Northern Victoria Application Project: The Ovens River.

Authors
Kirsten Barlow, Anna Weeks, Faith Githui, Brendan Christy, Xiang Cheng
The Ovens River near Myrtleford, Victoria (photo supplied by K. Barlow DPI Victoria).

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Kirsten Barlow ¹,²
Anna Weeks ¹,²
Faith Githui ¹,²
Brendan Christy ¹,²
Xiang Cheng ¹,²

¹ Future Farming Systems Research, Department of Primary Industries, Victoria, Australia
² eWater CRC, Innovation Centre, University of Canberra, ACT, Australia

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1 Executive Summary

1.1 Background
This research is part of the “Northern Victoria Focus Catchments (Goulburn and Ovens)” application project within the eWater CRC. The overall project is investigating how potential flow scenarios and the management of environmental flows can influence river and floodplain ecology.

The work presented in this technical report is focused on the hydrological component of the Northern Victoria application project and will investigate the surface water resources in the Ovens River catchment. The main aims of the work were to:

- present and analyse the input data for both the Source Catchments and CAT models, including spatial data, streamflow, climate and water extractions.
- investigate the application of PEST (parameter estimation tool) to calibrate a simple Base Model of the Ovens River using Source Catchments and discuss some of the landscape complexity which is not captured by the model.

1.2 Results
This technical report has presented the results of the first stage of an investigation into the importance of landscape connection and complexity in the prediction of streamflow at the catchment scale. In particular it presented the results of the parameterisation of a simple Base Model of the Ovens catchment, from which further complexity and the impacts on modelled streamflow can be assessed.

There was a significant component of the report which centred around gathering input data (stream flow, climate and extractions) and validating the input data, particularly the techniques for providing spatial climate data for catchment modelling. In terms of the climate data two quite different approaches to generating climate data for a Source Catchments scenario were investigated. The two methods used were:

- Climate from the 5km gridded data sourced from Queensland Department of Natural Resources and Environment’s SILO service
- Climate generated using the Catchment Analysis Tool (CAT), which involves scaling raw point-source climate station Bureau of Meteorology (BOM) data (sourced from QDNRE SILO service) by interpolated mean-monthly spatial layers using the ANUCLIM software.

In the Ovens Base Model there was good correlation between the climate generation techniques for the majority of sub-catchments. Each method had a number of advantages and disadvantages which were discussed within the report.

Automated processes were established to generate optimal hydrologic parameters for a scenario in Source Catchments using PEST and to create
standardised methods of reporting calibration results out of PEST. While the initial setup of the PEST files was complex, the automated process developed was able to generate the required PEST files quickly, run PEST and extract the results for analysis. This automation, combined with the power of PEST as a parameterisation tool was a key result from this work and we will allow us to continue to utilise PEST with Source Catchments into the future.

The initial calibration of the Base Model of the Ovens catchment presented in this report highlighted the need to incorporate more landscape complexity within the model. Only 60% of the modelled sub-catchments achieved an acceptable calibration based on the coefficient of efficiency and cumulative flows. In general the best calibrations appeared to be the upper sub-catchments in the Ovens and Buffalo Rivers as well as the King River upstream of Wangaratta. Generally the worst catchments were along the Ovens (including the Wangaratta gauges), with a significant number of the poorest parameterisations in sub-catchments with known town extractions and poor upstream model results.

1.3 The Next Steps

Using the Base Model and the automated PEST processes, the project will focus on the investigation of how landscape connection and complexity affect the prediction of streamflow at the catchment scale. However, before the increased complexity can be investigated there were a couple of factors which need to be corrected within the Base Model, specifically:

- Remove the climate anomalies from the scenario (i.e. remove the Mt. Buller, Mt. Hotham and Mt Buffalo Chalet climate stations from the climate generation model).
- Check climate and streamflow inputs for the particularly bad optimisation (403209 - Reedy Creek) and re-run the parameterisation using PEST and a range of different initial parameter values to determine if an improved parameterisation can be obtained.

The improved Base Model will then be used to start incorporating landscape complexity and analyse the impact on streamflow, determining whether increasing complexity is resulting in improvements in model predictions. The next steps in the investigation of landscape complexity are:

- Inclusion of town extractions (overall water balance)
- Inclusion of dam releases (timing and magnitude of flow in the downstream catchments)
- Inclusion of stream routing (hopefully using a sub-daily Muskingum routing method)
- Inclusion of groundwater interactions (particularly in the lower catchments around Wangaratta where we know that streams move between gaining and losing systems).

In addition to the investigation of landscape connection, extractions and dams, model robustness outside of the calibration period will be investigated. In particular does the model parameterisation hold when it is parameterised on
wet, dry or average rainfall periods and then cross validated. This analysis will utilise SIMHYD within the Base Model as well as CAT/CATNode to determine our confidence in the ability of the model to be utilised for future climate scenarios.

1.4 Recommendations

- **Parallel development of e2commandline and Source Catchments.** PEST linked to Source Catchments provided a powerful tool that can simultaneously optimise hundreds of Rainfall-Runoff models whilst accounting for stream routing, dam releases and extractions. It is unlikely that we would use Source Catchments without PEST, as such it is imperative the development of e2commandline is kept inline with Source Catchments so that future functionality within Source Catchments can be utilised while still allowing the use of PEST.

- **Source Catchments Plugin to fully automate the link to PEST.** It our view that PEST should be incorporated as a standard tool within Source Catchments. The current tools within the PEST plugin go a long way to meeting this however further development would be required to fully automate the process.

- **Manually drawn Source Catchment networks need to allow nodes at the gauge points.** To utilise the full capability of Source Catchments, i.e. include routing and dam models in the optimisation it is essential that the modelled streamflow at actual the gauge point can be obtained from Nodes. This was not possible for our manually drawn nodal network in Source Catchments (v1.02b) where we had to use the Link Outflow downstream from the sub-catchment to compare to our gauge data because the Node Outflow and Link Inflow did not account for the sub-catchment contributions. This limited the ability to include stream routing as these affected the Link Outflows and therefore the data that was being attributed to the Gauge.

- **Consider a groundwater loss term in SIMHYD.** Applying SIMHYD to the smaller sub-catchments in the Ovens Base Model was problematic as SIMHYD assumes that each sub-catchment is hydrologically isolated and that the only pathways for water export is evapotranspiration and stream flow; an assumption that does not hold for some of the smaller sub-catchments,. A number of the ephemeral systems had to cut off baseflow completely, despite the catchments having a 60-70% baseflow contribution because the groundwater store was infinite and able to continually leak water into the stream. Introducing a single groundwater loss term into SIMHYD could overcome this problem and increase the capacity of SIMHYD to describe these smaller upland sub-catchments, alternatively a more complex rainfall runoff model like Sacramento could be utilised.
2 Introduction

One of the significant challenges faced in the management of water resources is balancing water use to maintain healthy water resources that support growing communities and a thriving economy now and into the future. Climate change and land use change impacts on these water resources represents an additional challenge in their management. By utilising a range of modelling tools this project contributes to our understanding and management of water resources in Victoria. This project is also an important first step in increasing our understanding of the importance of landscape connection and complexity in managing our water resources. Specifically this project will contribute to the delivery of the “Northern Victoria Focus Catchments (Goulburn and Ovens)” application project within the eWater CRC.

2.1 Background - The Northern Victoria Application Project

The Ovens and Goulburn rivers contribute significantly to the water resources of the Murray-Darling Basin. For example North East Victoria (Upper Murray, Kiewa and Ovens Rivers) contributes 38% of the water to the Murray Darling Basin from only 2% of the land. As such the management of water resources within the area is essential not only to North East Victoria but the larger Murray Darling Basin. These two rivers are similar in many ways in terms of their geomorphology, land use, and vegetation communities, but the Ovens River is largely unregulated while the Goulburn is highly regulated. Both rivers have high environmental value and natural biodiversity. Irrigated and dryland agriculture are very important in both catchments, and contribute significantly to the Victorian and National economies.

In their natural state, both rivers’ off-channel floodplain wetlands, red gum forests, and other ecosystems would be strongly influenced by seasonal flooding. Although the Ovens River still floods frequently, the Goulburn River, regulated by Eildon Dam, does not. This project is investigating how changing landscapes and climates potentially impact on flow, and how these processes combined with the management of environmental flows could affect river and floodplain ecology.

The key outcomes for the application project in order of priority are

- A better capacity, based on eWater models, to manage the provision of water between environmental and consumptive uses, and to take into account future climate scenarios in planning and management.
- More effective planning of environmental outcomes (whilst meeting consumptive needs) arising from optimisation across storage management, water delivery, EWR delivery, changing irrigation industries, and river restoration works.
- More effective day-to-day (operational) management of environmental water reserves across full climatic range
- Greater capacity for integrated surface and groundwater management.

The key areas of activity to achieve the outcomes are summarised in Figure 1 which presents a conceptual model of the major activity areas for the Northern Victoria application project. From a DPI Victoria perspective one of the key outcomes from the project will be an understanding of how the role that land management and landscape
complexity have in influencing the water resources, which in turn affects ecological and environmental assets.

Figure 1 Conceptual model identifying major areas of activity for the Northern Vic application project

The work presented in this technical report is focused on the hydrological component of the Northern Victoria application project and will investigate the surface water resources in the Ovens River catchment. This report presents the first step towards understanding how changing land use and climatic conditions affect the Ovens River and the ecological resources within the catchment.

2.2 The target catchment

The Ovens River is the only largely unregulated catchment of the Murray. It has a high ecological significance, with parts of the Ovens nominated under the Heritage Rivers Act 1992 in recognition of the many significant features of these areas.

The Ovens River catchment is 6,295 km² which extends from the Murray River in the north, to the Great Dividing Range in the south. The catchment is diverse ranging from riverine plains near the Murray River and broad alluvial valleys around Myrtleford, to rugged alpine peaks and plateaux around the Great Dividing Range. Mt Buffalo, a large granite mass in the south of the basin, is an important landscape feature. While the Ovens River is largely unregulated, there are two small water impoundments at Lake Buffalo and Lake William Hovell with a combined capacity of 37.5 GL.
There are a range of land uses within the catchment including livestock production (sheep for meat and wool, beef cattle and some dairying) and horticultural production (traditionally tobacco, but now hops and vineyards). In the central and south-eastern regions of the Basin, hardwood logging and forest grazing are important.

