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Photo on cover: Irrigated agriculture in Coal River Valley (CSIRO)
Director’s Foreword

Following the November 2006 Summit on the southern Murray-Darling Basin (MDB), the then Prime Minister and MDB state Premiers commissioned CSIRO to undertake an assessment of sustainable yields of surface and groundwater systems within the MDB. The project set an international benchmark for rigorous and detailed basin-scale assessment of the anticipated impacts of climate change, catchment development and increasing groundwater extraction on the availability and use of water resources.

On 26 March 2008, the Council of Australian Governments (COAG) agreed to expand the CSIRO assessments of sustainable yield so that, for the first time, Australia would have a comprehensive scientific assessment of water yield in all major water systems across the country. This would allow a consistent analytical framework for water policy decisions across the nation. The Tasmania Sustainable Yields Project, together with allied projects for northern Australia and south-west Western Australia, will provide a nation-wide expansion of the assessments.

The CSIRO Tasmania Sustainable Yields Project is providing critical information on current and likely future water availability. This information will help governments, industry and communities consider the environmental, social and economic aspects of the sustainable use and management of the precious water assets of Tasmania.

The projects are the first rigorous attempt for the regions to estimate the impacts of catchment development, changing groundwater extraction, climate variability and anticipated climate change, on water resources at a whole-of-region-scale, explicitly considering the connectivity of surface and groundwater systems. To do this, we are undertaking the most comprehensive hydrological modelling ever attempted for the region, using rainfall-runoff models, groundwater recharge models, river system models and groundwater models, and considering all upstream-downstream and surface-subsurface connections.

To deliver on the projects CSIRO is drawing on the scientific leadership and technical expertise of national and state government agencies in Queensland, Tasmania, the Northern Territory and Western Australia, as well as Australia’s leading industry consultants. The projects are dependent on the cooperative participation of over 50 government and private sector organisations. The projects have established a comprehensive but efficient process of internal and external quality assurance on all the work performed and all the results delivered, including advice from senior academic, industry and government experts.

The projects are led by the Water for a Healthy Country Flagship, a CSIRO-led research initiative established to deliver the science required for sustainable management of water resources in Australia. By building the capacity and capability required to deliver on this ambitious goal, the Flagship is ideally positioned to accept the challenge presented by this complex integrative project.

CSIRO has given the Sustainable Yields Projects its highest priority. It is in that context that I am very pleased and proud to commend this report to the Australian Government.

Dr Tom Hatton
Director, Water for a Healthy Country
National Research Flagships
CSIRO
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1 Introduction

Following the November 2006 Summit on the southern Murray-Darling Basin (MDB), the then Prime Minister and MDB state Premiers commissioned CSIRO to undertake an assessment of sustainable yields of surface and groundwater systems within the MDB.

The project was a world first for rigorous and detailed basin-scale assessment of the anticipated impacts of climate change, catchment development and increasing groundwater extraction on the availability and use of water resources.

On 26 March 2008, the Council of Australian Governments (COAG) agreed to expand the CSIRO assessments of sustainable yield so that, for the first time, Australia would have a comprehensive scientific assessment of water yield in all major water systems across the country. This would allow a consistent analytical framework for water policy decisions across the nation, noting a cross link to the work of the COAG Climate Change Adaptation Sub Group.

The Tasmania Sustainable Yields Project (together with allied projects for south-west Western Australia and northern Australia) provides a nation-wide expansion of the assessments.

Determinations of sustainable yield and/or over-allocation require choices by communities and governments about the balances of outcomes (environmental, economic and social) sought from water resource management and use. These choices are best made in the light of sound technical information, and the fundamental underpinning information is a robust description of the extent and nature of the water resource.

While existing records of rainfall, streamflow and groundwater levels (and simulation models based on these data) provide a description of the resource from the past to the present, it is increasingly widely recognised that these data do not provide the best description of the likely extent and nature of the resource into the future, and thus no longer provide the best basis for planning. A careful examination of the likely implications of climate change on water resources is required as the basis for planning into the future. This includes a consideration of the direct effects (such as changes in rainfall and changes in evaporation) and indirect effects (such as changes in bushfire frequency and changes in water demand).

1.1 Terms of reference

The required baseline information for determining sustainable yields is thus an assessment of the current and likely future extent and variability of surface and groundwater resources. CSIRO’s Tasmania Sustainable Yields project will undertake such an assessment of Tasmania. The 18-month project (July 2008 to December 2009) will:

1) Develop transparent, consistent and robust methodologies for determining the extent of available water resources in the catchments/aquifers of the study area, including guidance on:
   a) how to utilise the historic flow records used in surface water models and the recharge assumptions used in groundwater models, to factor in climate change and other risks
   b) how to address the interaction between surface and groundwater systems
   c) appropriate models/methodologies to use in regions which do not have existing surface water or groundwater models and/or which do not have comprehensive water resource data
   d) ensuring that models/methodologies are capable of incorporating a range of ‘development’ scenarios or land use change activities
   e) identifying significant knowledge and information gaps.

2) In the application of the methodologies, use existing legislation, water plans or other arrangements to guide the assessment. For catchments or aquifers either without current water resource arrangements or with plans for which environmental outcomes and/or levels of extractive use are not clear, these parameters may be inferred and any assumptions clearly stated.
3) Apply the above methodology to estimate water availability and demand in 2030 in the light of climate change and other risks to provide:
   a) Estimates of water resources on an individual catchment and aquifer basis using four different scenarios:
      i) historic climate and current development
      ii) climate for the last 11 years and current development
      iii) 2030 climate change and current development
      iv) 2030 climate change and 2030 development of plantations, groundwater and proposed irrigation development.
   b) For each of the scenarios (i) to (iv) above, provide an assessment of the impact of water resource development on key environmental assets.

4) The project will need to ensure as a minimum, all the catchments proposed for irrigation development under the Tasmanian Government Drought Proofing strategy are incorporated in the study and will complement current water resource assessment projects underway by Tasmanian State government where applicable.

5) The study will provide output in a fashion suitable to inform the development and water management planning for those catchments.

6) The study address the impact of incremental change in catchment hydrology resulting from likely landuse change and variations in interception rates over time.

7) Work will be guided by a steering committee, chaired by the Commonwealth, with membership from the government of Tasmania and CSIRO and include appropriate consultative arrangements to address environment and industry concerns, noting the need to separate the issue of resource assessment from water resource allocation. CSIRO’s role will be to technically support the communication process.

This report is an internal working document of the project that sets out the methods being adopted to deliver on these terms of reference.

Important influences on the agreed methods are: (i) the 18-month timeframe for the project, that given start-up and reporting phases, essentially restricts technical work to 14 months; (ii) relevant modelling already undertaken by State agencies; and (iii) available technical capacity including that within government agencies and consultants. The overall approach of the project is to ensure a technically robust methodology appropriate to the available timeframe that draws on the best available data, models and techniques, especially considering relevant work already undertaken and the existing expertise and capacity of collaborating state agencies.
2 Project overview

The overall approach of the project includes: (i) definition of various future climate scenarios and the generation of time series of climate data to describe these scenarios; (ii) spatio–temporal modelling of the implications of these climate scenarios for catchment runoff and aquifer recharge; and (iii) propagating the runoff/recharge implications through existing river system and groundwater models including (where possible) explicit consideration of the surface–groundwater exchanges, and (iv) assessment and reporting of the implications for water availability and water use (Figure 1).

The remainder of this report is structured around the five linked components of the project (Figure 1). Section 3 defines the project region. Section 4 describes the scenarios that will be considered in the project, and then for each scenario describes the methods that will be used to define climate time series and other modelling inputs. Section 5 describes the methods that will be used to translate these into catchment runoff (and thence river inflows) for each scenario. Section 6 describes the methods that will be used to assess and model groundwater systems, including a description of the rainfall-recharge modelling. Section 7 describes the methods that will be used to model river systems. Section 8 outlines the methods for analysing modelling outputs and for reporting these. Section 9 details key aspects of data management processes and systems to be used by the project and Section 10 outlines the report management process.
3 Project region

The project region will encompass all of the catchments in Tasmania for which there is either current irrigated agriculture, or for which irrigation is proposed under the Tasmanian Government’s Drought Proofing Tasmania Strategy (http://www.dpiw.tas.gov.au/inter.nsf/WebPages/SSKA-7FJ722?open). The geographic extent of this project is shown in Figure 2 and the list of catchments to be considered can be found in Table 1.

<table>
<thead>
<tr>
<th>Reporting region</th>
<th># LWM catchment name</th>
<th>Surface Water models</th>
<th>Groundwater models</th>
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<td>1. Arthur-Inglis-Cam</td>
<td>1 Flinders Island</td>
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<tr>
<td>23 Arthur</td>
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<tr>
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3.1 Comparison with Tasmanian water management regions

The Tasmanian water management regions are shown in Figure 3 along with the reporting regions for the current project.
Figure 3: Tasmanian water management regions and reporting regions for the Tasmania Sustainable Yields project.

Generally the reporting regions of the project correspond fairly closely with the DPIW Tasmania water management regions. However, experience from the Murray-Darling Basin Sustainable Yields project suggested the need to keep the number of reporting regions to a manageable number. For this reason and those documented below, the following differences between the reporting regions and water management regions are noted:

- Approximately 40 percent only of the Arthur-Pieman water management region is included in the project region; it lies mostly in the Arthur catchment. Together with the Inglis and Flinders and King Island water management regions, it will be covered in the Arthur-Inglis-Cam reporting region.
- The Meander catchment (Meander water management region) will be reported in the South Esk reporting region as water from this catchment is diverted into the South Esk.
- The Rubicon catchment (Meander water management region) and Tamar Estuary catchments (Pipers-Ringarooma water management region) will be reported in the Mersey Forth reporting region.
• Approximately 20 percent only of the Huon-Gordon water management region is included in the project; it lies mostly in the Huon catchment. Together with all catchments of the Derwent-South East water management region it will be covered by the Derwent-South-east reporting region.

• Catchments in the limited reporting region will have an assessment of climate change and the impacts of this climate change on runoff and recharge carried out. However, as there is no irrigation in this region, no river modelling or groundwater modelling and assessments will be carried out.
4 Scenario definition

The project objectives require assessment of four separate scenarios. The first scenario (Scenario A) is based on the historical climate sequence. This will be taken as the observed climate (rainfall and potential evapotranspiration (PET)) from 1 January 1924 to 31 December 2007. For modelling river flows under this scenario, the current level of surface and groundwater development will be assumed. Scenario A will be used as the baseline against which assessments of relative change will be made.

The second scenario (Scenario B) is a ‘recent climate’ scenario. It will be based on an 84-year (same length as Scenario A) climate series generated from the rainfall and PET characteristics of the past 11 years (1 January 1997 to 31 December 2007). For modelling river flows under this scenario, the current level of surface and groundwater development will be used. Scenario B is therefore used to assess water availability should the climate in the future prove to be similar to that of the last 11 years.

The third scenario (Scenario C) is a future climate and current development scenario. It will be based on an 84-year (same length as Scenario A) climate series derived from a range of global climate model (GCM) projections of ~2030 climate. The range of GCM projections will encompass different GCMs and several global warming scenarios. The GCM projections will be used to modify the observed historical daily climate sequences as described in Section 4.3. Once again, for modelling river flows under this scenario, the current level of surface and groundwater development will be used.

