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Abstract

The Commonwealth of Australia *Water Act 2007* changed the priority for water use in the Murray-Darling Basin (MDB) to first ensure environmentally sustainable levels of extraction and then to maximise net economic returns to the community from water use. The Murray-Darling Basin Authority (MDBA) is expected to deliver a draft Basin Plan in 2011 providing a framework for future water planning. The Plan will include Sustainable Diversion Limits (SDLs) which define water diversions for consumption while maintaining environmental assets and ecosystem functions. The 2009 MDBA Concept Statement acknowledged that in some areas less information is available to determine the SDLs. The 2010 MDBA Guide to the Basin Plan proposed SDLs reducing the current long-term average surface water diversions to between 25 and 34% for the Goulburn-Broken region.

Representative farm-level models of irrigated dairy, horticulture and viticulture, and dryland broadacre, industries were developed to determine the likely impacts on farm income and farm enterprise mix if the price and quantity of irrigation water changes. Water for ecological benefits and ecosystem functioning was determined for a range of river health levels using a bottom-up approach identifying flow requirements for fish, riparian vegetation, invertebrates, and geomorphic and nutrient processes. A novel part of the analysis is the conjunctive use of water for both purposes, e.g. wetland filling and then pumping for irrigation. The linkages between changed land use and surface/ground water outcomes are assessed using a Catchment Analysis Tool. An experimental design of different proportions of water going to the environment and consumptive uses showed potential trade-offs between agricultural, environmental and surface/ground water outcomes. These trade-offs were examined to assess the impact of alternative water management on catchment welfare, and provide information about setting SDLs.

1. Introduction

In October 2010 the MDBA released its Guide to the MDBA Basin Plan (MDBA 2010) which proposed an aggregated reduction in MDB water use for irrigation of between 3000 and 4000 Gigalitres (Gl). This process is in response to the *Water Act 2007* (Australian Government undated). There has been substantial public reaction to the SDLs contained in the Guide as MDBA officers presented the proposals to regional audiences in irrigation areas.

The proposal to increase water for environmental purposes at the expense of water available for irrigated agriculture is aimed at meeting international wetland agreements and improving economic, environmental, and social outcomes for the whole Australian community. The 2009 MDBA Concept Statement (MDBA 2009) acknowledged that in some areas less information is available to determine the SDLs. Interpretations of the *Water Act 2007* in achieving these outcomes are the subject of legal opinion and public debate.

The Murray-Darling provides an example of the global challenge of water sharing between irrigation and environmental uses. This challenge will become more critical as irrigation expands world-wide to meet the food requirements of an expanding world population.

There has been substantial research interest in water sharing between environmental and consumptive (agricultural) uses (Bennett *et al.* 2010). In the work reported here we developed detailed representations of both ecological and farm economic responses for one catchment (the Broken River) to analyse alternative water sharing arrangements, and examine the trade-offs between environmental and agricultural responses to different water shares within a catchment. How sensitive are the different outcomes to variations in the SDL?

2. Background

There are two aspects of future water supply of potential interest to individuals, communities and governments in river catchments of the MDB. First is the aggregate quantity of water available. In this research we investigate two future scenarios for aggregate water supply – the historical pattern and the 2030 ‘dry’ climate as used in the CSIRO Murray-Darling Basin Sustainable Yields study (CSIRO 2008). The second aspect of water supply focuses on how water could be shared within either of these aggregate supply scenarios. The proportion of water going to the environment and irrigated agriculture was systematically varied under each supply scenario. Other factors influencing water supply include water trading and potential gains from improved water use efficiency in the catchment and on farms.

This research investigated the likely environmental, agricultural and surface/groundwater outcomes for alternative water supply and water sharing scenarios and presenting these outcomes for comparison. The objective of this paper was to develop and present an analytical framework for a detailed assessment of outcomes from different water sharing policies and discuss some initial results.

An important question was whether the environmental and farm outcomes are very sensitive to sharing arrangements. The Guide (MDBA 2010) presented only one SDL per catchment. The results presented here show outcomes for alternate SDLs and allow an examination of the trade-offs from alternative SDLs. As well as providing these responses, the work is novel in the level of detail in ecological system and agricultural farm modelling and prediction. There are many examples of studies investigating irrigation or environmental outcomes of water resource scenarios in isolation. This study develops a framework for simultaneous

analysis of the trade-off between irrigation and environmental outcomes of alternative policy and climate scenarios. Other studies have attempted this but with considerably less detail in the assessment of economic and environmental outcomes (e.g. Grafton *et al.*(2010)).

3. The Broken catchment

The Broken River is one of the tributaries of the Goulburn River in north-eastern Victoria (Goulburn-Murray Water undated). The Broken River Basin also includes the catchment of Broken Creek, a distributor off the Broken River with its affluence just downstream of Casey's Weir which flows in a north-westerly direction to the Murray River (Figure 1). The Basin covers 772,386 hectares.

The Broken River catchment formerly included two lakes, namely Nillahcootie and Mokoan. The latter has been decommissioned with most of the site to be rehabilitated as a major wetland complex consisting of nine pre-existing wetlands, the largest being Winton Swamp. There are 32,190 Megalitres (ML) of entitlement in the Broken River system, of which 5,960 ML are stock and domestic. Lake Nillahcootie has a capacity of 40,400 ML, 15% of the long term historical mean annual flow of 257,500 ML/year. Regulated releases of up to 1,800 ML/day can be made from this reservoir (SKM 2006).

Only 16% of the total catchment yield from the Broken River is allocated for human use within the catchment. In contrast 79% of catchment yield is diverted from the Goulburn catchment (Table1). The percentage of land irrigated in the Broken catchment is very low (2.2%). The MDBA Guide recommended a SDL of 25-34% for the Goulburn-Broken System and this will have potentially greater impacts in the Goulburn than the Broken.

