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Water 2010 Technical Paper 4

Quantifying return flows from irrigation

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Foreword

Water issues are now considered among the most important drivers and limitations for natural resource management in Australia. This includes management of biodiversity, primary production and environmental hazards like salinity and drought, through to urban and rural water supplies. A better understanding of water availability is needed across the entire continent, and is relevant to the implementation of key government policies such as Exceptional Circumstances and the National Water Initiative (NWI).

In 2004, the Bureau of Rural Sciences (BRS) recognised that Australia had no comprehensive and consistent source of information on the dynamic water balance, that is, on the spatial and temporal relationships between rainfall, evaporation, transpiration, drainage to ground and surface water, and runoff to rivers and storages. Addressing this fundamental knowledge gap became the primary focus of a project known as Water 2010.

Water 2010 is a BRS driven research collaboration designed to address the information needs of the National Water Commission (NWC), and to support the Department of Agriculture, Fisheries and Forestry (DAFF) in developing sound water policy. The project is designed to capture information on the water balance at a variety of scales, investigate the consequences for water resources of likely or desired changes in land use, population growth, climate and water policies and practices, and examine the potential impacts of these scenarios on communities, industries and regions to help identify the challenges for industries and regions and suggest opportunities and trade-offs.

In developing a national water balance model for Water 2010, BRS identified that the relationships between rainfall and runoff, deep drainage and surface and groundwater recharge on land under irrigation required greater investigation and analysis. The accurate quantification of return flows from irrigation depends on an improved understanding of these elements of the water balance.

The volume of return flow from irrigation is influenced by complex biophysical relationships and other externalities such as landuse change and resource management policies. A complete and consolidated Australian water balance will depend upon information being available for all water flows, to which return flow may contribute significantly.

This paper is the fourth in a series of Technical Papers describing the progress and outputs of the Water 2010 project. The paper describes a targeted review of research and data regarding the qualification and quantification of return flows from irrigation in Australia and provides recommendations for approaches to return flow estimation that could be adopted by Water 2010. BRS gratefully acknowledges the support of DAFF and the NWC in this Australian Government work.

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Executive summary

Quantifying return flows

Currently there is no accurate method for accounting for the return flows from all irrigation water use in Australia. These flows have been found to have significant consequences for the water quality and flow rate of river basins, particularly within irrigation regions where water use is concentrated and rivers are likely to be under stress.

Irrigation return flow components

The volume of water returning after irrigation for reuse within the catchment system is dependant on a variety of biophysical and human-induced components. In order to model irrigation return flows, the relationships between soil-type, irrigation method, climate, underlying geomorphology and crop-type must be understood.

Framework for estimation

This report aims to provide a framework and knowledge base for the development of an irrigation return flow modelling technique for use in the BRS Water 2010 River Basin Summaries. Two possible methods for estimating irrigation return flow are discussed based on return flow modelling literature and available return flow data in Australia.

Method I:
The sum of irrigation induced runoff and irrigation induced deep drainage.

Method I builds on previous modelling implemented under the Water 2010 water balance framework. It combines a rule-based algorithm for deep drainage from the calculated irrigation deficit with an equation for calculating the expected runoff from irrigation water. Irrigation volumes are based on a plant available water coefficient, describing the influence of broad land use categories on evapotranspiration. This method is immediately applicable to the River Basin Summaries and should be considered a first step towards a more accurate representation of irrigation return flows.

Method II:
Specification of irrigation landuse data and water-use efficiencies.

Method II requires a further collection of irrigation specific variables in order to produce a more representative estimation of return flows from different regions of Australia. It would require irrigation landuse type to be further classified in order to predict the expected irrigation method and correlated water use efficiency on a 1km grid scale. This would provide water modellers with a more accurate idea of actual irrigation water use and the likelihood of runoff and deep drainage due to excess water application.

Future work

A re-assessment of many of the modelling assumptions in the Water 2010 water balance approach is required to produce a model specifically for return flow accounting. A stand alone model representing the specific crops and their development phase, irrigation method and efficiency, climatic influences, soil texture profile change and groundwater recharge and discharge zones is necessary to accurately quantify the expected volume of irrigation return flows on both spatial and temporal scales. Ideally, vast improvements will be made to the monitoring of irrigation diversions and sharing of data in line with the prescribed outcomes of the National Water Initiative (NWI) in order to provide calibration data and actual irrigation application rates.

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1. Background

1.1 The Water 2010 project and return flow

At the present time there is significant uncertainty surrounding the quality and consistency of information on the availability of water, particularly the relationship between different components of the water cycle (Adamson *et al.* 2005). The primary focus of the Water 2010 project is to improve nation-wide awareness of the dynamic water balance, providing a comprehensive source of information to describe the spatial and temporal relationships between rainfall, evaporation, transpiration, drainage to ground and surface water, and runoff to rivers and storages. It is also intended that the project help develop a more integrated approach to the management of surface and groundwater resources.

In developing a national water balance model, BRS identified that the relationship between runoff, ground water recharge and deep drainage represented within the current Water 2010 framework required greater investigation and analysis (Barratt 2005). The accurate quantification of return flows depends on an improved understanding of these elements of the water balance. The volume of return flow is influenced by complex biophysical relationships and other externalities such as landuse change and resource management policies.

Water 2010 aims to produce a national water balance covering all significant water use, including groundwater systems, and considering landuse change, climate change and other externalities as elements of the water balance, as required under the National Water Initiative (NWI). A complete and consolidated Australian water balance will depend upon information being available for all water flows, to which return flow may contribute significantly.

1.2 Definition of return flow

In the broadest sense, return flow refers to any volume of water made available for reallocation to downstream users within the greater catchment system (Abel *et al.* 2004). This potentially reusable flow is often an important source of water (Clemmens *et al.* 2003), especially within river basins heavily involved in irrigation. Irrigation constitutes the emphasis of most return flow literature, describing the water returning to the superficial aquifer via surface runoff from flood irrigation, irrigation drainage and ground water discharge from irrigation areas (Heaney and Beare 2001, Water and Rivers Commission 2001, the Water Science and Technology Board 2004).