The fourth scenario (Scenario D) is a future climate and future development scenario. It will use the same climate series as Scenario C, but river inflows and irrigation demands will be modified to reflect catchment development. Catchment development will be limited to a consideration of ~2030 projections of commercial forestry plantations and changes in irrigated agriculture. The considerations of catchment development are thus limited to aspects that affect inflows and demand and for which reasonably reliable assessments are possible. Groundwater development will consider growth in groundwater use where this can be assessed.

4.1 Scenario A climate inputs

This task will produce the Scenario A gridded daily rainfall and areal potential evapotranspiration (APET) series for 1924 to 2007 (84 years) to be used as input for the hydrological modelling. The 1924 start date has been chosen as this is the start date of the Hydro Tasmania TEMSIM modelling (see Section 7 for details). Additionally, the distribution of rain gauges before 1920s was sparse, which could lead to errors in the SILO rainfall inputs before that time.

4.1.1 Methods

1. Compile 1924 to 2007 daily rainfall time series for Tasmania on a 0.05° x 0.05° (~ 5 km x 5 km) grid from the SILO data drill (www.nrm.qld.gov.au/silo; Jeffrey et al., 2001).

2. Calculate 1924 to 2007 daily APET series for Tasmania on a 0.05° x 0.05° grid, using the SILO data drill temperature and vapour pressure data as input to Morton’s wet environment evapotranspiration algorithms (http://www.bom.gov.au/averages and Morton, 1983; Chiew and Leahy, 2003).

4.2 Scenario B climate inputs

The drought of the last eleven years or so in the south-east of Australia may be outside the range of experience on which much current policy and management is based. The aim of Scenario B is to assess the likely water availability should these conditions continue for an extended period.

This task will produce an 84-year daily climate series, with the rainfall and PET characteristics of the past eleven years (1997 to 2007).
4.2.1 Methods

- In principle the results of the last 11 years of Scenario A modelling of runoff, river and groundwater flow could be reported as Scenario B. However, this would fail to capture the behaviour of groundwater and surface storages which respond to changes in recharge and streamflow on timescales of longer than a decade.

- The best approach would be to construct synthetic sequences based on the characteristics of the past 11-year climate period. However, stochastic generation of synthetic data that reproduces temporal and spatial statistics is not straightforward, and it takes considerable time to run the surface and groundwater models with hundreds of synthetic sequences.

- For this reason, one artificial climate sequence based on repeating the last 11 years data will be used (to give an 84-year sequence). This is one possible and arbitrary sequence, and the hydrological modelling results using this artificial climate sequence will provide a rough indication of longer-term surface storage and groundwater behaviour if the past 11-year period of climate continues into the future.

4.3 Scenario C climate inputs

This task will provide 45 variants of 84 years of daily climate series for a global average surface temperature ~2030 relative to ~1990, guided by global climate models (GCMs) from the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC AR4; IPCC, 2007) for three global warming scenarios. In addition to GCM-scale results, we will also assess climate that is dynamically downscaled from six of these GCMs using the Conformal Cubic Atmospheric Model, CCAM (McGregor, 2005).

4.3.1 Methods

1. Analyse results from the GCMs in the IPCC AR4 (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). Archived data that are available and will be used are: daily rainfall time series for 1981 to 2000 and for 2046 to 2065 from 15 GCMs; and monthly climate time series for 1870 to 2100 from 23 GCMs. For this reason, only the 15 GCMs with daily data will be used in this project.

2. The continuous monthly climate time series from the 15 GCMs will be used to calculate ‘constant scaling’ factors for changes in mean seasonal rainfall and other climate variables per degree global warming for each of the four seasons. This is done by plotting the mean climate variables (e.g. rainfall) against global average temperature simulated by the GCM, where the gradient of the linear relationship gives the change in the climate variable per degree global warming. The constant scaling factor is expressed as a percentage change (except for temperature where an absolute value is used) per degree global warming by dividing the absolute change by the mean value of the variable over 1981 to 2000.

3. The relative difference in the GCM daily rainfall for 2046 to 2065 and 1981 to 2000 will be used to calculate ‘daily scaling’ factors (percentage change in daily rainfall) for each rainfall percentile per degree global warming (each of the four seasons will be considered separately). These daily scaling factors will then be adjusted to match the constant scaling factors in Step 2. This is necessary because the daily scaling factors are estimated based only on two time slices (2046 to 2065 and 1981 to 2000), whilst the constant scaling factors are estimated based on continuous 2001 to 2100 GCM monthly simulations. The daily scaling method is used rather than the constant scaling method because it accounts for changes in the daily rainfall distribution, and not just changes in the mean seasonal rainfall (see Chiew, 2006). For the non-rainfall climate variables, the constant scaling method will be used.

4. Multiply the above daily scaling factors (per degree global warming) by the increase in global average surface temperature by ~2030 relative to ~1990 for three global warming scenarios from IPCC (2007) which consider different greenhouse gas and sulphate aerosol emission scenarios plus variations across a range of climate models in their global average response to enhanced greenhouse conditions (known as 'global
climate sensitivity'). Thus there will be a total of 45 climate variants (15 GCMs times three emission scenarios).

5. Use the daily scaling factors for the appropriate rainfall percentiles to scale the historical (1924–2007) SILO 0.05° gridded daily rainfall (see Chiew et al., 2008). This daily scaling approach therefore accounts for different changes in the different daily rainfall amounts, but assumes that the future daily rainfall sequence is the same as the observed historical sequence.

6. A sub-set of ‘higher quality’ GCMs will be determined to allow quantification of differences in 2030 changes when using the full set of GCMs versus a smaller set of higher quality GCMs. Selection of this higher quality set of GCMs will be based on an assessment of their reproduction of rainfall and MSLP climatology (mean, variance and seasonal cycle). This will allow a comparison of the sensitivity of hydrological impacts using the full versus higher-quality GCM derived Scenario C series.

7. Six GCMs (CSIRO Mk3.5, GFDL 2.0, GFDL 2.1, HADCM2, ECHAM/MPI, and MIROC) will be dynamically downscaled to a 0.5° (~60 km) scale using the CSIRO CCAM model in order to provide a finer spatial representation of changes in rainfall. Based on an analysis of the results of this downscaling, representative changes in rainfall at a finer scale across Tasmania may be chosen and therefore a new Scenario C climate sequence produced. Note that as this downscaling work represents research in progress rather than currently available science, this step cannot be guaranteed. This will be known in early 2009 as the downscaled results become available.

4.4 Scenario D future development

The purposes of this task are to estimate (i) the ~2030 developments in forest plantations and irrigated agriculture for the rainfall-runoff modelling of Scenario D (~2030 climate, ~2030 development); and (ii) the growth in groundwater extractions for the groundwater modelling of Scenario D.

4.4.1 Methods

1. Develop a ~2030 scenario for commercial forestry plantations for Tasmania. This will be done in conjunction with Forestry Tasmania, Private Forests Tasmania and the Bureau of Rural Sciences, and the hydrologic impact of this change in commercial forestry at the 0.05° grid cell scale will be assessed through application of the FCFC model (Brown et al., 2006).

2. Develop a ~2030 irrigation development scenario for Tasmania. This will be done in conjunction with the Tasmanian Department of Primary Industries and Water (DPIW) and be based on the Drought Proofing Tasmania strategy. This irrigation development will be represented through modification of the river models (Section 7).

3. Develop a ~2030 groundwater extraction development scenario for Tasmania. The lack of adequate groundwater data in Tasmania will make this problematic, as not only is current usage unknown, but the location of current pumping bores is also largely unknown. Where estimates of future changes in groundwater can be developed, these will be represented through modification of the groundwater models (Section 6).
5 Rainfall-runoff modelling

The purpose of this task is to estimate daily runoff across Tasmania for scenarios A, B, C and D (at 0.05° grids); and to modify/scale the historical catchment inflows by the relative daily difference between the rainfall-runoff modelled inflows for scenarios B, C and D relative to A.

Specifically, the rainfall-runoff modelling will estimate 84 years of daily catchment inflows for:

a) historical climate (1924 to 2007) and current development (Scenario A) – one single simulation based on the historical climate series;

b) ‘recent climate’ (1997 to 2007) and current development (Scenario B) – one single simulation based on the climate series generated in Section 4.2;

c) future (~2030) climate and current development (Scenario C) – 45 simulations based on 15 climate series for each of the low, medium and high global warming scenarios (from Section 4.3); and

d) future (~2030) climate and future development (Scenario D) – 45 simulations based on modifying the catchment inflows estimated in (c) to reflect ~2030 commercial forestry plantations and irrigation development (from Section 4.4).

Up to five lumped conceptual daily rainfall-runoff models (SIMHYD, Sacramento, IHACRES, AWBM and SMAR) will be used. This will allow comparison and assessment of modelled catchment inflows and determine whether different rainfall-runoff models provide similar estimates of the impacts of climate change on streamflow. All of the proposed models are relatively simple, lumped, conceptual models that translate climate input (primarily precipitation) into runoff.

5.1 Methods

5.1.1 Scenario A rainfall-runoff modelling

1. Set up rainfall-runoff models to run at 0.05° x 0.05° (~ 5 x 5 km) grids across Tasmania. The use of 0.05° grids will allow an appropriate representation of the spatial patterns and gradients in rainfall. Where necessary, snowmelt modelling will be carried out using the Degree-day method (see Beven, 2000 and Tan et al., 2005).

2. Calibrate the rainfall-runoff models against observed streamflow data from unregulated catchments (the same parameter values will be used for all grids within a catchment). Observed streamflow data since 1975 will be used for calibration (this is a compromise between a recent period to represent current development and a longer period to account for climatic variability). Calibration will be carried out using an objective function that incorporates the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970) of daily streamflow, together with a constraint to ensure that the total flow volumes are well modelled.

3. Estimate parameter values for all 0.05° grids across Tasmania. Parameter values for the “ungauged” grids will be based on a combination of values from the closest or hydrologically similar grid/catchment where calibration is possible and interpretation from the overall calibration and model regionalisation (e.g. Merz and Bloschl, 2004; Chiew and Siriwardena, 2005; Reichl et al., 2006; Viney et al., 2008).

4. Assess model performance (mainly against the objective function defined in Step 2), in particular the ability of the models to estimate streamflow in ungauged catchments. This will be done via a leave-one-out cross-verification of results in the gauged catchments. Sequentially, the parameter set calibrated for one of the gauged catchments will be removed from the pool of calibrated parameter sets used to regionalise results to the ungauged catchments. The remaining calibrated parameter sets will then be used to estimate regionalised parameters for this catchment and the modelled flows using this parameter set will be compared to the observed flows.
5. Run the rainfall-runoff models using historical climate data (1924 to 2007) to estimate daily runoff for 0.05° grids across Tasmania and aggregate the modelled runoff to estimate daily catchment inflows to all catchment inflow nodes. Compare the modelled daily catchment inflows with the existing catchment inflows used by DPIW. Results from the best rainfall-runoff model (identified from an assessment of cross-verification performance) or a weighted average of the results from all the models will be reported (see for example, Viney et al., 2008).