2.3 Source Catchments

Source Catchments is the modelling framework used in this report. It is a catchment scale water quality and quantity modelling framework that supports decision-making and a whole-of-catchment management approach. It allows you to model the amounts of water and contaminants flowing through unregulated and moderately regulated catchments and into major rivers, wetlands, lakes, or estuaries. This software gives access to a collection of models, data and knowledge that simulate the effects of climatic characteristics (like rainfall and evaporation) and catchment characteristics (like land-use or vegetation cover) on runoff and contaminant loads from catchments. The node based integrated model usually operates at daily time steps and can produce reports at varying temporal scales (from daily to annual) and spatial scales (from a single subcatchment to a whole of catchment).

2.4 Aims

This technical report presents the first stage of a larger project which is investigating how Source Catchments as a modelling framework and CAT can be used to answer questions relating to land-use change and climate change within the Ovens Catchment. The main focus of this report is to:

- present and analyse the input data for both the Source Catchments and CAT models, including spatial data, streamflow, climate and water extractions.
- investigate the application of PEST to a simple base model of the Ovens catchment.
- initial discussion of surface and groundwater interactions in the Ovens Catchment and how these are likely to influence surface water models.
- identify the next steps.
3 Methods

This section of the report details the data and methods used in the development of the Source Catchments and CAT models of the Ovens River. It includes an analysis of some of the input data sources. Typically Source Catchments and CAT work with information that is commensurate with publicly available data, although both models have different data requirements. Some spatial data layers have been created or modified to suit the particular needs of the project. Such modifications will be explained within each layer description below.

3.1 Location of the Catchment

The extent of the study area for the Ovens catchment is shown in Figure 2.

![Figure 2 Location of the Ovens catchment in Victoria, with CMA boundaries shown.](image)

3.2 Topographical Data

Digital Elevation Models (DEMs) are a raster representation of the earth’s surface (Figure 3). The DEM used in this project was a 100m grid of the Ovens River Catchment. The DEM was used to build the sub-catchment maps for both the Source Catchments and CAT models of the Ovens River. The sub-catchment map for the Ovens was built using 2CSalt (1.0.8 Prototype, eWater Toolkit) as we were having problems with Source Catchments (Source Catchments 1.0.2b) locking our sub-catchments to the stream gauges. There was also a challenge at the lower end of the Ovens River where both Source Catchments and 2CSalt had problems building a stream network and therefore sub-catchments that fitted with the known stream systems due to very small changes in elevation. To overcome this problem and ensure that the sub-catchment map and stream...
network created was accurate a stream layer (Figure 4), checked against satellite imagery in Google Earth, was essentially burnt into the DEM using ArcInfo © (ESRI Redlands, CA, USA). This DEM with the stream network pre-defined was then used to create the final sub-catchment map (Figure 5), a more detailed sub-catchment map with smaller sub-catchments was also generated but is not presented or used in this report.

**Figure 3** Spatial map of digital elevation for the Ovens catchment in Victoria.
Figure 4 Stream layer overlaid on satellite image in Google Earth (v5.1.3535.3218, April 2010) for the Ovens catchment in Victoria.

Figure 5 Sub-catchment map for the Ovens catchment in Victoria, showing (a) the stream network, and (b) the stream gauge numbers.
The slope (Figure 6) layer was derived from the DEM using ArcInfo © (ESRI Redlands, CA, USA). Slope is reported as degrees from horizontal and was utilised by the CAT model.

![Figure 6 Spatial map of degree slope for the Ovens catchment in Victoria.](image)

### 3.3 Climate Data

The Ovens catchment has been configured within Source Catchments using the SIMHYD rainfall runoff model as the method of generating streamflow at the gauge points. SIMHYD is a daily conceptual rainfall-runoff model that estimates daily streamflow using just two inputs daily rainfall and potential evapotranspiration data. Of these two inputs, rainfall is the key driver of the SIMHYD model with the potential evaporation (PET) used mainly to set the upper limit on evapotranspiration from the soil moisture store (Podger 2004).

#### 3.3.1 Methods of Climate generation

Two quite different approaches to generating climate data for a Source Catchments scenario were investigated, including a discussion of the advantages and disadvantages...
of each. Rainfall and PET sequences for each method have been generated to ensure that the two methods give comparable results. The two methods used were:

**Method 1: Climate from SILO 5km grids**

The first method takes 5km gridded data sourced from Queensland Department of Natural Resources and Environment’s SILO service and calculates daily rainfall and PET traces averaged over each of the sub-catchment areas. This spatial averaging is automatically applied when input data is loaded using the ‘Climate from ASCII grid files’ option in Source Catchments.

**Method 2: Climate interpolated using ANUCLIM software**

In the second method, 100m gridded climate data was generated using the Catchment Analysis Tool (CAT) (Appendix 1). The CAT method of climate generation involves scaling raw point-source climate station Bureau of Meteorology (BOM) data (sourced from QDNRE SILO service) by interpolated mean-monthly spatial layers. Interpolated surfaces are created using the ANUCLIM software (Hutchinson 2001) that combines a DEM and temporal climatic data to generate smoothed mean-monthly climate surfaces. The surfaces represent a climate gradient across space and account for elevation based climate variability.

Two different scaling approaches have been discussed in detail in Appendix 1. The first (‘Scale to BOM’) ensures that the climate sequence at the exact location of the climate station matches the BOM trace. Data surrounding the climate station is scaled proportionally based on the deviation of the ANUCLIM spatial layer from value of the ANUCLIM layer at the climate station. The second method (‘Scale to ANUCLIM’) ensures that the mean-monthly BOM climate data from 1975 to 2005 is spatially scaled to match the mean-monthly ANUCLIM layer value at a given point. Data surrounding the climate station is scaled proportionally based on the deviation of the ANUCLIM spatial layer from value of the BOM data at the climate station.

For use in Source Catchments the 100m gridded data was spatially averaged over sub-catchment areas using CAT then manually loaded for each unique sub-catchment/functional unit using the ‘Grid based Input Assignment’ option.

**3.3.2 Analysis of different climate generation techniques**

Spatiotemporal rainfall and PET (based on Morton’s wet environment potential evaporation) were averaged over the sub-catchment areas using three approaches:

- SILO 5km grids (method 1)
- Scale to ANUCLIM (method 2a)
- Scale to BOM (method 2b)

A frequency distribution of the difference in mean annual rainfall (Figure 7) shows that for both the ‘Scale to BOM’ and ‘Scale to ANUCLIM’ methods approximately 70% of the sub-catchments have mean annual rainfall values within 60mm of the ‘SILO’ mean annual rainfall value. A comparison of the annual rainfall mean, 10th, 25th, 75th, and 90th percentiles for the three approaches (Figure 8) also highlights the consistency between methods in most sub-catchments. With the majority of catchments showing minimal differences in range and percentiles, with no consistent pattern of difference between any method as you move from small to big catchments (Figure 8).
The differences in mean annual rainfall (mm) on a sub-catchment basis between the a) ‘Scale to BOM’ and ‘SILO’ approaches and the b) ‘Scale to ANUCLIM’ and ‘SILO’ approaches are shown in Figure 9a and Figure 9b respectively. The coefficient of efficiencies on a sub-catchment basis between the a) ‘Scale to BOM’ and ‘SILO’ data and the b) ‘Scale to ANUCLIM’ and ‘SILO’ data are shown in Figure 9c and Figure 9d respectively; with the coefficients of efficiency between the ‘SILO’ method and the ‘Scale to BOM’ and ‘Scale to ANUCLIM’ methods greater than 0.86 with a median coefficient of efficiency above 0.95. This shows good correlation between the three techniques of climate generation for the majority of sub-catchment areas.

![Graph showing differences in mean annual rainfall between approaches.](image)

**Figure 7** The percentage of sub-catchments with a difference in mean annual rainfall less than a certain value between the ‘Scale to BOM’ and ‘Scale to ANUCLIM’ and the ‘SILO’ methods of rainfall generation.

There are however a number of sub-catchments particularly using the ‘Scale to BOM’ method namely regions 403250, 403228 and 403233 that deviate significantly from the mean annual ‘SILO’ rainfall values (>100mm). It is interesting to note that the coefficient of efficiency of these regions is still quite high indicating perhaps a different rainfall interpolation around a few peak rainfall events that dominate in the mean annual calculation. In general the results (Figure 8) show that the uncertainty between methods increases at higher elevations where there is a greater rainfall gradient and greater margin for error in interpolation techniques.

Contributing to possible uncertainty in the scaled methods is the rainfall data from the climate stations located at higher altitudes on or near the peaks of Mt Hotham, Mt Buffalo and Mt Buller along the Southern mountainous range of the catchment. Both of the CAT scaling techniques but in particular the ‘Scale to BOM’ technique are susceptible to anomalies in the climate station data. The ‘Scale to BOM’ technique takes the climate station data as the ‘point of truth’ and scales surrounding grid cells with respect to this point.

Residual analysis of the daily rainfall from all climate stations in the Ovens catchment is presented fully in Appendix 2. The gradient of rainfall residual graph represents the general shift in rainfall patterns. A positive gradient value represents a period where the annual rainfall is greater than the long term mean annual value. A negative gradient value represents a period where the annual rainfall is less than the long term average.
Figure 10 shows the gradient of rainfall residuals for each of the climate stations contributing to climate generation for the Ovens catchment. From the rainfall residual gradient graph and the corresponding matrix of correlation coefficients (Figure 11) there are three identifiable climate stations that correlate poorly with their neighbours:

- 83085 - Mt Hotham
- 83024 - Mt Buller and
- 83073 - Mt Buffalo Chalet

As an example, the period around 1996 shows above the long term average rainfall at all climate stations except 83085 and 83024 where there appears to be a period of extreme drying. Many factors could be influencing the climate recorded at these stations including snowfall, climate influences from South of the range or even a dodgy rain gauge. For the sake of this analysis the simplest course of action is to remove them from the Ovens scenario altogether so that they have no influence on climate generation.

For this analysis the two CAT scaling methods have been compared against the SILO method however at this point there is no clear technique for determining which approach gives a better spatiotemporal representation of the rainfall. Further work including validation against additional rainfall stations needs to be carried out. Additionally the three approaches could be used to provide input data to the SIMHYD model and the confidence given to the data which gives the best representation of streamflow however generally a slight shift in model parameterisation will account for the difference in rainfall and it remains difficult to say which input data set results in better model performance.

