a dam usage factor of 1.

3.4 STORAGE DATA

3.4.1 Distribution of Dam Volumes

The volume of all catchment dams in all catchments was calculated using the volume surface area relationship described in Section 3.4.2. The distribution of the dam volumes is shown below in Figure 3.4.

Figure 3.4 – Distribution of Catchment Dam Volumes



The average volume within each of these groups was calculated, and entered into TEDI with the corresponding proportion. These values are detailed in Table 3.4 below.

Table 3.4 – Distribution of Existing Catchment Dam Volumes

Volume Range (ML)	0 to 0.1	0.1 to 0.2	0.2 to 0.3	0.3 to 0.5	0.5 to 0.75	0.75 to 1	1 to 1.5	1.5 to 2.5	2.5 to 5	5 to 50
Proportion of Total	16.4%	14.1%	10.9%	8.6%	9.4%	5.5%	7.8%	10.2%	6.3%	10.9%
Average Volume (ML)	0.06	0.15	0.25	0.40	0.61	0.89	1.2	2.0	3.9	19.5

The distribution of sizes of additional farm dams has been assumed to be the same as that for existing dams. Although planning approval information indicates that currently planned dams are typically much larger than most existing dams, the Shire of Yarra Ranges only requires that planning approval is sought for dams larger than 3 ML capacity. Of the existing catchment dams, more than 80% are smaller than 3 ML. Therefore, the information will be biased toward large dams, making the data non-representative.

3.4.2 Dam Surface Area – Volume Relationship

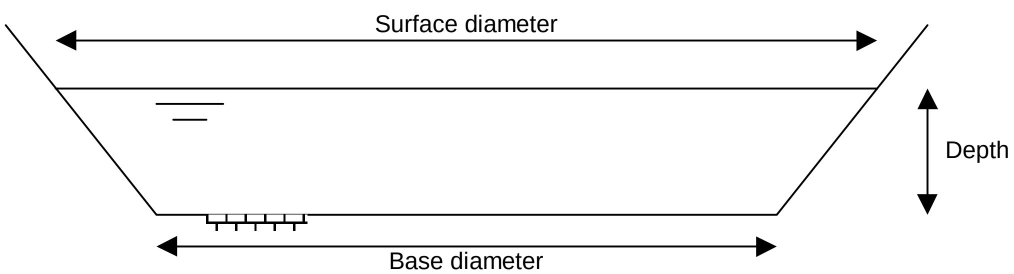
The relationship between the full surface area of a dam and its volume is complex. TEDI simplifies this by assuming a relation of the form

$$A = aV^b$$

where a and b are constants. Good and McMurray (1997) derived a relationship of this form where a = 1294 and b = 0.714.

The Good and McMurray relationship was compared with the geometrically calculated volume of a dam. The dam geometry was based on a round dam with a trapezoidal cross section. The ratio of the base diameter to the surface diameter was varied between 0.6 and 1.0, and the depth was varied from 1.5 m for a small dam to 3.5 m for a very large dam. This is shown in Figure 3.5 below.

Figure 3.5 – Basis of Geometric Volume Calculations



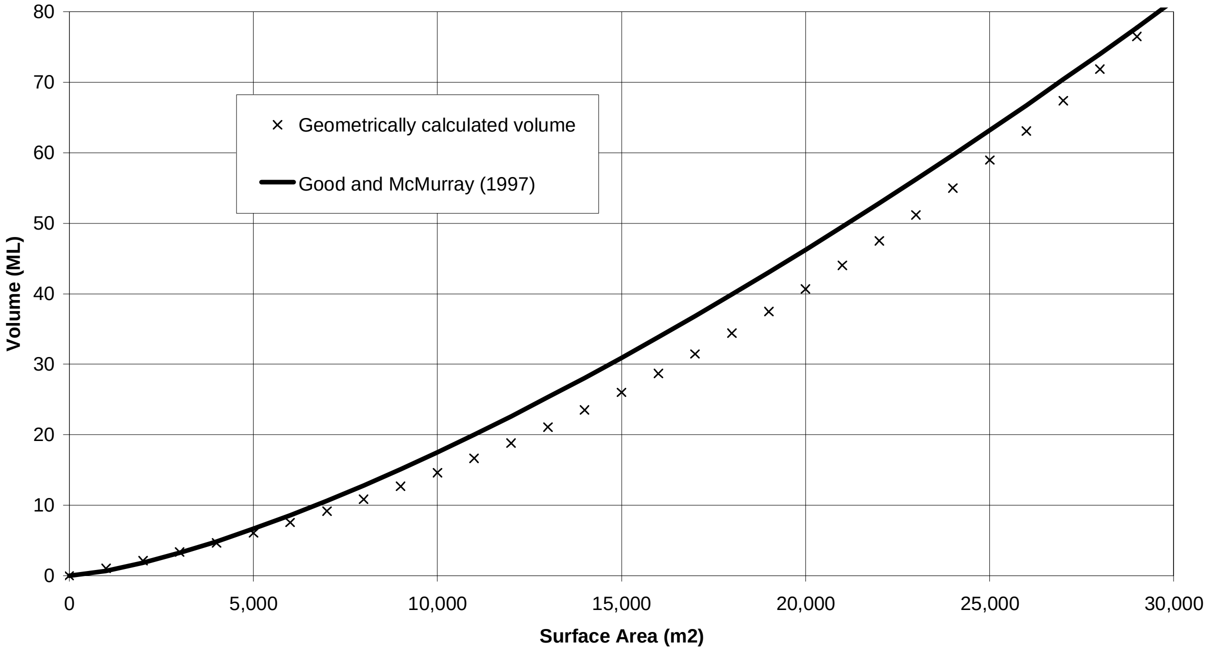
For a small dam (Volume = 1 ML), Depth = 1.5m, Base/Surface diameter = 0.6

For a large dam (Volume = 100 ML), Depth = 3.5m, Base/Surface diameter = 1

The actual shape of the dam does not affect the volume. The same relationship applies to square or round dams.

Figure 3.6 below shows how the geometrically calculated volume compares with the volumes calculated using the Good and McMurray relationship.

Figure 3.6 – Dam Volume Relationships



The largest catchment dam in the study area is 46 ML. Up to this volume the Good and McMurray relationship compares well with the geometrically derived relationship. Therefore, the Good and McMurray relationship has been used for this catchment.

3.5 CLIMATE DATA

3.5.1 Rainfall

Rainfall data was available for a number of sites around the catchment, but the best coverage of the catchment giving 30 years of data was obtained using the following gauges:

86142 Mt St Leonard Jan 1970 to Mar 2001

86070 Maroondah Weir Jan 1970 to Dec 1999

The monthly totals appeared to be complete for Mt St Leonard, however there were several gaps in the Maroondah record of 6 to 12 months. However, sufficient data exists to obtain a reliable average monthly pattern.

The rainfall applied to the catchment was the average of these two gauges. Although more rigorous methods of apportioning rainfall to a catchment exist (eg. Theissen polygons, isopleths), these are not warranted as only two rainfall records were used.

Average monthly rainfall applied to the Watts River catchment is given in Table 3.5 below.

Table 3.5 – Average Monthly Rainfall Applied to the Catchment

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain (mm)	80.3	62.2	80.6	103.1	104.7	113.2	105.4	130.3	125.1	123.1	115.9	106.4

3.5.2 Evaporation

Evaporation was available for two sites near the catchments. Despite both gauges having patchy, incomplete data, reliable monthly averages could still be determined.

Gauge 86142 Mt St Leonard Altitude 603m AHD

Gauge 86363 Tarrawarra Altitude 76m AHD

The evaporation applied to the catchment was the average of these two gauges. This is warranted since many of the dams in the catchment are at a reasonably high altitude.

Also, applying only the Tarrawarra evaporation data to the Watts River would not be realistic because the Tarrawarra gauge is in a more exposed location, in the middle of the Yarra Valley, increasing the potential for evaporation.

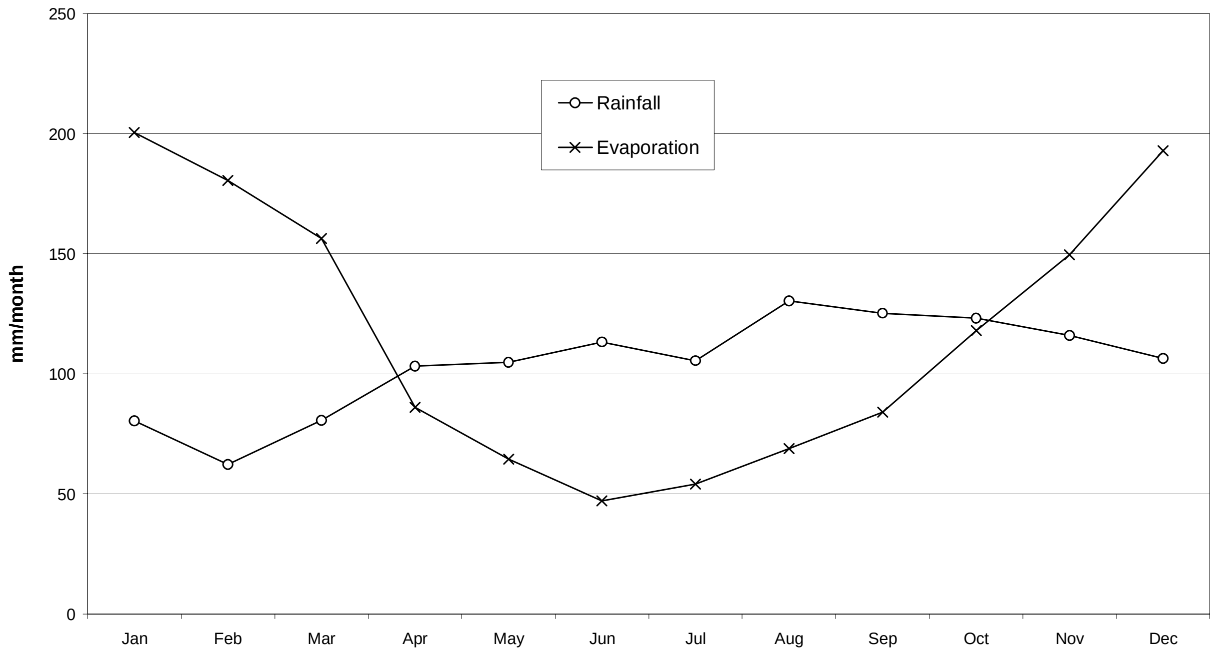
The average monthly evaporation used has been shown in Table 3.6 below.

Table 3.6 – Average Monthly Evaporation Applied in the TEDI Model

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evap (mm)	200.5	180.4	156.4	86.0	64.3	47.1	53.9	68.8	83.9	118.0	149.5	192.8

Both Rainfall and Evaporation monthly averages are shown below in Figure 3.7.

Figure 3.7 – Average Monthly Rainfall and Evaporation Used



4. RESULTS

The results of the TEDI model for the Watts River are presented in the following sections. The results have been presented in terms of:

- a summary of the number and volumes of dams and diversions within the catchment;
- details of average annual water harvesting volumes;
- seasonal variations in water harvesting volumes; and
- the net impact of catchment dams on streamflow as measured at the catchment outlet.

These results assume a dam usage factor of 2, as discussed in Section 3.3.3.

Section 4.1 gives results for the entire Watts River catchment, including all tributaries.

Separate results have been presented in Sections 4.2, 4.3, and 4.4 for:

Chum Creek (including Myers Creek)

Grace Burn Creek

Watts River (main stream not including Chum / Grace Burn Creeks)

Results for Chum Creek and Watts River (main stream) catchment have been calculated by apportioning streamflow based on catchment area, and proportioning catchment dams and licenses based on GIS location data.

Results for Grace Burn Creek catchment have been calculated by apportioning streamflow based on Melbourne Water flow data for Grace Burn diversion, and proportioning catchment dams and licenses based on GIS location data.

Other analyses were carried out as part of the study, and the results of these analyses are presented in **sections 4.5 and 4.6**. The analyses include:

- the effect of the dam usage factor on model results; and
- a dry spell analysis of streamflows.