5.1.2 Scenario B rainfall-runoff modelling

1. Run the rainfall-runoff models using the daily climate series for Scenario B (‘recent climate’ scenario, obtained from Section 4.2). This will provide a simulation of 84 years of modelled daily runoff.
2. Aggregate the modelled daily runoff for 0.05° grids to estimate daily catchment inflows to all catchment inflow nodes.

5.1.3 Scenario C rainfall-runoff modelling

1. Run the rainfall-runoff models using the 45 daily climate series for Scenario C (‘~2030 climate’ scenario, obtained from Section 4.3). This will provide 45 series of 84 years of modelled daily runoff – 15 for each of the low, medium and high global warming scenarios. For each of the low, medium and high global warming scenarios, calculate the mean annual runoff over the reporting region.
2. Use the modelled daily runoff from the series that give the 2nd and 14th highest mean annual runoff of the 15 runoff series from the high global warming scenario as the nominal 10th and 90th percentile modelled daily runoff series, and the 8th highest mean annual runoff from the medium global warming scenario as the nominal 50th percentile modelled daily runoff series. There are therefore three times 84 years of daily runoff series for Scenario C reflecting the 10th, 50th and 90th percentile series, named Cdry, Cmid, and Cwet.
3. For each of the above three series, aggregate the modelled daily runoff for 0.05° grids to estimate daily catchment inflows to all catchment inflow nodes.

5.1.4 Scenario D rainfall-runoff modelling

1. Modify the three daily catchment inflow time series from Scenario C to reflect future (~2030) expansion in forest plantations. The FCFC model (Brown et al., 2006) will be used to modify the daily modelled inflows to reflect the ~2030 plantations expansion scenario (as defined in Section 4.4).
Groundwater assessment and modelling

The groundwater assessment and modelling component of the project will collate existing data and knowledge to report on the occurrence, status and possible future condition of groundwater resources across the five reporting regions. This analysis will be reported at the reporting region scale, with explicit detail and assessment at the scale of the main aquifer units where background data is available.

Parts of reporting regions that are represented in an existing, transient numerical groundwater flow model will receive a quantitative assessment of the impacts of climate and current and future development through implementation of the four scenarios (A to D). This assessment will include an analysis of interactions between surface water and groundwater resources. For catchments without groundwater models, potential impacts of the four climate/development scenarios will be assessed qualitatively.

DPIW is nearing completion of a two-year project entitled ‘Development of Models for Tasmanian Groundwater Resources’, funded through the National Water Commission. The broad objectives of that project are to collate background information and build new models for about 20 areas located mostly along the north coast of Tasmania. The new models range in complexity from simple conceptual models with first order water balances (Class A models) through to calibrated, transient numerical groundwater flow models (Class C models). Many of the areas from the DPIW project align with the surface water catchments that now require groundwater assessment for the Tasmania Sustainable Yields project (Figure 4). The Class C models from this project will therefore be utilised in the Tasmania Sustainable Yields project.

6.1 Prioritisation of groundwater assessment areas

The approach for determining what types of assessment are to occur in each reporting region follows the model prioritisation scheme used previously by DPIW, at least where there is overlap. The different classes of DPIW models (A, B and C) were originally determined in 2007 using local knowledge and assessment of data availability and either current or potential future risk of stressed groundwater resources. Accordingly, a tiered approach has been adopted for the Tasmania Sustainable Yields project, whereby Tier 1 assessments capture the most detailed (Class C) groundwater model areas, Tier 2 assessments capture an intermediate level of detail and sometimes numerical (Class B) models, and Tier 3 assessments capture the most basic (Class A) models and those areas with very limited historical data or understanding of the groundwater resources (Table 2).

For those parts of the Tasmania Sustainable Yields project reporting regions not covered by DPIW’s modelling project, the groundwater team (including expert representatives from DPIW) selected either Tier 2 or 3 assessments (Table 2) at a meeting held in Adelaide on 23 September 2008.

Because groundwater flow systems are rarely constrained within surface water catchment areas, any groundwater assessment and reporting for the Tasmania Sustainable Yields project will focus on ‘areas’ within each reporting region, rather than specific surface water catchments. The overlap of between assessment areas and project catchments is depicted in Figure 4 and detailed in Table 2.

6.2 Preparation of contextual information

Contextual information such as hydrogeological characteristics, groundwater resource condition trends and any previous estimates of groundwater recharge or extraction are required to determine current and future groundwater availability.

6.2.1 Method

- The contextual information will be collated for each reporting region, regardless of tier, using the following approach:
• Liaise with DPIW hydrogeologists and ‘local experts’ to discover and acquire background reports and knowledge.

• Document information on the following topics for each reporting region:
  o Major aquifer types and potential for inter-connection/leakage.
  o Groundwater flow systems and their controls.
  o Likely groundwater-surface water interactions.
  o Previous estimates of recharge and/or discharge rates, and volume of water in storage.
  o Previous estimates of groundwater extraction, including extraction for irrigation, industrial and municipal purposes.
  o Distribution of groundwater salinity.
  o Trends in groundwater condition, where time-series water level and salinity data are available.

Figure 4: Extent of DPIW groundwater model areas (class A to C) with respect to surface water catchment areas requiring groundwater assessment for the Tasmania Sustainable Yields project.
6.3 Groundwater assessments

The level of technical assessment to be undertaken for each tier 1, 2 or 3 area within a reporting region will be commensurate with the quality and quantity of data, knowledge and models available to the project. The following sections provide an overview of the methodology for all assessment tasks, and a summary of which tasks will be performed in each reporting region is tabulated in Section 6.3.7.

6.3.1 Estimate groundwater extraction

Groundwater extraction for most purposes is currently unlicensed throughout Tasmania. Accordingly, irrigators are not obliged to have meters installed on their production wells so estimating actual groundwater extraction at the whole-of-aquifer or catchment scale is very difficult. The following method will be used to estimate current extraction for irrigation in this project:

Review publically-available literature including that presented on the Tasmanian Dairy Industry website (www.intodairy.com.au) to determine appropriate crop water requirement (CWR) values (over and above rainfall) for the types of crops currently grown in the assessment area. Calculate the total volume of irrigation water required by multiplying the CWR values with areas estimated from land use maps, aerial photographs and/or satellite imagery. Subtract the volume of surface water allocated (or ideally the volume extracted, if known) from the total volume to give an estimate of the annual rate of groundwater extraction for irrigation. Estimates of groundwater extraction for municipal and industrial purposes will be obtained by contacting the local Council offices.

Future groundwater extraction at 2030 will not be based on predictions of actual 2030 groundwater extractions as these predictions are not considered to be sufficiently reliable. Rather, the extractions used in this study will consist of ‘what-if’ scenarios designed in conjunction with DPIW representatives to attempt to determine sustainable extraction levels in accordance with a precautionary approach.

6.3.2 Groundwater level mapping

A map of watertable elevations can be used to infer the locations of groundwater recharge and discharge areas, and to delineate regional flow paths. For assessment areas where such a map is currently not available, a new map will be produced using historical depth to groundwater level (DTW) records obtained from DPIW. The historical dataset will mainly contain water levels measured at different times corresponding to when the wells were originally drilled. The selection of an ‘analysis window’ (e.g. 1 January 1988 to 1 January 2008) is recommended to produce a reasonably current map of watertable elevations and, at the same time, provide sufficient spatial coverage. Derivation of watertable elevations (metres AHD) will be performed by subtracting contoured DTW surfaces from the digital elevation model (DEM) supplied by DPIW.

6.3.3 Surface–groundwater connectivity mapping

Interactions between groundwater and surface water are likely to account for a significant component of the groundwater balance in many of the project areas, particularly as baseflow to streams. Establishing how the main groundwater and surface water resources in each region are connected will thus inform modelling efforts both as part of this and subsequent projects. Broadly the types of connection can be summarised as either:

- saturated, gaining stream
- saturated, losing stream
- saturated, variably gaining-losing stream
- unsaturated, losing stream.

This project will map potential connectivity by comparing known surface water elevations (e.g. at diversion structures or weirs) with groundwater elevations measured in wells located on either side of major rivers and streams. Where river stages are unknown, the surface water elevations may be approximated as the topographic elevations inferred from a DEM. Groundwater wells that have at least one watertable depth/elevation record within the last 10 years are
mapped with surface water elevations to highlight sections of watercourse where hydraulic potential exists for gaining or losing conditions.

Knowledge of stream bed material, geomorphology and underlying geology will be used to inform the likely degree of connection, including whether saturated or unsaturated conditions should prevail.

Quantitative assessment of groundwater discharge to streams could be undertaken using a simple flow net approach with Darcy’s Law. However this approach would yield flux estimates with very high uncertainty, particularly in those catchments dominated by fractured metamorphic and igneous rocks. Furthermore, this approach cannot incorporate temporal variability in hydraulic gradients and thus fluxes. Hence this project will only estimate surface–groundwater exchanges in surface water catchment areas where calibrated, numerical groundwater models exist and results can be supported by surface water modelling.

### Table 2: Groundwater assessment areas

<table>
<thead>
<tr>
<th>Reporting Region</th>
<th>Groundwater Assessment Area (DPIW Model Class)</th>
<th>Surface Water Catchment (catchment no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TIER 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arthur-Inglis-Cam</td>
<td>Mella / Togari (C)</td>
<td>Duck (27) / Montagu (26)</td>
</tr>
<tr>
<td>Mersey-Forth</td>
<td>Wesley Vale (C)</td>
<td>Mersey (pt 35) / Rubicon (pt 36)</td>
</tr>
<tr>
<td>Pipers-Ringarooma</td>
<td>Scottsdale (C)</td>
<td>Great Forester-Brid (46)</td>
</tr>
<tr>
<td><strong>TIER 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arthur-Inglis-Cam</td>
<td>Inglis-Cam (B)</td>
<td>Inglis-Flowerdale (29)</td>
</tr>
<tr>
<td>Mersey-Forth</td>
<td>Cam-Emu-Blythe (B)</td>
<td>Cam (30) / Emu (pt 31) / Blythe (pt 32)</td>
</tr>
<tr>
<td></td>
<td>Leven-Forth-Wilmot (B)</td>
<td>Forth-Wilmot (pt 34) / Leven (pt 33)</td>
</tr>
<tr>
<td>Pipers-Ringarooma</td>
<td>Ringarooma (B)</td>
<td>Ringarooma (48)</td>
</tr>
<tr>
<td>South Esk</td>
<td>Longford Basin (no DPIW model)</td>
<td>Macquarie (40), South Esk (41), North Esk (42)</td>
</tr>
<tr>
<td>Derwent-South East</td>
<td>Sorell Tertiary Basalt (A)</td>
<td>Coal-Pitt Water (pt 9)</td>
</tr>
<tr>
<td><strong>TIER 3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arthur-Inglis-Cam</td>
<td>Flinders Island (A)</td>
<td>Flinders Island (1)</td>
</tr>
<tr>
<td></td>
<td>Welcome (A)</td>
<td>Welcome (24)</td>
</tr>
<tr>
<td></td>
<td>King Island (A)</td>
<td>King Island (25)</td>
</tr>
<tr>
<td></td>
<td>remaining areas (no DPIW model)</td>
<td>Arthur (23) / Black-Detention (28) / Emu (pt 31) / Blythe (pt 32)</td>
</tr>
<tr>
<td>Mersey-Forth</td>
<td>Partial overlap with Mole Creek (A), Spreyton (A), Sheffield-Barrington (A) and Kimberley-Deloraine (A)</td>
<td>Mersey (pt 35)</td>
</tr>
<tr>
<td></td>
<td>remaining areas (no DPIW model)</td>
<td>Leven (pt 33) / Forth-Wilmot (pt 34) / Rubicon (pt 36) / Tamar Estuary E (43) / Tamar Estuary W (43)</td>
</tr>
<tr>
<td>Pipers-Ringarooma</td>
<td>remaining areas (no DPIW model)</td>
<td>Musselroe-Ansons (2) / George (3) / Scamander-Douglas (4) / North Esk (42) / Pipers (44) / Little Forester (45) / Boobyalla-Tomahawk (47)</td>
</tr>
<tr>
<td>South Esk</td>
<td>Partial overlap with Mole Creek (A) and Kimberley-Deloraine (A)</td>
<td>Meander (part 37)</td>
</tr>
<tr>
<td></td>
<td>remaining areas (no DPIW model)</td>
<td>Great Lake (38) / Brumby (39) / Macquarie (40) / South Esk (41)</td>
</tr>
<tr>
<td>Derwent-South East</td>
<td>Mt Wellington-Huonville (A) and Cygnet-Cradoc (A)</td>
<td>Huon (part 16)</td>
</tr>
<tr>
<td></td>
<td>remaining areas (no DPIW model)</td>
<td>Swan-Apsley (5) / Little Swanport (6) / Proser (7) / Carlton (8) / Tasman Peninsula (9) / Jordan (10) / Clyde (11) / Ouse (12) / Upper Derwent (13) / Lower Derwent (14) / Derwent Estuary N (15) / Derwent Estuary S (15)</td>
</tr>
</tbody>
</table>
6.3.4 Develop a conceptual model

