The 2006-07 drought in Australia: analysis in TERM-Water

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Abstract

TERM (The Enormous Regional Model) is a flexible regional computable general equilibrium (CGE) modelling framework for Australia. The master database contains 169 sectors and 56 regions.

TERM-Water is a new water-enhanced version of TERM. It represents irrigation sectors at the statistical division level in the Murray-Darling Basin. It also includes the rest of the Australian economy. This is an advance over previous models of irrigation activity. These usually cover one or more irrigation regions and do not cover non-irrigation sectors. TERM-Water distinguishes irrigation from dry-land sectors. It also pays attention to the mobility of farm factors between activities in response to water shortages.

The model allows for various degrees of water trading between users. The application we present is to the drought of 2006-07. The model accounts for both reduced water allocations to irrigation sectors and productivity losses in dry-land agriculture. With limited water trading, the drought reduces real GDP by 1.45%. More extensive water trading moves water to higher value uses as its scarcity rises, thereby diminishing the real GDP loss to only 1.27%. This difference of around $1.3 billion can be interpreted as the gain from water trading. The paper demonstrates that water trading is particularly valuable in times of drought.

Key Words

CGE modelling, water modelling, regional economies

JEL Codes

C68, Q11, Q25, R13.

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1. Introduction

This paper has two main parts. The first part, covering sections 2 to 6, describes the theoretical specification and data input for the farm sector in TERM-Water. TERM is a detailed multi-regional CGE model of Australia (Horridge *et al.* 2005). It can be applied with up to 56 regions and 169 commodities. TERM-Water is a new version created for analysing rural water issues. The second part, in section 7, contains an illustrative application of TERM-Water in which we make two simulations of the effects of the 2006-07 drought. In the first simulation we assume that there are only limited possibilities for trading water within regions and no possibility for trading between regions. The second simulation allows extensive trading possibilities both within and between regions. Comparison of simulation results allows us to assess the value to the economy of water trading in a severe drought.

2. Farm industries in TERM-Water

Farm industries in TERM-Water are defined by region, irrigation status and crop. Examples of farm industries are: Murrumbidgee/irrigated/cereal; Murrumbidgee/dry/non-dairy livestock; and Northern-NSW/dry/beef-cattle. Each farm industry produces just one commodity. However, all agricultural commodities are produced by several industries. For example, North-West-NSW/irrigated/cotton, Northern-NSW/irrigated/cotton, and Northern-NSW/dry/cotton all produce cotton.

We adopt the concept of single-product farm industries because it is in line with available data from the Australian Bureau of Statistics (ABS). These data show outputs by commodity and region. Data exist on the area of irrigation by broad activity, which serve as a starting point for splitting irrigated from dryland activity. At first glance it may seem that our single-product approach is in tension with the Australian reality of multi-commodity farm enterprises (e.g. wheat/sheep farms). However, in the theory described in this paper, a given farm enterprise can be part of several farm industries. Our model allows for price-induced movements of productive resources between farm industries. We can think of such movements as occurring at the farm level with the farm manager re-allocating labour, land and other resources between the production of different commodities.

3. Production functions for farm industries in TERM-Water

In TERM-Water, the production function for farm industry q in region d has the structure shown in Figure 1. Output is a Leontief function of: intermediate input; primary factor; and other costs. Other costs is a minor catch-all category used to include costs that are not explicitly identified in our database such as the costs of holding inventories.

As in other versions of TERM, intermediate input is a CES combination of inputs of goods 1 to n. Each of the goods 1 to n is a CES combination of the imported and domestic varieties. The domestic variety of good i is a CES combination of good i produced in each of the R regions.

Primary factor is a CES combination of three inputs: land & operator; physical capital (tractors, sheds, etc); and hired labour. Hired labour is a CES combination of labour of different occupations or skill categories.

The only part of the structure in Figure 1 that is a departure from earlier versions of TERM is the treatment of land & operator (the shaded part of Figure 1). In earlier versions, there were no underlying inputs generating land & operator. In TERM-Water, land & operator is a CES combination of inputs of land and of operator labour (the farmer).

Figure 1 shows further CES nests below the input of land. These take effect only for dry-land industries. For these industries, we have designed TERM-Water to account for two complications.

The first is that dry-land industries may sometimes use irrigable land. This will happen when there is a shortage of irrigation water causing irrigable land to be used as dry land. We handle this complication by treating irrigable land and dry land as CES substitutes in the creation of *effective* land in dry-land industries. In simulations of the effects of shortages of irrigation water, our model generates increases in the prices of irrigation water. This causes reductions in the rental value of irrigable land. Through CES substitution of irrigable and dry land in dry-land industries, the reduction in the rental value of irrigable land stimulates demand for this land to be used in dry-land industries.

The second complication is that feedgrain (possibly including purchased hay) can be used in dry-land livestock industries as a substitute for land: a given amount of livestock can be maintained on less land if we use more feedgrain. We handle this complication by treating feedgrain and effective land as CES substitutes in the creation of a dry-land livestock industry's *total* land input (a measure of land input with food, pasture or feedgrain, to support livestock). We assume that all feedgrain is domestically produced. As with other domestically produced intermediate inputs (inputs of domestic goods 1 to n) we model the input of feedgrain as a CES combination of inputs from the R regions.

While the first complication applies only to dry-land industries and the second only to dry-land livestock industries. For irrigation industries we set up the initial input-output data so that inputs of dry land are negligible. This ensures that the nests below total land in Figure 1 have no impact for irrigation industries. For sectors other than dry-land livestock, feedgrains are not substitutable with land.

In section 4, we discuss the details of the land & operator specification in Figure 1. We set out the implied demand equations for operator labour, irrigable land, dry land and feedgrain and we discuss implications for the demand for water. Because the other parts of the structure in Figure 1 are quite standard, they receive no further discussion in this paper. In section 5 we discuss the region-wide constraints applying to operator labour, irrigable land, dry land and physical capital.

4. Land & operator specification for farm industries in TERM-Water

We consider farm industry (q,d) where q refers to the industry's irrigation status and crop (e.g. irrigated/rice) and d refers to the industry's region (e.g. Murrumbidgee).

Composition of effective-land input

In deciding its inputs of irrigable land (LNI) and dry land (LND) we assume that farm industry (q,d)

chooses $\quad XLN(q, d, k),\ k \in \{LNI, LND\}$

to minimize $$\sum_k PLN(q,d,k) * XLN(q,d,k) \tag{1}$$

subject to $$XELFG(q,d,EL) = CES_k\left(XLN(q,d,k)\right) \tag{2}$$

where

XLN(q,d,k) refers to inputs to industry (q,d) of input k (irrigable land or dry land);

PLN(q,d,k) is the cost to industry (q,d) of using a unit of land of type k;[1] and

XELFG(q,d, EL) is a measure of (q,d)'s requirements for effective land.

We also define the cost of using a unit of effective land to industry (q,d) as:

$$PELFG(q,d,\ EL) = \frac{\sum_k PLN(q,d,k) * XLN(q,d,k)}{XELFG(q,d,EL)} \tag{3}$$

Models such as TERM-Water are computed with equations that are linear in percentage changes. The percentage-change equations arising from (1) to (3) that are included in TERM-Water are:

$$\begin{aligned} xln(q,d,k) &= xelfg(q,d,\ EL) \\ &\quad - \sigma_{ln}(q,d)\left[pln(q,d,k) - pelfg(q,d,EL)\right], \quad k \in \{LNI,\ LND\} \end{aligned} \tag{4}$$

and

$$pelfg(q,d,\ EL) = \sum_k SLN(q,d,k) * pln(q,d,k) \tag{5}$$

where

xln(q,d,k), x(q,d,land), pln(q,d,k) and p(q,d,land) are percentage changes in the variables defined by the corresponding uppercase symbols;

$\sigma_{ln}(q,d)$ is (q,d)'s the elasticity of substitution between irrigable land and dry land in the generation of the overall input of effective land; and

SLN(q,d,k) is the share of k (irrigable land or dry land) in (q,d)'s cost of using effective land, that is:

$$SLN(q,d,k) = \frac{PLN(q,d,k) * XLN(q,d,k)}{\sum_j PLN(q,d,j) * XLN(q,d,j)}, \quad k \in \{LNI,\ LND\} \tag{6}$$

Composition of total-land input

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[1] As we will see, in the case of irrigable land used by irrigated industries, this cost includes not only rent but also the cost of irrigation water.

In deciding its inputs of effective land (EL) and feedgrain (FG) we assume that farm industry (q,d)

chooses $\quad XELFG(q, d, k), \quad k \in \{EL, FG\}$

to minimize
$$\sum_k PELFG(q,d,k) * XELFG(q,d,k) \tag{7}$$

subject to

$$XTLOP(q,d,\text{total land}) = CES_k\left(XELFG(q,d,k) / AELFG(q,d,k)\right) \tag{8}$$

where

XELFG(q,d,k) refers to inputs to industry (q,d) of input k (effective land or feedgrain);

PELFG(q,d,k) is the cost to industry (q,d) of using a unit of input k (effective land or feedgrain)[2];

XTLOP(q,d, total land) is (q,d)'s total requirements of land (a composite of effective land and feedgrain or a measure of land input with associated food for maintaining livestock); and

AELFG(q,d,k) are variables that can be used to introduce productivity change. For example, if AELFG(q,d, effective land) increases by 50 per cent, then for any given input of feedgrain, industry (q,d) needs 50 per cent more effective land to achieve any given level of total land requirements. Equivalently, if AELFG(q,d, effective land) increases and effective land input is held constant, then industry (q,d) will need to increase its input of feedgrain to achieve a given level of total land input. As we will see, AELFG(q,d, effective land) can be used in simulations of the effects of changes in the weather.