### 3.3.3 Advantages & Disadvantages of each technique

<table>
<thead>
<tr>
<th>Advantage/Sustainability</th>
<th>QDNRE SILO 5km gridded data</th>
<th>CAT spatial scaling of point-source data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td>Daily spatial interpolation</td>
<td>Scenario specific climate grid resolution i.e. 100m</td>
</tr>
<tr>
<td></td>
<td>No climate gradient at the junction of climate stations</td>
<td>Greater elevation based climate discrimination</td>
</tr>
<tr>
<td></td>
<td>Data widely available</td>
<td>Ease of generating future climate changed data, correlated to historic data</td>
</tr>
<tr>
<td></td>
<td>Data less likely to be influenced by anomalies at specific climate stations</td>
<td>Ability to trace climate inconsistencies back to raw measured climate data</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>Size and handling of data 2.5GB for Ovens catchment compared to 40 MB for CAT method.</td>
<td>Mean-monthly spatial interpolation</td>
</tr>
<tr>
<td></td>
<td>Fixed grid resolution of 5km – potentially too coarse for paddock scale modelling.</td>
<td>Climate gradient at the junction of climate stations</td>
</tr>
</tbody>
</table>

Based on the detailed analysis above there is no clear technique for determining the most appropriate method for providing spatial climate data into a catchment model. Each climate generation technique could be considered equally valid and would give similar modelled results, with the exception of the elevated peaks (snowline) where there were...
differences in the climate sequences. Within this report the ‘Scale to BOM’ technique was selected as input into the Source Catchments SiMHYD model. This technique was chosen for several reasons:

- commensurate with input data for any modelling conducted in CAT rather than Source Catchments.
- strong relationship with the SILO 5km gridded data
- if the Source Catchments model is run at a finer spatial scale in the future this method had the capacity to provide finer climate resolution.

3.3.4 Recommendations for Source Catchments with regard to input data

The direct input QDNRE SILO 5km grids within Source Catchments certainly simplifies the process of obtaining consistent spatio-temporal data for catchment scale modelling based on historical data. It is still important, however to maintain the ability to load independent climate data for analysis of stochastic sequences, climate change analysis and direct linking to outside models that rely on different methods of climate generation. Recommendations for future versions of Source Catchments include:

- Optional ability to read QDNRE SILO 5km grids on a Functional Unit basis. This would allow the user to specify climate bands as functional units within the sub-catchments. An example where this could be important is say a sub-catchment with two dominant types of landuse, pasture on alluvial plains and forestry on areas of greater slope and elevation. Here you would expect a greater mean rainfall over the forestry component of the sub-catchment due to the increased elevation with a different streamflow contribution to the pasture component if the functional unit rainfall runoff models are uniquely parameterised.

- Batch methods to load climate data on a gauge region/Functional Unit basis using the ‘Grid based Input Assignment’ option.

- Ability to compare at a point the interpolated QDNRE SILO 5km gridded data to the actual measured climate station data.
Figure 8 A comparison of the annual rainfall mean, 10th, 25th, 75th, and 90th percentiles for three methods of spatio-temporal climate generation i) Scale to match BOM, ii) SILO gridded data (5km) and iii) Scale to match ANUCLIM.
Figure 9 The difference in mean annual rainfall (mm) on a sub-catchment basis between a) Scale to match BOM and SILO gridded data methods and b) Scale to ANUCLIM and SILO gridded data methods. The coefficient of efficiency between c) Scale to match BOM and SILO gridded data methods, d) Scale to ANUCLIM and SILO gridded data methods.
Figure 10 Gradient of rainfall residuals taken from the daily rainfall data of the 29 stations that contribute climate data to the Ovens catchment.
Figure 11 A matrix of correlation coefficients highlighting (in red) those climate station that correlate poorly with surrounding stations.
3.3.5 Climate trends over the study period

Climate data from 1975-2005 from several of the Bureau of Meteorology climate stations was used to determine whether there were any significant wetting or drying rainfall periods over the 31 year model run. Figure 12 shows the cumulative daily rainfall residuals from 1975 to 2005 for the Wangaratta climate station, similar trends were observed at other climate stations within the catchment including Bright and Myrtleford. The long term climate trends including a wetting period from 1989-1996 and a drying period from 1996-2005 were an important consideration in determining the calibration and validation periods for the model, along with the availability of streamflow data.

![Figure 12 Cumulative daily rainfall residual from 1975 to 2005 at the Wangaratta climate station (BOM site 82053) within the Ovens catchment in Victoria. The long term annual rainfall of 636mm is represented by the pink line.](image)

3.4 Land-use Data

The Ovens River catchment is 6,295 km² which extends from the Murray River in the north, to the Great Dividing Range in the south; with a broad range of land uses within the catchment. The southern end of the Ovens catchment is forested (56%) with extensive areas of National and State Parks as well as hardwood and softwood forestry. The river valleys and northern half of the catchment are dominated by pasture systems (36%). Additional land uses include cropping systems, horticultural production (traditionally tobacco, but now hops and vineyards) and urban areas.

Land use was classified using the Australia Land Use Mapping (ALUM) classification Version 5 (BRS 2001). There are a large number of land use options, including production of a variety of different annual and perennial crops such as salt bush, lucerne and native grasses. There were also land uses that represent urban landscapes, water bodies and pastures for grazing. Up-to-date and accurate land use mapping is imperative for CAT to produce accurate recharge estimates and to allow the investigation of land use change scenarios.
3.4.1 Current land use

The current land use layer for the Ovens catchment (Figure 15) was created by incorporating the landscape grouping data with the Australia Land Use Mapping (ALUM) classification Version 5 (BRS 2001) spatial layer.

The current land use spatial layer was ground tested using Google Earth. Urban in particular was poorly represented. With small patches of urban dotted all over the landscape and towns being poorly defined, see Figure 13(a) and Figure 14(a) for examples. The urban land use layer was updated by converting urban to rural residential, urban residential, trees, road and intensive animal production, see Figure 13(b) and Figure 14(b).

![Figure 13 Urban land use around Beechworth based on ALUM V5; a) the original land use layer, b) modified land use layer utilised by CAT.](image)

![Figure 14 Urban land use around Myrtleford based on ALUM V5; a) the original land use layer, b) modified land use layer utilised by CAT.](image)

The land use options currently available in CAT are reasonably extensive and can be further augmented by detailing the values of a number of land use parameters. The CAT also provides an option to implement different land management strategies such as crop rotations – e.g., a lucerne crop in Year 1 followed by wheat in Years 2 and 3 and then back to lucerne in Year 4. Two land-use layers were generated, the first for CAT included the detailed land-
use data (Figure 15a) and a second layer which grouped land-use into broad management categories for use in Source Catchments (Figure 15a).

Figure 15 Current land use practice in Ovens catchment for CAT project (a) detailed land use layer, and (b) manager layer with broad categories.
3.5 Soils Data

Soil attributes play a significant role in determining the hydrology of the catchment. Therefore soil properties potentially affect the parameterisation of Rainfall Runoff models within Source Catchments and therefore they may be used in determining the Functional Units for the model in combination with Land Use. While soil data was not used directly in the results presented within this report, it was an essential data source in exploring and understanding the catchment and will be used extensively in the next phase of the research.

The spatial map of soil type assignment (Figure 16a) was sourced from the 1:250,000 Statewide soil attribute coverage. Attribution of soil parameters were as reported in Smith (2002). To account for shallow soils which may limit root growth a spatial soil depth layer was created using a mixture of MrVBF (Gallant and Dowling 2003) and the pit soil data reported in McKenzie et. al. (2000) (Figure 16b).
Figure 16 Spatial map of (a) soil type and (b) soil depth for the Ovens catchment in Victoria.
3.6 Stream flow

Stream flow data is needed for the calibration of the rainfall runoff model used within Source Catchments and CAT. Stream flow data were obtained from the Victorian Water Resource Data Warehouse (VWQM2009) up to 2009 for 24 gauges: (Figure 17 and Table 1). Missing stream data was ignored in the parameterisation of the model, therefore no infilling of the stream traces was conducted. Graphical analysis was conducted for all of the stream gauges to ensure data quality.

![Figure 17 Stream gauge locations for the Ovens catchment in Victoria.](image-url)
Table 1 Years of stream flow measurement for each gauge in the Ovens Catchment, Victoria.

<table>
<thead>
<tr>
<th>Gauge Number</th>
<th>Gauge Name</th>
<th>Start Date</th>
<th>End Date</th>
<th>Total Years</th>
<th>Missing Data (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>403200</td>
<td>Ovens River @ Wangaratta</td>
<td>14/12/73</td>
<td>31/12/08</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>403205</td>
<td>Ovens River @ Bright</td>
<td>14/12/71</td>
<td>31/12/08</td>
<td>37</td>
<td>0</td>
</tr>
<tr>
<td>403209</td>
<td>Reedy Creek @ Wangaratta North</td>
<td>18/12/73</td>
<td>31/12/08</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>403210</td>
<td>Ovens River @ Myrtleford</td>
<td>13/12/72</td>
<td>31/12/08</td>
<td>36</td>
<td>2</td>
</tr>
<tr>
<td>403213</td>
<td>Fifteen Mile Creek @ Greta South</td>
<td>15/12/73</td>
<td>31/12/08</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>403214</td>
<td>Happy Valley Creek @ Rosewhite</td>
<td>08/12/73</td>
<td>31/12/08</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>403217</td>
<td>Rose River @ Matong North</td>
<td>01/01/73</td>
<td>31/12/08</td>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>403218</td>
<td>Dandongadale River @ Matong North</td>
<td>19/12/73</td>
<td>31/12/08</td>
<td>35</td>
<td>12</td>
</tr>
<tr>
<td>403220</td>
<td>Buffalo River @ Lake Buffalo</td>
<td>11/05/74</td>
<td>31/12/08</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>403221</td>
<td>Reedy Creek @ Woolshed</td>
<td>22/07/75</td>
<td>31/12/08</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>403222</td>
<td>Buffalo River @ Abbeyard</td>
<td>12/12/73</td>
<td>31/12/08</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>403223</td>
<td>King River @ Docker Road Bridge</td>
<td>17/01/74</td>
<td>31/12/08</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>403224</td>
<td>Hurdle Creek @ Bobinawarrah</td>
<td>08/07/75</td>
<td>31/12/08</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>403226</td>
<td>Boogy Creek @ Angleside</td>
<td>09/04/74</td>
<td>31/12/08</td>
<td>35</td>
<td>4</td>
</tr>
<tr>
<td>403227</td>
<td>King River @ Cheshunt</td>
<td>19/12/73</td>
<td>31/12/08</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>403228</td>
<td>King River @ Lake William Hovell</td>
<td>23/01/75</td>
<td>31/12/08</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>403230</td>
<td>Ovens River @ Rocky Point</td>
<td>17/01/75</td>
<td>31/12/08</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>403232</td>
<td>Mores Creek @ Wandiligong</td>
<td>30/11/72</td>
<td>31/12/08</td>
<td>36</td>
<td>3</td>
</tr>
<tr>
<td>403233</td>
<td>Buckland river @ Harris Lane</td>
<td>05/05/72</td>
<td>31/12/08</td>
<td>37</td>
<td>0</td>
</tr>
<tr>
<td>403240</td>
<td>King River @ Edi</td>
<td>16/06/79</td>
<td>31/12/08</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>403241</td>
<td>Ovens River @ Peechelba</td>
<td>01/07/93</td>
<td>31/12/08</td>
<td>16</td>
<td>36</td>
</tr>
<tr>
<td>403244</td>
<td>Ovens River @ Harrietville</td>
<td>05/02/87</td>
<td>31/12/08</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>403249</td>
<td>Three mile creek @ Wangaratta</td>
<td>03/06/00</td>
<td>31/12/08</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>403250</td>
<td>Ovens River @ Eurobin</td>
<td>30/12/00</td>
<td>31/12/08</td>
<td>8</td>
<td>55</td>
</tr>
</tbody>
</table>