A conceptual model will be presented for each groundwater assessment area, albeit very simple in those areas where little or no existing data or numerical models are available. This will include an explanation of the different groundwater flow systems, the locations and mechanisms by which the main aquifers are recharged and discharged, and at least a qualitative account of the importance of groundwater extraction and surface–groundwater interactions on the water balance.

6.3.5 Groundwater extraction indexing

The most rigorous method for assessing the current status (and thus potential future availability) of groundwater resources is to develop an accurate water balance. This involves estimation of all groundwater inputs and outputs to the system and, if temporal variability is important, an estimation of changes in groundwater storage. Rarely however are all of these parameters quantifiable to an accuracy of better than ±10 to 20 percent (maybe 50 percent). Because of this high degree of uncertainty, a simple measure of the ratio of groundwater extraction (E) to recharge (R) is often preferred, especially in data-poor regions.

Each of the Tier 1 and Tier 2 (and some Tier 3) groundwater assessment areas will have E/R calculated using groundwater extraction estimates and an appropriate assessment area-scale recharge rate. These recharge rates are already available for the majority of each reporting region, and will either be sourced from conceptual model reports for DPIW project areas (class A to C models) or via the literature in the case of areas not covered in the DPIW project. Parts of reporting regions for which recharge has not previously been estimated will utilise WAVES model results (Section 6.5). It is expected that the latter will be compared (and scaled if necessary) to a selection of appropriate recharge values from across the Tasmania Sustainable Yields project area.

Where relevant and possible, the groundwater extraction rate (E) will also be expressed as a ratio to the mean annual baseflow volume (B) derived through surface water modelling. E/B ratios may be a sensible tool for setting interim limits for groundwater allocation until more rigorous sustainable yield assessments can be undertaken.

For catchments in which future groundwater extraction at 2030 (E_f) has been estimated, the corresponding E_f/R or E_f/B value will also be presented, ideally using a scaled recharge rate derived through the climate scenario modelling (Section 6.5).

6.3.6 Identify groundwater management issues

In areas where a mature irrigation industry already exists, groundwater management issues may already have been realised, particularly where the volume of surface water entitlements has reached the maximum limit for allocation. An example of one issue that is emerging throughout Tasmania is drawdown interference between production wells located on adjacent properties.

In most catchments however, undesirable trends in resource condition are probably yet to be observed because in general, groundwater extraction is low. Future risks to the resource are likely to include:

- water quality decline, either through recycling irrigation drainage water or by intrusion of poorer quality water from the sea or interconnected, low-permeability formations
- stream depletion caused by groundwater pumping
- over-extraction as a result of increased demands exceeding the sustainable yield.

Even in areas where groundwater extraction is currently negligible, there may be potential for rising watertables and subsequent water logging of agricultural land as a result of excessive drainage beneath crops that are irrigated with surface water.

This project will document and discuss all likely groundwater management issues for each reporting region.
6.3.7 Assessment tasks per reporting region

Table 3 provides a detailed breakdown of which groundwater assessment tasks will be undertaken for each area within each reporting region. The table also indicates where contextual information and tasks have already been performed through the DPIW model development project – in these instances, the pertinent information and results just need to be summarised for the Tasmania Sustainable Yields project.

6.4 Groundwater resource condition indicators

Groundwater resource condition indicators (GRCIs) are required to facilitate comparison between current and simulated conditions for each of the four climate/development scenarios. The GRCIs developed in this project will be consistent across all of Tasmania but may not always be applicable to every catchment. They will be defined using the following criteria as a guide:

- ease of computation
- comparability to historical conditions and monitoring trends
- relevance to management issues; e.g. stream depletion caused by pumping, over-extraction relative to recharge, drawdown on groundwater-dependent ecosystems (GDEs) etc.

6.5 Rainfall-recharge modelling

Under scenarios A to D, impacts will occur due to differences in aquifer recharge and hence there is a need to develop climate-recharge relationships. The two main recharge mechanisms across Tasmania are likely to be (i) diffuse dryland recharge; and (ii) recharge from losing streams.

Groundwater models often include relatively simple recharge relationships such as a percentage of rainfall (or similar) linear relationship – sometimes with a threshold. The combination of the choice of recharge and hydro-geological parameters is required to match groundwater levels. The partitioning of the varying forms of recharge can be difficult and so the application of the rainfall data directly into the embedded relationships can be questionable.

Climate change will affect temperature and rainfall and therefore have a flow-on effect throughout the hydrological cycle (Loáiciga et al., 1996). In European studies, Lasch et al. (2002) showed that a 10 to 20 percent decrease in rainfall could lead to a 60 percent decrease in recharge. Conversely however, Eckhardt and Ulbrich (2003) showed that in an area where rainfall is predicted not to change, recharge was also predicted not to change. This lack of change in groundwater recharge was attributed to the decreased stomatal conductance that limited transpiration being balanced by the increased atmospheric demand, thus leaving overall ET almost unchanged. To enable climate scenarios to be modelled adequately, a soil-vegetation atmosphere transfer (SVAT) model that has the capability to model plant physiological feedbacks in response to increased CO₂ as well as modelling the water balance should therefore be used. The WAVES model (Zhang and Dawes, 1998) has been chosen for its balance in complexity between plant physiology and soil physics.
Table 3: Summary of groundwater tasks per assessment area for each reporting region, including the preparation of contextual information and numerical modelling of climate/development scenarios (tasks with ‘done’, ‘summarise’ or ‘tabulate’ require only a synthesis of recent work)

<table>
<thead>
<tr>
<th>Reporting Region</th>
<th>Assessment Area* (Tier)</th>
<th>Contextual Info</th>
<th>GW Extraction</th>
<th>GW Level Mapping</th>
<th>GW-SW Mapping</th>
<th>Conceptual Model</th>
<th>Extraction/Recharge Indexing</th>
<th>Management Issues</th>
<th>GW Modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthur-Inglis-Cam</td>
<td>Mella / Togari (1)</td>
<td>summarise</td>
<td>tabulate</td>
<td>done</td>
<td>develop *</td>
<td>summarise</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>Inglis-Cam (2)</td>
<td>summarise</td>
<td>tabulate</td>
<td>done</td>
<td>develop</td>
<td>summarise</td>
<td>required</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Flinders Is. (3)</td>
<td>summarise</td>
<td>tabulate</td>
<td>NR</td>
<td>develop</td>
<td>summarise</td>
<td>required</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Welcome (3)</td>
<td>summarise</td>
<td>tabulate</td>
<td>NR</td>
<td>NR</td>
<td>required</td>
<td>NA</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>King Is. (3)</td>
<td>summarise</td>
<td>tabulate</td>
<td>NR</td>
<td>NR</td>
<td>summarise</td>
<td>required</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Other (3)</td>
<td>collate</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>develop</td>
<td>NR</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>Mersey-Forth</td>
<td>Wesley Vale (1)</td>
<td>summarise</td>
<td>tabulate</td>
<td>done</td>
<td>develop *</td>
<td>summarise</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>Cam-Emu-Blythe (2)</td>
<td>summarise</td>
<td>tabulate</td>
<td>done</td>
<td>develop</td>
<td>summarise</td>
<td>required</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Leven-Forth-Wilmot (2)</td>
<td>summarise</td>
<td>tabulate</td>
<td>done</td>
<td>develop</td>
<td>summarise</td>
<td>required</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Other (3)</td>
<td>collate</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>develop</td>
<td>NR</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>Pipers-Ringarooma</td>
<td>Scottsdale (1)</td>
<td>summarise</td>
<td>tabulate</td>
<td>done</td>
<td>develop *</td>
<td>summarise</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>Ringarooma (2)</td>
<td>summarise</td>
<td>tabulate</td>
<td>done</td>
<td>develop</td>
<td>summarise</td>
<td>required</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Other (3)</td>
<td>collate</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>develop</td>
<td>NR</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>South Esk</td>
<td>Longford Basin (2)</td>
<td>collate</td>
<td>calculate</td>
<td>done</td>
<td>develop</td>
<td>develop</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>Other (3)</td>
<td>collate</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>develop</td>
<td>NR</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>Derwent-South East</td>
<td>Coal River Basin (2)</td>
<td>collate</td>
<td>calculate</td>
<td>develop</td>
<td>develop</td>
<td>develop</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>Mt Wellington-Huonville / Cygnet-Cradoc (3)</td>
<td>summarise</td>
<td>tabulate</td>
<td>NR</td>
<td>NR</td>
<td>summarise</td>
<td>required</td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Other (3)</td>
<td>collate</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>develop</td>
<td>NR</td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
</tbody>
</table>

* Note that where the groundwater assessment areas identified in Table 2 only partially overlap surface water catchments and reporting regions, they are grouped together in this table under the “Other” area category. * Map will be constrained using both hydraulics and hydrochemistry.
6.5.1 Diffuse dryland recharge

WAVES will be run at a series of points across Tasmania for a range of soil types and land uses to enable scaling factors to be determined that will enable the change in diffuse recharge to be determined across the project area for a given change in rainfall. The use of scaling factors to investigate the change in different modelling scenarios has previously been used successfully in investigating the hydrological impacts of climate change (Loáiciga et al., 2000). The outcome of this part of the project will be changes in diffuse recharge for the given changes in rainfall under the four scenarios across the project area.

Scenario A

1. Historical daily climate data will be extracted from SILO for the 84-year sequence (1 January 1924 to 31 December 2007) at 20 control points representing the range of annual rainfall encountered across the entire project area. WAVES will be employed to produce an annual time series of recharge rates for each soil/vegetation combination at these points (20 points x 6 soils x 3 vegetation).