Return flows also refer to the flows generated from other land use activities, which are quantified within the Water 2010 water resource summaries under the categories of residential, commercial/industrial and rural (stock/domestic). Generally, the quantification of these flows is closely monitored by water authorities and data should be sourced directly from these agencies. A methodology for accounting for these flows is outlined in more detail in Section 4.4.

1.3 Irrigation return flow and surrounding issues

While all flows are worthy of consideration, this report and the framework for return flow accounting will focus specifically on irrigation return flows. Water used for irrigation is more likely to produce surface runoff, deep drainage and consequent return flows, due to the over saturation of the soil and the concentrated physical proximity of water diversion facilities between users (Walker and Veitch 2001). The physical volumes of irrigation water and their associated flows must be considered significant, as irrigation uses 75 percent of the water extracted from Australia's rivers and groundwater systems (Hart *et al.* 2003) and the variable flows from these extractions have far reaching consequences on water quality, salinity levels and river flow regimes. According to the CSIRO (2005), runoff from furrow irrigation can be over 30 percent.

The actual volume of water returning to the river system after irrigation is dependant on connectivity to groundwater, crop type and development phase, rainfall, irrigation method, on farm reuse storage, evaporation from on farm storage and transportation, distance to river system, surrounding vegetation type, catchment condition, seasonal variation and slope. Soil type, geology and climatic region also influence evaporation, runoff, ground water recharge and return flow. Consideration of all these components will provide the core building blocks of the irrigation return flow framework.

Successful national water accounting will depend on an integrated effort from key stakeholders on all scales including farmers, other downstream users, irrigation authorities, government bodies, policy makers, geologists, hydrologists, soil scientists, hydrologists, meteorologists, hydraulic engineers and science communicators (See Appendix A).

A more accurate quantification of irrigation return flows will contribute to the goals of the NWI, as return flows are linked to many of Australia's leading water resource management issues. Initiatives for increased water trading and improvements in irrigation efficiency have had implications for the quantity and location of return flows, in turn impacting on the water quality and salinity of a catchment (Heaney and Beare 2001). As the regard for water as a precious commodity expands due to predicted decreases in water availability, changes in the volume and quality of return flows will also become a more topical issue to water managers. There is a need to accurately quantify all usable water bodies and flows, while being aware of the related impacts to water quality. The specific relationships between irrigation return flows and other water management issues are outlined within this section.

1.3.1 Water quality

The improvement of Australia's water quality is consistently a policy issue. Irrigation return flows have been deemed responsible for the degradation of water quality due to agricultural inputs of sediments, nitrogen, phosphorus, salts, pesticides and trace elements found in the water draining from irrigation districts via runoff and deep drainage, entering streams and rivers and adversely impact their quality and biological functioning (Clemmens *et al.* 2003). Proposed changes to agricultural land management practices such as minimum tillage, reduced fallows, perennial pastures and key line ploughing aim to reduce erosion and nutrient loss while retaining more run-off on farms (Keenan *et al.* 2004). Improving water quality by diverting and restricting return flows from irrigated areas has been undertaken as a policy action in the past, however, it only treats the symptom of poor water quality, without fully understanding the impact of reduced river flows (Christen *et al.* 2004).

1.3.2 Salinity

Restricting irrigation drainage flows has been a goal of Australian water policy due to the direct impact of irrigation flows on the salinity of water available for downstream users. Incentives and research funding has focused on salinity management, which has been recognised as a high impact threat to agriculture and drinking water quality. The 1988 salinity strategy in the Murray River system aimed to achieve improved water quality through irrigation drainage restrictions, in turn heavily impacting on water flows within the irrigation district. Since this time, irrigation water use has increased, while the river flows have been reduced (Christen *et al.* 2004).

The impacts of irrigation drainage on salinity are variable across water catchments as there is a complex relationship between return flows and ground water recharge, generally related to recharge rate and soil types (Heaney and Beare 2001). This complex relationship makes it difficult to make broad estimates regarding the amount of return flow responsible for increasing salt loads. In downstream areas of the Murray Darling Basin, the House of Assembly Public Works Committee (1999) estimated that over ten per cent of the irrigation application is seeping into the River Murray, causing a discharge of about 50 tonnes of salt per day.

1.3.3 Water trading

Water trading between irrigation regions can result in similar outcomes to those from improving water efficiency, as it affects the pattern of surface runoff, drainage and ground water recharge, resulting in altered return flows (Heaney and Beare 2001). Water trading also complicates the variables impacting on salinity levels within a certain area, transporting volumes of water to areas with more shallow soils or different irrigation efficiencies. The location of water use after trade determines whether the increase or decrease in return flows generated improves or reduces water quality, instilling positive or negative effects on users not directly related to the trade (Heaney *et al.* 2005). In the Murray it was found that trade downstream generally reduces return flows. In Western Australia, water entitlements aim to ensure that return flows cannot be used or traded for other purposes that did not create return flow, emphasising the importance of accurate measurements of use (Water and Rivers Commission 2001).

To combat the issue of different return flow volumes, water allocations to irrigators should be based on a net allocation, where the returning flows to the system are acknowledged and subtracted from the initial allocation (Close and Prasad 2002). Currently, most irrigation licences are defined as an entitlement to divert or pump a volume of water without regard to the quantity that returns back to the river system either via a surface drain or via groundwater (Young and McColl 2003). This has made the impacts of return flows difficult to quantify. However, managing the impacts of return flows could be relatively straight forward using a net allocation, with an understanding of return flow quantification (Abel *et al.* 2004).

