Methods to Assess Water Allocation Impacts of Plantations: Final Report

Mat Gilfedder, Lu Zhang, Tivi Theiveyanathan, Nico Marcar, Steve Roxburgh, Mark Littleboy, Fangfang Zhao, Yun Chen, Auro Almeida and Debbie Crawford

November 2010
Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills.

CSIRO initiated the National Research Flagships to address Australia’s major research challenges and opportunities. They apply large scale, long term, multidisciplinary science and aim for widespread adoption of solutions. The Flagship Collaboration Fund supports the best and brightest researchers to address these complex challenges through partnerships between CSIRO, universities, research agencies and industry.

The Water for a Healthy Country Flagship aims to achieve a tenfold increase in the economic, social and environmental benefits from water by 2025. The work contained in this report is collaboration between CSIRO, Department of Environment, Climate Change and Water NSW, and Department of Primary Industries Victoria.

For more information about Water for a Healthy Country Flagship or the National Research Flagship Initiative visit www.csiro.au/org/HealthyCountry.html


Copyright and Disclaimer

© 2010 CSIRO To the extent permitted by law, all rights are reserved and no part of this publication covered by copyright may be reproduced or copied in any form or by any means except with the written permission of CSIRO.

Important Disclaimer:

CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

Cover Photograph:

Description: Pine forest
Photographer: Mat Gilfedder
© 2010 CSIRO
CONTENTS

Acknowledgments ....................................................................................................... iv

Executive Summary ...................................................................................................... v

1. Background ......................................................................................................... 1
   1.1. Objectives ................................................................................................................. 1
   1.2. Milestones ................................................................................................................. 2
   1.3. Addressing the Milestones ........................................................................................ 3

2. Milestones #1, #2 - Workplan and Establish Project Steering Committee..... 3

3. Milestones #3, #4, #5, #6 – Catchment Modelling ............................................. 3
   3.1. FCFC Model .......................................................................................................... 4
       3.1.1. Input and output data ........................................................................................ 4
       3.1.2. Limitations and assumptions ........................................................................... 4
   3.2. Relevant Milestones .............................................................................................. 5

4. Milestones #7, #8, #9 – Site-specific Modelling ................................................ 8
   4.1. 3-PG/PERFECT/2CSalt Modelling .......................................................................... 8
       4.1.1. Input and output data ......................................................................................... 9
       4.1.2. Limitations and assumptions .......................................................................... 9
   4.2. Relevant Milestones .............................................................................................. 10

5. Milestones #10, #11: Communication and Final Report ................................ 13
   5.1. Relevant Milestones .............................................................................................. 13

6. Risk Based Framework ..................................................................................... 14

References .................................................................................................................. 15

LIST OF FIGURES

Figure ES 1. Independent estimate of impact of climate ($\Delta Q_{\text{clim}}$) and vegetation ($\Delta Q_{\text{veg}}$) change on observed streamflow in the case study catchments. All catchments showed a combination of both factors. .........................................................................................................................................................vi

Figure ES 2. Modelled impact of plantation expansion on streamflow reduction (Adjungbilly Catchment, NSW). In this case, the modelled impact of planting an additional 4000 ha of plantation varies between 0.5-2.0 ML/ha depending on location. .............................................................................................................................................................. vii

Figure 3.1. Independent estimate of impact of climate ($\Delta Q_{\text{clim}}$) and vegetation ($\Delta Q_{\text{veg}}$) change on streamflow in the case study catchments ........................................................................................................................................................................... 5

Figure 3.2. Two catchment examples of daily Flow Duration Curves for pre and post plantation expansion periods ............................................................................................................................................................................ 7

Figure 4.1. Comparison between measured monthly streamflow and calibrated 2CSalt predictions for 31 year measurement period 1967-2007 for the Adjungbilly Creek Catchment ........................................................................................................... 11

Figure 4.2. Modeled impact of plantation expansion on streamflow reduction (example using Adjungbilly Creek Catchment). In this example the modelled impact of planting an additional 4000 ha of plantation varies between 0.5-2.0 ML/ha depending on location within the catchment. ........................................................................................................... 12

LIST OF TABLES

Table 1.1. Milestones from the Deed of Variation – June 2009 ........................................... 2
Table 2.1. Project Steering Committee ................................................................................ 3
Table 3.1. Case studies selected for the FCFC modelling component .................................. 6
Table 4.1. Input data required for 3-PG/PERFECT/2CSalt .................................................... 9
ACKNOWLEDGMENTS

This project is a National Water Commission (NWC) initiative, funded through its Raising National Water Standards Program. The project is funded through the NWC, CSIRO and Forest & Wood Products Australia (FWPA) Project: ‘Methods to Accurately Assess Water Allocation Impacts of Plantations’.

We acknowledge the important role played by Richard Benyon (Principal Research Fellow, Forest Hydrology, Department of Forest and Ecosystem Science, The University of Melbourne) in initial leadership, development and planning of the project.

We acknowledge the time and assistance provided by the Project Steering Committee.
EXECUTIVE SUMMARY

Plantation forestry is an increasingly important land use in Australia. While plantations can present significant benefits, their potential impact on streamflow needs to be considered. It is important that this information be incorporated into the development of water resources management strategies.