2. The mean annual historical recharge will be calculated from the 84-year modelled recharge time series at each of the 20 control points for each soil/vegetation combination.

3. Historical recharge rates will be upscaled to the entire project area on a 0.05° (approx. 5 km) grid using GIS layers of annual average rainfall, soils and land use, and regression equations for rainfall-recharge on each soil/vegetation combination (as was carried out for the Murray-Darling Basin Sustainable Yields project).

4. From the 84-year modelled recharge time series, the mean annual recharge rate for consecutive 23-year periods (i.e. 62 periods from 1 January 1924 to 31 December 1946 up to 1 January 1985 to 31 December 2007) will be calculated to determine the 10th, 50th and 90th percentiles of the mean values for each soil/vegetation combination and control point.

5. Upscale Adry (10th percentile), Amid (50th percentile) and Awet (90th percentile) recharge rates to entire project area, and aggregate to aquifer extents. In groundwater modelled areas, a time series of recharge is needed for Adry, Amid and Awet. The 23-year temporal pattern of recharge will be stamped on the average annual recharge from the raster using the nearest control point with the most common soil and vegetation combination for the model domain.

Scenario B

1. An 11-year daily historical climate sequence for 1 January 1997 to 31 December 2007 will be extracted from the SILO data at 20 control points and run through the WAVES modelling procedure to produce an annual time series of recharge rates for each soil/vegetation combination at these points (20 points x 6 soils x 3 vegetation).

2. The mean annual recharge rate from the 11-year modelled recharge time series will be calculated at each of the 20 control points for each soil/vegetation combination, and upscaled to the entire project area on a 0.05° (approximately 5 km) grid using GIS layers of soils and land use, and regression equations for change in rainfall-change in recharge on each soil/vegetation combination. (NB: Recharge scaling factors (RSFs) may be calculated for Scenario B for reporting purposes).

3. Aggregate the mean annual recharge from pixel-scale to reporting region by averaging (NB. If aggregating RSFs rather than recharge rates, the averaging would be weighted to the 84-year mean Scenario A recharge rates). In groundwater modelled areas, a time series of recharge is needed for each model recharge zone. This will be conducted using the same method as Scenario A.

Scenario C

1. Use 45 daily-scaled variations of the historical (1 January 1924 to 31 December 2007) climate sequence generated from 15 GCMs with 3 different global warming scenarios for 2030 climate (low=0.7°C, medium=1.0°C, high=1.3°C).
2. Run all 45 climate sequences through WAVES for all soil/vegetation combinations and all 20 model points to produce 18,630 time series of annual recharge (45 climates x 20 points x 6 soils x 3 vegetation).

3. Produce 45 rasters of RSF by developing regression equations between change in rainfall and change in recharge for each combination of soil and vegetation.

4. From the 15 modelled RSF rasters, derived using climate data from the medium global warming scenario, select the 8th-highest RSF raster on a reporting region basis for Cmid. Similarly, select the 2nd and 14th-ranked RSF raster from the modelled results obtained using the high global warming scenario for Cdry and Cwet, respectively.

5. In a similar manner to scenario A, a relationship can be developed between the 23 yr average recharge and the 84-year average recharge to determine the 50th percentile 23-year raster of Cdry, Cmid and Cwet.

6. Aggregate Cdry, Cmid and Cwet from pixel-scale to aquifers, model recharge zones and reporting regions by averaging. In groundwater modelled areas, a time series of recharge is needed for Cdry, Cmid and Cwet for each model recharge zone. This will be conducted using the same method as Scenario A.

Scenario D

1. Same recharge as Scenario C except where large-scale (greater than 5 percent of the surface water catchment area) land use change is expected by 2030, e.g. replacement of annual grasses with plantation forestry. In such instances, three aggregated recharge rates (Ddry, Dmid and Dwet) will be determined for each aquifer/recharge area using the same approach as for Scenario C.

6.5.2 Surface–groundwater interactions

Surface–groundwater exchanges will be quantified where transient numerical groundwater flow models are available and have been implemented to test the different climate and development scenarios. Outputs from the groundwater models will be compared against flow losses or gains required to calibrate the river models. This approach may be iterative where groundwater and river models initially return different fluxes. It is anticipated that this will only be carried out for Scenario A, as changes in surface water-groundwater interactions under scenarios B, C and D are likely to be negligible.

6.6 Groundwater modelling approach

Large-scale numerical groundwater flow models currently exist for seven different assessment areas within three different reporting regions of the project area (see Figure 4). Three of the models are calibrated, transient (Class C) models while the remainder (Class B) are essentially uncalibrated, steady state modelling platforms. It is anticipated that only the Class C transient groundwater flow models will be implemented in this project to test the hydrological impacts of the four climate/development scenarios.

6.6.1 Scenario details for groundwater modelling

Scenario A

1. Run Scenario A using aggregated Adry, Amid and Awet recharge rates for 23 years from 1 January 2008 to 31 December 2030 and using current estimates of groundwater extraction. If the groundwater system has not reached dynamic equilibrium by 31 December 2030 the model will be run for a further 23-year period (repeating the sequence) to enable the trend in resource condition at 31 December 2030 to be measured more accurately.

2. Report on conditions at 31 December 2030 but focus on the rate of change (i.e. trend in condition) of the resource rather than absolute state (e.g. groundwater levels etc.), unless of course the groundwater system...
has achieved dynamic equilibrium within the 23-year period in which case absolute levels/fluxes should also be reported.

**Scenario B**

1. Run Scenario B using three consecutive sequences of the 11-year time series (33 years in total) from 1 January 2008 to 31 December 2040. Running the groundwater model out to 2040 has the advantage that if the groundwater system has not reached dynamic equilibrium by 31 December 2030 the trend in resource condition at 31 December 2030 can be measured more accurately.

2. Report as per Scenario A.

**Scenario C**

1. Run Scenario C using aggregated Cdry, Cmid and Cwet recharge rates applied for 23 years from 1 January 2008 to 31 December 2030 using the daily-scaled historical time series. If the groundwater system has not reached dynamic equilibrium by 31 December 2030 the model will be run for a further 23-year period (repeating the sequence) to enable the trend in resource condition at 31 December 2030 to be measured more accurately.

2. Report as per Scenario A.

**Scenario D**

1. For model domains in which there will be negligible change in land use (less than 5 percent of the surface water catchment area) by 2030, but groundwater extraction over the current footprint is likely to increase, run three scenarios Ddry, Dmid and Dwet using the aggregated Cdry, Cmid and Cwet recharge rates for 23 years from 1 January 2008 to 31 December 2030.

2. Where significant land use change is expected, run three scenarios Ddry, Dmid and Dwet as per Scenario C.

3. Report as per Scenario A.

### 6.6.2 Areas with existing transient numerical models

The three transient models cover five catchments; two models provide full coverage of three catchments (Great Forester-Brid, Montagu and Duck) while the other model overlaps parts of two catchments (Mersey and Rubicon) (Table 4).

<table>
<thead>
<tr>
<th>Region</th>
<th>Model</th>
<th>Developer/Class</th>
<th>Catchment(s) Covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipers-Ringarooma</td>
<td>Scottsdale</td>
<td>Aquaterra / C</td>
<td>Great Forester-Brid</td>
</tr>
<tr>
<td>Mersey-Forth</td>
<td>Wesley Vale</td>
<td>Aquaterra / C</td>
<td>Mersey (part), Rubicon (part)</td>
</tr>
<tr>
<td>Arthur-Inglis-Cam</td>
<td>Mella / Togari</td>
<td>Aquaterra / C</td>
<td>Duck, Montagu</td>
</tr>
</tbody>
</table>

**Method**

1. Run existing model to check calibration and confirm model setup is suitable.

2. Cross-check WAVES outputs with the recharge relationships within the existing model.

3. Cross-check the connectivity mapping with groundwater model conceptualisations.

4. Define the reporting points for GRClIs and confirm required outputs.

5. Setup and run scenarios A, B, C and D (Section 6.6.1) using the outputs from the WAVES recharge modelling and agreed future groundwater extraction.
6. Undertake a cross-comparison with the river system models of surface-groundwater exchanges.

7. Evaluate GRCIs for all scenarios for reporting.

6.6.3 Areas without existing transient numerical models

Numerical groundwater flow models will not be developed in this project for parts of reporting regions that are not already covered by an existing transient model, including those four areas where steady state models have already been developed through the recent DPIW project. Instead the assessment of impacts due to each climate/development scenario in these areas will be limited to a qualitative discussion about the likely effects of the modelled climate scenarios to recharge rates.
7 River modelling

The river modelling will utilise the existing ‘TasCatch’ surface water models developed for DPIW. These models cover the majority of the catchments included in the Tasmania Sustainable Yields project. Some models will require extension, and a number of new models will need to be developed to cover all the catchments included in the Tasmania Sustainable Yields project. The identified models to be extended to cover their entire catchments are: George, Pipers, Boobyalla-Tomahawk, Ringarooma, Brumby, Prosser, Coal-Pitt Water, Lower Derwent, Derwent Estuary-South and Swan-Apsley. The new models to be developed include: King and Flinders Island, Carlton, Tasman Peninsula, Freycinet Peninsula, Brumby’s Creek, Little Swanport and Tamar Estuary.

The original TasCatch models are coded as modified Australian Water Balance Models (AWBMs) with stream routing algorithms as described in Section 7.3. For the purposes of the Tasmania Sustainable Yields project, only the TasCatch river routing network will be used in conjunction with the gridded runoffs developed using the methodology outlined in Section 5.

The catchment sub-area delineation developed for the TasCatch models will be utilised to develop river routing network models. Each catchment is divided into sub-areas and is conceptually described by a node-link network. The input to each model will be a grid of catchment run-off in millimetres, converted to flow on a sub-area basis. Selected evaporation and rainfall inputs will also be used to model significant storages.

7.1 Sub-catchment delineation

In the TasCatch models, model sub-area delineation was performed using CatchmentSIM GIS software. The same approach will be used for the new model development, and extension of existing models.

CatchmentSIM is a 3D-GIS topographic parameterisation and hydrologic analysis model. The model automatically delineates watershed and subarea boundaries, generalises geophysical parameters and provides in-depth analysis tools to examine and compare the hydrologic properties of sub-areas. The model also includes a flexible result export macro language to allow users to couple CatchmentSIM with any hydrologic modelling package that is based on sub-area networks, such as Kisters modelling.

For the purpose of this project, CatchmentSIM will be used to delineate the catchment, break it up into sub-areas, determine their sizes and provide routing lengths between them.

These outputs will be visually checked to ensure they accurately represent the catchment, and modifications will be made as required.

7.2 Rainfall-runoff modelling

The existing TasCatch models use the AWBM Two Tap rainfall-runoff model (Parkyn and Wilson, 1997) in each separate sub-area, generally using a single set of calibration parameters for the whole catchment. The output of a given sub-area AWBM acts as the input for the sub-area immediately downstream, and so on. For the Tasmania Sustainable Yields project, the runoff modelling will be undertaken on a gridded basis using the methodology outlined in Section 5, for a number of different rainfall/runoff models. Sub-area runoff will be calculated on the proportion of area of each grid cell falling within each sub-area. The sub-area runoff will then be routed through the catchment using the same river networks developed for the TasCatch project.

