# Distinguishing Between Policy, Drought and International Events in the Context of the Murray Darling Basin Plan

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# Distinguishing between policy, drought and international events in the context of the Murray Darling Basin Plan

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March 2020

***Abstract***

This study starts by examining the background economic circumstances of the 2007 Water Act and the 2012 Murray Darling Basin Plan. During the 1990s, a competitive Australian dollar contributed to an expansion of some sectors in the Murray Darling Basin, notably wine grapes. From the turn of the millennium, two adverse background events brought difficulties for agriculture in the Basin. First, the millennium drought resulted in reduced irrigation water allocations and contributed to diminished dry-land productivity, notably in 2002-03 and from 2006-07 to 2008-09. Second, the Australian dollar appreciated markedly relative to levels of the 1990s in the wake of the mining boom. This diminished returns to agriculture.

In the context of background difficulties, there were mixed responses in Basin communities to the Water Act (McCormick 2007). Some farmers embraced the financial option that arose from proposed buybacks, using proceeds as an opportunity to restructure or retire. Others regarded buybacks as a threat to the viability of Basin communities. Using TERM-H2O, a multi-regional CGE model of Basin regions, previous studies showed that the marginal impacts of buybacks are second-order relative to drought, and can even be positive.

A change in political direction has resulted in a suspension of water buybacks, regarded by economists as the cheapest mechanism to increase environmental flows. The Basin Plan is at present concentrating on infrastructure upgrades. An updated version of TERM-H2O shows that a $4 billion program on upgrades between 2020 and 2024 to procure almost 500 GL of water for the environment would result in a net present value (NPV) welfare loss of $1.1 billion. The investment in upgrades increases jobs in the Basin by around 1000 relative to no investment for each of the five years of upgrades. Thereafter, Basin jobs increase by around 100 relative to no upgrades, based on estimated productivity gains arising from the upgrades.

This study also models the marginal impacts of increased public spending of $4 billion over 10 years on services in the Basin. This is treated as a substitute for infrastructure upgrades. In this scenario, the same volume of water rights, almost 500 GL, is set aside for environmental purposes. Each dollar spent on education, health and community services creates four times as many jobs as spending on infrastructure upgrades. That is, jobs in the Basin rise relative to base by between 1,800 and 2,100 over the decade of additional spending. The NPV of the welfare loss is $0.125 billion.

JEL: Q15, C68
Keywords: irrigation reforms; environmental flows, regional economic impacts

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***Contents***

## 1. *Hard times in the Murray-Darling Basin in the new millennium*

Several events have impacted adversely on the Murray-Darling Basin in recent decades. These include:

(1) The millennium drought, first in 2002-03, and then, particularly in the southern Basin, from 2006-07 to 2008-09;
(2) The soaring Australian dollar due to the mining boom from 2007 to 2015;
(3) Ongoing structural change and regional access to services; and
(4) Unforeseen international events

We examine each of these in turn.

### (1) *The millennium drought*

Wittwer and Griffith (2011) modelled the impact of drought in the southern Murray-Darling Basin using an earlier version of TERM-H2O. In the Central Murray region (based on now-defunct statistical sub-divisions), in which agriculture accounted for 22% of regional income (based on the 2006 census), the modelled decrease in real GDP relative to no drought was 19.7%. Over 13% of this loss arose in agriculture, with a further 4.9% arising from net water imports, necessary to sustain perennials. Food processing, through a decline in inputs, and services, via a decline in regional spending, accounted for the remainder of the loss. The Lower Murrumbidgee region suffered a 10% loss in real GDP. Agriculture's contribution of 13% was greater than the overall real GDP, made possible because net water sales contributed a positive 3.8% to the change in real GDP.

Key points from the modelling were that the aftermath continued from drought for years after, with depressed investment. Drought-induced job losses in the southern Murray-Darling Basin were around 6,000, but even several years after recovery, jobs remained around 1,500 below base due to a diminished farm capital base. A conclusion of the study was that a high Australian dollar would be a greater concern than either drought or water buyback policy in years subsequent to 2011.

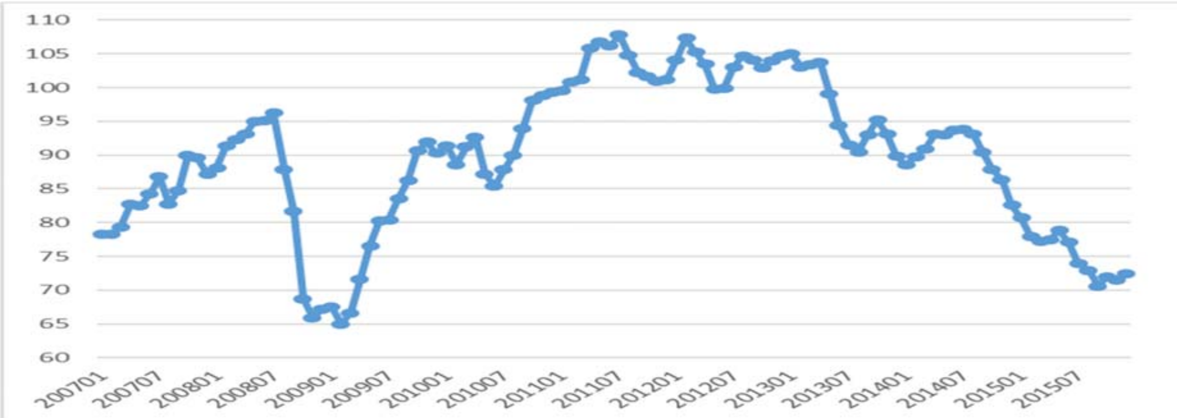
In retrospect, by the time a high dollar had become less of an issue after 2016, drought conditions returned. The period from 2017 to 2019 saw record rainfall deficits across much of the Basin (figure A2). In addition, temperatures were higher than during the years of the millennium drought, worsening effective rainfall deficits.

### *(2) The soaring Australian dollar due to the mining boom from 2007 to 2015*

Australia's agricultural output is highly exposed to international competition. In the 108 months from January 2007 to December 2015, the Australian dollar traded at a monthly average exceeding US80c for 86 of those months (figure 1).

Contrast this with the period from January 1991 to December 2006. The Australian dollar did not reach US80c in a single month out of the 192 months in this time (figure 2). Many industries took advantage in this time of the low dollar to expand and launch export sales. For example, Australia's vineyard plantings increased from 60,000 hectares to 167,000 hectares. Wine exports as a share of production volume rose from less than 14% in 1991 to over 50% in 2006.

