Melbourne Water

Estimation of Impact of Farm Dams on Streamflows

Olinda Creek

March 2002

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ESTIMATION OF IMPACTS OF FARM DAMS ON STREAMFLOWS

OLINDA CREEK

Melbourne Water

March 2002

PROJECT NO: VV8916

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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 Olinda Creek near Lilydale 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 Olinda Creek 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 Olinda Creek, the natural streamflow can be calculated as

Natural Streamflow =	Gauged Streamflow
Plus	Licensed Diversions
Plus	Farm Dam impact

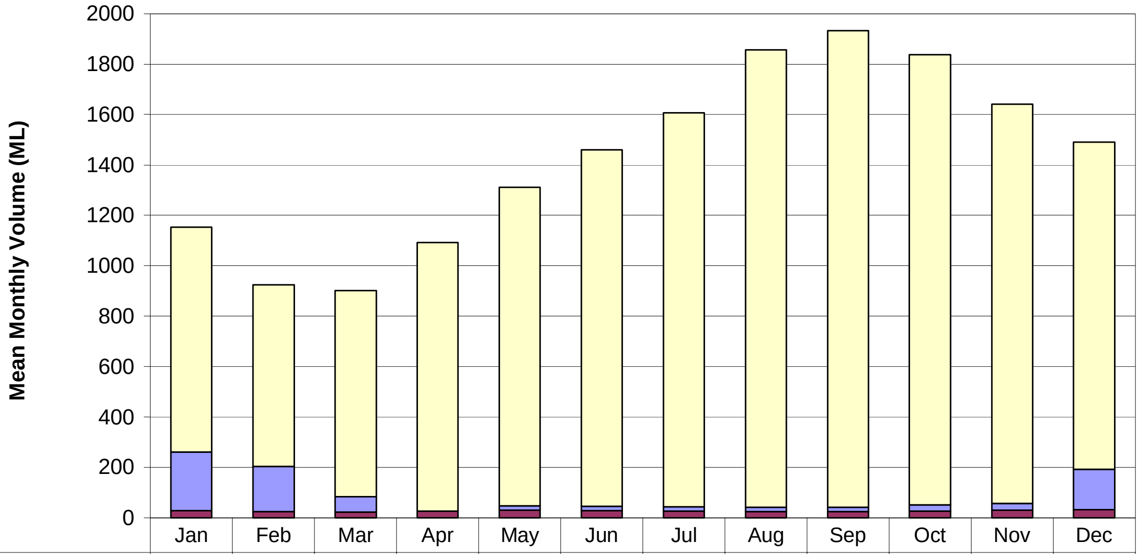
This process allows the effect of each diversion type to be assessed individually.

Results and Conclusions

Streamflow in Olinda Creek is affected by catchment dams, and will be further affected by additional catchment dams in future. Currently, approximately 1.4% of natural streamflows are being harvested by catchment dams.

- The current total volume of catchment dams in the Olinda Creek catchment is 151 ML, which represents 0.9% of the natural mean annual flow (49,730 ML).
- The current total volume of licensed diversions is 767 ML, which represents 4.4% 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 1.9% (327 ML).
- Assuming a dam usage factor of 2, the current level of catchment dam development has reduced 10 percentile high flows by approximately 1.4% (336 ML/yr), median flows by 2.0% (321 ML/yr), and 90 percentile low flows by 2.5% (313 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 0.6 ML.
- Dry spells are occurring more often, and are lasting longer than they would naturally. However, the majority of dry spells still start in February, the same as they would naturally.

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



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	891	722	818	1067	1263	1414	1562	1816	1892	1787	1585	1297
Current Diversions	233	180	60	0	17	17	17	17	17	24	27	160
Catchment Dams	29	24	23	26	30	29	27	24	24	27	31	33

1. INTRODUCTION

1.1 CATCHMENT DESCRIPTION

Olinda Creek rises to the east of Olinda Township in the Dandenong ranges, near Silvan reservoir. The stream flows generally north through natural forest before reaching the townships of Mt Evelyn and Lilydale, and passing through Lilydale Lake. Downstream of Lilydale, the creek has been straightened to maximise agricultural productivity in the surrounding farmland. Olinda Creek joins with both Stringybark Creek and the Yarra River south of the township of Yarra Glen.

Olinda Creek has a total catchment area of approximately 81 km^2, and an average annual rainfall of around 1070 mm, as described in Section 3.5.1. The current mean annual streamflow is estimated to be around 16,200 ML.

Upstream of Mt Evelyn, the catchment is heavily forested, despite some urban areas around Mt Evelyn and Kalorama townships. However, between Mt Evelyn and Lilydale, the catchment is predominantly urban, covering the suburbs of Mt Evelyn, Montrose, Mooroolbark, and Lilydale. Downstream of Lilydale, the catchment is extensively cleared, with areas of dairy farming, cattle grazing, vegetable crops, and several horse stud farms. A small area of viticulture exists on the Melba Highway, however these vineyards are irrigated using water from Stringybark Creek.

Also, the Lilydale Sewerage Treatment Plant, downstream of Lilydale, discharges treated effluent to the stream at a current rate of around 7 ML per day.

As with the rest of the Yarra Valley, an increasing number of properties in the Olinda Creek catchment are being used for irrigation intensive crops, such as viticulture. 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.

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.

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 Olinda Creek 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. Urban, stock, and domestic 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 Olinda Creek 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.

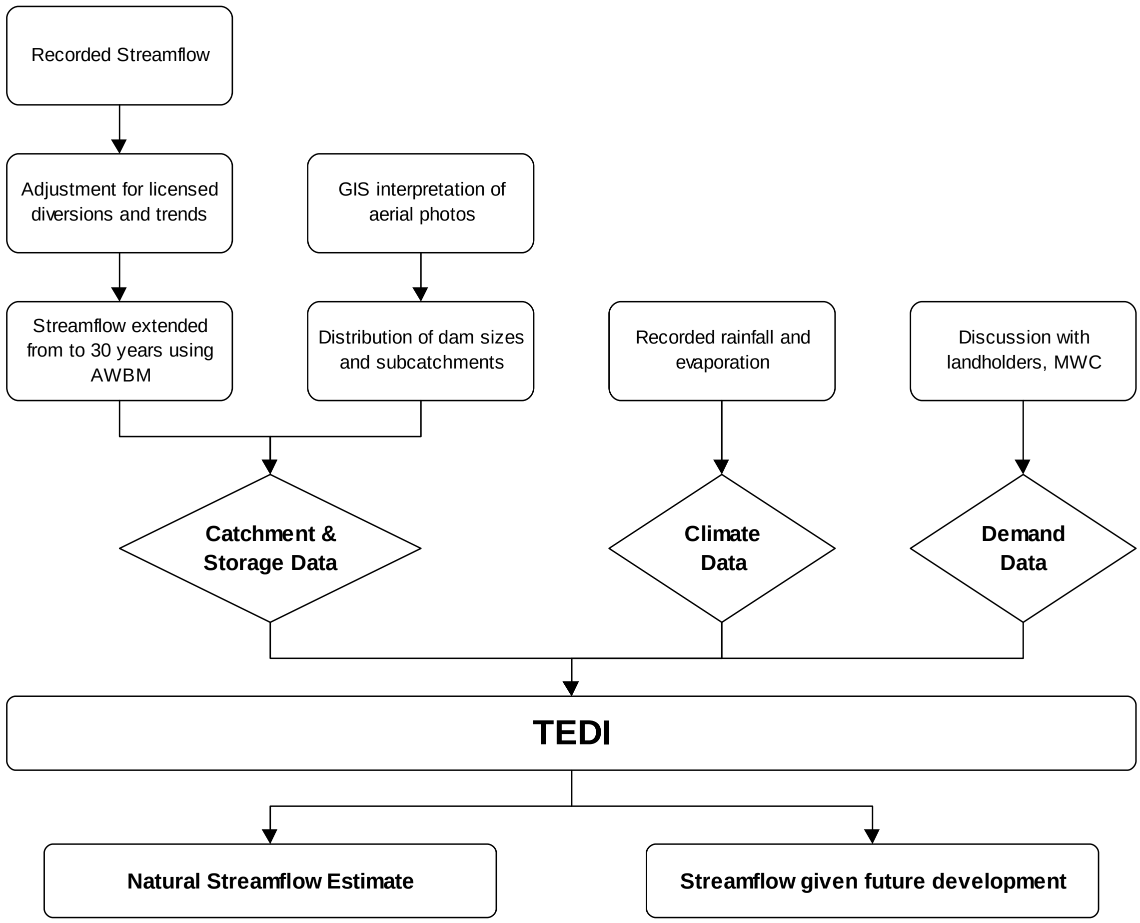
Climate Data

- **Average monthly rainfall and evaporation.**

2.3 MODELLING METHODOLOGY

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

Figure 2.1 – Schematic Of Modelling Methodology



The recorded streamflow data was only available for two sites in the catchment, neither of which were at the catchment outlet. Therefore, the recorded streamflow was firstly adjusted to make it representative of the entire catchment. Following that, the data was analysed to determine its quality and the significance of any trends. Also, the effect of licensed diversions was removed.

The streamflow record for Olinda Creek is available from 1987 to date. Since the model is required to be run over 30 years, the streamflow had to be extended back to 1970. This was completed using the AWBM model, as described in Section 3.1.4.