7.3 Channel routing

The river models route the sub-area flows from centroid to centroid. The TasCatch models incorporating AWBM use the common nonlinear routing power function storage relation.
The common nonlinear routing power function storage relation is:

\[ S = K \cdot Q^n \]

Where \( K \) is a dimensional empirical coefficient, the reach lag (time). \( K \) will be determined by:

\[ K = \alpha \cdot L_i^\alpha \]

Where:
- \( L_i \) = channel length (km)
- \( \alpha \) = channel lag parameter
- \( n \) = non-linearity parameter
- \( Q \) = outflow from channel reach (ML/day)

The models calibrated for each of the TasCatch catchments included the routing parameters. These routing parameters were generally consistent across catchments, and these parameters will be adopted as-is for the Tasmania Sustainable Yields project.

### 7.4 Extractions and diversions

#### 7.4.1 Water entitlements and farm dams

For the TasCatch project, information on the current water entitlement allocations in the TasCatch modelled catchments was obtained from DPIW from the Water Information Management System (WIMS) Dec 2006 and July 2007 dataset. The extractions or licences in the catchment are of a given surety (from 1 to 8), with surety 1 to 3 representing high priority extractions for modelling purposes and surety 4 to 8 representing the lowest priority. DPIW also provided estimates of unlicensed extractions in addition to allocations currently recorded in the WIMS database.

Where there are large storages downstream of a calibration site that are used for irrigation or town water, they will be explicitly included in the river modelling. The demands will be taken directly from the storages. These demands will be profiled on a monthly basis, and will be varied annually depending on the catchment runoff for the given year compared with the long-term average catchment runoff. In most cases the demand of these storages is unknown in which case an annual demand of 50 percent of storage capacity will be assumed.

As irrigation extractions (licences) are not monitored within Tasmania, there is no information available on the actual profile of the extractions from the river. In the absence of this information, a profile of irrigation over the season will be developed. This profile will be based on recorded releases from irrigation storages, and will be averaged over the period of record to give a monthly demand profile. Storages relevant to each region will be selected and an irrigation profile developed.

The annual variation in demand with rainfall and evaporation will be investigated by relationships between rainfall minus evaporation and total releases over the irrigation season where there are records of releases from storages. The change in demand for the explicitly modelled lakes due to change in climate for Scenario C will be determined based on this relationship.

#### 7.4.2 Environmental flows

Any current environmental flow entitlements will be explicitly modelled. For Scenario D, additional environmental flow releases from modelled storages can be incorporated.

#### 7.4.3 Diversions and catchment modifications

Due to Tasmania’s extensive hydro electric system, a large number of Tasmanian catchments are influenced by power station operation, or diversions of flows into storages for electricity generation. Diversions and storages have
been included in the existing TasCatch models, with flows downstream of power stations estimated as a long term average monthly flow.

For the Tasmania Sustainable Yields project, the flows downstream of power stations will be estimated using Hydro Tasmania’s system model, TEMSIM. TEMSIM simulates the operation of the Hydro generating system assuming Basslink is operational and that the Hydro is operating within the National Electricity Market (NEM). In the model, generation is offered according to current NEM rules and dispatch simulates NEM dispatch. The model produces daily estimates of generation, revenue, spills from storages, and flow through power stations. The model runs from 1924 to 2007, and uses estimates of inflows to storages as input. The inflow estimates are calculated based on a variety of methods, depending on available data, including regression analysis with available data and a water balance based on the storage volume and known outflows.

Use of TEMSIM data limits the running of the river models to years subsequent to 1924, as estimation of inflows to the storages is not possible prior to this date due to lack of available data. The starting conditions for the TEMSIM models will be as at 1 January 2008. The system will be assumed to be in the current state in all years.

As the inflows to TEMSIM were developed using different methodologies to the rainfall-runoff models used in TasCatch, the inputs to TEMSIM will need to be factored to allow for changes in hydro-electricity operation under Scenario C. These factors will be derived on a monthly basis by comparing the catchment yields under Scenario A to Scenario C. The factors will be based on the outputs from the surface water model which is most representative of the inflow to each storage. There are 48 inflow time series to the TEMSIM models which will require factoring. Under Scenario C, factors will be derived for the output of each climate model run. Under Scenario B, the inflows from 1997 to 2007 will be repeated as a time series from 1924 to 2008.

Other diversions and storages have been included in the existing models with varying degree of detail depending on the information available. In many cases there is no record of outflows from storages, so a rudimentary storage balance model was constructed with assumptions made about releases based on the water licence information. A similar method will be used in the extensions to the existing models and in development of new models.

There are several LWM catchments within the Tasmanian Sustainable Yields reporting regions that have been extensively modified by Tasmania’s hydro electric system; the Derwent, Mersey, and Forth-Wilmot catchments. In these catchments, areas dominated by hydro storages and power stations will not be represented by a river routing network. The sub-area runoff routing will not be preserved between sub-areas due to the influence of the hydro generation and corresponding TEMSIM model output. In these cases, the river routing model will effectively commence at the output of the lowest generation storage. Any upstream unimpeded (natural) catchments of specific interest will be individually modelled. TEMSIM model outputs at each generation location within that catchment will be available as a time series file should this location be of interest in terms of ecological impacts or water availability.

**7.5 Future irrigation development**

Future irrigation developments (Scenario D) will be included in the model by adding storages at the appropriate sub-area locations, and including the predicted increase in demand in the model. The increased demand will be profiled on a monthly basis and varied annually depending on the sub-area runoff for the given year compared with the long-term average sub-area runoff.

**7.6 Model inputs**

The input to the TasCatch models is gridded runoff in millimetres. TEMSIM requires catchment-scale runoff. Rainfall and evaporation inputs will also be utilised at specific storage locations to model storage behaviour. Sub-area runoff will be calculated on the proportion of area of each grid cell falling within each sub-area.
7.7 Running scenarios

7.7.1 Scenario A – historical

The river models will be run with Scenario A runoff modelled using the methodology outlined in Section 5.1.1, and TEMSIM inputs based on historical data from 1924 to 2007.

7.7.2 Scenario B – recent climate

The river models will be run with Scenario B runoff modelled using the methodology outlined in Section 5.1.2, and TEMSIM inputs based on repeating the 1997 to 2007 inflows.

7.7.3 Scenario C – future climate

The river models will be run with Scenario C runoff modelled using the methodology outlined in Section 5.1.3. The TEMSIM model inputs will be modified to enable TEMSIM to be run to produce relevant outputs. The TEMSIM inputs will be factored by a ratio of flows for Scenario C : Scenario A on a monthly basis for each climate model run. These factors will be determined using the outputs of the surface water model which most closely represents the inflows to the relevant storage.

This will produce a range of possible future climate outcomes which will be used to assess the most likely future yields as well as the extremes in these yields.

7.7.4 Scenario D – future climate and future development

The river models will be modified to include proposed future irrigation developments. These river models will then be run with Scenario D runoff modelled using the methodology outlined in Section 5.1.4.

7.8 Summary of river modelling method

The steps in the river modelling methodology are as follows:

- Extend models for the George, Pipers, Boobyalla-Tomahawk, Ringarooma, Brumby, Prosser, Coal-Pitt Water, Lower Derwent, Derwent Estuary-South and Swan-Apsley catchments.
- Develop new models for the King and Flinders Island, Carlton, Tasman Peninsula, Freycinet Peninsula, Brumby’s Creek, Little Swanport and Tamar Estuary catchments.
- Utilising the catchment delineation from existing TasCat models, plus extended and new catchments, river routing models will be developed to accept catchment run-off (mm) and convert to streamflow. Models will output catchment yield (ML/day) for the entire catchment and at selected sub-areas.
- Design database architecture for storing model input and output data.
- Develop automated process for importing gridded rainfall, evaporation and runoff data into the databases.
- Undertake a general assessment of gridded rainfall data against selected observed records to confirm reliability of dataset.
- Develop and code methodology for translating gridded runoff inputs into the defined sub-areas. In most cases, sub-areas are comprised of portions of multiple grid cells.
- Derive a profile for irrigation demand for each region where there is suitable data available using outflows from irrigation storage. Develop a relationship between irrigation demand and seasonal runoff.
- Develop model code for storage modelling, demand profiling and seasonal variability.
- Develop automated process for running all catchment models.
- Develop process for summation of individual river model outputs to a regional level.
• Develop reporting statistics, figures and tables for individual catchments, special interest points and on a regional basis. Develop process for automation and collation of these outputs.
• Run TEMSIM models from 1924 to 2007 using historical data.
• Setup Scenario A database and automation platform.
• Run all river models for Scenario A.
• Run Scenario A output reporting and collation routines.
• Validate Scenario A models against observed records and TasCatch models outputs to confirm reliability and consistency of results. Develop a process to address any identified issues.
• Run TEMSIM models using data from 1997 to 2007.
• Setup Scenario B database and automation platform.
• Run all river models for Scenario B.
• Run Scenario B output reporting and collation routines.
• Determine factoring for TEMSIM inputs for Scenario C based on representative catchments for storage inflows.
• Modify TEMSIM inputs and re-run TEMSIM for each Scenario C climate scenario.
• Setup Scenario C database and automation platform.
• Run all surface water models for all climate scenarios in Scenario C.
• Run Scenario C output reporting and collation routines.
• Modify river models to account for new irrigation developments.
• Develop interface to allow input of changes in demand to each sub-area in each river model (if required).
• Setup Scenario D database and automation platform.
• Run all surface water models for Scenario D.
• Run Scenario D output reporting and collation routines.
• Prepare detailed technical reports defining the aims, methods, results and conclusions of the river modelling for all 5 reporting regions across Tasmania.
• Finalisation of river modelling activities.
8 Assessment and reporting

The reporting will be based on the objectives, targets and reporting requirements of the Department of Environment, Water, Heritage and Arts (DEWHA) and DPIW. A summary of the documents which will be produced throughout the course of this project are given in Table 5.

8.1 Analysis of projected changes

8.1.1 Overall approach

The data from the scenario modelling will be summarised in ways that illustrate the key changes in water availability and the implications for water users and the environment. This will include simple long-term average changes, but the changes in the return period, duration and magnitude of low and high water availability events are also important. The model results will be summarised in indicators. However, it will not be possible, nor desirable, in all cases to define indicators that can be quantified into a single number without losing intuitive meaning. In such cases textual descriptions of important aspects of water security or environmental water regime will also be considered.

While changes in average water security, groundwater levels and flows are important, any changes in the frequency or severity of extreme droughts are of also important. The lower the frequency (longer the return period) of the drought chosen for analysis, the greater the uncertainty is likely to be, since the modelling is based on scaling of the historic sequence.

The exact indicators that will be reported are yet to be determined as they are dependent in part on the results of the project, however it is expected that the indicators to be reported will be similar to those reported in the Murray-Darling Basin Sustainable Yields project (examples can be found at http://www.csiro.au/partnerships/MDBSYReports.html).

8.1.2 Water balance components

Three water balances will be reported: (i) a simple whole-of-region water balance; (ii) a catchment water balance; and (iii) a groundwater balance.

