

The background of the top half of the page features a large, faint, light-blue watermark of the word "AITHER" in a bold, sans-serif font. The watermark is composed of several overlapping, semi-transparent letters that create a geometric, low-poly effect. The background itself is a solid dark teal color.

# **Water market impacts of on-farm water use efficiency programs that require entitlement transfer**

A Final Report prepared for the Department of Environment, Land,  
Water and Planning

Monday 18 December 2017

**A I T H E R**

## About Aither

Aither is an Australian economics and public policy advisory firm with deep expertise in water management, infrastructure and utility industries, the environment and natural resources.

Aither is a leading provider of independent water market advisory services in the Murray Darling Basin and beyond. We provide economic, policy, and strategic commercial advice, analysis and insights to policy makers, regulators and market participants. Through our work, we aim to support and improve better informed policy and decision making.

Our team is made up of water market experts with unparalleled depth and breadth of experience. We have led and advised on the development, implementation and assessment of major entitlement and market reforms across Australia. Recently we have advised on large commercial transactions in water entitlements and supported market participants in the development and implementation of innovative trading strategies. Our team is frequently sought after to present internationally on Australia's water entitlement and market reform journey.

In recognition of our credibility and commitment, Aither received the Australian Water Association Research Innovation Award (Victoria) for the development of our freely available annual [Aither Water Markets Report](#). These reports, along with our independent periodic market reporting to our clients, are underpinned by our comprehensive database of trading activity and responsive approach.

With established relationships with policy makers, system operators and market participants, we have a deep understanding of contemporary trends and drivers and offer unique insights. Aither understands the real risks and opportunities associated with market participation, and provide an independent perspective to government policy makers.

Our team provides services across policy advice and analysis, portfolio management, and commercial advice. This includes:

- analysis of the economic and social impacts of water trading and water reform
- economic modelling of allocation and entitlement markets
- development, implementation and review of water trading strategies
- reports on market activity and analysis of trends and drivers
- transactional due diligence and regulatory risk assessments
- management decision support tools
- investor, board and executive presentations
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# Executive summary

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## Context

- Irrigators in the southern Murray-Darling Basin have seen many changes in the water market in recent years. On the demand side, the cotton industry has expanded into southern New South Wales. There has also been a boom in the almond industry with a large area of new plantings. On the supply side, there has been a long term trend towards reduced water availability, due in part to climate change. At the same time, the share of water available to consumptive users has fallen as water has been recovered for the environment through Commonwealth water entitlement purchases. The trends affecting both demand and supply have contributed towards the increases in entitlement and allocation prices in recent years (Aither 2016b).
- The interactions of irrigators with the water market have also changed. Traditionally, irrigators sourced the majority of their water used from their own entitlements, often owning all the water they needed for their operations. Many irrigators are now more reliant on purchasing allocations, as well as alternatives such as leases which have become increasingly popular as the water market matures. Irrigators are making these choices, in part because many see a better use for the large amount of capital that is “locked up” by holding water entitlements on a permanent basis.
- The combination of increasing allocation prices and a greater percentage of irrigators sourcing water through allocations and allocation products has formed a risk for irrigated agricultural operations. There is debate around the extent to which irrigators are adequately managing this risk in their operations.
- Further, the emergence of this risk means that the potential water market impacts of government-funded on-farm water use efficiency (WUE) programs with entitlement transfer are highly relevant to irrigators, with even modest additional price increases having the potential to adversely affect the viability of a significant number of irrigators. The impacts are also relevant to governments as they make decisions about future water recovery.
- The Basin Plan outlines a target to recover 2750 billion litres (GL) of surface water entitlements in the Murray-Darling Basin. In addition, there are provisions in the Basin Plan to recover a further 450 GL through efficiency measures, subject to the requirement that ‘the efficiency contributions to the proposed adjustments achieve neutral or improved socio-economic outcomes’ (*Basin Plan 2012, 7.17*). This additional water is known as ‘upwater’.
- It is expected that some upwater could be recovered through on-farm WUE programs. These programs are intended to provide irrigators with capital to invest in improving the efficiency of their farm irrigation systems. In return, some or all of the water savings are transferred to the Commonwealth in the form of water access entitlements.
- On-farm WUE programs have been used in the past to recover water in the southern Murray-Darling Basin in relation to the 2750 GL target. For example, about 150 GL were recovered between 2009 and 2015 through the \$500 million on-farm component of the Sustainable Rural Water Use and Infrastructure Program. Looking forward, the main program for recovering upwater could be the Commonwealth On-Farm Further Irrigation Efficiency (COFFIE) Program, which is currently being piloted in South Australia.
- Aither has previously shown that, to the extent that on-farm WUE programs with entitlement transfer affect water allocation market prices, there can be a range of flow-on social and economic impacts on water market participants, upstream and downstream industries, and regional communities (Aither 2017).

- There is growing agreement that on-farm WUE programs that require entitlement transfer can lead to higher water prices (ABARES 2016; Aither 2016a; TCA and Frontier Economics 2017). As discussed below, this is because the volume of water used by participants can fall by less than the volume transferred to the Commonwealth. Water use can even increase. As a result, participants in WUE programs with entitlement transfer must either buy more or sell less water, which drives up water prices.
- Aither was engaged by the Victorian Department of Environment, Land, Water and Planning (DELWP) to critically assess the mechanisms by which on-farm WUE programs with entitlement transfer can lead to higher water prices and gather evidence based on the experiences of participants, statistical analysis of survey data, and economic modelling.

## Findings

### *Participants irrigate in more years*

- On-farm WUE programs typically increase the average value of water applied on land that has been upgraded. This is because the same total profit can be generated with less water. This is reflected in the threshold price at which temporary water becomes unviable in a season. A 2015-16 survey of Goulburn Murray irrigators found that those who had not upgraded their irrigation methods from government funding had an average threshold price of \$163 per ML. By contrast, those who had upgraded from government funding had an average threshold price of \$190 per ML. This difference is statistically significant (DEDJTR 2017).
- The increase in the average value of water leads to more frequent irrigation (i.e. irrigation occurs in more years). Suppose that a farmer's value of water before an upgrade was \$163 per ML. Above this price, the farmer was better off selling any allocations into the market. After an upgrade, the farmer's value of water increases to \$190 per ML. As a result, following the upgrade, for any price between \$163 and \$190 per ML it will now be profitable for the farmer to irrigate. Note that this does not depend on whether the farmer owns entitlements. Within this range, a farmer who owns entitlements will now use their own allocations (instead of selling), while a farmer who does not own entitlements now will buy allocations.

### *Participants may apply more water when they do irrigate*

- For irrigators the decision of whether to irrigate at all is distinct from how much water to apply when they do irrigate.
- On-farm WUE programs increase the water received by the crop as a proportion of the total water applied. In other words, more of the water applied is taken up by the crop as opposed to being 'lost' through evaporation, seepage and runoff. This is an intended and beneficial effect of on-farm WUE programs. However, the increase in WUE increases the additional production generated by adding water, which creates an incentive to increase water application rates in years when it is profitable to irrigate.
- This effect can be strong enough that on-farm WUE programs increase water application rates. This was evident in the water use of dairy farmers in Northern Victoria in years when it is profitable to irrigate. Since the introduction of on-farm WUE programs, the average water use associated with participants' water use licences has increased by about 50 to 100 ML per year (11 to 22 per cent) compared with non participants. This difference is also statistically significant in most years (McAllister et al. 2015 and McAllister et al. 2017).

### Water prices increase

- Because participants will irrigate more often and could apply more water when they do irrigate, the water use of participants may have increased due to on-farm WUE programs. At the same time, participants receive less water from their entitlements as some of their entitlement have been transferred to the Commonwealth. The increase in demand relative to supply causes water prices to increase for both entitlements and allocations.
- This is reflected in water market behaviour. Evidence suggests that some recipients of on-farm WUE investments (which are worth multiples of entitlement prices) with entitlement transfer have simply re-entered the market to re-establish their entitlement holdings, whereas others are now more reliant on buying allocations in the market. A recent survey of irrigators in the GMID showed a statistically significant relationship between those who have implemented on-farm irrigation upgrades and those who are reliant on allocation trade for their water use (GBCMA 2017).
- Many market participants believe that this behaviour has been one of several factors responsible for large increases in entitlement prices in the southern connected MDB (i.e. more than doubling in the last 3 to 4 years). There is some justification for this position. While this behaviour does not make a material difference individually, when aggregated, it can lead to significantly higher water prices.
- Aither's peer reviewed water market model was used to estimate the allocation price impacts of further water recovery through on-farm WUE programs that require entitlement transfer. The model is based on statistical analysis of data from the state water registers and makes a number of conservative assumptions. In particular, this version of the model does not capture the fact that any future on-farm WUE programs with entitlement transfer would be withdrawing water from a consumptive pool in which water is becoming increasingly scarce, especially in dry seasons.
- It was conservatively estimated that a further 450 GL of water recovery through on-farm WUE programs with entitlement transfer would lead to a \$13 per ML increase in water allocation prices to irrigators in northern Victoria in average water availability years. The impact is likely to be higher in extremely dry years, with an estimated increase of \$18 per ML. For consistency, these estimates were sourced from the same version of Aither's water market model that was used to assess the impacts of environmental water purchases in Aither (2016b). The current version of the model captures recent changes in demand for water allocations and shows markedly larger price impacts.