The National Water Initiative (NWI) recognises that large-scale plantation forestry is one example of a type of land use change which has the potential to intercept significant volumes of surface and/or ground water now and in the future. Many of the catchments that may sustain significant areas of new plantations are biophysically complex, with varying rainfall, soil depths and textures, groundwater characteristics and possible planting locations. All of these factors can lead to variability in the potential impacts of any new plantation development on catchment water yield.

Project objectives
The objective of this project was to develop and test models which can predict the impacts of the expansion of large-scale plantation forestry on streamflow and hence downstream water availability.

Specifically, the effects of past plantations on streamflow were examined, and methods for estimating the impact were tested. These methods can be used to predict impacts on streamflow of new plantations in order to:

1) Quantify current and future water availability;
2) Enable development of appropriate policy for management of the impacts of land use change on water resources, and;
3) Provide vegetation management tools to help maximise water benefits from catchments.

Two modelling approaches
To best meet the objectives, the project has applied/developed two modelling approaches which varied in their complexity and conceptualisation. These were:

1) Development of a method for quantifying the effects of past plantation development on streamflow, and testing of the Forest Cover Flow Change (FCFC) model for predicting changes in streamflow regime.
2) Development and testing of an improved catchment model which incorporates dynamic tree growth (3-PG/PERFECT/2CSalt), to enable quantitative or qualitative assessment of the site-scale impacts of new plantations on streamflow.
1) Catchment modelling

We analysed data from 19 catchments which have experienced significant changes in plantation area. These catchments range in size from 0.6 to 1402 km² and represent a range of climatic conditions. They all showed reductions in annual streamflow over the period of the records—a combination of the effects of plantation expansion as well as declines in rainfall (see figure below). The framework described in this study provides independent estimates of plantation and climate impacts on streamflow. It shows that the effect of plantation expansion on streamflow is not limited to small catchments. Plantation expansion reduces mean annual streamflow and also affects streamflow regime. In catchments with relatively low rainfall, large scale plantation expansion is likely to reduce low flows significantly, resulting in increased number of zero-flow days. In addition to the impact on catchment water yield this also has potentially serious in-stream ecological implications.

![Figure ES 1. Independent estimate of impact of climate ($\Delta Q_{clim}$) and vegetation ($\Delta Q_{veg}$) change on observed streamflow in the case study catchments. All catchments showed a combination of both factors.](image)

The Forest Cover Flow Change (FCFC) model was then tested using the data from the 19 selected catchments and the results showed that the model is capable of predicting plantation impacts on streamflow regime.

2) Site-specific modelling

An approach was developed to model the impact of within-catchment variation of rainfall, soil, hydrogeology, or plantation management on stream flow. The project integrated a detailed one-dimensional tree (3-PG) and pasture/crop (PERFECT) physiology modelling with a catchment hydrological model (2CSalt). The result is a modelling approach which can handle plantation dynamics (planting date, thinning, harvesting, and tree growth) to provide a monthly time-series end-of-catchment stream flow, which is sensitive to vegetation changes.

The project has developed an approach which enables us to look at trade-offs between plantation area (e.g. locations) and streamflow reduction by taking into consideration differences in soil, rainfall, etc. This approach can be used to identify sub-catchments on the basis of modelled plantation impacts (i.e. streamflow reduction per ha planted). With care in catchment validation, this approach can be used to provide a comparison of timber productivity with streamflow impacts.
Figure ES 2. Modelled impact of plantation expansion on streamflow reduction (Adjungbilly Catchment, NSW). In this case, the modelled impact of planting an additional 4000 ha of plantation varies between 0.5-2.0 ML/ha depending on location.

Risk-based framework

We propose that the two approaches used in this project be used as part of an overall risk based process, where the level of modelling resources is targeted based on the level of risk to water resources. An example of a three level approach is given below:

Lower risk / Higher uncertainty

As a first step, the project has demonstrated the use of relatively simple tools such as the Forest Cover Flow Change (FCFC) model. Data requirements are relatively low, and such models can provide insight into the impact on streamflow regime resulting from changes in forest cover. We have shown that the application of approach is achievable without significant additional data collection.

Medium risk / Medium uncertainty

More complex approaches like the 3-PG/PERFECT/2CSalt modelling approach require increased resources and data to run, but provide estimates of the variation in impact across the modelled area resulting from soil/climate/slope-management-practice differences.

To capture within-catchment variation it is necessary to use a more complex catchment modelling approach which can handle such variability. This project has developed a modelling approach to estimate the potential impacts of surface water interception by large-scale plantation forestry.

While this approach requires greater data and resources to apply, much of the data to run this type of approach already exists across large areas. It appears feasible to apply this method more broadly across multiple catchments. Approaches which require similar complexity of data have already been rolled out across large areas in recent years (e.g. 2CSalt roll out across upland areas of NSW).

Higher risk / Lower uncertainty

There are even more complex modelling techniques that are available (e.g. TOPOG: Dawes et al. 1997). To be useful they require a significant level of monitoring data, which comes at a high cost – often prohibitively high. Even if such approaches are deemed to be feasible, it is likely that they would be best used in a targeted manner, in areas where there are very high risks, or to manage particular high value assets.
1. BACKGROUND

This report provides an overview of the work undertaken to fulfil the Raising National Water Standards project: ‘Methods to Accurately Assess Water Allocation Impacts of Plantations’. This project aimed to develop methods to improve the accuracy of the assessment of the surface water allocation impacts of plantations.