4. Data and analysis

The analysis began with simulation of environmental and irrigator water demands within the Broken River catchment (Figure 2). The environmental demand represents the water required to achieve the desired ecological outcomes, expressed in the *Water Act 2007* as 'protect, restore and provide for the ecological values and ecosystem services for the Murray-Darling Basin'. The irrigator demand was modelled through representative farm models providing optimal water use and scaled up to the catchment level according to land-use areas. The allocation of water to meet environmental and irrigation demands was simulated in a daily water resource simulation model which includes representations of dam water levels, streamflow and the effect of water supply system constraints (i.e. dam-release valve and diversion rates). It is to be expected that demands will not be fully met, and the final component of the analysis is to evaluate the simulated allocation against the modelled demand. With decreasing allocation, relative to demand, the economic benefit (for agricultural demand) and the environmental benefits (for the environmental demand) will be compromised.

On the environmental side the first step was to develop environmental flow targets to meet the above environmental objectives. The environmental assets of concern were native fish, macroinvertebrates, riverine vegetation and geomorphology. An expert panel of ecologists was formed to consider these categories of environmental improvements (assets) and developed a set of 17 priorities. These priorities are in Table 2 and the expert panel rankings are in Figure 3.

These priorities were considered necessary to achieve the environmental objectives of the *Water Act 2007*, but for this research question they were separated into three levels of river health:

1. All 17 priorities to achieve the environmental objectives (Low risk);
2. The top 10 priorities to achieve a lower level (Medium risk); and
3. The top 5 objectives to achieve a still lower level (High risk).

These levels of river health are associated with different probabilities of achieving the overall environmental objectives and with different levels of water use. A program (eFlow Predictor) (eWater CRC undated a) was then used to generate flow regimes from the water demands for these levels of river health. The derived flow regimes were developed using historical flow records which incorporate regulation as a base and for a set of flow rules identify environmental water augmentation.

On the agricultural side the level of water availability to the average irrigated dairy and horticulture farms was systematically varied according to water balance shares of 90, 70, 50, 30 and 10% of full allocation. The models were used to capture the changes associated with best economic management for altered levels of irrigation water. The nature of the models allowed changes in both land area used for agricultural uses (the extensive margin) and the change in activity mix (the intensive margin). For instance, the dairy model was used to assess the likely changes in pasture mix (irrigated versus dryland, perennial versus annual) and sources of feed supply (supplementary feed purchased or use of fodder crops).

These water demands from agriculture and the environment were used as input to the Source Rivers model (eWater CRC undated b) from which water flow series were developed to achieve the environmental objectives for the three levels of river health. These water flow series were also checked to confirm that they would achieve the environmental objectives – consisting of an Environmental Flow Compliance analysis. That is, for each of the levels of river health a probability of achieving the environmental objectives was developed.

Patterns of water demand from the farm-level models were also used to predict changes in land use and these changes were used as input to the Catchment Analysis Tool (CAT). The CAT predicted changes in surface water flows and groundwater levels associated with alternative water sharing arrangements (Beverly *et al.* 2005).

4.1 Farm-level data

Commercial-scale, self-contained, whole of systems field experiments were established at the Dookie farm estate ((The University of Melbourne undated)) in the Broken catchment based on the research philosophy that new ways of managing the available water are required if wealth generation within irrigated regions is to be maintained or enhanced under future climate scenarios. The farming systems investigated were:

1. Irrigated dairy systems
 - aimed at achieving competitive profit with >70% (6Ml/ha), 33% (3Ml/ha) and <20% (1.5Ml/ha) of historical irrigation water allocations;
2. Irrigated horticulture and viticulture

- aimed at improving economic returns to irrigation of stone fruit, pome fruit and wine grapes through automated irrigation supported by objective scheduling based on soil moisture, evapotranspiration and canopy temperature; and
3. Broadacre cropping and dry land livestock
- aimed at adapting crop management to climate change, maximizing returns from conjunctive water use, and integrating crop and livestock successfully in a hotter and a drier climate.

Data collected include detailed agronomic and production data, costs and other bio-physical information covering all inputs and outputs from each system, so that calibration and validation of bio-physical and bio-economic simulation tools could be undertaken. Bio-physical modelling tools such as APSIM (Keating *et al.* 2003) and DairyMod (Johnson *et al.* 2008) are being used for paddock- to farm-scale simulation of impacts of climate change and management on productivity of the systems while the CAT is employed to investigate long term impacts of land use and management changes associated with low water availability under future climate scenarios at broader spatial scales.

4.2 Ecological responses

There are three components to the development of environmental water requirements used in this analysis: environmental objective setting and flow rules development, prioritisation of environmental objectives, and development of environmental flow regimes and volumes.

Environmental objective setting and flow rules development was undertaken through an expert panel approach. This incorporated expert knowledge of fish and invertebrate ecology, vegetation and nutrient dynamics, and geomorphology. The approach is referred to as ‘bottom up’ due to the identification of specific objectives (e.g. pool habitat for Murray Cod) which can be developed by the panel into environmental flow ‘rules’ for each objective. Hydraulic models and hydrologic data were used to quantify the rules. Hydraulic models (HEC-RAS) are one-dimensional (depth averaged velocity) representations of the field site for relating discharge to hydraulic conditions such as water depth and elevation (e.g. to identify fish passage or vegetation inundation), and velocity and bed-shear stress (e.g. to identify substrate disturbance events required). Hydrologic data were an extrapolated 100 year dataset for ‘natural’ conditions, i.e. no storage, and were used primarily to identify naturally occurring recurrence intervals and durations to inform rule setting.

Based on a one-day workshop and post-analysis discussions 17 environmental flow objectives were developed with flow rules for each objective which included the following:

- Objective focus e.g. fish, invertebrates, vegetation, nutrients, geomorphology;
- Habitat type impacted e.g. channel bed, slackwater, riffle/run, floodplain;
- Timing e.g. spring, summer;
- Magnitude of flow e.g. X ML/d;
- Frequency of flow e.g. continuous or Y times per season;
- Duration e.g. Z days; and
- Rationale and mechanism e.g. turnover of substrates to reduce smothering through adequate shear stress.

Prioritisation of environmental flow objectives was based on a subjective independent assessment by each of the six panel members ranking objectives from 1 to 17. The mean of

these rankings was used to identify priorities. Priorities were then lumped into three categories of low, medium and high risk to the environment. Compliance with all 17 flow rules provides low risk for the environment, compliance with the top 10 ranked rules provides medium risk, and compliance with only the top 5 ranked rules provides high risk to the environment.

