Water Banking –Land use Approach to Improve River Productivity and Environmental Performance

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Abstract

This paper presents the use of water banking concept (using aquifers as a natural underground dam) combined with different changing land use such as crop mixes to improve river water productivity and environmental performance. The goal of water banking, in general, is to efficiently allocate all available water to achieve an economic growth while achieving an environmental sustainability. As a case study, Water banking, along with two methods of managed aquifer recharge, have been modeled and tested under different crop mixes by using a dynamic modeling system approach for Murrumbidgee River Basin in Australia,. The results indicated that there is a clear trade-off between improving water use efficiency, agricultural productivity and environmental performance. Water banking is able to better manage biophysical demand, and enhance in-stream flows that are biologically and ecologically significant.

Key words: Water banking, groundwater, system management, river productivity, environmental flow.

1. INTRODUCTION

Water is a key resource to sustain human life. Therefore, sustaining growth in the human population requires even more water to be available. A reduction in water availability, conflicting water uses and other water-related environmental problems are rapidly increasing in many parts of the world. As an example, according to (DLWC 1998), in the Murrumbidgee River Basin (South-East of Murray Darling Basin-Australia), irrigation extraction and intensive cropping systems have led to major impacts on the river environment and water availability. Moreover, water demand is driven by cropping activities which result in higher river flows in summer season and altered the flow regimes, that by its turn, altered the seasonality of flows. This can have important ecological impacts as in the Nile Basin. Conjunctive water use is defined as combined use of surface and ground water systems to optimize resource use and minimize adverse effects by managing water systems as a single source. Traditionally, these water resources have been perceived and managed as isolated resources, even when there is a high hydraulic connectivity. There is currently growing recognition that the connectivity between these two sources is an important part of river system function, with significant implications for both water quantity and quality (Nyerges et al 2006). Water flow regimes, water security, aquatic ecology, salinity and nutrient loading can all be affected by the flow of water between surface water features and underlying aquifers. Surface water flows are therefore affected by the way the aquifer stores/flows are managed and vice versa.

According to Fullagar et al (2004), a conjunctive water use management approach is a logical step towards improved water management by making best use of the attributes of both surface water and groundwater systems. Therefore, conjunctive water management is an important component of future water management dealing with issues of water quantity, the environment, and natural hazards – issues that grow in priority as demands on Australia's water resources increase into the future. Thus, there is a need to explore a new management design approach. One of the best approaches to manage surface and ground water, as one single source, and adds more flexibility can be the adoption of the water banking approach. The goal of water banking in general is to efficiently allocate all available water to achieve economic growth while achieving environmental sustainability. In this paper, water banking is defined as uses and manages all available water resources as one single system. Therefore, the overall goal of the current study is to present and investigate the concept of water banking for farmers, as it is critical as the water banking design and operation, by examining water banking under different crop mixes.

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2. WATER BANKING CONCEPT AND GROUNDWATER SYSTEM

Water banking objectives and definition are completely diverse in the literature according to the authors or owners perspectives and the reason of use ("Idaho Water Resources Board" 1999, Laurent et al 2001, Klamath basin; Christine 2002, and Water Bank Company in the UK 2004). The common definition of the water bank is the foremost marketplace for trading, buying and selling water assets including water rights and water utilities (WaterBank Com, 2005). However, this not completely matched with this study objective. In this study, water bank will store water in aquifer as an underground dam during the high flow and wet season/year, to be released during drought or dry conditions. In addition, water banking refers to delivering water earlier than it is required and injecting it into groundwater so it is available to be pumped when required, Figure1). In other words, water banking redirect surface water to subsurface water until it is required with zero evaporation losses. Water banking is a new management approach to manage water resources with the ability to test and asses the impact of options for the allocation of limited water resources between agricultural production and the environment. Water banking can open the opportunity to release water from head dams at the beginning of the water year to mimic the natural flow and subsequently stored in the aquifer or to fill the water bank. At the point of high peak demand, during the summer months, release water from bank to satisfy the summer demand and then refill the bank after the peak demand season. Water banking could help to: (i) add flexibility in conjunctive water management,(ii) enhance in-stream flows that are biologically and ecologically significant,(iii) reduce water use in over allocated areas, (iv) reduce impact of water pumping on to stream, and (v) facilitate the legal transfer and market exchange of various types of surface, ground water and storage entitlement. In the Murrumbidgee catchment (the study area), Khan et al (2006) reported that, there is a potential opportunity for artificial recharge to store and inject water in deep aquifer for about 200GL as the water level declines and never rise up by natural recharge. Before discussing water banking issues in details, groundwater system use and formation in the study area is discussed first.