### Conclusions and implications

- This report provides evidence based on the experiences of participants and statistical analysis of survey and market data that water prices are likely to increase if further on-farm WUE programs that require entitlement transfer are undertaken.
- Higher water prices would affect the profitability and decisions of irrigators, with implications for structural adjustment. The resulting changes in irrigated agriculture would have implications throughout the agricultural supply chain and for regional communities, both positive and negative.
- Overall, some participants are likely to benefit from the funding provided. However there is a risk that other future participants may make inefficient decisions. There are also likely to be negative impacts on those irrigators that are not in a position to upgrade, or have already done so and are more reliant on allocation purchases. For these irrigators who are not participating, water market price impacts of an additional 450 GL of water recovery are likely to further accelerate the pace of adjustment at a time when change is already occurring at a rapid rate.

- These impacts may be relevant in deciding whether to recover further water through on-farm WUE programs, and should certainly be considered in the design any future on-farm WUE programs that require entitlement transfer with a view to addressing the risk of stranded assets.

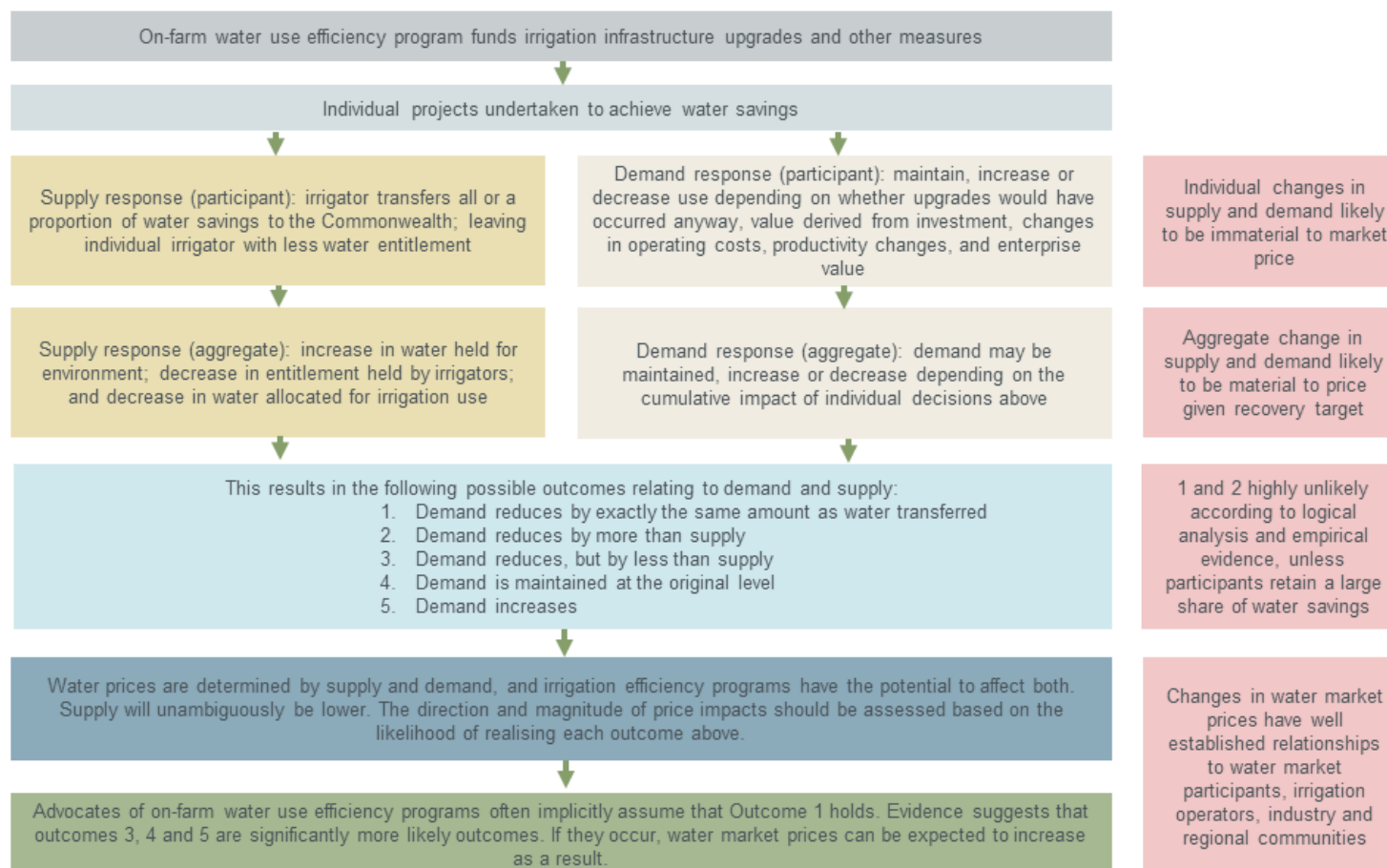
### *Assessing socio-economic neutrality*

- The potential magnitude of the water market impacts identified in this report mean that on-farm WUE programs with entitlement transfer may not meet the requirement that ‘the efficiency contributions to the proposed adjustments achieve neutral or improved socio-economic outcomes’. This depends in part on the definition of socio-economic neutrality.
- Aither (2017) has previously recommended that Basin governments should develop an agreed definition of socio-economic neutrality that is consistent with the intent of the Basin Plan. Based on this definition, Aither recommended that an independent assessment should be undertaken into the materiality of the water market impacts (and flow-on effects) of upwater measures.
- In the absence of other evidence on this topic, this report helps to fill this knowledge gap based on statistical evidence from historical on-farm WUE programs with entitlement transfer and based on Aither’s water market modelling. Further work could be completed based on a more detailed assessment of any proposed program and more detailed water market modelling.

### *The risk of stranded assets*

- The water market impacts associated with on-farm WUE programs that require entitlement transfer identified in this report also increase the risk of stranded assets. Specifically, there is a risk that irrigators will make decisions to invest in on-farm WUE measures without adequately understanding the cumulative feedback impacts on water prices. It might be profitable for an irrigator to participate in on-farm WUE programs with entitlement transfer if historical water prices prevail in the future, but if many other irrigators also upgrade water prices will increase and the same investment might be unprofitable.
- Failure to adequately consider the feedback impacts on water prices (or the other factors already placing upward pressure on allocation prices) could lead to inefficient investment and in the worst case scenario, stranded assets. Put simply, there is a material risk that government may be co-investing in irrigation infrastructure designed to operate for decades on farms that will not be irrigating in comparatively short periods of time.
- Stranded assets represent a poor outcome given the substantial public and private costs of investments in on-farm WUE measures. From a public perspective, this means less funding available for worthwhile government programs. From a private perspective, the costs associated with overcapitalisation could make the individual adjustment challenges faced by some on-farm WUE program participants more difficult.
- The risk of stranded assets is compounded by the recent changes in supply (due to buyback and climate change) and demand (due to investment in horticulture and cotton) in the water market, which are also contributing to higher water prices. For context, Aither (2016c) projected an increase in water demand by horticulture and cotton in the southern Murray-Darling Basin of about 380 GL per year between 2015-16 and 2020-21. This is the equivalent of 630 dairy or rice farms that currently use 600 ML per year.
- Given this underlying shift in water prices, even moderate additional increases in water prices due to on-farm WUE programs with entitlement transfer could have a significant impact on the profitability of upgraded farms. The design of any future on-farm WUE programs that require entitlement transfer should be cognisant of the increased potential for inefficient investment, including stranded assets.





**Figure 1** Framework for understanding changes in water supply, demand and price following on-farm WUE investment with entitlement transfer

# 1. Background

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The Basin Plan provides for an additional 450 GL of water recovery through efficiency measures in addition to the 2750 GL water recovery target. The main program being developed for achieving this target could be the Commonwealth On-Farm Further Irrigation Efficiency (COFFIE) Program, although there remains significant uncertainty. The COFFIE program provides irrigators with capital to invest in improving the efficiency of their farm irrigation systems. In return, some or all of the water savings are transferred to the Commonwealth in the form of water access entitlements.

Aither has been engaged by the Department of Environment, Land, Water and Planning (DELWP) to report on whether any future on-farm water use efficiency (WUE) programs with entitlement transfer across the southern Basin may be expected to have water market effects, and the implications of this, particularly in relation to socio-economic neutrality and the potential for stranded assets. A number of previous reports have highlighted the potential for water market effects (ABARES 2016; Aither 2016a; TCA and Frontier Economics 2017). However, these reports have approached the issue predominately from a theoretical perspective. This report clarifies the mechanisms involved and provides evidence based on the experiences of participants and statistical analysis of survey data and water use data.

## 1.1. Context

To understand the effects of on-farm water use efficiency (WUE) programs with entitlement transfer it is necessary to understand the recent trends and drivers of irrigated agriculture in northern Victoria, and the broader southern Murray-Darling Basin (sMDB).

On the demand side, there has been an expansion of the cotton industry into southern New South Wales. There has also been a boom in the almond industry with a large area of new plantings. On the other hand, the decline in milk prices will tend to suppress demand for water from the dairy industry, although the magnitudes are unclear (Aither 2016a).

On the supply side, there has been substantial variation in the annual availability of water. This has been the main driver of inter-seasonal variation in water allocation prices. However, there have also been important long term trends. Overall water availability in the sMDB has declined since the last century, due in part to climate change. At the same time, the share of water to consumptive users such as irrigators has fallen as water has been reallocated to the environment through Commonwealth water entitlement purchases (Table 1).