(i) The whole-of-region balance will simply be the balance of total rainfall, total evapotranspiration and generated runoff, based on the rainfall-runoff modelling; in this case the runoff reported is at the 5 km x 5 km grid scale.

(ii) The catchment water balance will be determined based on the extent of the catchment models used.

(iii) The reported groundwater balances will be based on the groundwater models that are used.

8.2 Environmental indicators

Environmental indicators will be determined primarily using the Conservation of Freshwater Ecosystem Values (CFEV) database (http://www.dpiw.tas.gov.au/inter.nsf/WebPages/CGRM-7JHVSJ?open). From the CFEV interrogation a list of recognised values from rivers, waterbodies, wetlands, karst, saltmarshes, estuaries and GDEs will be determined for each of the 5 reporting regions.

Using the list of recognised values, it is proposed to establish and document the susceptibility of these indicators to hydrology-related threats. This will be compiled either from scientific knowledge or a conceptual understanding of the hydrological regime requirements for the recognised values. It is essential that this assessment be carried out prior to any assessment of impact as it provides a transparent baseline assessment of the hydrological requirements.
Table 5: List of reporting deliverables from the TasSY project.

<table>
<thead>
<tr>
<th>Type</th>
<th>Title</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 x single page summaries (double-sided, glossy)</td>
<td>Whole of state summary</td>
<td>Project overview. No results.</td>
</tr>
<tr>
<td></td>
<td>Arthur-Inglis-Cam summary</td>
<td>Summary of water availability and changes under Scenarios A to D for the Arthur-Inglis-Cam.</td>
</tr>
<tr>
<td></td>
<td>Mersey-Forth summary</td>
<td>Summary of water availability and changes under Scenarios A to D for the Mersey-Forth.</td>
</tr>
<tr>
<td></td>
<td>Pipers-Ringarooma summary</td>
<td>Summary of water availability and changes under Scenarios A to D for the Pipers-Ringarooma.</td>
</tr>
<tr>
<td></td>
<td>South Esk summary</td>
<td>Summary of water availability and changes under Scenarios A to D for the South Esk.</td>
</tr>
<tr>
<td></td>
<td>Derwent-south east summary</td>
<td>Summary of water availability and changes under Scenarios A to D for the Derwent-south east.</td>
</tr>
<tr>
<td>6 x 14 page overview reports</td>
<td>Whole of state overview</td>
<td>Changes in climate and runoff across the whole of Tasmania.</td>
</tr>
<tr>
<td></td>
<td>Arthur-Inglis Cam overview</td>
<td>Changes in surface and groundwater availability and associated environmental impacts under Scenarios A to D for the Arthur-Inglis-Cam.</td>
</tr>
<tr>
<td></td>
<td>Mersey-Forth overview</td>
<td>Changes in surface and groundwater availability and associated environmental impacts under Scenarios A to D for the Mersey-Forth.</td>
</tr>
<tr>
<td></td>
<td>Pipers-Ringarooma overview</td>
<td>Changes in surface and groundwater availability and associated environmental impacts under Scenarios A to D for the Pipers-Ringarooma.</td>
</tr>
<tr>
<td></td>
<td>South Esk overview</td>
<td>Changes in surface and groundwater availability and associated environmental impacts under Scenarios A to D for the South Esk.</td>
</tr>
<tr>
<td></td>
<td>Derwent-south east overview</td>
<td>Changes in surface and groundwater availability and associated environmental impacts under Scenarios A to D for the Derwent-south east.</td>
</tr>
<tr>
<td>5 x detailed technical reports</td>
<td>Climate</td>
<td>Detailed methods and current and projected future climate change for the whole of Tasmania.</td>
</tr>
<tr>
<td></td>
<td>Runoff</td>
<td>Detailed methods and current and projected future runoff for the whole of Tasmania.</td>
</tr>
<tr>
<td></td>
<td>Rivers</td>
<td>Detailed methods and current and projected future water availability for all 61 catchment models in all 5 reporting regions.</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td>Detailed methods and groundwater model results where groundwater models currently exist; groundwater assessments under current and projected future scenarios for all other areas.</td>
</tr>
<tr>
<td></td>
<td>Environment</td>
<td>Detailed methods, and ecological impacts of current and projected future changes in surface and groundwater availability.</td>
</tr>
</tbody>
</table>

Using Scenario A as a baseline, it is proposed to establish Flow Stress Ranking (FSR) indices for each of the 5 reporting regions or catchments to determine the most ‘at risk’ region or catchment as a result of the scenario modelling. This will provide an initial assessment of the most impacted catchments. This analysis combined with other hydrological statistics derived from the scenario modelling, including both rivers and system inflows, will be used to assess the impact of the scenarios on the environmental indicators. This will be a qualitative assessment as many of the aspects of the flow regime requirements of indicators are not fully understood.

The outputs from the analysis will be a report for each region detailing the impact on environmental indicators resulting from the modelled scenarios (A to D). The reports will have feature-based results highlighting specific environmental indicators or components (i.e. geomorphic features or fish communities) that are likely to be impacted. The reporting will also include geographically based results, highlighting spatial patterns of change for each scenario.

Figure 5 outlines the methodology to be followed for assessing the environmental impacts of changes in hydrology.
8.3 Analysis of uncertainty

All modelling results are subject to uncertainty. This project produces scenario model assessments, which are of the type: “IF this or that climate and development scenario occurs THEN the surface and groundwater resource availability and distribution would change in the following ways”. There is uncertainty in both the “IF” and the “THEN” terms.

Uncertainty will be considered implicitly in each of the groups. From the Murray-Darling Basin Sustainable Yields project experience, most of the uncertainty will come from the “IF” term, i.e. the climate projections, thus the focus of the uncertainty assessments will be on the climate projections. However, the uncertainty of runoff modelling will also be assessed by running five different rainfall-runoff models across all catchments and comparing results.
9     Data management

The amount and diversity of data, models and reports to be used or produced within this project and the two allied sustainable yields projects (South-West Western Australia and Northern Australia) requires a professional and integrated approach to data management. To this end, formalised data management will be undertaken across all three projects. The key goals are to ensure that data used or generated within the projects are: (i) accessible to those that need it; (ii) safe from being lost or corrupted; (iii) managed according to requirements of data suppliers; (iv) secure from those who should not see it; and (v) has demonstrable integrity (i.e. it has a documented lineage showing how it was produced/where it came from etc.).

To achieve these goals the Data Management Team will take responsibility for: (i) provision of secure centralised computing facilities (including data storage and processing); (ii) provision of project collaboration tools and data exchange facilities); (iii) ensuring all data collected for the project is appropriately described and licensed; (iv) ensuring a full audit trail of all steps of the analysis process is captured; and (v) ensuring commitments made to third parties with respect to data and models are fulfilled.

9.1     Computing infrastructure

Data storage and processing will, where possible, be performed using the CSIRO WRON Computing Facility (Figure 6). This facility, at the CSIRO Black Mountain Laboratories, has been designed specifically to support both the management and high-speed processing of large amounts of data as required by these projects.

The core of the WRON facility power is a 20 unit cluster made up of 9th generation servers with 2 x Xeon 64 bit dual-core CPUs coupled with 4Gb of RAM each. Each cluster unit has direct high speed access to up to 100Tb of storage via Qlogic 4Gb Fibre Channel HBA cards. A Hitachi AMS 1000 Tagma SAN provides the current 100 Tb of storage. The AMS provides both Network Attached Storage (NAS) and Storage Area Network (SAN) in a flexible system that can be reconfigured easily to allocate storage to the sub-systems. A 160Tb Tape robot looks after archiving, backup and data transport. Finally a clustered web front-end provides significant capability to deliver standards-based web services through both open and secure channels. This component will be required for the delivery of certain project tools to project teams.

The facility is housed in a purpose built server room providing stable temperature, humidity and power environment for the high density rack systems. The facility provides 230A@240V 3 phase and 50KW of sensible cooling. Logged card access for entry to and exit from the facility is required. The facility is secured as per the Australian Commonwealth Defence Signals Directorate ACSI-33 guide lines to store and process In-confidence classified data, meeting the stringent physical access, network isolation, authentication, and authorisation requirements. Onsite 24-hour security guards provide physical security to the facility and are alerted of any after-hours access.

The WRON Computing Facility provides two data storage options: (i) a network accessible file system with 100 Tb space; and (ii) a relational database system (Microsoft SQL Server (Enterprise) 2005. Both will be used to support data storage for the project.

A full backup of the entire WRON Data Store server is not possible on a daily or even weekly basis due to the large volumes of data being stored. Therefore, the backup mechanism employed for the project will be a shadow copy then area backup on request approach. That is, data is copied to tape areas in up to 15Tb chunks and backed up at the user’s request. A differential backup will be performed on a weekly basis whereby the tape archive is updated only with changes that have occurred within the data directories.
9.2 Data management

9.2.1 Data storage

The WRON Computing Facility will provide all required storage, processing, backup and security requirements, and will be home to all project datasets as well as core GIS, remote sensing and time-series data. It will be the single ‘point of truth’ for all data and accessible to all members of the project. Where possible, the creation of copies of datasets will be avoided so as to ensure all are using the same versions of data.

A fixed directory structure for the storage of all file-based datasets will be used and is yet to be determined, but will be similar to that used for the Murray-Darling Basin Sustainable Yields project, i.e. organised by reporting regions and project teams.

Data will be stored in raw format and, where necessary, in processed format. Access to sensitive datasets will be restricted and the project manager will designate those staff to be granted access to such data. All data development will be carried out within personal workspaces outside of the project directory, and a significant workspace area is being created on the WRON server to accommodate this. Once a dataset has been finalised and is ready for use it will be copied into the project directory along with its metadata statement.

9.2.2 Metadata

A key element of data management will be to ensure that every dataset collected for, or generated by, the project is adequately described (i.e. has a metadata statement). Each project team will be asked to provide metadata for the datasets they create according to the project metadata profile (Appendix A). The Project Data Manager will have responsibility for ensuring that all datasets are adequately described.

An online project catalogue (described below) will be developed. This will allow all members of the project to identify those datasets that have been collected, or generated, and access the metadata for these datasets.
It is critical to the project that any reported result can be traced back to the original source data. Metadata helps establish this audit trail by showing all data sources, model parameters, software versions, etc. that have been used to generate a reported result. The protocols, processes and tools established within the current data management environment are designed to enable this audit trail.

9.2.3 Data licences

All data obtained from third parties for this project need to have a valid licence that has been accepted by CSIRO. Licence agreements will be processed by the Project Data Manager in cooperation with CSIRO Legal Services, who need to conduct a risk assessment on all license contracts. This will ensure that licences are accepted under terms agreeable to CSIRO and endorsed by those with appropriate delegation.

Where possible, CSIRO will actively seek to enter into schedule-based licences with data suppliers to limit the number of licences to be processed. Access to project data will be in accordance with all licence conditions, and it is important that all users recognise any and all limitations, usage requirements, and acknowledgements specified in a licence or terms of use document. The project manager is the delegate required to sign data licences, once they are cleared by Legal Services. A data licence is essentially a binding contract and therefore the responsibility of adherence to licence conditions resides with the project manager who signs the document.