3. STUDY AREA GROUNDWATER USE AND FORMATION

Groundwater is a poorly understood resource in the Murray Darling Basin (MDB), and particularly in the Murrumbidgee catchment. The Murrumbidgee catchment can be broadly divided into three major hydro geological areas, (Figure 2 Upper Murrumbidgee Fractured, Mid Murrumbidgee Alluvium and Lower Murrumbidgee Alluvium). This study focuses on the lower Murrumbidgee groundwater area since most irrigation demand is extracted in this area. Lower Murrumbidgee Alluvium, downstream of Narrandera unconsolidated alluvial deposits, consisting of layers of sand, silt, clay and peat, occur. This alluvial system consists of three major aquifers i.e. the shallow Shepparton, intermediate Calivil and the deep Renmark Formations (Brown and Stephenson, 1991). The total annual recharge to the shallow aquifer is estimated to be around 127,000 ML (Webb, 2000). The current entitlements are around 55,000 ML, which shows potential for more extraction opportunity. Water movement through the deep aquifers is generally from East to West except in the area with major groundwater pumping around Darlington Point. Recharge to the deep aquifers is mainly from the Murrumbidgee River downstream of Narrandera and from the irrigation areas with estimated average annual recharge around 335,370 ML/year (Kumar, 2002).

In the last 10 years, local imbalance between groundwater recharge and discharge has resulted in around 10-20 meters residual drawdown in deep aquifers over large areas between Darlington Point and Hay, which provides storage opportunities for managed aquifer recharge. This is confirmed by individual deep piezometer trends downstream of Narrendera and Hay, Figure 3(a) and Figure 3(b). Rising groundwater trend downstream of Hay could be attributed to an increased area of rice growing adjacent to the river and/or losses from the river. Residual groundwater drawdown in deeper aquifers offer a potential for these aquifers to be artificially recharged using good quality water by new dedicated bores or existing bores. This can help to reduce the Stalinization of deeper aquifers as well as offer evaporation free secure underground storage and could work as underground water bank. Groundwater use in the lower Murrumbidgee area has been increased with a declination of surface water allocation. According to (NSW-EPA, 2001), the drought and its associated impacts such as the blue-green algae crisis and reduced surface water allocation, and diminishing surface supplies leads to increase the groundwater use.

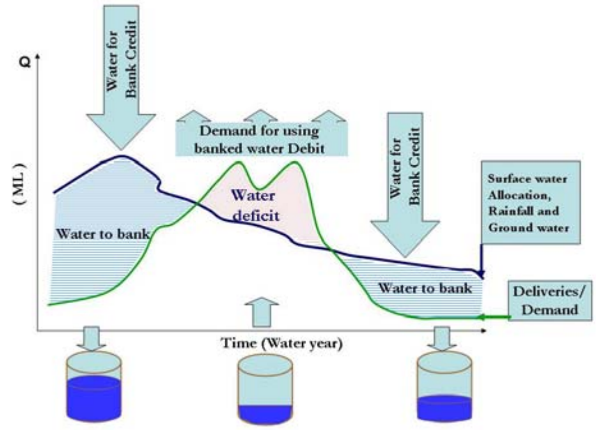

Figure 1 Water bank operational concept

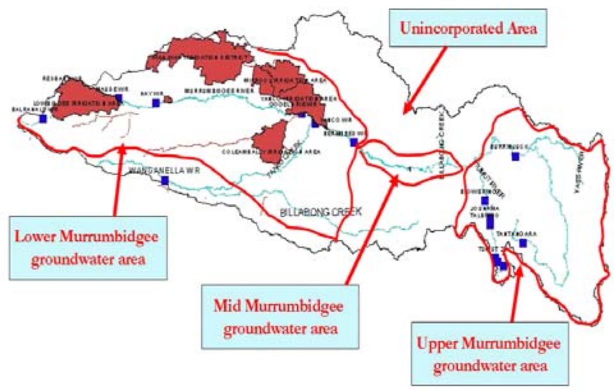

Figure 2 Murrumbidgee groundwater management area

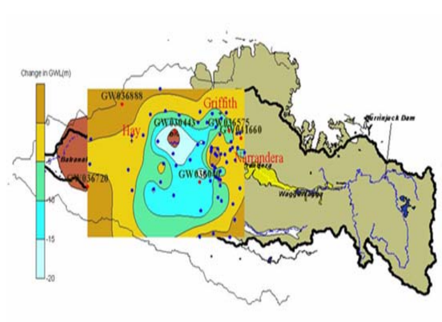

Figure 3 (a) Changes in Deeper Groundwater Levels between Narrandera and Hay from 1990 to 2003