**Table 1 Cumulative water entitlements purchased by Commonwealth Government – registered at start of water year (GL)**

Entitlement type	07-08 <sup>1</sup>	08-09	09-10	10-11	11-12	12-13	13-14	14-15
Vic 1A Greater Goulburn HRWS	-	1	54	96	182	187	187	188
Vic Murray HRWS	-	6	75	138	222	228	229	229
NSW Murray HS	-	-	-	1	3	9	15	15
NSW Murrumbidgee HS	-	-	-	-	3	4	5	5
SA Murray HS	-	1	39	67	93	96	96	96
Vic 1A Greater Goulburn LRWS	-	1	10	11	11	11	11	11
Vic Murray LRWS	-	1	10	11	11	11	11	11
NSW Murray GS	-	8	171	195	218	248	253	253
NSW Murrumbidgee GS	-	14	64	99	152	184	189	189
<b>Total</b>	<b>0</b>	<b>32</b>	<b>424</b>	<b>618</b>	<b>895</b>	<b>978</b>	<b>995</b>	<b>996</b>

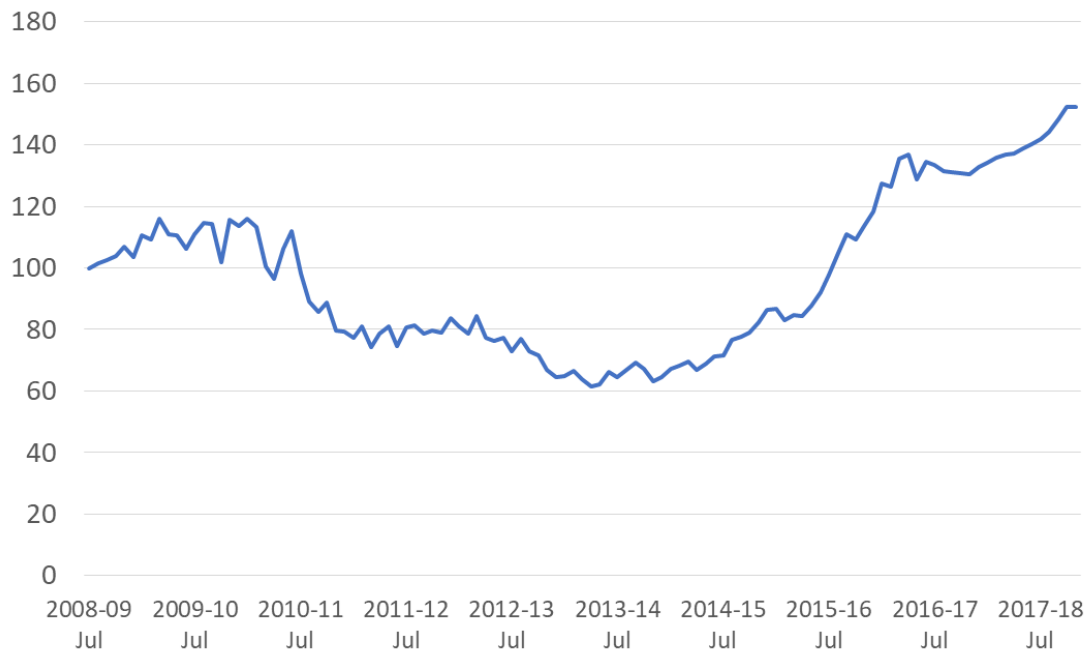
Source: Aither 2016(b).

Note: 1) While water was purchased by the Commonwealth Government in 2007-08, Aither has assumed that these entitlements would not have been registered to the Commonwealth Government until the beginning of the next water year – i.e. the Commonwealth Government would not have received any water allocations from these entitlements in the year in which they were purchased. This assumption was confirmed with the Department of the Environment.

2) These estimates do not include an additional 110 GL of purchases through other mechanisms, including water purchased through irrigator-led group proposals and water purchased through the Victorian Government associated with the Goulburn-Murray Water Connections Program.

The trends affecting both demand and supply have contributed towards the increases in entitlement and allocation prices in recent years. Aither's market entitlement price index has more than doubled in value over the previous four years and now exceeds the peak values of 2009-10 (Figure 2). As mentioned above, allocation prices are more variable and more likely to be driven by short run considerations such as seasonal conditions (Figure 3).

Aither modelling shows that changes in demand and environmental water purchases between 2005-06 and 2015-16 have led to an underlying increase in water allocation prices of \$5 per ML in wet seasons and \$150 per ML in very dry seasons. Further underlying increases in water allocation prices were projected between 2015-16 and 2020-21 (Aither 2016a). There is uncertainty around the extent to which some irrigators are aware of these fundamental shifts and their implications. Without being aware of these trends, irrigators may be making decisions based on past conditions rather than future conditions.



Source: Aither data.

**Figure 2 Aither southern Murray-Darling Basin entitlement index (not adjusted for inflation)**



Source: Aither data.

Note: Combined volume weighted average price across all southern Murray-Darling Basin trading zones.

**Figure 3 Monthly allocation prices in the southern Murray-Darling Basin (not adjusted for inflation)**

The interactions of irrigators with the water market have also changed. Traditionally, irrigators sourced the majority of their water used from their own entitlements. Many irrigators are now more reliant on allocation purchases, as well as alternatives such as leases which have become increasingly popular. According to TCA and Frontier Economics (2017) more than half of dairy farmers in northern Victoria are now net purchasers of allocations, and 60 per cent purchased allocations in 2013-14. The trend towards allocation purchases is evident in the following case study:

*An irrigator has been farming all his life and has owned his 2500ha mixed cropping farm in Northern Victoria for over 20 years. He irrigates approximately 170ha each year with 20ha of tomatoes and the rest in winter grains and fodder crops, which he supplies to the dairy industry. He sold all of his HRWS to reduce farm debt and as long as the price is below \$230/ML, he buys between 1000-1500ML on the allocation trade market each year. Although he acknowledges that he doesn't have adequate water entitlements, he is not in a financial position to buy back HRWS. (GBCMA 2017, p.12)*

To some extent, an increased reliance on buying allocations is attributable to irrigators transferring entitlements to the Commonwealth. However, it has also gained popularity as a business model more generally, especially among new entrants to irrigated agriculture who may not currently be in a financial position to compete for entitlements with new permanent plantings and investors. While this option can make sense for some businesses, it has led to some irrigators being more exposed to risks of high allocation prices.

These contextual factors are relevant for understanding both the possible impacts on water prices and the consequences for irrigators. For example, a further increase to already increased allocation prices could have a severe impact on the profitability and viability of businesses that are reliant on buying allocations.

## 1.2. Report structure

The remainder of this report is structured as follows. Section 2 evaluates the overall logic of the argument that on-farm WUE programs with entitlement transfer result in increased water allocation and entitlement prices. Section 3 presents empirical evidence in relation to this argument based on the experiences of participants and statistical analysis of survey data and water use data. This draws heavily on case studies and surveys in relation to the Farm Water Program, led by the Goulburn Broken Catchment Management Authority. The purpose of this report is not to evaluate the water market impacts of the Farm Water Program but to consider how the findings from the Farm Water Program provide evidence for assessing the future impacts of an additional 450 GL from on-farm WUE programs with entitlement transfer. The implications for socioeconomic neutrality and the risk of stranded assets are discussed in Section 4.

## 2. Conceptual approach to explaining market impacts

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It is helpful to understand how water market impacts might arise from on-farm WUE programs with entitlement transfer. To achieve this, three items are presented and discussed below:

- an identification of the nature and range of social and financial impacts that can arise from water recovery programs (including on-farm WUE programs with entitlement transfer)
- a basic conceptual model and working hypothesis for how on-farm WUE investments influence social and financial outcomes, through changes in the water market
- a framework for considering the likely nature and direction of changes in water supply, demand and price that may follow cumulative on-farm WUE investment.

### 2.1. Potential impacts of water recovery programs

The following diagram is adapted from Aither (2017). It presents a typology of impacts that can result from water recovery programs (of which on-farm WUE with entitlement transfer is one type), across different stakeholders. The black boxes indicate the focus of this report.

This figure highlights that program participants are not the only group that may be affected by a water recovery program (as has been suggested by definitions of socio-economic neutrality in the Basin Plan). Typically, there can be flow-on effects on all irrigators (including those not participating in on-farm WUE programs with entitlement transfer) as well as on irrigation infrastructure at different scales (including operators of that infrastructure) and beyond.

