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AUSTRALIAN AGRICULTURAL & RESOURCE ECONOMICS SOCIETY

The economic impact of water reductions during the Millennium Drought in the Murray-Darling Basin

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Contributed paper prepared for presentation at the 56th AARES annual conference, Fremantle, Western Australia, February7-10, 2012

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Summary

The recent drought saw the lowest inflows on record in the Murray-Darling Basin in 2006. Water use by irrigation in 2007-8 and 2008-9 was about one third that of pre-drought levels. Understanding how irrigation adapted to less water is key both to provide information to help plan for the future and data for model calibration. Complicating this objective was the concurrent international food price crisis of 2008 and an increase in water trading in the basin. This presents a challenge in unpacking the effects of commodity price changes, input substitution, productivity gains and water trading from the effect of reduced water availability. In this paper we seek Our objective is to unpack the various effects.

We used publicly available price and production data to calculate a price index and adjust gross value data in actual dollars using this index; some price and volume data are not available, so the adjustment is approximate for total irrigation. We calculated productivity both in terms of output volumes per unit of water and in terms of adjusted gross value per unit of water.

In 2007-8 and 2008-9, overall water use in irrigation was down to about 31 % and 33 % respectively of the 2000-01 value. In 2008-9, the gross value of irrigated agricultural production was down to 86 % in unadjusted terms, but 80 % in commodity price adjusted terms. The gross value (adjusted) per unit of water more than doubled (at 241 %).

The aggregated data obscure the variation of water use in different industries. Water use by cereals, grapes and fruit and nuts changed little. Rice, cotton, meat (pasture) and dairy all reduced their water use substantially (to as little as 1 % of the 2000-1 value in the case of rice in 2007-8). Dairy, cereals, rice and meat all experienced significant price rises in 2007-8, whereas prices of cotton and grapes fell. In cereals, the higher prices and the modest change to water use resulted in a large increase (to 187 %) in gross value; some of this was due to higher prices, the remainder to productivity gains. Cereal production increased in the north of the MDB and fell in the south; we speculate that cotton growers swapped to winter cereals, whereas rice growers did not. For rice, which is a high water use crop, the price rise was insufficient to outweigh the decline in water availability, and production fell.

All industries show increases in productivity by value or by volume per unit of water. The greatest increase was in dairy: dairy farmers adapted to water scarcity and high water prices by substituting bought-in feed for irrigated pasture.

Water trading increased after 2006; importantly, inter-regional trade increased greatly, from a few tens of gigalitres (GL) per year before 2006 to more than 500 GL/yr in 2008-9. The source of traded water was from the Murrumbidgee and to a

lesser extent Murray NSW; buying regions were South Australia and to a lesser extent Murray Victoria. Much of this trade was away from rice and dairy and towards horticulture. Trade thus offset some of the impact of reductions in water availability, buffering South Australia and the Victorian Lower Murray from very low allocations.

1 Introduction

Since the release of the Guide to the Murray-Darling Basin Plan (MDBA, 2010), there has been intense debate about total water diversions and water set-aside for the environment. The debate has been accompanied by a range of figures about the likely impact including employment effects of reduced water availability for irrigation and on the wider Murray-Darling Basin economy.

The Millennium Drought (2000-2010) provides a natural experiment to learn how irrigators in the Murray-Darling Basin adapted to less water. The capacity to adapt to less irrigation water is of particular interest because the objective of the Murray-Darling Basin Plan is to restore the balance between diversions for irrigation and municipal and industrial uses with the water requirements of the riverine, floodplain, wetland and estuarine ecosystems (MDBA, 2010). New sustainable diversion limits will reduce the volume of water available for irrigation. The volume of water that will be set-aside for environmental flows is, on the average, 2,750 GL per year. The diversion limits would result in cuts to surface water for irrigation from the average 1994-2001 diversion volume of 10,945 GL/yr (MDBA, WAM) of about 25 %.

Here, we review evidence of the impacts of reduced water availability discernible through published statistics documenting changes in water diversions, gross value of irrigated agricultural production (often hereafter, gross value), water use efficiency, and commodity prices. We evaluate the change in output for the Basin as a whole resulting from reduced water supply. We also discuss how the response varied amongst industries and regions, influenced by price changes, substitution of inputs, water use efficiency increases, crop/crop substitutions, and expanded water trading. We discuss how the analysis carried out here can be further refined and how analysis of drought outcomes can be utilised to better calibrate economic models of irrigator and regional response to reduced irrigation water supply.

2 The physical dimensions of the "Millennium Drought"

The recent drought (sometimes referred to as the Millennium Drought) was the worst in the last 110 years (Timbal, 2009), which is the period of high quality records available for such comparisons.

A significant feature of the drought was the higher temperatures than those experienced in past droughts (Murphy and Timbal, 2007), and the seasonal pattern of the reduced rainfall (Timbal, 2009). In addition, inflows into the Murray River in the ten years to 2009 were about half the historic average (MDBA, 2009, and Figure 1), and those in 2006 were considerably less than the previous historic minimum. Inflows during the main inflow period from June to October were in 2006 less than 10 % of those in the long term mean.

Figure 2 shows the anomaly (departure from the long term mean) in the annual mean temperature, averaged across the Murray-Darling Basin (Hennessy et al., 2008). The temperature anomaly (and therefore the actual mean temperatures) has risen over the last few decades, and is now about 1°C greater than the long-term mean.

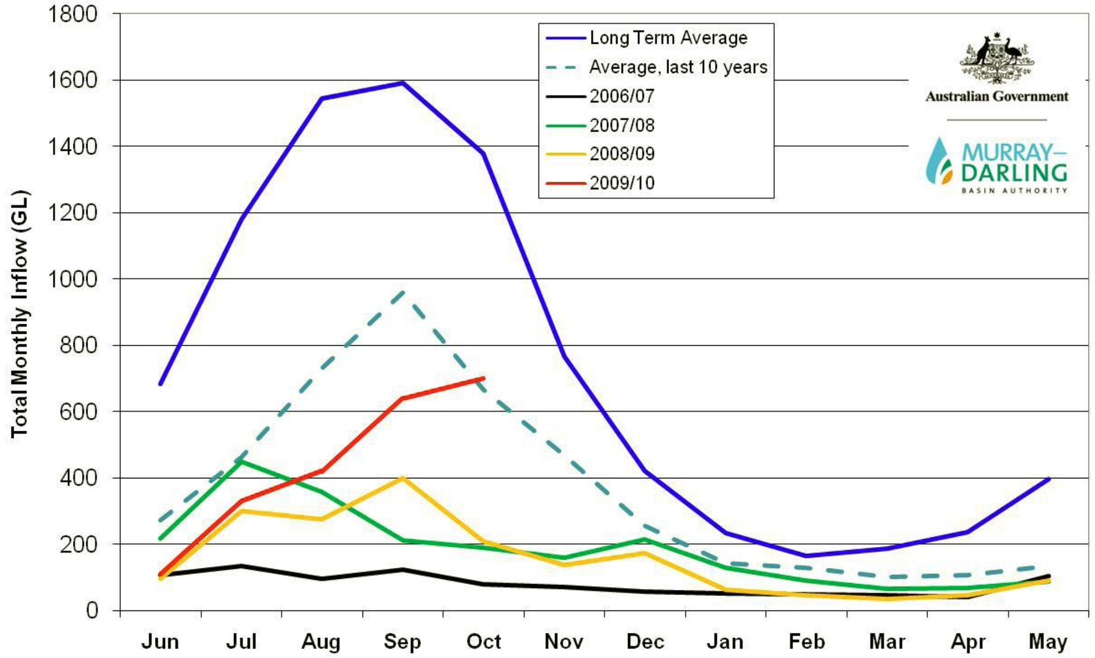

Figure 1 Murray System inflows (excluding Snowy and Menindee inflows). Source: MDBA (2009).