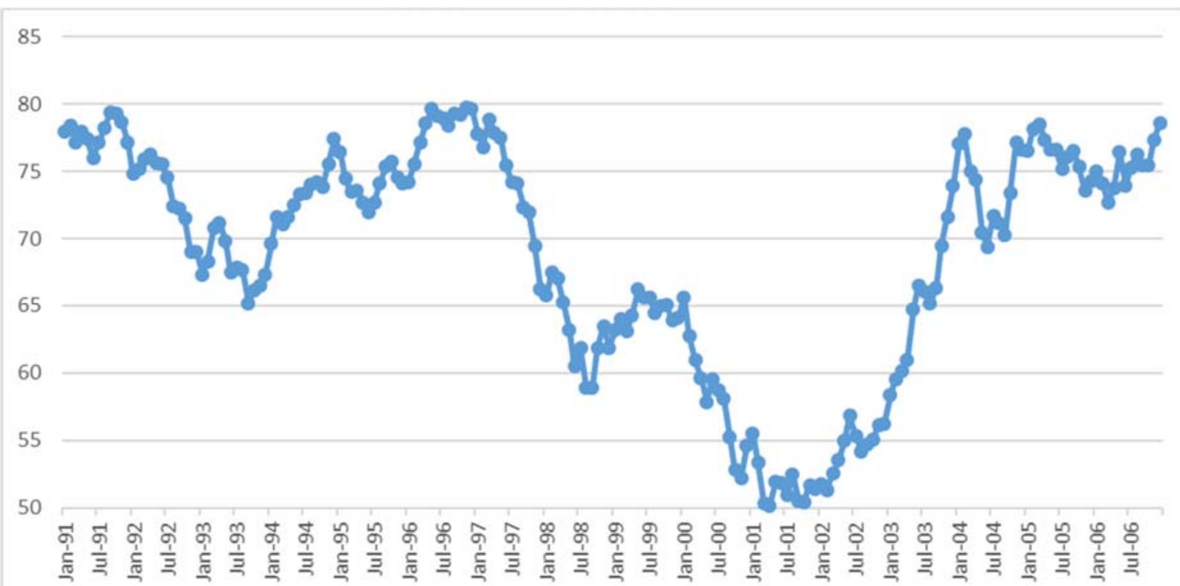
**Figure 1: The US/AUS exchange rate, 2007 to 2015**




Source: http://fx.sauder.ubc.ca/cgi/fxdata

There was stark contrast in the following years. A combination of prolonged drought from 2006 to 2008 and a stronger dollar thereafter lowered returns to grape-growers. From being a shining light in export expansion, the wine industry struggled with a loss of competitiveness as the mining boom strengthened the Australian dollar. Drought diminished water allocations, raising the costs of grape productions as prices fell. Consequently, national plantings fell to less than 150,000 hectares by 2012 (Anderson and Pinilla, 2017).

**Figure 2: The US/AUS exchange rate, 1991 to 2006**




Source: http://fx.sauder.ubc.ca/cgi/fxdata

*(3) Ongoing structural change and access to services*

In the early 1950s, agriculture's share of GDP in Australia was around 20%. At the time, the national population was less than 9 million. Now, the national population exceeds 25 million and agriculture's share of GDP is well under 3%. In the Murray-Darling Basin, agriculture's share of regional income in 2015-16, based on the 2016 census, was less than 19%. That is, the Murray-Darling Basin, perceived by many as the food bowl of Australia, is now less farm-intensive in its total economic structure than all of Australia was in the early 1950s. Some of this structural change is a success story: Australia's farm productivity has grown since the 1950s, with labour requirements falling markedly.

Downstream processing of food and beverage products in the Basin accounts for around 5.5% of the income base of the Basin. That leaves three-quarters of the income base of the Murray Darling Basin in industries other than agriculture and downstream processing. With a changing economic structure over time, citizens in and out of the Basin are increasingly dependent on services. Quality of life depends on adequate access to various services. These include health, education, child care, aged care and recreational services. Provision of may of these services is heavily dependent on public funding. With any diminution of such funding, the Basin is vulnerable to disadvantage relative to other regions.

Basin inhabitants should be wary of public spending programs which move the emphasis away from the provision of scarce services in the region.

*(4) Unforeseen international events*

The dairy sector, which uses around one-sixth of the irrigation water in the Basin in a normal year, suffered during the millennium drought as water became scarce. Some dairy farmers sold their diminished annual allocations during drought, using the proceeds to buy in stock feed. This adaptation enabled them to make the best of difficult circumstances. Regions outside the Basin had stock feed available at prices low enough to make the trade viable.

Circumstances have changed. Russian-backed rebels shot down Malaysian Airlines flight 17 over eastern Ukraine in July 2014. The European Union imposed trade sanctions on Russia in response. Russia retaliated by banning all imports from Europe. Europe's biggest market for dairy products before the ban had been Russia. Russia also banned Australian imports. These actions pushed global prices for dairy products down, adversely affecting the profitability of dairy farms (Brooks 2016). Even without the drought that crept over the Basin in 2017 and worsened in 2018 and 2019, dairy farmers would have struggled given the MH17 disaster.

## ***2. Confusing policy and catastrophe***

In an adverse event such as drought, critics will assign blame for economic losses to a coincident policy, in this case, the 2007 Water Act (Australian Government 2007). Community opposition to the Water Act may have arisen from structural stresses that farmers were experiencing at the time. Through 2007, the Australian dollar rose steadily and drought was worsening in the Basin. Farmers and communities were under stress as jobs were being lost due to drought and declining international competitiveness. An unintended consequence of the Water Act is that some farmers felt during a time of stress that they were being treated as part of the problem rather than part of the solution.

The two main spending components of the 2007 Water Act were Commonwealth buybacks of irrigation water rights and public spending on infrastructure upgrades. Let us examine buybacks first. We note that buybacks were fully compensated at market prices and voluntary. Some contest the notion that buybacks were voluntary on the basis that some farmers were compelled to sell water rights due to financial stress. The alternative was potential bankruptcy.

Without any quantitative analysis, we can infer that if farmers sell water rights voluntarily at market prices, they are no worse off due to the buyback process. TERM-H2O modelling (Dixon *et al*., 2011) revealed that far from depressing Basin regions, buybacks actually resulted in a small increase in overall spending.

Dixon *et al.*'s modelling showed an expected reduction in irrigation farm output, with some losses alleviated by increased water trading. Water moved to irrigation activities in which it was more valuable as it became scarcer due to buybacks. In practice, some chose to make more efficient use of capital by leasing access to water allocation rather than owning water rights. However, the reduction in irrigation output in a normal year was partly offset by an increase in dry-land output in the Basin with a transfer of some farm factors into dry-land activities. The unexpected model result that buybacks increase Basin household spending relative to no buybacks arises because the Commonwealth's purchases raise the price of water by reducing the volume available for economic uses. Since irrigators are the initial holders of water rights, they benefit from the rise in water price. Overall, there is a net export of water from irrigators to the Commonwealth, and the increase in water price contributes to a terms-of-trade gain for farmers.

Some critics of buybacks at the time asserted that they were equivalent to a permanent drought. The record rainfall event in the two years 2011 and 2012 drowned out this criticism. However, we can compare the direct impacts of drought alongside buybacks (table 1). Drought diminishes dry-land productivity, rainfall on irrigated land and water allocations. There is no direct compensation and the process is involuntary. Buybacks provide a stark contrast: they are fully compensated and voluntary. A volume of 3500 GL proposed early in the process would have reduced water available for irrigation by around 32%, implemented over a number of years so that farmers could gradually introduce water-saving measures, lessening the impact of buybacks on irrigated output.

**Table 1: Estimates of direct impacts of drought and buybacks on Murray-Darling Basin farming**

| | Drought 2007-08 relative to base[a] | Fully implemented buybacks (3500 GL) relative to forecast |
|---|---|---|
| Dry-land productivity | -20% | 0 |
| Irrigation: rain | -52% | 0 |
| :water | -52% | -32% |
| Compensation | No | Full |
| Process | Involuntary | Voluntary |

a Scaled to Basin-wide impacts from estimates of southern Basin impacts reported in Wittwer (2011).

Some groups including the NSW Irrigators' Council did not believe the modeled result that the impact on southern Basin farm output would be small with fully implemented buybacks (NSWIC 2010). Their argument was that with the rise in the price of water, producers would lose competitiveness in international markets. But in addition to modelling an increase in the price of water of around $100/ML, TERM-H2O results also indicated a fall in the rental on irrigated land which largely offset the water price increase, so that the impact on total costs of production was minor (Dixon *et al*., 2011).