Group	Description of impacts
<b>General public</b>	<ul style="list-style-type: none"> <li>Government funding of water recovery projects at expense of funding for other social, environmental, and economic policy priorities</li> <li>Nation-wide outcomes and impacts from efficiency measures on the general public, including economic, environmental and social impacts from environmental water</li> </ul>
<b>Program delivery partners</b>	<ul style="list-style-type: none"> <li>Impacts on demand for water use efficiency services and equipment</li> <li>Employment for suppliers of water use efficiency equipment and services, program managers and staff</li> </ul>
<b>Individual participants</b>	<ul style="list-style-type: none"> <li>Reduced water entitlement</li> <li>Grant funding and other capital cost contributions</li> <li>Impacts on operating costs</li> <li>Impacts on water demand</li> <li>Changes to risk profile</li> <li>Impacts on land value</li> <li>Impacts on productivity</li> <li>Impacts on lifestyle</li> </ul>
<b>Water market participants</b>	<ul style="list-style-type: none"> <li>Cumulative changes in water demand from participants result in potential water allocation and entitlement market impacts</li> <li>These have financial impacts on other market participants, both positive and negative</li> </ul>
<b>Irrigation infrastructure</b>	<ul style="list-style-type: none"> <li>Changes in distribution of water use may have an impact on revenue and cost base for IIOs</li> <li>Could be a need to increase prices for remaining water users in irrigation areas</li> <li>Potential for stranded assets given behavioural responses and water market effects</li> </ul>
<b>Industry</b>	<ul style="list-style-type: none"> <li>Direct production impacts from recipients</li> <li>Indirect production impacts from other water market participants</li> <li>Financial impacts on upstream suppliers</li> <li>Financial impacts on producers / processors / distributors</li> <li>Impacts on employment by industry</li> </ul>
<b>Regional communities</b>	<ul style="list-style-type: none"> <li>Cumulative employment and financial impacts could affect community services, housing prices, wages, and local economic activity</li> </ul>

Source: Adapted from Aither (2017).

Note: The black boxes highlight the focus of this report. The impacts can be both positive and negative.

**Figure 4 Typology of socio-economic impacts related to water recovery**

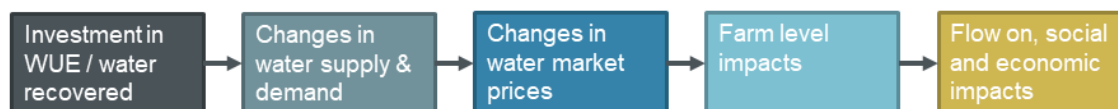
## 2.2. A basic conceptual model

Figure 4 highlights potential impacts, and points to ways in which impacts might occur, but a specific conceptual model more clearly shows the relationship between on-farm WUE programs with entitlement transfer and water prices.

Figure 5 is a basic conceptual model of how investment in on-farm WUE programs with entitlement transfer could lead to water market effects, and consequently, social and financial impacts. This model represents the basis of a working hypothesis this report sets out to test. In this model, the basic elements are that:

- Investment in on-farm WUE related infrastructure or activity occurs, which returns water to the environment through water savings
- This leads to changes in both supply of and demand for water (water recovered to the environment [supply], and changed circumstances of on-farm WUE program participants [demand])
- This can lead to changes in water market prices
- Changes in water prices mean there are impacts in the water market (which importantly, affect all water market participants, not just those participating in on-farm WUE programs with entitlement transfer), along with changes in broader agricultural markets

- In turn, changes in the dynamics in the water and agricultural markets contribute to flow on financial and social impacts or adjustment effects (including those identified for different groups in Figure 1).



Source: Aither.

**Figure 5 Basic conceptual model of impact of on-farm WUE programs with entitlement transfer**

If the basic premise of this model is accepted, which includes that positive or negative social or financial impacts could result from on-farm WUE investment with entitlement transfer (because water market prices would not be held constant, and could go up or down), it is then necessary to further confirm how such impacts may occur and whether they are likely to be positive or negative. To do this, it is necessary to better understand changes in water demand following on-farm WUE investment with entitlement transfer relative to supply (because this is the key determinant of water market price impacts).

It is relatively well understood and accepted that water recovery will reduce the total water available for consumptive irrigation purposes (which, holding all other factors constant would be expected to increase water prices). It has generally been assumed (including by water recovery programs) that water demand will fall by the same volume as the water recovered, which would be required to avoid water market impacts (because if the supply and demand balance does not change, prices should not change). However, other outcomes are also possible.

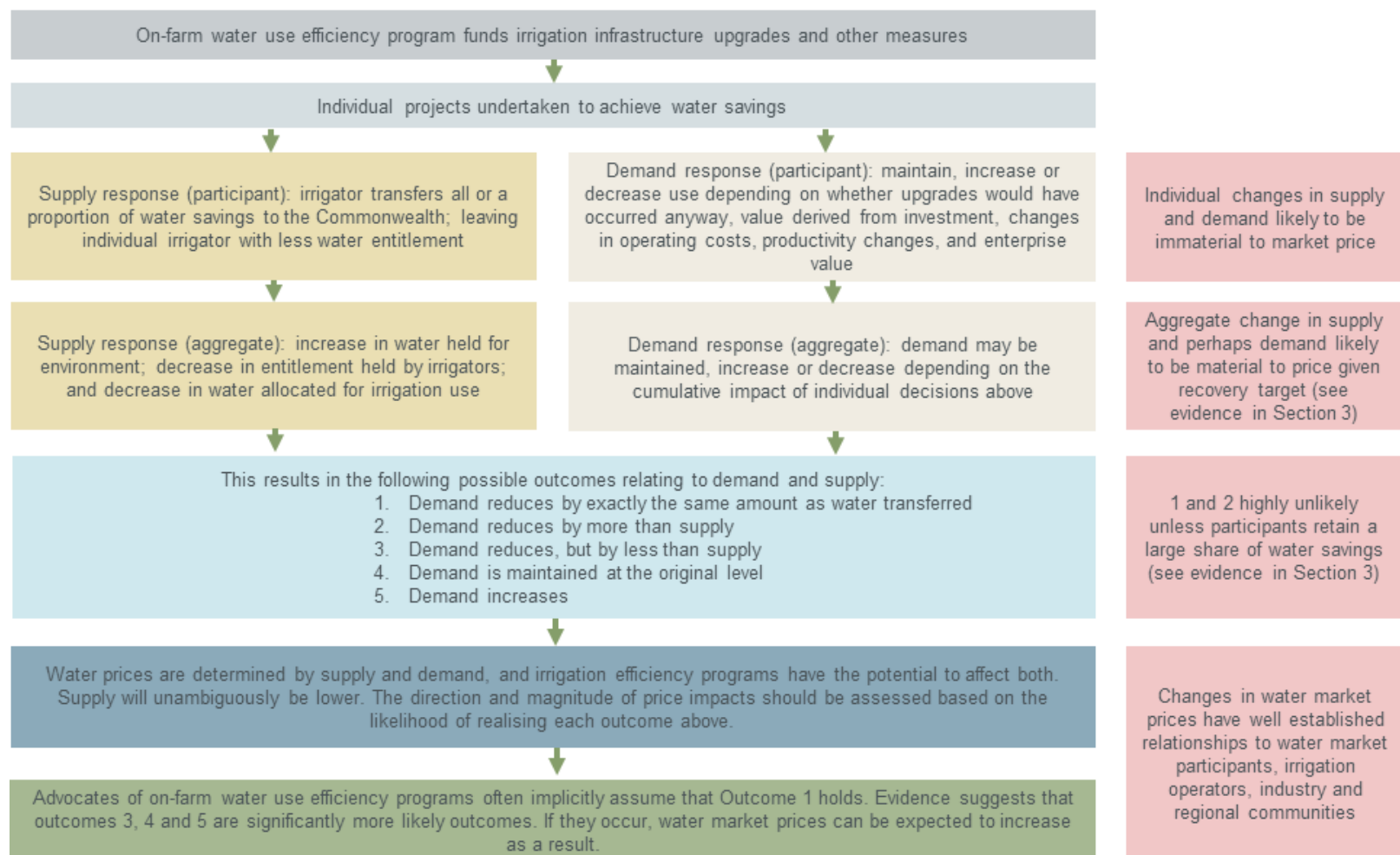
## 2.3. A framework for understanding supply and demand changes

A more detailed framework is required to better understand and interrogate supply and demand changes. Figure 3 outlines the potential individual and aggregate level changes that may follow from on-farm WUE investment, and the possible outcomes that result. Key points are that:

- The distribution of the water savings matters – i.e. how much of total savings are transferred to the Commonwealth versus that retained by an irrigator. The greater the proportion transferred the greater chance an irrigator will seek more water from the allocation market following an upgrade.
- Aggregate level changes in water demand and supply are important in the context of prices – i.e. the cumulative impact of recovering 450 GL from on-farm WUE programs will tend to exceed the cumulative impact of recovering 150 GL. Moreover, the relationship between recovery and price will tend to be non-linear, with a doubling of recovery causing the increase in price to more than double.
- Water use could hold steady, increase, or decrease, depending on a range of factors related to individual enterprises (including the proportion of project water savings retained by an irrigator), with the aggregate response reflecting these individual decisions.



- For assumptions contained in WUE programs with entitlement transfer about the absence of water market impacts to hold, water use must reduce by the same amount as the supply reduction.
- Several other supply and demand outcomes are possible (including demand reducing by less than supply). If these occur, water market prices will increase, potentially leading to a range of flow on social and financial impacts.



Source: Aither.

**Figure 6 Framework for understanding changes in water supply, demand and price following on-farm WUE investment with entitlement transfer**

### 3. Evidence of water market impacts

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The conceptual model and framework outlined above point to the need to better establish the water supply and demand responses to on-farm WUE programs that require entitlement transfer. Results of different components of empirical analysis are presented below, consistent with the main steps in the basic conceptual model (Figure 2).