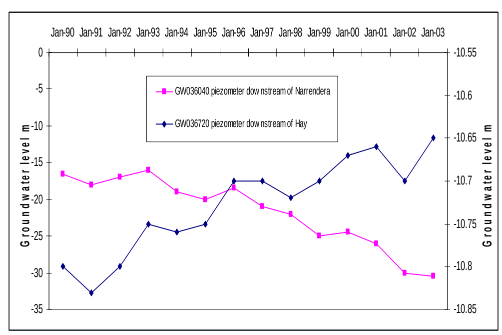

Figure 3(b) Deep Groundwater Levels at downstream of Narrendera and Hay (data source: Khan S. et al 2004)

4. WATER BANKING ISSUES

This study investigates the water banking approach in terms of the management of surface and ground water resources available in the Murrumbidgee catchment to satisfy the irrigation demand increase and resolve this dispute between irrigation and environmental demand. A water bank has several issues that need to be considered. One of the main issues is the spatial constraint, where water might be banked behind dams, on-stream, off stream and underground (aquifer). According to Khan, (2004), Willem et al. (2005) and Pratt water study (2004a), they argued the possibility of a water saving option for Murrumbidgee River system from system losses of 200GL with the possibility of using the aquifer downstream. Another issue is regarding the recharge rate to be either natural or artificial. The natural recharge rate is demonstrated by the sustainable yield or extraction limit from ground water system. This study tests the water banking approach under both recharge methods: injection and infiltration. The objective of this study is to present the use of water banking concept to the farmers and water managers (that it is critical and important for its design and operation to improve the environmental performance of the river) to look at all the issues of water banking such as clogging, water quality, salinity, recharge rate and cost issues is beyond the scope of this study. In addition, in order that water banking can function efficiently, several issues are to be considered such as institutional arrangements to legalize short-term and long term releases and delivery of banked water, adequate hydrological capacity to allow storage and delivery without significant potential water loss, economic and environmental validity and social consideration. Also, water banking could be planned for a long term or short term according to the climatic conditions.

5. IRRIGATION DEMAND MANAGEMENT AND CROP MIX

Managing the water supply system is conceptually simple, a matter of working with physical regulations of hydrology and engineering principles. Demand management on the other hand depends on several variables linked to human needs, behavior which changes over time and space. Moreover, irrigation water demand management is particularly difficult due to uncontrolled variables such as climate and also when economic and environmental perspectives are integrated in irrigation demand management with realities of biophysical processes. Irrigation demand management can be considered as a tool or mechanism that can modify the level of peak demand and timing of irrigation water demand. Integrated irrigation demand management in agricultural areas is the best strategy to optimize the use of the available water resources (Elmahdi, et al 2005a). According to White and Fane (2001), demand management is intended to support conservation either through changes in the consumer behavior or changes to the supply of resources using technology or policy. The behavior of the consumer can be changed through increasing their knowledge or by setting up polices and/or incentives. But changes to the supply of resources can be delivered with alternative sources of irrigation such as pumping, on- and off-farm storages, or increasing the efficiency of irrigation use, or by applying alternative management or policy such as water banking. The crop water demand of the irrigation areas in this study is dominant during summer months from October to March. The peak demand and diversion (over 200GL/monthly) has been shifted and decreased after implementing the environmental flow demand. This summer concentration of flow represents a significant shift from the natural flow pattern in the river. Thus the main objective of irrigation demand management in this context is to minimize the peak demand of irrigation water which will modify and improve the seasonality of flow. In addition, water scarcity and decreasing water allocations, encourages decision makers and water managers to look for improved management through changes in cropping pattern systems (Elmahdi, 2005b). No doubt that the water value depends not only on its quantity but also on its quality, reliability, time of availability and location. Irrigation demand management has been recognized as an essential and effective policy tool for sustainable irrigation systems by providing water for farmers: economic efficiency as return from irrigation areas, social equity and welfare and ecological sustainability. In general, demand management options could be achieved through: i) Increased system efficiency, ii) new irrigation systems (using high technology) and iii) changing the crop mix.

Changes of crops both temporally and spatially could be used to reduce the water demand. Improving crop mix by focusing on both winter and summer crops but mainly on winter crops could help to improve environmental outcomes and optimize the water use. Additionally, modeling of cropping mix should consider many variables such as new crop intensity, new crop water requirements, economic aspects, production, yield and long term impact of new systems on the soil quality. This study focuses on testing different crop mix scenarios from winter, summer and perennial crops and its impact with and without water banking. This could be achieved by developing integrated biophysical economic environmental model using system dynamics approach, which is described in details in the next section.