Environmental flow rules were then used as input into the hydrologic tool eFlow Predictor (eWater CRC undated a) to develop environmental flow regimes. The model augmented the regulated flow regime using the environmental flow rules and allows determination of the volume of the augmented flow i.e. the water volume (and timing of these augmentations) required to satisfy environmental flow rules.

4.3 Farm economic models

Whole-farm models were constructed for the irrigated dairy and horticulture industries in the Broken catchment. Other models for the irrigated viticultural and dryland broadacre industries are also being developed. These were linear programming (LP) models developed to be representative of the farm industries in the catchment.

4.3.1 Irrigated dairy farm model

Victoria's dairy industry uses more than half the state's total irrigation water (ABS 2006). Irrigation water for growing pastures and forages is becoming less available and its price is rising. Therefore it is important that the dairy industry makes the best use of the available water to remain economically competitive. Perennial pastures have occupied 70-80% of the irrigated milking area of the farm with annual pastures occupying 20-30% and forage crops (mainly lucerne and maize) occupying only 2% (Armstrong *et al.* 1998). It is important to include outcomes from biophysical predictions in the whole farm economic model to fully evaluate the impacts of financial performance. Linking the outputs of biophysical models with farming system tools can help to bridge this gap (Cullen *et al.* 2010).

The objective function in the model was the maximisation of the total gross margin for the farm for an average year and subject to typical constraints or restrictions on resource availability. The objective was maximized over a single year. Gross margin was defined as the difference between returns from milk plus stock sales and variable costs. Costs considered were animal health, breeding, and milking, plus costs for conservation of silage, cropping, and the purchase of off-farm grain and supplements.

4.3.2 Irrigated horticulture farm model

A representative horticultural farm model for the Goulburn catchment has been developed and described by (Ramilan *et al.* 2011). Principal orchard crops in north-east Victoria are pear, apple and stonefruit. All orchards depend on irrigation water because rainfall is insufficient to cover evapo-transpiration demand. The whole-orchard economic optimising model included simulated water profit functions and water saving strategies. The model was developed to explore the economic consequences of different tactical decisions in a water-constrained environment. The model allows construction of curves showing the trade off between alternative objectives.

4.4 River modelling

The modelling of water allocation process was based on the integration of water supply and demand through a network allocation model. Source Rivers ('RiverManager') (eWater CRC undated b), is currently being developed by the eWater CRC partners using The Invisible Modelling Environment (Rahman *et al.* 2003). Source Rivers can be used to construct river system simulation models that trace the temporal movement of water through the system (Welsh and Podger 2008). The model also has the capability to track the ownership of water volumes and route the flows as they move through the system. The model can be applied to both urban and agricultural systems and uses a node-link network to represent the river basin where nodes represent the physical units such as reservoirs, aquifers, townships, agriculture and industries and links represent the connection between the nodes. The model works on a daily time step.

Three steps in the simulation of a regulated river system were:

- A resource assessment of the supply available in the river and storages and an estimation of water demand. Both consumptive and non-consumptive users can be modelled using Source Rivers. Agricultural demands can be estimated using models such as PRIDE or IQQM, or can be input as a time series demand;
- The amount of water required to be released from the storage to meet the orders along the system was calculated by accumulating daily water orders from both consumptive and non-consumptive uses after allowing for travel time, losses/gains in conveyance and flow constraints; and
- Reservoir releases were routed down the system by supplying water to different water users based on the orders placed, by carrying out a water balance at each node where water is either extracted or added.

A Source Rivers model was set up for the Broken catchment. To assess the resources available a detailed hydrologic modeling and stream flow simulation was carried out using the hydrologic modelling tool SimHYD. The calibrated and validated hydrological model was used to simulate historical flows since 1896 and was used as input in the Source Rivers model.

Monthly agricultural water demand estimated using the farm LP models was disaggregated into daily values and these were used in the model. Source Rivers has the capability to integrate environmental flows requirements in water allocation scenarios. The time series of environmental demands were estimated using eFlow predictor and used as an input. The model generated several outputs including volume supplied and unmet demand for each demand node. This information was used to assess the level of supply security and shortfall and its recurrence interval, which is valuable information for water resource managers in their decision making.

4.4.1 Integrating agricultural and environmental demands into the river modelling

The integration process involved:

1. Using the farm LP models (irrigated dairy and horticulture) to estimate optimum farm plans and farm income for the water shares (90%, ..., 10%) available at the farm level. The average per farm water requirements were developed for each share;
2. These per farm water requirements were scaled up to the catchment level according to the area of irrigated agriculture (this number was only 2% in the Broken);

3. These aggregated irrigation water requirements were input as demands into the Source Rivers model:
4. The environmental flows required for the three levels of river health (High, Medium and Low according to the number of priorities being met) were also input as demands into the Source Rivers model;
5. Source Rivers developed the stream flows allocated to irrigated agriculture and the environment after accounting for the river, stream and other hydrological characteristics.

4.5 Catchment modelling framework

The catchment modelling framework used in this study was CAT (Beverly et al.(2005)). This is a physically based eco-hydrological modelling framework that has been developed to model the effects of landuse/land management, climate variability and/or climate change on catchment dynamics with links to a suite of saturated flow models ranging from a simple lumped approach to fully distributed three-dimensional groundwater models. The CAT framework comprises a suite of farming systems models ranging in complexity from a simple crop factor approach to phenologically based crop and pasture modules. In this paper the input to CAT (changes in farm land use due to changed water availability) have been provided by the farm LP models.

The process was to use the Parameter Estimation (PEST) model ((Doherty 2010)) to derive an irrigation schedule and corresponding crop parameters to match the irrigation demands developed by the farm-level models for dairy and horticulture based on the dominant soil profile of the catchment. Once the irrigation schedule and parameter sets were developed the CAT was used to simulate the Broken catchment response (only 2.2% of the area is irrigation). Each simulation was from 1980-2010 with climate conditions held constant for each scenario. Only the irrigation schedule and associated irrigation crop parameter sets were modified for each scenario.