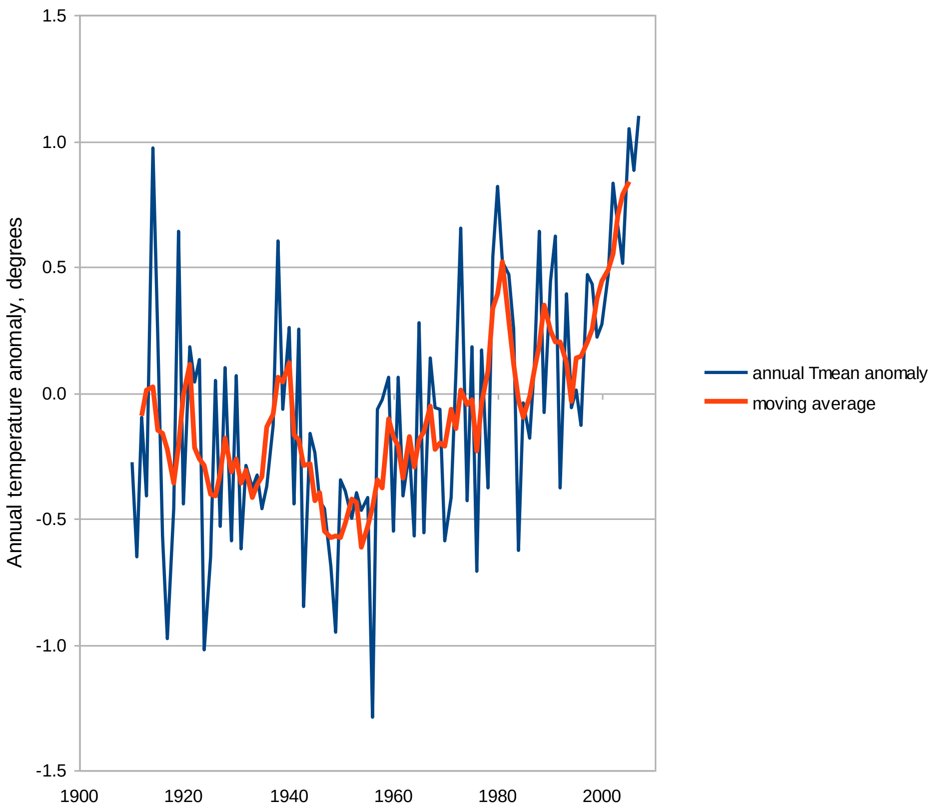

Figure 2: Annual temperature anomaly (departure from the 1961-1990 mean) for the Murray-Darling Basin. Source for temperature anomaly values: Hennessy et al. (2008).

The overall consequence of these changes for the irrigation industry in the Murray-Darling Basin is seen in declining total irrigation diversions since 1994-5 (Figure 3). Figure 3 also shows declining flow through the barrages since 1996-7.

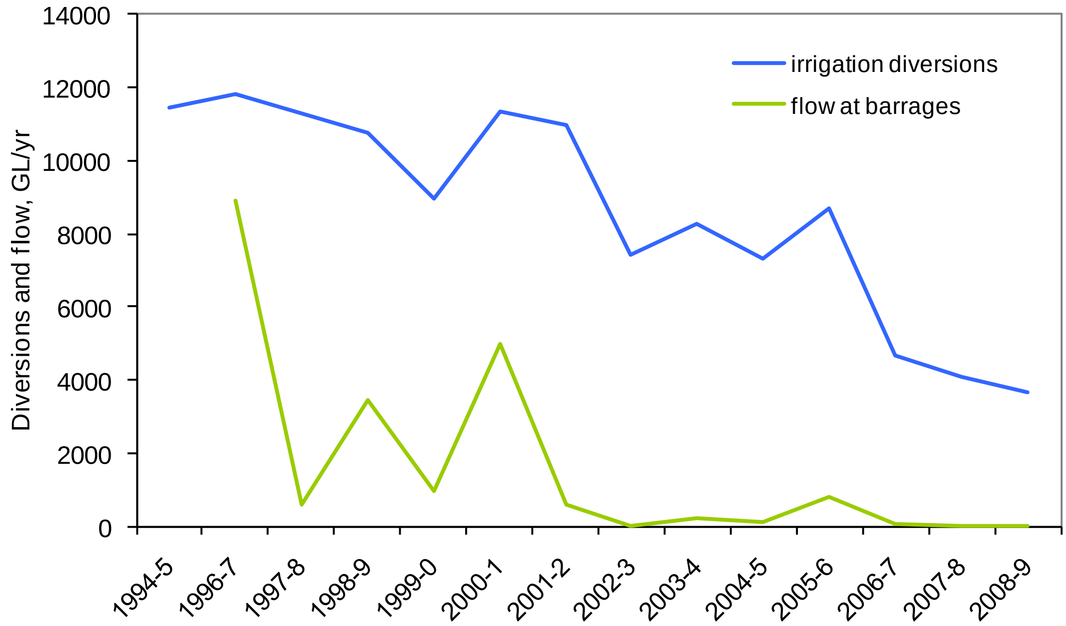

Figure 3. Irrigation diversions in the Murray-Darling Basin and flow at the barrages. Source: MDBA (2011).

3 Basin-scale impact of the drought on the irrigation – the statistical picture

The gross value of irrigated agricultural production and the volume of water diverted for irrigation as reported by the Australian Bureau of Statistics (ABS, 2008; ABS, 2010) are shown in the Table 1. From these readily available statistics, a superficial comparison of 2000/01 with 2007/08 suggests that a 67% decline in water available for irrigation led to a 0.1% reduction in nominal gross value.

Table 1. Nominal value of irrigated agricultural production (GVIAP) and irrigation water use in the MDB.

	2000-1	2005-6	2006-7	2007-8	2008-9
Nominal GVIAP \$m[1]	5,085	5,522	4,922	5,079	4,349
Water use, GL[1,2]	10,516	7,370	4,458	3,142	3,492

[1] Source: ABS (2008; 2010)
[2] The figures here are water use from ABS: although of similar magnitude, they are not directly comparable to the diversion figures from MDBA in Figure 3; the first is water use on the farm, the second is diversion from the river.

A comprehensive understanding of the effects of the drought on the irrigation sector requires that the confounding effects of commodity price trends must be accounted for. Figure 4 shows the price changes (relative to 2000-1) of some major irrigated commodities. We deflated the ABS reported gross value figures with an irrigated agricultural commodity price index. Appendix 1 describes the method that we used to construct a price index for the Murray Darling Basin. Table 2 shows the results of adjusting nominal gross value with this index.

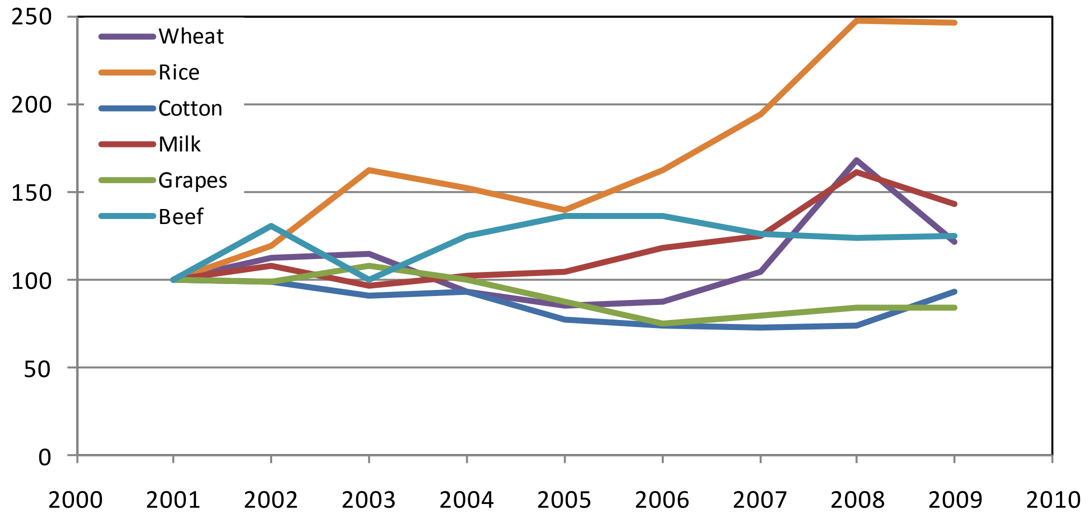

Figure 4. Prices changes (using 2000-1 as a base of 100) of some major irrigated agricultural products. Source: ABARES (2011).

Table 2. Irrigated agricultural commodity price index adjusted gross value of irrigated agricultural production in the MDB.

	2000-1	2005-6	2006-7	2007-8	2008-9
Nominal GVIAP \$m[1]	5,085	5,522	4,922	5,079	4,349
Commodity price index[2]	100	98	101	111	107
Adjusted GVIAP \$m[3]	5,085	5,635	4,873	4,576	4,064

[1] Source: ABS (2008; 2010)
[2] Source: ABARES (2011), with calculations in this paper
[3] Source: calculations, this paper

Figure 5 shows the nominal gross value, water use, and price index for MDB irrigation in aggregate. Figure 6 shows the water use, adjusted gross value, and implied water productivity, \$ (in millions) per unit of water (in GL).