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 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 no significant tributaries exist within 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 was undertaken of the natural streamflow and the current streamflow record as calculated by the TEDI model. 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 Olinda Creek catchment, are described below.

3.1.1 Recorded Streamflow Data

The two streamflow gauges within the catchment are **229602 Olinda Creek at Beresford Rd** (Lilydale), and **229609 Olinda Creek at York Rd** (Mt Evelyn).

The Lilydale gauge is located downstream of Lilydale. Its subcatchment area is approximately 52 km^2, which is around 65% of the total catchment area. Being downstream of substantial urban areas, the gauge is significantly affected by urban stormwater runoff.

The Mt Evelyn gauge is located at the upstream end of the urban section of the catchment, and is therefore more likely to be representative of natural flow conditions. The gauge's subcatchment area is 32 km^2, which is around 40% of the total catchment area.

A comparison of records from the two gauges has shown that the Lilydale gauge was reading incorrectly for four years, between January 1991 and April 1995. This combined with the effect of urban development on the gauge readings made this gauge unsuitable for direct use in the modelling process.

Daily streamflow data for the Mt Evelyn gauge was available from 1987 through to 1999. An inspection of the data was undertaken, and it was found to be generally good, but with frequent gaps of 10 days or more. These gaps were ignored, and were filled in later when the streamflow record was extended to 30 years.

The Mt Evelyn gauge data was then adjusted to make it representative of the whole Olinda Creek catchment. This was achieved by increasing the daily flow proportionally based on both area and rainfall.

To increase the flow based on rainfall, each subcatchment was assigned a rainfall gauge as follows:

upstream of Mt Evelyn	Silvan rainfall gauge
between Mt Evelyn and Lilydale	average of Silvan and Lilydale rainfall gauges
downstream of Lilydale	Lilydale rainfall gauge

In this way, the streamflow contribution of each subcatchment was calculated, producing an estimated total flow for Olinda Creek.

3.1.2 Adjustment of Flows for Licensed Diversions

For all of the 30 year period, licensed diversions were removing water from the stream. 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.

The licensed diversion usage volumes were removed from the Mt Evelyn gauge data before it was adjusted to represent the entire catchment. Only licences located upstream of the gauge were included. In this way, the final flow estimate for Olinda Creek was representative of the total catchment without any licensed diversions.

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.

3.1.3 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 3.1 below shows the actual flows with the modelled flows. The line through the centre is the long term trend, given by the $\beta_1 t$ term in the above equation.

Figure 3.1 – Modelled Flows, Actual Flows, and Long Term Trend

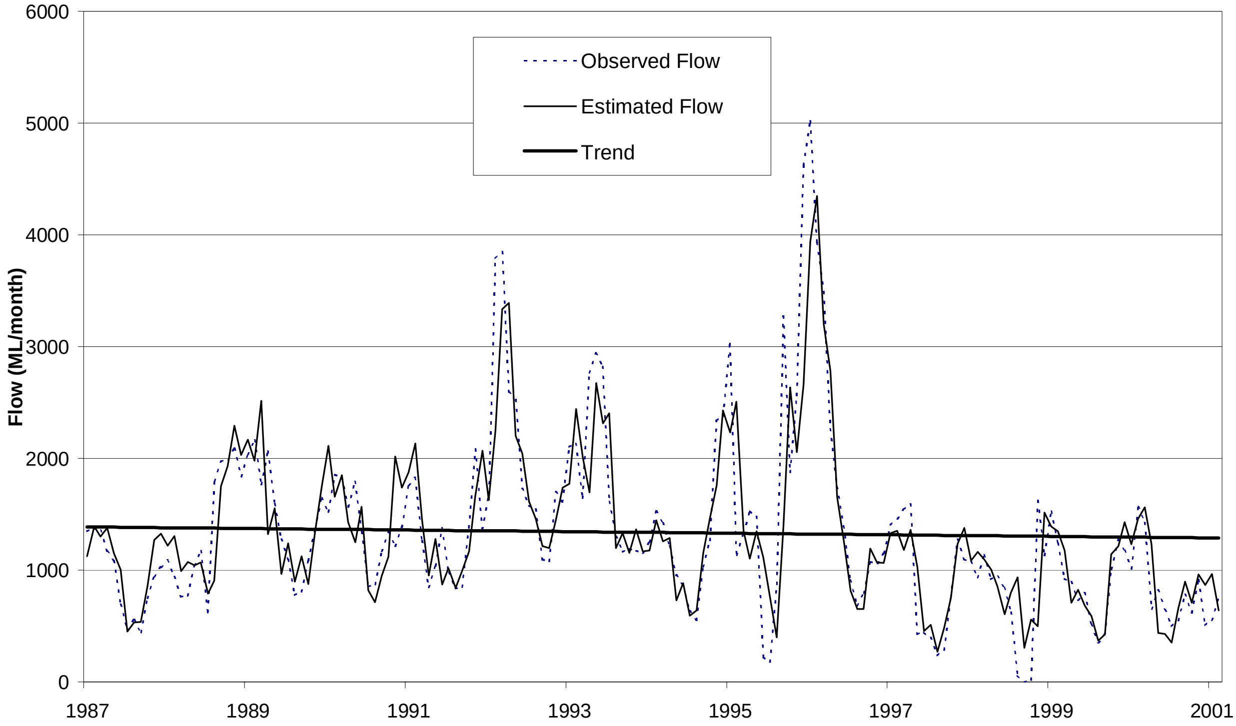


Table 3.1 – Calibrated Coefficients

Independent Variable	Coefficient	Coefficient Value
	β_0	-19.4
t	β_1	-0.59
R	β_2	4.95
$\sin(2\pi i/12)$	β_3	-45.6
$\cos(2\pi i/12)$	β_4	-167.5
Q_{t-1}	β_5	0.72

Using Table 3.1, the long term trend in the data can be calculated. Over 14 years, the month parameter **t** reaches a maximum of 168 months. Therefore, the long term trend over 14 years is an decrease in the average monthly flow of 99 ML, or about 7.1%.

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 0.20. This indicates that, assuming the streamflow data contains no long term trend, then the chances of obtaining a value for β_1 of -0.59 or less is about 1 in 5.

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

3.1.4 Extending the Length of Flow Record to 30 Years

The estimated streamflow data for the Olinda Creek catchment outlet covers the period from August 1987 to September 2001, only 14 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 ‘$\mathbf{K_b}$’.
- The length of time required for water in a stream to reach the catchment outlet depends on the surface recession constant ‘$\mathbf{K_s}$’.

Table 3.2 – AWBM Parameters Used

Storage 1		Storage 2		Storage 3		B	Kb	Ks
a	d	a	d	a	d			
0.2	0	0.1	5	0.7	240	0.25	0.4	0.99

3.1.5 Final Input into TEDI

The extended streamflow series 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 Olinda Creek 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:

Olinda Creek (upstream of Mt Evelyn gauge)	32.1 km^2
Olinda Creek (between Mt Evelyn and Lilydale gauges)	20.4 km^2
Olinda Creek (downstream of Lilydale gauge)	28.4 km^2
TOTAL	**80.9 km^2**

A map of the Olinda Creek catchment is shown in Appendix B.

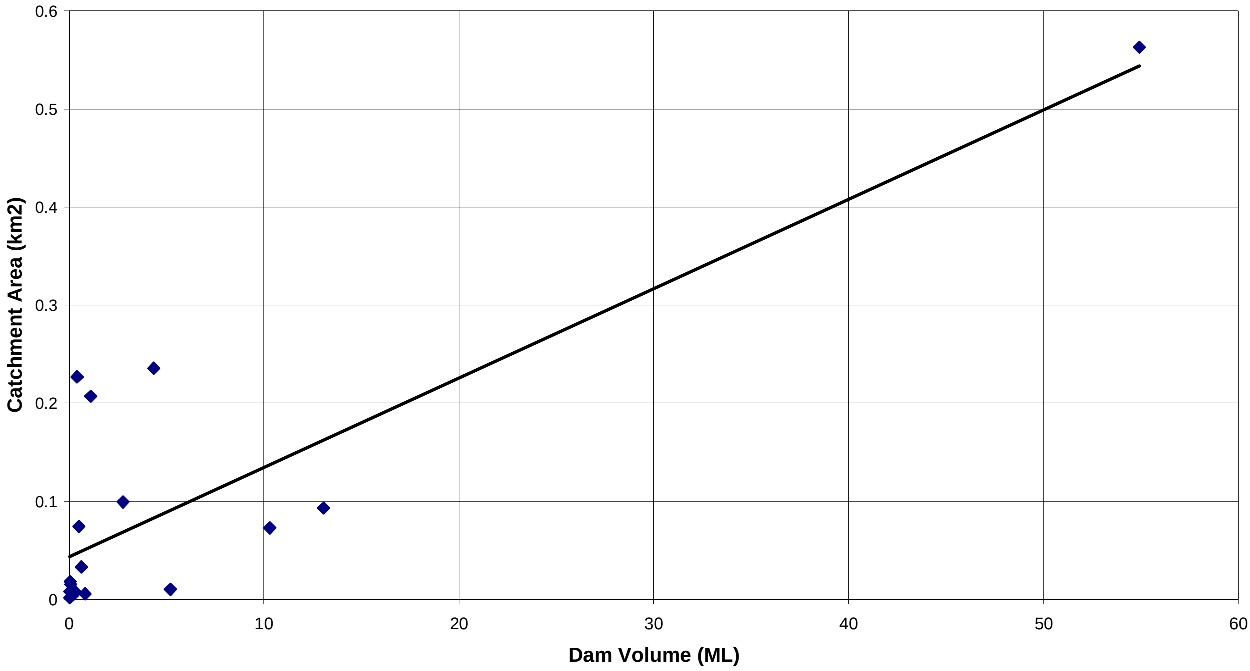
3.2.3 Subcatchment Areas for a 5 ML and 100 ML Dam

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 19 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 0.09 km^2 and 0.95 km^2 respectively.