4.6 Comparing environmental, economic and ground/surface water outcomes

Results from the analysis varied according to the types of analysis and units of measurement. Environmental outcomes for native fish populations, invertebrates, riverine vegetation and geomorphology were presented as risks and/or compliance in meeting the objectives of environmental improvement specified in the *Water Act 2007*. Farm-level results were presented as changes in average incomes and enterprise (land use) mixes for the representative farms. Catchment water supply outcomes were presented as changes in stream flows associated with different water sharing rules.

In future analyses it may be possible to bring some of these different outcomes into a single metric to represent changes in social welfare. Economic valuation methodologies and existing results are available to attempt such a combination (e.g. Morrison and Hatton McDonald (2010), Bennett *et al.* (2008)), but this extension is not attempted in the present paper.

4.7 Issues not included in the analysis

There are a number of aspects of improved water use that were not included in this analysis. These include:

- New farm-level technologies for water use in growing pastures and fodder crops;

- New river system structures and technologies that can improve the efficiency of water delivery at the catchment level;
- Possible conjunctive use of water for both agriculture and the environment;
- The effects of water trading; and
- Possible water purchase and use by the Commonwealth Environmental Water Holder (Robinson and Docker 2010).

The results presented here were also only for historical water flows representing the catchment water supply without any reductions due to climate change. Further assessment of the potential reduction in aggregate water supply will be conducted once the overall analytical framework is confirmed.

5. Results

The results in this paper are preliminary and are discussed to illustrate outcomes from the analytical framework, rather than being final numbers for policy analysis.

5.1 Farm-level results

As the water allocation declined both total farm gross margin (Figures 4 and 5) and catchment area (Figures 6 and 7) declined. The results are interpreted as short run responses to a change in water allocation – they do not account for potential changes to asset structures and farm sizes, nor consider water trading. The decline in area irrigated and farm income is in direct proportion to irrigation water available.

5.2 Water sharing results from the Source Rivers model

The results presented here are preliminary and illustrative for 90, 50 and 10% SDL. For this analysis the farm-level water demand was increased to represent 10% of the catchment area so that the SDL impact for a larger proportion of consumptive water could be considered.

The results presented in this section are average stream flows (ML/year) at Gowangardie Weir (Figure 1) based on historical catchment inflows. The period of analysis was 1992 to 2004. Average water allocations to the environment are shown in Table 3, where the stream flows required to achieve High levels of environmental health were (as expected) greater than the levels needed to achieve Medium or Low levels of improvement. At each level of SDL there was little difference in stream flows to achieve High or Medium levels of environmental health, but less water was required to achieve the Low level of environmental health.

Patterns of environmental stream flow demand and supply for Low, Medium and High levels of environmental risk are shown in Figures 8 to 10. From 1992 to 2004 environmental demands exceeded stream flows by up to 2.5 GL in some years but were nearly fully met in others. The patterns of water deficit (demand exceeding supply) do not vary substantially between risk scenarios for this (low) level of water diversion for consumptive purposes.

A typical hydrograph of stream flow showing natural flow, current flow and augmented flow is in Figure 11. The achievement of environmental objectives may only be an event added to existing flows, which might not be a large increase if it can be delivered precisely.

5.3 Compliance with achieving environmental objectives

Compliance with environmental objectives was analysed as the proportion of years that each of the 17 target rules (Table 2) was met in a natural flow regime. Results are expressed in a scale from 0 (bad) to 1 (representing outcomes as good as natural conditions in all years). The compliance results are given in Table 4. In a number of cases environmental flow rules are not satisfied in any year. This indicates the insensitivity of the compliance analysis i.e. pass or fail with no indication of the level of compliance. For example, the High Flow (rule 4a) recommends 170 ML/d continuously between April and October. If flow falls below this magnitude for a single day over this period then a fail is highlighted for that year. Where compliance could not be assigned a value (NaN), suggesting the flow rule is not met by natural flows, this is a consequence of different length datasets used for the flow rule determination compared to the flow rule compliance assessment. Flow rule determination was based on a 100 year dataset whereas compliance could only be assessed against a considerably shorter and particularly dry period (1991-2006) for which regulated data was available. Future analyses will be based on an extrapolated dataset and an approach to determine the level of compliance, rather than pass/fail, will be developed.

The compliance assessment suggests that there is little variation in the levels of stream health highlighting the insensitivity of the modelling and the minor influence regulation has in the Broken River.

5.4 Ground and surface water outcomes

The stream flow contributions predicted by CAT are in Table 5. These results are the impact on total stream flow after adjusting for the non-irrigated portion. As expected, stream flows increase as the level of agricultural water demanded decreases. Ground water changes have not been modelled.

6. Discussion

There are three important aspects of the analytical framework developed in this paper which can contribute to SDL policy discussions. First, the research develops detailed representations of both environmental and agricultural responses to changed water supplies within a catchment. Environmental targets were developed for particular ecological assets (native fish, invertebrates, riverine vegetation and geomorphology) and agricultural representations of particular industries were developed for the analysis.

Second, the investigation of alternative SDLs allows consideration of tradeoffs from alternative policies. The *Water Act 2007* specifies one level of sustainability and this approach has been followed by the MDBA in developing its Guide. We have set aside legal questions of what the *Act* means to ask the question of what would different water sharing arrangements provide in terms of environmental and agricultural outcomes.

Third (and perhaps most importantly) we have considered different levels of environmental health expressed as alternative compliance or probabilities of achieving ecological targets. We assessed the attainment of environmentally sustainable levels of stream health for particular ecological assets through development of a set of bio-physical priorities and then used water flow models to determine outcomes for each level. The provision of levels of stream health objectives rather than a set of minimum flow recommendations substantially

improves the trade-off analysis and in doing so also enables identification of the impacts of reducing water to the environment, e.g. *what is likely to be compromised?*

The results presented here are a first pass for a catchment where the level of water diversion for consumptive uses is relatively low. Further analysis for an increased level of diversion to agriculture will be conducted. The analysis will be extended to include improvements in water use efficiency at the farm and river system level and to investigate the potential effects of conjunctive uses of water. An alternative climate scenario will also be analysed.