1.1. Objectives

The Objectives of the Project were to:

a. Develop and test methods and models for identifying surface water catchments where new plantation developments will have high and low impacts on water availability and dilution flows:
   
   a) Methods will be delivered as detailed technical documents and practical guidelines to enable agencies to run plantation scenarios through water balance models in a nationally consistent manner, utilising best available knowledge of temporal and spatial patterns of forest water use;
   
   b) The detailed methods, models and guidelines will enable prediction of plantation water interception and the potential effect of this on water allocation and where applicable, dilution flows, for use in water planning over the next two to five years;

b. Provide methods and test models to enable accurate quantitative, or where suitable input data are not available, qualitative assessment of the site-scale impacts of new plantations on stream-flow for accounting for water allocation impacts of plantations in a consistent way across Australia:

   a) Methods and models will account for local factors such as topography and soil (including effects of plantation location within the catchment), climate (including effects of rainfall and rainfall seasonality), tree species, rotation length and management options such as thinning, based on a synthesis of the available data and models of tree water use across Australia;
   
   b) The information will be delivered as detailed technical documents and practical guidelines and predictions of water yield for a range of conditions for direct use by jurisdictions in catchment management and planning decisions. Delivery will include a series of user workshops.
### 1.2. Milestones

The milestones in the original contract were amended through a Deed of Variation in June 2009. These milestones are listed in full in Table 1.1.

**Table 1.1. Milestones from the Deed of Variation – June 2009**

<table>
<thead>
<tr>
<th>#</th>
<th>Milestone Description and expected Outcomes</th>
<th>Start Date</th>
<th>End Date</th>
<th>Outputs</th>
<th>Performance Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Signing of Funding Agreement</td>
<td>1/05/08</td>
<td>25/06/08</td>
<td>Signed funding agreement</td>
<td>Agreement signed by NWC and CSIRO by 28 June. Separate agreement between CSIRO and FWPA signed by 15 July.</td>
</tr>
<tr>
<td>2</td>
<td>Detailed work plan an establishment of Steering Committee</td>
<td>1/06/08</td>
<td>31/07/08</td>
<td>Detailed project work plan</td>
<td>Steering committee established and first meeting held. Completed work plan agreed to by Steering Committee.</td>
</tr>
<tr>
<td>3</td>
<td>Plantation Risk Assessment: Identify areas of recent and obtain input data for running the FCFC model</td>
<td>01/07/08</td>
<td>31/12/08</td>
<td>Input data layers suitable for running the FCFC model obtained for up to 10 regions with high recent or potential for plantation expansion</td>
<td>Input data compiled for up to 10 catchments or regions</td>
</tr>
<tr>
<td>4</td>
<td>Plantation Risk Assessment: calculate changes in daily stream-flow using the FCFC model</td>
<td>01/07/08</td>
<td>31/08/09</td>
<td>Flow duration curves documented for up to 10 catchments for 2008, 2015, 2020, 2030.</td>
<td>Flow duration curves produced and documented</td>
</tr>
<tr>
<td>5</td>
<td>Catchment Risk Assessment: run changes through water management models to assess impacts on water allocations and entitlements, and on dilution flows and salt concentrations in regions where salinity is an issue down-stream of the affected catchments</td>
<td>01/10/08</td>
<td>31/08/09</td>
<td>Down-stream water allocation and salinity impacts documented for up to 10 catchments or regions (subject to availability of the necessary river routing models and hydrological data)</td>
<td>Risk assessments completed and documented for up to 10 catchments or regions</td>
</tr>
<tr>
<td>7</td>
<td>Tools to assist accurate estimation of the importance of site-scale influences on water allocation impacts of plantations: build model components</td>
<td>01/07/08</td>
<td>30/06/09</td>
<td>Model components identified</td>
<td>Modelling framework agreed</td>
</tr>
<tr>
<td>8</td>
<td>Tools to assist accurate estimation of the importance of site-scale influences on water allocation impacts of plantations: calibrate model against data</td>
<td>01/01/09</td>
<td>30/09/09</td>
<td>Model applied and run for up to 10 test catchments</td>
<td>Accuracy model against observed stream flow data</td>
</tr>
<tr>
<td>9</td>
<td>Tools to assist accurate estimation of the importance of site-scale influences on water allocation impacts of plantations: documenting the site assessment method</td>
<td>1/10/09</td>
<td>28/02/10</td>
<td>A detailed ‘Methods’ technical document and practical guidelines</td>
<td>Documents and guidelines available for users</td>
</tr>
<tr>
<td>10</td>
<td>Communication of project outputs to each jurisdiction to inform State hydrological assessment frameworks in two series of workshops</td>
<td>16/06/09</td>
<td>16/04/10</td>
<td>FCFC workshops (1 per jurisdiction) Site-scale modelling workshops (1 per jurisdiction)</td>
<td>Number of state agencies trained and planning to use the methods</td>
</tr>
<tr>
<td>11</td>
<td>Final reporting to NWC and delivery of products to users</td>
<td>1/03/10</td>
<td>30/06/10</td>
<td>Final report. Presentations and workshops organised for all jurisdictions</td>
<td>Report completed and delivered on time. Attendance at user workshops.</td>
</tr>
</tbody>
</table>
1.3. Addressing the Milestones

The 11 Project Milestones can be lumped into four main categories. These four categories have been used to provide a clear description of how the project has addressed the milestones. The following sections in this report describe the work undertaken within this project, in terms of how they address the milestones.