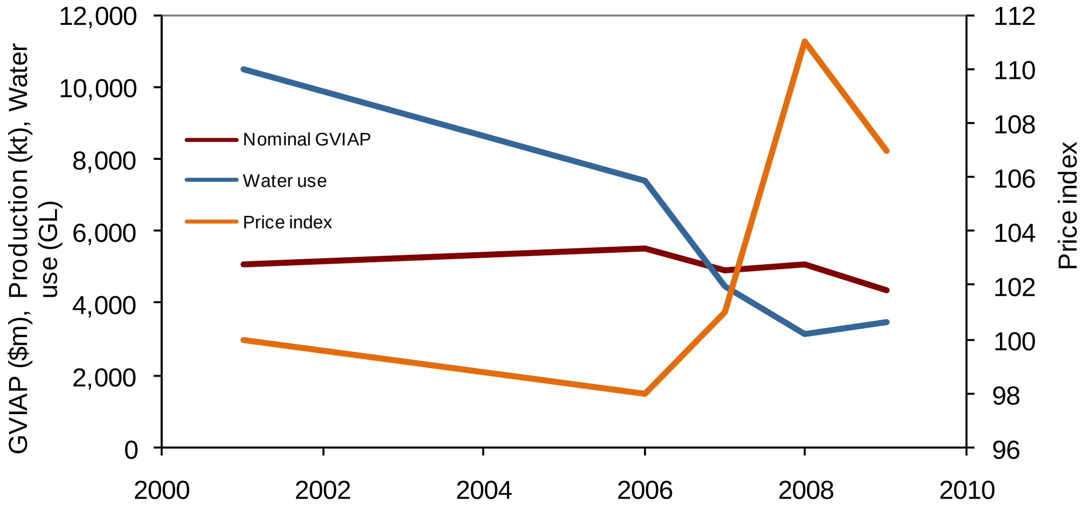

Figure 5. MDB aggregate nominal gross value, water use (left axis) and irrigated agricultural commodity price index (right axis) for the years 2000-1 to 2008-9.

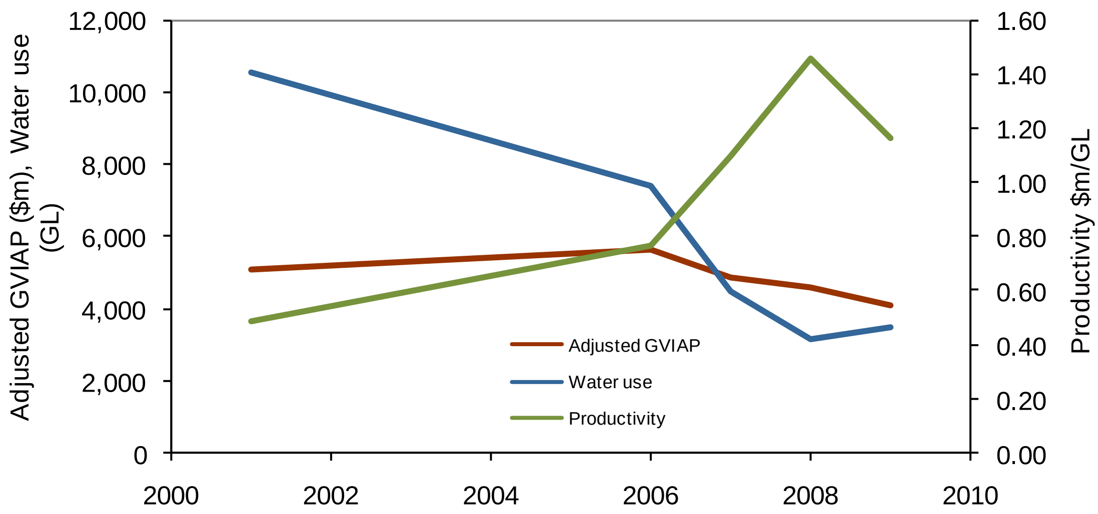

Figure 6. MDB aggregate adjusted gross value, water use (left axis) and productivity of water (in terms of adjusted gross value per volume of water used) (right axis) for the years 2000-1 to 2008-9.

While price trend data for all irrigation industries are not available, what is available appears to suggest that water reductions account for only some of the change in gross value. Price had a modest impact, slightly offsetting the decline due to water. Price falls in cotton, grapes and other commodities were offset by price rises in milk and grains (for rice the price more than doubled in the period), and overall, prices rose slightly.

Overall, a 67 % decline in water use from 2000-1 to 2008-9 (from 10,516 GL to 3,142 GL, Table 1) was accompanied by a 14 % decline in nominal (unadjusted) gross value (from $5,085 m to $4,349 m, Table 1), and a 20 % decline in price index adjusted gross value (from $5,085 m to $4,064 m, Table 2). The implied $/GL productivity (in millions of 2001 dollars per GL of water) more than doubled during the period. Our irrigated agricultural commodity price index calculation for the period suggests that only 7 % of the change in gross value can be attributed to commodity price trends (Table 2). Improved productivity appears to be the major effect offsetting the decline in water availability. The major factors contributing to enhanced productivity varied considerably by commodity as outlined in more detail below.

It should also be clear by inspection of Figure 6 that the implied elasticity of gross value with respect to water (that is, the change in gross value per change in water use) varies considerably with the choice of period over which the calculation is made. Indeed, since the adjusted gross value increased from 2000-1 to 2005-6 and later decreased, the implied elasticity will differ in sign as well as magnitude for some periods.

4 Drought impacts on individual industries

The basin-wide irrigation data hide important issues. There are considerable regional and commodity differences across the MDB. The statistical evidence by major irrigation sector is described in this section.

4.1. Cotton

In cotton, as shown in Table 3 and Figure 7, there was a decline in employment of 42 %, from 2001 to 2006; at the same time, water use declined about 40 %, production declined about 23 %, and gross value declined about 18 %. It would appear that in this period, water use reductions in cotton were partially offset by gains in production and value per unit of water (and these are not explained by price, which fell about 25 % in the period), some of which may be due to greater labour productivity (as shown by the decline in employment from 2000-1 to 2005-6, Table 3). A continuing decline in cotton water use of 80 % from 2005-6 to 2007-8 led to an 80 % decline in production at a time when prices changed little and gross value declined 75 %. Thus, the decline of cotton value of production in this period seems almost entirely driven by water availability, accompanied by no further gains in value per unit of water.

Table 3. Cotton in the MDB. ABS (2008; 2010)

	2000-1	2005-6	2006-7	2007-8	2008-9
Nominal GVIAP $m[1]	1,111	798	457	194	562
Cotton production kt[2]	755	579	250	113	315
Cotton export price $/kg[2]	2.31	1.71	1.69	1.70	2.16
Water use, GL[1]	2,599	1,574	819	283	793
Employment in cotton[1]	2,950	1,700			

[1] Source: ABS (2008; 2010)
[2] Source: ABARES (2011)

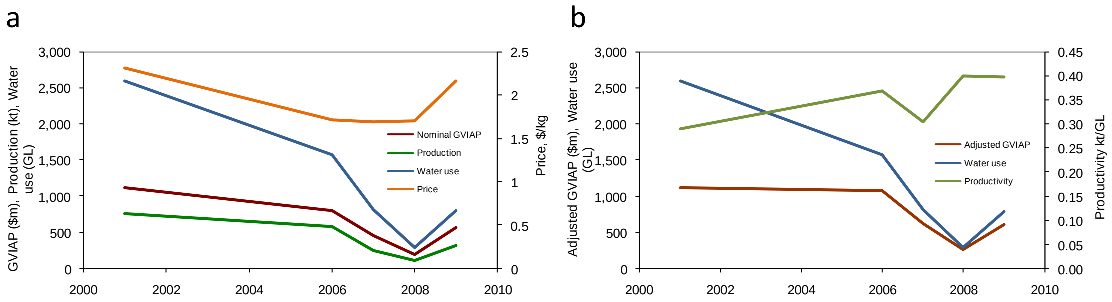

Figure 7. a. Cotton nominal gross value of irrigated agricultural production, water use and irrigated agricultural commodity price index. b. Cotton adjusted gross value, water use and productivity of water (in terms of cotton output per volume of water used).