Figure 3.2 shows the relationship between catchment areas and dam volumes.

Figure 3.2 – Catchment Area vs Dam Volume



3.2.4 Total Volume of Existing Catchment Dams

The total volume of existing unlicensed catchment dams within the Olinda Creek catchment was found to be 151 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.

The volumes within each catchment are as follows:

Olinda Creek (upstream of Mt Evelyn gauge)	7.9 ML
Olinda Creek (between Mt Evelyn and Lilydale gauges)	79.2 ML
Olinda Creek (downstream of Lilydale gauge)	64.2 ML
TOTAL	**151.3 ML**

It should be noted that the above volumes do not include Silvan Reservoir. This has been ignored because it does not contribute flows to the Olinda Creek catchment, and it collects the majority of its water from sources outside the catchment.

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 37 ML (24%).
- The total volume of all stock dams in the catchment is 115 ML (76%).

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 15 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 Olinda Creek catchment was based on the pattern used for a previous study for Hoddles Creek. The Hoddles Creek catchment is approximately 15 km east of Olinda Creek, with similar climate and similar irrigation types including orchards, vegetable crops, 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.

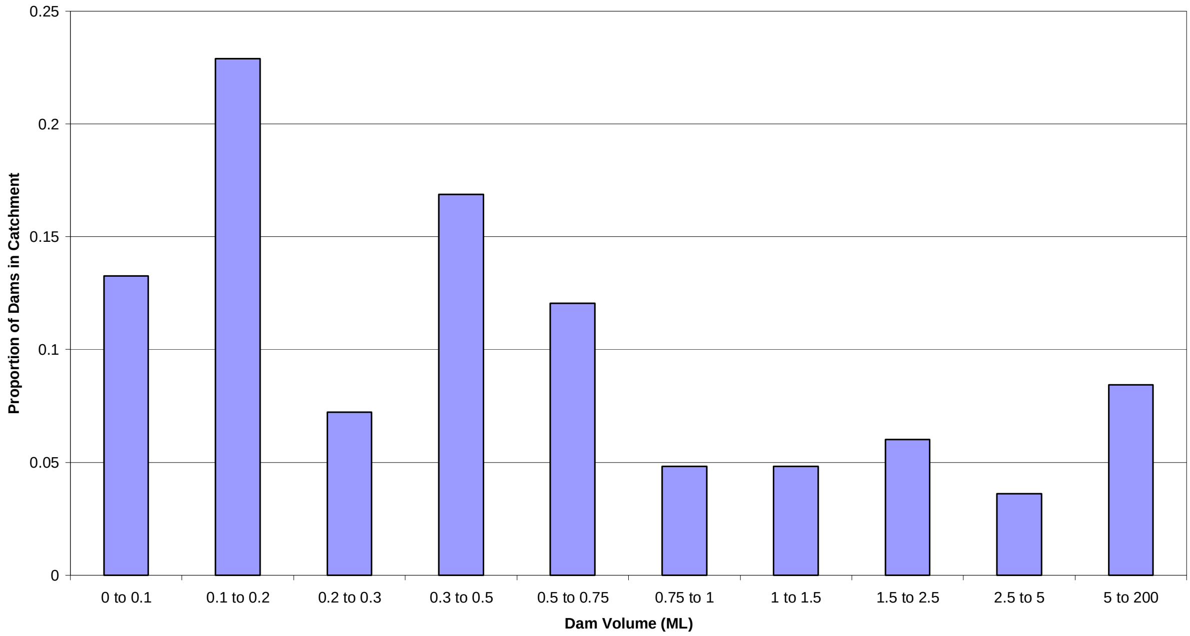
This factor applies only to irrigation dams. Stock / domestic dams always have a dam usage factor of 1.

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 3.3.

Figure 3.3 – 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	13.3%	22.9%	7.2%	16.9%	12.0%	4.8%	4.8%	6.0%	3.6%	8.4%
Average Volume (ML)	0.07	0.14	0.26	0.39	0.59	0.88	1.2	1.9	3.0	15.4

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 90% 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

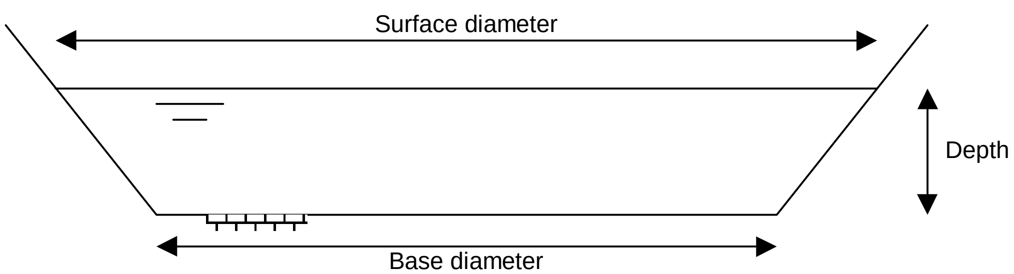
The relationship between the full surface area of a dam and its volume is complex. TEDI simplifies this by assuming a relation of the form

$$A = aV^b$$

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 3.4 below.

Figure 3.4 – Basis of Geometric Volume Calculations



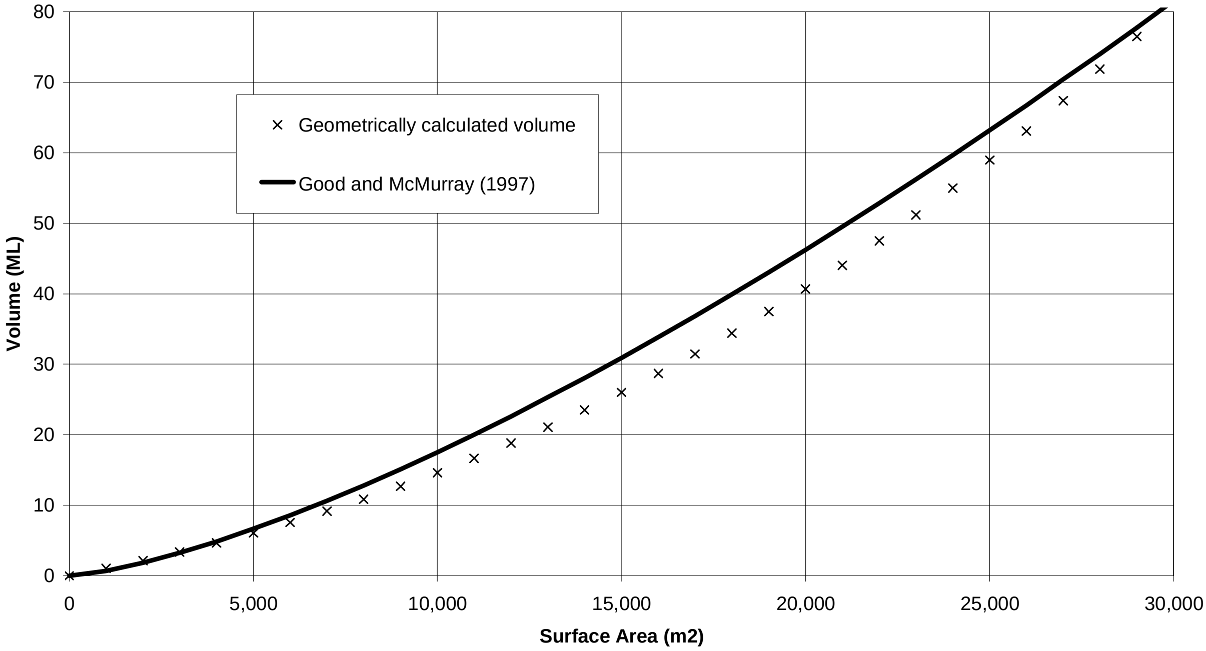
For a small dam (Volume = 1 ML), Depth = 1.5m, Base/Surface diameter = 0.6

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

Figure 3.5 – Dam Volume Relationships



The largest catchment dam in the study area is 55 ML, located on Olinda Creek, near Hull Road in Lilydale. 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:

86066	Lilydale	Jan 1970 to Oct 2001	(north end of catchment)
86106	Silvan	Jan 1970 to Dec 2001	(south east of catchment)

The monthly totals appeared to be complete, thus no infilling was required for the TEDI model.

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 within the locality.

Average monthly rainfall applied to the Olinda Creek 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)	63.2	54.6	63.7	85.5	102.2	101.2	91.9	111.4	107.5	106.1	93.4	85.1

3.5.2 Evaporation

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

Gauge 86104	Scoresby	Altitude 90m AHD
Gauge 86363	Tarrawarra	Altitude 76m AHD

The evaporation applied to the catchment was the average of these two gauges.