6. INTEGRATED BIOPHYSICAL MODELING APPROACH

Modeling of water resources systems can be undertaken using a variety of approaches. It is important that to select an appropriate approach, based on the model requirements (in terms of parameters, spatial and temporal resolution), data available, expertise of users and the degree to which processes are understood (series on model choice 2005). According to Elmahdi et al. (2006a), modeling the irrigation system that considers the economic and environmental aspects, is a difficult modeling challenge. The model structure becomes very complex, introducing many factors and their interrelationship. In addition, Elmahdi et al. (2005) claimed that meeting irrigation demand and achieving positive environmental and economic outcomes requires improved modeling tools to analyze the implications of alternative policies. Therefore, there is a need to explore new modeling approaches to represent the complex relationships found in irrigation systems. One of those promising options is System Dynamics, a feedback-based, object-oriented approach (Simonovic, 2000). According to Simonovic and Fahmy (1999), System Dynamics is based on a theory of system structure and a set of tools for representing complex systems and analyzing their dynamic behavior (from the system structure, the system behavior is generated). The most important feature of System Dynamics modeling is to elucidate the endogenous structure of the system, to see how different elements of the system actually relate to one another in the complex system (Shi and Gill, 2005).

In this study, system dynamics modeling approach is utilized. It is a way to organize software as a collection of discrete objects that incorporate both data structure and system behavior (Simonovic et al., 1997). Data are organized into discrete objects. These objects could be concrete (such as a river gauge or river reach) or conceptual (such as a management or policy decision). The issue of data limitations is significant in modeling irrigation water systems. However, system dynamics offers an efficient approach in order to utilize effectively the available data and to understand the processes. The dynamics of the system could be understood through simulation of the system over time. Describing of the system and its boundaries, by using the main variables and its mathematical functions, which represent the physical processes, to generate the model behavior, is one of the main steps of a system dynamics model.

7. INTEGRATED BIOPHYSICAL –WATER BANKING CONCEPTUAL MODEL

Crop water requirements depend on many factors such as temperature, humidity, rainfall and evaporation and are affected by several factors such as climatic forecasted growing condition and water allocation. Therefore, the cropping pattern of the different cultivated crops under a given allocation is a variable that can be used to improve the productivity of consumed water. Therefore, a Network Simulation Model (NSM) was developed using a system dynamics approach (full description of system dynamics and NSM can be found in Elmahdi et al. 2005b and 2006a) as an appropriate tool to analyze irrigation demand management strategies. NSM is linked with crop decision optimization module (CDOM) and water trading module (WTM) to be able to capture a good level of agreement of farmer's crop and water use/trading decisions, Figure 4). This model is designed to operate on a monthly basis on three levels (field/crop, irrigation areas and catchment) to assist water managers in analyzing the system's behavior under various management scenarios. NSM incorporates a wide range of complexities likely to be encountered in water resource management: surface and ground water sources, water trading between sources within system constraint such as maximum ground water pumping rates, environmental flows, and channel capacity. Moreover, NSM has been calibrated and validated with level of accuracy 0.5-2% error (Elmahdi et al 2006b).

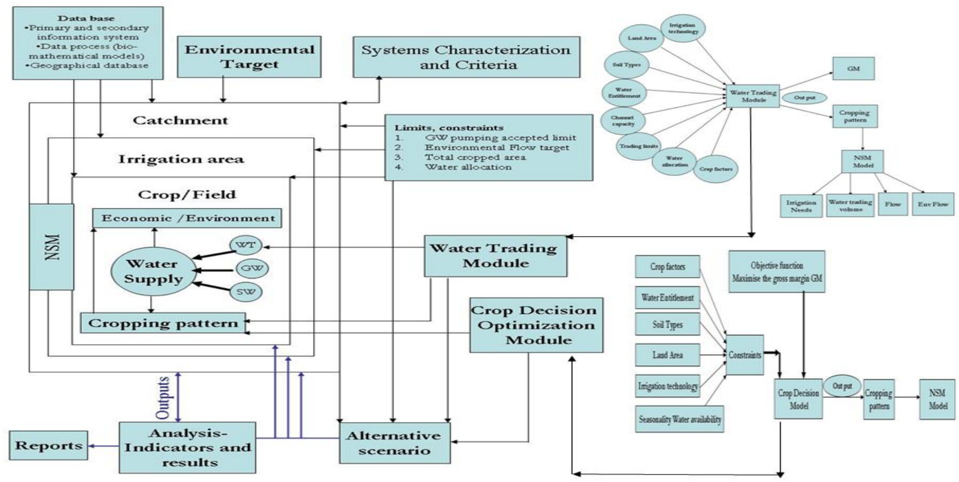

Figure 4 NSM integrated framework

In this research context, a water trading mechanism facilitates the water movement between irrigation areas or water banks. Figure 5 shows the water banking conceptual framework, assuming two main irrigation areas A and B (MIA Murrumbidgee Irrigation Area and CIA Coleambally Irrigation Area) on both sides of the river. Assuming each irrigation area has or develops its water bank which is able to manage its water resources (surface and ground water) as one single resource. In the case that water availability exceeds biophysical crop water requirements, the irrigation area will intend to store water into its aquifer by using managed aquifer recharge (MAR) technology (injection or infiltration).While in the case that biophysical crop water requirements exceed the total water available (surface and ground water) to the area and its water bank, this irrigation area will intend to buy its needs (water deficit) from another area's water bank (based on the average historical price within system constraints such as groundwater pumping capacity, environmental flow rules, river channel capacity and trading limitations). This water trading mechanism is able to facilitate water movement and achieve better management of the whole system (surface and ground water) which gives economic benefits.