4.2. Dairy

The dairy industry benefited from higher milk prices from 2000-1 (Table 4 and Figure 8). Dairy farmers also substituted bought-in feed for irrigated pasture in times of high water prices. The gross value of dairy rose 19 % from 2000-1 to 2007-8, at a time when the farm gate price of milk rose 175 %; the change in adjusted gross value was from \$804 m to \$547 m at 2001-2 milk prices, a fall of 32 %, whereas production fell 14 %. The water use in the same period fell 78 % – a fall more than twice that of the adjusted gross value. The apparent increase in efficiency (more than doubling the production value per unit of water) is probably largely explained by substituting bought-in feed for irrigated pasture. Employment fell 22 % from 2001 to 2006, when water use declined 39 %, and adjusted gross value of the industry fell 5 %; that employment declined more than gross value suggests some productivity gains.

Table 4. Dairy in the MDB

	2000-1	2005-6	2006-7	2007-8	2008-9
Nominal GVIAP \$m[1]	804	901	763	962	792
Milk production ML[2, 3]	10,967	9,050	9,090	9,400	8,930
Farm gate milk price c/L[2,3]	28.2	33.1	33.2	49.6	42.4
Water use, GL[1]	1,693	1,028	600	366	322
Employment in dairy[1]	8,860	6,920			

[1] Source: ABS (2008; 2010)
[2] Source: ABARES (2011)
[3] The milk production implied by GVIAP / price is two to three times greater than the figures given here. The figures here are independent production figures from ABARES (2011), but are for the whole of Australia, which is dominated by the MDB production: we used the ABARES figure for the MDB.

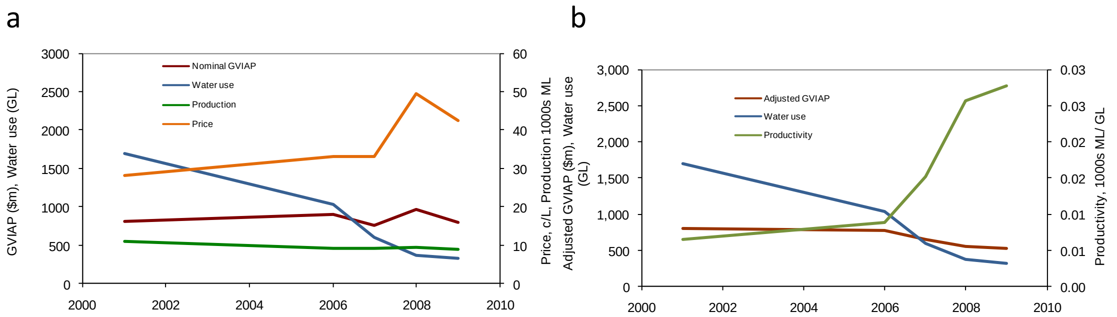

Figure 8. a. Dairy nominal gross value, water use and irrigated agricultural commodity price index. b. Dairy adjusted gross value, water use and productivity of water (in terms of milk output per volume of water used).

4.3. Rice

For rice in the Murray-Darling Basin, water use and production both fell from 2000-1 to 2005-6, and then reduced almost to zero in 2007-8, when production was about 1 % of the 2000-1 level) (Table 5 and Figure 9a). The figures for the price and production of rice are taken from ABARES Australian Commodities 2010 report (ABARES, 2010), and we assumed that the production, which is reported for all of Australia, is wholly from the Murray-Darling Basin. Despite the price more than doubling, the adjusted gross value declined dramatically, driven by the huge decrease in water use (Figure 9b). Productivity (in terms of physical production per unit of water) may have increased, but the values are noisy and a trend is not clear. The decrease in water use by the rice sector was much greater than the general decrease in water use: presumably water went to other uses on rice farms or was sold to other farms or regions. (As we will show later, the Murrumbidgee, a major rice growing area, sold significant volumes of water to other irrigation regions in the later years of the drought.)

Table 5. Rice in the MDB

	2000-1	2005-6	2006-7	2007-8	2008-9
Nominal GVIAP $m[1]	349	274	55	7	34
Rice production kt[2]	1643	1003	167	18	65
Rice price $/t[2]	213	283	346	414	528
Water use, GL[1]	2,418	1,252	239	27	101

[1] Source: ABS (2008; 2010)
[2] Source: ABARES (2010)

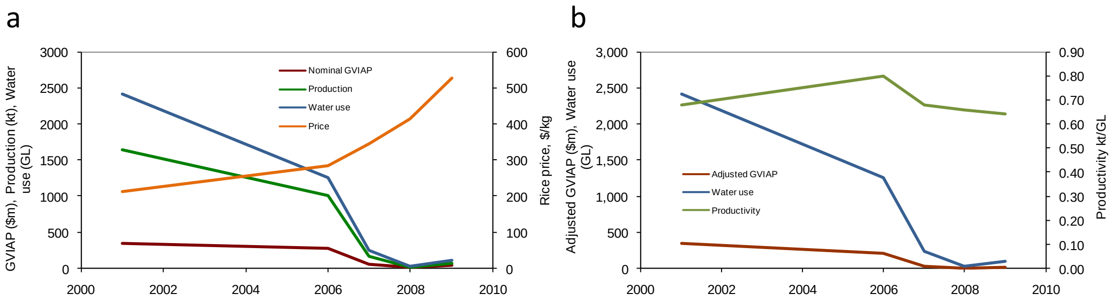

Figure 9. a. Rice nominal GVIAP, water use and irrigated agricultural commodity price index. b. Rice adjusted GVIAP, water use and productivity of water (in terms of rice output per volume of water used).

4.4. Irrigated cereals

Irrigated cereals (winter wheat and other crops) used roughly the same amount of water throughout the period, with an increase in 2007-8 when wheat prices were at their peak (Table 6 and Figure 10a). Nominal gross value increased (Figure 10a), and adjusted gross value increased but less so (Figure 10b). No trend in productivity can be seen; the data are too noisy.

Table 6. Irrigated cereals in the Murray-Darling Basin

	2000-1	2005-6	2006-7	2007-8	2008-9
Nominal GVIAP $m[1]	149	180	191	269	279
Cereals production kt[2]	641	889	788	690	992
Wheat[3] price $/t[4]	232	203	242	390	281
Water use, GL[1]	751	624	572	805	707

[1] Source: ABS (2008; 2010)
[2] Cereal production figures are not available: the figures here are calculated as GVIAP / price
[3] Wheat price data used – other cereals assumed to be correlated to wheat price
[4] Source: ABARES (2010)

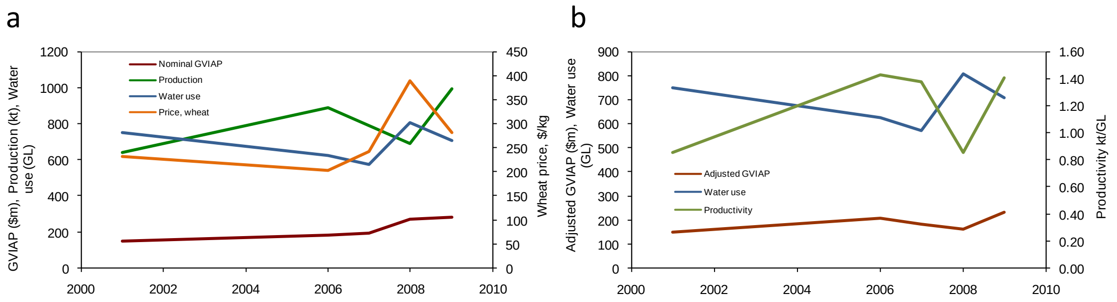

Figure 10. a. Irrigated cereals nominal gross value, water use and irrigated agricultural commodity price index. b. Irrigated cereals adjusted gross value, water use and productivity of water (in terms of cereal output per volume of water used).

The irrigated cereal industry is spread throughout the MDB and is not homogenous (unlike rice or cotton). There are considerable regional differences, with the cereal farmers in the north of the basin increasing production and water use from 2005-6 to 2007-8 while those in the south reduced production and water use (Figure 11). The north is broadly the Lachlan, the Darling and its tributaries, whereas the south is the Murrumbidgee, the Murray and its southern tributaries. Presumably, in the north, cotton growers swapped to winter cereal production while in the south cereal production appears to have declined with the lesser water availability.