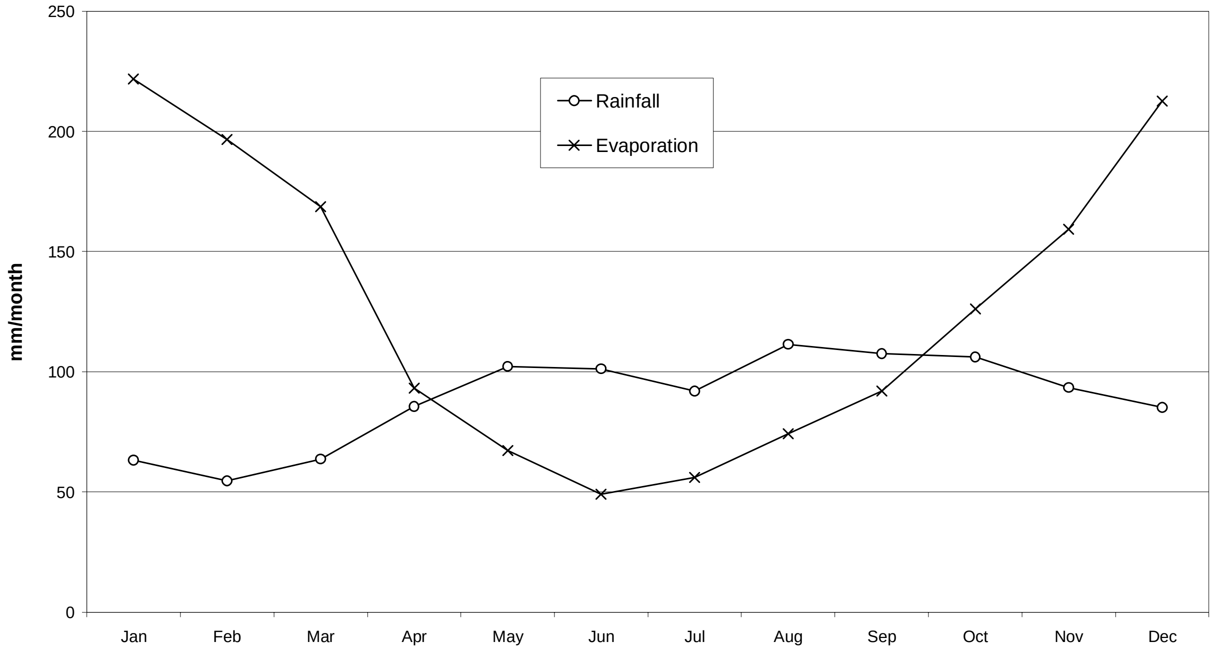
The average monthly evaporation used for the TEDI model has been shown in Table 3.6 below.

Table 3.6 – Average Monthly Evaporation Applied in the Model

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evap (mm)	221.7	196.7	168.7	93.2	67.3	49.0	56.0	74.2	91.9	126.2	159.2	212.6

Both Rainfall and Evaporation monthly averages are shown below in Figure 3.6.

Figure 3.6 – Average Monthly Rainfall and Evaporation Used



4. RESULTS

The results of the TEDI model for Olinda Creek are presented in the following section. 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.

Other analyses were carried out as part of the study, and the results of these analyses are presented in **sections 4.2 and 4.3**. The analyses include:

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

4.1 OLINDA CREEK

4.1.1 Dams and Diversions Within the Catchment

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

Current Licensed Diversions		
Direct Diversions	62 licences	665 ML
Winterfill Diversions	5 licences	102 ML
Total Diversions	**67 licences**	**767 ML**
Current Catchment Dams	83 dams	151 ML
Future Catchment Dams	3 dams	~10 ML

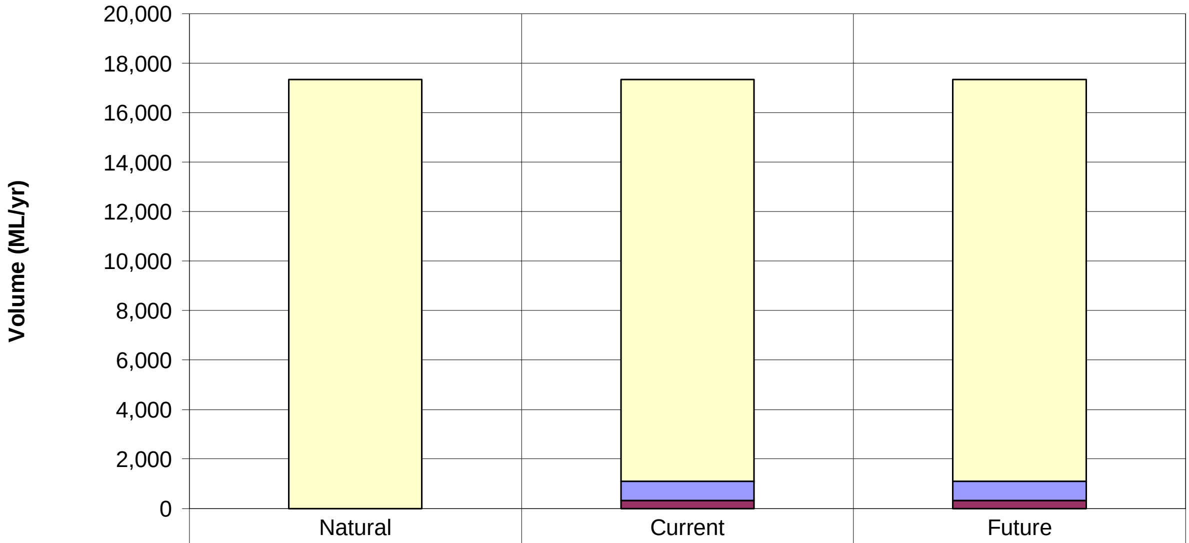
Details of licensed diversions within the catchment were provided by Melbourne Water in January 2002.

The majority of the dams and licenses are located toward the northern end of the catchment near Yering, and on the eastern side of the catchment, east of Lilydale. scattered dams exist in a narrow band along Olinda Creek up to the Mt Evelyn gauge, and several exist near the township of Olinda and Kalorama. The dams are shown in the map in Appendix B.

4.1.2 Annual Harvest Volumes

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	17,339	16,244	16,238
Diversions	0	767	767
Catchment Dams	0	327	333

The graph shows that the natural mean annual flow is 17,339 ML. Currently, 327 ML of this is harvested by catchment dams, and 767 ML is harvested by licensed diversions.

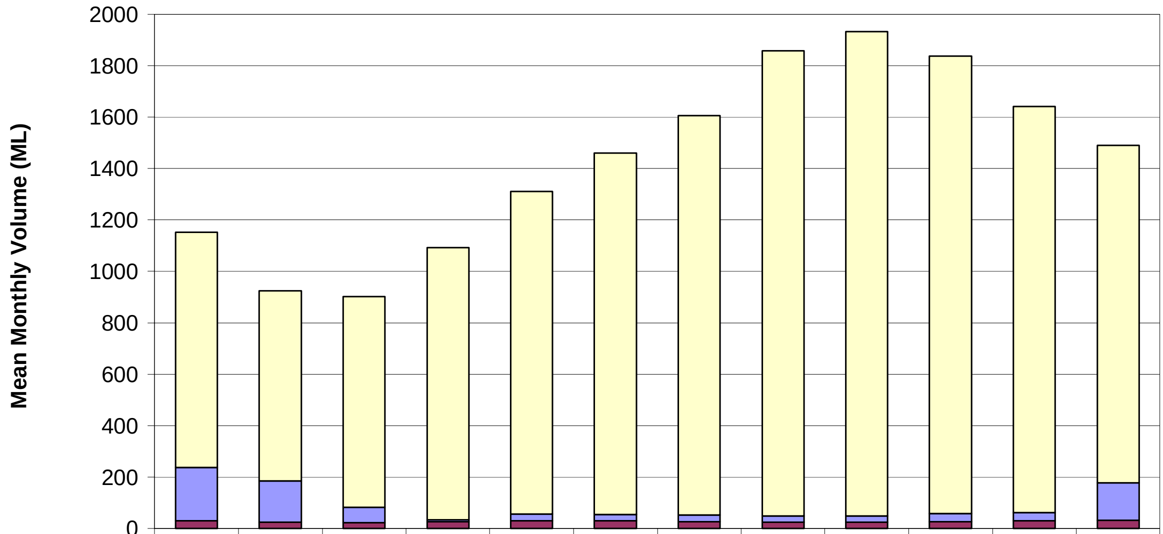
Clearly, the total volume harvested within the catchment by diversions and catchment dams is small, only approximately 6.3% of the natural mean annual flow.

4.1.3 Seasonal Variation in Harvesting

Water harvest volumes vary significantly through the year. Typically, harvest volumes are greatest between December and February when streamflow is lowest, and harvest volumes are typically low during other months.

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	916	740	818	1059	1255	1407	1554	1808	1884	1780	1581	1312
Current Diversions	208	161	59	8	25	24	25	25	24	31	31	145
Catchment Dams	29	24	23	26	30	29	27	24	24	27	31	33

Water harvest volumes by catchment dams are typically fairly constant throughout the year, peaking at 33 ML during December, and dropping to 24 ML during February, and also August and September. This constant demand reflects the low proportion of irrigation dams present in the catchment, as discussed in Section 3.3.1.