2. MILESTONES #1, #2 - WORKPLAN AND ESTABLISH PROJECT STEERING COMMITTEE

A project workplan was developed.
- Milestone #1 Funding Agreement was signed.
- Milestone #2 Project Steering Committee was established (Table 2.1). Project Workplan was presented at November 2008 PSC meeting.

Table 2.1. Project Steering Committee

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSIRO</td>
<td>Richard Benyon, Mat Gilfedder</td>
</tr>
<tr>
<td>National Water Commission</td>
<td>Nigel Hayball</td>
</tr>
<tr>
<td>Forest and Wood Products Australia Limited (FWPA)</td>
<td>Chris Lafferty</td>
</tr>
<tr>
<td>Australian Plantations Products and Paper Industry Council (A3P)</td>
<td>Gavin Matthew</td>
</tr>
<tr>
<td>Dept of Water, WA</td>
<td>Phillip Kalaitzis, Renee Dixon</td>
</tr>
<tr>
<td>Department of Water, Land &amp; Biodiversity Conservation, SA</td>
<td>Darryl Harvey</td>
</tr>
<tr>
<td>Department of Primary Industries, Victoria</td>
<td>Greg Day</td>
</tr>
<tr>
<td>Department of Primary Industries, Parks, Water &amp; Environment, Tasmania</td>
<td>David Nicholls*</td>
</tr>
<tr>
<td>NSW Department of Industry &amp; Investment</td>
<td>Stephen Elliot</td>
</tr>
<tr>
<td>Queensland Department of Environment and Resource Management</td>
<td>Mark Foreman</td>
</tr>
<tr>
<td>NT Dept of Natural Resources, Environment, The Arts &amp; Sport</td>
<td>Ian Lancaster, Chris Wicks</td>
</tr>
</tbody>
</table>

* withdrew from PSC early in the Project

3. MILESTONES #3, #4, #5, #6 – CATCHMENT MODELLING

These Milestones cover the first main modelling component within the project. This component involved the application of the Forest Cover Flow Change (FCFC) model (Brown et al. 2006) to a range of case-study catchments.

The Forest Cover Flow Change model (FCFC) is designed to adjust a time series of observed or simulated daily flow to account for changes in forest cover (Brown et al., 2006). FCFC is a relatively simple tool using a wizard style interface that steps through input data, analysis and generation of new time series of flows. Users can readily generate different time series of flow for different proportions of forest cover.

This section outlines the FCFC model data requirements, assumptions, and maps the project milestones to specific project outputs.
3.1. FCFC Model

The Forest Cover Flow Change (FCFC) model is currently available for download from the eWater CRC Toolkit website: [http://www.toolkit.net.au/tools/FCFC](http://www.toolkit.net.au/tools/FCFC)

3.1.1. Input and output data

The inputs to FCFC are:

- **Rainfall** – a continuous time series of rainfall data that represents the rainfall across the catchment,
- **Potential evapotranspiration** – a continuous time series of potential evapotranspiration data that represents the potential evapotranspiration across the catchment,
- **Streamflow** – daily streamflow values at the outlet of the catchment. This data may be observed at a gauging station or come from another model. This data are used for model calibration and generation of new flow time series,
- **Proportion of forest cover** – This is used to represent the forest cover conditions that existed during the time series of flow data.
- **Catchment area** – This is required for depth conversion of runoff for flow inputs or outputs.

The outputs from FCFC are:

- Time series of **daily streamflows**, or
- Distribution of **daily streamflows**, expressed as a Flow Duration Curve (FDC) modified for a user input of change in total forest cover.

3.1.2. Limitations and assumptions

The FCFC model is designed to investigate the impacts of changes in forest cover on flow. It must be recognised that the amount of data available to validate this model was limited. The major data sets used to assess the method were from Australia and South Africa, for catchments sized from 18 to 320 ha.

When using this tool the modeller needs to take into consideration that:

- This tool uses several optimisers to find the optimum solution for fitting flow duration curves and estimating a single bucket rainfall runoff model. Under certain circumstances this may not reach a suitable solution, in such cases the model will give an error message. This tool is not appropriate for these catchments.
- A results screen is provided so that modellers can assess the fit of the model under current conditions to gauged streamflow. If the fit is deemed to be too poor then this tool should not be used in that catchment.
- Generated flows should be checked to ensure that the change in flows is consistent with the change in forest cover.
- This tool is only appropriate for changes in forest cover and is not appropriate for other land use changes.
- The tool is not appropriate in catchments with significant irrigation or regulation.
3.2. Relevant Milestones

This component of the project included:

1) Compilation of catchment data to investigate changes in streamflow caused by climate impacts and plantation expansion impacts.