1.3.4 Climate change

The impact of a warming and more extreme climate brings issues associated with water availability to a heightened level of concern. By 2030, it is expected that the Australian region will experience a warming of 0.4–2.0°C, with a 10–50% increase in days over 35°C and up to 15% less rainfall year-round in the south-east and in spring in Queensland (Pearman *et al.* 2003). When projected annual changes in rainfall are combined with changes in potential evaporation, a clear pattern of decreasing water availability emerges. Given demographic and land-use changes are likely to result in increased water demand, a reduction in water supply due to climate change represents a significant new dimension to water management and accounting.

1.3.5 Improving irrigation efficiencies

Irrigation efficiency is a concept describing the effectiveness of an irrigation system to deliver water for crop evapotranspiration, minimising drainage to aquifers or streams (Abel *et al*. 2004). The Australian Bureau of Statistics (ABS 2005) has reported a trend over the last decade to improve irrigation technologies following government initiatives. However, Australia still has relatively low rates of irrigation efficiency, therefore return flows form a substantial part of water available to downstream users (Heaney and Beare 2001).

Irrigators use a variety of methods to irrigate their crops and pastures, including surface (such as flood, furrow, basin or border check), drip or trickle and sprinkler (microspray, portable irrigators, hose irrigators, large mobile machines and solid set). Traditional irrigation techniques such as flood or furrow generate irrigation runoff via surface water, drainage schemes and accession to groundwater tables that eventually reach the river system (Heaney *et al*. 2005). Higher rates of irrigation efficiency correspond to less irrigation return flows, as water is used most effectively for crop evapotranspiration. The direct relationship between irrigation efficiency and return flow has been demonstrated by the decrease in returns from irrigation districts following the promotion of water use efficiencies after the implementation of the cap in the Murray system (Close and Prasad 2002).

2. Data on irrigation return flows

According to the Australian Water Resources Assessment (NLWRA 2000), of the 78 percent of Australia's water management areas possessing information on water availability and allocation, only eight percent source their resource quantity assessments on reliable recorded and surveyed data. The remainder admit data is based on approximate analysis without measured data. Gaps in data related to water use were identified by all states and territories, as was the large extent of un-metered and/or unregulated systems. Limitations in measurement are also related to the sluggish nature of low flows in Australia, as slow moving waterways are more difficult, expensive and labour intensive to perform velocity analyses (Water Science and Technology Board 2004). However, in order for the desired outcomes of the NWI to be met, the mismatch between data availability and quality and the requirements of decision makers must be rectified. There is a strong need for national standards for water accounting, as reporting and metering have been defined as key elements of the 2004 NWI intergovernmental agreement (the Senate 2004).

The Australian Irrigation Water Provider Industry Benchmarking Report provides the most representative information and data available for regulated irrigation systems (ANCID 2005). After examination of the information in the report, it is apparent that compared to the grid representing irrigation activities used by BRS, the report may be unrepresentative of actual irrigation taking place across the continent (Welsh *et al.* 2007). Opportunistic, unregulated irrigation is probably making up a significant proportion of irrigation water applied, yet little information is available regarding crop types and methods used in these regions.

In order to validate the results of modelled irrigation return flow estimates, metered data from appropriate water authorities is needed for comparison. This information would also be helpful in determining the river basins that are most impacted by return flows and where further work should be concentrated. However, there is very little recognition by water accounting bodies of the quantities of return flows contributing to the water system. An ABS publication stated that, "since the agricultural industry does not use water in-stream, or supply water to other users, water use is equal to water consumption" (Trewin 2004). This method of water accounting discounts any volume of return flows from irrigators to other downstream users. This is contradictory to the research conducted by Heaney and Beare (2001) for the irrigation districts in the Murray Darling Basin and work by Clemmens *et al.* (2003), who maintained return flows and irrigation drainage upstream represent a substantial proportion of water diversions, which is subsequently used by downstream irrigators.

Victoria attempted its first state wide water accounting project using 2003/04 water data and "required a number of assumptions to be made and illustrated areas of both high and low data accuracy and availability" (DSE 2005). However, it represented a positive step for return flow accounting, as it is the only government report documenting monitored irrigation return flows, including them with catchment runoff and treatment-plant discharge in constituting the surface water resource. The inaugural water account project for Victorian River Basins, published in July 2005, provides information on return flows for four of their 29 river basin summaries.

Irrigation return flows as a percent of irrigation diversion for these river basins is shown below.

River Basin	Irrigation District Diversions (ML)	Irrigation Return Flow (ML)	Irrigation Return Flow (%)
Murray	1,112,800	146,600	13.1
Werribee	8,830	400	4.5
Thompson	254,660	19,170	7.5
Goulburn	1,476,280	0	0

Table 1. Victorian Water Accounts 2003/04: Return Flow Data

The Victorian return flow measurements are based solely on information sourced from the individual irrigation water providers at an irrigation system scale. The 2003/04 report did not undertake a detailed data collection of return flows, only examining those river basins where irrigation volumes were very large. Time constraints also contributed to the under-reporting of return flows. In the 2004/05 water accounts report, a stronger emphasis has been placed on return flow data collection (although the dataset is still largely incomplete). Data is sourced from the monitoring of channel outflows (fairly accurate) and irrigation drains (much less accurate, especially where there is a cross connection from channel to drain).

The non-accounting of return flows in the majority of catchments has greater implications for their reporting methods, as it undermines the validity of inflow estimations. In the Victorian Water Accounts report, where diversions are small relative to the total volume in stream (around <10%), inflows have been back calculated as the sum of basin outflows plus diversions (DSE 2005). Therefore, inflows are being over-estimated, as water returning to the river system after irrigation is being accounted for twice. This was recognised as a limitation by the consulting company in charge of the data colation (Brad Neal pers. comm. 2005).