In passing, it also needs to be noted that prior to the Water Act, state legislation put the environment first and required water administrators – if the environment was at risk – to simply reduce allocations without compensations. This is why when the extent of MDB over-allocation was recognized in 1999, the Murray Darling Basin Commission contracted a CSIRO-led team to assess the social and economic consequences of taking an average of 1500 GL of water from the Southern Connected River Murray water users without compensation (Young et al 2002).

To summarise, there appear to be several reasons why buybacks have become a scapegoat for hard times among some people within Basin communities. First, the 2007 Water Act may have conveyed the impression among those concerned for the health of the river that farmers were the problem in the Basin. Second, the Act was introduced at a time when Australian farmers were losing international competitiveness due to a soaring Australian dollar resulting from the mining boom. Third, when the Act was introduced the Basin was in drought. Droughts are always associated with community stress. No matter how conditioned and how resilient these communities, when water is scarce these communities must always be expected to be wary of any policy changes – even though unbundling and more speedy trading arrangements was, in theory, enabling them to cope more easily.

### *3. A case for public provision of infrastructure upgrades*

The historical methods used to establish irrigation schemes in Australia were not efficient. These included soldier settlement schemes introduced after each world war. Such schemes were likely to be inefficient because they assumed that returned soldiers would make able farmers. For some returned soldiers this may have been so, but for others, such schemes may have resulted in a mismatch of skills, aptitude and vocation. For decades, irrigation crops were subjected to heavy protection in Australia. However, the past few decades have seen substantial reforms with the removal of protection. Australian producers in the Basin are exposed to the vagaries of international markets.

Irrigation has enabled the establishment of plantations on land that otherwise would not receive sufficient rain to sustain perennials. It has resulted in flexible farm technologies. For example, in wet years the relative abundance of water ensures that rice production is profitable.

Council of Australian Government (COAG) reforms have resulted in the separation of land and water rights. The establishment of water trading markets has enhanced flexibility within the Basin. Indeed, the millennium drought was a severe test of the resource allocation within the Basin. One issue that arose during the millennium drought was the vulnerability to reduced water allocations that arose from the extent of perennial plantings. At the time, a rapid expansion in vineyard plantings fueled by a low dollar and high grape prices in the late 1990s resulted in water shortfalls towards the end of the millennium. Water trading was a necessary mechanism to cope with drought but excessive perennial plantings may make it impossible to satisfy all water requirements as water allocations drop.

The historical context of irrigations scheme itself is an example of policy-induced market failure. Another example of market failure might be that some water infrastructure is shared by many users. This applies to both irrigation works and town water supply infrastructure. There may be justifications on the basis of market failures for some public spending on infrastructure upgrades. However, infrastructure upgrades are not included in the federal budget, because they are regarded as part of capital rather than current expenditure. As capital works, they should be subjected to similar cost-benefit analysis as other projects. It is highly probable that if subjected to similar analysis as other projects, the spending on upgrades would be a fraction of total past and proposed future spending.

Significantly and as a result of National Competition Policies, the now largely abandoned National Water Initiative's risk assignment and water pricing arrangements, water supply utilities were turned into corporations, full-cost pricing was introduced and entitlement holders required to accept the full costs of dealing with climate change, season variability and meeting any environmental targets set before 2014. In return, States were required to unbundle water entitlements and issue access entitlements in perpetuity rather than for a limited period of time.

### 4. *Getting the rules sorted out*

Despite COAG reforms, one of the barriers to effective implementation of water policy in the Murray Darling Basin concerns potential conflicts between Commonwealth and state policy. Significantly, the Commonwealth wanted to play a larger role and, as a result, introduced a new Commonwealth Water Act and, in order to be allowed this role, offered to make $10 billion available to take over responsibility for the management of the Basin. Significantly, States accepted this offer on the condition that an independent Murray Darling Basin Authority rather than a Commonwealth Minister would be responsible for preparing a Basin Plan and the Federal Department responsible for securing environmental water entitlements. These initiatives – often incorrectly described as part of the Basin Plan rather than the broad constellation of arrangements used to reform water use –allowed the Commonwealth funded expansion of storage capacity and capture in the northern Basin. Queensland and New South Wales were, however, slow to place a cap on and begin metering water use in much of the Darling's unregulated system.

The Menindee Lakes fish kills in 2019 in part reflected the volume of water removed upstream by irrigators at a time of encroaching drought. In retrospect, given the severity drought from 2017 until 2019 in the northern Basin, the Menindee Lakes fish kill may have occurred eventually even with smaller volumes being extracted upstream. Nevertheless, this environmental disaster brought the Basin Plan to national attention underpinned also by an ABC Four Corners program that drew attention to the extent of water theft in the Northern Basin. Given the political dimension of these oversights, it may take years before trust and respect and health returns to the system.

### 5. *Appropriate instruments to address policy issues*

Dixon et al. (2011) showed that buybacks reduce farm output in the Basin by a small percentage, and that buyback proceeds are potentially beneficial to Basin regions. Wheeler and Cheesman (2013) presented details of the motivations of farmers for selling water to the Commonwealth. Buybacks remain the most efficient way of procuring water for the environment, yet have entered folklore as damaging local economies and without any recognition of the value of many of the other reforms made during the first decade of this century. This is despite the willingness of farmers to participate in the buyback program and sell water to the Government on the understanding it would be placed in the hands of the Commonwealth Environmental Water Holder. Instead, political leaders and industry representatives worked tirelessly to use buybacks as a scapegoat for woes in the Basin instead of recognising that, since the turn of the millennium, adverse economic forces and seasonal conditions were the prime cause. This culture has cast aside the analysis of experts in their respective fields.

Structural change has been necessary in view of adverse seasons, an unfavourable exchange rate, international trade sanctions and improvements in technology. An appropriate public response to stress within and outside the Basin to adverse impacts in agriculture is to address market failures and welfare considerations.

This study presents two sets of results. The first examines the consequences of investing of $4 billion of infrastructure upgrades in the Basin in order to obtain environmental water. The second imposes a similar diversion of water away from economic uses to the environment while spending an additional $4 billion in the Basin on services.

## *6. Scenario 1: Modelling of proposed infrastructure upgrades from 2020 to 2024*

The scenario depicted in this study allocates $800 million of infrastructure upgrades to Murray-Darling Basin regions in each of five years from 2019-20 to 2023-24. The objective is to increase efficiency in irrigated agriculture and town water usage so nearly 500 GL of irrigation water entitlements are diverted for environmental purposes. Investments at the regional level have been mapped from data provided by Marsden Jacob at the natural resource management region (NRM) to SA3 regions within TERM-H2O.[3]

The productivity of irrigation agriculture rises successively from 2021 to 2025. ABARES provided estimates of increased outputs. We assumed that three-quarters of the increased irrigation output estimated by ABARES was due to factor transfers and one quarter due to productivity gains.