2) Results from the application of the FCFC model to catchment case studies

3) Use of the FCFC modelling results to provide input to regulated river management model (IQQM) for the Murrumbidgee to investigate downstream impacts on water availability

Specifically:

- **Milestone #3** Input data (rainfall, historical forest cover, stream gauged flow data) was obtained for 19 catchments

  This component of the project evaluated the impacts of plantation expansions on streamflow by analysing data from plantation affected catchments. In total 19 catchments were selected based on the availability of streamflow, meteorological, and plantation data. The selected catchments ranged in size from 0.6 to 1402 km² and represented different climatic conditions (see Table 3.1 – see next page).

- **Milestone #4** Analysis of data, and application of FCFC model to 19 catchments.

  The Forest Cover Flow Change (FCFC) model was tested using the data from the 19 selected catchments and the results showed that the model is capable of predicting plantation impacts on streamflow regime.

  All the selected catchments showed reductions in annual streamflow over the period of the records and plantation expansion is likely to be responsible for the observed streamflow reduction. Decline in rainfall would also contribute to the decreased streamflow.

  The framework described in this study provides independent estimates of plantation and climate impacts on streamflow (Figure 3.1).

![Figure 3.1. Independent estimate of impact of climate (ΔQclim) and vegetation (ΔQveg) change on streamflow in the case study catchments](image-url)

Methods to assess water allocation impacts of plantations: Final report 5
Table 3.1. Case studies selected for the FCFC modelling component

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Gauging Station(ID)</th>
<th>State</th>
<th>Area (km²)</th>
<th>Rainfall (mm)</th>
<th>PET (mm)</th>
<th>Streamflow (mm)</th>
<th>Plantation cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Adelong Ck</td>
<td>Batlow RD (410061)</td>
<td>NSW</td>
<td>144</td>
<td>810</td>
<td>1055</td>
<td>265</td>
<td>17.34</td>
</tr>
<tr>
<td>Adjungbilly Ck</td>
<td>Darbalara (410038)</td>
<td>NSW</td>
<td>391</td>
<td>1011</td>
<td>930</td>
<td>212</td>
<td>30.08</td>
</tr>
<tr>
<td>*Amamoor Ck</td>
<td>Zachariah (138102)</td>
<td>QLD</td>
<td>133</td>
<td>1104</td>
<td>1080</td>
<td>244</td>
<td>9.58</td>
</tr>
<tr>
<td>*Baffle Ck</td>
<td>Baffle (134001B)</td>
<td>QLD</td>
<td>1402</td>
<td>945</td>
<td>1365</td>
<td>139</td>
<td>6.82</td>
</tr>
<tr>
<td>Batalling Ck</td>
<td>Batalling (612016)</td>
<td>WA</td>
<td>16.64</td>
<td>629</td>
<td>1089</td>
<td>33</td>
<td>19</td>
</tr>
<tr>
<td>Bombala River</td>
<td>Bombala/Falls (222019/222009)</td>
<td>NSW</td>
<td>559</td>
<td>783</td>
<td>779</td>
<td>181</td>
<td>11</td>
</tr>
<tr>
<td>Burnt out Ck</td>
<td>(A5030529)</td>
<td>SA</td>
<td>0.6</td>
<td>806</td>
<td>1117</td>
<td>28</td>
<td>67</td>
</tr>
<tr>
<td>*Cam River</td>
<td>Cam (14212)</td>
<td>TAS</td>
<td>225.8</td>
<td>1411</td>
<td>1004</td>
<td>632</td>
<td></td>
</tr>
<tr>
<td>Crawford River</td>
<td>Lower Crawford (238235)</td>
<td>VIC</td>
<td>606</td>
<td>728</td>
<td>996</td>
<td>73</td>
<td>24.18</td>
</tr>
<tr>
<td>Darlot Ck</td>
<td>Homerton Bridge (237205)</td>
<td>VIC</td>
<td>760</td>
<td>688</td>
<td>995</td>
<td>78</td>
<td>13.3</td>
</tr>
<tr>
<td>Delegate River</td>
<td>Quindong (222008)</td>
<td>NSW</td>
<td>1135.7</td>
<td>859</td>
<td>726</td>
<td>134</td>
<td>14</td>
</tr>
<tr>
<td>Eumeralla River</td>
<td>Eumeralla (237206)</td>
<td>VIC</td>
<td>502</td>
<td>725</td>
<td>987</td>
<td>56</td>
<td>19.84</td>
</tr>
<tr>
<td>*Finniss Ck</td>
<td>(A4260504)</td>
<td>SA</td>
<td>191</td>
<td>840</td>
<td>1164</td>
<td>127</td>
<td>5.92</td>
</tr>
<tr>
<td>*Gilmore Ck</td>
<td>Gilmore (410059)</td>
<td>NSW</td>
<td>277</td>
<td>1307</td>
<td>854</td>
<td>317</td>
<td>15.09</td>
</tr>
<tr>
<td>Goobarragandra Ck</td>
<td>Lacmalac (410057)</td>
<td>NSW</td>
<td>673</td>
<td>1009</td>
<td>952</td>
<td>419</td>
<td>8.32</td>
</tr>
<tr>
<td>*Inglis River</td>
<td>Inglis (14210)</td>
<td>TAS</td>
<td>172.1</td>
<td>1593</td>
<td>977</td>
<td>790</td>
<td></td>
</tr>
<tr>
<td>Jingellic Ck</td>
<td>Jingellic (401013)</td>
<td>NSW</td>
<td>390</td>
<td>838</td>
<td>1018</td>
<td>138</td>
<td>27.50</td>
</tr>
<tr>
<td>Mosquito Ck</td>
<td>Struan (A2390519)</td>
<td>SA</td>
<td>1130</td>
<td>631</td>
<td>1074</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Pine Ck</td>
<td>Broadford (405290)</td>
<td>VIC</td>
<td>3.2</td>
<td>629</td>
<td>953</td>
<td>37</td>
<td>100</td>
</tr>
<tr>
<td>*Pipers River</td>
<td>Piper (19204)</td>
<td>TAS</td>
<td>297.3</td>
<td>898</td>
<td>1073</td>
<td>294</td>
<td></td>
</tr>
<tr>
<td>Red Hill</td>
<td>Red Hill (410998)</td>
<td>NSW</td>
<td>1.95</td>
<td>761</td>
<td>900</td>
<td>109</td>
<td>78</td>
</tr>
<tr>
<td>*Tinana Ck</td>
<td>Teddington HW (138005A)</td>
<td>QLD</td>
<td>1174</td>
<td>1038</td>
<td>1257</td>
<td>199</td>
<td>22.54</td>
</tr>
<tr>
<td>Traralgon Ck</td>
<td>Koornalla (226410)</td>
<td>VIC</td>
<td>89</td>
<td>959</td>
<td>827</td>
<td>272</td>
<td>70</td>
</tr>
<tr>
<td>Upper Denmark River</td>
<td>Kompup (603003)</td>
<td>WA</td>
<td>243</td>
<td>742</td>
<td>1006</td>
<td>37</td>
<td>15.17</td>
</tr>
<tr>
<td>Yate Flat Ck</td>
<td>Woonanup (603190)</td>
<td>WA</td>
<td>56.32</td>
<td>742</td>
<td>1006</td>
<td>65</td>
<td>33.57</td>
</tr>
</tbody>
</table>