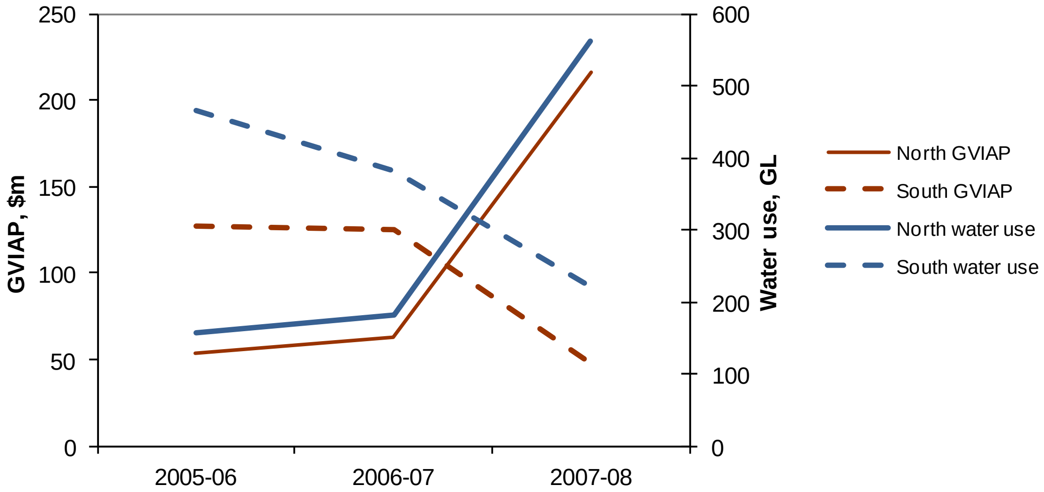

Figure 11. Regional variation in irrigated cereal gross value (actual prices) and water use.

4.5. Irrigated pasture meat production

Meat production figures are available from ABS for beef, and for sheep and other meat. We have summed the figures and deal with overall meat production. The water use in meat production decreased from 2000-1 to 2005-6, and then decreased more sharply in the following three years (Table 7 and Figure 12a). Initially offsetting the decline in water use was price which almost doubled, so that nominal gross value rose from 2000-1 to 2005-6. However, the later large decrease in water use and hence production over-rode the effect of the price increase, and nominal gross value fell. The adjusted gross value decreased throughout the period, despite an increase in productivity (Figure 12b).

Table 7. Meat in the MDB

	2000-1	2005-6	2006-7	2007-8	2008-9
Nominal GVIAP* $m[1]	508	736	723	258	234
Meat production kt[2, 3]	244	219	232	82	67
Meat price[4] $/kg[5]	2.08	3.37	3.12	3.13	3.5
Water use GL[1]	1,534[6]	994	534	291	225

[1] Source: ABS (2008; 2010)
[2] Meat production figures are not available: the figures here are calculated as GVIAP / price
[3] Sum of beef, lamb and other
[4] Average of beef and lamb
[5] Source: ABARES (2011)

[6] The 2000-1 water use is for “pasture other than dairy”, rather than for beef, lamb and other, and so may differ a little from a figure strictly comparable to the later water use figures

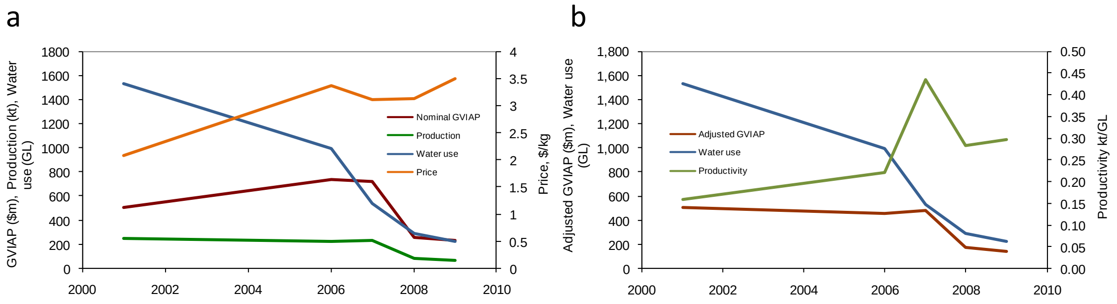

Figure 12. a. Beef, sheep and other meat nominal gross value, water use and irrigated agricultural commodity price index. b. Beef, sheep and other meat adjusted gross value, water use and productivity of water (in terms of meat output per volume of water used).

4.6. Grapes

Unlike the broadacre irrigation industries, which have nominal gross values of around or less than one million dollars per gigalitre, and in the case of rice and cereals around a quarter of a million dollars per gigalitre, the irrigated grape industry is high value. Nominal gross value of grapes is about two million dollars per gigalitre. Although gross value is not the same as profitability, grape water use remained roughly constant, despite a fall in the price of grapes (Table 8 and Figure 13). Furthermore, grapes are a perennial crop, and must be watered to preserve the productive potential for future years and many grape growers had contracts with winemakers. Nominal and adjusted gross value both generally increased, and productivity appears to have increased though the data are noisy (Table 8, Figure 13).

Table 8. Grapes in the MDB

	2000-1	2005-6	2006-7	2007-8	2008-9
Nominal GVIAP $m[1]	785	721	651	1104	870[2]
Grape production kt[3]	960	1,170	1,000	1,600	1260
Grape price $/t[4]	820	616	650	691	690
Water use, GL[1]	469	515	534	434	439

[1] Source: ABS (2008; 2010)
[2] The figure given in ABS is $598m, but this value is $272m less than the sum of the NRM regional totals also given in ABS. We have therefore added $272m to the total. Other figures that use this figure for calculation also change.
[3] Grape production figures are not available: the figures here are calculated as GVIAP / price
[4] Source: ABARES (2011)

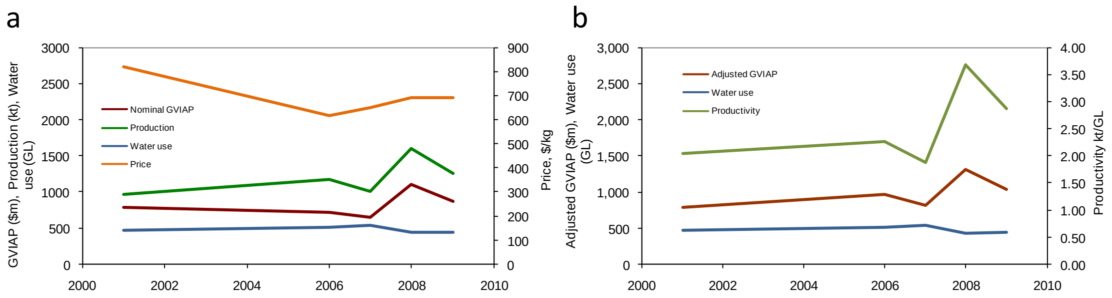

Figure 13. a. Grapes nominal gross value, water use and irrigated agricultural commodity price index. b. Grapes adjusted gross value, water use and productivity of water (in terms of physical output per volume of water used).

4.7. Fruit and nuts, vegetables and nurseries (flowers and turf)

We consider these three industries together, since they responded similarly. The three industries have gross values that range from two to three million dollars per gigalitre (fruit and nuts) to more than ten million dollars per gigalitre (nurseries). As with grapes, water use remained roughly constant in fruit and nuts and fell only modestly in vegetables and nurseries (Table 9 and Figure 14). Fruit and nuts are a perennial crop to which water must be applied every year if the crop is not to be lost, whereas although vegetables and flowers and turf are annuals, their high value per unit of water applied was likely an explanation for the modest decline in water use. Overall nominal gross value rose in all three industries (Table 9 and Figure 14). However, prices are not available, and so adjusted gross value cannot be estimated, and nor can the impact of price and productivity trends.