The percentage-change equations arising from (7) and (8) that are included in TERM-Water are:

$$\begin{aligned} xelfg(q,d,k) - aelfg(q,d,k) &= xtlop(q,d) \\ &- \sigma_{tlop}(q,d)\left[pelfg(q,d,k) - \textstyle\sum_j SELFG(q,d,j) * pelfg(q,d,j)\right] \\ &- \sigma_{tlop}(q,d)\left[aelfg(q,d,k) - \textstyle\sum_j SELFG(q,d,j) * aelfg(q,d,j)\right] \quad , \quad k \in \{EL, FG\} \end{aligned} \tag{9}$$

where

xelfg(q,d,k), pelfg(q,d,k), aelfg(q,d,k) are percentage changes in the variables defined by the corresponding uppercase symbols;

$\sigma_{tlop}(q,d)$ is (q,d)'s the elasticity of substitution between effective land and feedgrain in the generation of input of total land; and

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[2] PELFG(q,d, EL) are defined by (3). PELFG(q,d, FG) can be defined in a standard way in terms of prices of feedgrain from different regions via the CES specification in the bottom right hand corner of Figure 1.

SELFG(q,d,j) is the share of j (effective land and feedgrain) in (q,d)'s cost of total land, that is:

$$\mathrm{SELFG(q,d,j)} = \frac{\mathrm{PELFG(q,d,j) * XELFG(q,d,j)}}{\sum_k \mathrm{PELFG(q,d,k) * XELFG(q,d,k)}} \quad , \mathrm{j} \in \{\mathrm{EL, FG}\} \ . \tag{10}$$

Composition of land-&-operator input

In deciding its inputs of total land (TL) and operator labour (OP), we assume that farm industry (q,d)

chooses XTLOP(q, d, k), k ∈ {TL, OP}

$$\text{to minimize} \quad \sum_k \mathrm{PTLOP(q,d,k) * XTLOP(q,d,k)} \tag{11}$$

$$\text{subject to} \quad \mathrm{XLOKH(q,d,OP)} = \mathrm{CES_k}\left(\mathrm{XTLOP(q,d,k)}\right) \tag{12}$$

where

XTLOP(q,d,k) refers to inputs to industry (q,d) of input k (total land or operator labour);

PTLOP(q,d,k) is the cost to industry (q,d) of using a unit of input k[3];

XLOKH(q,d,LO) is a measure of (q,d)'s total requirements of land & operator (LO).

The percentage-change equations arising from (7) and (8) that are included in TERM-Water are:

$$\mathrm{xtlop(q,d,k)} = \mathrm{xlokh(q,d,LO)} - \sigma(\mathrm{q,d})\left[\mathrm{ptlop(q,d,k)} - \sum_j \mathrm{S(q,d,j) * ptlop(q,d,j)}\right], \quad \mathrm{k} \in \{\mathrm{TL, OP}\} \tag{13}$$

where

xtlop(q,d,k), ptlop(q,d,k), xlokh(q,d,LO) are percentage changes in the variables defined by the corresponding uppercase symbols;

σ(q,d) is (q,d)'s the elasticity of substitution between total land and operator labour in the generation of the overall input of land & operator; and

S(q,d,j) is the share of j (total land or operator labour) in (q,d)'s cost of land & operator, that is:

$$\mathrm{S(q,d,j)} = \frac{\mathrm{PTLOP(q,d,j) * XTLOP(q,d,j)}}{\sum_k \mathrm{PTLOP(q,d,k) * XTLOP(q,d,k)}} \quad , \mathrm{j} \in \{\mathrm{TL, OP}\} \ . \tag{14}$$

Structure of input-output data for farm industries

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[3] Movements in PTLOP(q,d,OP) are determined by movements in the demand for and supply of owner operators (see subsection 2.3). Percentage movements in PTLOP(q,d,TL) are determined according to:

$$\mathrm{ptlop(q,d,TL)} = \sum_k \mathrm{SELFG(q,d,k) * (pelfg(q,d,k) + aelfg(q,d,k))} \ .$$

by a cost-share weighted average of the percentage movements of effective land and feedgrain plus a cost-share weighted average of the aelfg(q,d,k), k ∈ {EL, FG}.

Are the equations (4), (5), (9) and (13) flexible enough to be applied to all farm industries in the determination of their demands for different types of land, feedgrain and operator labour? In any case, how are water demands being handled? To answer these questions we start by looking at Figure 2.

Figure 2 shows the input-output columns for farm industries in region d. We assume that there are I(d) irrigated industries and H(d) - I(d) dry industries. The top part of the figure covers the flows of intermediate inputs valued at basic prices, together with associated margins and taxes (BAS, MAR, TAX). Although our specification of demands for feedgrain is different from that adopted for other intermediate demands, there is no problem in our database from including feedgrain in the top part of Figure 2.

The middle part of Figure 2 covers other costs and the rental values of inputs of physical capital.

The lower part (shaded), which is the focus of this paper, shows values of hired and operator labour, rental values of irrigable and dry land and values of irrigation water (water obtained from an irrigation authority, by allocation or trading, or from rain falling on land being used by irrigated industries). The figure indicates that:

all farm industries use hired labour and operator labour;
only irrigated industries use irrigation water;
only dry industries use non-negligible amounts of dry land; and
all farm industries use irrigable land (that is land that can receive water from river- and dam-based irrigation systems controlled by water authorities) but only small amounts are used in dry industries.

With regard to the last point, when irrigable land is used in dry industries it is not irrigated. Irrigable land will be allocated to dry industries when there is insufficient irrigation water to service all of the available irrigable land.

With these points in mind, we return to Figure 1, and discuss how TERM-Water deals with demands for irrigable and dry land, feedgrain, operator labour and water for both irrigated and dry industries.

Demands for irrigable and dry land, feedgrain and operator labour

In TERM-Water we force irrigated industries to use only irrigable land by having in our database negligible values for the use of dry land by these industries. In terms of (4) and (5), SLN(q,d,LND) is close to zero and SLN(q,d,LNI) is close to one whenever q refers to an irrigated industry. Consequently, for an irrigated industry, pelfg(q,d,EL) reflects only movements in the cost to the industry of using irrigable land, pln(q,d,LNI). Thus, for irrigated industries, the substitution term in (4) is close to zero and the demand for irrigable land moves in line with the demand for effective land. TERM-Water produces percentage changes in demand by irrigated industries for dry land, xln(q,d,LND), that reflect price-induced substitution between irrigable land and dry land. But these results are of no importance and have no implications for the rest of the model because demand for dry land by irrigated industries is negligible.

For dry industries, we allow TERM-Water to use both dry land and irrigable land. We model these as good substitutes by adopting a high value for σ_{ln}(q,d) whenever q refers to a dry industry: recall that when irrigable land is used by a dry industry this land is similar to dry land because it is not irrigated.

For dry livestock industries we model effective land and feedgrain as good substitutes, by adopting a high value for $\sigma_{tlop}(q,d)$ in (9) whenever q refers to a dry livestock industry. Our reasoning here is that a given number of livestock can be maintained on a small allocation of land with a large allocation of feedgrain or on a large allocation of land with a small allocation of feedgrain. As mentioned earlier, if q is not a dry livestock industry, then we remove the possibility of quantitatively significant feedgrain/effective-land substitution by ensuring that the cost of the total land input is almost entirely accounted for by effective land.

For all farm industries, we adopt a low value for the substitution elasticity [$\sigma(q,d)$ in (13)] between operator labour and total land. For irrigation industries, this is approximately equivalent to assuming a fixed amount of operator labour per hectare of land used. This is because for an irrigation industry, input of effective land and total land move closely in line with hectares of irrigable land.

What does the adoption of a low value for $\sigma(q,d)$ in (13) mean for dry industries? For dry industries, the connection between effective land, XELFG(q,d,EL), and hectares of land input is not as tight as for irrigation industries. Nevertheless, with high substitution between irrigable and dry land [high values for $\sigma_{ln}(q,d)$] we can think of XELFG(q,d,EL) as being the number of hectares of land used.[4] For dry non-livestock industries, total land is approximately XELFG(q,d,EL)/AELFG(q,d,EL). Thus, we can think of total land for dry non-livestock industries as being hectares adjusted for productivity or weather conditions. With a low value for $\sigma(q,d)$ in (13) we are assuming that the amount of operator labour required in a dry non-livestock industry for a given amount of hectares moves with the productivity of the land: more operator labour is needed per hectare in good seasons than in bad seasons.

Finally, what does the adoption of a low value for $\sigma(q,d)$ in (13) mean for dry livestock industries? These industries have the extra complication of total land input being formed by feedgrain as well as productivity-adjusted effective land. In approximate terms, a low value for $\sigma(q,d)$ in these industries means that we need a fixed amount of operator labour per unit of fodder-supplied land where fodder encompasses both pasture and feedgrain.