*Catchments not used in plantation impact assessment due to either plantation developed on native forest sites or lack of plantation data.

**The calibration periods for Pine Ck and Red Hill are defined as the first three years since plantation development. Monthly data are used to develop the relationship between rainfall and runoff in the calibration periods due to lack data of periods before plantation.
The effect of plantation expansion on streamflow is not limited to small catchments as this study demonstrated and it is linearly related to proportional plantation area in a catchment. Plantation reduces not only mean annual streamflow but also affects streamflow regime. In catchments with relatively low rainfall, large scale plantation expansion is likely to reduce low flow significantly, resulting in increased number of zero-flow days. Figure 3.2 shows flow duration curve (FDC) for the pre/post plantation expansion for a “lower rainfall” (Mosquito) and “higher rainfall” (Yate Flat) catchments.

![Flow Duration Curves](image.png)

**Figure 3.2. Two catchment examples of daily Flow Duration Curves for pre and post plantation expansion periods**

- **Milestones #5 and #6** Results for the application of FCFC model and the downstream impacts were documented in the following report:

This study demonstrated that the impact of plantations on water resources could be estimated by linking the FCFC model with river planning models such as IQQM. This way the impacts of plantation can be expressed in terms of changes in water allocation and diversion, which are directly relevant to water resources management. The approach developed in this study has the potential to be applied to other catchments in Australia and elsewhere for estimating plantation impacts on water security.
4. **MILESTONES #7, #8, #9 – SITE-SPECIFIC MODELLING**

The second main modelling component of the project used a more detailed approach than the first component. This allowed for investigation of within-catchment variation of plantations on stream flow.

The 2CSalt model (Stenson *et al.* 2005) was developed within the CRC for Catchment Hydrology to investigate the impact of land-use change on stream flow and stream salinity. The water-balance terms were obtained by running a 1-D agricultural water balance model (PERFECT: Littleboy *et al.* 1992). This allowed variation in vegetation impacts on streamflow to be modelled across the modelled catchment.

The current project replaced the PERFECT modelling of forested areas with a tree physiological growth model (3-PG: Landsberg and Waring, 1997) to provide water-balance time-series under plantations. Replacing PERFECT with 3-PG had several advantages:

1) Tree growth was actually modelled, i.e. the water balance changed over time as the forest matured. In PERFECT the forest was modelled as an unchanging mature forest.

2) Planting date, thinning date, harvesting date could be incorporated into the predictions. This helped in improving the historical calibration where these dates were known.

3) Tree water use was affected by climate/soil/species – so the resultant water balance terms reflected variation in these conditions across the modelled area.

4) The 3-PG model grew trees, and therefore wood productivity could be modelled in addition to forest water use.

This section outlines the 3-PG/PERFECT/2CSalt model data requirements, assumptions, and maps the project milestones to specific project outputs.

### 4.1. 3-PG/PERFECT/2CSalt Modelling

The 3-PG software can be obtained by contacting the Forest Systems Group at CSIRO Ecosystems Sciences (<http://www.csiro.au/products/3PGProductivity>).

The PERFECT/2CSalt is part of the eWater Toolkit as a prototype model. Access to the model will need to be arranged through contacting the eWater CRC directly (<http://www.ewater.com.au/>).
4.1.1. Input and output data

The input requirements for 3-PG/PERFECT/2CSalt modelling were much greater than for the FCFC modelling described in Section 3 of this report. Data on hydrogeology, topography, soil, land-use history, and climate were all required (summarised in Table 4.1).