* percentage of recorded flow from 1/1/1976 or start of record to 31/12/2005

3.7 Stream and Groundwater Extractions

Town and groundwater extractions throughout the Ovens catchment have the potential to significantly impact on streamflow. Town extractions in particular have the potential to significantly affect streamflow over summer periods where streamflow is generally low and town extractions are generally high.

3.7.1 Calculating town extractions for Source Catchments

To date we have been unsuccessful in obtaining detailed data on actual town extractions within the Ovens catchment area. To allow the extractions to be incorporated into the Source Catchments model, daily town extractions were determined from the Lower and Upper Ovens REALM models (SKM 2005; 2007).

Daily urban demands were generated for Glenrowan, Moyhu, Oxley, Wangaratta, Whitfield (Lower Ovens) and Bright, Harrietville, Porepunkah and Myrtleford (Upper Ovens). The daily urban demands (ML) were derived by calculating monthly demands using the REALM regression equations (SKM 2005; 2007) and downscaling these to a daily basis using daily rainfall (R) and evaporation (E) data from SILO (Table 2).
Table 2 Rainfall and evaporation data used in the calculation of urban demands

<table>
<thead>
<tr>
<th></th>
<th>Rainfall (R)</th>
<th>Evaporation (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>82009</td>
<td>82053</td>
</tr>
<tr>
<td>Glenrowan</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Moyhu</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Oxley</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Wangaratta</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Bright</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harrietville</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porepunkah</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myrtleford</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Evaporation at station 83079 was obtained from REALM model on a weekly basis and thus had to be disaggregated into daily values to conform to the daily evaporation data from the other stations.

3.7.1.1 Regression equations used for the Lower Ovens

The regression equations used for the Lower Ovens were:

\[
\text{Glenrowan (ML)} = 0.0263 \times E_{82039} - 0.0165 \times R_{\text{Glen}} - 0.2297 \times \text{Date} + 463.2251
\]

\[
\text{Moyhu (ML)} = 0.0167 \times E_{82039} - 0.0107 \times R_{\text{Moy}} + 2.4421
\]

\[
\text{Oxley (ML)} = 0.0239 \times E_{82039} - 0.0108 \times R_{\text{Ox}} + 2.0828
\]

\[
\text{Wangaratta (ML)} = 1.3042 \times E_{82039} - 0.6208 \times R_{\text{Wang}} - 9.1074 \times \text{Date} + 18478.8184
\]

where ‘date’ is a decimal date and the sub-area rainfall is calculated from the given stations and their corresponding Thiessen weights [ ]:

\[
\begin{align*}
R_{\text{Glen}} : & \text{ 82053 [0.44], 83031 [0.56]} \\
R_{\text{Moy}} : & \text{ 82009 [0.94], 83031 [0.06]} \\
R_{\text{Ox}} : & \text{ 82009 [0.58], 82053 [0.38], 83031 [0.04]} \\
R_{\text{Wang}} : & \text{ 82053 [1]} \\
\end{align*}
\]

3.7.1.2 Regression equations used for the Upper Ovens

The regression equations for the Upper Ovens utilise net evaporation (Evap\text{net}) calculated using the 83012 and 83079 climate stations (Table 2):

\[
\text{Evap\text{net}} = \text{Evaporation (mm/month)} - \text{Rainfall (mm/month)}
\]

and three constants to define monthly demand:

\[
\text{Demand (ML/month)} = c1 \times (\text{Evap\text{net}})^2 + c2 \times (\text{Evap\text{net}}) + c3
\]

where the constants c1, c2 and c3 for each town were:

<table>
<thead>
<tr>
<th></th>
<th>Bright</th>
<th>Harrietville</th>
<th>Porepunkah</th>
<th>Myrtleford</th>
</tr>
</thead>
<tbody>
<tr>
<td>c1</td>
<td>0.00053</td>
<td>0.00006</td>
<td>0.00010</td>
<td>0.00046</td>
</tr>
<tr>
<td>c2</td>
<td>0.19667</td>
<td>0.01638</td>
<td>0.04166</td>
<td>0.14834</td>
</tr>
<tr>
<td>c3</td>
<td>50.16082</td>
<td>5.50990</td>
<td>11.80031</td>
<td>61.37012</td>
</tr>
</tbody>
</table>

eWater CRC
- 23 -
3.7.1.3 Generating daily time series of urban demands
To disaggregate the monthly urban demands into daily values was a two step process.

Firstly the regression equations (SKM 2005; 2007)) were applied to the daily rainfall and evaporation data to obtain a daily time series which was then aggregated to monthly. It should be noted that these regression equations were applied to monthly data in REALM (SKM 2005; 2007) and so the daily volumes calculated in this step are not the actual daily or monthly volumes. These volumes were only used to determine daily proportions (= daily/month) for use in step 2. Then the daily proportion for a given month was multiplied by the corresponding monthly urban demand as modelled by REALM to generate a daily time series for use in Source Catchments.

3.7.2 Groundwater extractions
Information on groundwater extractions in the Ovens catchment were obtained from Goulburn Murray Water (Figure 18). This data was provided on a monthly basis, with the confidence in the data increasing overtime due to increased metering and monitoring of the system. While groundwater extractions were not considered within the base models of the Ovens, the connectivity between groundwater and surface-water systems within the catchment suggest that these may need to be taken into account in more detailed modelling scenarios, or at least used in the discussion of surface-water models.
Figure 18 Groundwater extractions in the lower and upper ovens showing licensed extractions for irrigation as well as the domestic and stock (D & S) extractions.
Figure 19 Network diagram of the Source Catchments model a) base model and b) base model incorporating town extractions.
3.8 Model structure

The Source Catchments model of the Ovens Catchment was initially set up to provide a base model of the Ovens catchment for parameterisation with PEST. The main features of the base model (Figure 19a) include:

- 25 sub-catchments defined by the stream gauge network.
- CAT ‘Scale to BOM’ technique was used to provide input climate data for the Source Catchments model.
- Rainfall runoff was modelled with Source Catchments using SIMHYD. SIMHYD was chosen as it represents a simple lumped conceptual daily runoff model, with relatively few parameters. SIMHYD has been extensively used, with applications including the Murray Darling Basin Sustainable Yields project which utilised the model across the entire Murray Darling Basin (CSIRO 2008).
- Parameterisation of the model was conducted using PEST (Watermark Numerical Computing, Australia 2010).
- No node models, routing or extractions were used.
- The model was built in Source Catchments (v1.0.2b) and parameterisation was run using the e2commandline version.

The second Source Catchments model of the Ovens catchment (Figure 19b) had the same structure as the base model, but incorporated town extractions. The extractions were incorporated as a daily time series at nodes in the 403244, 403205, 403250, 403201 and 403200 sub-catchments. We were unable to configure the PEST calibration to run with extractions as extractions could only be incorporated as a plugin feature within this version of Source Catchments. This has since been overcome with more recent versions.

3.9 Parameter Estimation

The hydrological model in Source Catchments was parameterised using PEST a model-independent parameter estimation program (Watermark Numerical Computing, Australia 2010). PEST is similar to existing nonlinear parameter estimation software (it uses a powerful, yet robust, estimation technique that has been extensively tested on a wide range of problem types), however it can be wrapped around an existing model such as Source Catchments. PEST adjusts model parameters until the fit between model outputs and laboratory or field observations is optimised in the weighted least squares sense.

The objective function used was the squared sum of residuals between observed and a predicted time-series. In this project PEST was applied and the sum of residuals squared was calculated using the measured stream gauge data (no in-filled data was used).

Parameters were calibrated over the period 1990-2005 mainly due to the consistent availability of stream gauge data over this period. To investigate the performance of different parameter estimation approaches the PEST output files were used along with a number of statistical functions to assess model fit achieved by running PEST.
1. The Nash Sutcliffe Coefficient of Efficiency, calculated on a daily basis, was used to assess the predictive power of hydrological models. It is defined as:

\[ CoE = 1 - \frac{\sum_{t=1}^{T} (Q_t^o - Q_t^m)^2}{\sum_{t=1}^{T} (Q_t^o - Q_t^o)^2} \]

where \( Q_o \) is observed discharge, and \( Q_m \) is modelled discharge. \( Q_{o_t} \) is observed discharge at time \( t \) (Nash and Sutcliffe 1970). Nash–Sutcliffe efficiencies can range from \(-\infty\) to 1, where:

- an efficiency of 1 (\( E = 1 \)) corresponds to a perfect match of modelled discharge to the observed data,
- an efficiency of 0 (\( E = 0 \)) indicates that the model predictions are as accurate as the mean of the observed data, and
- an efficiency less than zero (\( E < 0 \)) occurs when the observed mean is a better predictor than the model.

While a CoE of 0.6 is viewed as acceptable, a CoE of 0.8 or higher was believed to provide a good representation of streamflow at the gauge.