4.1 WATTS RIVER (ENTIRE CATCHMENT)

4.1.1 Dams and Diversions Within the Catchment

A range of different dam and diversion types exist within the Watts River catchment. The dams and diversions included in the study include:

Current Private Licensed Diversions		
Direct Diversions	43 licences	392 ML
Winterfill Diversions	5 licences	58 ML
Total Diversions	**48 licences**	**450 ML**
Current Catchment Dams	128 dams	368 ML
Future Catchment Dams		~10 ML

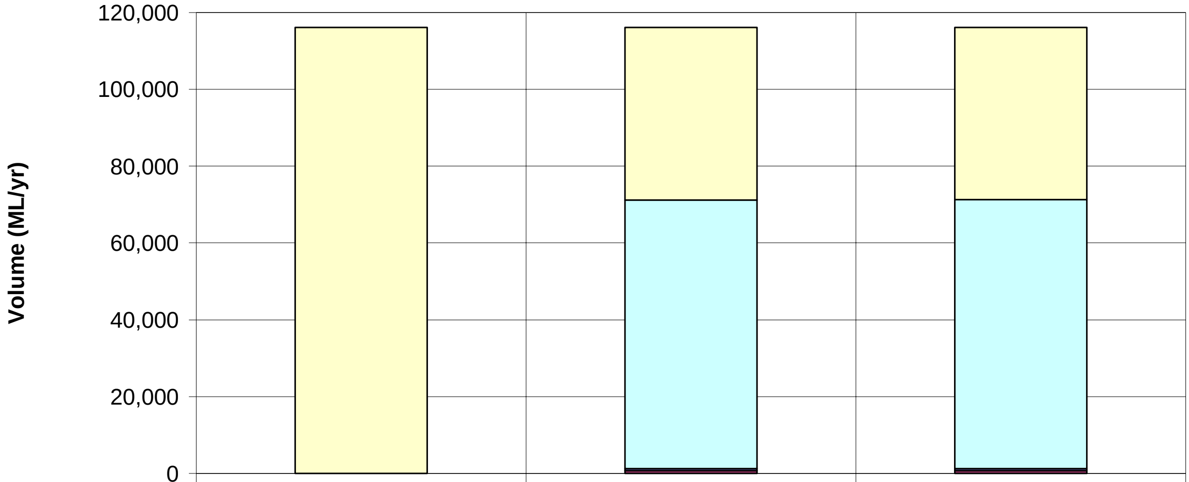
Details of licensed diversions within the catchment were provided by Melbourne Water in December 2001.

The majority of the dams and licenses are located in the lower reaches of the catchment, near Healesville. However, some dams exist in the upper reaches of the Chum Creek catchment. The dams are shown in the map in Appendix B.

4.1.2 Annual Harvest Volumes for Watts River (Entire Catchment)

The volume of water harvested by catchment dams and diversions is presented in Figure 4.1 below, assuming a dam usage factor of 2.

Figure 4.1 – Annual Harvest Volumes as a Part of Mean Annual Flow



	Natural	Current	Future
Streamflow	116,083	44,867	44,856
MWC Diversions	0	70,000	70,000
Private Diversions	0	450	450
Catchment Dams	0	766	777

The graph shows that the natural mean annual flow is over 116,000 ML. Currently, 766 ML of this is harvested by catchment dams, and 450 ML is harvested by licensed diversions. Melbourne Water urban diversions, including Grace Burn diversion and Maroondah reservoir, harvest approximately 70,000 ML annually.

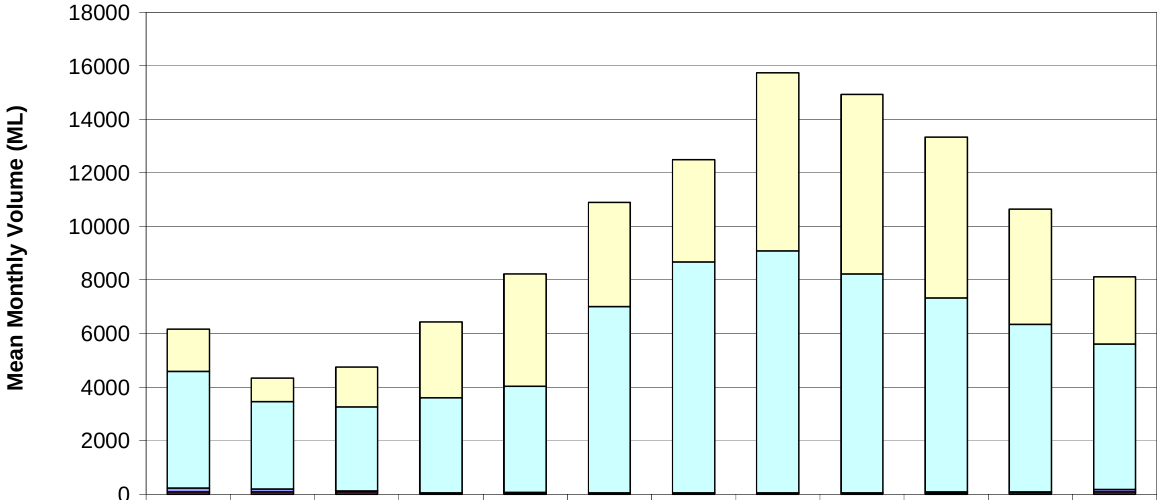
Clearly, the total volume harvested within the catchment by private diversions and catchment dams is small, only approximately 1% of the natural mean annual flow.

Note that the estimate of Melbourne Water urban diversion harvest volume is approximate, interpreted from historic diversion information for the period 1987 to 1998.

4.1.3 Seasonal Variation in Harvesting for Watts River (Entire Catchment)

Water harvest volumes vary significantly through the year. Figure 4.2 below shows this seasonal fluctuation in harvest volumes and streamflow in terms of the average monthly flow throughout the year, assuming a dam usage factor of 2.

Figure 4.2 – Seasonal Water Harvest Volumes



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	1567	873	1474	2832	4190	3883	3819	6655	6707	6011	4310	2507
MWC Diversions	4370	3270	3150	3540	3970	6960	8610	9030	8160	7250	6250	5440
Private Diversions	126	98	35	3	13	13	13	13	13	17	17	88
Catchment Dams	96	93	84	56	48	41	45	42	48	59	70	86

During January and February, catchment dams typically harvest over 90 ML per month, dropping down to less than 50 ML from May to September.

On average, licensed diversions harvest over 80 ML per month between December and February, peaking at 126 ML in January. During other months, the harvest volumes are much lower, with typically less than 20 ML from May to November.

Of the remaining flows, between 50% and 80% is diverted into Maroondah reservoir, leaving unallocated flows which vary from 873 ML in February, to more than 6700 ML in September. The unallocated flows represent between 20% and 50% of natural streamflows.

Note that the estimate of Melbourne Water's urban diversion harvest volume is approximate, interpreted from historic diversion information supplied by Melbourne Water for the period 1987 to 1998.

4.1.4 Impact of Catchment Dams on Streamflow for Watts River (Entire Catchment)

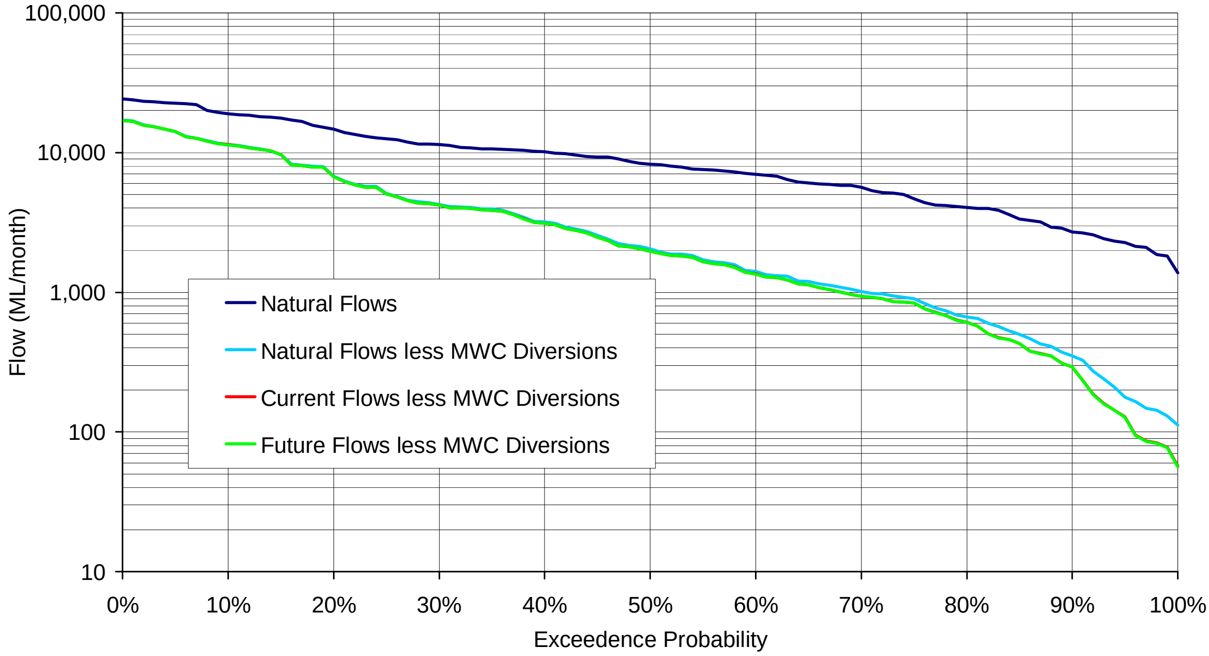
The figure below shows that the effect of the current level of catchment dam development is small compared to the total streamflows in the Watts River catchment, even during periods of low flow.

Figure 4.3 is a flow exceedence chart for the Watts River outlet, at Tarrawarra. This curve is a way of showing how often flows in the river are higher than a given value.

For example, the chart shows that the probability of the natural monthly flow exceeding 10,000ML is 40%. Another way of saying this is that, on average, a total monthly flow of 10,000ML or more will occur 40% of the time, or four months in ten.

It should be noted that the flow exceedence curves shown in Figure 4.3 are based upon data between 1987 and 1998 only, as this is the only time during which a meaningful comparison can be made between the streamflow data generated by the TEDI model and Melbourne Water urban diversion data.

Figure 4.3 – Flow Exceedence Curves for Natural, Current Development, and Future Development Scenarios



This chart shows that the effect of catchment dam development is small for both high and low flows. The existing catchment dam development reduces the streamflow by around 55ML during months with high flows, which is around 0.3% of natural flows. Streamflow is reduced by 75 ML during months with low flows, which is around 2.8% of natural flows.

Clearly the effect of catchment dams is minimal compared to the effect of Melbourne Water urban diversions, which harvest more than 7000 ML during months with high flows, and typically more than 2000 ML during months with low flows.

Table 4.1 shows the impact on streamflows of each 1 ML of additional catchment dam development, assuming a dam usage factor of 2.

Table 4.1 – Impact of Catchment Dam Development on Annual Streamflows

	Q_{90}	Q_{50}	Q_{10}	Q_{mean}
Natural Annual Streamflow	75,704	119,061	147,081	116,083
Reduction in Streamflow per ML of catchment dam development	1.0	0.6	0.5	0.7

This table shows that for high flow (Q_{10}) years, 1 ML of additional catchment dam development reduces the annual flow by approximately 0.5 ML. For low flow (Q_{90}) years, 1 ML of additional catchment dam development reduces the annual flow by approximately 1.0 ML.

For example, if the catchment contained 200 ML of additional catchment dams, the reduction in annual streamflow would be 100 ML in wet years and 200 ML in dry years.

4.2 CHUM CREEK

4.2.1 Dams and Diversions Within the Catchment

A range of different dam and diversion types exist within the Chum Creek catchment. The dams and diversions included in the study include:

Current Private Licensed Diversions		
Direct Diversions	27 licences	175 ML
Winterfill Diversions	4 licences	44 ML
Total Diversions	**31 licences**	**219 ML**
Current Catchment Dams	90 dams	186 ML
Future Catchment Dams		~5 ML

Details of licensed diversions within the catchment were provided by Melbourne Water in December 2001.

The majority of the dams and licenses are located in the middle to lower reaches of the Chum Creek catchment, with only a few dams in the Meyers Creek catchment. The dams are shown in the map in Appendix B.