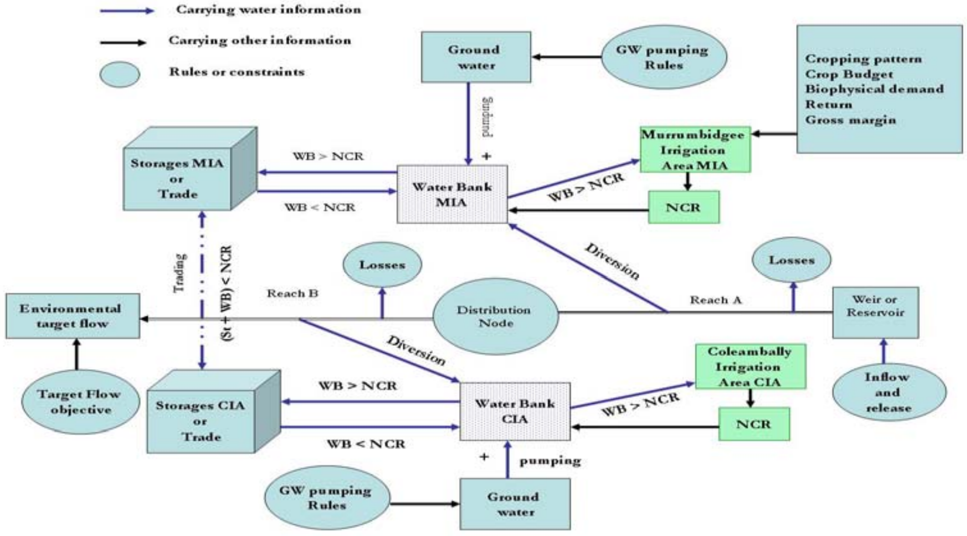

Figure 5 Water banking modeling conceptual approach

8. SCENARIOS

In this particular study, the scenarios attempt to answer questions that help to improve water productivity and environmental performance by testing several options (water banking and crop mixes). Several options have been identified both from the literature and from the two consulting workshops with stakeholders. These were held under the Cooperative Research Centre-Irrigation Future (CRC-IF) with key stakeholders and the irrigation community. They have identified several options which have supposedly gained community acceptance as the best possible demand management options to improve the seasonality of flows and environmental flows are: market based approach reduction to surface water demand, conjunctive water use (forms of MAR that include Aquifer Storage and Recovery (injection) wells and basin infiltration), better irrigation and spreading water demand with improved cropping mix, increase system efficiency, increase end use efficiency, substitute water use by using en-route storage. These options are the more plausible and acceptable demand management options from irrigation community perspectives. However, some of these options cannot be applied, or it is unclear who will invest in their application. These options need to be properly studied. Therefore, the scenarios should aim to ensure that the Murrumbidgee water system is managed for the greatest possible long-term and short-term environmental and economic benefit. Thus, this study focuses on water banking and changing crop mixes options and asses them using environmental and economic assessment criteria. These criteria examine the impact of the water banking approach (that would effectively influence the dynamics of water use, allocation, management, economics and environmental quality) with different crop mix option to improve water productivity and satisfy environmental flow. These options were combined to give three scenarios as follows:
Scenario 1: is the base case with the current conditions of cropping system and without water banking.
Scenario 2: is a scenario that adds to the base case different crop mixes. This scenario simulates a situation of changing the crop mix under the same level of water supply or availability. Under this scenario, four variations were simulated to test their consequence or impact on water system, environment and agricultural income/productivity. These variations include:

1. mixed cropping (balanced mix from summer, winter and annual crops)
2. summer scenario (increasing the summer crops area and decreasing winter crops area)
3. winter scenario (increasing the winter crops area and decreasing summer crops area)
4. area reduction scenario “cutting’ (demonstrating the impact of cutting or reducing the area of crops with a high water requirement by 50%).

Scenario 3: This scenario is similar to Scenario 2 (changing crop mix), except that water banking is introduced. This scenario seeks to understand the impact of water banking as a new water management system (regulation) to supply and store water underground by two methods: recharge of groundwater through infiltration into the basin, or through injection by using water wells that already exist in the area or introduced to new wells.

