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A Methodology for Estimating Regional Agricultural Water Use

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A Methodology for Estimating Regional Agricultural Water Use

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A METHODOLOGY FOR ESTIMATING REGIONAL AGRICULTURAL WATER USE

Kim Hawthorne
Centre of Environment and Energy Statistics

ABSTRACT

Water statistics are currently of keen interest to Australia's governments, academics and the general public. This is partly because south-east Australia (where the majority of the population is located) has been experiencing drought conditions for several years. This resulted in restrictions limiting the use of water by households and industry (including agriculture) in many cities and most irrigation areas.

A range of agencies are involved in compiling water statistics and the Australian Bureau of Statistics (ABS) is one of these. To date the ABS has released two Water Accounts, which provide state level information on the supply and use of water in the Australian economy. The ABS Water Account has been useful at a macro level. However as it only provides state level data, it is of limited use in regional planning and decision-making. Demand exists for regional information at finer spatial boundaries than the state level and at boundaries the ABS does not typically use in the design or output of its surveys.

This paper presents the results of the application of a simple methodology to calculate agricultural water use for Statistical Local Areas (SLAs) and for river basins. The focus of the paper is on the methodology and its advantages and disadvantages. A key advantage is that the methodology is statistically straightforward to implement. However, a significant disadvantage is that assumptions underpinning the method are such that the errors associated with the estimates are likely to be large. Additional auxiliary data could reduce these errors, but at present the likely errors contained in the estimates presented here mean that they should be used with great caution.

The ABS is progressing work on other methodologies, for example land parcel surveys and meshblock coding of the Agricultural Census aimed at producing high quality information for small areas. These, along with the additional data of water use collected in ABS surveys since 2002–03, will lead to better regional information in the future.

1. INTRODUCTION

There is increasing demand on the ABS to produce more frequent and regional data from its regular surveys including small area statistics on water supply and use. Small area estimates refer to estimates for geographic areas finer than those for which ABS sample surveys were originally designed to provide reliable estimates. For example, the annual Agriculture Survey will produce state or Statistical Division (SD) level data, generally with Relative Standard Errors (RSEs) in the order of 5–15%. ABS censuses, such as the population and agricultural censuses, enable the release of information at smaller levels than sample surveys; however they are only conducted every five years. Generally as the size of the output area decreases, without large sample size increases or good quality auxiliary information, the reliability of the information also decreases.

1.1 Focus on water

Water statistics are currently the focus of intense interest to Australia's governments, academics, analysts and the general public. This is partly because south-east Australia (where the majority of the population is located) has been experiencing drought conditions for more than three years. As a result, restrictions have been in place limiting the use of water by households and industry (including agriculture) in many cities and most irrigation areas. The direct impact of the drought on the economy through reduced agricultural output in 2002–03 is estimated to have been around –0.9 percentage points on the volume growth of GDP between 2001–02 and 2002–03 (ABS, 2004a).

While the recent drought has focused attention on water in Australia, concern over water resources extends back several decades (Australian Water Resources Council, 1965). In 1994 the Council of Australian Governments (COAG) embarked on a series of reforms aimed at delivering the efficient and sustainable use of water in Australia. Since then information on all aspects of water use and management has been keenly sought. The ABS is one of a range of agencies involved in supplying data. The two editions of the *Water Account for Australia* (ABS, 2000; ABS, 2004b) have been and are being used at all levels of government, industry, media and by some sophisticated academic users of information. The Water Account has been useful at a macro level. However as it only provides state level data it is of limited use for regional planning or decision-making. Several studies have developed regional estimates of water use using the first Water Account in combination with other data sources (e.g. Appels, et al., 2004).

1.2 Project incentive and focus

The ABS Water Statistics User Group meeting in August 2004 highlighted the need for better regional and more timely information on water supply and use. At the Centre of Environment and Energy Statistics (CEES) Advisory Board meeting, also held in August 2004, members (consisting of senior officials from a variety of State and Commonwealth agencies) suggested that the ABS should conduct more detailed analyses. This paper is commensurate to the demand from both these groups.

This paper presents the results from an ABS project designed to explore a simple method for calculating regional estimates of agricultural water use. The first results were presented at the 55th Session of the International Statistical Institute in Sydney, May 2005 (Hawthorne, 2006). The results presented here are only the first statistical methodologies applied by the ABS in order to develop a better understanding of regional water supply and use. Collaboration with other agencies and stakeholders will be essential for developing better estimates of water supply and use at regional levels.