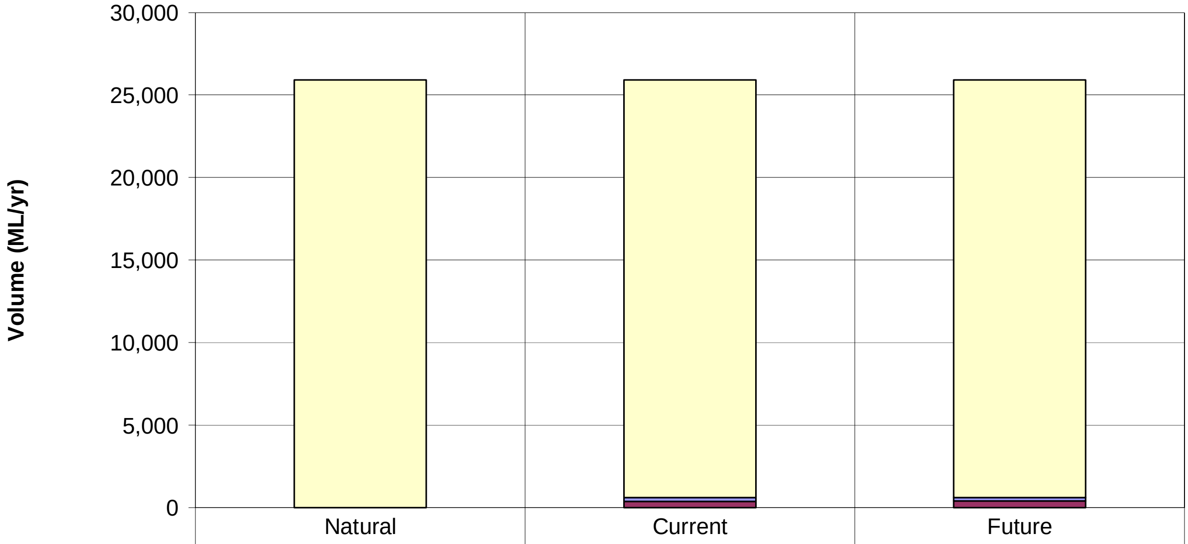
Natural Chum Creek streamflows have been assumed to make up 22.3% of the natural flow for the entire catchment, based on area.

Also, because Chum Creek contains 50.6% of the catchment dams in the entire Watts River catchment, it has been assumed that these dams are responsible for 50.6% of the natural streamflow reduction.

4.2.2 Annual Harvest Volumes for Chum Creek

The volume of water harvested by catchment dams and diversions is presented in Figure 4.4 below, assuming a dam usage factor of 2.

Figure 4.4 – Annual Harvest Volumes as a Part of Mean Annual Flow



	Natural	Current	Future
Streamflow	25,929	25,322	25,317
Private Diversions	0	219	219
Catchment Dams	0	388	393

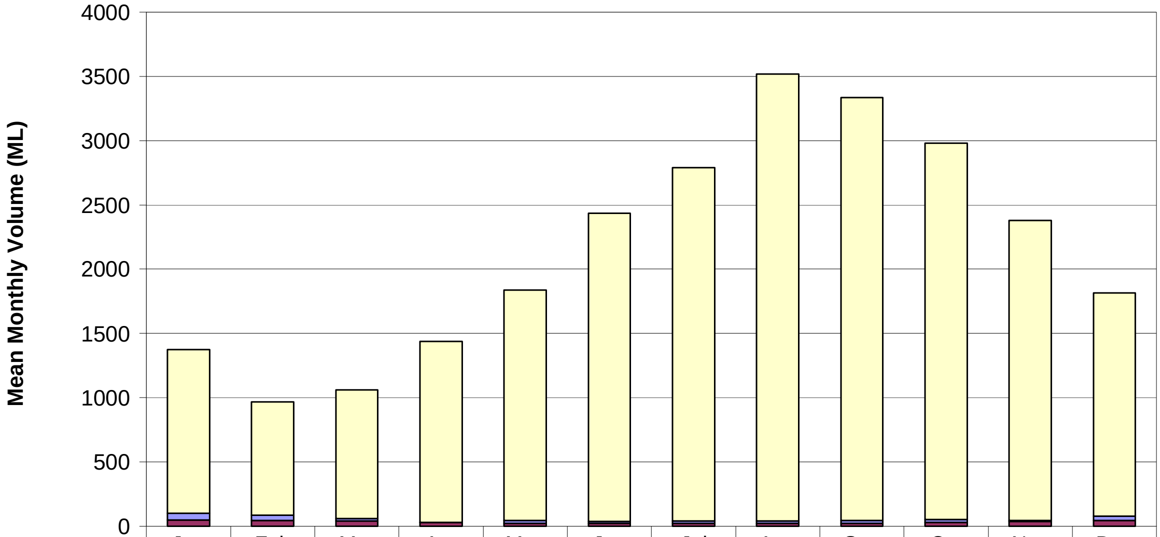
The graph shows that the natural mean annual flow is over 25,900 ML. Currently, 388 ML of this is harvested by catchment dams, and 219 ML is harvested by licensed diversions. There are no Melbourne Water urban diversions in the Chum Creek catchment.

Clearly, the total volume harvested within the catchment by private diversions and catchment dams is small, only approximately 2.3% of the natural mean annual flow.

4.2.3 Seasonal Variation in Harvesting Within Chum Creek

Water harvest volumes vary significantly through the year. Figure 4.5 below shows this seasonal fluctuation in harvest volumes and streamflow in terms of the average monthly flow throughout the year, assuming a dam usage factor of 2.

Figure 4.5 – Seasonal Water Harvest Volumes



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	1276	881	1001	1405	1793	2395	2747	3475	3292	2929	2334	1734
Private Diversions	52	40	16	3	19	19	19	19	19	21	9	36
Catchment Dams	48	47	43	28	24	21	23	21	24	30	35	43

During January and February, catchment dams typically harvest over 45 ML per month, dropping down to less than 25 ML from May to September.

On average, licensed diversions harvest over 40 ML per month between December and March, peaking at 52 ML in January. During other months, the harvest volumes are much lower, with typically less than 20 ML from May to November.

Unallocated flows range from less then 900 ML in February, to almost 3500 ML in August, representing between 90% and 99% of natural streamflows.

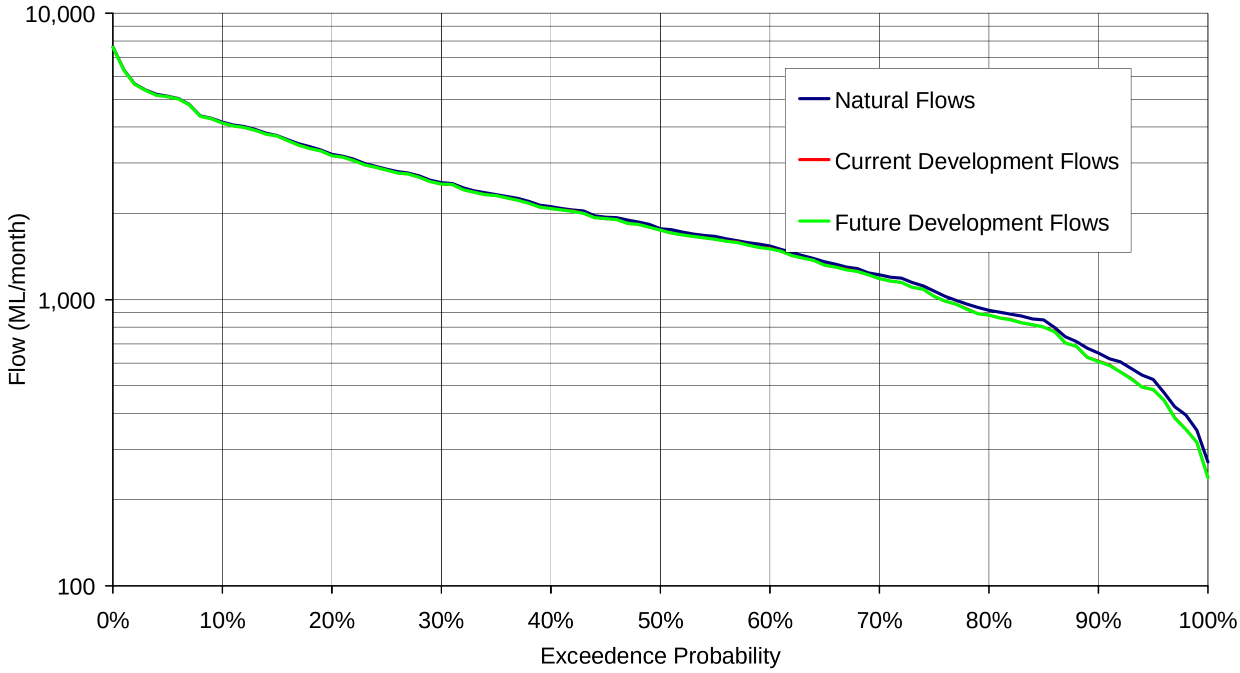
4.2.4 Impact of Catchment Dams on Streamflow Within Chum Creek

The figure below shows that the effect of the current level of catchment dam development is small compared to the total streamflows in the Chum Creek catchment, even during periods of low flow.

Figure 4.6 is a flow exceedence chart for the Chum Creek outlet, at Healesville. This curve is a way of showing how often flows in the river are higher than a given value.

For example, the chart shows that the probability of the natural monthly flow exceeding 4000ML is 10%. Another way of saying this is that, on average, a total monthly flow of 4000ML or more will occur 10% of the time, or one month in ten.

Figure 4.6 – Flow Exceedence Curves for Natural, Current Development, and Future Development Scenarios



This chart shows that the effect of catchment dam development is small for both high and low flows. The existing catchment dam development reduces the streamflow by around 25ML during months with high flows, which is around 0.6% of natural flows. Streamflow is reduced by 40 ML during months with low flows, which is around 6.4% of natural flows.

Table 4.2 shows the impact on streamflows of each 1 ML of additional catchment dam development, assuming a dam usage factor of 2.

Table 4.2 – Impact of Catchment Dam Development on Annual Streamflows

	Q_{90}	Q_{50}	Q_{10}	Q_{mean}
Natural Annual Streamflow	16,910	26,594	32,853	25,929
Reduction in Streamflow per ML of catchment dam development	1.1	1.1	1.1	1.1

This table shows that for high flow (Q_{10}) years and low flow (Q_{90}) years, 1 ML of additional catchment dam development reduces the annual flow by approximately 1.1 ML.

For example, if the catchment contained 200 ML of additional catchment dams, the reduction in annual streamflow would be 220 ML in both wet years and dry years.

4.3 GRACE BURN CREEK

4.3.1 Dams and Diversions Within the Catchment

A range of different dam and diversion types exist within the Grace Burn Creek catchment. The dams and diversions included in the study include:

Current Private Licensed Diversions		
Direct Diversions	3 licences	52 ML
Winterfill Diversions	1 licence	14 ML
Total Diversions	**4 licences**	**66 ML**
Current Catchment Dams	16 dams	69 ML
Future Catchment Dams		~2 ML

Details of licensed diversions within the catchment were provided by Melbourne Water in December 2001.

Dams in the Grace Burn Creek catchment are located predominantly in the lower reaches, near Healesville. The dams are shown in the map in Appendix B.