These scenarios are tested under two different time scales: short-term and long-term scales. Briefly, the main management options were tested in this study using the following modeling approaches:
Crop mix: changing crop mix areas using different cropping pattern systems resulting from CDOM and WTM.
Water banking: simply redirecting surface water during (low peak demand-winter months) to the underground aquifer for storage purpose and re-abstracting groundwater during demand periods (summer months).

9. RESULTS AND ANALYSIS

Results for each scenario, returned from the NSM model, are provided in a data intensive way, providing information about resources use, crop yields, and gross margin per area and megalitre per irrigation area and for each crop and environmental index for the whole catchment. However, to provide more coherent analysis, the model results are compared using a trade-off tool, which enables assessment along two dimensions: water productivity and environmental outcomes, Figure 6. It compares the relative change % in agricultural income (compared to the base case) on the horizontal axis, and the relative change % in the environmental index (compared to base case on the vertical axis). The cross point in the centre of the Figure is a neutral point of no change (i.e. Base Case Scenario). Therefore, any management options, which deliver outcome in the upper right hand segment, are assessed to deliver positive outcomes on both economic and environmental measures, and therefore are ‘highly recommended’. Outcomes in the bottom left segment represent negative impacts for both agriculture and environment and are clearly 'not recommended'. The top left segment represents outcomes where economic outcomes are negative but environmental gains occur, and it is here where government subsidies may make some initiatives feasible and desirable (where the community is prepared to pay the subsidy). Whilst the final segment in the bottom right corner represents outcomes where there is a positive economic gain but poor environmental outcomes and these are not seen to be desirable in a context of declining environmental values.

In order to maximize the outcomes of management options for water supply and demand it is preferable that model results are placed in the top-right corner of the matrix shown in Figure 6. Figure 7 shows the performance of Scenario 2 compared to the base case scenario (point 0, 0). It can be seen that the 'mixed' cropping sub-scenario is located in the top right segment, giving a positive environmental result which is 7% better than the base case scenario. This means that the model predicts that this sub-scenario is able to provide environmental flow better than the status quo (in fact, providing environmental flows per year 2-5 months more than the base case during dry years and low allocation periods). Also, the mixed cropping scenario shows a 13% positive benefit in agricultural income compared to the base case. This translates to an additional \$12 – \$26M in gross margin (at base case prices and costs) with less water use by 80GL-100GL. The water productivity in terms of \$/ML is \$137/ML compared to the base case \$116/ML. Obviously, there are implications in terms of the marketability of production and other enterprise constraints, however, such positive results warrant further investigation into barriers to switching crops. It can be seen that one other sub-scenario, the 'summer' variation provides an increase in economic benefit (giving a 3% (\$4-\$6M) improvement in agricultural income), but delivers a reduction in environmental performance. Clearly, such an outcome is not aligned with the definition of success for this research. All other sub-scenarios (winter and cutting) under scenario 2 are located in the top left segment with positive environmental performance but with a negative impact on agricultural income. From this analysis, mixed cropping sub-scenario is the best and is recommended as the best management option under Scenario 2 (changing crop mixes).