The agriculture industry was chosen as the focus of the research because it had the highest water consumption of any industry or sector in Australia in 1996–97 and 2000–01. The industry accounted for approximately two-thirds of the Australian total water use (ABS, 2000; ABS, 2004b). The project's primary aim was to use a simple methodology to combine the Agricultural Census commodity data with Water Account water use data to produce estimates of agricultural water use at the SLA, river basin and drainage division level. The focus of the paper is more on the methodology than the results. The advantages and disadvantages of the methodologies used and potential methodologies that may be explored in future research papers are the main discussion points.

2. SPATIAL BOUNDARIES AND DATA SOURCES

2.1 Spatial boundaries

The spatial boundaries used by the ABS are the Australian Standard Geographical Classification (ASGC) boundaries. These boundaries are population based and are "designed to meet user needs for social, demographic and economic statistics" (ABS, 2001). The ASGC boundaries are hierarchical and the main hierarchy is used here. The hierarchy starts with Census Collection Districts (CDs), which aggregate to Statistical Local Areas, then to Statistical Sub-Divisions, Statistical Divisions and finally to the State. The ABS uses the ASGC boundaries in the collection and output of its statistics.

In contrast, within environmental statistics there are a number of different spatial boundaries. There are topographical/physical boundaries like river basins and groundwater provinces; administrative boundaries such as Local Government Areas (LGAs); State and Commonwealth agreed boundaries (which are based on bioregions where possible) such as National Action Plan boundaries for salinity and water quality and Natural Heritage Trust regions; hybrid boundaries such as Agro-Ecological Regions which use LGA (ASGC) boundaries as the basic classificatory unit and classify them to classes based on climate, geology, landform, soil and vegetation; as well as the numerous government agencies who use self-defined boundaries. Demand exists for information at these and other environmental boundaries that the ABS does not use in the collection or output of its statistics.

The spatial boundaries for which estimates are produced in this project are the ASGC population based boundaries (ABS, 2001), mainly SLAs, and the geographical/physical boundaries of river basins (Geoscience Australia, 1997).

The ASGC boundaries were used since the ABS Agricultural Census collects and disseminates information based on these boundaries. River basin boundaries were used to demonstrate the application of the methodology to non-ASGC boundaries. A river basin is generally defined as the area drained by a river and its tributaries where surface run-off collects. A river basin forms a sub-basin of drainage divisions. In Australia there are 245 river basins amalgamating to twelve drainage divisions (Appendix A).

2.2 Data sources

The *Water Account, Australia, 2000–01* (ABS, 2004b) was released in 2004. The Water Account published state level totals of water supply and use by industry. Data for the water account came from a variety of sources with a variable degree of consistency and reliability. No formal estimates of sampling error, such as RSEs, exist for the

Water Account estimates. However extensive consultation with environment and agriculture agencies at the state and territory level was carried out to obtain external peer review of the data.

The ABS Agricultural Census is undertaken every five years; with data available from 2001. The scope of the Agricultural Census is all establishments undertaking agricultural activity with an estimated value of agricultural operations (EVAO) greater than $5,000. The Agricultural Census provides estimates of the area irrigated, in hectares (ha), of a variety of crops down to the Statistical Local Area (SLA) level. For this analysis agricultural industries of interest are:

- Vegetables
- Sugar
- Fruit
- Grapes
- Cotton
- Rice
- Dairy farming
- an 'Other' category, which comprises livestock, pasture, grains and other activities.

Most of the published state level estimates of the various commodities have RSEs of less than 5%. For some states with limited production of certain commodities, RSEs are greater than 25% (ABS, 2002).

The small area (SLA) data from the Agricultural Census has some known problems. For example in approximately 20% of SLAs the Area of Holding (AOH) for the SLA exceeds the total area of rural land in the SLA. This is due to a number of units on the Agricultural frame whose location address details are not recorded precisely enough to accurately code their geographic location. There are also some large farms which operate across SLA boundaries and have been coded to the SLA of predominant operations.

3. METHODOLOGY

3.1 Methodology

There are a range of techniques available for calculating small area estimates. Our research has concentrated on a method that applies state level averages to SLA level data. This method is referred to as a broad area ratio estimator with auxiliary information (Appendix B). This technique is simple and is only the foundation of work in the area of calculating agricultural water use, or any industry's water use, for areas smaller than the state level. The ABS will also explore whether better quality auxiliary information exists that could be used to construct estimates. Such information, which may be held by State and Commonwealth government departments, is an essential component in producing good small area estimates in the future.