Table 9. Fruit and nuts, vegetables and nurseries (flowers and turf) in the MDB

	2000-1	2005-6	2006-7	2007-8	2008-9
Fruit and Nuts					
Nominal GVIAP $m[1]	701.2	1,011.0	1,207.1	1,182.0	1,032.5
Water use, GL[1]	372	413	417	356	374
Vegetables					
Nominal GVIAP $m[1]	467.7	554.6	556.3	718.3	564.2
Water use, GL[1]	166	152	125	124	121
Nurseries					
Nominal GVIAP $m[1]	90.3	149.8	128.7	225.5	119.4
Water use, GL[1, 2]		12	13	9	9

[1] Source: ABS (2008, 2010)
[2] Water use figure for 2000-1 not available

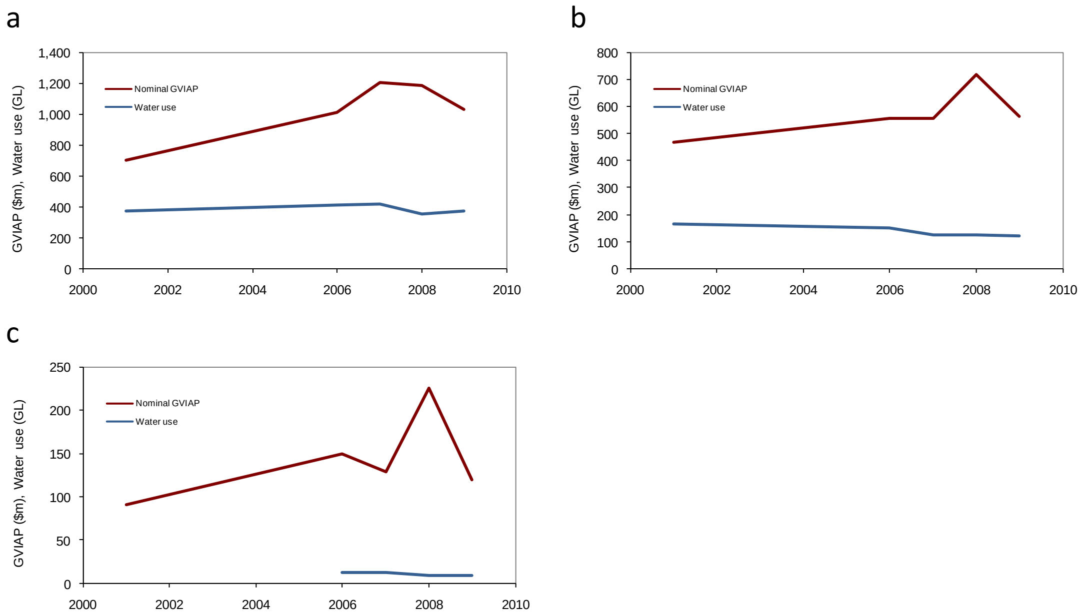

Figure 14. a. Fruit and nuts nominal gross value and water use (irrigated agricultural commodity price not available). b. Vegetables nominal gross value and water use (irrigated agricultural commodity price not available). c. Nurseries nominal gross value and water use (irrigated agricultural commodity price not available).

4.8. How did water trade help?

Generally, most irrigation industries appear to have increased the value of production per unit of water. Across the MDB and all sectors the increase from 2000-1 to 2008-9 of the price adjusted gross value per gigalitre of water was about 2.4 (Figure 6). This is presumably a combination of increased efficiency, and a concentration into more valuable enterprises through water trading.

Thus, while the irrigation industry experienced some decline in value and also in employment, with some industries and regions more impacted than the average, the decline was less than would be expected from the change in water use alone. The National Water Commission has shown that water trading offset some of the impact of reductions in water availability (NWC, 2010a). Figure 15 shows small and variable trade before 2005/6 (except 1999-2000, when Murrumbidgee sold about 100 GL, and Murray NSW bought that amount). From 2005-6 there is a jump in water trading; the major trade is out of NSW, especially Murrumbidgee, and into Victoria Murray and SA irrigation (MDBA, 2011).

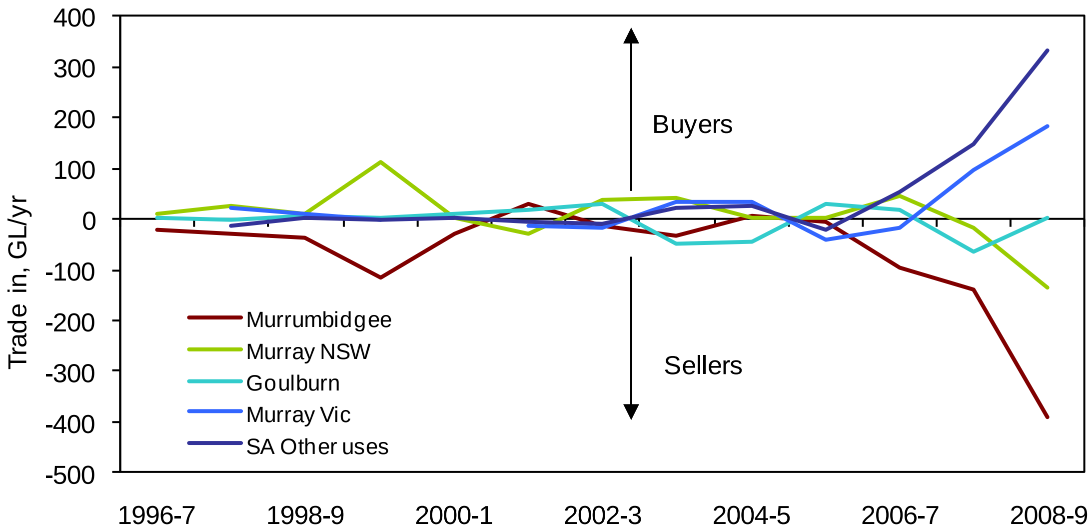

Figure 15. Water volumes traded into some major regions of the Murray-Darling Basin. Negative numbers indicate water traded out of a region. Source: MDBA (2011). We have taken SA "Other uses" in the MDBA Water Audit Monitoring Reports (MDBA, 2011) as irrigation.

There is evidence that the water market by facilitating the transfer of water from low- to higher-valued uses during the Millennium Drought mitigated the economic losses to the irrigated agricultural sector in the Murray-Darling Basin and the larger regional economy (ABARE-BRS, 2010; Mallawaarachchi and Foster, 2009). For example, Peterson et al. (2004, 2005) estimated the benefits of intra and inter-catchment trade in a dry year in the Murray-Darling Basin at A$ 550 million. The volumes of water traded provide evidence that irrigators use the market to adapt to changing conditions. Seasonal trades in allocations dominate the market, e.g. in the 2006-2007 water year a quarter of all irrigated farms in the Murray-Darling Basin participated in the market (Ashton et al., 2009) and half of all water allocations were traded in the basin in the 2007-2008 water year (NWC, 2009). In the 2007-2008 water year four-fifths of trades were intra-catchment and one-fifth inter-catchment.

As shown in Figure 16 and Figure 17, the price of water peaked at the height of the drought in 2007/8, just as the volumes of inter-regional water trade were increasing. Thus, while water trade undoubtedly provided irrigators with greater flexibility, buyers paid high prices for this flexibility.

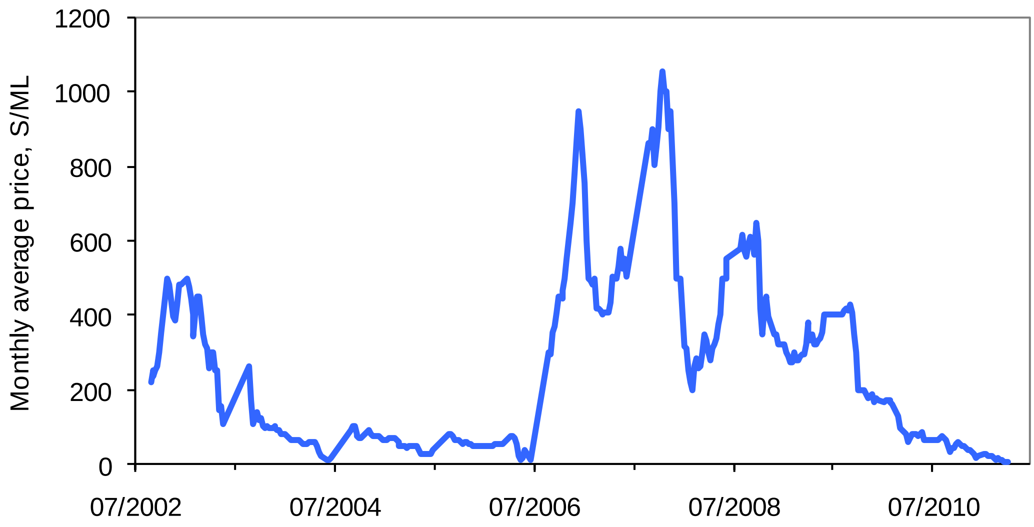

Figure 16. Average monthly sale price in the Goulburn Zone 1A trading zone. Source Watermove (2011) (data for 2007 onwards) and Kaczan et al. (2009) (data pre-2007).