The cost of using different types of land and the demand for water

We assume that irrigated industry (q,d) needs a technologically or exogenously fixed amount of water [C(q,d,LNI)] per hectare of irrigable land used. This rules out the possibility of using land in an irrigated industry with less than the ideal amount of water per hectare. If there is a shortage of irrigation water, then we assume that not all of the irrigable land is used in irrigated industries.

[4] More accurately, the high value of $\sigma_{ln}(q,d)$ means that XELFG(q,d,EL) is approximately a linear combination of XLN(q,d,LNI) and XLN(q,d,LND). It is approximately the sum of land inputs to (q,d) where a unit of land of type k is defined as the area that had a rental value in (q,d) of $1 in the data for our base period.

Irrigation water can be obtained from a water authority, via trading or an allocation, or it can be supplied by nature. Whatever the source, we assume that for all industries in region d the value per unit of irrigation water is PW(d). Thus, the value of irrigation water used per hectare in irrigated industry (q,d) is C(q,d,LNI)*PW(d). Although irrigation water is not used on dry land, it is algebraically convenient to include the coefficient C(q,d,LND), with the value zero. This allows us to express the cost to all farm industries of using a unit of irrigated or dry land [PLN(q,d,k)] as:

$$PLN(q,d,k) = PLNR(q,d,k) + C(q,d,k) * PW(d) \quad , k \in \{LNI, LND\} \qquad (15)$$

where PLNR(q,d,k) is the rental rate applied to land of type k used by (q,d). In percentage change form for inclusion in TERM-Water, (15) is written as:

$$\begin{aligned} PLN(q,d,k) * pln(q,d,k) &= PLNR(q,d,k) * plnr(q,d,k) \\ &\quad + C(q,d,k) * PW(d) * [c(q,d,k) + pw(d)] \end{aligned} \quad , k \in \{LNI, LND\} \qquad (16)$$

where the lowercase symbols are percentage changes in the variables denoted by the corresponding uppercase symbols.

As mentioned already, for dry land industries we use variations in AELFG(q,d,EL), appearing in (8), to represent variations in rainfall. In simulations in which climatic conditions are ideal in region d, AELFG(q,d,EL) is set at one for dry land industries. In simulations representing severe drought conditions AELFG(q,d,EL) may be set as low as 0.2. For irrigated industries AELFG(q,d,EL) will normally be set at one: under our assumption that C(q,d,LNI) is determined technologically, variations in climatic conditions affect the quantity of irrigable land that is used by irrigated industries but not the productivity of that land.

5. Region-wide constraints and the determination of rental rates for factors and prices for water

Determination of rents

In the current version of TERM-Water we assume that each region d has available fixed amounts of the factors irrigable land, dry land, operator labour and agricultural capital, that is there is a fixed amount of each f in the set {LNI, LND, OP, K}. For each f, TERM-Water allocates this fixed amount between the H(d) farm industries in region d in a price sensitive way according to the optimization problem

choose Z(q,d,f), q= 1, 2, …, H(d)

to maximize $$\sum_q PZ(q,d,f) * Z(q,d,f) \qquad (17)$$

subject to $$ZTOT(d,f) = CET_q\left(Z(q,d,f)\right) \qquad (18)$$

where

Z(q,d,f) is the supply of factor f to industry (q,d);

ZTOT(d,f) is a measure of the total quantity of factor f available in region d; and

PZ(q,d,f) is the rental rate for factor f when used by industry (q,d). In section 4, PZ(q,d,LNI) and PZ(q,d,LND) were denoted as PLNR(q,d,LNI) and PLNR(q,d,LND), and PZ(q,d,OP) was denoted as PTLOP(q,d,OP).

Optimization problems (17) - (18) give TERM-Water percentage change equations describing the supply of factors to industries. These equations take the form:

$$z(q,d,f) = ztot(d,f) + \tau(d,f) * \left(pz(q,d,f) - \sum_v R(v,d,f) * pz(v,d,f)\right) \quad \text{, for all (q,d) and f,} \tag{19}$$

where

z(q,d,f), ztot(q,d,f) and pz(q,d,f) are percentage changes in the variables denoted by the corresponding upper-case symbols;

R(v,d,f) is industry (v,d)'s share of the total rental value of factor f in region d; and

τ(d,f) is a positive parameter (transformation elasticity) that reflects the ease with which factor f can be moved between industries in region d.

With demands specified through the optimization problems set out in section 4, and with supplies specified through the optimization problems set out in this section, TERM-Water determines rental rates via market-clearing equations:

$$XTLOP(q,d,OP) = Z(q,d,OP) \quad \text{, for all (q,d)} \tag{20}$$

$$XLOKH(q,d,K) = Z(q,d,K) \quad \text{, for all (q,d)} \tag{21}$$

$$XLN(q,d,LNI) = Z(q,d,LNI) \quad \text{, for all (q,d)} \tag{22}$$

$$XLN(q,d,LND) = Z(q,d,LND) \quad \text{, for all (q,d)} \tag{23}$$

Determination of the price of irrigation water

Supply and demand for irrigation water in region d is given by:

$$ZW(d) = AW(d) + NatW(d) + TRADE(d) \tag{24}$$

and

$$XW(d) = \sum_q C(q,d,LNI) * XLN(q,d,LNI) \tag{25}$$

where

ZW(d) is the supply of irrigation water in region d;

AW(d) is the amount of irrigation water allocated to region d via the irrigation system;

NatW(d) is the amount of irrigation water supplied to irrigation industries in region d through rainfall;

TRADE(d) is the net amount of irrigation water obtained by region d from trade with other regions;

XW(d) is the demand for irrigation water in region d; and the remaining notation in (25) is as defined earlier.

Market clearing for irrigation water means that

$$XW(d) = ZW(d) . \tag{26}$$

In TERM-Water, the prices of irrigation water [PW(d)] adjust to achieve (26).

To allow for different water trading regimes we include in TERM-Water equations of the form:

$$PW(d) = \sum_{g=1}^{G} Dummy(d,g) * PWG(g) \text{ for all } d \tag{27}$$

and

$$\sum_d Dummy(d,g) * TRADE(d) = 0 \text{ for all } g \tag{28}$$

where

G is the number of groups of regions that form separate water trading blocks;

PWG(g) is the price of irrigation water in trading group g; and

Dummy(d,g) = 1 if d is in trading group g and zero otherwise.

If no trade is possible between regions, then G is simply the number of regions and (27) and (28) reduce to:

$$PW(d) = PWG(d) \text{ for all } d \tag{29}$$

and

$$TRADE(d) = 0 \text{ for all } d \text{ .} \tag{30}$$

If trade is possible between all regions, then G= 1 and (27) and (28) reduce to:

$$PW(d) = PWG(1) \text{ for all } d \tag{31}$$

and

$$\sum_d TRADE(d) = 0 \text{ .} \tag{32}$$

If there are two water trading groups, one consisting of regions 1 to R_1 and the other consisting of regions R_1+1 to R, where R is the number of regions, then (27) and (28) reduce to:

$$PW(d) = PWG(1) \text{ for all } d= 1, \ldots, R_1 \text{ and } PW(d) = PWG(2) \text{ for all } d= R_1+1, \ldots, R \tag{33}$$

and

$$\sum_{d=1}^{R_1} TRADE(d) = 0 \quad \text{and} \quad \sum_{d=R_1+1}^{R} TRADE(d) = 0 . \tag{34}$$

6. Preparation of the database.

The ABS (2006) published a 2001-02 national input-output table containing 109 sectors. The agricultural sectors represented are sheep, grains, beef cattle, dairy cattle, pigs, poultry and other agriculture. The first task was to split the agricultural sectors so as to include most of the key outputs of the Murray-Darling Basin. For this study, grains have been split into rice and other cereals. Other agriculture has been split into fruit, grapes, sugar cane, vegetables and other agriculture. In addition, we split services-to-agriculture into domestically-focused services (i.e., shearing, fruit picking, aerial-spraying) and export-oriented cotton-ginning. This latter split was necessary to ensure that cotton production faces appropriately elastic demand.

The next task was to split the disaggregated national database into 56 regions. This requires estimates of regional shares of national production for each industry. ABS Agstats were the main source data for this split. For commodities, the national split requires regional shares of national usage for each final user (i.e., households, investors, exports), plus estimates of regional shares of national imports. Horridge *et al*. (2005) describes in detail the task of producing the master database.

The task of adapting the master database of TERM to TERM-Water requires several additional steps. First, the TERM database is aggregated so as to represent key agricultural sectors and associated downstream sectors (i.e., ginned cotton, meat products, dairy products, flour & cereals, processed fruit & vegetables, refined sugar and wine & spirits). In the regional dimension, the database is aggregated to 18 regions, including 12 in the Murray-Darling Basin.

Available water accounts (ABS catalogue no. 4610.0 and 4618.0) provide estimates of water use by industry at the state level. The next step is to allocate water usage by industry to the regional level. Since the theory of TERM-Water includes a distinction between dry land and irrigated production in each region, a further step is to split relevant sectors: we split dairy cattle, cotton, non-dairy livestock, cereals, fruit, sugar cane and other agriculture into dry land and irrigated sectors. The basis of the split comes from ABS Agstats data on the number of irrigated hectares in grazing and cropping. Agstats data provide estimates of the split between dry land and irrigated cotton, but not on other individuals sectors within the TERM-Water database.