3. Modelling irrigation return flows

3.1 Irrigation return flow modelling research in Australia

Due to wide recognition of the underdeveloped state of metered or measured water accounting in Australia, many scientists have developed a variety of hydrological soil water balance models to estimate flows through a catchment system. While few have specifically focused on return flows, many of the principles and major components of Australian soil water balance models are applicable to return flow models and should be assessed. For a complete overview of the soil water balance models available in Australia, refer to Water 2010 Technical Paper 1 (Ranatunga *et al.* 2007).

For the purpose of this report, three possible approaches to modelling drainage from irrigation, including water balance modelling, are discussed. It should be recognised that modelling irrigation return flows is currently the focus of a considerable amount of research in Australia and most models have not yet been fully validated against known return flow values.

3.1.1 Tiddalik model

Researchers at the CSIRO have been working towards an irrigation area return flow model, *Tiddalik*, which was presented at the MODSIM conference in July 2005 and is detailed by Hornbuckle *et al.* (2005). *Tiddalik* is used for the prediction of drainage return flows, based on a thoroughly researched understanding of the major drivers of return flows and the influence of variable land management techniques. Its developers aim to produce a transparent framework that is targeted towards irrigation companies for management of specific regions. The outcomes and results of the model could be utilised within all irrigation regions, as it can predict drainage return volumes and salt loads to streams and major river systems. It is also useful for assessing the management and operational options for meeting license conditions applied to return flows.

Tiddalik entails a detailed examination of land use down to the paddock level, including the planting dates of specific crop types in certain paddocks, before creating a node-link approach following water flows. The model's core building blocks include:

- evapotranspiration,
- soil water balance,
- upflux,
- watertable,
- subsurface drainage,
- irrigation system and
- on-farm storage.

3.1.2 SALSA model

The Australian Bureau of Agricultural and Resource Economics (ABARE) have created a model less directly related to irrigation return flows, but with hydrological components applicable to return flow calculations. They developed scenarios with an objective to analyse the impacts of return flows on salinity and their economic implications, sourcing raw data directly from private farms and irrigators over a few years (Anna Heaney pers. comm. 2006). The Salinity and Landuse Simulation Analysis (SALSA) modelling framework incorporates the relationships between land and water use, vegetation cover, surface and ground water hydrology and agricultural returns (Bell and Heaney 2001). It is useful as an application of return flow modelling for the calculation of both the direct and diffuse economic impacts of changing water management and would be of interest to policy makers and major stakeholders.

The specifics of the hydrological component of the *SALSA* model are further described in work by Heaney and Beare (2001). It incorporates the relationship between rainfall, evapotranspiration and surface water runoff, and the effect of different land uses on ground water recharge and discharge rates. Evapotranspiration is recognised as a function of precipitation, ground cover and the irrigation rates and efficiencies. The mean irrigation efficiency rates for the Murray Darling region were sourced from the Department of Environment, Heritage and Aboriginal Affairs in 2000, with efficiency ranging between 75 and 80 percent for horticulture and as low as 50 percent for flood irrigation. Soils are also considered, as the ratio between water applied and runoff was found to be dependant on the recharge fraction of the area described by different soil types. Heavy upland soils range from 50-60 percent, while sandy soils give 100 percent recharge fractions (Bell and Heaney 2001).

3.1.3 Water balance models

Researchers from CSIRO Land and Water reviewed studies from irrigated regions of Australia for information on deep drainage and crop water use. Deep drainage and crop water use (evapotranspiration) were considered the most difficult components of the water balance to determine accurately, as this movement of water beyond the rootzone will vary with a range of factors including species and variety, stage of growth, crop vigour, soil conditions and watertable conditions (Humphreys *et al.* 2003).

The water balance technique for determining deep drainage is based on the equation:

$$DD = I + R - SD - ET - \Delta SWC$$

Where:

DD = Deep Drainage beyond the rootzone (specified depth) (or upflow if negative)
I = Irrigation
R = Rain
SD = Surface Drainage
ET = Evapotranspiration
ΔSWC = Change in soil water content (final minus initial) in the rootzone

Variable results were observed for deep drainage under cotton, rice and pasture, with the amount of deep drainage influenced by a range of management practices. Generally lighter soils lead to higher levels of deep drainage, however extreme variability can exist within the one soil type, field and landuse.

The review concluded that there is lack of good quantitative data for validating components of the water balance across the range of crops, climatic regions, site and seasonal conditions and management in Australia. Water balance models need to be used to estimate crop water use requirement and deep drainage for broad scale estimates; however such models need to be evaluated against quantitative data across a range of environments (Humphreys *et al*. 2003).

3.2 Return flow models developed outside Australia

Return flow models developed outside Australia are generally not directly applicable to return flow hydrology in Australian irrigation areas due to the variation of catchment processes between continents. However, some recent decisions and directions taken in the western United States are worthy of mention.

Until recently, unmeasured irrigation return flows in California, such as ungauged surface flows and subsurface flows, were determined by a percentage of diversion, typically a negotiated value. The application of a generic percentage was found to be highly inappropriate. The more scientifically based Lower Colorado River Accounting System (LCRAS) is now used, determining return flows based on remote sensing, weather station based evaporation estimates, and river flows (Bureau of Reclamation 1999).

4. Possible approaches for estimating irrigation return flows in Water 2010

The methods described below are appropriate for different time scales. Method 1 can be implemented immediately, while the data collection necessary for Method 2 is yet to be completed. The most accurate estimates for quantifying return flows will be based on the information necessary for future methods, as the most favourable outcomes will only be achievable through a concerted effort not only to improve return flow modelling, but to increase the level of flow monitoring and data collection across Australia.

4.1 Method 1 – Deep drainage and runoff from modelled irrigation demand

In order to estimate return flow, the contribution from both runoff and deep drainage needs to be considered. Within the framework of the current Water 2010 steady-state water balance model, runoff and deep drainage amounts generated from modelled irrigation water demand in irrigated areas could be added together to generate return flow values for these areas. These values could be described as a potential return flow. They represent the volume of water available to flow to the nearest water body, either through runoff or deep drainage.