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Format</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Elevation Model (DEM)</td>
<td>Grid</td>
<td>ESRI AsciiGrid Elevation (m)</td>
</tr>
<tr>
<td>Groundwater Flow System (GFS)</td>
<td>Polygon</td>
<td>ESRI Shape file Aquifer depth (m) Groundwater level (m) Groundwater salinity(mg/L) Specific yield Positive water level (m) Ksat (m/d) GFS text descriptor</td>
</tr>
<tr>
<td>Soils map</td>
<td>Polygon</td>
<td>ESRI Shape file Soil name Soil texture (A and B) Bulk density Soil depth Soil structure (optional) WHC (optional) Site fertility index</td>
</tr>
<tr>
<td>Land use map</td>
<td>Polygon</td>
<td>ESRI Shape file Land use code (alphaN)</td>
</tr>
<tr>
<td>Land capability map (Optional)</td>
<td>Polygon</td>
<td>ESRI Shape file Land capability code (N)</td>
</tr>
<tr>
<td>Climate zones (O)</td>
<td>Polygon</td>
<td>ESRI Shape file Climate zone code</td>
</tr>
<tr>
<td>SILO (1958-2008)</td>
<td>spreadsheet</td>
<td>Converted to 3PG format Daily RF, Rad, Tmax, Tmin, WS, frost, VPD</td>
</tr>
<tr>
<td>Streamflow</td>
<td>spreadsheet</td>
<td></td>
</tr>
<tr>
<td>Stream salinity</td>
<td>spreadsheet</td>
<td></td>
</tr>
</tbody>
</table>

4.1.2. Limitations and assumptions

The 3-PG/PERFECT/2CSalt modelling approach had many assumptions. Some of the key assumptions are listed here:

- 3-PG required a calibrated species file for each tree species (including a “native forest” case). We used existing species files – and the growth predictions were not validated and tested for the specific catchments used in this study.
- 3-PG did not have a robust mechanism to estimate groundwater extraction by trees.
- 3-PG estimated surface run off from equations using curve numbers which were obtained from site conditions – no calibration was performed.
- 3-PG required a site fertility factor which is an index obtained from site and soil properties which was not tested for accuracy in each case study.
- 3-PG required soil water holding capacity and maximum rooting depth to estimate available water. These data were difficult to obtain for some catchments, and we used surrogate methods to estimate available water.
- 2CSalt’s application was restricted to headwater upland areas, with local-scale groundwater flow systems (GFS). It was not applicable in area with regional GFS.
- 2CSalt assumed that there is a gaining stream. It had no capacity for the stream to lose water to an underlying groundwater system.
• 2CSalt assumed that the scale of the groundwater hydrology is reflected in the surface topography, that each sub-catchment is independent, and the model did not route water between sub-catchments. The total catchment flow was the sum of the sub-catchments.

• 2CSalt did not consider interactions between adjacent land-uses.

4.2. Relevant Milestones

This component of the project included:

1) Developing the modelling framework, i.e. combining the tree growth model with the catchment model;

2) Compiling data for nine catchment case studies across multiple States; and

3) Applying the modelling framework to the nine catchments

Specifically:

• **Milestone #7** The use of a 3-PG/2CSalt approach was agreed at the Project Steering Committee meeting in November 2008.

An approach was developed to modelling the impact of plantation expansion on catchment water yield which allows the impact of within-catchment variation of rainfall, soil, hydrogeology, or plantation management to be modelled and produce an end-of-catchment streamflow response.

A combination of plantation modelling and groundwater modelling was required to estimate the likely water yield impacts if different locations within a catchment are to be planted. This report describes the novel integration of detailed one-dimensional tree (3-PG) and pasture/crop (PERFECT) physiology modelling with a catchment hydrological model (2CSalt).

3-PG (a widely used forest growth/water use model with spatial application) and PERFECT (a widely used pasture/crop growth/water use model) were run to generate monthly surface water balance terms for forested and pasture areas. 2CSalt (a catchment hydrological model developed within the CRC Catchment Hydrology), which incorporates groundwater response and within-catchment hydrological variability, provided monthly time-series for end-of-catchment streamflow, for the different land uses modelled.

• **Milestone #8** The modelling approach was applied to nine catchment case studies across four States (NSW x4, VIC x3, WA x1, TAS x1). The following case studies were used:

  o NSW: Goobragandra River @ Lacmalac (#410057)
  o NSW: Gilmore Creek @ Gilmore (#410059)
  o NSW: Adelong Creek @ Batlow Rd (#410061)
  o NSW: Adjungbilly Creek @ Darbalara (#410038)
  o VIC: Crawford River @ Lower Crawford (#238235)
  o VIC: Eumeralla River @ Eumeralla (#237206)
  o VIC: Darlot Creek @ Darlot Creek (#237205)
  o TAS: Flowerdale River @ Moorleah (#14215)
  o WA: Yate Flat Creek @ Woonanup (#603190)
The 3-PG/PERFECT/2CSalt modelling approach was used to run modelling scenarios – which were used to build relationships between the cumulative impacts on streamflow at the end-of-catchment and hypothetical plantation expansion on available land compared with current land use, on a catchment-by-catchment basis. For the three Victorian case studies, the CATPlus modelling framework was used to link 3-PG with a modified 2CSalt model – to take advantage of existing links to input data within that framework in Victoria.