**Figure 2: Macro impact, Murray Darling Basin, scenario 1**
(% deviation from base)

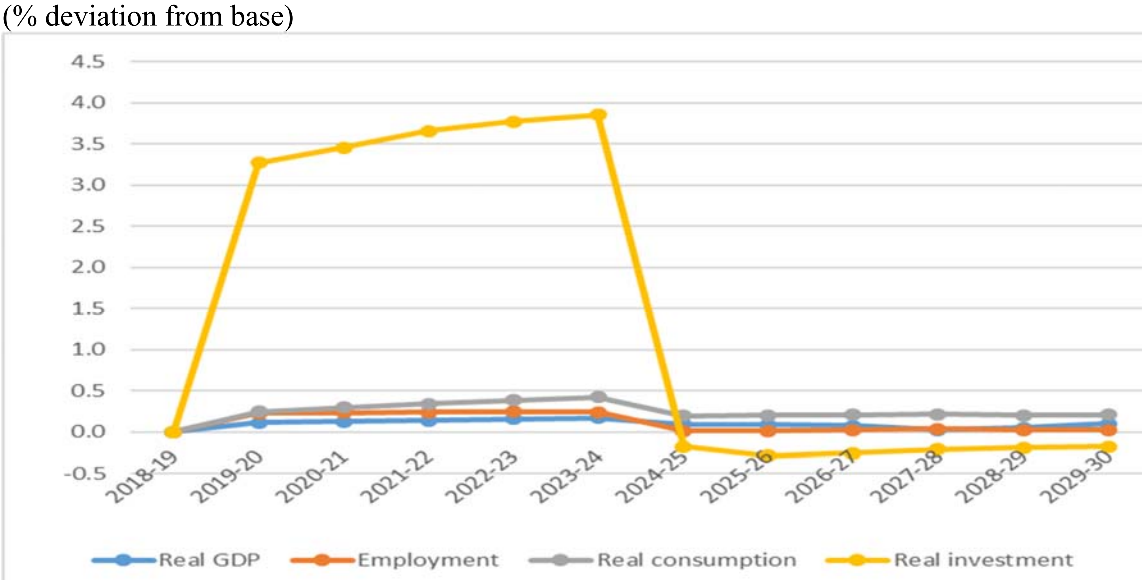
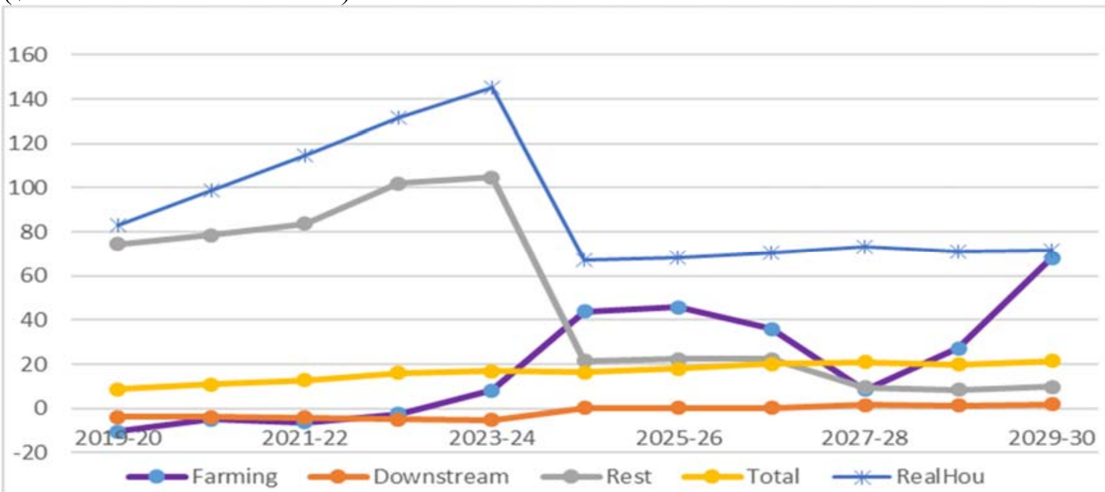



Figure 2 shows percentage deviations in Basin-wide macro variables. The investment phase raises Basin-wide investment by around 3.5% above forecast. At the same time, Basin-wide employment rises by around 0.25% or around 1000 jobs. Once the investment phase has ended and almost 500 GL of water rights allocated to the environment, employment moves back towards base. From 2024-25, Basin-wide employment increases by around 100 jobs relative to the base.

[3] Tables A2 and A3 show assumed year-on-year rainfall and dryland productivity.

**Figure 3: Value-added by broad sector and aggregate consumption, Murray Darling Basin, scenario 1**
($m deviation from the base)




During the investment phase, there are small farming output losses relative to the base. This reflects the removal of some irrigation water from economic purposes.

From 2024-25 to 2026-27, farm value-added in the Basin rises above the base by around $20m (figure 3). That there is a decline in 2027-28 and 2028-29 reflects two years of severe drought, in which the productivity gains in irrigated sectors are more than offset by reduced availability of water under the plan. In drought, the marginal product of water is many-fold higher than in normal years, so that there are farm output losses relative to base due to water being removed from irrigation.

In some regions, irrigation output declines. This is because irrigation productivity gains are offset partly by reductions in water allocations but mostly by water trading. Griffith and Wagga include relatively large production of irrigated annuals. Reduced water allocations have the effect of pushing up water prices and pushing annual producers, whose shares of total irrigation production in these two regions are relatively large, towards trading.

Figure 4 illustrates the marginal impacts of policy for one region, Murray River-Swan Hill, relative to modelled year-on-year seasonal variations. Figure 5 repeats the comparison for the entire Basin. These figures show that the impacts of substantial infrastructure spending in the region and eventual productivity improvements relative to base are small compared with seasonal variations.

**Figure 4: Value-added by broad sector and aggregate consumption, Murray River –Swan Hill**

($m year-on-year changes due to seasonal variation) ($m deviation from the base due to infrastructure upgrades)