4.2 Method 2 – Inclusion of irrigation efficiency in land use mapping

Irrigation application rates and efficiencies should be considered essential to achieving accurate runoff and deep drainage estimates. In Australia, potential evaporation significantly exceeds rainfall in all but the wettest areas, currently confining significant runoff to wet areas occurring in the southeast (including Tasmania), over the eastern ranges and in the north. Drainage has a broadly similar pattern, though with added variability through the influence of soil texture (Raupach *et al.* 2001). While climate should be a dominant variable, in irrigated areas the method of water application is also significant to water flows.

The overview and summary table created in Appendix B allocates an irrigation efficiency variable for river basins containing irrigation water providers. The information on expected irrigation method was based on data of varying quality, sourced from state and territory agencies, farmers and agronomists interpreting readily available landuse imagery (Robert Smart pers. comm. 2006). The summary table provides an approximate irrigation efficiency value (Fairweather *et al.* 2003) for each of the river basins containing regulated irrigation supply systems. These values could be used as a starting point for water modellers for the inclusion of an irrigation efficiency variable to the deep drainage and runoff equations from Method 1 (see Figure 1).

BRS water modellers could make adjustments to the deep drainage model, making it more specific to a variety of irrigation methods by adding more than just a cropping and non-cropping multiplier and a cultivation fraction of one for cropping, cotton or sugarcane. Alternatively, an additional rule could be included based on river basin polygons, where each polygon has a multiplier for the efficiency of the major irrigation method in that river basin.

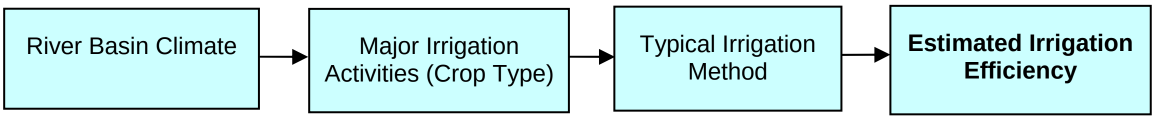

Figure 1. Model inputs needed to account for irrigation efficiencies

Ideally, the land use map will be improved to include an irrigation-type grid over every irrigated cell, making the return flow model more representative of the likely irrigation efficiency and related return flow for each area. Collection of irrigation data and information regarding the ratio between surface water runoff and ground water discharge would be extremely helpful in terms of allowing inclusion of irrigation efficiency in the Water 2010 model.

4.3 Future methods

Irrigation return flows should be represented through spatial modelling, responding to seasonal changes in water use variables and updated irrigation efficiencies for each irrigated cell. A more specific landuse classification grid should aim to distinguish between landuse types with different irrigation efficiencies.

Recommended landuse classes include:

- irrigated horticulture
- irrigated rice
- irrigated cotton
- irrigated pasture
- irrigated summer crop and
- irrigated winter crop.

This landuse grid should be interpreted alongside a soil grid, climate grid, irrigation efficiency grid, a groundwater grid and a monthly Leaf Area Index (Allen *et al.* 1998) grid to estimate plant growth stage and related evapotranspiration. An inverse distance weighting for each irrigation cell in relation to the closest river system would add to the accuracy of estimations for the likelihood of runoff and deep drainage water becoming return flows. The BRS work on connected water systems, studying the connectivity of aquifers to rivers, could also be incorporated (Eloise Nation pers. comm. 2006).

Improvements to the model can only be achieved through the delivery of transparent water monitoring and accounts by irrigators in line with the expected outcomes of the NWI. Scientific research should focus on building a greater knowledge of the groundwater/return flow relationship and applying this knowledge to each of the river basins, moving towards an understanding of the physical nature of each river basin, the location of local underground aquifers, the whereabouts of water recharge and areas of inflows returning to the river system.

4.4 Other return flows

An in-depth analysis of the other types of return flows included in the Water 2010 river basin summaries (residential, commercial, rural) was not achievable in the time available for this project. However, return flows generated from all water consumption is worthy of thorough analysis, especially where there are correlations with water availability in water-stressed urban environments or water quality issues from industrial discharges.

4.4.1 Definition and controlling factors

Water 2010 considers three broad use categories including residential, commercial/industrial and rural (stock/domestic). However, return flows are rarely described in these terms within other return flow literature. The definitions for Water 2010 can be considered as follows.

Residential and rural (stock/domestic) return flows include stormwater and sewerage that is returned to the river at a point where there is a possibility for further reuse of this water. It is different to reuse water that is recycled for use within the same township and does not include water discharged into the ocean.

Commercial/industrial developments have the potential to generate large volumes of waste water through water-use intensive refining and processing activities. Different levels of pollutants lead to different regulations regarding the discharge of this water. If the water is treated to an acceptable level, the water discharged to a river system could be classed as return flow.

These types of return flows are far less dependent on the biophysical catchment system and far more related to the direct human management of the water. The water discharged from residential, commercial, industrial and rural domestic water systems depends on the choices made regarding how water is used, to what level it is treated and to where it is directed at the end of its designated use.

4.4.2 Availability of data

Within urban systems, all water is monitored by some form of water management body. According to the Environmental Protection Agency (EPA), approximately 70 percent of water piped into urban areas in New South Wales is returned via sewerage systems to sewage treatment plants. Following treatment, almost all this water is discharged to creeks, rivers, estuaries or the ocean (EPA 2003).

As a residential example, the Australian Capital Territory provides very comprehensive statistical information regarding the volume of water returning to the Murrumbidgee system. After treatment, Australian Capital Territory Electricity and Water (ACTEW) returns 35 GL/yr to be reused downstream, which is around 55 percent of water extracted for human use (ACTEW 2004). However, the Australian

Capital Territory should be recognised as a city unconnected to the coast. Other major coastal cities discharge almost all potential domestic return flow to the ocean, resulting in zero return flow.