A first step was to calibrate the 3-PG/PERFECT/2CSalt model for a historical period. The comparison between modelled and observed streamflow is given for Adjungbilly Catchment in Figure 4.1 as an example.

![Figure 4.1. Comparison between measured monthly streamflow and calibrated 2CSalt predictions for 31 year measurement period 1967-2007 for the Adjungbilly Creek Catchment](image)

The calibrated model was then used to generate plantation expansion scenarios, showing modelled impacts from a gradual expansion of plantation area. The results were displayed as charts showing the modelled impact resulting from increasing the plantation area on streamflow for each catchment (example shown in Figure 4.2). It should be noted that each catchment showed a different response in streamflow reduction resulting from varying the planting location.

The relationship in Figure 4.2 is made up of two curves – a red one which indicates the impact resulting from planting “higher water impact” sub-catchments first, while the blue curve indicates the impact of planting “lower water impact” sub-catchments first. The right-hand-end of both curves converge to the same point (i.e. full afforestation), however the variability in possible stream flow response is shown by the distance between the two curves.
Figure 4.2. Modelled impact of plantation expansion on streamflow reduction (example using Adjungbilly Creek Catchment). In this example the modelled impact of planting an additional 4000 ha of plantation varies between 0.5-2.0 ML/ha depending on location within the catchment.

- **Milestone #9** 3-PG/SCSalt modelling approach documented in report
  
  The 3-PG/SCSalt modelling approach and its application to the case-study catchments is documented in the following report:
  
5. **MILESTONES #10, #11: COMMUNICATION AND FINAL REPORT**

The project organised and presented 15 workshops, across capital cities and regional centres. The workshops were run in Adelaide, Canberra, Sydney, Melbourne, Hobart, Mount Gambier, Perth, Darwin and Brisbane.

Advice from the Steering Committee members was taken to generate lists of potential attendees. These typically encompassed policy and technical agency staff from the “water” and “forest” areas, staff from timber industry groups, timber companies, and catchment management boards.

The contents of the workshops included:

- A brief overview of the project, describing its aims and expected outputs and outcomes; and
- Detailed presentations describing:
  - Background to estimating impacts of plantation expansion on streamflow, and issues relating to the separation of climatic effects from vegetation effects;
  - The use of the FCFC model to estimate impact of forest cover change on stream flow;
  - Description, input needs, and outputs for the 3PG/2CSalt approach; and
  - Discussions with potential users as to how best to use the model for assessing impacts of new plantations on water allocations in surface water catchments, including how to link the model outputs with local water allocation models.

5.1. **Relevant Milestones**

These workshops specifically address Milestone 10a and 10b in the contract. These were:

- **Milestone #10a** Seven workshops: June-July 2009 – catchment modelling (FCFC model) approach and background (summary published as Gilfedder et al. 2009).

- **Milestone #10b, #11** Eight workshops: May-July 2010 – catchment modelling (FCFC) and site-specific modelling (3-PG/2CSalt) (summary published as Gilfedder et al. 2010).

The Final Report (this report)

- **Milestone #11** Final Report submitted (this report).
6. RISK-BASED FRAMEWORK

This project has investigated the use of two different modelling approaches which both have the ability to provide estimates of the impact on stream flow resulting from expansion of large-scale plantation forestry.

1) Forest Cover Flow Change (FCFC)
2) 3-PG/PERFECT/2CSalt

In deciding which approach is most suitable, decisions need to be made about the level of certainty required. There will be a trade-off between this certainty and the level of effort and resources needed to parameterise and run a particular model.

As part of a risk-based process, and given the large uncertainties that exist in predicting the impact of large-scale plantation forestry on streamflow across large (1000 km²+) catchments, it may be sensible to use the precautionary principle.

In cases where water resources are stressed, or where the potential for large development (which may lead to water resources becoming stressed) – more data will be required to reduce uncertainty. An example of a staged approach could be:

1. Lower risk / Higher uncertainty
   Simple tools such as the **Forest Cover Flow Change (FCFC) model** exist which can be used. Data requirements are relatively low, and such models can provide insight into impact on flow seasonality resulting from changes in forest cover. We have shown that the application of this level of approach is achievable without significant additional effort.

2. Medium risk / Medium uncertainty
   More complex approaches like **3-PG/PERFECT/2CSalt** require increased resources and data to run, but provide estimates of the variation in impact across the modelled area.

   Much of the data to run this type of approach already exists across large areas, and it still appears feasible to apply this method more broadly. Approaches which require similar complexity of data have already been rolled out across large areas in recent years (e.g. 2CSalt roll out across upland areas of NSW).

3. High risk / Lower uncertainty
   There are even more complex modelling techniques that are available (e.g. TOPOG: Dawes *et al.* 1997). To be useful they require a significant level of monitoring data, which comes at a high cost—often prohibitively high. It is likely that such approaches would be best used in a very targeted manner, and applied to areas where there are very high risks, or to manage particular high value assets.
REFERENCES