2001-02, the year of the national input-output table on which we base TERM, was the most recent of the years in which water was relatively abundant. Given this, in the TERM database, we assign a relatively low initial unit value to water used by irrigators, $60 per megalitre. Next, we had to reassign primary factor values in each irrigation industry, to include the value of water used in production. We wrote a program that reduced capital rentals by 30% in the database. A justification for this is that the value of water used in irrigation sectors tends not to appear as a material input in the input-output table prepared by ABS. Water rights may be embedded in the industry GOS. In addition, we moved 30% of labour in the original database to GOS in irrigated sectors. We do not know the precise split between owner-operators and hired labour: on family farms, the latter is likely to be a small share, whereas on corporate holdings, it may be somewhat larger. In the irrigation sectors, we reassign GOS after reducing both capital rentals and the wages bill by 30%. Water's value is based on the initial price multiplied by the estimated volume of usage. We distribute 50% of the remaining GOS to each of owner-operators and irrigated land. A negligible value is assigned to dry-land rentals. Given the unit cost of water imposed above, cost shares for water are between 10 and 20% in the irrigated dairy cattle sector, 5 and 15% in the irrigated cotton sector and around 40% in the rice sector.

In order to implement CES substitution between feedgrains and pasture, no adjustment is required to the database. We interpret the feedgrain usage in the livestock sectors in the published input-output table as that of a typical (i.e., not in drought) year. We split the initial returns to land in dry-land sectors half each to the dry-land factor and owner-operators.

7. Applying TERM-Water: the effects of drought in 2006 and the benefits of trading irrigation water

The regional distribution of the 2006-07 drought

Extreme events characterised rainfall in south eastern Australia and the mixed farming area of Western Australia in 2006. From the perspective of irrigators in the Murray-Darling Basin, almost the entire Snowy Mountains region suffered record rainfall deficits in the year (figure 3). Rainfall deficits in the other catchment regions were marginally less severe. Water allocated to irrigators was cut by around two thirds across the southern Murray-Darling basin, reflecting catchment deficits due to drought conditions.

Winter crops in the south western and south eastern regions of the continent suffered due to record dry spells. In Western Australia, this occurred from May to July 2006 (figure 4), while south eastern Australia suffered acute rainfall deficits from August to October 2006 (figure 5).

Modelling the 2006-07 drought in TERM-water

Using TERM-Water, we estimate the economic impact of the drought of 2006-07. We report two simulations, one with restricted water trading and another with more extensive inter-regional water trading allowed between irrigators. For each simulation, we ascribe shocks to irrigation sectors via reduced water availability. In dry-land crop sectors, we ascribed negative productivity shocks in response to rainfall deficits. Therefore, we are able to capture the consequences of the drought both to dry-land farmers and irrigators. In addition, we ascribe negative land productivity shocks to the dry-land livestock sectors.

In the short-run setting of our simulation, we assume that capital stocks and land are fixed in aggregate (with limited mobility between farm industries). A critical assumption in the labour market is that real wages can drop as the labour market weakens due to drought. In addition, labour is imperfectly mobile between regions. This means in a region in which labour market conditions deteriorate more than average, adjustment is via a greater fall in real wages than the national average, combined with jobs losses and some migration to other regions.

Table 1 contains the shocks given to the model. Column of table 1 shows water availability relative to normal. This availability concerns irrigation rather than dry-land sectors. For example, the rest of South Australia (RoSA) has no change in water availability (i.e., water =100), reflecting the absence of irrigation activity that is significant nationally. However, the drought affected dry-land activities in RoSA, reflected in productivity losses. For example, the productivity index in RoSA dropped from 100 (a normal year) to 47.6 for dry-land cereal. In western NSW and Victoria, the productivity impact of drought was assumed to be worse, with an index of 40 in many regions.

In the first scenario, water trading is allowed only within each region, and then only between different crop types and different livestock activities, without trades between crops and livestock. In the second scenario, we allow trading between all irrigators in each region, and between regions of the southern Murray-Darling Basin. Before examining the modelled national impact of the drought, we first use a back-of-the-envelope calculation to estimate the direct impact of the drought. Let PRIM(i,d) be each sector's primary factor returns, PRIM_AgDry the national sum of returns to dryland agricultural sectors and PRIM_ID the national returns summed across all sectors and regions. Dryland agriculture's share of national primary factor returns (i.e., PRIM_AgDry/ PRIM_ID) is 2.59%. Let aprim represent the primary factor deterioration across agricultural dryland sectors due to drought. This sum is -1.16% (= $\sum_i \sum_d$ [PRIM(i,d)/PRIM_ID*-aprim(i,d)]), indicating that primary factor productivity in dryland agriculture has fallen by an average of 45% (=-1.16/2.59) at the national level. Next, we calculate the impact of lost water on the economy. Let VWATER be the initial value of irrigation water. Its share of primary factor returns is 0.11%. The cut in irrigation water availability [xwat(i,d)] summed across all regions and sectors at initial water prices is equal to 0.05% of GDP (= $\sum_i \sum_d$ [VWATER(i,d)/PRIM_ID*-xwat(i,d)]), indicating a 45% reduction in national irrigation water availability (=-0.05/0.11). Therefore, our back-of-the-envelope calculation at initial prices ($BOTE_0$) indicates a loss in real GDP of 1.21% (=-1.16 +-0.05). As the marginal products of primary factors in agriculture fall with technological deterioration, so their rental prices will fall. Therefore, PRIM_AgDry/PRIM_ID will decline due to drought. Conversely, as the irrigation water becomes scarcer, its price will rise. If we repeat the BOTE exercise using final instead of initial factor and water prices, primary factor deterioration contributes -0.93% and irrigation water losses -0.11% to a total real GDP outcome of -1.04% (table 2).

Our BOTE exercise does not consider the impact of employment. The capital/labour ratio (K/L) moves with the real wages to rate-of-return on capital ratio (w/r). In the short run, capital is fixed in each non-agricultural sector and farm capital is fixed in aggregate. If real wages are fixed, then as the marginal product of capital falls with technological deterioration, so too does national employment. In the labour market closure used in this application, we allow real wages to fall in the short run but they do so not by a smaller proportion than capital rates-of-return. Real wages (using the GDP deflator instead of CPI) fall by 0.86% whereas the average rate-of-return on capital falls by 2.0%. Consequently, with K/L rising (with fixed capital stocks) as w/r rises, national employment falls (-0.84%, table 3, contributing -0.45% to the modelled loss in real GDP (table 2). The contribution of primary factor productivity is smaller than either BOTE calculation, with losses being distributed across labour and taxes. Reduced production and indirect tax revenues contribute 0.23% of the overall 1.43% loss in GDP. The modelled income loss due to reductions in irrigation water availability is larger than either BOTE calculation at 0.16% of GDP.

The indirect impacts, concentrated under the heading "labour", depend to some extent on what we assume concerning the short-run link between regional income and regional household consumption. In many short-run settings, real aggregate household consumption is exogenous. We think this an unrealistic depiction of the response to severe drought, and one that would underestimate the economic consequences. We have tied nominal aggregate consumption to aggregate nominal income in each region.

Comparing the two scenarios, the water endowment loss recorded in table 2 falls from -0.16% to -0.10% of GDP when restrictions on water trading are lifted. Less restrictive water trading reduces extreme water price hikes, leading to a decline in the value share of water in GDP relative to the first scenario. The other main impact is on labour: the employment loss nationally diminishes so that the contribution to the GDP loss shrinks from -0.45% to -0.37%. The difference in income losses between limited water trading and more widespread water trading in response to the drought is 0.17% of GDP, equal to around $1.2 billion (based on the GDP for 2001-02, the year of the database). This large efficiency gain reflects the importance of moving water to maximise the value of farm output as its scarcity rises. Table 3 shows the national macro results for other indicators, reflecting the decomposition showing in table 2. Real consumption, real investment and employment fall by a smaller percentage in the water-trading scenario.

The estimated impact of the drought (real GDP loss of 1.43% with limited trading or 1.26% with water trading between all irrigators in the southern Murray-Darling basin) is greater than the impact that will be recorded in the national accounts for 2006-07. The mining boom is stimulating growth at the same time as the drought is depressing it – and absorbing jobs lost in agriculture. This contrasts with the 2002-03 drought, in which there was no compensating boom in mining and real GDP fell sharply relative to forecasts at the beginning of that year.

Next, we consider the impact of the drought on regional economies of Australia. Following the national BOTE calculation, without adding across regions, regional BOTE dryland productivity losses are $\sum_i$ [PRIM(i,d)/PRIM_I(d)*-aprim(i,d)]. For lost irrigation water, the formula is $\sum_i$ [VWATER(i,d)/PRIM_I(d)*-xwat(i,d)]. Once again, the BOTE calculations of real GDP losses do not quite match the simulated outcomes for the two scenarios (see table 2). Nevertheless, the BOTE calculations follow the rankings of the regions in the simulations: the largest loser among the regions of the southern Murray-Darling basin is Wimmera in all cases. Agriculture's share of primary factor income in Wimmera in the initial database is higher than for any other region in the model.