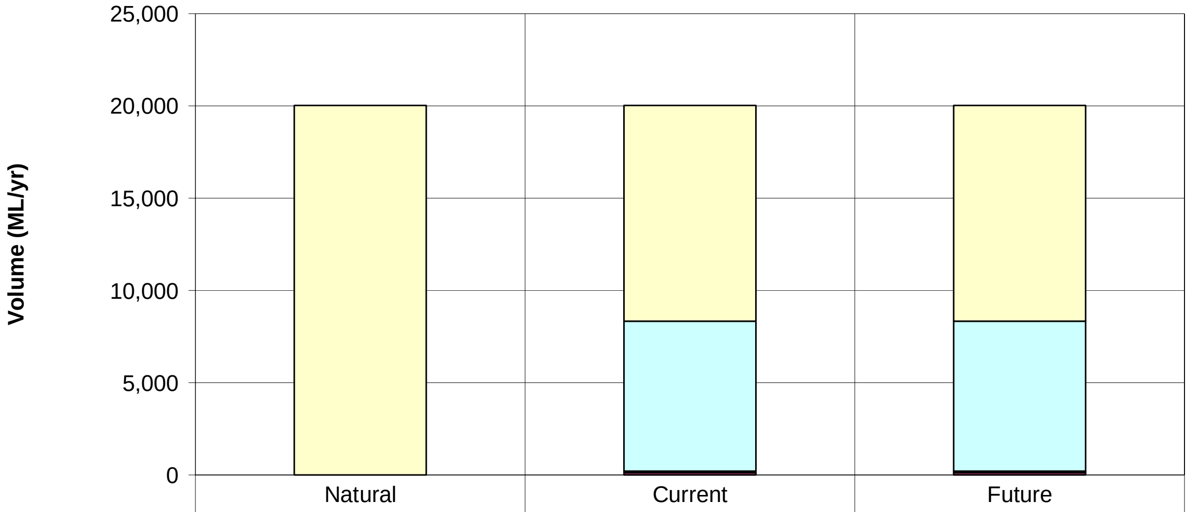
Natural Grace Burn Creek streamflows have been assumed to make up 17.2% of the natural flow for the entire catchment, based on area.

Also, because Grace Burn Creek contains 18.7% of the catchment dams in the entire Watts River catchment, it has been assumed that these dams are responsible for 18.7% of the natural streamflow reduction.

4.3.2 Annual Harvest Volumes for Grace Burn Creek

The volume of water harvested by catchment dams and diversions is presented in Figure 4.7 below, assuming a dam usage factor of 2.

Figure 4.7 – Annual Harvest Volumes as a Part of Mean Annual Flow



	Natural	Current	Future
Streamflow	20,010	11,675	11,673
MWC Diversions	0	8,125	8,125
Private Diversions	0	66	66
Catchment Dams	0	143	145

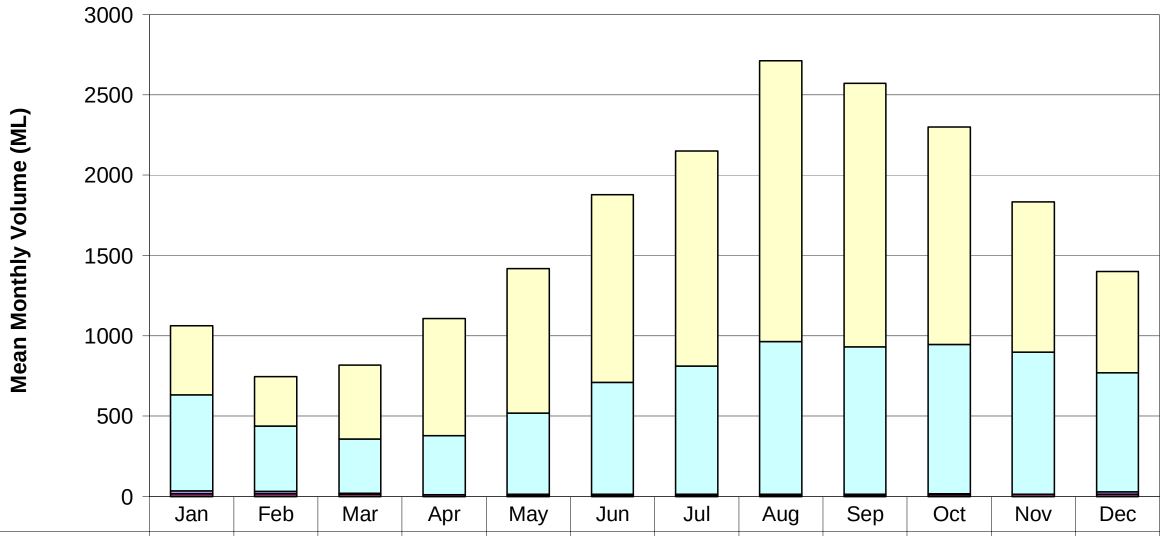
The graph shows that the natural mean annual flow is approximately 20,000 ML. Currently, 143 ML of this is harvested by catchment dams, and 66 ML is harvested by licensed diversions. The Melbourne Water urban diversion on Grace Burn Creek harvests an average of 8125 ML annually.

Clearly, the total volume harvested within the catchment by private diversions and catchment dams is small, only approximately 1% of the natural mean annual flow.

4.3.3 Seasonal Variation in Harvesting Within Grace Burn Creek

Water harvest volumes vary significantly through the year. Figure 4.8 below shows this seasonal fluctuation in harvest volumes and streamflow in terms of the average monthly flow throughout the year, assuming a dam usage factor of 2.

Figure 4.8 – Seasonal Water Harvest Volumes



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	429	308	460	730	899	1166	1341	1751	1641	1354	938	628
MWC Diversions	597	408	337	368	503	698	796	948	917	927	882	743
Private Diversions	18	14	5	0.2	7	6	7	7	6	7	2.2	12
Catchment Dams	18	17	16	10	9	8	8	8	9	11	13	16

Catchment dams typically harvest up to 18 ML during January, dropping down to less than 10 ML from May to September.

On average, licensed diversions harvest over 12 ML per month between December and February, peaking at 18 ML in January. During other months, the harvest volumes are much lower, with almost no harvesting at all in April, and typically less than 7 ML from May to November.

Of the remaining flow, Melbourne Water urban diversions harvest between 30% and 60%. The unallocated flows reaching the catchment outlet vary from less than 310 ML in February to 1751 ML in August.

Note that the estimate of Melbourne Water's urban diversion harvest volume is approximate, interpreted from historic diversion information supplied by Melbourne Water for the period 1970 to 2001.

4.3.4 Impact of Catchment Dams on Streamflow Within Grace Burn Creek

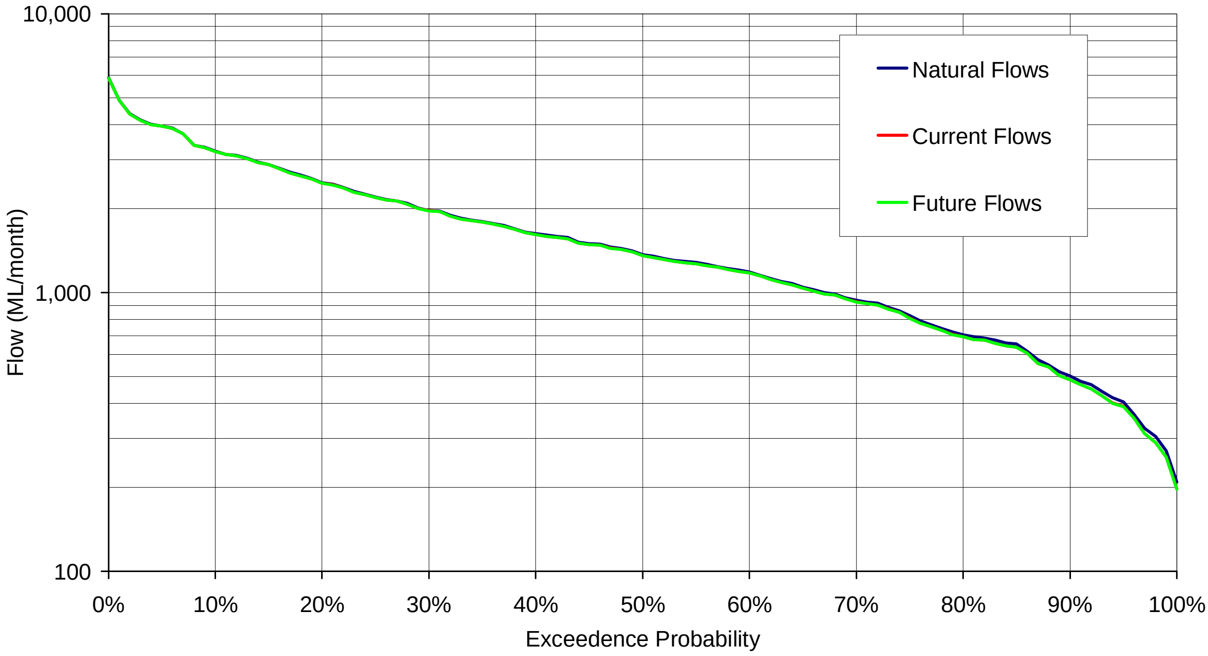
The figure below shows that the effect of the current level of catchment dam development is small compared to the total streamflows in the Grace Burn Creek catchment, even during periods of low flow.

Figure 4.9 is a flow exceedence chart for the Grace Burn Creek outlet, at Healesville. This curve is a way of showing how often flows in the river are higher than a given value.

For example, the chart shows that the probability of the natural monthly flow exceeding 2000ML is 30%. Another way of saying this is that, on average, a total monthly flow of 2000ML or more will occur 30% of the time, or three months in ten.

Due to limitations inherent in the streamflow data generated by the TEDI model, it is not possible to accurately show the effect of Melbourne Water urban diversions in this chart.

Figure 4.9 – Flow Exceedence Curves for Natural, Current Development, and Future Development Scenarios



This chart shows that the effect of catchment dam development is small for both high and low flows. The existing catchment dam development reduces the streamflow by around 10ML during months with high flows, which is around 0.3% of natural flows. Streamflow is reduced by 14 ML during months with low flows, which is around 2.8% of natural flows.

Table 4.3 shows the impact on streamflows of each 1 ML of additional catchment dam development, assuming a dam usage factor of 2.

Table 4.3 – Impact of Catchment Dam Development on Annual Streamflows

	Q_{90}	Q_{50}	Q_{10}	Q_{mean}
Natural Annual Streamflow	13,049	20,523	25,353	20,010
Reduction in Streamflow per ML of catchment dam development	1.1	1.1	1.1	1.1

This table shows that for high flow (Q_{10}) years and low flow (Q_{90}) years, 1 ML of additional catchment dam development reduces the annual flow by approximately 1.1 ML.

For example, if the catchment contained 200 ML of additional catchment dams, the reduction in annual streamflow would be 220 ML in both wet years and dry years.

4.4 WATTS RIVER (MAIN STREAM)

This section refers to the Watts River catchment excluding Grace Burn and Chum Creeks.

4.4.1 Dams and Diversions Within the Catchment

A range of different dam and diversion types exist within the Watts River subcatchment. The dams and diversions included in the study include:

Current Private Licensed Diversions		
Direct Diversions	13 licences	165 ML
Winterfill Diversions	0 licences	0 ML
Total Diversions	**13 licences**	**165 ML**
Current Catchment Dams	22 dams	113 ML
Future Catchment Dams		~3 ML

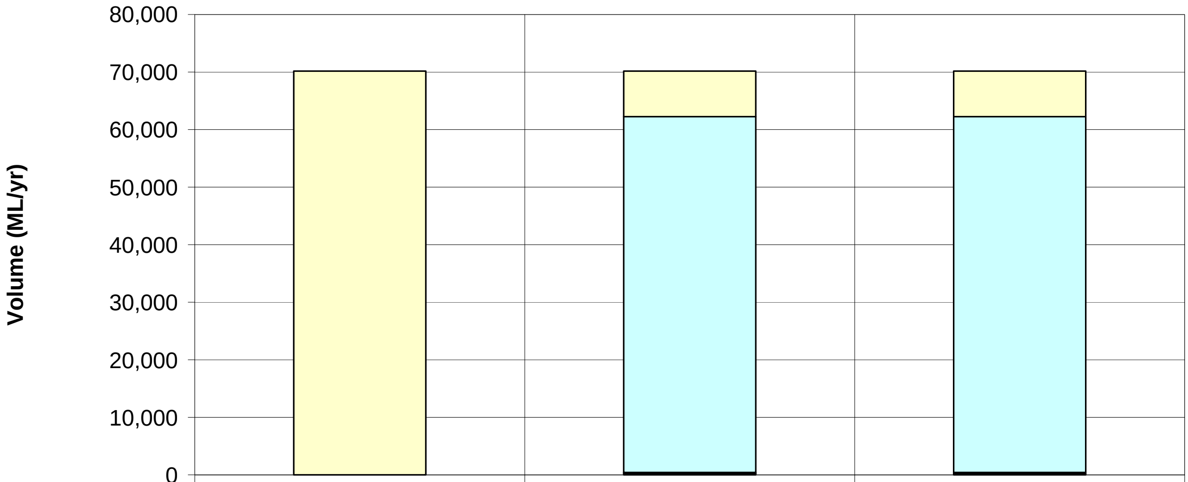
Details of licensed diversions within the catchment were provided by Melbourne Water in December 2001.