On average, licensed diversions harvest over 140 ML per month between December and February, peaking at 208 ML in January. During other months, the harvest volumes are much lower, with typically less than 30 ML from May to November.

However, the majority of flows are unallocated, varying from 740 ML in February, to almost 1900 ML of unallocated flows in September.

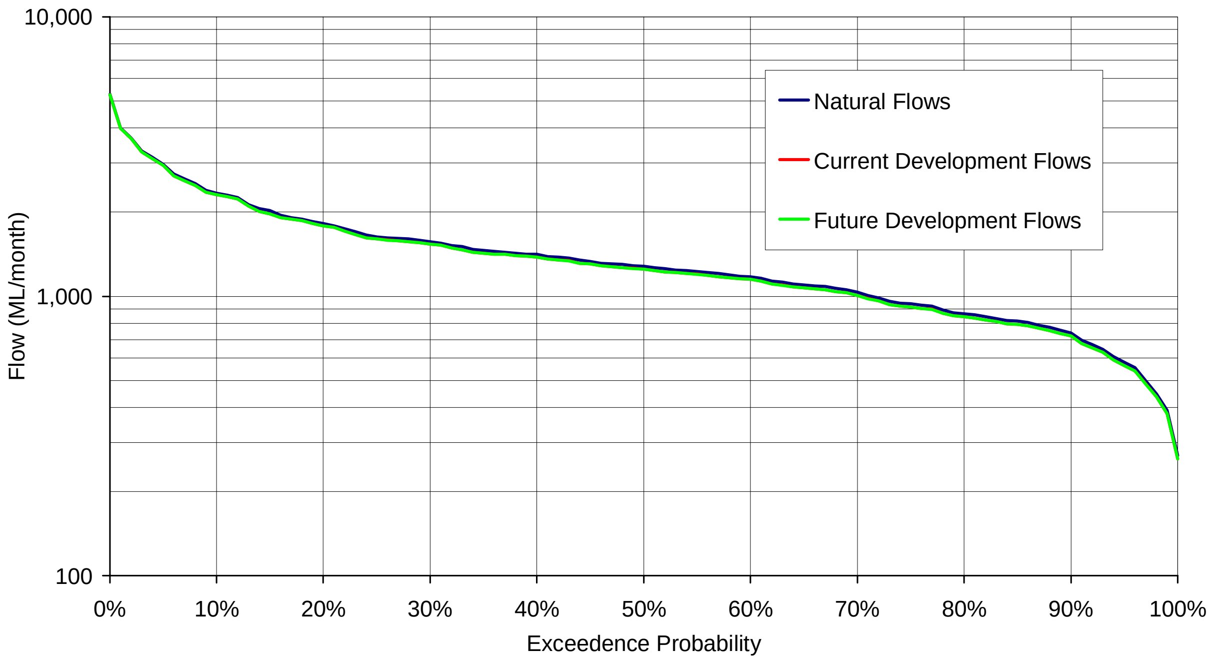
4.1.4 Impact of Catchment Dams on Streamflow

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

Figure 4.3 is a flow exceedence chart for the Olinda Creek outlet. 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 total monthly flow exceeding 1000ML is 70%. Another way of saying this is that, on average, a total monthly flow of 1000ML or more will occur 70% of the time, or seven months in ten.

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 40ML during months with high flows, which is around 1.7% of natural flows. Streamflow is reduced by 20 ML during months with low flows, which is approximately 2.6% of natural 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	12,278	15,998	23,648	17,339
Reduction in Streamflow per ML of additional catchment dam development	0.59	0.55	0.60	0.59

This table shows that for both high flow (Q_{10}) and low flow (Q_{90}) years, 1 ML of additional catchment dam development reduces the annual flow by approximately 0.6 ML.

For example, if the catchment contained an additional 200 ML of catchment dams, the reduction in annual streamflow would be 120 ML in both wet and dry years.

4.2 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.

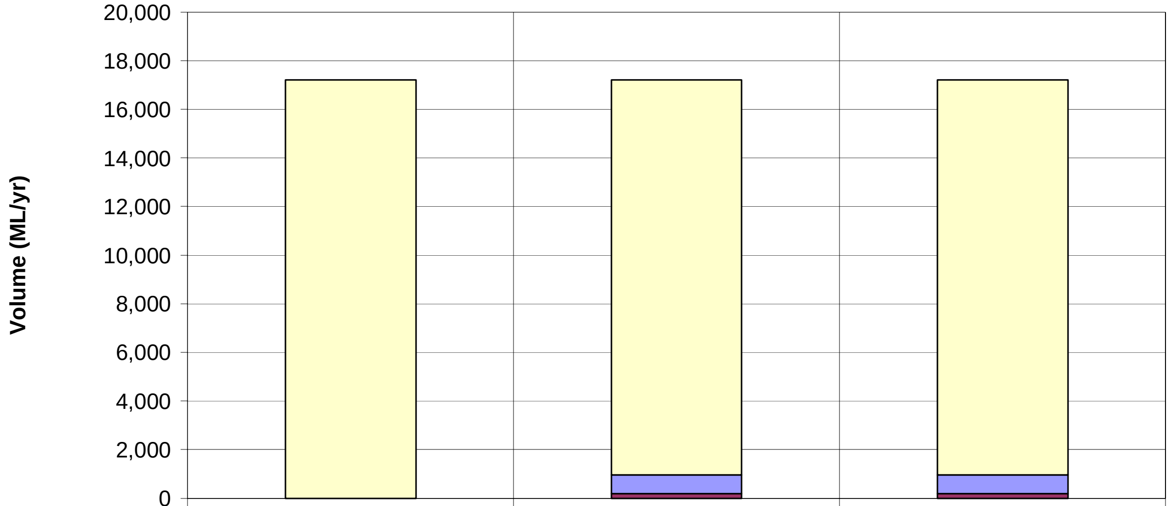
The discussions to determine the most appropriate dam usage factor took place for a similar streamflow study for Steels, Pauls, and Dixon's Creeks, located in the Yarra Valley near Yarra Glen (Egis 2001). Since those discussions took place, it has been decided that an investigation into the effect of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

4.2.1 Difference in Annual Harvest Volumes

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

Figure 4.4 – Annual Harvest Volumes When Dam Usage Factor = 1



	Natural	Current	Future
Streamflow	17,207	16,244	16,240
Diversions	0	767	767
Catchment Dams	0	196	200

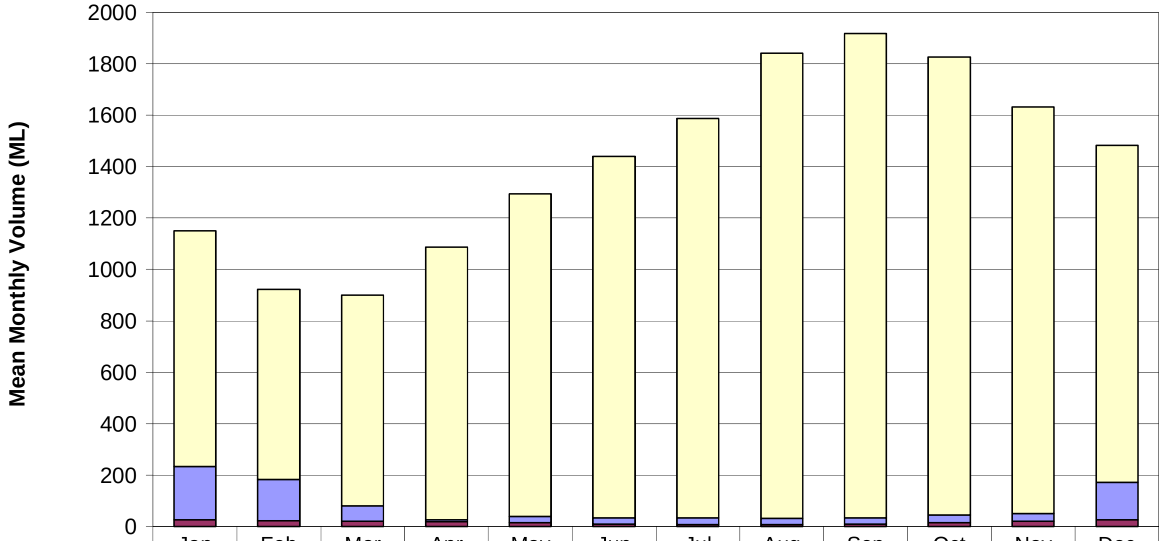
Catchment dams harvest half as much, only taking 196 ML for the current scenario, and harvest up to 200ML for the future development conditions. Licensed diversions are unchanged at 767 ML annually.

Reducing the dam usage factor has decreased the estimated natural mean annual flow by around 132 ML to 17,207 ML.

4.2.2 Difference in Seasonal Harvest Volumes

The graph in Figure 4.5 below shows that the volumes of water harvested by catchment dams changes when the dam usage factor is reduced, as expected. The pattern of usage has changed as well, with a more seasonal variation in harvest volumes evident.

Figure 4.5 – Seasonal Water Harvest Volumes When Dam Usage Factor = 1



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unallocated	916	740	818	1059	1255	1407	1554	1808	1884	1780	1581	1312
Current Diversions	208	161	59	8	25	24	25	25	24	31	31	145
Catchment Dams	26	22	21	19	14	9	8	7	9	14	20	26

Rather than steady demand throughout the year, catchment dams harvest more water during summer months, up to 26 ML during January. Harvest volumes are less during other months, dropping below 10 ML per month between June and September.