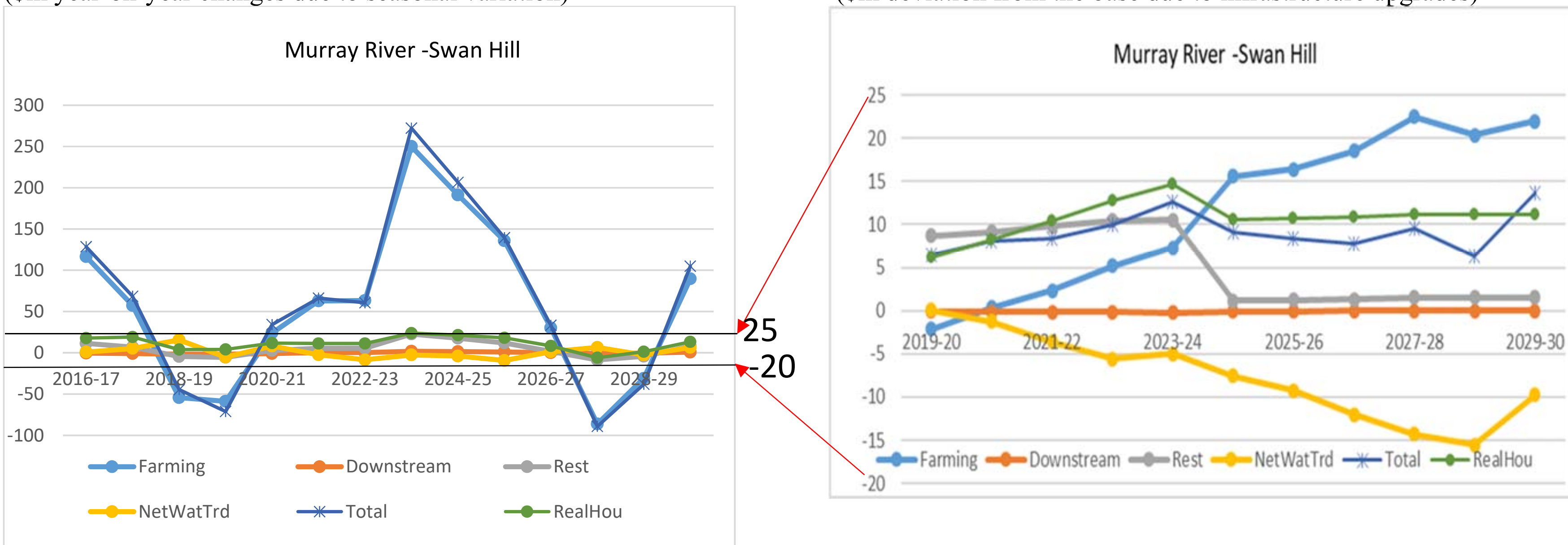
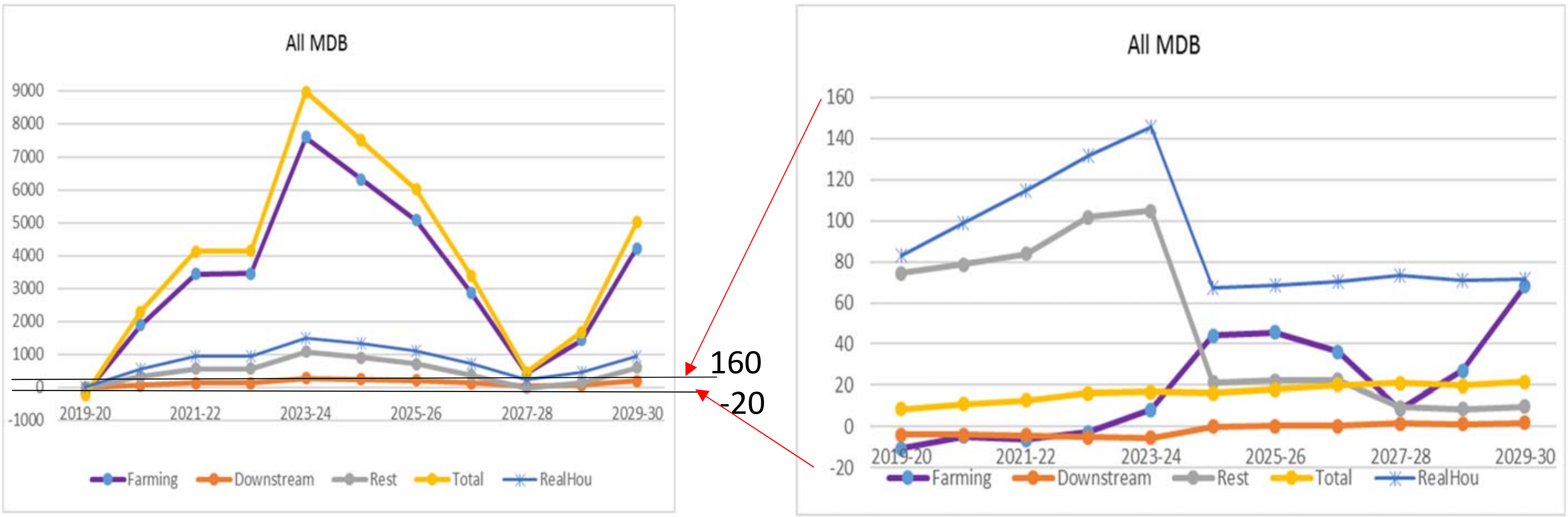


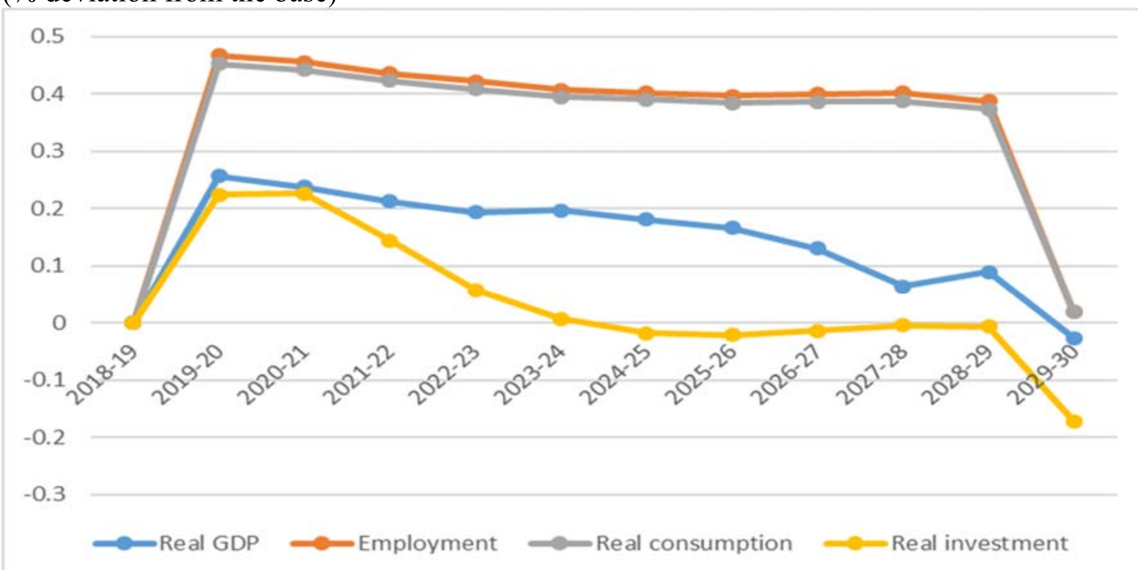
**Figure 5: Value-added by broad sector and aggregate consumption, all Murray Darling Basin**
($m year-on-year changes due to seasonal variation)



The annualised welfare impact of the upgrades from a national perspective is minus $45 million. If we use the usual NPV calculation (of deviation in current consumption minus the real discounted increase net foreign liabilities in the final simulation year), the welfare loss is $1.1 billion. That is, public spending of $4 billion results in a welfare loss that is a substantial proportion of the money spent.

## 7. *Scenario 2: Modelling of increased funding of services in the Basin from 2020 to 2029*

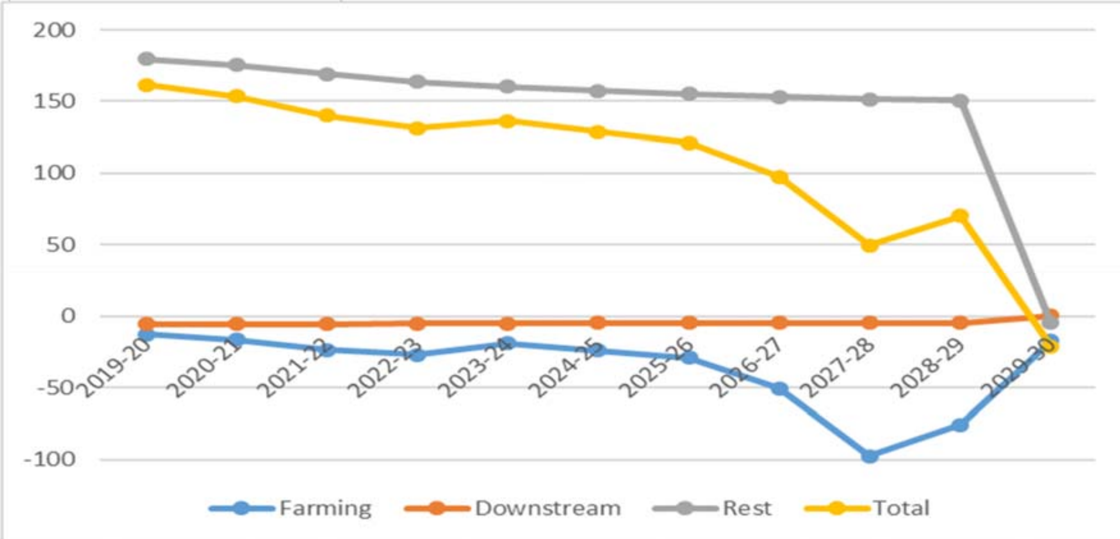
**Figure 6: Macro impact, Murray Darling Basin, scenario 2**
(% deviation from the base)




In this scenario, Basin regions receive $4 billion over 10 years, allocated by region to the same dollar amounts as the infrastructure spending total over 5 years in scenario 1.[4] Almost 500 GL of water rights are removed from economic use. This time, the funds target services, namely health, education and community care. This spending has immediate regional benefits. Real GDP in the Basin rises to around 0.4% above base for all years of the decade in which the spending occurs. Employment initially rises by 2100 jobs in 2019-20 relative to the base. That is, half the dollar amount of infrastructure spending results in twice as many jobs. The employment gain relative to base tapers off slightly over time, so that in 2028-29, the final year of additional services spending, Basin jobs are around 1800 above the base. The finding that spending on relatively labour-intensive services creates four times as many jobs per dollar spent as comparable spending on infrastructure upgrades is consistent with Wittwer and Dixon (2013).