9.2.4 Data exchange

External data exchange (between CSIRO and other project partners) will be an essential process for completion of the project. A File Transfer Protocol (FTP) site has been enabled for exchange with external agencies and the Tasmania Sustainable Yields project SharePoint site may also be utilized for transfer of small datasets, i.e. less than one to two gigabytes. If there are extremely large datasets it may be necessary for an organization to copy them to LTO tape media or DVD, and then post them to WRON server administrator to load onto the system locally.

9.2.5 Data standards

Two following standard projections will be used for the project: (i) Geographic, GDA94; and (ii) Map Grid of Australia Zone 55 (MGA55), ie UTM Zone 55S projection based on the GDA94 datum. Polygon areal calculations will be based on the MGA55 projection. All spatial data should be in ESRI GIS compatible format and supplied with explicit projection and attribute information. Elevation values should be in metres AHD. No common file naming system will be employed due the large number and diverse requirements of tools and datasets to be employed. However, project teams will be encouraged, where possible, to use names which describe their context adequately and try to be systematic within dataset series.

9.2.6 Post-project data management activities

At the completion of the project, any post-project data management activity prescribed in a data licence will be undertaken by the Project Data Manager. This will include tasks such as: (i) ensuring that an audit trail exists for all project results; (ii) ensuring all project data is archived; and (iii) ensuring datasets, models and software are removed from the WRON Computing Facility where required by a licence agreement.

9.3 Data management tools

A key responsibility of the Data Management Team will be the provision of tools to support collaboration, data storage and reporting. These are yet to be determined based on project needs.
9.3.1 Metadata catalogue

The metadata catalogue consists of a user interface and associated database. The database will contain the description of each dataset used within the project (see Appendix A). This includes, where possible, data provided by external agencies as well as that produced by the project.

The catalogue serves two main functions:

1. Description – providing a means for capturing the description of a dataset through either a web interface or by harvesting metadata documents produced automatically by modelling software; and

2. Discovery – providing the ability to search for datasets. A search will return a list of candidate records and then give the user the ability to view the entire metadata record including the paths to the files that make up the dataset.

To ensure the metadata catalogue contains entries for all the data used in the project, a system to closely couple metadata records with datasets will be implemented. This system will regularly scan the project directory to make sure a description of all data stored in the file system exists. Data managers will be notified of any data for which a description does not exist.

9.3.2 Data licence database

A database of all data licences is being scoped as a tool for streamlining the licensing process as well as to ensure requirements of these licences are accessible, understood, and fulfilled. CSIRO Legal Services are developing data transfer forms which can be incorporated into a web based tool for streamlining the data licensing process. The forms will include information outlining the required use of the data, and will also require the user to specify when the data is needed by. This will help flag the priority of the data license. The timelines for rolling out this tool are still unclear, due to available resources. In the absence of this tool we will maintain a spreadsheet which will contain all data/model license details for the Tasmania Sustainable Yields project.
10 Report management

Dealing with the volume of reports being produced within the Sustainable Yields projects, and the large number of authors, requires the use of tools that have been purpose-built to support distributed multi-document collaboration. In the Murray-Darling Basin Sustainable Yields project, the Reporting Team used Microsoft’s SharePoint\(^1\) web product to manage storage, revision and distribution of all reports. This was most successful - in fact it is difficult to imagine how high quality report production could have otherwise been managed and sustained – and a similar approach is being implemented for the new set of Sustainable Yields projects.

10.1 Computing infrastructure

Windows SharePoint Services (WSS) is a web portal used for collaboration and is easily accessible through an Internet browser such as Internet Explorer. It provides a very intuitive and flexible platform for storing and managing documents, calendars, lists and announcements.

SharePoint is a hosted application and must be hosted on a Windows server. The current CSIRO implementation is SharePoint Application Server (WSS 3.0) with a separate backend Database Server (SQL 2000). The application and the database servers are currently virtual machines (ESX platform), however the database server is being migrated to its own physical machine and SQL upgraded to SQL 2005. The hardware is located in the CSIRO Sydney Data Centre.

10.2 Operational management

10.2.1 SharePoint sites

SharePoint runs off \(<http://teams.csiro.au/sites>\). Individual project sites are located under this, e.g. \(<http://teams.csiro.au/sites/SYShare>\) is the entry-level site for all Sustainable Yields projects. Each project has its own set of sub-sites under this site for project and product management, communications with reference panels and steering committee, etc.

10.2.2 Access and permissions

Access to SharePoint is via a username and password. For internal (CSIRO) users, these are automatic and go through the in-house network authentication. Accounts are created for external users with usernames and passwords automatically generated by the account manager. Accounts are active for six months and passwords for three months. Users are automatically notified of impending account and password expiry.

Access to individual sites is managed by the site owner (typically the project coordinator). Within each site, the site owner sets permissions that restrict the activity of each individual – ranging from full control to read only.

10.2.3 Maintenance and backup

The SharePoint environment is actively monitored using System Centre Operations Manager to pre-empt any application/system issues. This significantly reduces the risk of downtime associated with full database, corrupt indexing, etc.

CommVault Galaxy\(^2\) agents are deployed for file system and database backups. A full backup is done every last Friday of the month, with nightly incrementals (Mon,Tue,Wed,Thu), and differential every Friday. DocAve\(^3\) is used to

\(^{1}\) <http://www.microsoft.com/australia/bpio/collaboration/default.aspx?WT.srch=1>

provide for a more fine-grained recovery of SharePoint data elements, with full backups every Saturday and incremental backups every four hours.

Microsoft have a scheduled upgrade / bug fix release every two months and the CSIRO SharePoint will have a similarly-scheduled maintenance programme to maintain the currency of the production version.

10.2.4 Security

Locally, every CSIRO computer runs McAfee Agent\(^4\) which blocks viruses from attacking the site. The Microsoft Forefront suite of security products performs a similar role when access is external. The system also uses a sophisticated Active Directory\(^5\) arrangement to secure information on the site for both internal and external clients.

Physical security and physical protection for CSIRO servers within the Sydney Data Centre conform to the ACSI 33 security manual\(^6\). The facility is housed within the Fujitsu Data Centre, North Ryde, Sydney where CSIRO servers are located within a locked cage (top, bottom and sides). That Centre is very highly secured with cameras, bullet-proof glass and doors, handprint recognition entry, etc.

\(^3\) [http://www.avepoint.com/products/]
References


### Appendix A – Project Metadata Profile

<table>
<thead>
<tr>
<th>DESCRIPTIVE INFORMATION</th>
<th>[Description]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Name of the dataset.</td>
</tr>
<tr>
<td><strong>Directory Path/File Name</strong></td>
<td>Please specify a file name(s) only. Path will be allocated by data coordinators when the data is moved to the new directory structure.</td>
</tr>
<tr>
<td><strong>Custodian</strong></td>
<td>The name of the organisation responsible for creating and maintaining the dataset (e.g. CSIRO Land and Water).</td>
</tr>
<tr>
<td><strong>Project Area</strong></td>
<td>The project team the work has been produced within/obtained for. Please select from the following list. If many, select ‘Reporting’</td>
</tr>
<tr>
<td></td>
<td>- groundwater</td>
</tr>
<tr>
<td></td>
<td>- catchment Yield</td>
</tr>
<tr>
<td></td>
<td>- river Modelling</td>
</tr>
<tr>
<td></td>
<td>- reporting.</td>
</tr>
<tr>
<td><strong>Progress</strong></td>
<td>Is the dataset a draft version or a final version? Please select from the following list.</td>
</tr>
<tr>
<td></td>
<td>- original</td>
</tr>
<tr>
<td></td>
<td>- draft</td>
</tr>
<tr>
<td></td>
<td>- final.</td>
</tr>
<tr>
<td><strong>Coordinate Reference System</strong></td>
<td>What coordinate reference system (if applicable) has been used for the data? Please select from the following list.</td>
</tr>
<tr>
<td></td>
<td>- Geographic_GDA94</td>
</tr>
<tr>
<td></td>
<td>- Lambert Conformal</td>
</tr>
<tr>
<td></td>
<td>- N/A (not applicable)</td>
</tr>
<tr>
<td></td>
<td>- other (please specify).</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td>Indicate the format the data is stored in (e.g. ASCII text, ARC/INFO coverage), the digital representation used (e.g. point, raster, vector, text) and the software version number (if applicable).</td>
</tr>
<tr>
<td><strong>Data Licence</strong></td>
<td>Has a licence for this data been obtained for the project? If so, where is it?</td>
</tr>
<tr>
<td><strong>Contact organisation</strong></td>
<td>The name of the organisation responsible for the creation and maintenance of the dataset (possibly same as custodian).</td>
</tr>
<tr>
<td><strong>Name</strong></td>
<td>The name of the person responsible for creating or maintaining the dataset.</td>
</tr>
<tr>
<td><strong>Phone Number</strong></td>
<td>The phone number of the person responsible for creating or maintaining the dataset.</td>
</tr>
<tr>
<td><strong>Email Address</strong></td>
<td>The email address of the person responsible for creating or maintaining the dataset.</td>
</tr>
<tr>
<td><strong>Abstract</strong></td>
<td>A brief and simple summary of the dataset content. This field should include:</td>
</tr>
<tr>
<td></td>
<td>- the reason for creating/obtaining the dataset</td>
</tr>
<tr>
<td></td>
<td>- the spatial and temporal scales of the dataset (if applicable) and</td>
</tr>
<tr>
<td></td>
<td>- the main features of the dataset.</td>
</tr>
<tr>
<td><strong>Search words</strong></td>
<td>List a number of words which can be used to search a catalogue and find this dataset.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LINEAGE (This information is required to ensure an audit trail exists)</th>
<th>[Description]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Input</strong></td>
<td>What datasets (if any) have been used to develop the dataset? Include version numbers/dates if applicable.</td>
</tr>
<tr>
<td><strong>Processing Steps</strong></td>
<td>What processing steps have been taken during the process of creating the dataset? Give enough information such that someone else can repeat the processing.</td>
</tr>
<tr>
<td><strong>Tools</strong></td>
<td>What tools were used to process the data (e.g. IQQM model). Give version numbers if applicable.</td>
</tr>
<tr>
<td><strong>Parameter List</strong></td>
<td>List any parameters and their values that were used in the process.</td>
</tr>
<tr>
<td><strong>Positional Accuracy</strong></td>
<td>How close are the locations of spatial objects in relation to their true positions on the earth’s surface (if applicable).</td>
</tr>
<tr>
<td><strong>Attribute Accuracy</strong></td>
<td>Do the values assigned to attributes mimic realistic values. This must include what classification method is used to assign values to dataset features, how well the features correspond with the method, and factors influencing attributes.</td>
</tr>
<tr>
<td><strong>Logical Consistency</strong></td>
<td>Do all objects in the dataset have logical relationships or does the data have discrepancies? (e.g. Do all boundaries meet, do polygons close, and are all points labelled?)</td>
</tr>
<tr>
<td>ATTRIBUTES (This information should be provided for all key attributes in the datasets)</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Name</strong></td>
<td>Name of the attribute.</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td>What is the set of valid values for this attribute? Describe each code if applicable.</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>Description of the attribute.</td>
</tr>
<tr>
<td><strong>Metadata Date</strong></td>
<td>The date that this metadata file was created.</td>
</tr>
<tr>
<td><strong>Additional Metadata</strong></td>
<td>Any comments that cannot be provided under other headings.</td>
</tr>
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</table>