Harvesting from licensed diversions remains unchanged.

The unallocated flows are also unchanged, with summer flows reaching a low of nearly 722 ML in February, and winter flows peaking near 1900 ML in September.

4.2.3 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 4.1.4. 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 20 ML during months with high flows (Q_{10}), which is around 1% of natural flows. Streamflow is reduced by 20 ML also during months with low flows (Q_{90}), which is between 2.6% of natural flows.

Figure 4.6 - Flow Exceedence Curves when Dam Usage Factor = 1

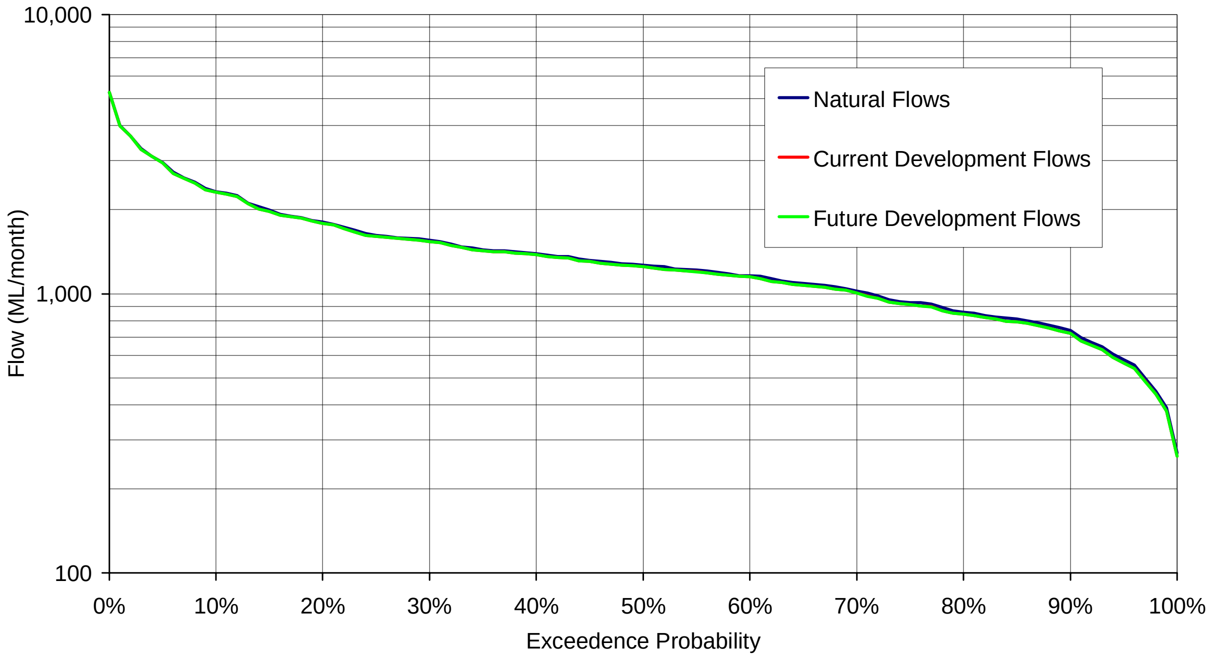


Table 4.2 below shows the difference in the effect on streamflow of each 1 ML of catchment dam development.

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 0.37 ML. This compares with a reduction in annual flow of 0.60 ML when the dam usage factor is two.

Table 4.2 - Impact of Catchment Dam Development When Dam Usage Factor = 1

	Q_{90}	Q_{50}	Q_{10}	Q_{mean}
Natural Annual Streamflow	12,162	15,864	23,510	17,207
Reduction in Streamflow per ML of catchment dam development	0.37	0.34	0.38	0.37

4.3 SPELL ANALYSIS

4.3.1 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 Olinda Creek. Specifically, a dry spell analysis is required for the natural and current streamflow series produced by the TEDI model.

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. **For Olinda Creek between 1970 and 2001, the natural 95 percentile exceedence flow was 580 ML/month.**

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.

4.3.2 Recorded Dry Spells

The table below details the dry spells recorded between 1970 and 2001 for the natural and current flow series.

For the current series, the longest dry spell recorded was 3 months, which occurred once between February and April 1983, and again between February and April 2000. The shortest dry spell recorded was 1 month, which occurred twice during the current flow series.

Table 4.3 – Details of Recorded Dry Spells

Series	Spells Counted	DS_{max}	DS_{10}	DS_{50}	DS_{90}	DS_{min}	DS_{mean}
Natural	11	3 months	3 months	2 months	1 month	1 month	1.8 months
Current	12	3 months	3 months	2 months	1.1 months	1 month	2.1 months

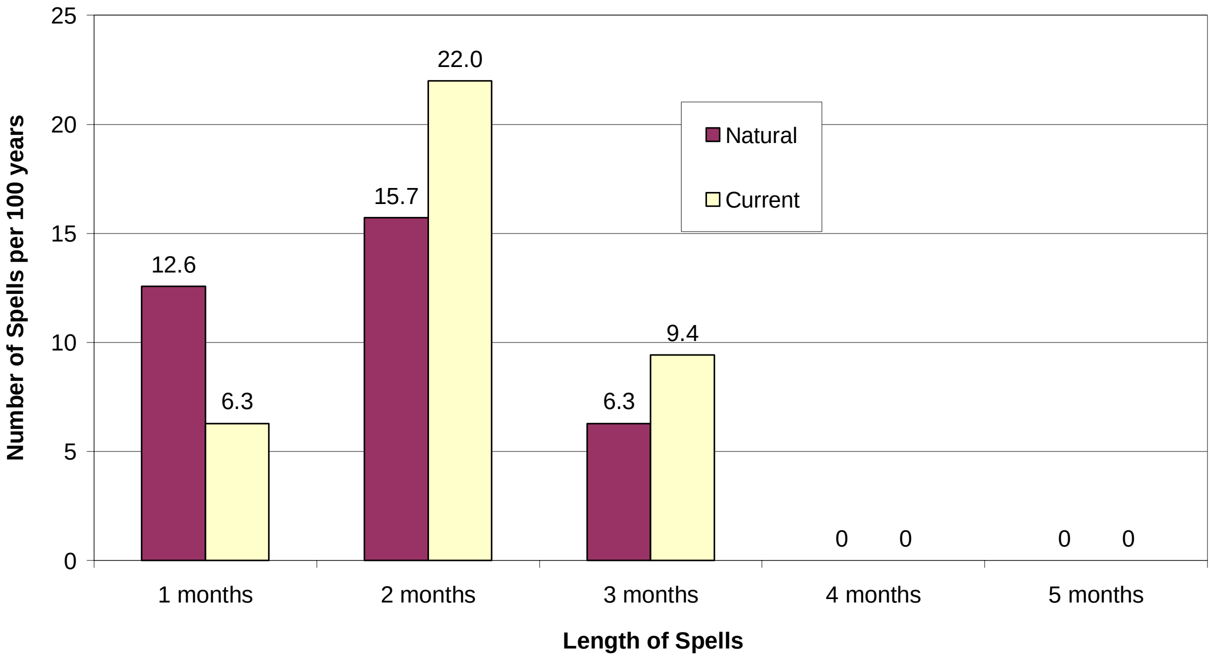
4.3.3 Frequency of Dry Spells

A histogram showing the length and number of dry spells per 100 years is shown in Figure 4.7. It shows that spells of 1 month duration occur infrequently, with around 6 dry spells likely to occur over 100 years currently, compared with 13 dry spells naturally.

However, spells longer than this are now more common, with over 29 dry spells of 2 months or more likely to occur over 100 years currently. That equates to one dry spell of 2 months or more every 3.4 years.

These longer spells would occur less often naturally, with only 22 spells of 2 months or more likely to occur.