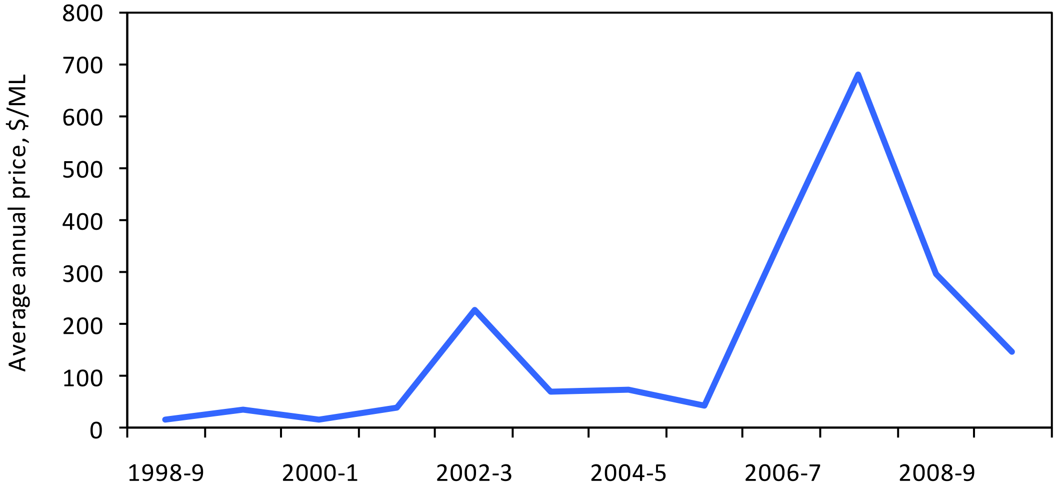

Figure 17. Annual average sale price in the Murray Irrigation area. Source: Murray Irrigation (2011).

5 Discussion

The drought impacted irrigated agriculture in the Murray-Darling Basin heavily, but different industries and regions responded quite differently. The different responses were due to industry specific factors, including input costs and output prices, availability of substitutes for water, and whether the crop is an annual. The overall impacts are summarised in Figure 18 and Figure 19. Water use and price adjusted gross value of irrigated agricultural production in 2008-09, expressed as a percentage of the 2000-01 value, for irrigation overall and several major commodities. which show the water use and gross value of irrigated agricultural production in 2007-08 and 2008-09 as a percentage of the 2000-01 value.

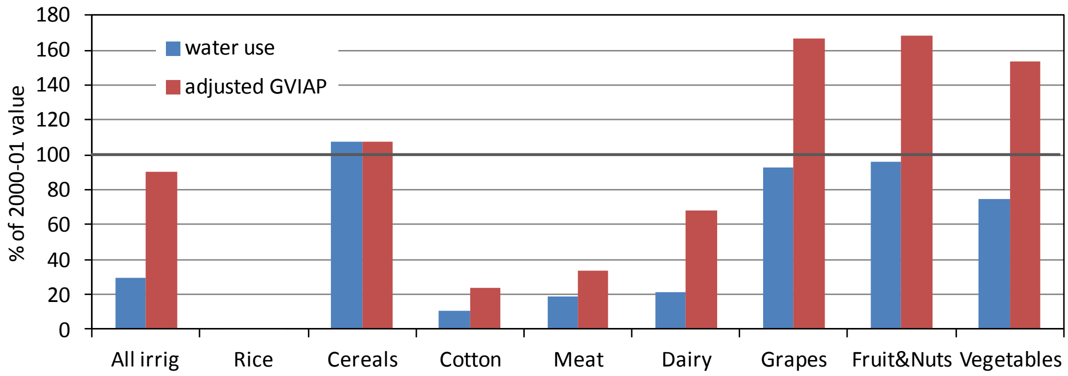

Figure 18. Water use and price adjusted gross value of irrigated agricultural production in 2007-08, expressed as a percentage of the 2000-01 value, for irrigation overall and several major commodities.

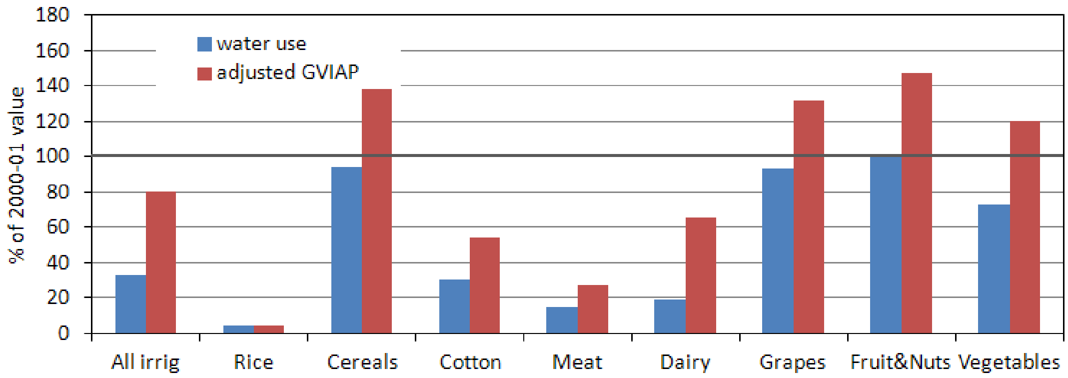

Figure 19. Water use and price adjusted gross value of irrigated agricultural production in 2008-09, expressed as a percentage of the 2000-01 value, for irrigation overall and several major commodities.

5.1. Irrigation overall

Figure 18 and Figure 19. Water use and price adjusted gross value of irrigated agricultural production in 2008-09, expressed as a percentage of the 2000-01 value, for irrigation overall and several major commodities. show that in 2007-08 and 2008-9, water use in irrigation overall was down to about 31 % and 33 % respectively of the 2000-01 value. The individual industries are ordered in the figures from least to greatest value per unit volume of water used (as shown in Table 10). With the exception of cereals, the decline in water use shown in the figures corresponds to the value per unit of water use. Water use by cereals, grapes and fruit and nuts changed little; the former seems to have been used as an alternative annual crop particularly in the north of the basin, whereas the others are high value perennial crops with neither the flexibility nor incentive (high prices) to reduce water use. Vegetables, which are an annual crop are also high value, and reduced their water use modestly. The big water use reductions were in rice, cotton, meat (pasture) and dairy.

Table 10. Gross value of production per unit volume of water use, average from 2005-06 to 2008-09.

Industry	GVIAP / water use $ m / GL
Nurseries	15
Vegetables	4.6
Fruit & Nuts	2.9
Grapes	1.8
Dairy	1.8
Meat	1.0
Cotton	0.6
Cereals	0.3
Rice	0.3

In 2008-09, the gross value of irrigated agricultural production was down to 86 % in unadjusted terms, but 80 % in price adjusted terms. The gross value (adjusted) per unit of water more than doubled (at 241 %).

5.2. Industry sectors

As pointed out above, water use varied greatly in different industries. Table 3. Cotton in the MDB. ABS (2008; 2010) to Table 8 show that dairy, irrigated cereals, rice and meat all experienced significantly higher commodity price (and the price rise for dairy, cereals and rice was even greater in 2007-8), whereas prices of cotton and grapes fell slightly. In the case of cereals, the price rise and the modest change to water use resulted in a large increase (to 187 %) in the gross value, some of which was explained by the price rise, with the remainder due to productivity gains. Cereal production increased in the north of the MDB and fell in the south; we speculate that cotton growers swapped to winter cereals, whereas rice growers did not. For rice, the higher prices were insufficient to outweigh the decline in water availability, and production fell.

All industries showed increases in productivity by value or by volume (where figures are available) per unit of water. The greatest increase was in dairy, resulting from the substitution of bought-in feed for irrigated pasture when water was scarce and expensive.

Since many of these industries are concentrated regionally (cotton in the north, rice in southern NSW, dairy in the south), these differences resulted in different regional impacts.

5.3. Four key trends

Four key trends appear to explain most of the changes in water use and productivity during the drought.