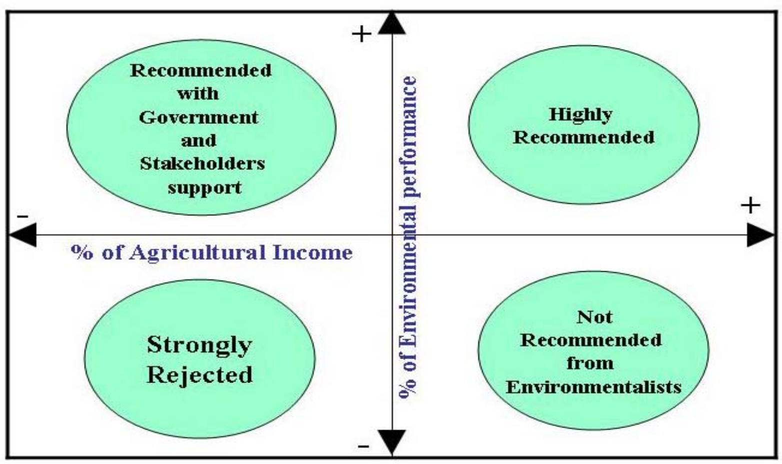

Figure 6 Trade-off between agricultural income and environmental performance

Figure 8 shows the trade-off for Scenario 3 compared to the base case scenario (point 0, 0). Again, the 'mixed' cropping sub-scenario is located in the top right segment, with either variation of water banking under infiltration or injection recharge methods. This variation gives a positive benefit on the environmental indicator of 8% with infiltration, and 10% with injection methods. This means it is able to provide environmental flow better than base case by providing environmental flows 3-7 months more than base case per year during the study period. Also, this option has a positive economic benefit of 3% (\$4-\$6 million) with injection and 9% (\$10-\$15 million) with infiltration, compared to base case. Overall, this means that the use of water banking under mixed cropping sub-scenario may be able to provide a higher gross margin to farmers but still deliver potential water savings of 80GL. Compared to scenario 2, winter and cutting sub-scenarios are located in the top left segment with positive higher environmental performance but with also higher negative impact on agricultural income. However, the summer sub-scenario with water banking (scenario 3) has moved from the bottom right to be located in the top left segment. It gives 0.5% improvement in environmental performance with infiltration and 1% improvement with injection and with negative impact on agricultural income under both recharge methods. Water banking is able to improve the environmental performance under the summer sub-scenario compared to the summer scenario without water banking, but only with a negative impact on the agricultural income of 1% for infiltration water banking and for 6% injection water banking. From this analysis a 'mixed' cropping sub-scenario with water banking under infiltration and injections is the best and recommended sub-scenario as the best management options for scenario 3.

From the above analysis, two management options (sub-scenarios) have been selected to be further analyzed and compared to the base case. These include: Scenario 2 (mixed cropping under changing crop mixes) and Scenario 3 (mixed cropping with water banking under infiltration and injection recharge). It is clear that all sub-scenarios use less water when compared to the base case, Figure 8. In addition, the 'mixed' cropping sub scenario under Scenario 2 and Scenario 3 (with water banking) gave the same level of total water use but less than the base case scenario by around 80GL (5% - 7% of total water use). This is attributed to the fact that the crop mix, applied in these scenarios, is different from the crop mix in the base case. However, mixed cropping (scenario 2) shows a better gross margin compared to the other sub-scenarios, figure 9. It is obvious that the 'mixed' cropping sub-scenario under Scenario 2 gives the highest gross margin compared to all other scenarios and the base case by 10%-15% ($20m-$30m). This could be attributed to the level of water use and in turn total water cost and also to the crop production and market price of crops into mixed cropping sub-scenario and water banking cost. The second highest sub-scenario is the mixed copping sub-scenario under scenario 3 (crop mix with water banking) with infiltration recharge method by 8% better than base case (scenario 1). Moreover, these three sub-scenarios show a slight difference in potential water saving (1-5 GL/year). This potential for water saving depends upon the management option and the external conditions. Crop mix (Scenario 2) by itself is able to save around 70GL-78GL while crop mixing with water banking (Scenario 3) is able to save around 75GL-83GL under infiltration and injection recharge methods. It is very clear that improving the environmental performance depends upon the potential water saving resulting from each scenario, Figure 10. Mixed cropping (scenario 2) gave about 7% improvement in environmental performance. However, by adding water banking to mixed cropping (scenario 3), about 8-10% improvement in environmental performance was achieved. This is in comparison to the base case. From the previous results, it is clear that there are different trade-offs between each management option and its environmental and economic outputs.