Figure 4.7 – Number and Length of Dry Spells per 100 Years



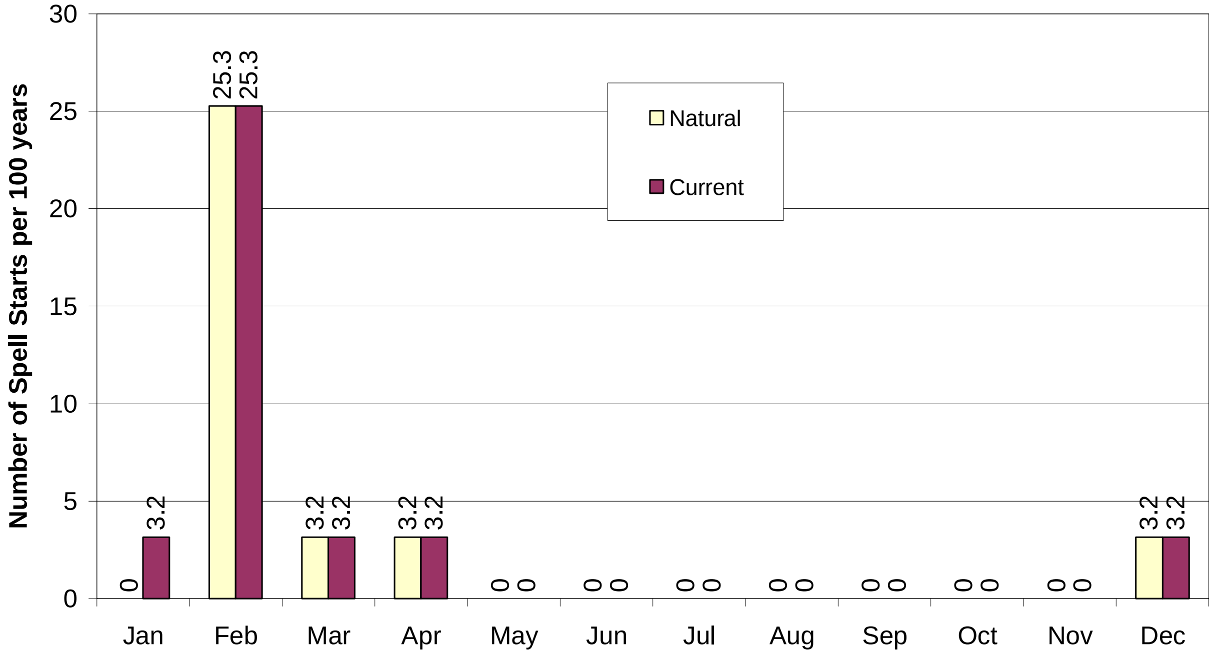
4.3.4 Seasonal Variation of Dry Spells

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

Clearly, February is the most likely month for dry spells to start, with a total of 66% of dry spells starting in this month in the current series. Some dry spells also start during December, January, March, and April.

Also, the chart shows that the current level of catchment dam development has not significantly affected the start month of spells, although some spells are expected in January in the current scenario, whereas none were expected in January for natural development conditions.

Figure 4.8 – Starting Months for Low Flow Spells



5. CONCLUSIONS

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

- The natural mean annual streamflow is between 17,339 ML and 17,207 ML, depending on the dam usage factor.
- Licensed diversions are presently harvesting around 767 ML annually, which is approximately 4.4% of the natural mean annual streamflow. Catchment dams are harvesting between 196 ML and 327 ML annually depending on the dam usage factor, which is approximately 1.0% to 1.9% of the natural mean annual streamflow.
- Licensed diversion water harvesting peaks in January at an average of 233 ML per month, which is approximately 20% of the mean natural streamflow for the month.
- With a dam usage factor of 2, catchment dam water harvesting is steady throughout the year, between 24 and 33 ML per month.
- With a dam usage factor of 1, catchment dam water harvesting peaks in January, with 26 ML harvested on average for that month. This is approximately 2.3% of the natural mean flow for January.
- For every 1 ML of additional catchment dam development, the annual flow in the catchment will be reduced by either 0.6 ML or 0.37 ML, depending on whether the dam usage factor is 2 or 1 respectively.
- Dry spells are occurring more often, and are lasting longer than they would naturally. However, the majority of dry spells still start in February, the same as they would naturally.

6. REFERENCES

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Institution of Engineers Australia (1998), *Australian Rainfall and Runoff*, 1998.

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

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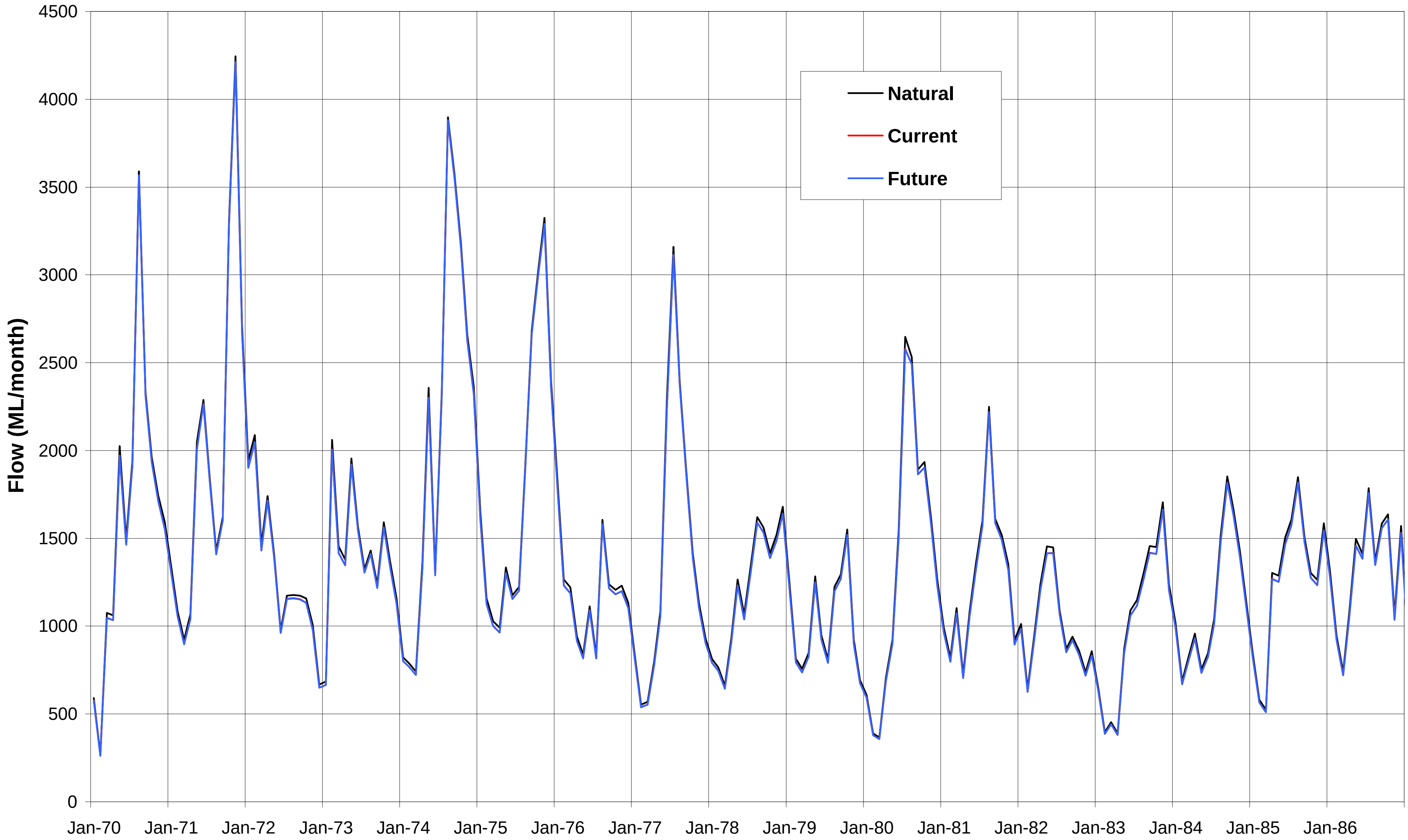
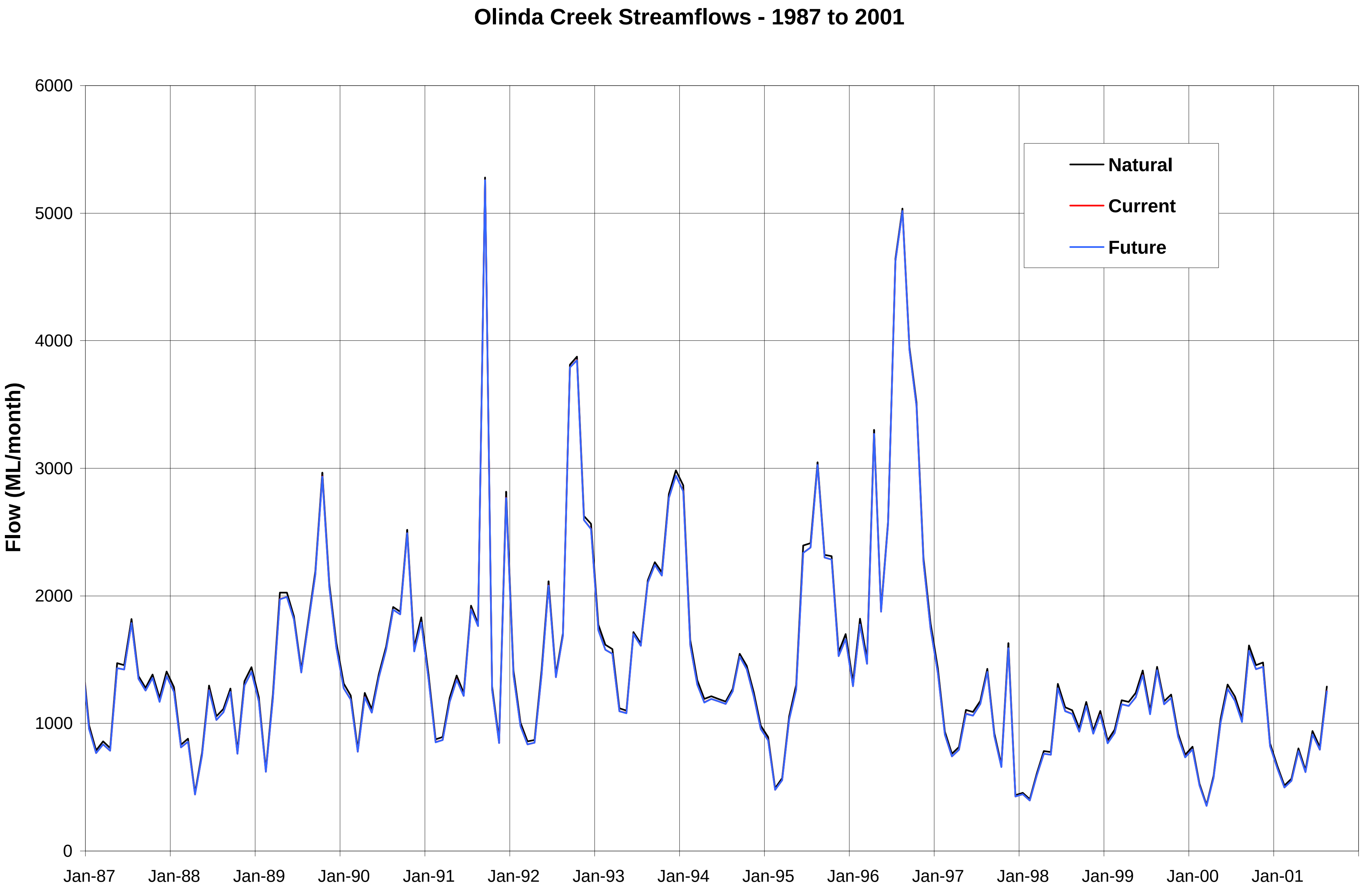
APPENDIX A – STREAMFLOW SERIES