2. Cumulative flow

Cumulative flow was calculated on dates where measured data was available, so while it may not reflect the full model period it is not adversely affected by missing data in the observed data series.

\[ CumFlow\% = \left( 1 - \frac{\sum_{t=1}^{T} (Q_t^o)}{\sum_{t=1}^{T} (Q_t^m)} \right) \times 100 \]

To date two PEST optimisation methods have been applied to the Ovens catchment

1. The 9 SIMHYD parameters for each of the 25 sub-catchments optimised simultaneously. No weighting. Total of 225 parameters.

2. 7 SIMHYD parameters systematically optimised one sub-catchment at a time starting from the upstream sub-catchments and working down. (Two parameters fixed: pervious fraction = 1, impervious threshold = 1). Total of 7 parameters per optimisation.

3.9.1 Automation of PEST calibration

Much effort has been spent setting up a process to facilitate model calibration and formatting of the PEST outputs. An automated process was developed in MATLAB utilising PEST, e2_commandline (Source Catchments v1.0.2b) and four files from the Source Catchments PEST plugin (parameters.dat, param_groups.dat, parval.dat and config_template.tpl). The process was designed to allow the user to specify an order for optimising catchments. For example, one could specify to simultaneously optimise all upstream catchments then hold these parameter sets fixed and proceed to optimise the routing for these catchments. The aim was to achieve better calibration by limiting the number of parameters for any given optimisation process and to alleviate issues around the correlation of parameters between different models.
Figure 20 Automated PEST calibration allowing the user to specify an order to optimise catchments.

3.10 Model validation

The Ovens sub-catchment SIMHYD models were validated against the available streamflow data from a 15 year period (1976-1989). The year 1975 was omitted to provide a warm-up period over which the soil moisture store and groundwater store could stabilise.
4 Results and Discussion

4.1 PEST1 (9 parameters and 25 sub-catchments simultaneously)

The first PEST parameterisation was conducted on all of the 9 SIMHYD parameters for each of the 25 sub-catchments simultaneously. This meant that PEST was trying to optimise a total of 225 parameters at once using a single objective function of the sum of residuals squared for the entire catchment. There was no weighting of daily flows between the sub-catchment.

Not surprisingly the calibration using PEST1 was poor, with the majority of catchments having a CoE of less than 0.4. Sub-catchments with higher flow dominated the parameterisation as objective functions were not weighted and consequently they had a slightly higher CoE. In addition to the poor parameterisation of the model, the run time for PEST1 was quite long as every parameter-iteration ran every parameter within the model.

Sensitivity analysis for this calibration showed the model to be most sensitive to the pervious fraction $p$. This was expected as the pervious fraction partitions the input rainfall and redirects a portion directly to stream. In the majority of catchments this was pushed to a maximum of 1.0. Due to the nature of the catchment land use (very little impervious urban area) and previous PEST results the pervious fraction was fixed to $p=1$ for all future PEST parameterisations, forcing all rainfall to infiltrate the soil. By forcing the pervious fraction to 1 the Impervious Threshold becomes superfluous, as all water infiltrates and there is no impervious evapotranspiration. Due to the poor results a more detailed analysis of PEST1 has not been presented.

4.2 PEST2 (7 parameters and systematic optimisation of sub-catchments)

The second PEST parameterisation was conducted on 7 SIMHYD parameters (pervious fraction = 1 and impervious threshold = 1 were fixed) and systematically optimised one sub-catchment at a time starting from the upstream sub-catchments. In this calibration each sub-catchment was individually optimised using the automated process described in 3.9.1. The upstream sub-catchments were optimised first followed by the next level of downstream sub-catchments and so forth. This approach had a number of advantages including only parameterising 7 parameters per optimisation.

PEST2 was used to parameterise the base model of the Ovens catchment (Figure 19a), which was essentially a series of linked SIMHYD models, with no accounting for town extractions, stream losses, stream routing or dam releases.

4.2.1 PEST2 - analysis of the calibrated parameters

The seven calibrated parameters for each sub-catchment were analysed across the Ovens catchment. With the analysis exploring the distribution of parameter values as well as the sensitivity.
4.2.1.1 Soil Moisture Store Capacity

The Soil Moisture Store Capacity defined the amount of water that can be held within the soil profile, with defined lower and upper limits in SIMHYD of 1-500 mm. Almost 50% of the sub-catchments had an optimised Soil Moisture Store Capacity of 500, the defined upper limit (Figure 21a). The higher Soil Moisture Store Capacity values allowed more water to be held within the soil by the model, resulting in a slight decrease to streamflow. It did not however significantly reduce soil evapotranspiration which was proportional to the fullness of the store (limited by PET) rather than the size. That the Soil Moisture Store Capacity was regularly reaching the upper limit, represented a significant limitation of this calibration, particularly as it was the most sensitive parameter for the SIMHYD model (refer to section 4.2.2). This limitation was due to gradient driven optimisers (such as PEST) generally giving up when a sensitive parameter hits an upper or lower limit.

The Soil Moisture Store Capacity reaching the defined upper limit was indicative of too much available water within the system, as SIMHYD was trying to store the water rather than passing it through to streamflow. The water balance in some of the sub-catchments could be improved by changing the upper and lower limits of some parameters, including extractions or including some storage and losses within the catchment. However, the analysis presented in this report has shown that SIMHYD does not cope well when there are ephemeral streams and a lot of available water within the system as there is no process other than evapotranspiration that allows water to leave the system, for example loss to groundwater systems including shallow aquifers that discharge further down the catchment or deep aquifers.

![Figure 21 PEST2 calibrated parameters a) Soil Moisture Store Capacity and b) Baseflow Coefficient by sub-catchment.](image)
4.2.1.2 Baseflow Coefficient

The Baseflow Coefficient defines the proportion of water in the groundwater store that was released to stream. The Baseflow Coefficients across the Ovens catchment (Figure 21b) were generally quite low (less than 0.1) indicating that the optimisation was trying to shut this baseflow process off. This was expected in the Ovens catchment as a number of the upland streams were ephemeral, only flowing after rainfall events.

In general this base model contained too much available water within a number of the sub-catchments which it tried to get rid of through the groundwater store, which has no upper-limit. If the baseflow coefficient was too high this resulted in a groundwater dribble to stream that became significant (e.g.: Figure 22). This was a problem as SIMHYD has no mechanism for this groundwater to be lost to aquifers and exported from the sub-catchment. There was a significant correlation between catchments with a high baseflow coefficient and a poor coefficient of efficiency.

![Figure 22](image)

Figure 22 PEST 2 – observed and modelled (SIMHYD) streamflow for sub-catchment 403214.

4.2.1.3 Infiltration Coefficient and Infiltration Shape

After the Soil Moisture Store Capacity the Infiltration Coefficient (Figure 23a) and Infiltration Shape (Figure 23b) were generally the two most sensitive parameters in the SIMHYD model. The Infiltration Coefficient and Infiltration Shape defined the amount of water that could move into the soil while the remainder was forced directly to stream as infiltration excess runoff. These parameters had a significant impact on the shape and amplitude of the modelled stream trace. In the Ovens catchment, especially along the King river branch the Infiltration Coefficient was reaching the maximum value of 400, indicating that the system was trying to minimise the infiltration excess runoff. Other sub-catchments showed a wide distribution of Infiltration Coefficients.
4.2.1.4 Interflow Coefficient
Most of the Interflow Coefficients across the catchment were low (less than 0.1) (Figure 24a). Forty percent of the sub-catchments had an Interflow Coefficient of 0, which resulted in no water leaving the system as interflow runoff, with the water passing into either the soil moisture or groundwater stores.

4.2.1.5 Recharge Coefficient
The trends within the Recharge Coefficient were less clear than the other parameters (Figure 24b). In some sub-catchments it was trying to remove water from the soil moisture store and pass it through to the groundwater store, increasing the baseflow dribble discussed earlier. In other sub-catchments it was trying to cut off the movement of water into the groundwater store to cut off the baseflow dribble. As observed in (Figure 24b), there was great variability in the recharge coefficient across the catchment as the optimiser tried to find the lesser evil, baseflow dribble or interflow runoff.
Figure 24 PEST2 calibrated parameters a) Interflow Coefficient and b) Recharge Coefficient by sub-catchment.

4.2.1.6 Rainfall Interception Store Capacity
The Rainfall Interception Store Capacity (Figure 25) defined an upper limit on the interception evapotranspiration. Understandably as the optimiser was generally trying to remove water from the system we can see that for a lot of the catchment this parameter was reaching its maximum value of 5.
4.2.2 PEST2 - sensitivity of parameters

During optimisation PEST generated a sensitivity file that ranked parameters in terms of how sensitive the model was to that parameter. The PEST parameter sensitivities were analysed for each sub-catchment (Figure 26). The model sensitivity ranking was not consistent across all sub-catchments, but in general the parameters could be ranked from most sensitive to least sensitive as soil moisture store capacity, infiltration coefficient & shape, recharge coefficient, baseflow coefficient, interflow coefficient and rainfall interception store capacity.
4.2.3 PEST2 - model performance

Across the Ovens catchment there was significant variability in the model parameterisation and model performance in terms of predicting streamflow for each sub-catchment. Model performance in terms of the CoE was variable across the sub-catchments (Figure 27) with a broad distribution of CoE’s (Figure 28). Over the calibration period (1990-2005) 65% of the sub-catchments had and acceptable CoE (>0.6), while during the validation period (1976-1989) only 58% of sub-catchments had an acceptable CoE. For both the calibration and validation periods 20% of sub-catchments have a good coefficient of efficiency of 0.8 or greater. However, Figure 27 and Table 3 highlight that the top 20% of sub-catchments over the calibration period do not necessarily match the top 20% of sub-catchments over the validation period.

Figure 27 Coefficient of efficiency (CoE) for PEST2 for the a) calibration (1990-2005) and b) validation (1976-1989) periods.

Figure 28 Frequency distribution of coefficient of efficiencies (CoE) for each sub-catchment over the calibration (1990-2005) and validation (1976-1989) periods.
Not surprisingly there was some correlation between the number of days of stream data the model has to calibrate over and the CoE. In particular sub-catchment 403250 shown in red in Figure 29a) had only 830 days of data out of a potential 5844. Of all of the upland sub-catchments this one had the poorest coefficient of efficiency. Given the available data this sub-catchment will be removed from future scenarios and merged with the downstream sub-catchment.

**Figure 29** Days of data used to calculate coefficient of efficiency and percentage difference for a) calibration (1990-2005) and b) validation (1976-1989) periods.