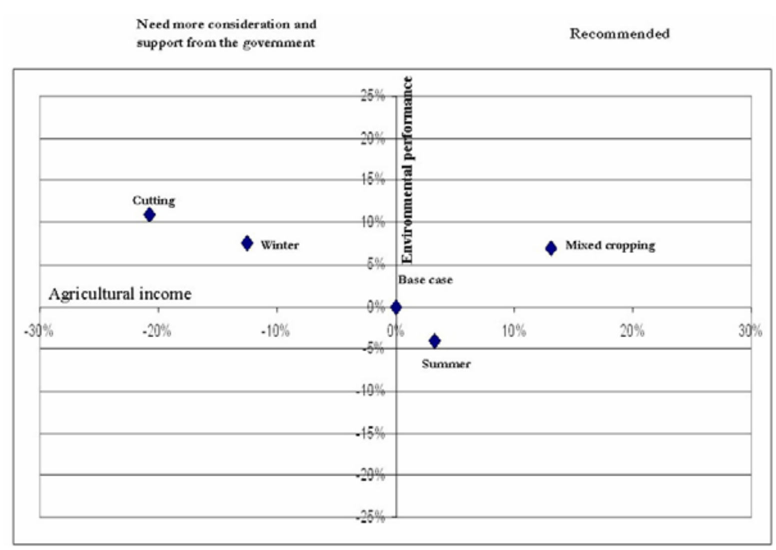

Figure 7 Trade-off for the best variation under scenario 2

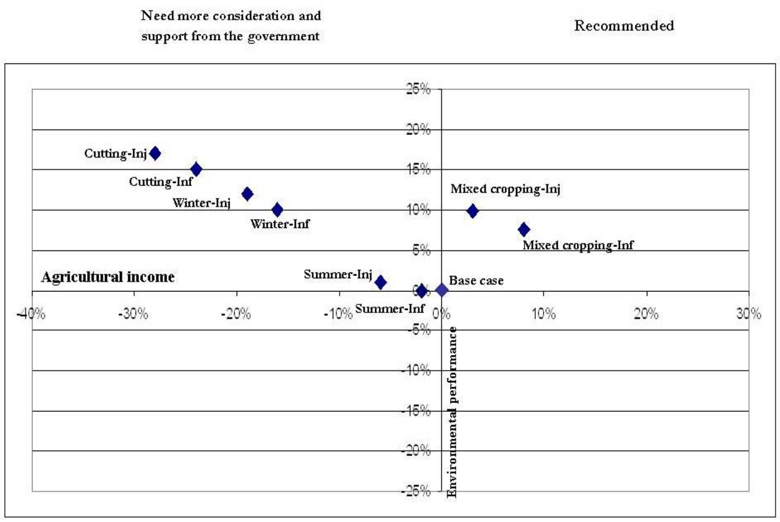

Figure 8 Trade-off for the best variation under scenario 3

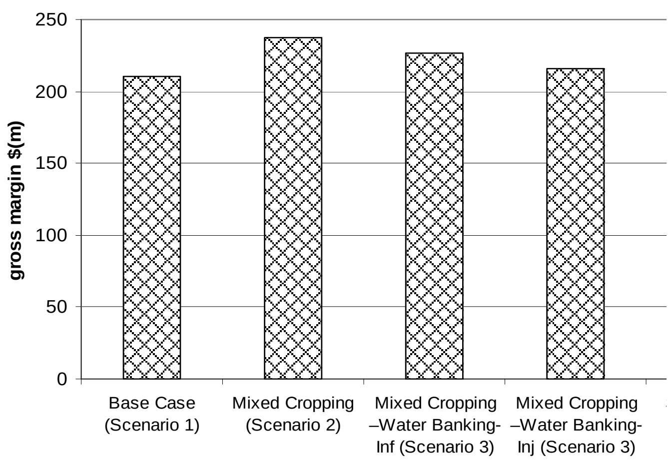

Figure 9 Average gross margins

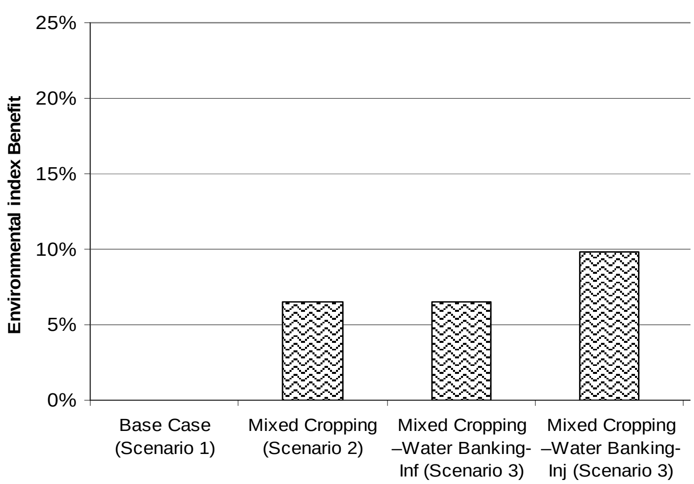

Figure 10 Average environmental benefits

10. CONCLUSIONS

The NSM model was used to evaluate the proposed alternative that is defined by water availability and demand. The relevance of the model is illustrated by an application to the Murrumbidgee river catchment and its irrigation areas. The model is used to evaluate and identify the change in economic and environmental performance of various water management strategies. The economic and environmental performance is measured by a set of indicators which include use of land and water resources, resources productivity, economic and environmental indicators. The model was used to simulate the base-line condition and to evaluate two other alternatives of supply and demand management options, taking into account farmers' crop decisions. These scenarios were compared to the base case scenario that reflects the system status quo. This analysis indicated that there was a clear trade-off between agricultural income and environmental performance in improving the seasonality of flows. Water banking is able to manage biophysical demand in a better way, and to enhance in-stream flows that are biologically and ecologically significant. Water banking approach can be applied to several countries in the Nile Basin when surface water and groundwater system are connected such as in Egypt. The best alternatives for each scenario that showed an improvement in environmental performance and water productivity were: mixed cropping under (Scenario 2) and Water banking with mixed cropping (scenario 3) under infiltration and injection. Finally, these results indicated that the NSM model tool developed a dynamic system that can provide water uses overview. It can also provide a basis for examining the impact of physical changes to the system and for interactions with agricultural productivity, economics and livelihoods. It is not a detailed catchment hydrology model but is a tool that has the potential to help stakeholders to simulate and optimize the system, by evaluating and analyzing the key decision variables.

11. ACKNOWLEDGMENTS

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