All of the dams and licenses are located in the lower reaches of the Watts River subcatchment, between Maroondah Reservoir and the river outlet. The dams are shown in the map in Appendix B.

4.4.2 Annual Harvest Volumes for Watts River (Main Stream)

The volume of water harvested by catchment dams and diversions is presented in Figure 4.10 below, assuming a dam usage factor of 2.

Figure 4.10 – Annual Harvest Volumes as a Part of Mean Annual Flow



	Natural	Current	Future
Streamflow	70,145	7,869	7,866
MWC Diversions	0	61,875	61,875
Private Diversions	0	165	165
Catchment Dams	0	235	239

The graph shows that the natural mean annual flow is over 70,000 ML. Currently, 235 ML of this is harvested by catchment dams, and 165 ML is harvested by licensed diversions. Melbourne Water urban diversions harvest almost 7900 ML annually.

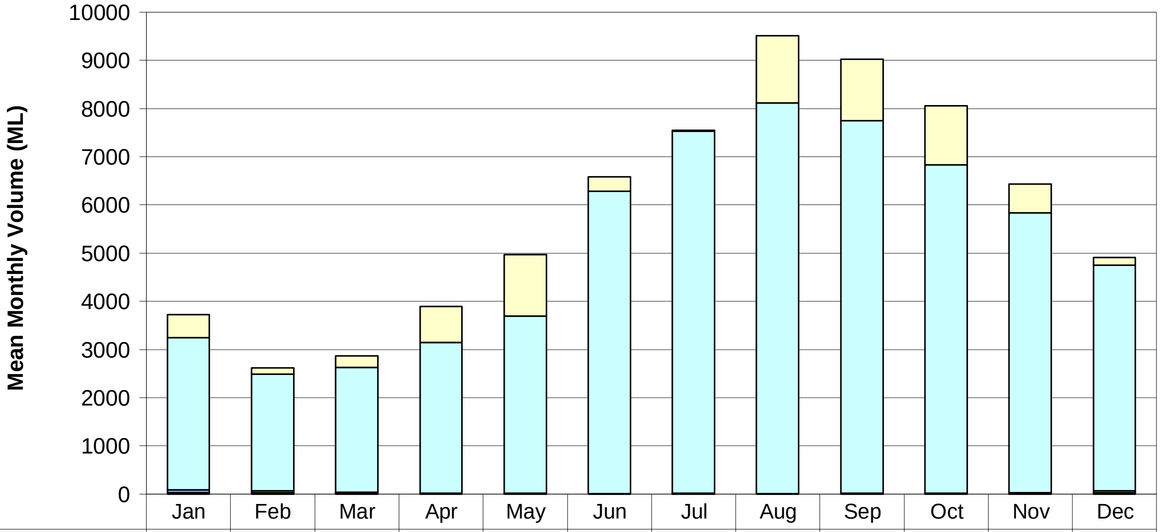
Clearly, the total volume harvested within the catchment by private diversions and catchment dams is small, only approximately 0.6% of the natural mean annual flow, or almost 5% of the flow remaining after Melbourne Water urban diversion harvesting.

Note that the estimate of Melbourne Water urban diversion harvest volume is approximate, interpreted from historic diversion information for the period 1987 to 1998.

4.4.3 Seasonal Variation in Harvesting within Watts River (Main Stream)

Water harvest volumes vary significantly through the year. Figure 4.11 below shows this seasonal fluctuation in harvest volumes and streamflow in terms of the average monthly flow throughout the year, assuming a dam usage factor of 2.

Figure 4.11 – Seasonal Water Harvest Volumes



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	480	133	233	744	1277	303	13	1392	1271	1233	601	163
MWC Diversions	3156	2413	2593	3125	3675	6268	7518	8106	7735	6806	5804	4678
Private Diversions	57	44	15	0.3	0.3	0.3	0.3	0.3	0.3	1.9	6.8	39
Catchment Dams	29	28	26	17	15	12	14	13	15	18	22	26

Between November and March, catchment dams typically harvest over 20 ML per month, dropping down to as little as 12 ML per month during June.

On average, licensed diversions harvest over 30 ML per month between December and February, peaking at 57 ML in January. During other months, the harvest volumes are much lower, with typically less than 1 ML from April to September.

Of the remaining flows, typically around 90% is diverted into Maroondah reservoir. However, the estimates of Melbourne Water urban diversion harvesting shown above are approximate only, interpreted from historic diversion information supplied by Melbourne Water for the period 1987 to 1998.. Unallocated flows may be significantly more or less than shown above depending on the urban diversion harvest volume for each month.

4.4.4 Impact of Catchment Dams on Streamflow within Watts River (Main Stream)

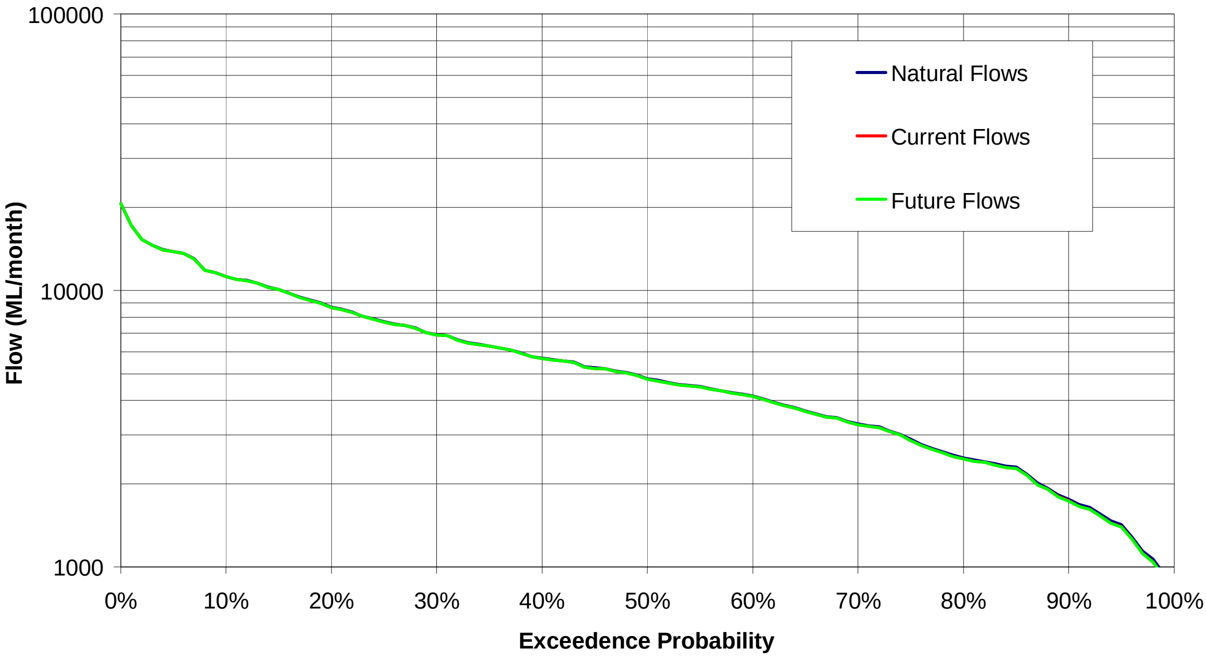
The figure below shows that the effect of the current level of catchment dam development is small compared to the total streamflows in the Watts River subcatchment, even during periods of low flow.

Figure 4.12 is a flow exceedence chart for the Watts River outlet, at Tarrawarra, excluding flows from Grace Burn and Chum Creeks. This curve is a way of showing how often flows in the river are higher than a given value.

For example, the chart shows that the probability of the natural monthly flow exceeding 4000ML is 60%. Another way of saying this is that, on average, a total monthly flow of 4000ML or more will occur 60% of the time, or six months in ten.

Due to limitations inherent in the streamflow data generated by the TEDI model, it is not possible to accurately show the effect of Melbourne Water urban diversions in this chart.

Figure 4.12 – Flow Exceedence Curves for Natural, Current Development, and Future Development Scenarios



This chart shows that the effect of catchment dam development is small for both high and low flows. The existing catchment dam development reduces the streamflow by around 16ML during months with high flows, which is around 0.1% of natural flows. Streamflow is reduced by 75 ML during months with low flows, which is around 1.4% of natural flows.

Table 4.4 shows the impact on streamflows of each 1 ML of additional catchment dam development, assuming a dam usage factor of 2.

Table 4.4 – Impact of Catchment Dam Development on Annual Streamflows

	Q_{90}	Q_{50}	Q_{10}	Q_{mean}
Natural Annual Streamflow	45,745	71,944	88,875	70,145
Reduction in Streamflow per ML of catchment dam development	1.1	1.1	1.1	1.1

This table shows that for both high flow (Q_{10}) years and low flow (Q_{90}) years, 1 ML of additional catchment dam development reduces the annual flow by approximately 1.1 ML.

For example, if the catchment contained 200 ML of additional catchment dams, the reduction in annual streamflow would be 110 ML in both wet and dry years.

4.5 SENSITIVITY OF MODEL TO DAM USAGE FACTOR

In Section 3.3.3, the dam usage factor was given as 2. That means that on average, the volume of water used annually from each irrigation catchment dam is assumed to be twice its capacity. Although some dams may be used many times over, other dams may not be used at all. After discussion with Melbourne Water, it was decided that a factor of 2 was an appropriate average.

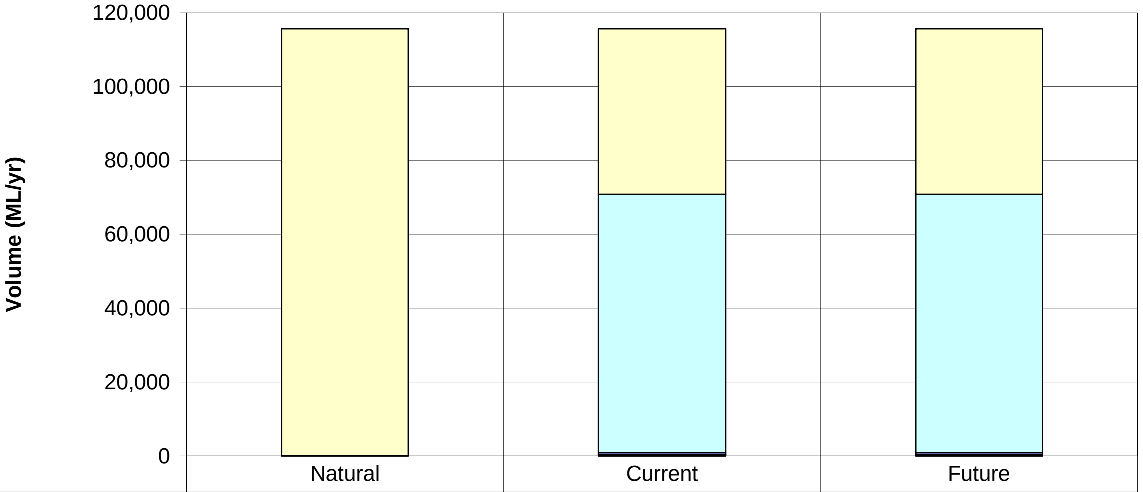
The discussions to determine the most appropriate dam usage factor took place for a similar streamflow study for Steels, Pauls, and Dixon's Creeks, located in the Yarra Valley near Yarra Glen (Egis 2001). Since those discussions took place, it has been decided that an investigation into the effect of varying the dam usage factor is important in understanding the relationship between farm dams and catchment streamflow.

The following sections are a comparison of model results given in the previous section, to the model results obtained for the entire catchment if the dam usage factor is reduced to one.

4.5.1 Difference in Annual Harvest Volumes

The graph below shows that the annual harvest volumes for catchment dams are reduced different when the usage factor is reduced to one, as expected.