7. Conclusion

If analytical resources are available, the use of detailed modelling and predictive analyses at the catchment level can develop information to help assess SDLs for guidance in river catchment planning.

Table 1. Water resources and water usage in the Broken and Goulburn Basins

Water source	Broken Basin			Goulburn Basin		
	Total water resource	Total use	%	Total water resource	Total use	%
	ML	ML	%	ML	ML	%
Surface water	257,500	43,300	16	1,958,600	1,540,500	79
Groundwater	NA	NA		NA	NA	
Recycled water	630	330	52	9,390	6,660	71

Source: (Goulburn-Murray Water undated), NA not available

Table 2. Priorities for environmental improvements, Broken catchment

Expert panel priorities for environmental improvements
1a - Invertebrate diversity and abundance (UNDESIRABLE FLOW) ^a
1b - Native fish diversity (UNDESIRABLE FLOW)
1c - Extent of submerged macrophyte beds – winter/spring (UNDESIRABLE FLOW)
1d - Extent of submerged macrophyte beds - summer (UNDESIRABLE FLOW)
2a - Macrocrustacean abundance – avoiding prolonged disturbance
2b - Recruitment of larval/juvenile fish (e.g. low flow summer spawners)
3a - Fish passage - entire reach (e.g. Golden Perch, Murray Cod)
3b - Maintain coarse substrate quality
3c - Maintain bank macrophyte communities
4a - Inundation of flow-dependent veg (e.g. Persicaria)
5a - Movement/spawning trigger
5b - Bench inundation for vegetation inundation, organic matter recruitment
5c - Terrestrial invertebrate habitat (soil moisture as habitat and veg promotion)
6a - Contribute to overall stream productivity through floodplain connections
6b - Channel maintenance, pool scour, bar creation
7a - Promote wetland veg and fauna, and nutrient and sediment exchange
7b - Promote floodplain vegetation

^a Undesirable flow means one that should be prevented rather than provided

Table 3. Average annual environmental supply according to water share and environmental health

Environmental risk level ^a				
		Low	Medium	High
	%	ML/year	ML/year	ML/year
SDL	90	93,827	93,794	88,759
(agricultural proportion)	70			
	50	102,472	102,402	96,834
	30			
	10	119,535	119,853	114,271

^a Risk to the environment: Low - achieving all 17 priorities, Medium – achieving top 12 priorities, High – achieving top 5 priorities

Table 4. Performance of water allocation scenarios against environmental flow demands

Priority number ^a	Sustainable Diversion Limit		
	10%	50%	90%
1 a-d	0.3^b	0	0
2b Low Flow	1	1	1
2a Low Flow	NaN^c	NaN	NaN
3b Low Flow Fresh	0.45	1	1
6a Bank full	1	1	1
5a High Flow Fresh	NaN	NaN	NaN
3a Low Flow Fresh	1	1	1
5b High Flow Fresh	1	1	0.89
4a High Flow	0	0	0
7a Overbank	1	1	1
3c Low Flow Fresh	NaN	NaN	NaN
5c High Flow Fresh	0.5	0.5	0.5
7b Overbank	1	1	1
6b Bankfull	1	1	1

^a Priority numbers as in Table 2, ^b 0 = flow rule not satisfied in any year, 1 = flow rule satisfied in at least the same number of years as it is met under the natural regime, ^c Flow rule is not met by natural flows

Table 5. Estimated surface water impacts of changed agricultural water shares ^a

Increase in stream flow			
SDL	% of total stream flow	Ml/year (mean annual)	
70%	2.4	10,688	
50%	3.6	16,639	
10%	7.0	31,174	