Commercial/industrial institutions are obliged to take a serious approach to water monitoring due to the risk of industrial waste problems. High strength or high volume wastewater contributors are required to undertake regular wastewater sampling and monitoring as a condition of their approval to discharge to a sewer, maintaining a dedicated flow meter on discharge lines, with regular meter readings (Western Australia Water Corporation 2005). Most water regulators across Australia would hold this water flow data.

4.4.3 Possible approach to accounting for other return flows

All domestic, industrial and residential coastal establishments should be assumed to generate zero return flows. In these areas, water management and accounting should focus on the possibilities for water reuse and water recycling. The percentage volume of water reused within townships or industrial plants is likely to grow due to the pressure of decreasing water availability. Water 2010 may look to include these water recycling volumes in future river basin water accounting summaries.

For all inland water users, an estimation of the returning volumes should be based on a collation of the best available measured water data for each water use type. Water use is usually specifically channelled and can be quantified by measuring stream outflow from the particular system. BRS should establish contacts with appropriate water management bodies for those river basins with significant water diversions, in order to establish an average rate of return flow for each of the specified water use categories.

5. Conclusion and recommendations

The application of a complex irrigation return flow model is not suitable for the Water 2010 annual water resource summaries, as many of the ideal data inputs are not currently available. Method 1 combines an irrigation runoff value with the irrigated deep drainage value from the Water 2010 model and does not require additional data inputs, making it immediately workable within the current Water 2010 framework.

5.1 Future research and directions

Ideally, the irrigation return flow model should predict flow changes in response to:

- improved irrigation efficiencies
- flood events
- drought events
- losing or gaining river systems
- changing land use
- water reuse initiatives

In order to achieve this level of understanding, water accounting in Australia is in need of greater research and more accurate data. Land use coverage data must be improved to better understand land management practices. Irrigation diversions need to be better monitored and information should be readily available. Groundwater – surface water interactions need further research. These improvements will require a concerted communication effort with all water authorities and irrigation districts to obtain raw data as it becomes available. Strengthening the collaboration between science bodies could also facilitate information exchange.

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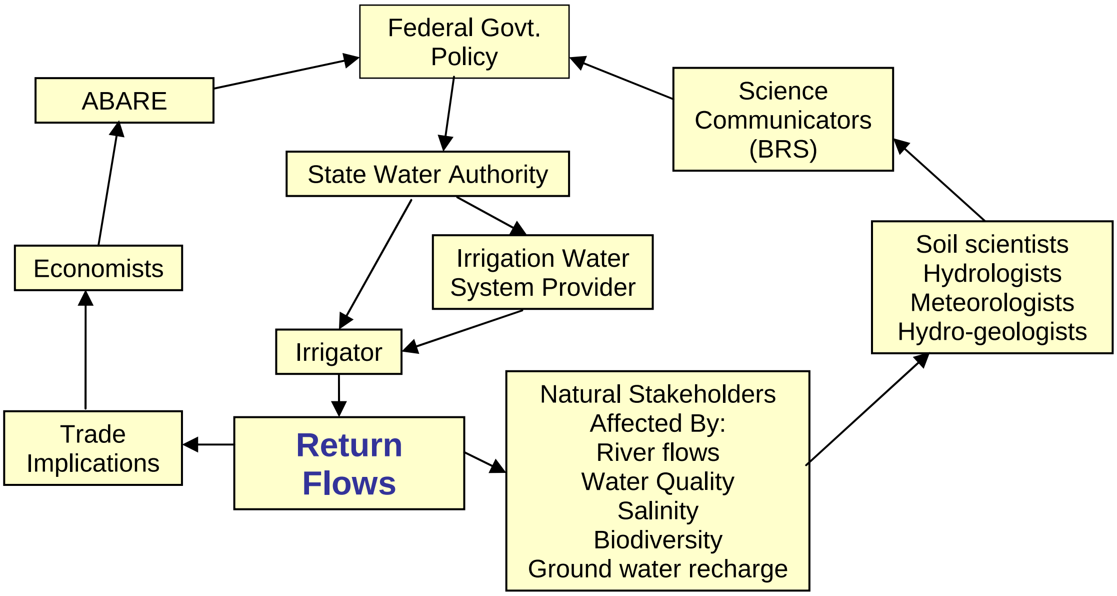
APPENDIX A

A conceptual framework of water stakeholders and their relationships.



APPENDIX B

River Basins containing irrigation water provider systems. Major crop types, irrigation methods and efficiencies are shown.