As the scarcity of water worsens, we might expect water to move away from sectors with relatively high water-intensities. We can measure livestock water-intensity as VWATER_LIVE(d)/PRIM_LIVE(d), where VWATERLIVE is the sum of the value of water used and PRIM_LIVE the sum of primary factor returns in irrigation livestock sectors in each region. For irrigated crops, we designate the corresponding water intensity in each region as VWATER_CROP(d)/PRIM_CROP(d). In regions other than Murrumbidgee and Murray in NSW, the initial cost share of water in total primary factor costs is much higher for livestock sectors than cropping. The Murrumbidgee and Murray regions are exceptions because they include most of Australia's rice production in the initial database. For example, in the Murray region, VWATER_CROP/PRIM_CROP is 22% compared with 17% for VWATER_LIVE/PRIM_LIVE. This means that in scenario one, the price of water rises more for livestock than crops in Murray, whereas in other regions, the price of water for livestock rises less than for crops (table 8).

Three regions end up being net sellers of water, Murray in NSW and Goulburn and Ovens-Murray in Victoria. In each case, holders of water rights face a price increase when water is opened to inter-regional trading. Comparing tables 4 and 5, we note that real GDP improves with less restricted water trading in all regions other than Murray NSW. This indicates that there are efficiency gains in Goulburn and Ovens-Murray from allowing broader water trading: water is sold by livestock sectors to crops and other regions.

A puzzle arises in the following regions: Murrumbidgee, Mallee and Murray Lands. This is that despite regional real GDP faring better with more liberal water trading in the second scenario, aggregate consumption falls further than in the first scenario. The dominant reason for this outcome is that each of these three regions is a net exporter of grapes to other regions. Water trading reduces price pressures on grapes dramatically: the producer price rises by 64% in the first scenario and only 24% in the second. This contributes to a negative terms-of-trade impact on these regions in the second scenario relative to the first. The GDP price index reflects the terms-of-trade impact in each case: the index rises in Murrumbidgee by 4.6% in the first and only 3.0% in the second scenario. The drop in Mallee is from 8.9% to 5.1% and in Murray Lands from 5.3% to 1.6%.

Table 3 includes the percentage change in national prices and outputs for agriculture, plus base level primary factor costs for each sector, for the restricted trading and full water trading scenarios. Changes in income due to more liberal water trading reflect the terms-of-trade impacts, as shown in lower half of table 3. Water trading alleviates the extreme scarcity of water, thereby driving down the average price of farm outputs. This lowers the costs of users of farm outputs, including other farm sectors and downstream processing. One example of rising scarcity due to drought concerns the grape sector in Australia. Since the 2004 vintage, rising outputs have imposed sharply declining prices on grapes, especially from warm climate irrigation regions. The 2007 vintage is seeing a marked recovery in prices due to the drought-induced supply decrease. For some growers, output losses will outweigh price increases. For others, drought may bring a recovery in income. Actual price hikes for grapes are likely to be closer to those of our first scenario rather than the second, reflecting in part structural changes due to export growth unrelated to the drought.

Rice output, which falls by over 91% without inter-regional water trading, falls slightly more when water trading is permitted. However, Murrumbidgee rice growers produce slightly more rice in the second scenario. Pre-simulation water usage by the rice industry in these two regions is 1,442 GL, compared with 63 GL following the second simulation.[5]

While we expect water trading to move water to activities in which it yields a higher income per megalitre, we also expect perennial crop and livestock producers to be willing to pay a high price for water during drought so as to preserve future income-earning capacity. The substitution between feedgrains and pasture for livestock provides an avenue of ensuring that livestock herds do not shrink excessively in response to drought: the national output change we report in each simulation of around 3% for dairy cattle (table 3) is consistent with either reduced output per head or culling of the less productive herd members. In the case of grapes and fruit, incomes per unit of water are generally higher than for annual crops. Although the direction of water trades that we model is broadly consistent with our expectations, we believe that the addition of dynamics to the model would enhance our treatment of perennials and livestock herds.

How do our modelled prices for water compare with observed water trades in 2006-07? At this stage, we do not have comprehensive estimates of volume-weighted averages of water prices traded over the entire year. Summaries of newspaper releases downloadable at http://www.infarmation.com.au indicate that in the NSW Murray Irrigation water exchange, the average price in mid-August was $180 per megalitre. By late August, prices in northern Victoria had reached $300 per megalitre. By early November, prices in the region were over $600 per megalitre. At the same time, over the border in the Murray Valley, the price was just over $300 per megalitre. In early December 2006, temporary Goulburn prices reached $780 per megalitre, peaking at around $900 per megalitre a week or so later. In the first scenario, the price of water in Murray NSW post-simulation was $258 per megalitre for crops and $291 per megalitre for livestock, between the trading prices observed in mid-August and early November. In the second scenario, the post-simulation water price across the southern Murray-Darling basin was $313 per megalitre. This is much lower than observed spot trading prices in northern Victoria, while the post-simulation water prices for scenario one for Goulburn and Ovens-Murray cropping were much higher than this. We might infer that scenario one entails more restrictive trading and scenario two more liberal trading than occurs in practice at present. In addition, available data indicates that water allocations may have been cut by more than the 70% we modelled across northern Victoria and southern New South Wales. With more detailed data on both cuts in allocation and average water trading prices across regions, we will able to adjust the parameters of the model if need be.

8. Concluding remarks and future directions

The analysis of results in section 7 shows how the interaction between theory and the database drives modelled outcomes. It follows that if we revise the estimates of water

[5] The ABS publication *Water Account Australia* (catalogue no. 4610.0) reflects net sales of water by rice growers in response to drought. In 2000-01 (the second most recent year in which water was relatively abundant), NSW rice growers used 1,924 GL of water compared with 624 GL in 2004-05 (table 2.10 of respective editions). Rice growers have continued selling water since the 2002-03 drought, as its scarcity value has remained high.

used by region and sector, the results may change and the pattern of water trades may also change. We believe that moving to a dynamic model is an important future task. As indicated already, this will help with the decisions of producers who wish to preserve capital under threat from drought, be it in the form of a plantation, a vineyard or a livestock herd. Even with relatively restricted water trading, we might expect annual crop producers to sell water to perennial producers in drought as the latter seek to maintain their future income-earning capacity. Another reason for moving to dynamics is that will enable us to use inputs from water allocation models, such as those using REALM software (Perera *et al*., 2005). At present, we treat water supply as exogenous. Some additional insights will come from modelling allocation decisions in response to year-by-year water supplies (Dixon *et al*., 2005). This would be helpful when it comes to combining hydrological detail, which is based on catchments rather than statistical divisions, with TERM-Water.

A recent development in the preparation of the TERM master database has been obtaining industry level data at the statistical local area (SLA) level. The ABS has 2001 census data of industry employment at the 3-digit ANZSIC level by SLA. These are not quite sufficient for the sectoral detail in TERM-Water though importantly, they cover dairy cattle. In addition, Davidson *et al.* (2004) provide disaggregated estimates of agricultural output at the SLA level. One option we are considering is to represent catchment regions in a bottom-up manner in future versions of TERM, based on combinations of SLAs. This is a substantial data preparation task the importance of which we will better understand as we proceed further with model development.

References

ABS (2006) *Australian National Accounts: Input-Output Tables - Electronic Publication, 2001-02*, Catalogue no. 5209.0.55.001.

Davidson, A., Elliston, L., King, J. and Brennan, J. (2004) *Contribution of plant industries to regional economies*, ABARE project no. 2875, Date request from Plant Health Australia Categorisation Group.

Dixon, P., Schreider, S. and Wittwer, G. (2005) "Combining engineering-based water models with a CGE model", chapter 2 in Productivity Commission, *Quantitative tools for microeconomic policy analysis*, Conference Proceedings, 17-18 November, 2004, Canberra.

Perera, B., James, B. and Kularathna, M. (2005) "Computer software tool REALM for sustainable water allocation and management", *Journal of Environmental Management* 77(4): 291-300.

Horridge, M., Madden, J. and Wittwer, G. (2005) "Using a highly disaggregated multi-regional single-country model to analyse the impacts of the 2002-03 drought on Australia", *Journal of Policy Modelling* 27(3):285-308, May.