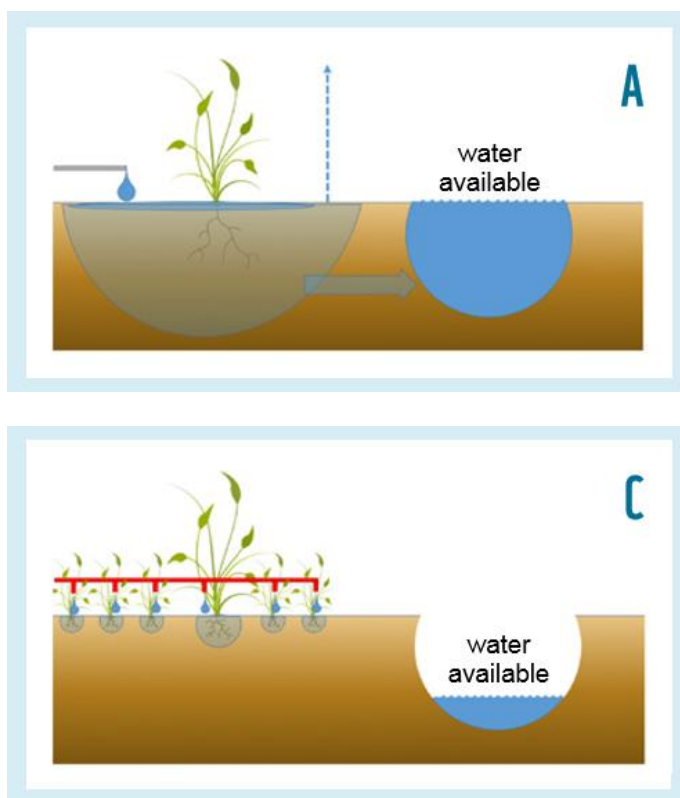
#### 3.1. Individual changes in water demand

Technological change that reduces the resources required to produce output does not necessarily reduce resource use. This paradox was first noted by William Stanley Jevons in 1866, who observed that coal use increased in Britain after the introduction of more efficient steam engines. Although less coal was required to produce the same amount of power, British businesses increased their use of power as the more efficient steam engines had made power less expensive, thus leading to an overall increase in demand for coal. This shows the importance of considering behavioural responses to technological change. It also shows the potential for significant private investment to increase resource use efficiency. The Jevons paradox have been applied to on-farm WUE programs globally (Figure 7), with arguments that increases in irrigation efficiency could lead to increased irrigation (WWF 2017).

In the context of on-farm WUE programs, understanding effects on water demand requires understanding the behaviour of individual irrigators, and specifically the volume of water they demand at different prices. This can be disaggregated into two related decisions:

- whether to irrigate in a particular season
- if so, what volume of water to apply in the season.

On-farm WUE programs affect both decisions.



Before WUE investment

After WUE investment:  
increased irrigation

Source: WWF (2017).

**Figure 7 On-farm WUE programs and the Jevons Paradox**

### 3.1.1. Decisions about irrigating in a particular season

The decision about whether to irrigate in a particular season is relatively straightforward. When making initial planting decisions, irrigators will irrigate unless the price of water exceeds their average value of water. On-farm WUE programs increase the average value of water because the same total profit can be generated with less water.

Suppose an irrigator can produce \$1200 of profit per hectare (based on \$2000 of revenues and \$800 of costs excluding water). At an application rate of 10 ML per hectare, irrigation will be profitable whenever the price of water is less than \$120 per ML, while at higher water prices the cost of water would exceed the profit generated from the water. Suppose an on-farm WUE program reduces the application rate to 8 ML per hectare without having any other effects. Irrigation will now be profitable whenever the price of water is less than \$150 per ML. This means that irrigation will occur more frequently than without the on-farm WUE program. (The water market implications of irrigating in more years are discussed further below.)

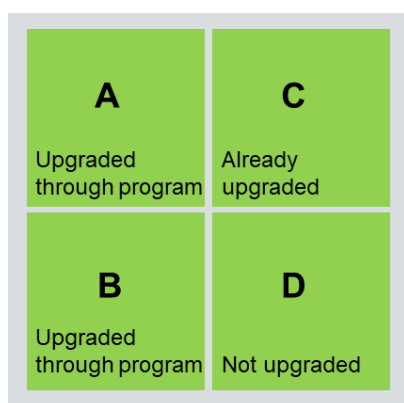
#### Key assumptions

For simplicity, this assumes no changes in revenues or costs. There could be changes in revenues and costs if on-farm WUE programs result in irrigators changing crops (see evidence below). Even without changes in crops, changes in revenues and costs are likely. For example, energy costs can increase with pressurised irrigation systems, while labour costs can decrease with infrastructure

that improves flow rates. The calculations are also slightly more complicated for irrigators with permanent plantings that could be damaged if not irrigated.

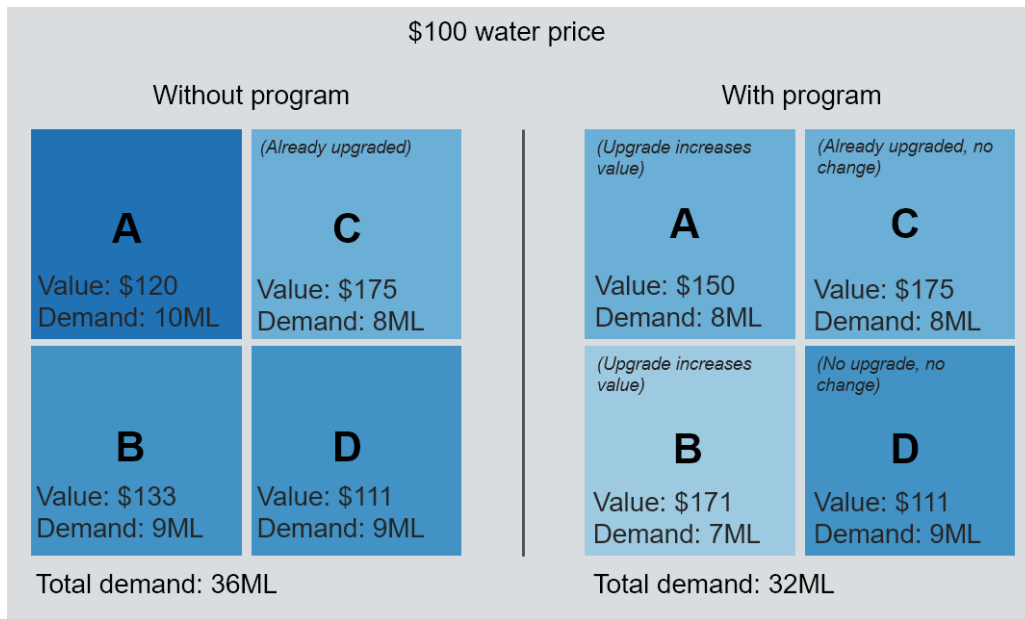
This is supported by empirical evidence. A 2015-16 survey of Goulburn Murray irrigators found that those who had not upgraded their irrigation methods from government funding had an average threshold price of \$163 per ML. By contrast, those who had upgraded from government funding had an average threshold price of \$190 per ML. The difference is statistically significant. Since the survey was undertaken in a dry season, both reported average thresholds prices could be higher than usual. Of the 384 landholders who participated in the survey, 161 responded to the question on their threshold price (DEDJTR 2017).

This effect is illustrated in the hypothetical example below. Suppose there are four irrigators (or equivalently a single irrigator with four paddocks) (Figure 8). Two have upgraded their infrastructure through the on-farm WUE program, leading to higher average values of water. The other irrigators have either already upgraded their infrastructure or not upgraded their infrastructure, meaning that their average values of water are unaffected by the program.



**Figure 8** Irrigators in hypothetical example of efficiency upgrade

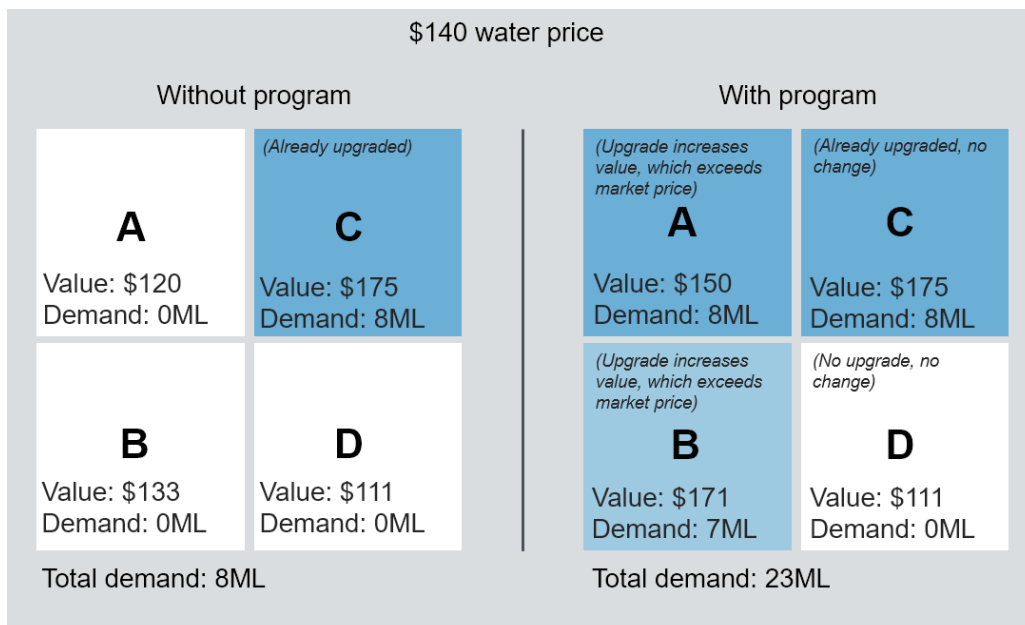
The following figures show demand by these irrigators at different water prices. Figure 9 shows demand at \$100 per ML. At this price, all irrigators would be irrigating because their value of water exceeds the market price, with or without the on-farm WUE program. In this example, water demand falls as a result of the program, although this might not occur in practice (see section below on the volume of water applied in a particular season).