Figure 4.13 – Annual Harvest Volumes When Dam Usage Factor = 1



	Natural	Current	Future
Streamflow	115,722	44,867	44,861
MWC Diversions	0	70,000	70,000
Private Diversions	0	450	450
Catchment Dams	0	405	411

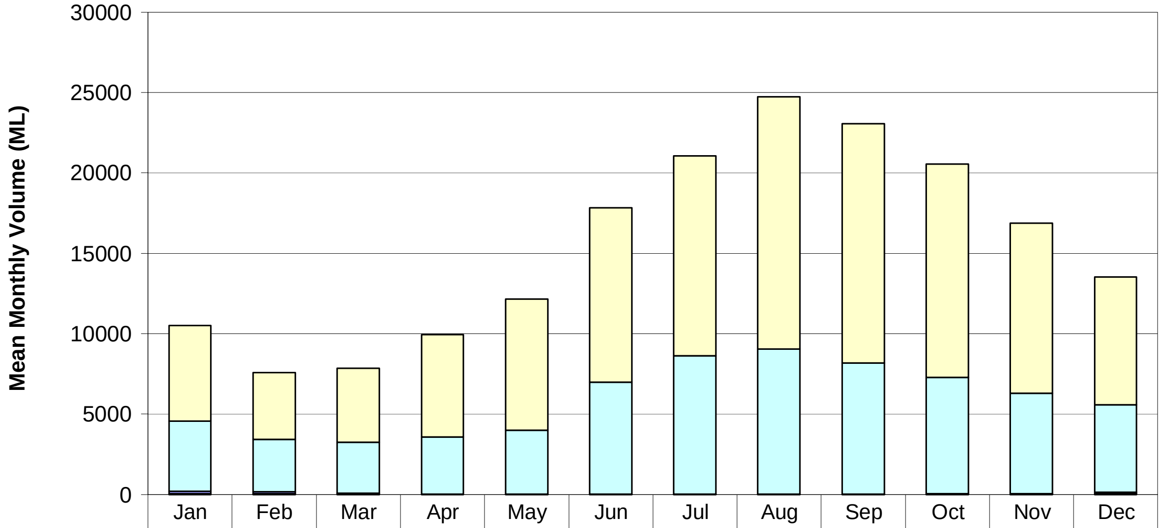
Catchment dams harvest half as much, only taking 405 ML for the current scenario, and harvest up to 411ML for the future development conditions. Licensed diversions are unchanged at 450 ML annually.

Reducing the dam usage factor has decreased the estimated natural mean annual flow by around 361 ML to 15,722 ML.

4.5.2 Difference in Seasonal Harvest Volumes

The graph in Figure 4.14 below shows that the volumes of water harvested by catchment dams changes when the dam usage factor is reduced, as expected. However, the pattern of usage remains approximately the same.

Figure 4.14 – Seasonal Water Harvest Volumes When Dam Usage Factor = 1



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	5937	4143	4624	6372	8160	10843	12429	15685	14867	13261	10559	7947
MWC Diversions	4370	3270	3150	3540	3970	6960	8610	9030	8160	7250	6250	5440
Private Diversions	126	98	35	3	13	13	13	13	13	17	17	88
Catchment Dams	66	65	53	25	18	11	15	12	18	29	40	56

Catchment dams harvest the most water during summer months, over 60 ML per month during January and February. Harvesting drops during other months, as little as 11 ML in June.

Harvesting from licensed diversions remains unchanged.

The unallocated flows are also unchanged, with summer flows reaching a low of less than 870 ML in February, and winter flows peaking near 6700 ML in September.

4.5.3 Difference in Effect of Catchment Dams on Streamflow

The flow exceedence curve obtained when the dam usage factor is reduced to one is virtually unchanged to that in Section 4.4.4. The effect of catchment dam development is still small for both high and low flows. The existing catchment dam development reduces the streamflow by around 22 ML during months with high flows, which is around 0.1% of natural flows. Streamflow is reduced by 45 ML during months with low flows, which is around 1.6% of natural flows.

Figure 4.15– Flow Exceedence Curves when Dam Usage Factor = 1

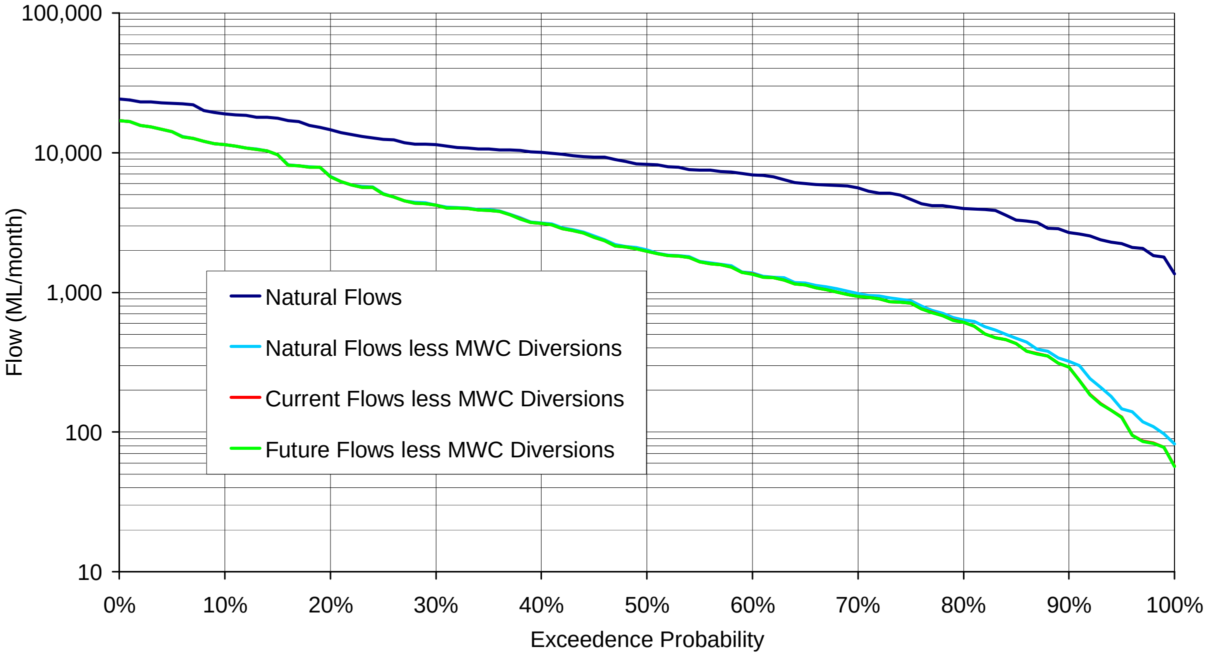


Table 4.5 below shows the difference in the effect on streamflow of each 1 ML of catchment dam development.

This table shows that if the dam usage factor is one, then for both high flow (Q_{10}) and low flow (Q_{90}) years, 1 ML of catchment dam development reduces the annual flow by approximately 0.6 ML. This compares with a reduction in mean annual flow of 0.7 ML when the dam usage factor is two.

Table 4.5 - Impact of Catchment Dam Development When Dam Usage Factor = 1

	Q_{90}	Q_{50}	Q_{10}	Q_{mean}
Natural Annual Streamflow	75,346	118,701	146,720	115,722
Reduction in Streamflow per ML of catchment dam development	0.6	0.6	0.6	0.6

4.6 SPELL ANALYSIS

4.6.1 Background

A dry spell analysis is an investigation into periods of low flow in the stream below a given threshold flow, and the characteristics of such periods.

Melbourne Water has requested that a dry spell analysis be undertaken for the streamflow data on the Watts River. Specifically, a dry spell analysis is required for the natural and current streamflow series produced by the TEDI model, and also for each of these series with the Melbourne Water urban diversions removed.

Because detailed information on Melbourne Water diversions was only available from 1987 to 1998, the spell analysis was only undertaken on data for this period.

After discussion with Melbourne Water, it was determined that the threshold low flow value should be the monthly 95 percentile exceedence flow (5 percentile low flow) for the natural flow series. Threshold high and low flows are given in Table 4.6 below.

Table 4.6 – Threshold Flows for the Watts River Catchment

Flow	Natural	Natural less MWC diversions
95%ile low flow	2,266 ML/month	386 ML/month
5%ile high flow	22,553 ML/month	11,747 ML/month

For this analysis, the natural 95 percentile exceedence flow of 2266 ML/month was applied as the threshold flow throughout.

However, because it is based on monthly flow data the spell analysis is limited.

Monthly flows may not accurately reflect the conditions in the catchment because streamflows can vary so quickly. If streamflows are extremely low for 29 days of the month, and then a storm occurs on the 30th day, then the total monthly streamflow may appear normal. In this case, the analysis would not reveal this dry spell.

This problem cannot be rectified because the TEDI model only provides streamflow estimates as monthly series. However, the monthly analysis does provide a coarse indication of the prevalence of long term dry conditions.

4.6.2 Recorded Dry Spells

The table below details the dry spells recorded between 1980 and 2001 for the natural and current flow series.

The spells found in the natural and current series after the removal of Melbourne Water urban diversions were exactly the same. The longest spell found was 19 months, between December 1996 and June 1998.

It is worth noting that the average time between dry spells decreased considerably after the removal of Melbourne Water urban diversions, from nearly 30 months to almost 4 months.

Table 4.7 – Details of Recorded Dry Spells

Series	Spells Counted	DS_{max}	DS_{10}	DS_{50}	DS_{90}	DS_{min}	DS_{mean}
Natural	4	3 months	3 months	2.5 months	1.3 months	1 month	2.3 months
Current	4	4 months	3.7 months	2 months	1 month	1 month	2.3 months
Natural *less* MWC diversions	14	19 months	10.1 months	4 months	1.3 months	1 month	5.4 months
Current *less* MWC diversions	14	19 months	10.1 months	4 months	1.3 months	1 month	5.4 months

4.6.3 Frequency of Dry Spells

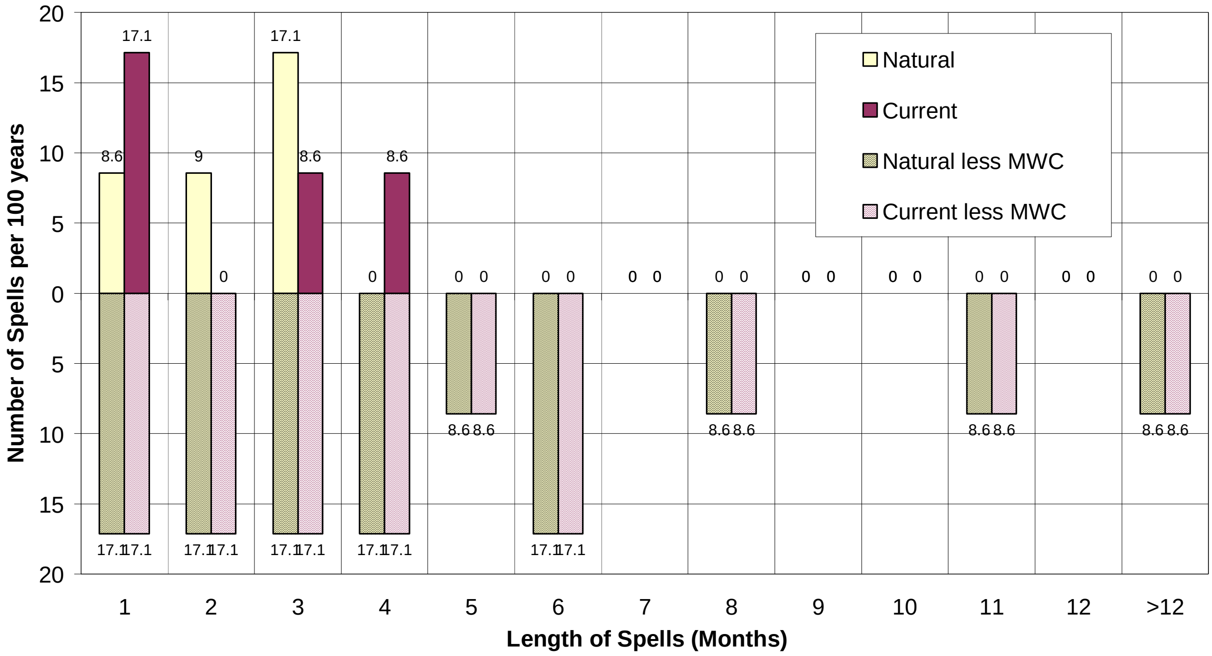
A histogram showing the length and number of dry spells per 100 years is shown in Figure 4.16. It shows that Melbourne Water urban diversions have a significant impact on the number and length of dry spells occurring in the catchment.