- Increased water use efficiency (increased physical output per unit of water input) is evident in most irrigated commodities but with variation across industries.
- Input substitution in dairy, where purchased feed was substituted for on farm irrigated production, more than made up for the lower water availability. In addition some water was sold. Thus despite much less water, gross value declined relatively little. Less obvious and less easily gleaned from readily available statistics are a range of capital, labor and management substitutions for water that underlie the trend toward increased water use efficiency.
- Water trade allowed the highest value horticulture and viticulture in the Basin to stay in production, while annual crops and pasture with a lower marginal value and more flexibility in demand for water were fallowed and water sold. Significant inter-basin trading from Murrumbidgee (primarily a rice growing region) to the SA and Victorian Murray (primarily horticultural and viticultural irrigation regions) is the most significant example.
- Substitution of lower irrigation requirement crops for higher irrigation requirement crops appears to be a response in the northern irrigation regions, where cotton production decreased, but irrigated cereals production increased.

5.4. Two phases of the drought?

Cotton, dairy, rice and meat, showed some decrease in water use from 2000-1 to 2005-6, with some compensating effects from productivity increases and sometimes commodity prices. However, they all showed a greater decrease in water use from 2006 onwards and, with the exception of dairy using input substitution in the form of bought-in feed, the impact was not compensated by other factors. The overall water use in irrigation in the basin reduced in 2002-3 and remained at about that level until 2005-6, and then reduced to about half that level or less from 2006-7 to 2008-9 (Figure 1).

Thus, the drought may be thought of as progressing in two phases:

- phase 1, to 2006 - some reductions in water for irrigation (water for the environment declined dramatically, as shown by flow through the barrages, Figure 1), largely accommodated through efficiency gains, some reductions in output;
- phase 2, from 2006 - greater reductions in water for irrigators, with dramatic declines in output of some industries (rice and cotton), dramatic price rises in grains and milk (and to a lesser extent meat) in 2008, more valuable industries and dairy (which could substitute feed for irrigated pasture) retained production. In parallel, there was a large increase in water trading especially out of rice and dairy regions and into horticultural regions.

In the first phase, despite the dry conditions, there was sufficient inflow and water in storage to keep irrigation going, albeit at somewhat less than its level in wetter times. After 2006, inflows and storages were able to supply water only at much reduced levels (Kirby et al., 2010).

5.5. What can we learn and apply to the Murray-Darling Basin Plan?

There are some key differences between reductions in water availability due to drought and those due to returning water to the environment under the proposed Murray-Darling Basin Plan (MDBA, 2010). Firstly, drought brings a reduction in rainfall, as well as a reduction in water available for diversion; drought is often accompanied by sunnier conditions and warmer daytime temperatures. Thus, the demand for irrigation water increases: all other things being equal, this effect is absent in the planned water availability reductions (Wittwer, 2011).

Secondly, the reductions in irrigation water availability under the Plan is a long-term and predictable effect, which presumably will result in long-term capital adjustments, both within and amongst industries and regions. A drought, on the other hand, is shorter term (though the recent drought was a decade long!) and less predictable; long term adjustments may be hastened or modified during a drought, but many effects are presumably short term and water use will revert to something like earlier levels once a drought is over.

Notwithstanding these differences, it seems reasonable to suppose that some of the experience of the drought will be seen again in response to planned reductions in water availability for irrigation. Reductions in water availability under the Plan will lead to reductions in output and value, but both are likely to reduce less than pro-rata with the reduction in rainfall: across Basin irrigation as a whole, a decline of 67 % in water during the Millennium Drought resulted in a decline in 20 % in adjusted gross value of irrigated agricultural production. Productivity gains within sectors, substitution of inputs and water trading among sectors and regions will all continue, and offset some of the impacts of reduced water availability.

Water trading, still developing as a routine practice, is likely to increase. Despite an increase in water availability following the end of the drought in 2009-10, water trade in the Basin increased by 20 % in entitlements and 22 % in allocations (NWC, 2010b); some of the entitlement trade was due to purchases by the Commonwealth, without which entitlement trading may have decreased.

It is also reasonable to suppose that different sectors and regions, and particularly perennial and annual cropping sectors, will respond differently. The long-term nature of planned cuts will presumably, all other things being equal, allow perennial industries to adapt with confidence; presumably, they will not show much if any decline in water use.

5.6. What are the gaps?

The analysis and discussion in this paper should be regarded as preliminary. There are many gaps.

First and foremost, there are considerable gaps in the data. Price, production, gross value and water use data are available for few industries: only cotton had all four sets of data for the period of the drought (and few earlier data); dairy had all four sets only by employing the dubious assumption that the national production could be used for the basin – the alternative of calculating production from the gross value and price led to a basin production two to three times the reported national production. Meat and grapes had price, gross value and water use data. Cereals required the (probably reasonable) assumption that all the cereals other than wheat had prices correlated to the wheat price.

However, even amongst the data that are available, there are inconsistencies. The price history data in the Australian Commodities quarterly publications of ABARE do not always refer to the same commodity from one period to the next (grapes being a case in point, where the grape chosen as the price indicator differs in different periods), and figures for a given period differ from one quarterly to another. Some ABS tables are incomplete in their Gross Value of Irrigated Agricultural Production report, and the Water Use in the Murray-Darling Basin report does not report water use in 2000-1 for all the industries in the Gross Value reports. At the regional level, figures for diversions and trading from the MDBA Water Audit Monitoring Reports are based on different areas to the figures for gross value and water use from the ABS reports.

These data gaps do not prevent some broad analysis with some reasonable assumptions, as we have done here, but they do prevent detailed assessment. We think the broad trends that we have shown are probably correct, but we doubt that the exact numbers are robust and would be likely to change with further evidence.

We have dealt with the impact at the industry level. Several studies based on irrigation farm surveys have been undertaken (Ashton and Oliver, 2009; Ashton, Hooper and Oliver, 2010; Ashton and Oliver, 2011), and from which Hughes (2011) developed farm production functions. The farm production functions show the importance of water in enterprise yield and farm production, and show greater elasticity of broadacre farms than horticulture farms: this is consistent with the industry level findings discussed here. Using the farm level production functions to model the industry level outcomes would fulfil one of our aims with this analysis, that of providing data for calibration of models. The studies also discuss other factors that are important in farmers' economic behaviour, particularly issues such as the increase in debt over the course of the drought, the components of the debt, and debt servicing ratios (ratio of interest payments to total farm cash receipts) (Ashton, Hooper and Oliver, 2010). Useful insights may be gained by studying the links between regional / industry level responses and farmers' economic behaviour.

It should be noted that we have in this paper dealt mainly with gross value, and not costs or profit. The response of the industry to changed circumstances such as reduced water is presumably to maximise profit; a deeper analysis, particularly of costs, is required.

6 Conclusions

The reduction in water availability in the drought had a large impact on irrigation, but the impact varied greatly amongst industries. The decrease in the gross value of production (adjusted for price trends) was less than proportional to the reduction in water use. The higher value perennial industries in South Australia and Victoria largely maintained their water use, through purchasing water, mainly from rice in the Murrumbidgee and to some extent from dairy. Large price rises buffered cereals, dairy and to some extent meat from the worst effects. Dairy also bought in feed, and sold water. Cotton, and rice in particular, decreased water use and production very substantially. All industries increased their productivity, some of which was no doubt driven by the drought but, inasmuch as productivity has increased for many decades, some increase was presumably not drought related.

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Appendix 1: Irrigated Agricultural Commodity Price Index Calculation

For each industry for which we have figures, the gross value of irrigated agricultural production in a later year, GVIAP200X is adjusted according to the price in a later year, P200x and the price in 2001, P2001, as follows:

$$GVIAP_{200X}^{Adj} \quad = \quad GVIAP_{200X}\left(\frac{P_{2001}}{P_{200X}}\right)$$

To work out an irrigated agricultural commodity price index, for irrigation as a whole, we summed the adjusted and nominal gross value for those industries for which we have figures, and took the ratio of the sums, multiplied by 100:

$$GPI \quad = \quad 100\sum_{i=1,N} GVIAP_{200X}^{Adj} \Big/ \sum_{i=1,N} GVIAP_{200X}$$

The index thus calculated is therefore weighted according to the fraction of the gross value of each industry in the index. The industries for which we have figures are cotton, dairy, cereals, rice, grapes and meet (beef, and lamb plus other) (see Figure 4 – lamb plus other is very similar to beef). We further assumed that cereal prices are correlated to wheat prices. These industries account for between 55 % and 73 % of the gross value of irrigation in the MDB during the period under study. We further assumed that the general price index thus calculated applied to the whole industry – that is that the weighted average of the industries not represented in the price index behaved the same as the weighted average of the industries in the price index. Other assumptions are probably just as reasonable.