^a Compared to 100% allocation

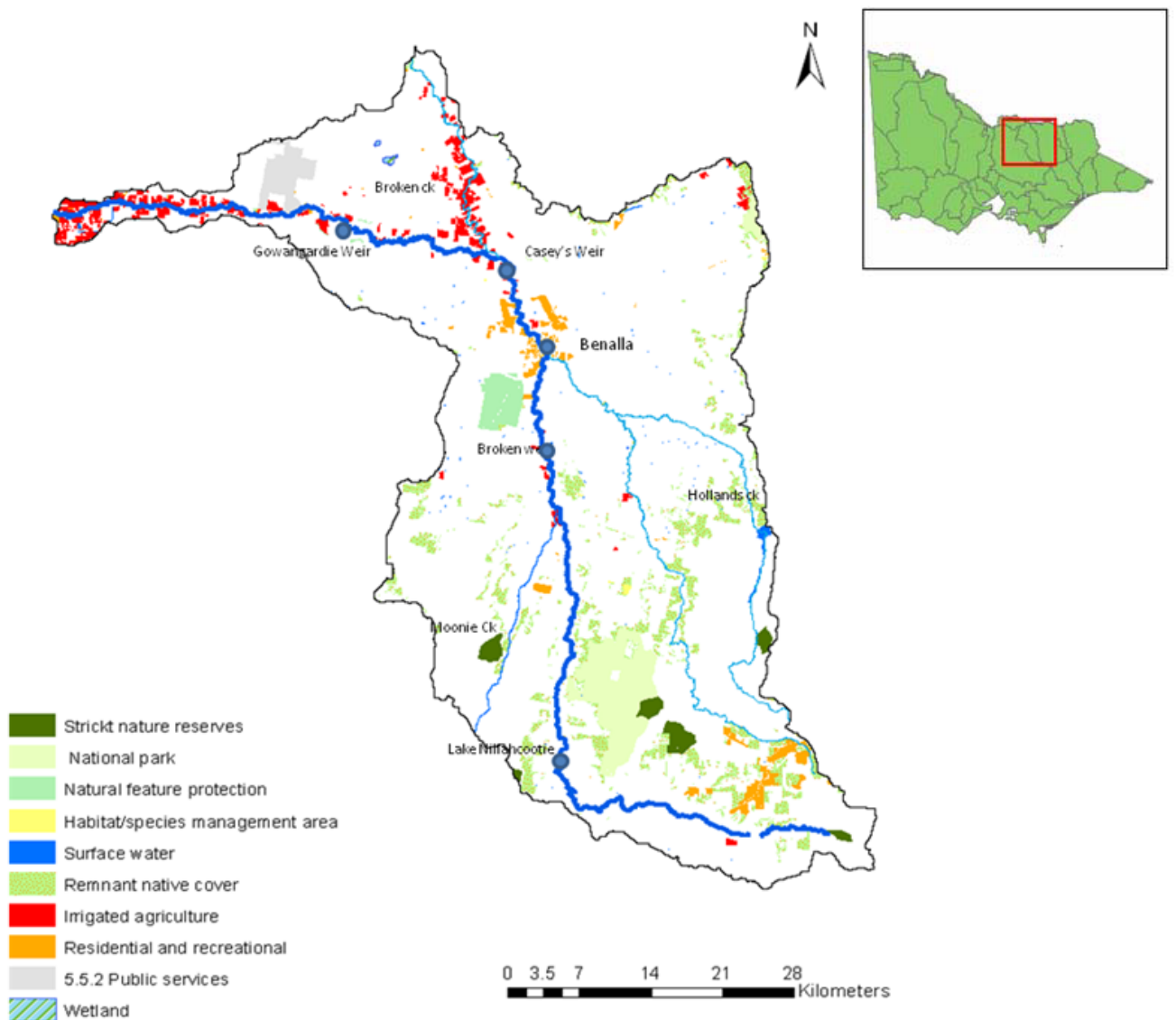


Figure 1. The Broken River catchment in Victoria

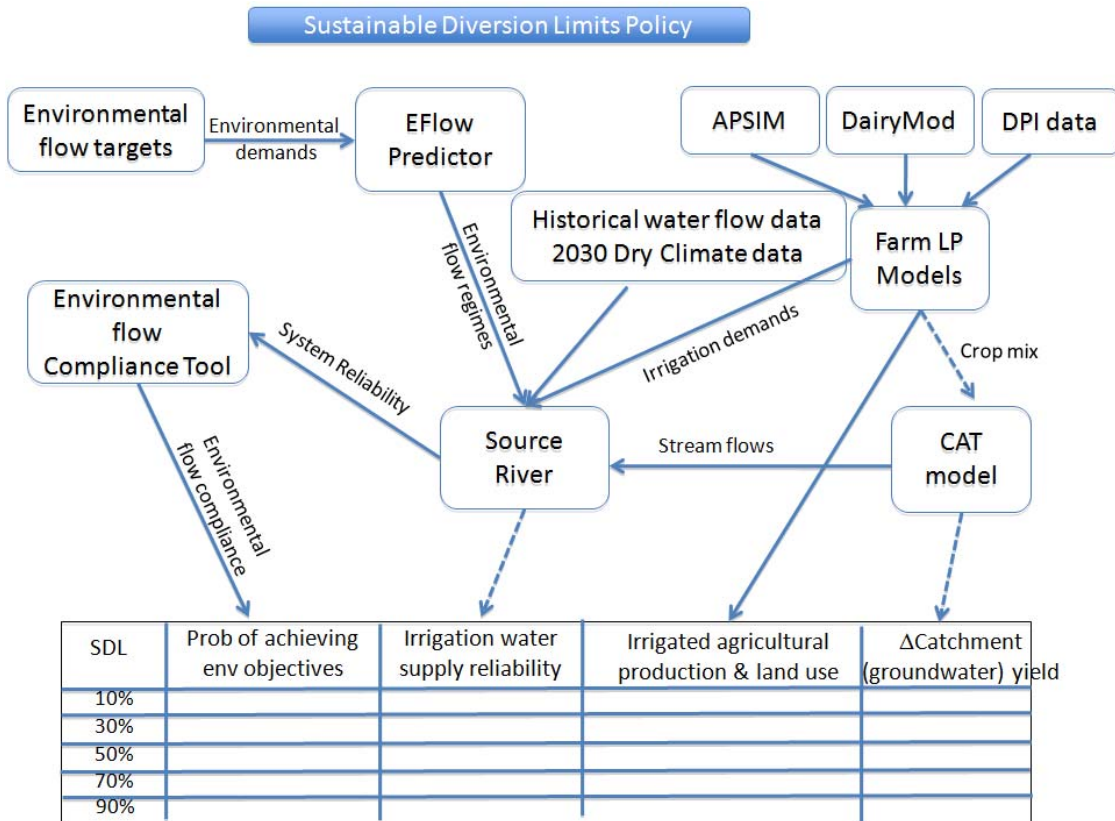


Figure 2. Schematic of models and data to address the water sharing question

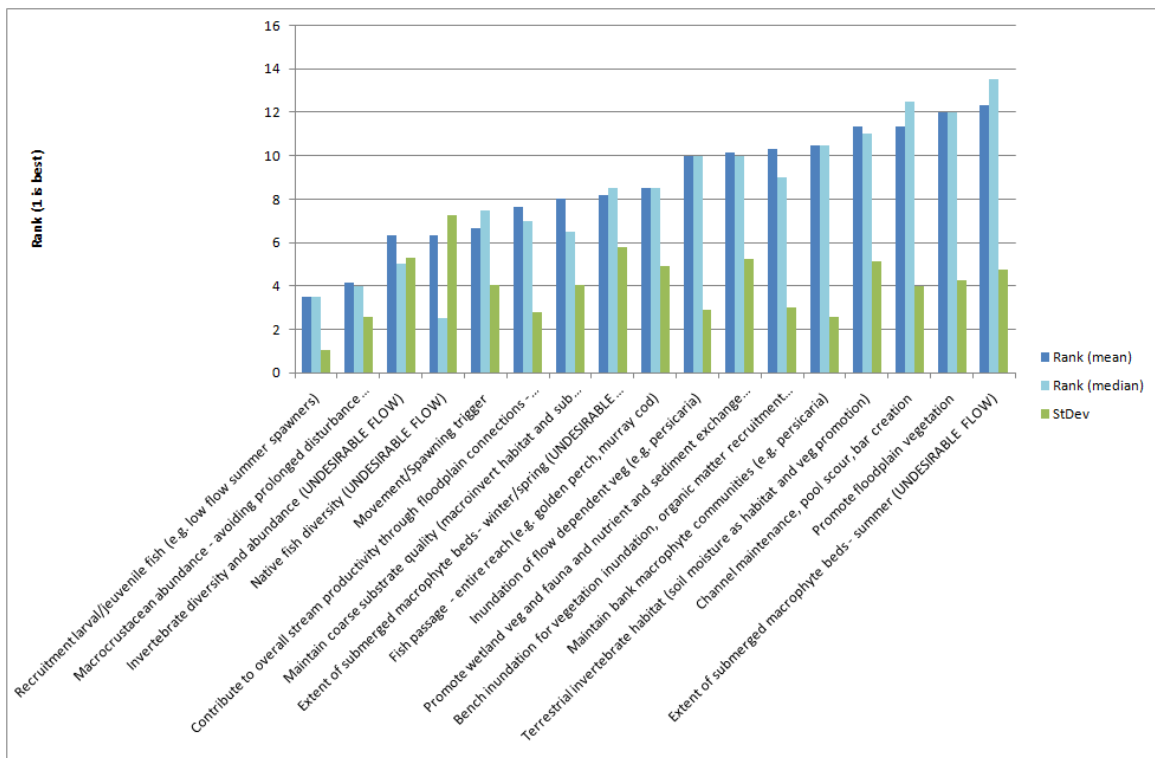