[4] This may not be a realistic level of additional spending. The Basin accounts for 3.8% of the national economy. If we assume that such spending were extended to all regions except the mainland capital cities on a per capita basis, it would cover one-third of the national population, requiring additional spending of around $3.5 billion per annum over a decade. This gives some perspective on the magnitude of funding that might be required with infrastructure upgrades.

**Figure 7: Value-added by broad sector, Murray Darling Basin, scenario 2**
($m deviation from the base)




In this scenario, there is an unambiguous decline in farm output relative to base due to the removal of water from economic uses between 2019-20 and 2024-25 (Figure 7). Again, in the drought years of 2027-28 and 2028-29, the losses are larger. But there is also an unambiguous gain in Basin income, driven mainly by an increase in services value-added. When additional funding ends, as in 2029-30, activities in services sectors return to near base.

The annualised welfare impact of increased public spending on Basin services plus removal of 500 GL of water from irrigation is minus $5 million. The NPV calculation of the welfare loss is $0.125 billion, but a small fraction of the $4 billion spent. This welfare loss is close to the value of annual foregone farm production in the Basin. It is a much cheaper way of obtaining water for the environment than infrastructure upgrades and provides a much better use for public funds by bolstering scarce services in Basin regions.

## *8. Conclusion*

The theoretical problem with infrastructure upgrades is that they seek, with a single instrument, to address two policy objectives at once, namely to provide water for the environment and to maintain jobs and incomes within the Basin. It would be more efficient to use two separate policies. Buybacks are a relatively efficient means of increasing environmental water flows and are much cheaper than upgrades. Increases in public funding of services within Basin regions will create many more regional jobs than upgrades. The contrast between the national welfare impacts of infrastructure funding relative to setting water aside for the environment while increasing services spending is extreme. In the infrastructure upgrade scenario, $4 billion of public spending results in a welfare loss of $1.1 billion. This is nine times greater than the $0.125 billion welfare loss associated with the alternative “two instruments” scenario.

A further adverse consequence of subsidising water infrastructure within the Basin is that it results in overinvestment in certain farm activities. In particular, the Basin is now over-exposed to almond plantings. Although at present prices, almond plantings are providing high rates of return, it has come at the expense of flexibility. That is, with too many hectares of permanent plantings, the Basin’s annual water allocations in drier years may be too low to cover the water requirements of perennials. Moreover, almond plantings have pushed up the price of water within the Basin, thereby impacting on the profitability of the producers of other perennials who wish to buy temporary water in drier years.

## Appendix

*Preparation of a suitable CGE model for Basin scenarios: TERM-H2O*

Water use by crop varies substantially across the Basin, driven by changes in seasonal conditions, water allocations and farm output prices. In the drought of 2002, water use in rice production dropped by more than 70% relative to the previous year. In 2008, water used in rice production was only 2% of that in 2006 (ABS cat. 4618.0). The challenge in devising TERM-H2O (Dixon et al., 2011) was to come up with a theory that tracks approximately changes in water use in response to changes relative water scarcity .

Table A1 shows the extent of variation in water availability across the Murray-Darling Basin from 2007-08 to 2017-18. The data shown in the table includes updates from earlier studies (Dixon et al. 2011; Wittwer and Griffith 2011), including the relatively wet years of 2010-11 and 2011-12. The additional years of data serve to illustrate features of TERM-H2O that are useful in both dry and wet years.

2008-09 was the last season of the millennium drought in the southern Basin; in the northern Basin, the drought broke early in 2008. The water price shown reflects temporary water trades in the southern Basin. The water price reflects current water availability, rainfall conditions and farm output prices. For example, in 2007-08 prior to the GFC, a biofuels boom drove up crop prices and the marginal product of water with it. Table A1 (row 13) shows that the water price in 2008-09 was $298/ML with drought still prevailing in the southern Basin, whereas in the previous year it was $680/ML prior to the GFC-induced collapse in commodity prices. Rice is the most water-intensive of crops grown in the Basin and therefore the most responsive to changes in water price. In the past decade or so, the volume of water used in rice production has varied from 27 GL in 2007-08 to 1434 GL in 2012-13 (Table A1, row 3).

Turning to perennials, water used for grapes dropped below 400 GL only in the La Nina years 2010-11 and 2011-12, when rainfall was sufficiently high to reduce irrigation requirements (Table A1, row 6). The upward trend in water used by other perennials reflects a substantial increase in almond plantings since 2007.[5]

Table A1 also shows water used in pasture, hay and silage (row 8). These feed products are either inputs into livestock production locally, or are sold outside the Basin. The table shows a 40-fold difference in the price of water between 2007-08 (i.e., $680/ML) and 2011-12 ($16/ML) (Table A1, row 13). Even in a drought when the price of livestock feed rises, it is highly probable that a livestock farmer within the Basin would gain by selling water to fund feed purchases instead of using scarce water to grow on-farm livestock feed. Dairy farmers in the drought years up to and including 2019 did not regard this as an option due to depressed output prices.

[5] See http://growing.australianalmonds.com.au/wp-content/uploads/sites/17/2014/06/ Australian-Almond-Insights-2013-14-LR-WEB.pdf (accessed 29 August 2016).

**Table A1: Water use in the Murray-Darling Basin**

| Year | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 | 2014-15 | 2015-16 | 2016-17 | 2017-18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Area irrigated ha*10^6 | 1.0 | 0.9 | 1.0 | 1.2 | 1.4 | 1.6 | 1.6 | 1.4 | 1.2 | 1.4 | 1.5 |
| 2 Not irrigated ha*10^6 | 94.6 | 95.1 | 94.2 | 83.8 | 93.6 | 88.4 | 89.1 | 87.8 | 82.8 | 88.7 | NA |
| Crop | Water used (GL) | | | | | | | | | | |
| 3 Rice | 27 | 101 | 205 | 755 | 1134 | 1434 | 912 | 876 | 299 | 935 | 725 |
| 4 Cotton | 283 | 793 | 764 | 1789 | 1906 | 2735 | 2676 | 1114 | 1294 | 2420 | 2505 |
| 5 Other annuals | 1044 | 1066 | 719 | 537 | 725 | 1334 | 1368 | 1226 | 815 | 912 | 1066 |
| 6 Grapes | 434 | 439 | 428 | 303 | 365 | 463 | 415 | 431 | 428 | 374 | 410 |
| 7 Other perennials | 356 | 374 | 450 | 379 | 475 | 567 | 713 | 502 | 664 | 598 | 678 |
| 8 Pasture, hay, silage | 997 | 719 | 998 | 744 | 1270 | 2041 | 1941 | 2025 | 1438 | 1423 | 1681 |
| 9 Total | 3141 | 3492 | 3564 | 4507 | 5875 | 8574 | 8025 | 6174 | 4938 | 6662 | 7065 |
| | Source (GL) | | | | | | | | | | |
| 10 Irrigation schemes | NA | 1573 | 1830 | 1705 | 2768 | 4228 | 3494 | 3212 | 2088 | 2874 | 3098 |
| 11 Groundwater | NA | 1069 | 989 | 570 | 568 | 686 | 863 | 844 | 926 | 713 | 976 |
| 12 Other (dams, creeks, etc.) | NA | 850 | 745 | 2232 | 2539 | 3660 | 3668 | 2118 | 1924 | 3075 | 2991 |
| 13 Water price (AUS$/ML)* | 680* | 298* | 148* | 26* | 16* | 51 | 64 | 106 | 168 | 85 | 120 |