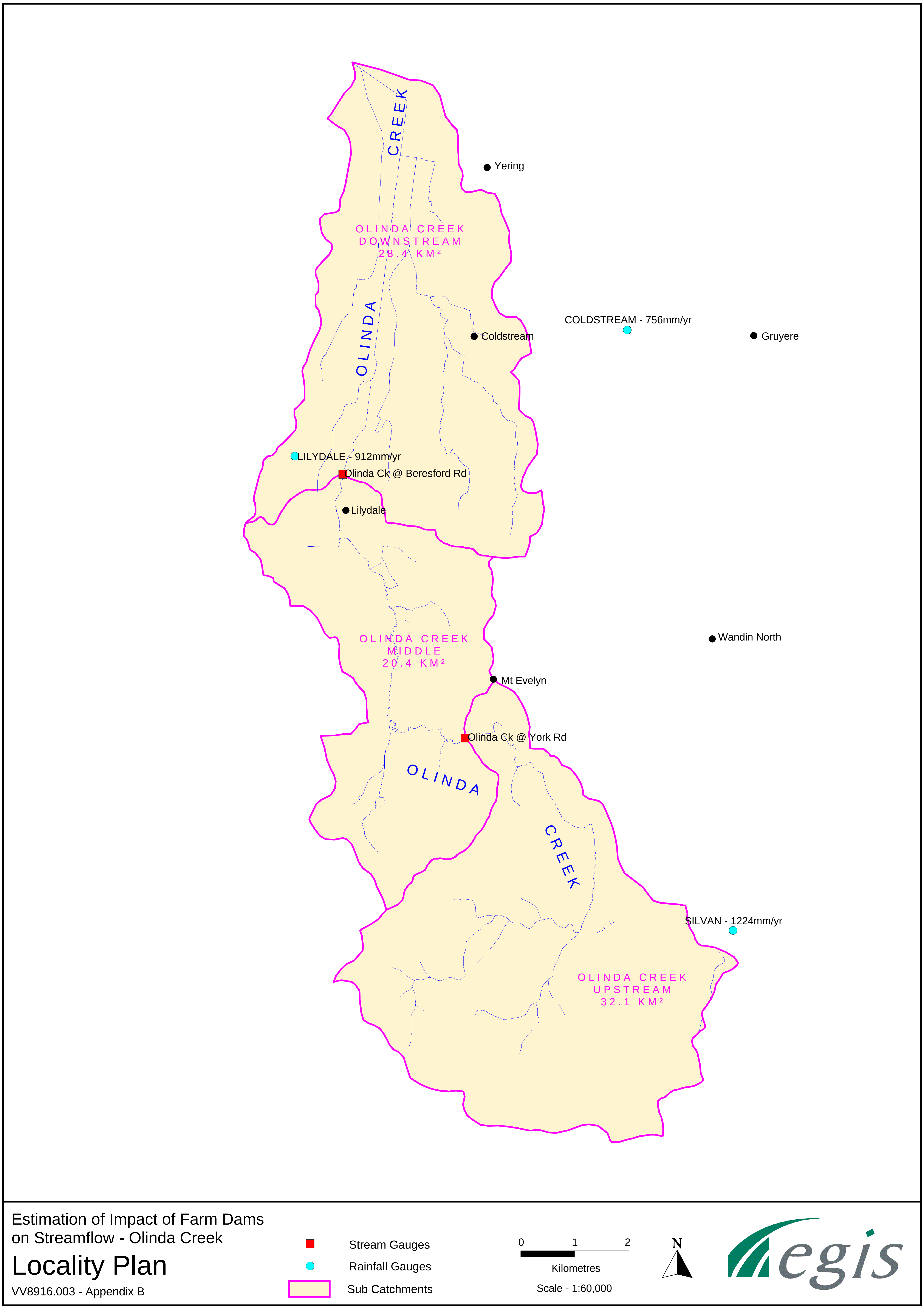
Olinda Creek Streamflows - 1970 to 1986





Olinda Creek Streamflows - 1987 to 2001
Flow (ML/month)
6000
5000
4000
3000
2000
1000
0
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Natural
Current
Future

APPENDIX B – CATCHMENT MAPS



Estimation of Impact of Farm Dams
on Streamflow - Olinda Creek

Locality Plan

VV8916.003 - Appendix B

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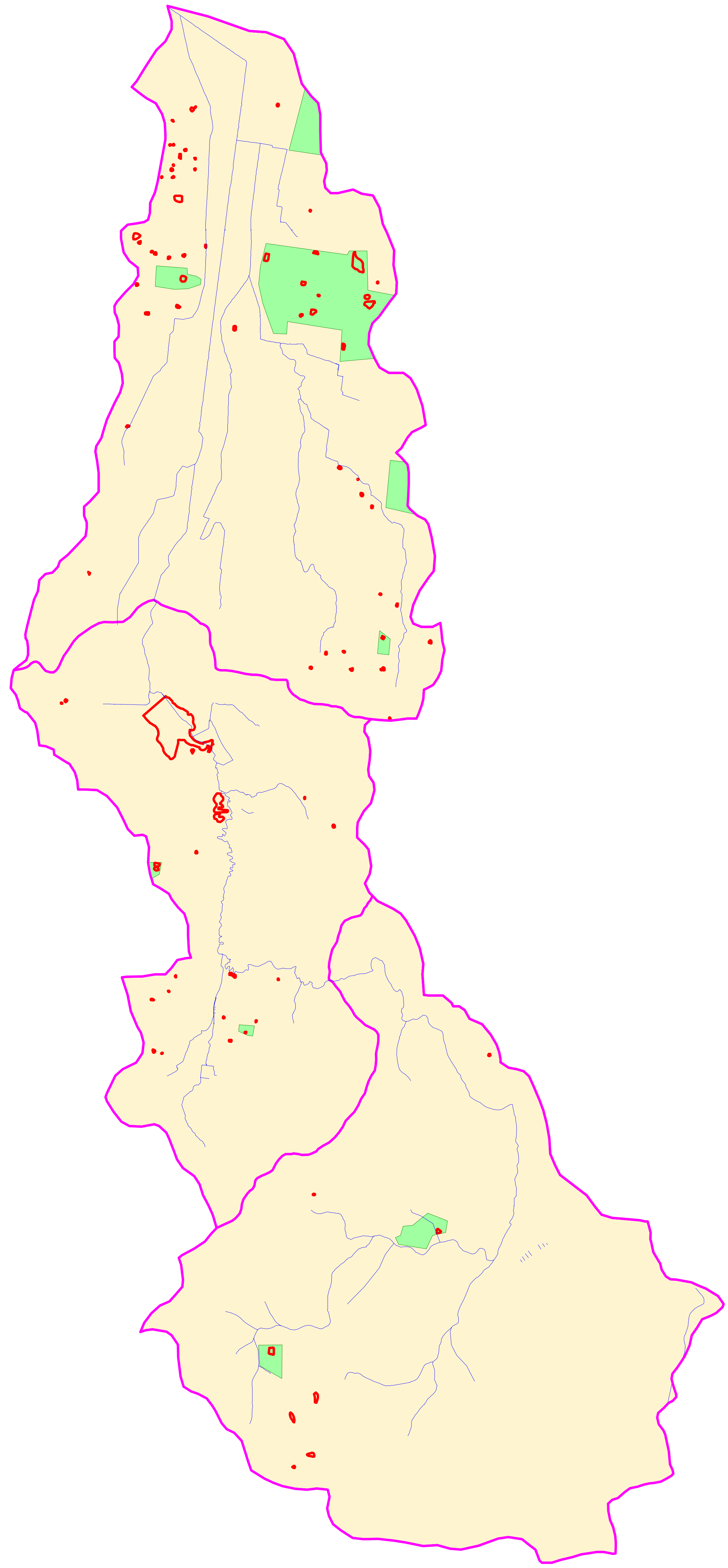

Estimation of Impact of Farm Dams on Streamflow - Olinda Creek

Dam Locations

VV8916.003 - Appendix B