Figure 3. Expert panel rankings of environmental priorities

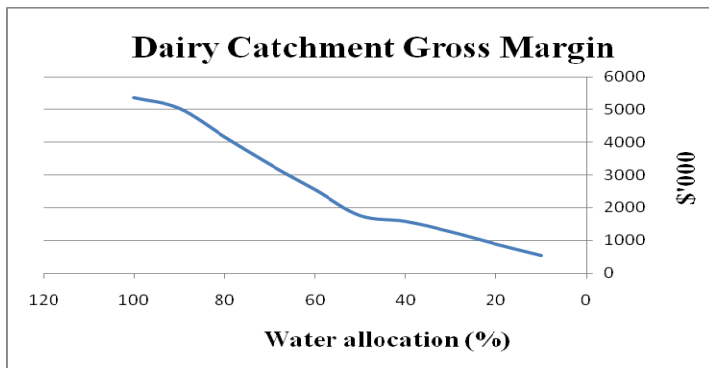


Figure 4. Change in irrigated dairy total farm gross margin with water allocations

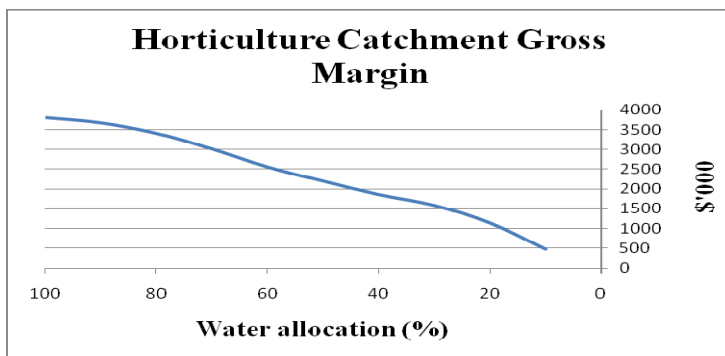


Figure 5. Change in irrigated horticulture total farm gross margin with water allocations