Figure 1. Production function for a farm industry

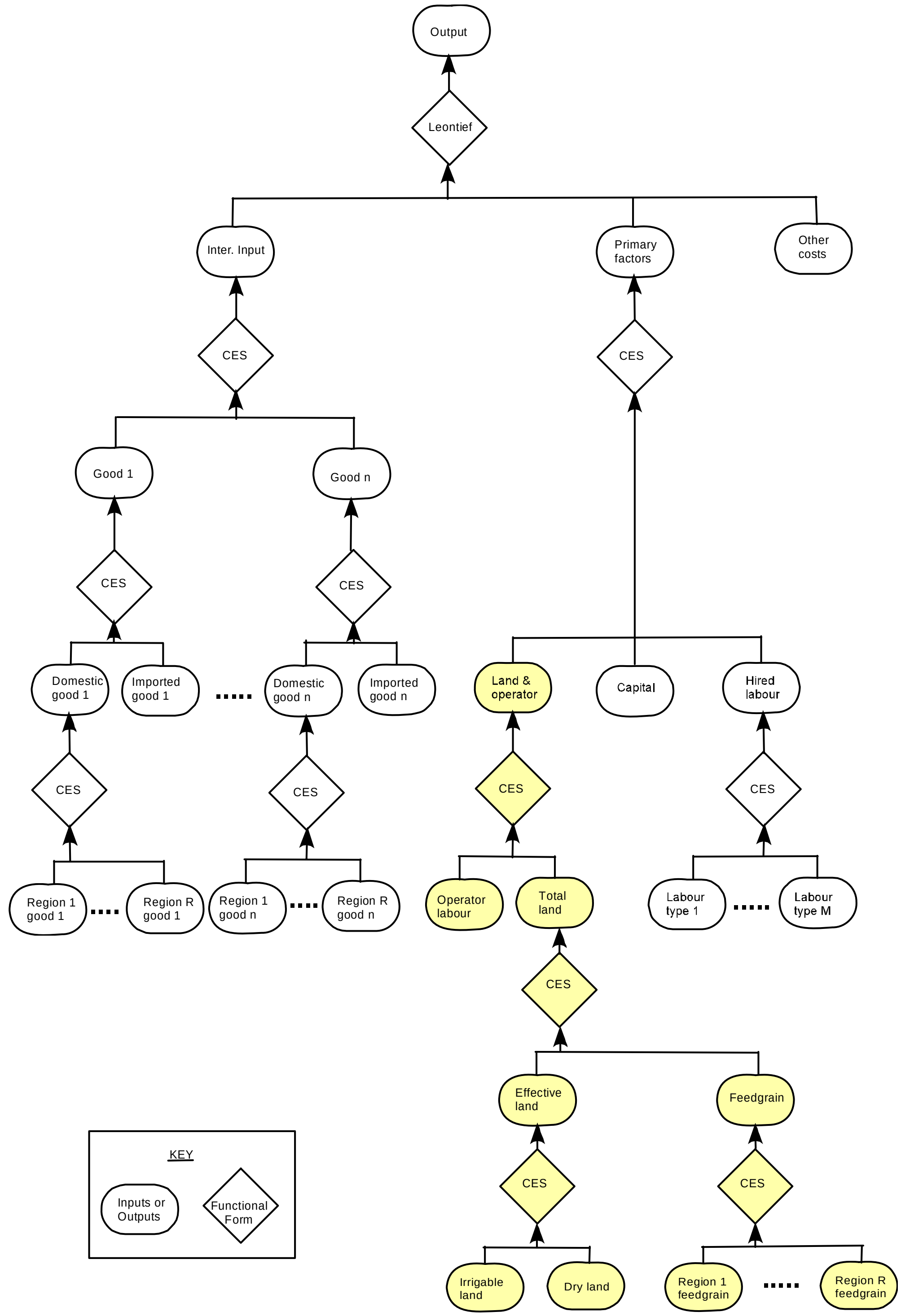

Figure 2. Farm industries in region d in the input-output data for TERM-Water*

	Irrigated industries					Dry industries					
	1	2	…,	…,	I(d)	I(d)+1	I(d)+2	…,	…,	H(d)	
BAS	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
MAR	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
TAX	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Capital	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Other costs	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Hired labour	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Operator labour	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Dry Land	~	~	~	~	~	√	√	√	√	√	
Irrigable land	√	√	√	√	√	√	√	√	√	√	
Irrigation water	√	√	√	√	√	-	-	-	-	-	
Value of output	Totals					Totals					

* Y indicates use
A large √ indicates significant use and a small √ indicates minor use.
~ indicates a negligible use
- indicates zero use