*Source*: ABS Cat. 4618.0, various years.
*http://www.murrayirrigation.com.au/water/water-trade/water-exchange-history/ provided Murray Irrigation weighted sales that were reasonable indicators of average weighted southern MDB trading prices.

*The baseline*

The baseline against which the infrastructure upgrades scenario is modelled consists of variations in water allocations, rainfall and dryland productivity across regions. During a prolonged drought, dryland productivity may collapse before water allocations are reduced. During recovery, dryland output may recover before water allocations recover. The baseline adds to the difficulty of modelling but serves to make the scenario more realistic: farmers do not have average seasonal conditions every year and must deal with uncertainty. Marginal policy impacts may vary with seasonal conditions, particularly with respect to water trading in the southern Basin.

**Table A2: Dry-land winter crop productivity in baseline**
(2015-16 =100)

| | NSW-MDB | Vic-MDB | Qld-MDB | SA-MDB |
|---|---|---|---|---|
| 2015-16 | 100 | 100 | 100 | 100 |
| 2016-17 | 118 | 143 | 125 | 134 |
| 2017-18 | 78 | 124 | 83 | 103 |
| 2018-19 | 65 | 96 | 64 | 86 |
| 2019-20 | 67 | 96 | 64 | 86 |
| 2020-21 | 89 | 119 | 92 | 107 |
| 2021-22 | 112 | 119 | 92 | 107 |
| 2022-23 | 112 | 119 | 92 | 107 |
| 2023-24 | 140 | 149 | 115 | 134 |
| 2024-25 | 127 | 136 | 104 | 122 |
| 2025-26 | 115 | 123 | 95 | 111 |
| 2026-27 | 96 | 103 | 79 | 92 |
| 2027-28 | 77 | 82 | 63 | 74 |
| 2028-29 | 85 | 91 | 70 | 82 |
| 2029-30 | 107 | 114 | 88 | 102 |

**Table A3: Irrigation water allocations**
(2015-16 =100)

| | NSW-MDB | Vic-MDB | Qld-MDB | SA-MDB |
|---|---|---|---|---|
| 2015-16 | 100 | 100 | 100 | 100 |
| 2016-17 | 170 | 140 | 170 | 83 |
| 2017-18 | 158 | 130 | 158 | 100 |
| 2018-19 | 41 | 42 | 41 | 99 |
| 2019-20 | 41 | 42 | 41 | 79 |
| 2020-21 | 70 | 71 | 70 | 134 |
| 2021-22 | 86 | 87 | 86 | 115 |
| 2022-23 | 73 | 73 | 73 | 110 |
| 2023-24 | 109 | 110 | 109 | 105 |
| 2024-25 | 133 | 134 | 133 | 108 |
| 2025-26 | 160 | 160 | 160 | 86 |
| 2026-27 | 150 | 151 | 150 | 130 |
| 2027-28 | 71 | 71 | 71 | 149 |
| 2028-29 | 65 | 65 | 65 | 135 |
| 2029-30 | 110 | 111 | 110 | 134 |

*Devising appropriate model theory from observed data*

Table A1 points us to some necessary features of TERM-H2O. First, we require a split between dry-land and irrigated agriculture. The table (lines 1 & 2) indicates that irrigation makes up less than 2% of the land used in agriculture in the Basin. Lines 1 & 2 of the table show that the area of dry-land and irrigated agriculture varies from year to year, depending on water availability and output market conditions. The model requires some mobility of irrigable land between irrigated and dry-land technologies.

Line 6 of Table A1 indicates that rainfall variability alters irrigation water requirements. Water availability and rainfall are exogenous in the CGE model, but we need to distinguish between the two. That is, if there is a rainfall deficit, we need to shock water supply in the model (both rainfall and water allocations), which will lead to substitution away from water in the production function of the irrigated industry. We treat impacts in dry-land agriculture differently, by ascribing production shocks to depict the impact of drought.

Wide variations from year to year in water usage for rice and cotton indicate there is considerable flexibility in the production of annuals. Line 5 of Table A1 refers to other annuals that are less water-intensive, particularly vegetables. Since water is a smaller share of the total costs of production for other annuals, the responsiveness to changes in the water price is smaller than for rice or cotton. As was the case for grapes, other annuals used less water than usual in 2010-11 and 2011-12 due to above-average rainfall.

Given the substantial investments that go into establishing vineyards and orchards, we need to depict factor rigidity in perennials. When water is scarce, as was evident in 2007-08 and 2008-09, perennial sectors purchase water from other users in response to diminished water allocations. Even if the water price soars, the costs of destruction to perennial plantations in terms of foregone future income may far exceed the additional water costs in a water-scarce year. Factor rigidity is imposed by including specific capital for perennials, whereas annuals use capital that is mobile between different farm activities.

Specific capital (i.e., the herd) is also used in livestock production. Feed inputs into livestock production are substitutable by region. On-farm pasture used to feed livestock is treated as a separate farm sector. In response to worsening water scarcity, feed inputs may switch from on-farm pasture to inputs from elsewhere.

Changes in relative output prices alter the allocations of mobile capital, operator labour, dry land and irrigable land between activities. These factors follow a constant elasticity of transformation (CET) form.

Another important feature of TERM-H2O concerns water trading possibilities. The main stylized assumption is that irrigation water is perfectly tradable between irrigation sectors and regions of the southern Basin. That is, water is traded at a single price in the southern Basin in the model, which approximates reality. In the northern part of the Murray-Darling Basin, which consists of far-flung tributaries, we assume that water is tradable within a region but not between regions.