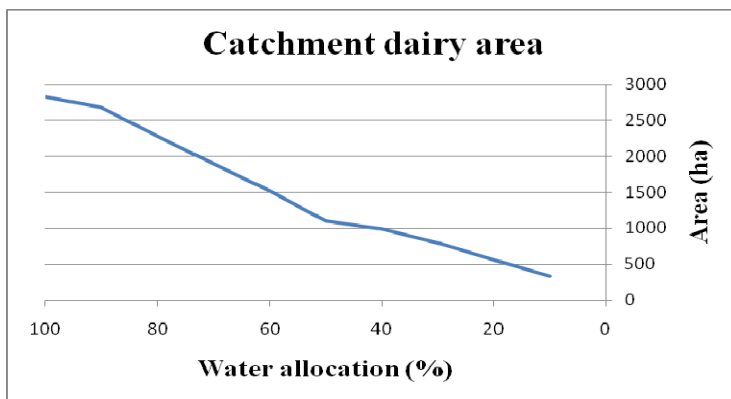


Figure 6. Change in irrigated dairy area with water allocations

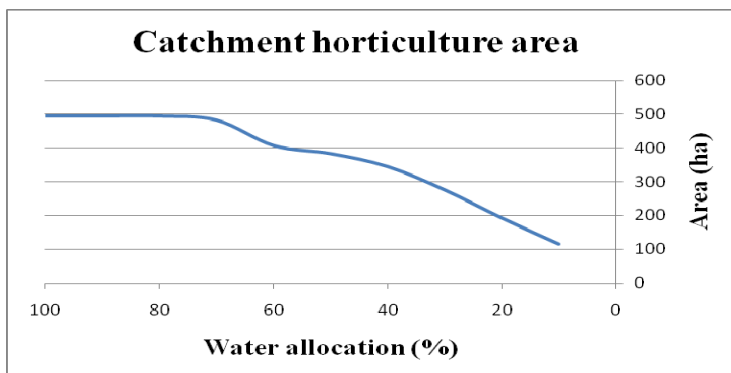


Figure 7. Change in irrigated horticulture area with water allocations

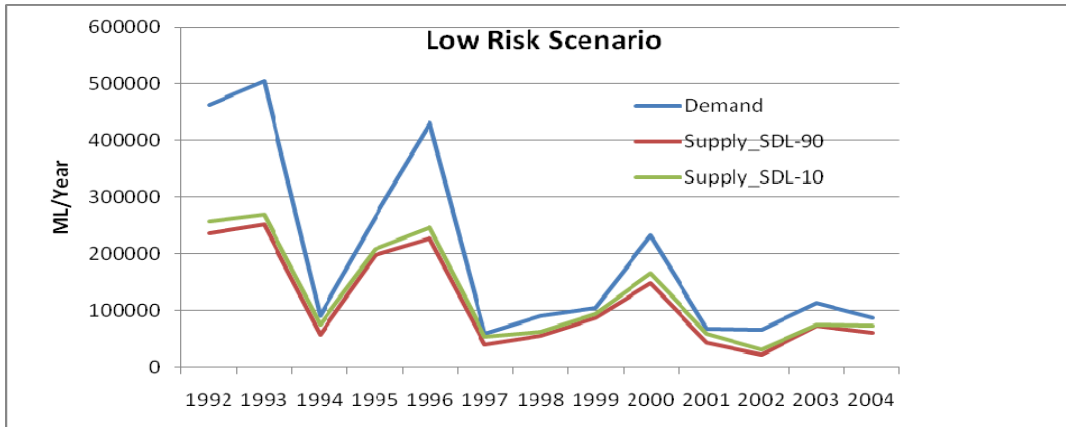


Figure 8. Annual patterns of supply and demand for environmental water, Low risk scenario (meet all 17 priorities)

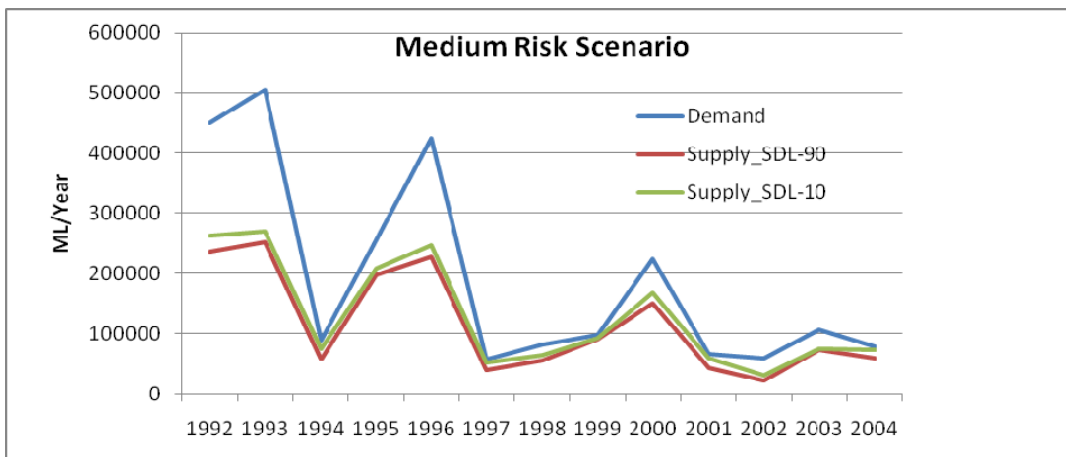


Figure 9. Annual patterns of supply and demand for environmental water, Medium risk scenario (meet top 10 priorities)

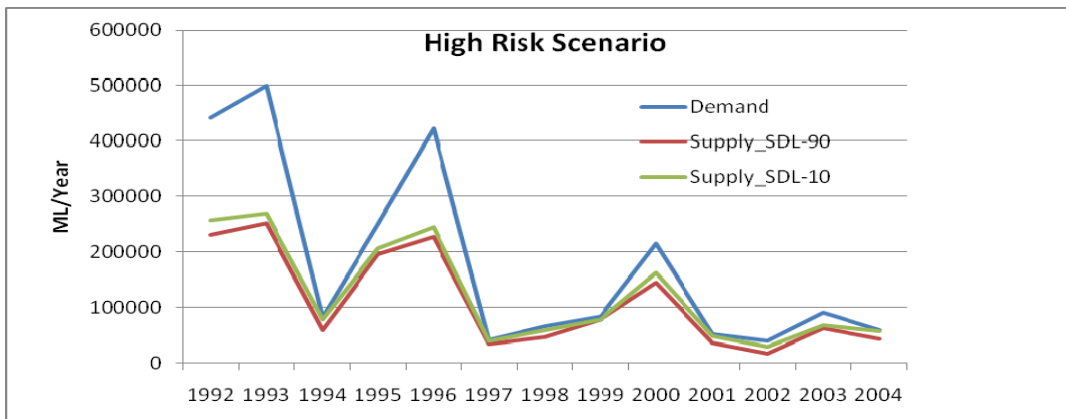


Figure 10. Annual patterns of supply and demand for environmental water, High risk scenario (meet top 5 priorities)

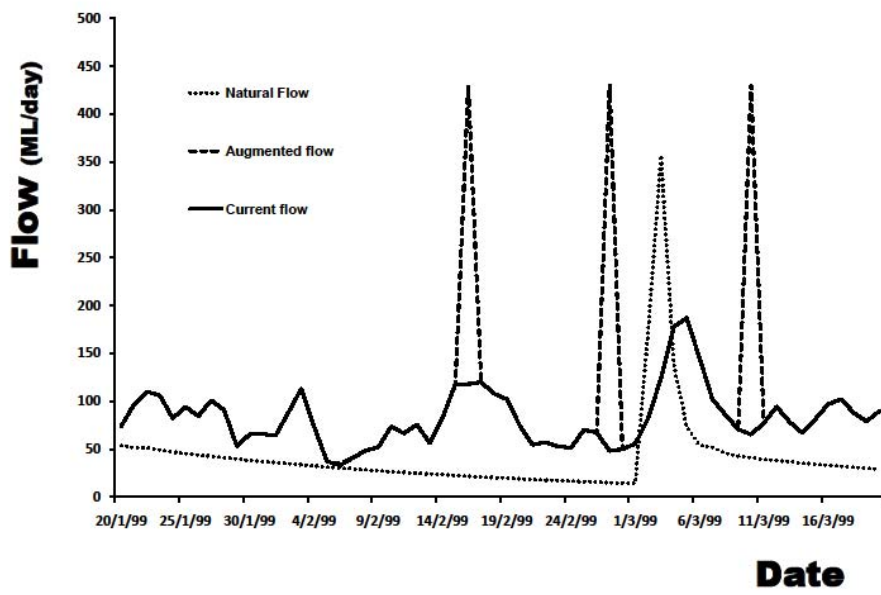


Figure 11. Example hydrograph of stream flows, natural, current and augmented

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