Note: Darker boxes mean greater water demand. This only includes demand by the four farmers in question.

**Figure 9 Quantity demand falls at \$100 per ML**

At \$140 per ML (Figure 10) only irrigators who have upgraded will find it profitable to operate (because their value of water continues to exceed the market price, whereas this does not hold for those who have not upgraded). Hence, the on-farm WUE program brings two additional irrigators into operation. This results in higher water demand for prices between the average values of water with and without the on-farm WUE program.



Note: Darker boxes mean greater water demand. White means no demand.

**Figure 10 Quantity demand increases at \$140 per ML**

At \$180 per ML (Figure 11) it is not profitable for any of the irrigators to operate (because the market price exceeds the value of water in all cases), and demand will be zero, with or without the on-farm WUE program.

\$180 water price			
Without program		With program	
<b>A</b> Value: \$120 Demand: 0ML	<i>(Already upgraded)</i> <b>C</b> Value: \$175 Demand: 0ML	<i>(Upgrade increases value, but beneath market price)</i> <b>A</b> Value: \$150 Demand: 0ML	<i>(Already upgraded, no change)</i> <b>C</b> Value: \$175 Demand: 0ML
<b>B</b> Value: \$133 Demand: 0ML	<b>D</b> Value: \$111 Demand: 0ML	<i>(Upgrade increases value, but beneath market price)</i> <b>B</b> Value: \$171 Demand: 0ML	<i>(No upgrade, no change)</i> <b>D</b> Value: \$111 Demand: 0ML
Total demand: 0ML		Total demand: 0ML	

Note: White boxes mean no demand.

**Figure 11 Quantity demand unchanged at \$180 per ML**

This illustrates that the effect of on-farm WUE programs on demand is not necessarily simple. It is possible for demand to fall at low prices, increase at moderate prices, and be unaffected at high prices. However, this is a simplified example, and different producers can have significant differences in their value of water (e.g. some may have much greater value than \$180 per ML). The key message is provided in the second example – i.e. that irrigation occurs more often as a result of on-farm WUE programs because it is worthwhile for irrigators to operate (produce) at higher prices than would otherwise be the case. The bigger the pool of participants, the larger this effect is likely to be.

### 3.1.2. Volumes of water to apply in a particular season

So far, the analysis has implicitly assumed that irrigators have no flexibility to adjust water use. Where irrigators have the flexibility to adjust water use, irrigators must also decide what volume of water to apply. This involves equating the price of water with the marginal value of water. If this condition does not hold, it will be profitable to adjust water use. For example, if the price of an additional ML is \$140 and it would generate \$200 of revenue, the irrigator would increase profits by \$60 from applying that water.

On-farm WUE programs can affect the marginal value of water in two ways. First, on-farm WUE programs increase the proportion of water applied that is received by the crop, and in turn translates into greater production, which creates an incentive to add more water. This effect can be strong enough that on-farm WUE programs increase water application rates. For example, instead of reducing water application rates from 5 ML per hectare to 4 ML per hectare, water application rates

could increase above 5 ML per hectare. Even if water application rates do not increase, this effect means that water application rates will not fall by as much as they otherwise would have. An indirect source of evidence that this has occurred is that 64 per cent of Goulburn Murray Irrigation District irrigators who participated in on-farm WUE programs said that they increased production following modernisation (GBCMA 2017). This is consistent with the effect described above.

Second, on-farm WUE programs can affect the marginal value of water by making it profitable to change towards crops (and cropping systems) with a higher marginal value of water (or, equivalently, are more water intensive). There are numerous examples of this occurring, including the following case studies:

*A farmer in the Loddon valley with drip and gravity irrigation systems undertook improvements including upgrading the gravity system, changing paddock and bay size configurations, upgrading supply channels, land re-lasered, and installation of drainage lines and two reuse systems. It provided substantial labour savings, but a key benefit was that it enabled a more flexible cropping regime. Previously the area was only used for winter crops because water and labour efficiency was not adequate for more frequent watering of summer maize or other summer crops.*

*Cropping farmers in northern Victoria made upgrades including channel remodelling, outlet size increases, lasering and remodelling of bays, and one kilometre of channel was decommissioned. Previously due to the labour and water use required they were reluctant to do much summer cropping. Now they are more comfortable with a higher proportion of summer crops. Post upgrade, the farm is now double cropping following canola with soya beans, whereas previously it would mostly have been winter cereals.*

*A dairy farmer undertook reconfiguration and other improvements under the Farm Water program, and commented that post upgrade: "We are less water logged and pasture growth is more. Instead of resting for 4 to 5 days after irrigating before grazing we can graze after 3 days. 2 extra days of no water logging means more growth and better quality pasture. There is also more tonnes per ha of feed produced." However, owing to drier than estimated conditions and changes in crop mix following upgrade, the farm used 1100 ML which was above the 800 ML estimated to be needed post upgrade. (RMCG 2015)*

These effects can be strong enough that on-farm WUE programs increase water application rates. This was evident in the water use of dairy farmers in Northern Victoria. Since the introduction of on-farm WUE programs, the average water use associated with participants' water use licences has increased by about 50 to 100 ML per year (11 to 22 per cent) compared with non participants. This difference is also statistically significant in most years (McAllister et. al. 2015 and McAllister et. al. 2017).

### **3.2. Individual changes in water supply**

The transfer of entitlements to the Commonwealth reduces the supply of allocations to consumptive users. This depends on the extent of water savings and the proportion of water savings retained by irrigators. Note that the entitlements transferred would all come from the consumptive pool.



### 3.3. Cumulative water market impacts

Water prices are determined by aggregate supply and demand, and on-farm WUE programs with entitlement transfer have the potential to affect both. If the decline in demand is equal to the fall in supply, there will be no price impact. If the decline in demand is less than the fall in supply or demand increases, water prices will increase as a result of on-farm WUE programs with entitlement transfer.

How do on-farm WUE programs with entitlement transfer affect the demand for water relative to supply? In the previous sections, we have shown that demand could increase, and that if demand does fall, the magnitude will likely be less than the fall in supply (note that mathematical proofs are detailed in Appendix A). This is because irrigators with flexible production systems will irrigate more often, especially at higher prices, and; irrigators will generally use more water when they irrigate than would be predicted based on technical assessments of water savings. The implication is that water prices will likely increase as a result of on-farm WUE programs with entitlement transfer.

These changes in demand and supply are also reflected water market behaviour. Evidence suggests that some recipients of on-farm WUE grants (which are worth multiples of entitlement prices) have simply re-entered the market to re-establish their entitlement holdings, whereas others are now more reliant on buying allocations in the market. A recent survey of irrigators in the GMID showed a statistically significant relationship between those who have implemented on-farm irrigation upgrades and those who are reliant on allocation trade for their water use (GBCMA 2017). This was also corroborated by participants:

*A farmer changed from an old style gravity channel, to a high flow modern pump and riser system. There was extensive land lasering, installation of a reuse system and installation of automation functionality, amongst other improvements.*

*Previously much area was annual pasture with some areas irrigated only occasionally. Post upgrade the farmer increased the area irrigated and moved to the majority of the area being perennials. This came about largely because of the lower labour costs required with the new system. Other saved costs included reduced channel maintenance. There was a small increase in pumping costs, but this was much lower than the saved labour and other operating costs.*

*Due to the change in the farming system, and the transfer of water savings, this particular farmer was participating in the temporary market for water more frequently.*  
RMCG (2015)

Many market participants believe that this behaviour has been at least in part responsible for increases in entitlement prices in the southern connected MDB (i.e. more than doubling in the last 3 to 4 years). There is some justification for this position. While this behaviour does not make a material difference individually, the aggregate effects this can lead to significantly higher water prices.

#### 3.3.1. Water market modelling of aggregate impacts on allocation prices

Aither's peer reviewed water market model was used to estimate the allocation price impacts of further water recovery through on-farm WUE programs. The model is based on statistical analysis of data from the state water registers. The version of the model used in this report is identical to the version used to model the impacts of Commonwealth environmental water purchases for consistency and is documented in Aither (2016a) and Aither (2016b).

A number of assumptions were made in modelling the allocation price impacts of water recovery through on-farm WUE programs, including:

- **No demand shift.** The model captures the supply shift associated with the transfer of water entitlements to the Commonwealth, but assumes that demand is unchanged. The empirical evidence presented in this report suggests that demand could increase as a result of on-farm WUE programs, especially in dry seasons. (The supply shift does not consider the potential for water savings to be retained by irrigators or the potential for negative impacts on return flows.)
- **No recent hardening of underlying demand.** The version of the model used in this report includes all data available when the impacts of Commonwealth environmental water purchases were modelled, specifically 1998-99 to 2014-15. More recent versions of the model with data to 2016-17 show that irrigators have become markedly less sensitive to price.
- **No future projected increase in demand.** The version of the model used in the report does not capture projected growth in the demand by horticulture and cotton in the southern Murray-Darling Basin. As discussed above, evidence now suggests that this growth is likely to be significant.