Figure 3: Rainfall deficiencies for all 12 months of 2006

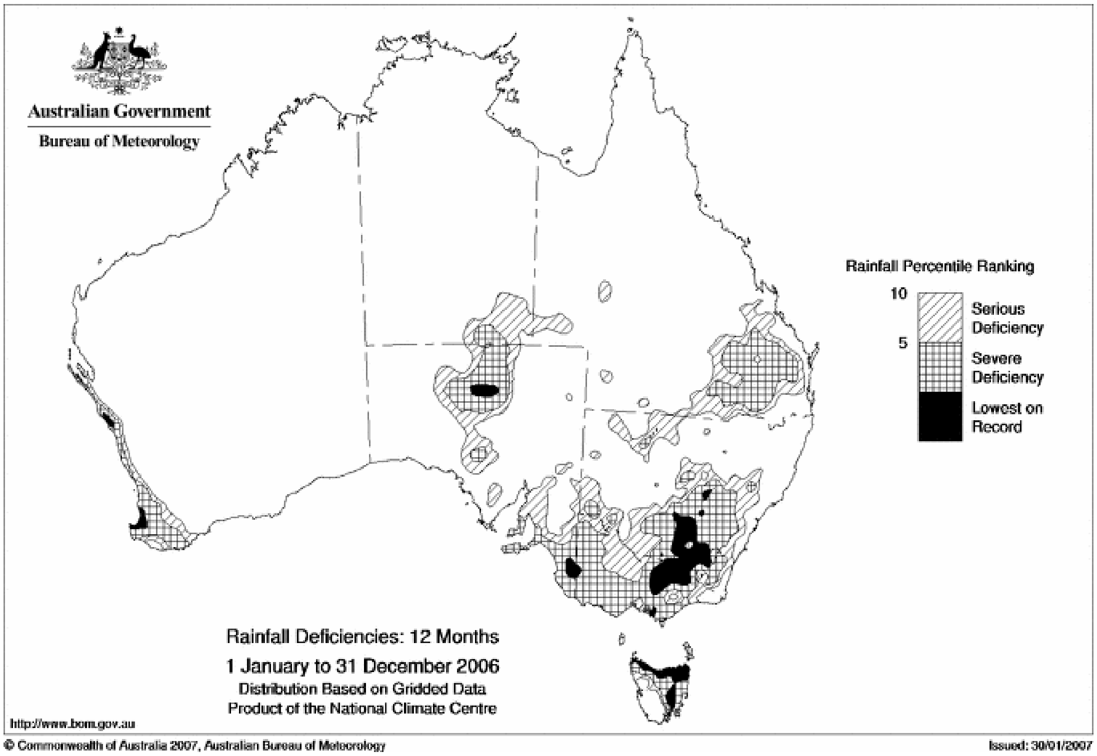

Figure 4: Rainfall deficiencies for May to July, 2006

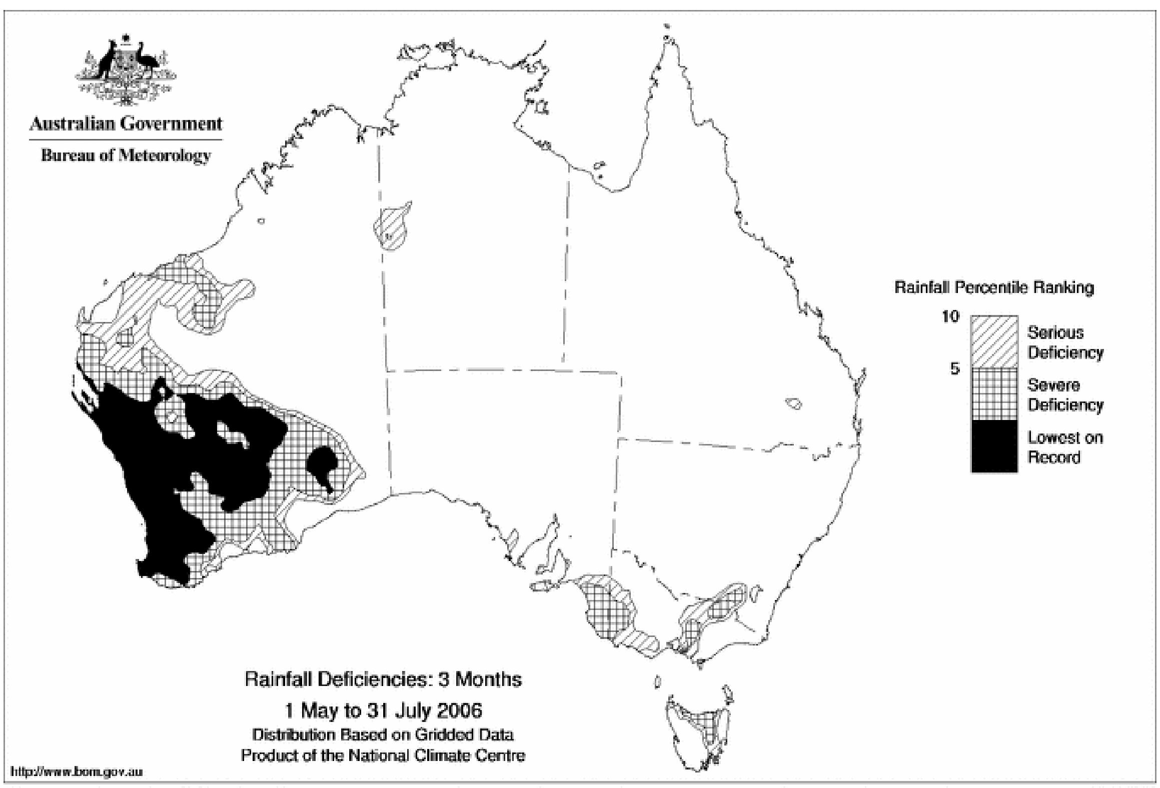

Figure 5: Rainfall deficiencies for August to October, 2006

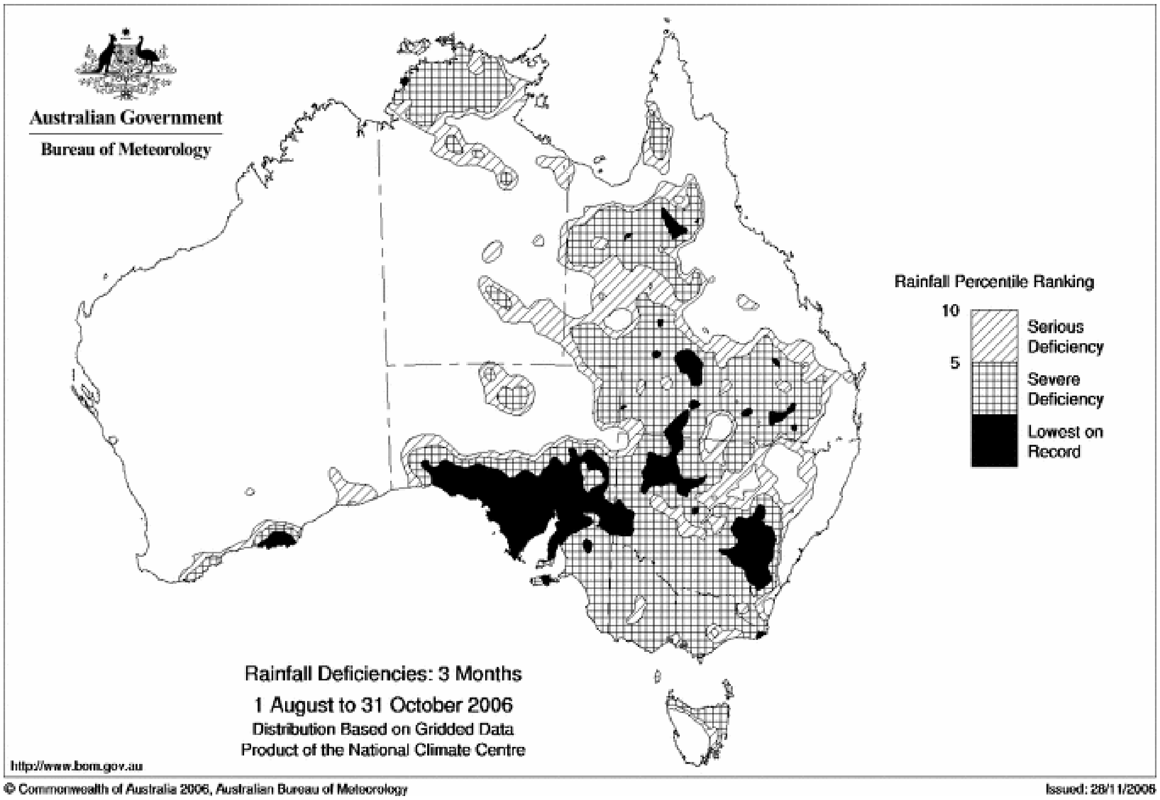

Table 1: Shocks depicting the direct impacts of the 2006-07 drought[a] (% change from base case)

	Water	Cereal Dry-land	Dry-land pasture	Cotton Dry-land	Fruit Dry-land	Sugar Cane Dry-land	Other Agriculture Dry-land
RoNSW	80	66.7	0.0	-	76.9	76.9	66.7
NorthernNSW	80	40.0	83.3	71.4	71.4	-	50.0
NorthWestNSW	60	40.0	83.3	71.4	71.4	-	50.0
CentrlWstNSW	60	50.0	66.7	50.0	50.0	-	50.0
MrmbidgeeNSW	30	40.0	57.0	40.0	40.0	-	40.0
MurrayNSW	30	40.0	57.0	-	40.0	-	40.0
FarWestNSW	60	40.0	60.6	-	-	-	-
RoVIC	40	50.0	77.0	-	50.0	-	50.0
WimmeraVIC	30	40.0	57.0	-	40.0	-	40.0
MalleeVIC	30	40.0	57.0	-	40.0	-	40.0
LoddonCmpVIC	30	40.0	57.0	-	40.0	-	40.0
GoulburnVIC	30	40.0	57.0	-	40.0	-	40.0
OvensMrryVIC	30	40.0	57.0	-	40.0	-	40.0
RoQLD	80	66.7	76.9	66.7	66.7	66.7	66.7
DarlSWQld	60	66.7	66.7	66.7	66.7	-	66.7
RoSA	100	40.0	59.0	-	47.6	-	47.6
MurrayLndsSA	50	40.0	57.0	-	47.6	-	47.6
RoA	50	66.7	71.5	62.5	62.5	-	66.7

a Water column: base case water availability =100; other columns: base case total factor productivity = 100.

Table 2: Decomposition on national real GDP, income side and regional real GDP (% change from base case)

	$BOTE_0$	$BOTE_1$	Limited water trading	Water trading
Water	-0.05	-0.11	-0.16	-0.10
Labour	0	0	-0.45	-0.37
Capital	0	0	0	0
Primary factor productivity	-1.16	-0.93	-0.59	-0.58
Production/indirect taxes	0	0	-0.23	-0.21
Total	-1.21	-1.04	-1.43	-1.20
Regional real GDP:				
MurrumbidgeeNSW	-9.9	-4.9	-8.2	-8.0
MurrayNSW	-8.0	-3.2	-8.2	-10.0
WimmeraVIC	-31.1	-20.0	-18.6	-14.4
MalleeVIC	-15.5	-8.4	-11.0	-9.3
LoddonVIC	-2.8	-1.6	-2.8	-2.6
GoulburnVIC	-3.8	-1.8	-5.3	-4.1
OvensMrryVIC	-1.9	-1.1	-3.5	-3.0
MurrayLndsSA	-3.3	-1.5	-5.7	-4.4

Table 3: National macro results (% change from base case)

	Limited water trading		Water trading		
Real Hou	-1.54		-1.32		
Real Inv	-1.36		-1.18		
Real Gov	0		0		
Exp Vol	-1.81		-1.69		
Imp Vol	-1.17		-1.07		
Real GDP	-1.43		-1.26		
Agg Employ	-0.84		-0.68		
Avg real wage	-0.86		-0.74		
Agg Cap Stock	0.00		0.00		
GDPPI	-1.60		-1.53		
CPI	-1.41		-1.42		
ExportPI	0.46		0.43		
National output	Output	Price	Output	Price	Δ income $m
Cereals	-50.9	45.8	-49.9	44.0	-57
Rice	-90.8	66.3	-93.9	70.8	-30
DairyCattle	-2.8	12.2	-3.4	14.5	136
OtherLivestock	-5.3	6.5	-5.3	6.4	77
Cotton	-11.7	35.3	-10.1	28.2	-51
Grapes	-12.4	64.7	-5.3	24.0	-343
Vegetables	-6.5	20.1	-2.0	3.7	-464
Fruit	-7.8	25.2	-3.3	9.5	-681
Sugar cane	-9.8	54.2	-8.3	44.9	-102
Other Agri	-10.3	45.9	-8.3	36.3	-250

Table 4: Regional macro outcomes of drought, restricted water trading (% change from base case)

	RoNSW	Northern NSW	NorthWest NSW	CentrlWst NSW	Mrmbidgee NSW	Murray NSW	FarWest NSW	RoVIC	Wimmera VIC	Mallee VIC	LoddonCmp VIC	Goulburn VIC	OvensMrry VIC	RoQLD	DarlSWQld	RoSA	MurrayLnds SA	RoA
RealHou	-1.94	0.61	-1.45	-2.42	-1.52	-2.02	-1.68	-1.79	-4.92	0.02	-2.78	-1.36	-3.85	-1.11	0.66	-1.91	3.31	-0.52
RealInv	-1.33	-3.76	-5.10	-2.97	-5.78	-6.32	-1.73	-1.35	-10.13	-6.52	-2.70	-4.38	-3.75	-1.09	-1.67	-1.79	-3.36	-0.19
RealGov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ExpVol	-0.75	3.31	1.91	2.21	0.12	0.09	0.53	-3.20	2.22	3.82	2.78	3.41	3.52	0.43	3.38	-11.36	-1.07	-0.83
ImpVolUsed	-1.22	-2.77	-4.73	-2.53	-3.21	-3.03	-2.03	-1.05	-9.40	-4.89	-2.16	-3.00	-1.73	-0.88	-1.02	-1.45	-1.44	-0.55
RealGDP	-0.65	-6.99	-9.41	-5.86	-8.25	-8.23	-1.88	-0.93	-18.56	-11.02	-2.79	-5.32	-3.47	-0.73	-3.84	-2.07	-5.71	-1.51
AggEmploy	-0.84	-0.78	-1.52	-1.30	-1.30	-1.32	-1.06	-0.87	-2.68	-1.35	-1.21	-1.55	-1.87	-0.72	-0.91	-0.84	-1.27	-0.68
Real wage	0.24	-7.65	-9.08	-4.94	-7.73	-7.71	-1.40	-0.16	-17.62	-12.05	-1.48	-5.26	-1.74	-0.40	-5.10	-1.17	-8.10	-1.75
GDPPI	-2.77	5.24	5.55	1.84	4.61	4.59	-1.31	-2.33	12.49	8.93	-1.35	2.13	-1.77	-1.86	2.53	-1.41	5.27	-0.31
CPI	-1.48	-1.44	-1.64	-1.47	-1.50	-1.47	-1.39	-1.40	-1.79	-1.43	-1.31	-1.19	-1.18	-1.36	-1.44	-1.53	-1.25	-1.21
ExportPI	-0.04	-0.68	-0.41	-0.47	0.03	0.03	-0.14	1.03	-0.47	-0.78	-0.58	-0.70	-0.72	-0.22	-0.69	3.10	0.26	0.32