Naturally, dry spells are limited to 3 months duration or less. But the current level of catchment dam development has increased the number of short spells (1 month duration) and increased the maximum spell duration to 4 months. Typically, a total of 34 dry spells could be expected every 100 years.

Harvesting by Melbourne Water urban diversions has increased the number of dry spells. Typically, around 120 dry spells can be expected to occur every 100 years, which is more than one every year.

Also, the length of dry spells has increased significantly, with 75% of dry spells lasting up to 6 months. It is likely that around 9 dry spells every 100 years will last longer than 1 year.

Figure 4.16 – Number and Length of Dry Spells per 100 Years



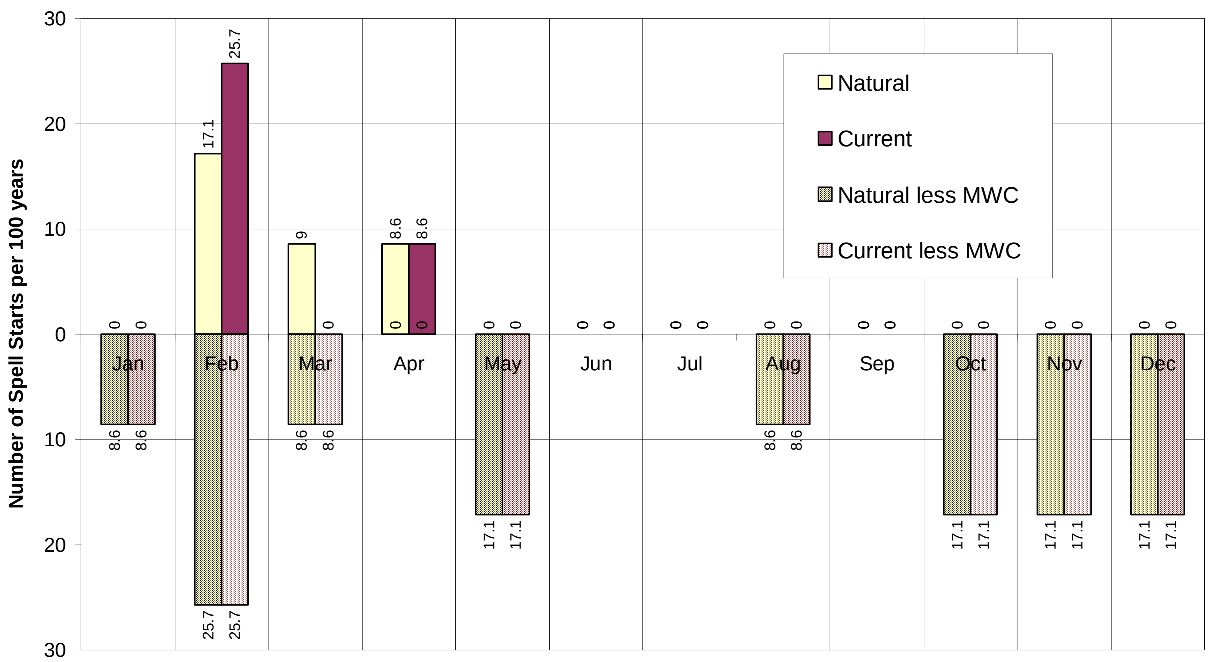
4.6.4 Seasonal Variation of Dry Spells

The chart below shows how the dry spells vary seasonally in terms of their starting month.

Naturally, dry spells are likely to start between February and April. However, the present level of catchment dam development has resulted in more dry spells occurring in February, earlier in the season.

Harvesting by Melbourne Water urban diversions has resulted in spells starting in all months, except in April, June, and July, which are usually high flow months.

Figure 4.17 – Starting Months for Low Flow Spells



5. CONCLUSIONS

Watts River (Entire Catchment)

The current level of catchment dam development is reducing streamflows in the Watts River catchment.

- The natural mean annual streamflow is between 116,083 ML and 115,722 ML, depending on the dam usage factor.
- Licensed diversions are presently harvesting around 450 ML annually, which is approximately 0.4% of the natural mean annual streamflow. Catchment dams are harvesting between 405 ML and 766 ML annually depending on the dam usage factor, which is approximately 0.3% to 0.7% of the natural mean annual streamflow.
- Melbourne Water's urban diversions harvest around 70,000 ML annually, about 60% of natural mean annual flows. Seasonally, harvesting varies between 3150 ML and 9030 ML per month. This harvesting accounts for between 48% and 75% of natural monthly streamflows.
- Licensed diversion water harvesting peaks in January at an average of 126 ML per month, which is approximately 2.0% of the mean natural streamflow for the month.
- With a dam usage factor of 2, catchment dam water harvesting peaks in January and February, with 96 ML and 93 ML harvested on average for each month. This is approximately 1.6% and 2.1% of the natural mean flows for each month respectively.
- With a dam usage factor of 1, catchment dam water harvesting peaks in January and February, with 66 ML and 65 ML harvested on average for each month. This is approximately 1.1% and 1.5% of the natural mean flows for each month respectively.
- For every 1 ML of catchment dam development, the annual flow in the catchment will be reduced by either 1.1 ML or 0.6 ML, depending on whether the dam usage factor is 2 or 1 respectively.
- Dry spells are lasting longer, and are occurring earlier in the summer season than they would naturally as a result of catchment dam development.

Chum Creek

The current level of catchment dam development is reducing streamflows in the Chum Creek catchment.

- The natural mean annual streamflow is 25,929 ML assuming a dam usage factor of 2.
- Licensed diversions are presently harvesting around 219 ML annually, which is approximately 0.8% of the natural mean annual streamflow. Catchment dams are harvesting 388 ML annually assuming a dam usage factor of 2, which is approximately 1.5% of the natural mean annual streamflow.
- Licensed diversion water harvesting peaks in January at an average of 52 ML per month, which is approximately 3.8% of the mean natural streamflow for the month.
- With a dam usage factor of 2, catchment dam water harvesting peaks in January and February, with 48 ML and 47 ML harvested on average for each month. This is approximately 3.5% and 4.8% of the natural mean flows for each month respectively.
- For every 1 ML of catchment dam development, the annual flow in the catchment will be reduced by 1.1 ML, assuming a dam usage factor of 2.

Grace Burn Creek

The current level of catchment dam development is reducing streamflows in the Grace Burn Creek catchment.

- The natural mean annual streamflow is 20,010 ML assuming a dam usage factor of 2.
- Licensed diversions are presently harvesting around 66 ML annually, which is approximately 0.3% of the natural mean annual streamflow. Catchment dams are harvesting 143 ML annually assuming a dam usage factor of 2, which is approximately 0.7% of the natural mean annual streamflow.
- Melbourne Water's Grace Burn Creek diversion harvests around 8125 ML annually, about 41% of natural mean annual flows. Seasonally, harvesting varies between 343 ML and 963 ML per month. This harvesting accounts for between 30% and 60% of natural monthly streamflows.
- Private licensed diversion water harvesting peaks in January at an average of 18 ML per month, which is around 1.7% of the mean natural streamflow for the month.
- With a dam usage factor of 2, catchment dam water harvesting peaks in January and February, with 18 ML and 17 ML harvested on average for each month. This is approximately 1.7% and 2.3% of the natural mean flows for each month respectively.
- For every 1 ML of catchment dam development, the annual flow in the catchment will be reduced by 1.1 ML, assuming a dam usage factor of 2.

Watts River (Main stream, excluding Chum and Grace Burn Creeks)

The current level of catchment dam development is reducing streamflows in the Watts River catchment.

- The natural mean annual streamflow is 70,145 ML assuming a dam usage factor of 2.
- Licensed diversions are presently harvesting around 165 ML annually, which is approximately 0.2% of the natural mean annual streamflow. Catchment dams are harvesting 235 ML annually assuming a dam usage factor of 2, which is approximately 0.3% of the natural mean annual streamflow.
- Melbourne Water's Maroondah Reservoir diversion harvests around 61,875 ML annually, about 88% of natural mean annual flows.
- Private licensed diversion water harvesting peaks in January at an average of 57 ML per month, which is around 1.5% of the mean natural streamflow for the month.
- With a dam usage factor of 2, catchment dam water harvesting peaks in January with 29 ML harvested on average for the month. This is approximately 0.8% of the natural mean flows for the month.
- For every 1 ML of catchment dam development, the annual flow in the catchment will be reduced by 1.1 ML, assuming a dam usage factor of 2.

6. REFERENCES

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Photo Mapping Services, aerial orthophoto mosaic of Dandenongs / Yarra Ranges, flown March – April 2000 at 1:15,000.