Similar to the CoE results approximately 50% of the sub-catchments had an acceptable prediction of the percent difference in cumulative streamflow (Figure 30) over both the calibration (1990-2005) and validation (1976-1989) periods. However, the majority of sub-catchments were over-predicting streamflow, some by up to 80% more than the observed flow data.

**Figure 30** Percent difference in cumulative flow over the a) calibration (1990-2005) and b) validation (1976-1989) periods.
In terms of the cumulative flow predicted, one catchment (Reedy creek 403209) stands out, in that streamflow was under-predicted by 80% (refer to Figure 31). In the parameterisation of this catchment PEST has minimised the Soil Moisture Store Capacity and the Rainfall Interception Store while maximising the Recharge Coefficient, the opposite to the majority of the other catchments. The results for this catchment may have been a problem with optimisation pushing some of the parameters to the upper or lower bounds initially and not moving (may need to alter the initial parameter values), gradient driven optimisers (such as PEST) often give up when a sensitive parameter hits an upper or lower limit.

The temporal analysis for each sub-catchment is presented in Appendix 3. A summary of the minimum, maximum, 25th percentiles, 75th percentiles and mean of the annual stream flow (ML/year) was created for both the calibration and validation period (Figure 32). In general the modelled mean annual streamflow values were comparable for the upland catchments and got progressively worse as you approached the bottom of the catchment.

All of the results presented were used to create a summary of the model results (Table 3) which included:

- the model’s ability to match streamflow for calibration and validation periods (CoE < 0.6 = poor, 0.6 < CoE < 0.8 = acceptable, CoE > 0.8 = good)
- the model’s ability to match cumulative streamflow for calibration and validation periods (0-10% = good, 10% to 20% = acceptable, 20-100% = poor)
- A score was calculated as a percentage of a maximum 16 points, where the CoE and cumulative flows in the calibration and validation periods could earn a maximum 4 points each (poor=0, acceptable =2, good=4).
- a list of upstream sub-catchments contributing error to modelled response
- a list of possible factors that could influence the results
Figure 31 Comparison of measured and modelled streamflow over calibration and validation periods for sub-catchment 403209 (Reedy Creek).
Figure 32 The min, max, 25th and 75th percentiles and mean measured and modelled data over a) calibration and b) validation periods
### Table 3 Summary of sub-catchment results including daily Coefficient of Efficiencies (CoE) and % difference in cumulative flow during the calibration and validation periods.

With green shading presenting good, pink shading presenting acceptable and red presents a poor result.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>403213</td>
<td>FIFTEEN MILE CREEK @ GRETA SOUTH</td>
<td>0.85</td>
<td>9</td>
<td>0.76</td>
<td>13</td>
<td>81</td>
<td>403222,403218,403217</td>
<td>Dam releases</td>
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<td>8</td>
<td>81</td>
<td>403222,403218,403217</td>
<td></td>
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<td>BUFFALO RIVER @ LAKE BUFFALO</td>
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<td>9</td>
<td>0.81</td>
<td>13</td>
<td>81</td>
<td>403222,403218,403217</td>
<td></td>
</tr>
<tr>
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<td>14</td>
<td>81</td>
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<td></td>
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<tr>
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<td>KING RIVER @ DODGER ROAD BRIDGE</td>
<td>0.82</td>
<td>7</td>
<td>0.79</td>
<td>11</td>
<td>81</td>
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<td></td>
</tr>
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<td>KING RIVER @ CHESHUNT</td>
<td>0.66</td>
<td>-3</td>
<td>0.81</td>
<td>-7</td>
<td>81</td>
<td>403228</td>
<td>Dam releases</td>
</tr>
<tr>
<td>403240</td>
<td>KING RIVER @ EDI</td>
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<td>0.82</td>
<td>-17</td>
<td>81</td>
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<td></td>
</tr>
<tr>
<td>403244</td>
<td>OVENS RIVER @ HARRIETVILLE</td>
<td>0.83</td>
<td>-6</td>
<td>0.61</td>
<td>6</td>
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<td>DANDONGADALE RIVER @ MATONG</td>
<td>0.60</td>
<td>-2</td>
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<td>-7</td>
<td>56</td>
<td>403209</td>
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</tr>
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<td>REEDY CREEK @ WOOLSHED</td>
<td>0.80</td>
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<td>0.70</td>
<td>25</td>
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<td>0.17</td>
<td>20</td>
<td>0.00</td>
<td>0</td>
<td>44</td>
<td>403220</td>
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</tr>
<tr>
<td>403205</td>
<td>OVENS RIVERS @ BRIGHT</td>
<td>0.80</td>
<td>33</td>
<td>0.77</td>
<td>39</td>
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<td>Town extractions</td>
</tr>
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<td>HURDLE CREEK @ BOBINAWARRAH</td>
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<td>36</td>
<td>0.69</td>
<td>38</td>
<td>25</td>
<td>403223</td>
<td></td>
</tr>
<tr>
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<td>20</td>
<td>0.78</td>
<td>27</td>
<td>25</td>
<td>403210,403220</td>
<td>Dam release, Town extractions, Cumulative error from upstream catchments</td>
</tr>
<tr>
<td>403226</td>
<td>BOGGY CREEK @ ANGLESIDE</td>
<td>0.79</td>
<td>24</td>
<td>0.59</td>
<td>21</td>
<td>13</td>
<td>403210,403220</td>
<td></td>
</tr>
<tr>
<td>403232</td>
<td>MORSES CREEK @ WANDILIGONG</td>
<td>0.68</td>
<td>56</td>
<td>0.58</td>
<td>48</td>
<td>13</td>
<td>403210,403220</td>
<td></td>
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<tr>
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<td>Buckland Creek @ Harris Lane</td>
<td>0.74</td>
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<td>0.59</td>
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<td>13</td>
<td>403210,403220</td>
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<tr>
<td>403249</td>
<td>THREE MILE CREEK D/S YARRAWONGA RD</td>
<td>0.52</td>
<td>25</td>
<td>0.00</td>
<td>0</td>
<td>19</td>
<td>403213</td>
<td>Town extractions, climate data (Mt Buffalo Chalet climate station). Small calibration data set</td>
</tr>
<tr>
<td>403250</td>
<td>OVENS RIVER @ EUROBIN</td>
<td>-1.63</td>
<td>26</td>
<td>0.00</td>
<td>0</td>
<td>19</td>
<td>403205,403233</td>
<td>Review the catchment area, possible that high flows are bypassing gauge through 403209. Town extractions (large), Cumulative error from upstream catchments, Ground water interactions, Mapping of stream network and sub-catchment through billabongs, anabranches and floodplains.</td>
</tr>
<tr>
<td>403200</td>
<td>OVENS RIVER @ WANGARATTA</td>
<td>-0.39</td>
<td>69</td>
<td>-0.14</td>
<td>68</td>
<td>0</td>
<td>403220,403224,403223</td>
<td>Review the catchment areas, possible that this gauge incorporates high flows from the Owens River. Cumulative data, Mapping of stream network and sub-catchment through billabongs, anabranches and floodplains.</td>
</tr>
<tr>
<td>403209</td>
<td>REEDY CREEK @ WANGARATTA NORTH</td>
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<td>-84</td>
<td>0.07</td>
<td>-81</td>
<td>0</td>
<td>403221</td>
<td></td>
</tr>
<tr>
<td>403210</td>
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<td>0.44</td>
<td>38</td>
<td>0.46</td>
<td>40</td>
<td>0</td>
<td>403225,403214</td>
<td>Town extractions and Cumulative error from 403250 &amp; 403214</td>
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<tr>
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<td>0.29</td>
<td>58</td>
<td>0</td>
<td>403205,403233</td>
<td></td>
</tr>
</tbody>
</table>

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*eWater CRC*
From the summary table (Table 3) the best overall catchments appeared to be the upper catchments in the Ovens and Buffalo Rivers as well as the King River upstream of Wangaratta. Generally the worst catchments were along the Ovens, further down the catchments and a significant number of the poorest parameterisations were sub-catchments with town extractions and poor upstream model results. A number of factors were influencing the modelled results at any given gauge point including:

- Cumulative error as a poor calibration from an upstream catchment will propagate downstream
- The available calibration data sets
- Input data including climate as well as stream networks and sub-catchment boundaries particularly towards the bottom of the catchment where billabongs, anabranches (during high flow events) and floodplains all have an impact.
- Model conceptualisation and the catchment processes incorporated

The results presented in this report were for the Base model of the Ovens catchment, which was designed as a simple rainfall runoff model so that the advantages of incorporating more landscape details and better model conceptualisation on predicted stream flow could be assessed. A third PEST parameterisation was attempted of the Base model plus urban extractions; however we could not get PEST to run with the model as extractions were incorporate as a plugin, this is not a problem in the more recent version of source catchments and this step is still be completed. In addition to incorporating urban extractions into the model, the overall conceptualisation of the model needs to be considered. In particular, the selection of SIMHYD as the base-model, surface and ground water interactions and finally the sub-catchment boundaries and flow paths at the bottom of the catchment.

SIMHYD as a conceptual rainfall runoff model assumes that all sub-catchments are hydrologically contained and that what goes in must at some time go out as streamflow or evaporation unless you switch off baseflow completely and just let the infinite groundwater store continually fill. In reality water will leave the sub-catchments and drain to neighbouring catchments through ground water or it may be lost from the Ovens catchment through deep aquifers. If the SIMHYD model was to be applied to some of these smaller upland sub-catchments conceptually it would need some mechanism to handle situations where water-in (rainfall) is much higher than water-out (streamflow). This could be in the form of a groundwater discharge factor that allows the groundwater store to drain over time into a store disconnected from the stream.

Traditionally groundwater and surface water have been studied and managed as separate resources, with limited attention given to considering the groundwater and surface water systems together despite the inherent interactions and dependencies. While the river reaches in the upper part of the Ovens appear to be consistently gaining from groundwater resources with baseflow indices typically ranging from 60 to 70%, in the lower Ovens the river is clearly losing water to groundwater systems in winter when the river is high and it fluctuates between gaining and losing fluxes over the summer months (Cheng and Reid 2010). This complexity, particularly in the lower Ovens where
the stream changes from gaining to losing over time will affect the prediction of streamflow. Hopefully, further research on the groundwater-stream interactions will allow some of this complexity to be incorporated into the Ovens catchments model in the future.