BASIN NAME	Irrigation Water Provider System *	State	Main Culture Irrigated ^	Expected Irrigation Type "	Estimated Water use Efficiency #	Second Culture ^	Expected Irrigation Type "	Estimated Water use Efficiency #
BARRON RIVER	SW Mareeba-Dimbulah AUQSMD	QLD	Sugar Cane	Spray	65-90	Mangoes	Spray	65-90
HAUGHTON RIVER	North Burdekin AUQBNT	QLD	Sugar Cane	Spray	65-90	Vegetables	Spray	65-90
HAUGHTON RIVER	SW Burdekin-Haughton AUQSBR	QLD	Sugar Cane	Spray	65-90	Small Crops	Spray	65-90
BURDEKIN RIVER	South Burdekin AUQBST	QLD	Sugar Cane	Spray	65-90	Vegetables	Spray	65-90
BURDEKIN RIVER	SW Burdekin-Haughton AUQSBR	QLD	Sugar Cane	Spray	65-90	Vegetables	Spray	65-90
BURDEKIN RIVER	SW Bowen Broken AUQSBW	QLD	Pasture	Spray	65-90	Lucerne	Spray	65-90
DON RIVER	SW Burdekin-Haughton AUQSBR	QLD	Sugar Cane	Spray	65-90	Small Crops	Spray	65-90
PROSERPINE RIVER	SW Proserpine AUQSPR	QLD	Sugar Cane	Spray	65-90	Small Crops	Spray	65-90
PIONEER RIVER	Pioneer Valley AUQPVT	QLD	Sugar Cane	Spray	65-90	Sugar Cane	Spray	65-90
PIONEER RIVER	SW Pioneer River AUQSPI	QLD	Sugar Cane	Spray	65-90	Small Crops	Spray	65-90
PLANE CREEK	Pioneer Valley AUQPVT	QLD	Sugar Cane	Spray	65-90	Sugar Cane	Spray	65-90
PLANE CREEK	SW Eton Water AUQSEW	QLD	Sugar Cane	Spray	65-90	Sugar Cane	Spray	65-90
FITZROY RIVER (QLD)	SW Nogoa Mackenzie AUQSEM	QLD	Cotton	Flood/Furrow 50/50	55-70	Citrus	Spray	65-90
FITZROY RIVER (QLD)	SW Lower Fitzroy AUQSLF	QLD	ND	ND	ND	ND	ND	ND
FITZROY RIVER (QLD)	SW Dawson Valley AUQSDV	QLD	Cotton	Flood/Furrow 50/50	55-70	Lucerne	Spray	65-90
FITZROY RIVER (QLD)	SW Callide Valley AUQSCV	QLD	ND	ND	ND	ND	ND	ND
BOYNE RIVER	SW Boyne River AUQSBO	QLD	Citrus	Spray	65-90	Dairy	Spray	65-90
KOLAN RIVER	SW Bundaberg AUQSBU	QLD	Sugar Cane	Spray	65-90	Macadamias	Spray	65-90
BURNETT RIVER	SW Three Moon Creek AUQSTM	QLD	Lucerne	Spray	65-90	Forage Crops	Spray/Furrow 50/50	65-80

BURNETT RIVER	SW Upper Burnett AUQSUB	QLD	Citrus	Spray	65-90	Dairy	Spray	65-90
BURNETT RIVER	SW Bundaberg AUQSBU	QLD	Sugar Cane	Spray	65-90	Macadamias	Spray	65-90
BURNETT RIVER	SW Barker-Barambah AUQSBB	QLD	Broad Acre Crops	Spray	65-90	Cotton	Spray	65-90
BURRUM RIVER	SW Bundaberg AUQSBU	QLD	Sugar Cane	Spray	65-90	Macadamias	Spray	65-90
MARY RIVER (QLD)	SW Mary River AUQSLM	QLD	Sugar Cane	Spray	65-90	Tree crops	ND	ND
BRISBANE RIVER	SW Warrill Valley AUQSWV	QLD	Vegetables	Spray	65-90	Dairy	Spray	65-90
BRISBANE RIVER	SW Lower Lockyer AUQSLL	QLD	Vegetables	Spray	65-90	Dairy	Spray	65-90
BRISBANE RIVER	SW Central Lockyer AUQSLV	QLD	Vegetables	Spray	65-90	Lucerne	Spray	65-90
LOGAN-ALBERT RIVERS	SW Warrill Valley AUQSWV	QLD	Vegetables	Spray	65-90	Dairy	Spray	65-90
LOGAN-ALBERT RIVERS	SW Logan River AUQSLR	QLD	Dairy	Spray	65-90	Lucerne	Spray	65-90
THOMSON RIVER	SRW Macalister AUVSOM	VIC	Permanent Pasture	Flood	55-65	Annual Pasture	Flood	50
LATROBE RIVER	SRW Macalister AUVSOM	VIC	Permanent Pasture	Flood	55-65	Annual Pasture	Flood	50
WERRIBEE RIVER	SRW Bacchus Marsh AUVSOB	VIC	Vegetables	Spray	65-90	Orchards	Flood/Spray	65-80
WERRIBEE RIVER	SRW Werribee AUVSOW	VIC	Vegetables	Spray	65-90	Various	Flood/Spray	65-80
MILLICENT COAST	Southeast Region (SA) AUSSET	SA	Pasture	Spray	65-90	Grape Vines	Trickle	75-90
COAL RIVER	Southeast (TAS) AUTSET	TAS	Peas	Spray	65-90	Grape Vines	Trickle	75-90
TAMAR RIVER	Cressy-Longford AUTCLT	TAS	Annual Pasture	Spray	65-90	Peas	Spray	65-90
PIPER-RINGAROOMA RIVERS	Winnaleah AUTWIT	TAS	Annual Pasture	Spray	65-90	Potatoes	Spray	65-90
BROKEN RIVER	G-MW River Diverters AUVGMD	VIC	Annual Pasture	Flood	55-65	Permanent Pasture	Flood	55-65
BROKEN RIVER	G-MW Murray Valley AUVGMM	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	55-65
BROKEN RIVER	G-MW Shepparton AUVGMS	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	55-65
GOULBURN RIVER	G-MW Shepparton AUVGMS	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	55-65
GOULBURN RIVER	G-MW Central Goulburn AUVGMG	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	55-65
GOULBURN RIVER	G-MW Rochester AUVGMC	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	55-65
CAMPASPE RIVER	G-MW Rochester AUVGMC	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	55-65