## Results

It was estimated that a further 450 GL (long term average annual yield) of water recovery through on-farm WUE programs with entitlement transfer would lead to a \$13 per ML increase in water allocation prices to irrigators in northern Victoria in average water availability years. The impact is likely to be highest in extremely dry years, with an estimated increase of \$18 per ML.

These results are conservative given the assumptions outlined above. In particular, the results do not capture the fact that any future on-farm WUE programs with entitlement transfer will be withdrawing water from a consumptive pool in which water is becoming increasingly scarce, especially in dry seasons. Based on preliminary analysis that accounts for recent developments in the water market, Aither believe that the price impacts could be significantly higher and further modelling work could be undertaken.

**Table 2 Estimated water allocation price impacts of a further 450 GL of water recovery from on-farm WUE programs with entitlement transfer**

Scenario	Modelled price – without additional programs (\$/ML)	Modelled price – with additional programs (\$/ML)	Potential price impact of additional programs (\$/ML)
Repeat of extreme dry year (similar to 2008-09)	\$429	\$447	\$18
Repeat of average year (similar to 2005-06)	\$92	\$105	\$13

Source: Aither water allocation price model (2015 version).

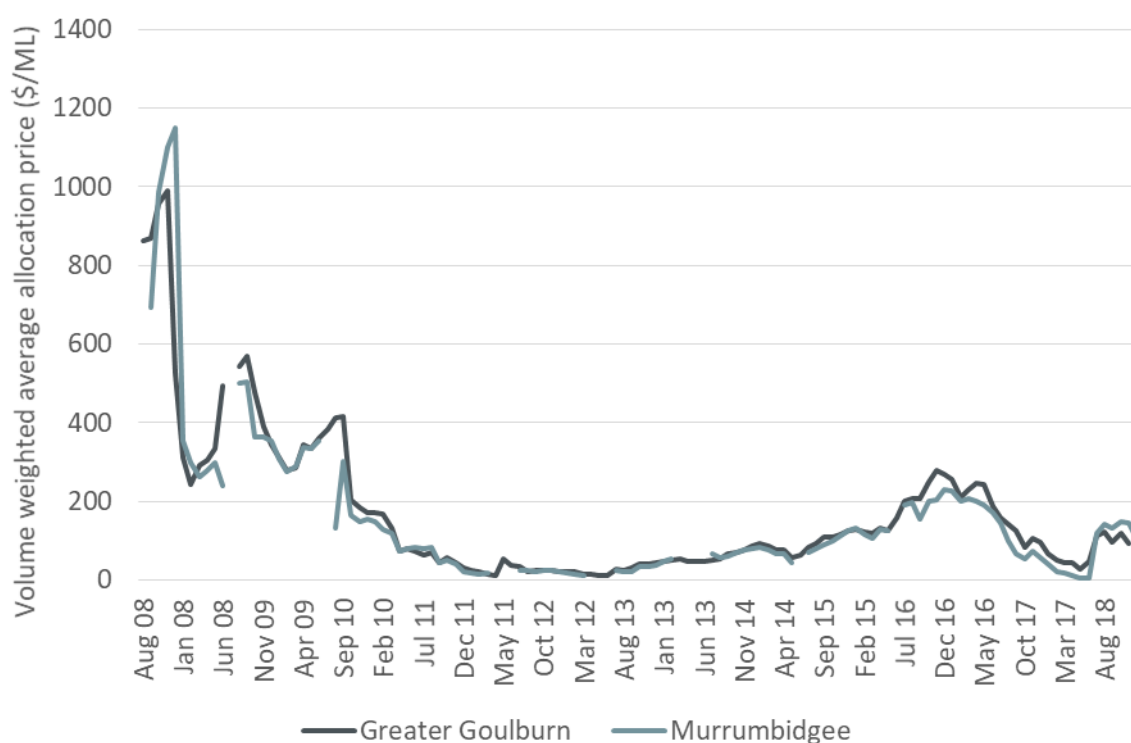
### 3.3.2. Entitlements

An increase in the price of water allocations (temporary water) will flow through to water entitlements (permanent water). The value of an entitlement is derived from anticipated allocations to the

entitlement and the values of those allocations, as well as considerations around risk. This is evident when examining the value of different entitlements, with more reliable entitlements having a higher value, all else equal. Entitlements in regions where allocations are scarcer also tend to be more valuable. This means that if on-farm WUE programs with entitlement transfer increase allocation prices, there will also be an increase in entitlement prices.

### 3.3.3. Allocation prices across southern connected systems

On-farm WUE programs with entitlement transfer in any part of the southern Murray-Darling Basin (sMDB) will tend to affect prices across the sMDB. This is because, although there are some significant constraints, water can generally be traded throughout the sMDB, as evidenced by prices being largely equalised in most years (Figure 12). The ability to trade throughout the sMDB means that decisions made about participation in on-farm WUE programs with entitlement transfer in New South Wales and South Australia are likely to affect Victorian farmers (or vice versa). For example, a reduction in supply relative to demand in the Murrumbidgee due to on-farm WUE programs with entitlement transfer would increase the prices in the Murrumbidgee leading to trade into the Murrumbidgee (in years when the inter-valley trade constraint is not preventing Murray to Murrumbidgee trade). This movement of water would increase prices in the rest of the sMDB, where there would now be fewer allocations available.



Source: Aither.

Note: Missing values indicate not recorded trades.

**Figure 12 Monthly average allocation prices in the Greater Goulburn and NSW Murrumbidgee**

### 3.4. Farm level impacts

The discussion above explains why on-farm WUE programs with entitlement transfer increase water prices. These price impacts are relevant for developing a full understanding of the socio-economic impacts.

Without accounting for higher water prices (and other feedback effects), the key impacts of on-farm WUE programs with entitlement transfer on irrigators are predictable (Column 1 of Table 3). Only irrigators who participate in the programs will be affected. Most importantly, profitability would tend to increase as participation is voluntary (assuming they make rational and informed decisions about future costs and benefits including water costs and the energy costs associated with modernised systems). Output would also generally increase due to lower production costs. The impacts on the use of inputs, including water, is ambiguous.

However, this is complicated by the feedback effect of higher water prices (Column 2 of Table 3). The feedback effect has an impact on all irrigators, irrespective of whether they participate in the programs. Higher water prices increase the profitability of irrigators who own entitlement and sell water and reduce the profitability of irrigators who need to buy water allocations. In Northern Victoria, there has been an increase in the proportion of irrigators who are reliant on the allocation market. These irrigators are likely to be the most adversely affected from higher water prices. Higher water prices reduce output and water use.

As is typical of industries with long lived assets, it could take many years before these the full effects are realised. From a structural adjustment perspective, the direct effect of on-farm WUE programs with entitlement transfer on participants is to slow structural adjustment to the extent that it increases the profitability of agriculture. By contrast, the water market effect on other irrigators tends to accelerate structural adjustment, which in some cases is already occurring at a rapid pace.

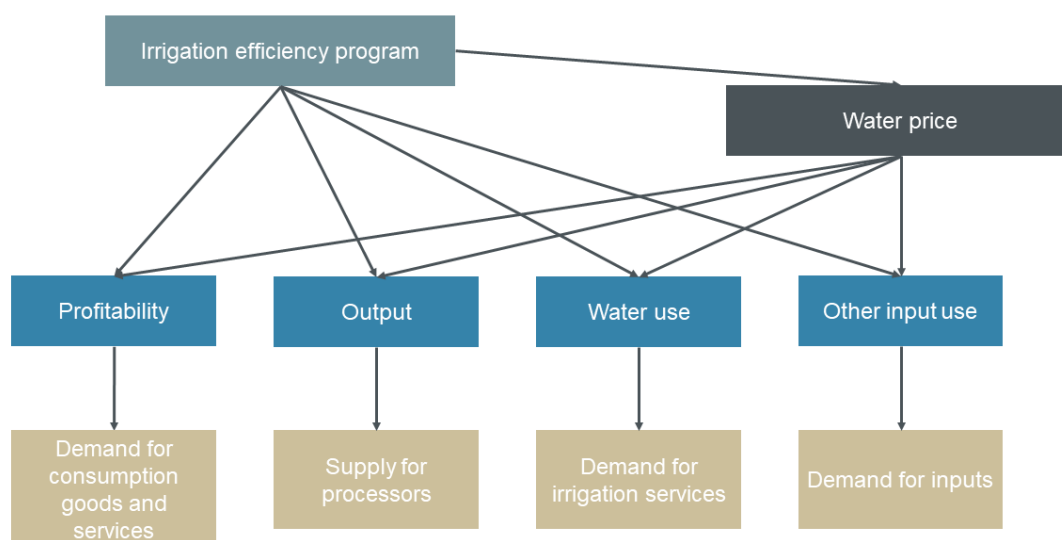
**Table 3** Impact of on-farm WUE programs with entitlement transfer on irrigators

	<b>Direct effect from technological change (program participants only assuming no feedback effect)</b>	<b>Water market effect from higher water prices (impacts on all irrigators)</b>
Profitability	Increase as participation is voluntary (although could decrease in some cases if irrigators underestimate future water prices)	Increase for water sellers and decrease for water buyers
Output	Increase due to lower production costs	Decrease due to higher production costs
Water use	Ambiguous due to effects outlined above	Decrease due to higher water prices
Other inputs	Could increase or decrease, depending on the changes in output and the input mix	Could increase or decrease, depending on the changes in output and the input mix

Source: Aither.