Finally the further work maybe required to further refine the sub-catchments at the bottom of the Ovens catchment, particularly 403200 (Wangaratta) and 403209 (Reedy Creek). There is a single gauging point on the Ovens River at Wangaratta (Figure 33), but two stream gauges which represent different ratings (403200 and 403242). We used the results for 403200 which was rated for the Ovens at Wangaratta and ignored 403242 which was rated for the combined flows from the Ovens at Wangaratta and inflow from Reedy Creek (during higher flow events). In doing this we directed all of the flow from Reedy Creek (403209) downstream of Wangaratta for the full modelled period to try and reduce the complexity. This simplification of the changing flow paths through the billabongs and anabranches during different flow stages may have affected the results.
Figure 33. Location of the Wangaratta Stream Gauge (403200 and 403242) showing the stream system around Wangaratta and direction of Reedy creek flow during high and low flow periods.
5 Conclusions

This technical report has presented the results of first stage of an investigation into the importance of landscape connection and complexity in the prediction of streamflow at the catchment scale. In particular it presented the results of the parameterisation of a simple Base Model of the Ovens catchment, from which further complexity and the impacts on modelled streamflow can be assessed.

There was a significant component of the report which centred around gathering input data (stream flow, climate and extractions) and validating the input data, particularly the techniques for providing spatial climate data for catchment modelling. In terms of the climate data two quite different approaches to generating climate data for a Source Catchments scenario were investigated. The two methods used were:

- Climate from the 5km gridded data sourced from Queensland Department of Natural Resources and Environment’s SILO service
- Climate generated using the Catchment Analysis Tool (CAT), which involves scaling raw point-source climate station Bureau of Meteorology (BOM) data (sourced from QDNRE SILO service) by interpolated mean-monthly spatial layers using the ANUCLIM software.

In the Ovens Base Model there was good correlation between the climate generation techniques for the majority of sub-catchments. Each method had a number of advantages and disadvantages which were discussed within the report.

Automated processes were established to optimise a scenario in Source Catchments using PEST and to create standardised methods of reporting calibration results out of PEST. While the initial setup of the PEST files was complex, the automated process developed was able to generate the required PEST files quickly, run PEST and extract the results for analysis. This automation, combined with the power of PEST as a parameterisation tool was a key result from this work and we will allow us to continue to utilise PEST with Source Catchments into the future.

The initial calibration of the Base Model of the Ovens catchment presented in this report highlighted the need to incorporate more landscape complexity within the model. Only 60% of the modelled sub-catchments achieved an acceptable calibration based on the coefficient of efficiency and cumulative flows. In general the best calibrations appeared to be the upper sub-catchments in the Ovens and Buffalo Rivers as well as the King River upstream of Wangaratta. Generally the worst catchments were along the Ovens (including the Wangaratta gauges), with a significant number of the poorest parameterisations in sub-catchments with known town extractions and poor upstream model results.
5.1 The Next Steps

Using the Base Model and the automated PEST processes, the project will focus on the investigation of how landscape connection and complexity affect the prediction of streamflow at the catchment scale. However, before the increased complexity can be investigated there were a couple of factors which need to be corrected within the Base Model, specifically:

- Remove the climate anomalies from the scenario (i.e. remove the Mt. Buller, Mt. Hotham and Mt Buffalo Chalet climate stations from the climate generation model).
- Check climate and streamflow inputs for the particularly bad optimisation (403209 - Reedy Creek) and re-run the parameterisation using PEST and a range of different initial parameter values to determine if an improved parameterisation can be obtained.

Once we are happy with the Base Model; acknowledging that it won't provide a perfect prediction of streamflow given the previous discussion; we will start incorporating landscape complexity and analyse the impact on streamflow, to determine whether increasing complexity is resulting in improvements in model predictions. The next steps in the investigation of landscape complexity are:

- Inclusion of town extractions (overall water balance)
- Inclusion of dam releases (timing and magnitude of flow in the downstream catchments)
- Inclusion of stream routing (hopefully using a sub-daily Muskingum routing method)
- Inclusion of groundwater interactions (particularly in the lower catchments around Wangaratta where we know that streams move between gaining and losing systems).

In addition to the investigation of landscape connection and complexity, the final factor that we wish to investigate is the robustness of the model to changes in climate patterns. In particular does the model parameterisation hold when it is parameterised on wet, dry or average rainfall periods and then cross validated. This analysis will utilise SIMHYD within the Base Model as well as CAT/CATNode to determine our confidence in the ability of the model to be utilised for future climate scenarios.

5.2 Recommendations

- Parallel development of e2commandline and Source Catchments. PEST linked to Source Catchments provided an amazingly powerful tool that can simultaneously optimise hundreds of Rainfall-Runoff models whilst accounting for stream routing, dam releases and extractions. It is unlikely that we would use Source Catchments without PEST, as such it is imperative the development of e2commandline is kept inline with Source Catchments so that future functionality within Source Catchments can be utilised while still allowing the use of PEST.
- Source Catchments Plugin to fully automate the link to PEST. It our view that PEST should be incorporated as a standard tool within Source
Catchments. The current tools within the PEST plugin go a long way to meeting this however further development would be required to fully automate the process.

- **Manually drawn Source Catchment networks need to allow nodes at the gauge points.** To utilise the full capability of Source Catchments, i.e. include routing and dam models in the optimisation it is essential that the modelled streamflow at actual the gauge point can be obtained from Nodes. This was not possible for our manually drawn nodal network in Source Catchments (v1.02b) where we had to use the Link Outflow downstream from the sub-catchment to compare to our gauge data because the Node Outflow and Link Inflow did not account for the sub-catchment contributions. This limited the ability to include stream routing as these affected the Link Outflows and therefore the data that was being attributed to the Gauge.

- **Consider a groundwater loss term in SIMHYD.** Applying SIMHYD to the smaller sub-catchments in the Ovens Base Model suggested that in the upland catchments the assumption that each sub-catchment is hydrologically isolated and that the only pathways for water export is evapotranspiration and stream flow were flawed. A number of the ephemeral systems had to cut off baseflow completely, despite the catchments having a 60-70% baseflow contribution because the groundwater store was infinite and able to continually leak water into the stream. Introducing a single groundwater loss term into SIMHYD could overcome this problem and increase the capacity of SIMHYD to describe these smaller upland sub-catchments.

### 6 Acknowledgements

The authors of this report would like to acknowledge the financial support of the Department of Primary Industries Victoria and the eWater CRC which has enabled this research to be conducted. The authors would also like to acknowledge and thank the following individuals and organisations for their input and support of the research:

- Robin Ellis from the Queensland Department of Environment and Resource Management for his help in developing the ability to use PEST with Source Catchments, as well as his input into discussions of parameterisation approaches.
- The North East Catchment Management Authority
- The Catchment and Climate team (particularly David Waters and Alex Miller) for the support in the application of Source Catchments.
7 References


SKM (2005) REALM model development for the Upper Ovens river catchment. Sinclair Knight Merz Pty Ltd, Malvern, Australia.


Appendix 1: Climate generation for spatio-temporal modelling using the Catchment Analysis Tool (CAT)

The Catchment Analysis Tool (CAT) incorporates a number of tools to generate historic and future climate sequences. Climate sequences are generated on a daily time-step at a user-defined spatial resolution. Spatial resolution is defined by the cell size of the ASCII Digital Elevation Model (DEM) that underlies the scenario and generally ranges between $1m^2$ to $1000m^2$.

Daily point source climate station data across Australia are sourced from the Queensland Department of Natural Resources and Environment’s SILO service. The daily ‘Patched Point Data’ uses interpolation methods discussed in Jeffery et al. (2001) to infill any missing data within the daily Bureau of Meteorology measurements for a given climate station. Typical climate attributes used for spatiotemporal modelling include rainfall, minimum and maximum temperature, radiation, evaporation and vapour pressure.

The point location of each climate recording station is used in conjunction with the ArcInfo © Geographic Information System proximity command to create a climate proximity surface (Figure 34). This surface represents the nearest climate station for any point within the catchment.

**Figure 34** Point location of climate stations overlayed on climate proximity surface showing an example of the temporal rainfall data from one climate station.
A1.1 CATCLIM: The generation of climate changed data for spatiotemporal modelling

The Catchment Analysis Toolkit (CAT) climate change module, CATCLIM, has been developed to generate future climate patterns to assess the likely impacts of climate change on cropping systems in Victoria. CATCLIM is a user-interface that sits within the CAT modelling framework and enables flexible, repeatable, batch methods to generate future climate data (Figure 35).

![Figure 35 CAT interface showing rainfall pattern of change for the month of May, with CATCLIM module opened.](image)

**A1.1.1 Overview of CATCLIM**

CATCLIM has been developed as a tool to generate future climate sequences based on the International Panel of Climate Change (IPPC) predictions of future global warming scenarios. The model also accounts for regional impacts of global warming in Victoria, using spatial maps of the expected pattern of change in climate developed by CSIRO (Hennessy et al. 2006). Figure 36 gives a general overview of climate generation using CATCLIM. The model scales the historical climate data then generates a spatially interpolated daily climate sequence which can be utilised in a number of catchment and farming systems models.
A1.1.2 Input Requirements
The IPCC estimates are available at the global scale and predict increasing mean temperatures as well as elevated atmospheric CO₂ concentrations for a range of future scenarios including low, medium and extreme increase in global warming. CATCLIM requires an input file containing global warming factors as percent values for each of the global warming scenarios to be run.

The mean-monthly pattern of change data comes from CSIRO’s global atmosphere models (CCAM-Mark2 and CCAM-Mark3) 50x50 km grid-cell pattern for Victoria (Hennessy, 2006).

Figure 36 Overview of future climate generation using CATCLIM.
Method of generating future climate sequences

A downscaling technique is used to de-trend historic daily data over a specific baseline period. The de-trended data is then scaled by annual climate prediction estimates from the International Panel of Climate Change (IPCC) and spatial mean-monthly pattern-of-change maps developed by CSIRO.

The methods employed to generate the scaled climate data are described below. For a more detailed discussion refer to Anwar et al. (2007).