LODDON RIVER	G-MW Rochester AUVGMC	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	55-65
LODDON RIVER	G-MW Swan Hill Pumped AUVGMH	VIC	Stone Fruit	Trickle/Spray 50/50	65-90	Grape Vines	Trickle	75-90
LODDON RIVER	G-MW Pyramid-Boort AUVGMP	VIC	Annual Pasture	Flood	55-65	Perennial Pasture	Flood	50
LODDON RIVER	G-MW Torrumbarry AUVGMK	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	50
AVOCA RIVER	G-MW Torrumbarry AUVGMK	VIC	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	50
MURRAY-RIVERINA	Murray Irrigation AUNMIT	NSW	Rice	Flood	50	Annual Pasture	Flood	50
MURRAY-RIVERINA	West Corurgan AUNWCT	NSW	Summer Cereal	other	65-80	Winter Cereal	Other	65-90
MURRUMBIDGEE RIVER	Murrumbidgee AUNMUT	NSW	Rice	Flood	50	Horticulture	Spray	65-90
MURRUMBIDGEE RIVER	West Corurgan AUNWCT	NSW	Summer Cereal	other	65-80	Winter Cereal	Other	65-90
MURRUMBIDGEE RIVER	Coleambally AUNCIT	NSW	Wheat	other	65-80	Rice	Flood	50
LACHLAN RIVER	Murray Irrigation AUNMIT	NSW	Rice	Flood	50	Annual Pasture	Spray	65-90
LACHLAN RIVER	Murrumbidgee AUNMUT	NSW	Rice	Flood	50	Horticulture	Spray	65-90
LACHLAN RIVER	Jemalong AUNJIT	NSW	Lucerne	Spray	65-90	Maize	Spray	65-90
BENANEE	Euston AUNEUT	NSW	Grape Vines	Trickle	75-90	Pasture	Spray	65-90
BENANEE	Western Murray AUNWMT	NSW	Grape Vines	Trickle	75-90	Citrus	Spray	65-90
MALLEE	Central Irrigation AUSCIT	SA	Grape Vines	Trickle	75-90	Citrus	Spray	65-90
MALLEE	Golden Heights AUSGHT	SA	Citrus	Spray/other 50/50	65-90	Grape Vines	Trickle	75-90
MALLEE	Lower Murray AUSLMT	SA	Perennial Pasture	Spray	65-90	Annual Pasture	Spray	65-90
MALLEE	Sunlands AUSSUT	SA	Citrus	Spray/other 50/50	65-90	Grape Vines	Trickle	75-90
MALLEE	Euston AUNEUT	NSW	Grape Vines	Trickle	75-90	Pasture	Spray	65-90
MALLEE	First Mildura AUVFMT	VIC	Grape Vines	Trickle	75-90	Citrus	Spray	65-90
MALLEE	Sunraysia - System AUVSRT	VIC	Grape Vines	Trickle	75-90	Citrus	Spray	65-90
MALLEE	Sunraysia - Diverters AUVSRD	VIC	Grape Vines	Trickle	75-90	Citrus	Spray	65-90
WIMMERA-AVON RIVERS	Wimmera-Mallee AUVWMT	VIC	Perennial Pasture	Flood	55-65	Lucerne	Flood	50

BORDER RIVERS	SW Macintyre Brook AUQSMB	QLD	Mixed Cropping	Spray	65-90	Mixed Cropping	Spray	65-90
MOONIE RIVER	SW St George AUQSSG	QLD	Cotton	Flood/Furrow 50/50	55-70	Grape Vines	Spray	65-90
MACQUARIE-BOGAN RIVERS	Trangie Nevertire AUNTNT	NSW	Cotton	other	65-90	Lucerne/Pastures	Spray	65-90
CONDAMINE-CULGOA RIVERS	SW St George AUQSSG	QLD	Cotton	Flood/Furrow 50/50	55-70	Grape Vines	Spray	65-90
CONDAMINE-CULGOA RIVERS	SW Maranoa River AUQSMR	QLD	Pasture	Spray	65-90	Small crops - pumpkins	Spray	65-90
CONDAMINE-CULGOA RIVERS	SW Upper Condamine AUQSUC	QLD	Cotton	Flood/Furrow 50/50	55-70	Sorgum	Spray	65-90
CONDAMINE-CULGOA RIVERS	SW Chinchilla Weir AUQSCW	QLD	Cereal Crop	Spray	65-90	Cereal Crop	Spray/Furrow 50/50	65-80
WARREGO RIVER	SW Cunnamulla AUQSCA	QLD	Cotton	Flood/Furrow 50/50	55-70	Small crops	Spray	65-90
PAROO RIVER	SW Cunnamulla AUQSCA	QLD	Cotton	Flood/Furrow 50/50	55-70	Small crops	Spray	65-90
DARLING RIVER	Western Murray AUNWMT	NSW	Grape Vines	Trickle	75-90	Citrus	Spray	65-90
LOWER MURRAY RIVER	Lower Murray AUSLMT	SA	Perennial Pasture	Spray	65-90	Annual Pasture	Spray	65-90
LOWER MURRAY RIVER	Renmark AUSRIT	SA	Grape Vines	Trickle	75-90	Ochards	Flood	50
LOWER MURRAY RIVER	Angas Bremer AUSABT	SA	Grape Vines	Trickle	75-90	Potatoes	Spray	65-90
GAWLER RIVER	Barossa Valley Area AUSBAT	SA	Grapes Vines	Trickle	75-90	Pasture	Spray	65-90
PRESTON RIVER	Harvey Water AUWSWT	WA	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	50
COLLIE RIVER	Harvey Water AUWSWT	WA	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	50
HARVEY RIVER	Harvey Water AUWSWT	WA	Perennial Pasture	Flood	55-65	Annual Pasture	Flood	50
GASCOYNE RIVER	Gascoyne Irrigation AUWGCT	WA	Vegetables	Spray	65-90	Fruit	Spray	65-90
LYNDON-MINILYA RIVERS	Gascoyne Irrigation AUWGCT	WA	Vegetables	Spray	65-90	Fruit	Spray	65-90
ORD RIVER	Ord Irrigation AUWORT	WA	Cane	Flood	50	Melons	Flood	50
LEICHHARDT RIVER	SW Julius Dam AUQSJD	QLD	ND	ND	ND	ND	ND	ND

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