Table 5: Regional macro outcomes of drought, full water trading in southern MDB (% change from base case)

	RoNSW	Northern NSW	NorthWest NSW	CentrlWst NSW	Mrmbidgee NSW	Murray NSW	FarWest NSW	RoVIC	Wimmera VIC	Mallee VIC	LoddonCmp VIC	Goulburn VIC	OvensMrry VIC	RoQLD	DarlSWQld	RoSA	MurrayLnds SA	RoA
RealHou	-1.53	-0.33	-2.26	-2.69	-3.03	-4.32	-1.26	-1.33	-3.67	-2.68	-2.52	-1.55	-3.24	-1.02	0.14	-1.88	-0.57	-0.41
RealInv	-1.09	-3.94	-5.25	-2.98	-5.68	-7.92	-1.48	-1.07	-7.71	-6.25	-2.45	-3.89	-3.33	-1.00	-1.79	-1.67	-3.49	-0.14
RealGov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ExpVol	-0.58	3.08	1.81	2.04	0.55	0.73	0.48	-3.23	1.93	3.58	2.52	3.07	3.16	0.59	3.10	-10.66	-0.68	-0.81
ImpVolUsed	-1.03	-3.22	-5.10	-2.71	-3.78	-4.69	-1.78	-0.83	-6.64	-5.36	-2.05	-2.72	-1.37	-0.90	-1.33	-1.44	-2.41	-0.51
RealGDP	-0.52	-7.05	-9.39	-5.76	-7.95	-9.97	-1.63	-0.66	-14.36	-9.28	-2.61	-4.13	-2.97	-0.69	-3.88	-1.98	-4.42	-1.35
AggEmploy	-0.66	-0.87	-1.56	-1.26	-1.63	-2.01	-0.82	-0.64	-0.71	-1.35	-1.09	-1.07	-1.49	-0.63	-0.95	-0.75	-1.20	-0.54
averealwage	0.17	-7.08	-8.49	-4.61	-6.71	-7.55	-1.33	-0.11	-13.08	-8.43	-1.41	-3.75	-1.51	-0.36	-4.77	-1.01	-4.49	-1.58
GDPPI	-2.47	4.46	4.81	1.49	3.03	3.35	-1.12	-2.08	10.44	5.13	-1.33	1.11	-1.64	-1.82	2.10	-1.49	1.58	-0.34
CPI	-1.47	-1.53	-1.74	-1.55	-1.65	-1.70	-1.43	-1.40	-1.76	-1.62	-1.38	-1.31	-1.29	-1.39	-1.48	-1.57	-1.42	-1.25
ExportPI	0.00	-0.64	-0.39	-0.43	-0.06	-0.09	-0.13	0.97	-0.41	-0.73	-0.53	-0.63	-0.65	-0.23	-0.64	2.85	0.19	0.28

Table 6: Regional sectoral outputs, restricted water trading (% change from base case)

	RoNSW	Northern NSW	NorthWest NSW	CentrlWst NSW	Mrmbidgee NSW	Murray NSW	FarWest NSW	RoVIC	Wimmera VIC	Mallee VIC	LoddonCmp VIC	Goulburn VIC	OvensMrry VIC	RoQLD	DarlSWQld	RoSA	MurrayLnds SA	RoA
Cereal DryL	-35	-71	-69	-55	-70	-71	-72	-60	-67	-69	-70	-70	-71	-35	-30	-71	-71	-30
Cereal Irig	-74	-2	-43	-90	-27	-19	..	-44	..	-83	-76	-97	..	-11	9	-9	..	-90
Rice	..	..	..	..	-99	-85	..	..	..	..	..	-62	..	..	..	..	..	..
DairyCat DryL	9	17	23	12	13	11	..	10	13	13	9	6	9	2	3	8	7	5
DairyCat Irig	-9	-24	-25	-25	-22	-64	..	-48	..	-61	-67	-60	-62	-3	-17	15	-37	-35
OthLivsto Dry	-1	7	10	-2	-1	-3	-8	-4	4	-2	-4	-11	-10	-10	-10	-3	-6	-8
OthLivsto Irg	-16	-8	-23	-24	-49	-40	-24	-36	-54	-23	-31	-25	-28	-15	-28	-1	-25	-33
Cotton DryL	..	-13	-9	..	..	..	..	..	..	..	..	..	..	..	-26	..	..	..
Cotton Irig	..	-1	-15	-34	-7	..	..	..	..	..	..	..	..	-15	-25	..	..	..
Grapes	-32	..	-24	-43	-2	21	..	-94	..	-62	6	-63	-69	..	..	41	-18	-80
Vegetables	..	13	4	..	12	18	..	-23	..	10	16	-12	..	12	14	..	-13	-21
Fruit DryL	-22	-26	-22	-62	-76	-67	..	-63	-67	-75	-64	-76	-75	-42	-38	-64	..	-44
Fruit Irig	9	22	20	14	24	28	..	-37	-69	8	18	-24	-22	20	22	-14	-28	5
SugarCane DryL	6	..	..	..	..	..	..	..	..	..	..	..	..	-17	..	..	..	..
SugarCane Irig	..	..	..	..	..	..	..	..	..	..	..	..	..	-4	..	..	..	-90
OthAgri Dry	-26	-71	-69	-52	-68	-69	..	-55	-67	-69	-68	-70	-66	-26	-20	-67	-68	-20
OthAgri Irig	25	44	40	25	39	50	17	29	28	53	58	39	13	36	5	53	23	-10

Table 7: Regional sectoral outputs, full water trading across southern MDB(% change from base case)

	RoNSW	Northern NSW	NorthWest NSW	CentrlWst NSW	Mrmbidgee NSW	Murray NSW	FarWest NSW	RoVIC	Wimmera VIC	Mallee VIC	LoddonCmp VIC	Goulburn VIC	OvensMrry VIC	RoQLD	DarlSWQld	RoSA	MurrayLnds SA	RoA
Cereal DryL	-36	-71	-69	-55	-70	-69	-74	-61	-68	-70	-72	-74	-72	-34	-30	-70	-72	-30
Cereal Irig	28	12	-26	-43	-3	-35	-1	7	0	3	-35	-18	0	4	17	56	0	-41
Rice	-24	0	0	0	-94	-94	0	0	0	0	0	-68	0	0	0	0	0	0
DairyCat DryL	14	24	30	19	19	18	0	13	15	19	16	11	14	8	8	14	14	11
DairyCat Irig	-20	-18	-18	-63	-25	-64	0	-57	0	-95	-85	-98	-91	-34	-40	5	-76	-62
OthLivsto Dry	0	8	12	0	0	1	-8	-5	2	-1	-2	-12	-10	-7	-9	-1	-5	-7
OthLivsto Irg	-28	-39	-60	-58	-44	-42	-52	-46	-51	-50	-52	-57	-54	-47	-52	-28	-57	-58
Cotton DryL	0	-19	-15	0	0	0	0	0	0	0	0	0	0	0	-31	0	0	0
Cotton Irig	7	0	-12	-11	0	0	0	0	0	0	0	0	0	-10	-22	0	0	0
Grapes	6	0	-50	-42	-26	-41	0	-8	0	-29	0	-10	-6	0	0	27	-8	-40
Vegetables	-1	-2	0	-6	-2	-1	0	0	0	3	2	-1	0	-2	-1	3	-8	-7
Fruit DryL	-35	-38	-34	-70	-81	-64	0	-75	-80	-81	-61	-83	-82	-52	-48	-73	0	-56
Fruit Irig	8	8	6	6	10	11	0	5	8	7	6	4	7	6	7	6	-11	8
SugarCane DryL	0	0	0	0	0	0	0	0	0	0	0	0	0	-22	0	0	0	0
SugarCane Irig	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	-59
OthAgri Dry	-33	-73	-72	-57	-70	-71	0	-60	-71	-72	-71	-74	-70	-31	-26	-70	-72	-28
OthAgri Irig	38	38	34	31	37	39	33	45	47	47	51	45	52	32	5	58	29	30

Table 8: Water price change (% relative to base case) and net water sold (GL)

	Limited trading			Trading	
	Crop	Livestock	Net GL sold	All	Net GL sold
Mrmbidgee NSW	617	473	0	421	-93
Murray NSW	330	387	0	421	175
Wimmera VIC	11783	454	0	421	-23
MalleeVIC	1458	203	0	421	-80
LoddonCmp VIC	725	245	0	421	-12
Goulburn VIC	3739	184	0	421	57
OvensMrry VIC	3183	224	0	421	7
MurrayLndsSA	1307	190	0	421	-31