Define the daily reference data \( r_m,t \), spanning the period \( y_1 \) to \( y_2 \) where \( y_1 \) is the start year of the reference period, typically 1935, \( y_2 \) the end year, typically 1990 and \( t \) is a daily date-stamp. Extract the daily reference data \( r_m,t \) for a given calendar month \( m \). Fit a linear regression line \( T = a \times MA(r_m,t) + b \) to the mean-annual (MA) daily-monthly reference data versus the projection year. De-trend the daily-monthly data,

\[
s_{m,t} = r_{m,t} - a(y_1 - y_1)
\]

where \( r_{m,t} \) are the daily-monthly reference data, \( a \) is the gradient of the linear regression line \( T \) and \( y_1 \) is the reference year. Centre the de-trended data around zero,

\[
u_{m,t} = s_{m,t} - \bar{s}_{m,t}
\]

where \( \bar{s}_{m,t} \) is the mean of the de-trended sequence \( s_{m,t} \). Calculate a baseline value \( B_m \) for the year 1990 for each calendar month. This anchors the projections to the IPCC reference year of 1990.

\[
B_m = \bar{s}_{m,t} + \frac{a(y_2 - y_1)}{2}
\]

The future maximum and minimum temperature projections are then calculated as a value shifted from the baseline year.

\[
x_{m,t} = u_{m,t} + y_2 - y_1 + B_m + (Pat_m \times GWF_{y_1})
\]

where \( u_{m,t+y_2-y_1} \) are the daily-monthly de-trended data between \( y_1 \) and \( y_2 \), \( B_m \) is the baseline value calculated for each calendar month, \( Pat_m \) is the pattern of change value defined at the co-ordinates of the reference data for month \( m \) and \( GWF_{y_1} \) is the global warming factor predicted by the IPCC for the future year \( y_1 \). Rainfall and radiation are scaled from the baseline year

\[
x_{m,t} = (u_{m,t+y_2-y_1} + B_m) \times (1 + Pat_m \times GWF_{y_1})
\]

The monthly-daily data are then recombined to form the full daily climate changed sequence.

Outputs

The standard output of CATCLIM is a daily text file containing the climate changed sequences for minimum temperature, maximum temperature, rainfall and radiation. The file is formatted in a similar manner to the ‘patched-point’ SILO data (Figure 37). Information including input files and settings are written into the header of the file. Other options include writing the file in a binary format. It is also possible to output the spatially interpolated climate data as a series of daily ASCII layers if required.
A1.1.5 **Useful functionality of CATCLIM user-interface**

While the main intent of the CATCLIM is to generate climate-changed sequences for use in spatiotemporal modelling there is a number of added functionalities that lie within the user-interface that allow for ease of climate generation, repeatability and reliability, batch processes and consistency. Some of the extra features are listed as follows:

- Can generate climate change data for any number of climate stations. For example; can generate future climate data for every climate station within Victoria or can filter out a specific region such as Gippsland.

- Can interpolate point climate data over space to give full spatiotemporal data set at a user-defined cell-size.

- Allows the user to
  - specify a baseline period to de-trend temporal data
  - select from variations in predicted IPCC Global warming factors, i.e. low, medium or high
  - interrogate the pattern of change data. User can click on any point in Victoria and get a full listing of the monthly pattern of change for all climate parameters
  - specify the period of de-trended data used to generate future climates from. For example the user could select data from a dry period (1999 to 2009) and loop this around five times to generate 50 years of de-trended data which is then scaled to generate the future climate sequence
  - specify the start and end date of the projected climate sequence
  - specify output format either text or binary and adds a header to all output files giving a summary of settings and input files.
  - select from multiple climate change pattern of change models, i.e. Mk1, Mk2 and Mk3. User simply provides the individual CSIRO monthly pattern of change files.

- Converts the individual CSIRO monthly pattern of change files into compact ASCII layer with attached look-up table.

---

**Figure 37** Example of CATCLIM output file

<table>
<thead>
<tr>
<th>Date</th>
<th>T.Max</th>
<th>T.Min</th>
<th>Rain</th>
<th>Radn</th>
</tr>
</thead>
<tbody>
<tr>
<td>19350101</td>
<td>33.8</td>
<td>18.1</td>
<td>0.000</td>
<td>25.9</td>
</tr>
<tr>
<td>19350102</td>
<td>36.3</td>
<td>18.1</td>
<td>0.000</td>
<td>23.9</td>
</tr>
<tr>
<td>19350103</td>
<td>31.3</td>
<td>18.1</td>
<td>0.000</td>
<td>23.9</td>
</tr>
</tbody>
</table>
- Generates baseline and pattern of change summary files for each climate station for cross-validation.
- Generates a shape file of the climate station locations, extracting the latitude/longitude information from the BOM point source weather data.

### A1.2 Spatial interpolation of point-source climate data

Because climate stations are located sparsely, point-source climate data is scaled according to interpolated mean-monthly (1975-2005) spatial layers. Interpolated surfaces are created using the ANUClim software (Hutchinson 2001) that combines a DEM and temporal climatic data to generate smoothed mean-monthly climate surfaces (Figure 38). The surfaces represent a climate gradient across space and account for elevation based climate variability. The ANUClim surfaces are used to generate mean-monthly spatial scaling factors (r-factors) which are then used to scale the daily point source climate station data.

![Figure 38 ANUClim mean-monthly interpolated rain fall (1975-2005) for months a) Match and b) June.](image)

#### A1.2.1 Banding climate layers to decrease model complexity

The Catchment Analysis Tool runs a series of complex biophysical models on each unique combination of input data including climate data, soil type, topography and land use. With five climate attributes, minimum temperature, maximum temperature, rainfall, evaporation and radiation, each with twelve mean-monthly spatial scaling layers the number of unique polygons quickly becomes so large that it is not practicable to run all combinations. To reduce the number of unique combinations the input layers are banded in such a way that the user has control of the complexity of the scenario. The user can choose to have constant bands i.e. 10mm bands for rainfall, set the bands manually, or use a minimum deviation technique in which the number of bands are specified then the...
band limits optimised so that approximately the same number of data points fall within each band. The data value assigned to the band can be selected from the mean, mid-point or median of the data within the band. For climate attributes banding is generally calculated for the mean annual layer then applied across each of the mean-monthly layers.

Figure 39 Application of a course banding to the mean-annual ANUCLIM Rainfall using the mean-minimum deviation technique.

A1.2.2 Methods of spatially scaling point-source climate data

A1.2.2.1 Method 1: Scale to match Bureau of Meteorology (BOM) data over run period

This method ensures that the climate sequence at the exact location of the climate station matches the BOM trace. Data surrounding the climate station is scaled proportionally based on the deviation of the ANUCLIM spatial layer from value of the ANUCLIM layer at the climate station.

Scaling factors for rainfall, evaporation and solar radiation are calculated as follows:

\[ R_{ANUCLIM\text{banded},m} = \text{bands}(R_{ANUCLIM,m}) \]  

where \( R_{ANUCLIM,m} \) is the mean-monthly rainfall/radiation ANUCLIM layer for month \( m \) and \( \text{bands}(R_{ANUCLIM,m}) \) is the banded mean-monthly rainfall/radiation ANUCLIM layer form month \( m \).

The mean-monthly spatial scaling factors \( r_{\text{rain,rad, evap}} \) are calculated as

\[ r_{\text{rain,rad, evap}} = \frac{R_{ANUCLIM\text{banded},m}}{R_{ANUCLIM\text{banded},m,CS}} \]
where $R_{ANUCLIM\text{banded},m,CS}$ is the value of $R_{ANUCLIM\text{banded},m}$ at the specific location of the Climate Station (CS). Using this formulation the scaling factor at the exact location of the climate station will always equal one. The climate at this point will be fully correlated with the BOM data for that climate station.

Shift factors for temperature are calculated as follows:

$$T_{ANUCLIM\text{banded},m} = \text{bands}(T_{ANUCLIM,m})$$  \hspace{1cm} (8)

where $T_{ANUCLIM,m}$ is the mean-monthly minimum/maximum temperature ANUCLIM layer for month $m$ and $\text{bands}(T_{ANUCLIM,m})$ is the banded mean-monthly ANUCLIM layer form month $m$.

The mean-monthly spatial shift factors $r_{\text{temp}}$ are calculated as

$$r_{\text{temp}} = T_{ANUCLIM\text{banded},m} - T_{ANUCLIM\text{banded},m,CS}$$  \hspace{1cm} (9)

where $T_{ANUCLIM\text{banded},m,CS}$ is the value of $T_{ANUCLIM\text{banded},m}$ at the specific location of the Climate Station (CS). Using this formulation the shift factor at the exact location of the climate station will always equal zero.

### A1.2.2.2 Method 2: Scale to match ANUCLIM (1975-2005)

This method ensures that the mean-monthly BOM climate data over the period 1975 to 2005 is scaled to match the mean-monthly ANUCLIM layers. Data surrounding the climate station is scaled proportionally based on the deviation of the ANUCLIM spatial layer from value of the BOM data at the climate station.

The spatial scaling factors $r_{\text{rain,radn,evap}}$ are calculated as

$$r_{\text{rain,radn,evap}} = \frac{R_{ANUCLIM\text{banded},m}}{R_{BOM \text{1975--2005},m,CS}}$$  \hspace{1cm} (10)

where $R_{BOM \text{1975--2005},m,CS}$ is the mean-monthly value of the BOM data at the Climate Station (CS).

The mean-monthly spatial shift factors $r_{\text{temp}}$ are calculated as

$$r_{\text{temp}} = T_{ANUCLIM\text{banded},m} - T_{BOM \text{1975--2005},m,CS}$$  \hspace{1cm} (11)

where $T_{BOM \text{1975--2005},m,CS}$ is the mean-monthly value of the BOM data at the Climate Station (CS).
Appendix 2: Rainfall residuals for climate stations within the Ovens catchment
Appendix 3: PEST2 (7 parameters and systematic optimisation of sub-catchments)

<table>
<thead>
<tr>
<th>Site</th>
<th>baseflow coefficient</th>
<th>infiltration coefficient</th>
<th>infiltration shape</th>
<th>interflow coefficient</th>
<th>recharge coefficient</th>
<th>rainfall interception store capacity</th>
<th>soil moisture store capacity</th>
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<td>400.00</td>
<td>0.95</td>
<td>0.00</td>
<td>0.00</td>
<td>5.00</td>
<td>500.00</td>
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<td>0.03</td>
<td>0.44</td>
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<td>500.00</td>
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<td>500.00</td>
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<td>500.00</td>
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<td>0.04</td>
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<td>207.35</td>
</tr>
</tbody>
</table>

Table 4 PEST2 optimised parameters for sub-catchments within the Ovens catchment.