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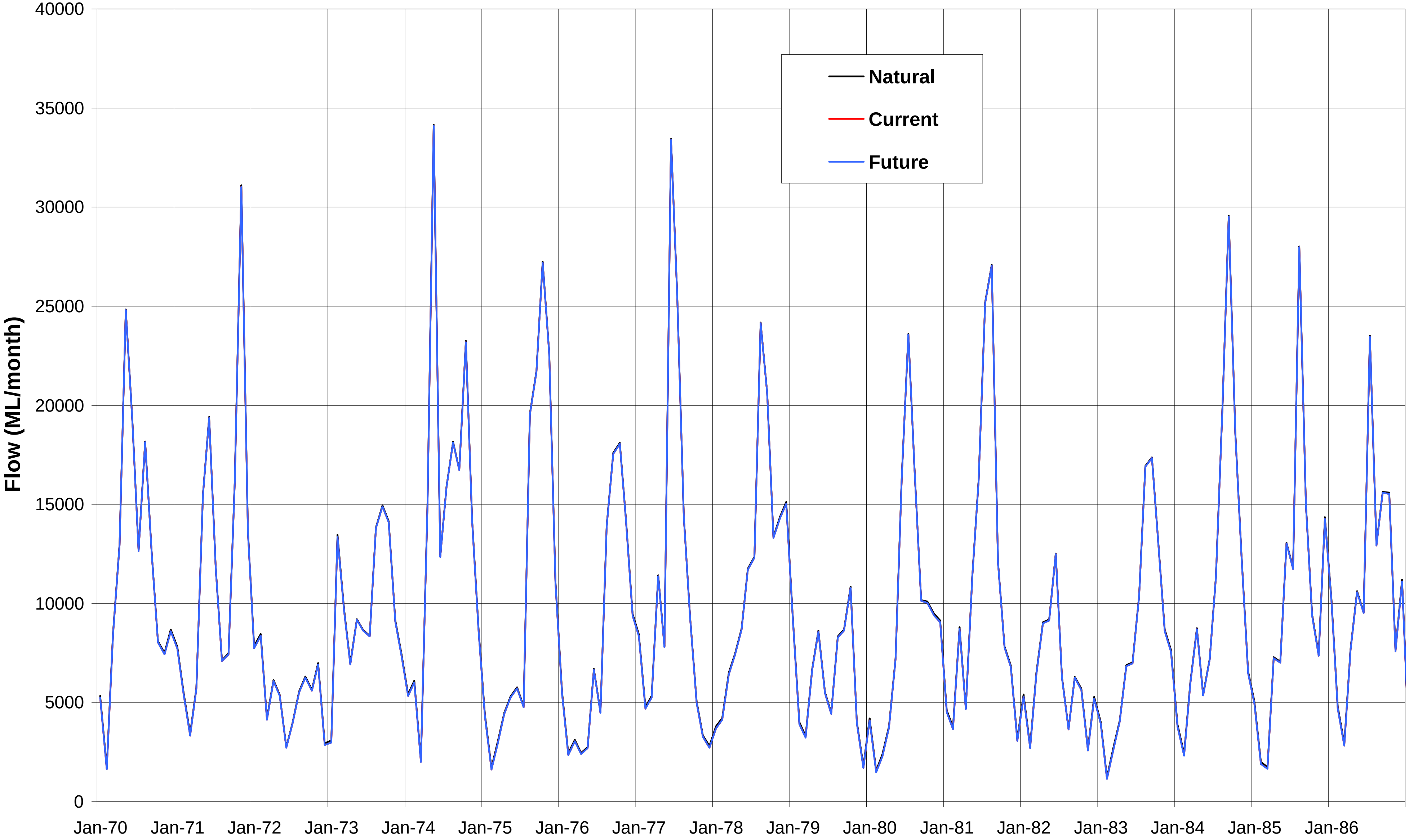
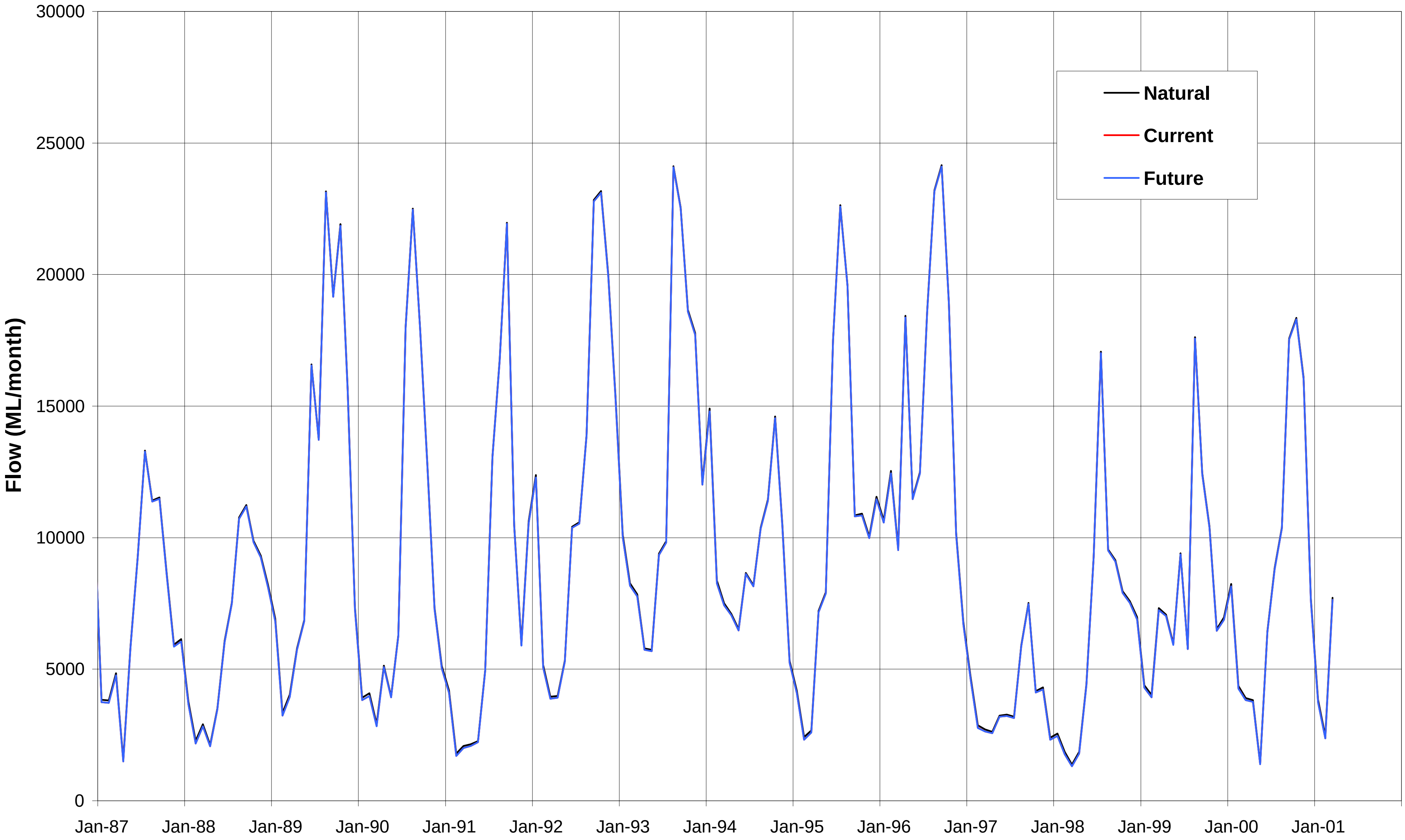
APPENDIX A – STREAMFLOW SERIES

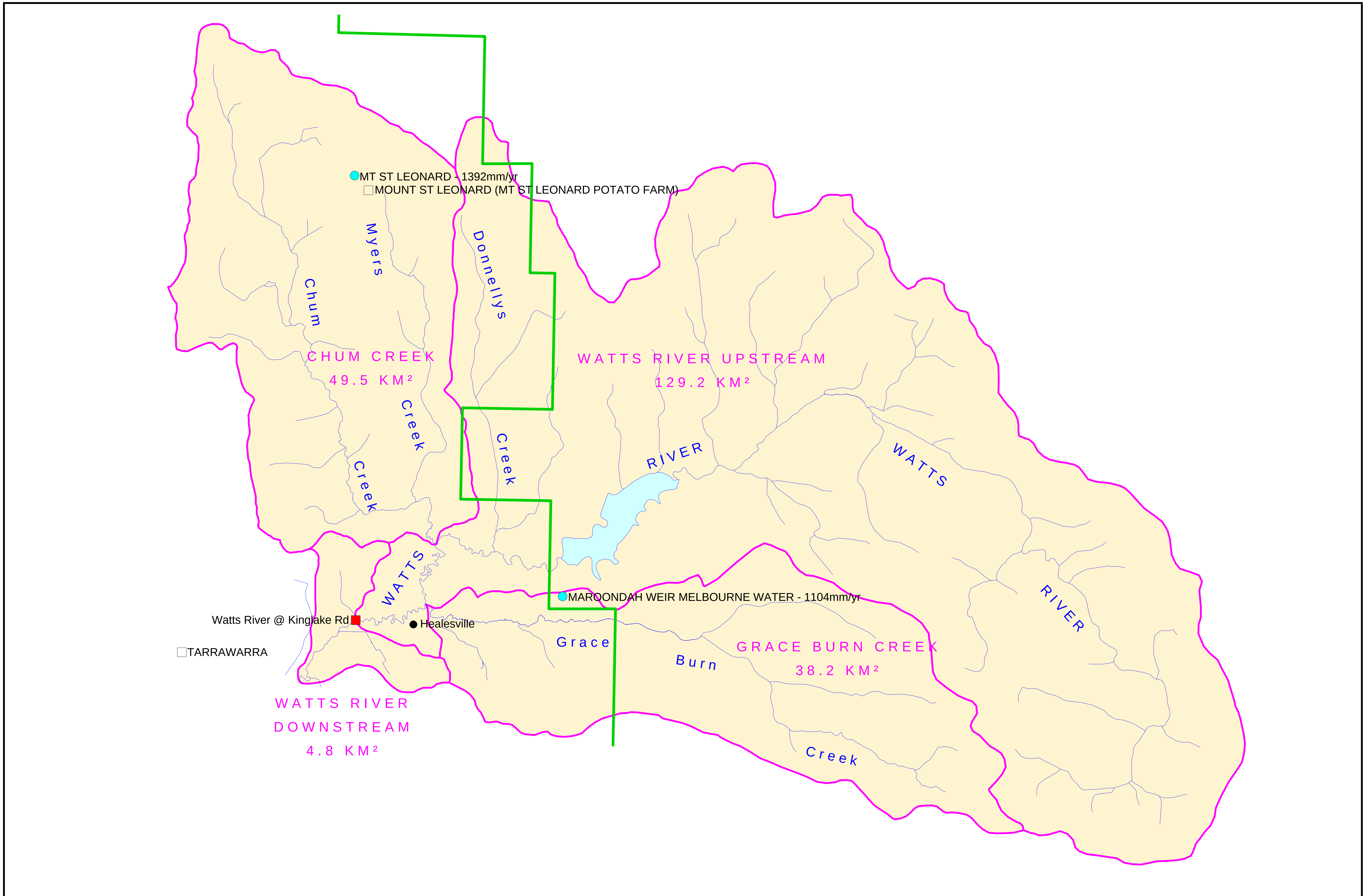
Watts River Streamflows - 1970 to 1986



Watts River Streamflows - 1987 to 2001



APPENDIX B – CATCHMENT MAPS



Estimation of Impact of Farm Dams on Streamflow - Watts River

Locality Plan

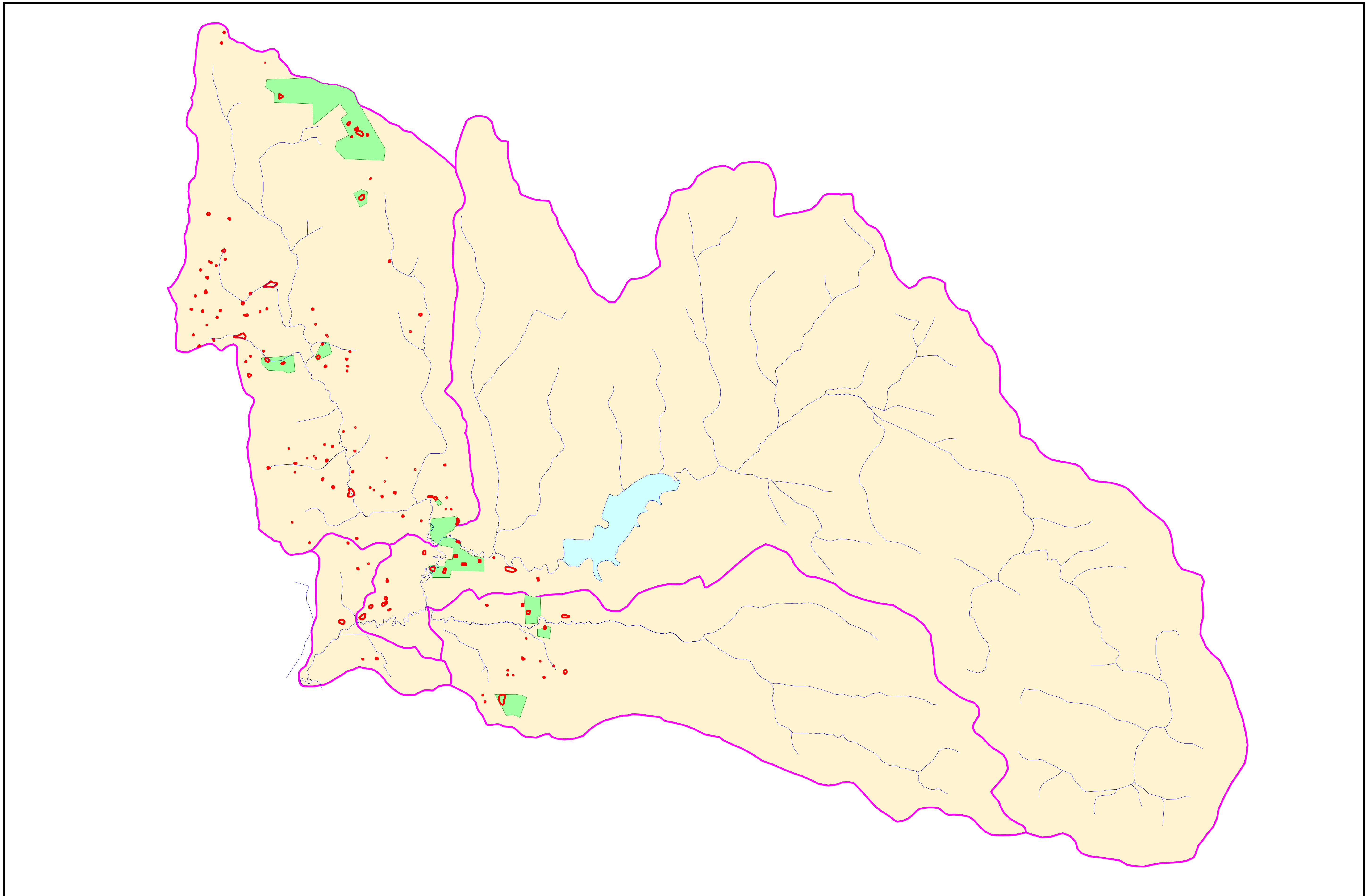
VV8916.002 - Appendix B

- Evaporation Gauges
- Stream Gauges
- Rainfall Gauges
- Limit of Aerial Photography
- Sub Catchments

0 1 2
Kilometres
Scale - 1:75,000

N

egis



Estimation of Impact of Farm Dams on Streamflow - Watts River

Dam Locations

VV8916.002 - Appendix B

Dams
Irrigation Areas
Sub Catchments

0 1 2
Kilometres
Scale - 1:75,000

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