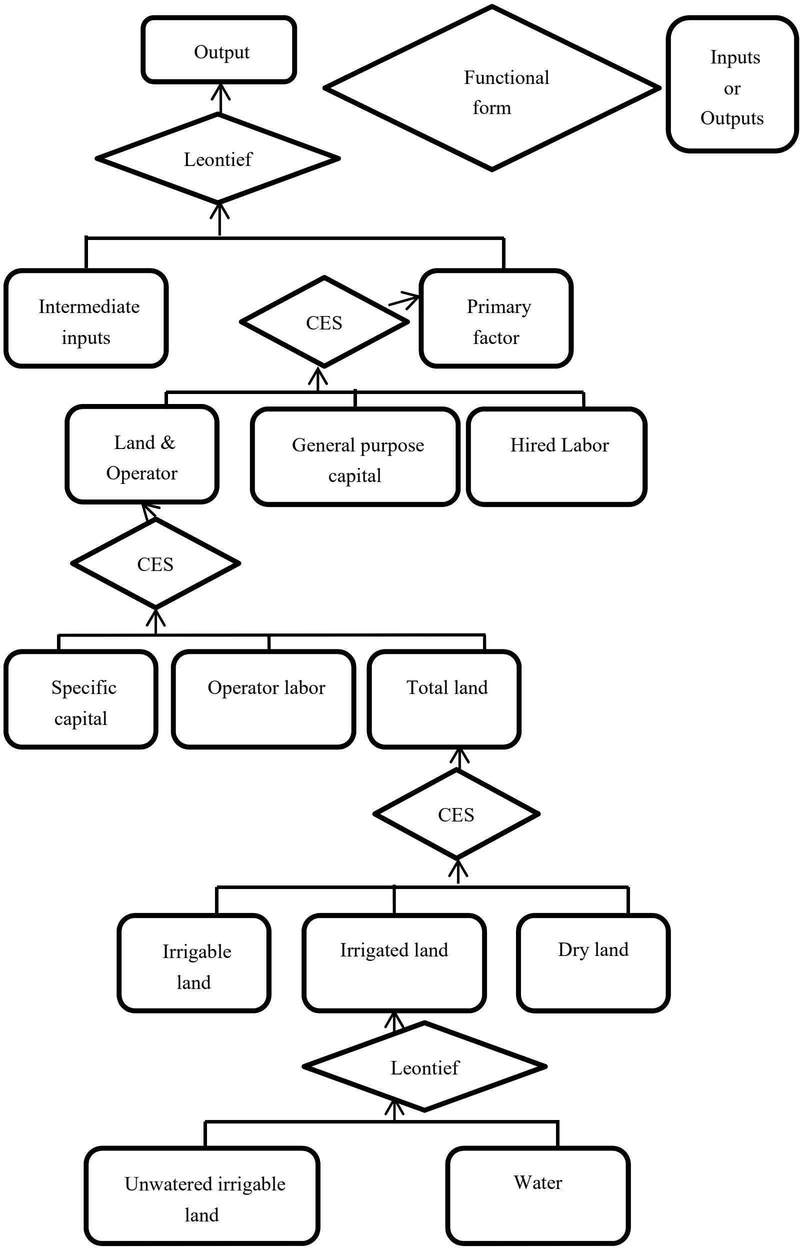
*Main Modifications in TERM-H2O*

Figure A1 shows us that TERM-H2O's Leontief bundle of intermediate input and primary factor follows the conventional theory of a CGE model in the Dixon et al. (1982) school. The key difference from a conventional dynamic CGE model emerges in the elaboration of farm factor mobility. The primary factor in Figure A1 is a CES nest of hired labour, general-purpose capital and land & operator. Hired labour is a CES nest of occupations. General-purpose capital, including farm implements and sheds, is mobile at the farm level between different activities. The land & operator factor is a CES bundle of specific capital, operator labour and land. Annual crops will use a negligible amount of specific capital, whereas it is significant in livestock and perennial production.

As is evident at the bottom of figure A1, land is a CES nest of three types of agricultural land, namely dry land, irrigable land without water and irrigated land. If water allocations fall, some irrigated land will switch to irrigable land without water, and may switch back in subsequent time periods with the restoration of usual water allocations. In terms of hectares, dry land, which cannot be irrigated, dominates farming in the Murray-Darling Basin (Table A1, rows 1 & 2). Without water, irrigable land is far less productive per hectare than with water. With water using technologies constant, a fixed amount of water inclusive of effective rainfall is required per hectare of irrigable land for a given output. An important modification to the updated version of TERM-H2O arose from the initial conditions of 2015-16. Table A1 shows that total water use in 2015-16 was far below 2012-13 levels. In earlier versions of TERM-H2O, total irrigable land used for irrigation was exogenous. Now, the hectares of irrigable land used for irrigation vary in proportion to aggregate regional water use. This prevents the price of water from collapsing as it becomes more abundant: 2015-16 was a moderately dry year.

TERM-H2O includes a dry-land technology and an irrigated technology for each of the following: grains, cotton, hay & fodder and other agriculture. Rice, grapes, almonds and vegetables have irrigation technologies only. The livestock sectors follow the theory of dry-land technologies but require substantial inputs of hay & fodder which may be either dry-land or irrigated, on-farm or purchased.

**Figure A1: Production function for farm industries**



*Extreme rainfall deficiencies in the Basin from 2017 to 2019*
**Figure A2**

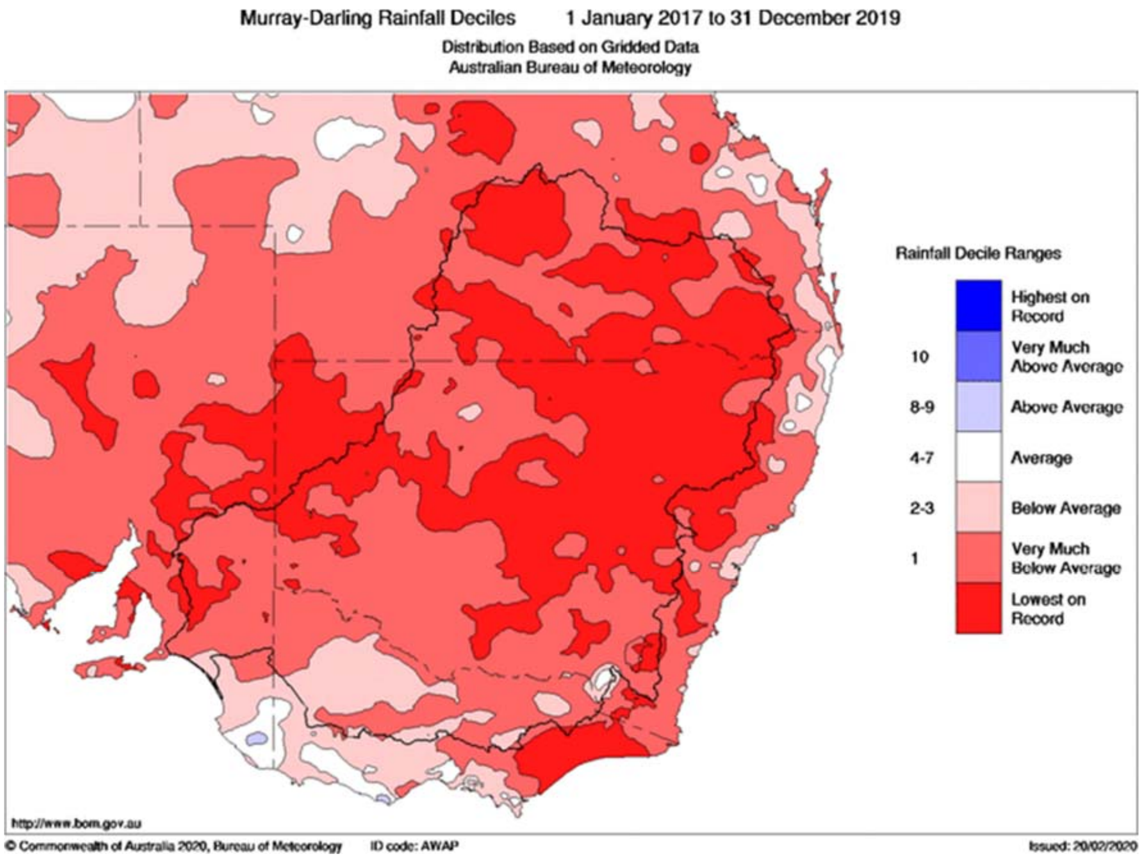



Figure A2 shows the three year rainfall deciles for the Basin to the year ending 2019. Almost the entire Basin suffered decile one rainfall in this time while around half the entire area of the Basin had its driest ever three ear period.

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