### 3.5. Cumulative flow on impacts

The agricultural impacts of higher water prices also have a number of well-established implications in other markets, both positive and negative (Figure 13) (Hone et. al. 2009; Frontier Economics 2010). For example, changes in the profitability of irrigation enterprises affects the incomes of farming households. This affects their demand for goods and services, such as restaurants and schools. Changes in irrigated output affects the supply available for processors. Changes in water use affects the demand for irrigation services provided by water corporations. There can also be implications for demand for farm labour and other inputs. In turn, these flow on impacts in other markets can have social impacts for local communities.



Source: Aither.

Note: Does not include all benefits and costs. For example, excludes costs of on-farm WUE programs not borne by irrigators and environmental benefits. See Hone et. al. (2009) and Frontier Economics (2010) for empirical evidence on the directions and magnitudes of these linkages.

**Figure 13 Conceptual model showing selected impacts of on-farm WUE programs with entitlement transfer**

## 4. Conclusions and implications

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### 4.1. Conclusions

Numerous authors have noted the possible water market impacts of on-farm WUE programs with entitlement transfer. This report has clarified the mechanisms involved, and more importantly, has provided evidence based on the experiences of participants and statistical analysis of data that water prices could increase materially if further on-farm WUE programs that require entitlement transfer are undertaken. Higher water prices would affect the profitability and decisions of irrigators, with implications for structural adjustment. The resulting changes in irrigated agriculture would have implications throughout the agricultural supply chain and for regional communities, both positive and negative. These changes would be occurring against a backdrop of growing underlying water prices and an increasing reliance by some irrigators on purchasing allocations.

This was a rapid assessment based on available data and further research would be valuable in refining estimates of the water market price impacts and quantifying the broader implications.

### 4.2. Implications

The findings of the report have important policy implications. In particular, water market impacts may be relevant in deciding whether to recover further water through on-farm WUE programs, and should certainly be considered in the design any future on-farm WUE programs that require entitlement transfer with a view to addressing the risk of stranded assets.

#### 4.2.1. Assessing socio-economic neutrality

The potential magnitude of the water market impacts identified in this report mean that on-farm WUE programs with entitlement transfer may not meet the requirement that 'the efficiency contributions to the proposed adjustments achieve neutral or improved socio-economic outcomes'. This depends in part on the definition of socio-economic neutrality.

Aither (2017) has previously recommended that Basin governments should develop an agreed definition of socio-economic neutrality that is consistent with the intent of the Basin Plan. Based on this definition, Aither recommended that an independent assessment should be undertaken into the materiality of the water market impacts (and flow-on effects) of upwater measures.

In the absence of other evidence on this topic, this report helps to fill this knowledge gap based on statistical evidence from historical on-farm WUE programs with entitlement transfer and based on Aither's water market modelling. Further work could be completed based on a more detailed assessment of any proposed program.

#### 4.2.2. The risk of stranded assets

The water market impacts associated with on-farm WUE programs with entitlement transfer identified in this report also increase the risk of stranded assets. Specifically, there is a risk that irrigators will make decisions to invest in on-farm WUE measures without adequately understanding the cumulative feedback impacts on water prices. It might be profitable for an irrigator to participate in on-farm WUE

programs with entitlement transfer if historical water prices prevail in the future, but if many other irrigators also upgrade water prices will increase and the same investment might be unprofitable.

Failure to adequately consider the feedback impacts on water prices (or the other factors already placing upward pressure on allocation prices) could lead to inefficient investment and in the worst case scenario, stranded assets. Put simply, there is a material risk that government may be co-investing in irrigation infrastructure designed to operate for decades on farms that will not be irrigating in comparatively short periods of time.

Stranded assets represent a poor outcome given the substantial public and private costs of investments in on-farm WUE measures. From a public perspective, this means less funding available for worthwhile government programs. From a private perspective, the costs associated with overcapitalisation could make the individual adjustment challenges faced by some on-farm WUE program participants more difficult.

The risk of stranded assets is compounded by the recent changes in supply (due to buyback and climate change) and demand (due to investment in horticulture and cotton) in the water market, which are also contributing to higher water prices. For context, Aither (2016c) projected an increase in water demand by horticulture and cotton in the southern Murray-Darling Basin of about 380 GL per year between 2015-16 and 2020-21. This is the equivalent of 630 dairy or rice farms that currently use 600 ML per year.

Given this underlying shift in water prices, even moderate additional increases in water prices due to on-farm WUE programs with entitlement transfer could have a significant impact on the profitability of upgraded farms. The design of any future on-farm WUE programs with entitlement transfer should be cognisant of the increased potential for inefficient investment, including stranded assets.



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# Appendix: Mathematical proofs

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Suppose a farmer has the following profit function per hectare:

$$\Pi = P_Q f(\alpha W) - P_W W - F \quad \text{if } W > 0 \quad (1)$$

$$\Pi = c \quad \text{if } W = 0 \quad (2)$$

Where  $\Pi$  is profit,  $P_Q$  is the price of output,  $f$  is the production function,  $\alpha$  is the proportion of water applied that reaches the crop,  $W$  is the water applied,  $P_W$  is the price of water,  $F$  are fixed costs of irrigated production, and  $c$  is the profit from dryland production.

We now want to find the profit maximising water demand  $W^*$  for a given  $\alpha$ .

## First and second order conditions

The first order condition is:

$$\frac{\partial \Pi}{\partial W} = \alpha P_Q \frac{\partial f(\alpha W)}{\partial W} - P_W = 0 \quad (3)$$

This says the marginal value product of  $W$  must equal the marginal cost of  $W$ .

If the production function is concave the second order necessary condition will also hold.

Solving this equation for  $W$  gives  $\hat{W}$  the optimal interior water application, which depends on the production function and the parameters in the model, including  $\alpha$ .

## Total condition

The total condition is:

$$P_Q f(\alpha \hat{W}) - P_W \hat{W} - F \geq c \quad (4)$$

$$P_W \leq \frac{P_Q f(\alpha \hat{W}) - F - c}{\hat{W}} \quad (5)$$

This says that the price of water must be less than the average value of  $W$ , accounting for the opportunity cost of land.

Hence:

$$W^* = \hat{W} \quad \text{if } P_W \leq \frac{P_Q f(\alpha \hat{W}) - F - c}{\hat{W}} \quad (6)$$

$$W^* = 0 \quad \text{if } P_W > \frac{P_Q f(\alpha \hat{W}) - F - c}{\hat{W}} \quad (7)$$

## Effect of on-farm WUE on water demand

### Marginal effect

There are two ways in which on-farm WUE affects the marginal net benefit from increasing  $W$ . This is evident from (3) which shows that as irrigation efficiency increases more of the water applied reaches the crop, which increases the marginal net benefit. At the same time, the water that reaches the crop becomes less valuable because of diminishing returns in the production function, which reduces the marginal net benefit. The overall effect is ambiguous, and hence  $\hat{W}$  could increase or decrease.

However, we do know that if  $\hat{W}$  decreases, the decline will be less than water savings.

The marginal net benefit from increasing  $W$  will increase as irrigation efficiency increases, assuming that water savings are returned to the government if:

$$\alpha'' P_Q \frac{\partial f(\alpha'' W'')}{\partial W} - P_W > \alpha' P_Q \frac{\partial f(\alpha' W')}{\partial W} - P_W \quad (8)$$

Water savings  $S$  are defined as the reduction in  $W$  required to keep output constant when  $\alpha$  is increased. Hence:

$$\alpha'' W'' = \alpha' W' \quad (9)$$

and

$$\frac{\partial f(\alpha'' W'')}{\partial W} = \frac{\partial f(\alpha' W')}{\partial W} \quad (10)$$

As a result (8) cancels to  $\alpha'' > \alpha'$ , which holds by assumption.

This rebound effect is created because more of the water applied reaches the crop.

### Total effect

We also know that the average value of  $W$  must increase.

This will apply if the following condition holds:

$$\frac{P_Q f(\alpha'' \hat{W}) - F - c}{\hat{W}} > \frac{P_Q f(\alpha' \hat{W}) - F - c}{\hat{W}} \quad (11)$$

This cancels to  $f(\alpha'' \hat{W}) > f(\alpha' \hat{W})$ , which will apply as long as we are not operating on the part of the production function where increasing the volume of water received by the crop reduces output.

### Implications

This shows that irrigation efficiency investments have behavioural effects. Irrigators who upgrade their infrastructure will irrigate more often, and when they do irrigate their water use will fall by less than the projected water savings. The changes in demand and supply of water in the consumptive pool will result in higher prices. This will affect both allocations and entitlements. The question is one of magnitudes, which is the focus of the empirical analysis.

## Assumptions

The main assumption in this analysis is that irrigators are profit maximising. Many irrigators do think explicitly about the average value of water in their decision making. Those that do not will have to behave as though they do to remain in business.

The results do not depend on specific assumptions about the type of infrastructure project, industry or production function.

# Document history

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