Four key steps were used to calculate the regional water use estimates in this paper. These are as follows:

Step 1: Calculate the mean application rate for State and crop type

The state mean application rate – megalitres (ML) of water per hectare (ha) – can be calculated for each state and crop type. The application rate for each crop applies statewide.

For example in NSW in 2001 the Water Account estimated that there was 174,000 ML of water used for grapes; and the Agricultural Census estimated that there were 31,600 ha of land irrigated for grapes. From this information we can estimate the mean application rate for grapes grown in NSW in 2000–01 to be 5.5 ML/ha (174,000/31,600).

Step 2: Calculate SLA total agricultural water use

To calculate the total irrigated agricultural water use for a particular crop in an SLA the mean application rate is multiplied by the hectares of the crop within the SLA of interest. For example, in the Mudgee SLA in NSW it was estimated, from the 2001 Agricultural Census, that there was 2,300 ha irrigated for producing grapes. Combining this with the application rate of 5.5ML/ha from Step 1, an estimated water use for grapes for Mudgee SLA is 12,650 ML (5.5×2,300).

The total irrigated agricultural water use within the SLA is then calculated by summing together the water use for each crop type (grapes, vegetables, sugar, fruit, cotton, rice, dairy farming and other). This methodology for Steps 1 and 2 is outlined in Appendix B.

Step 3: Area-weighting to river basins

A Geographic Information System (GIS) such as MapInfo© can be used to calculate the area of an SLA that concords to a river basin. This concordance information, combined with the SLA estimates from Step 2, can be used to give a river basin estimate of total agricultural water use (Appendix C).

For example the Hay SLA falls within both the Murrumbidgee and Lachlan river basins. Using Steps 1 and 2 the estimated total agricultural water use for Hay is 205,000 ML. With 48% of Hay's area in the Lachlan and 52% of its area in the Murrumbidgee, the area-weighting methodology used in this paper attributes 48% of the Hay SLA estimated total agricultural water use to the Lachlan river basin and 52% to the Murrumbidgee river basin. That is: 98,400 ML ($0.48\times205{,}000$) to the Lachlan river basin, and the 106,600 ML ($0.52\times205{,}000$) to the Murrumbidgee river basin.

Step 4: Summing river basin estimates to drainage divisions

Estimates of the area irrigated and water use were then calculated for the 12 drainage divisions in Australia. To calculate the drainage division estimates the river basin estimates were summed together. See Appendix A for the list of drainage divisions and river basins.

3.2 Quality declaration

Modelled small area estimates are subject to three main sources of error: sampling error; non-sampling error; and model error.

3.2.1 Sampling error

Sampling error occurs because a sample, rather than the entire population is surveyed. One measure of the likely difference resulting from not including all units in a survey is given by the standard error. Standard errors are often expressed as a percentage of the estimates to which they refer, resulting in a sampling error measure called the relative standard error (RSE).

Measures of sampling error are provided for the Agricultural Census information. Most of the published state level estimates of the various commodities have RSEs of less than 5%. For some states with limited production of certain commodities, RSEs for those commodities are greater than 25% (ABS, 2002).

The Water Account was compiled from a variety of sources, with a variable degree of consistency and reliability, and no formal estimates of sampling error exist. As such, calculating a sampling error measure for modelled small area estimates is not straightforward. It can be expected that in areas of high agricultural water use, sampling errors are smaller and conversely, in areas of low agricultural water use, sampling errors would be generally higher.

Further research into appropriate sampling error measures for modelled small area estimates is required.

3.2.2 Non-sampling error

Non-sampling error arises from inaccuracies in collecting, recording and processing the data. The most significant of these errors are:

- misreporting of data items
- deficiencies in coverage
- non-response
- processing errors.

Every effort is made to minimise these errors by the careful design of questionnaires and efficient data processing procedures.

3.2.3 Model specification error

Model specification error is the third source of error in modelled small area estimates. In applying a model, certain assumptions are made which, in reality, may not hold to a certain degree. The assumption underlying the models used to produce the SLA estimates is that on average, the rate of water use per hectare for any given crop type, is the same for each SLA within a given state. Ideally region and crop specific application rates would be readily available, i.e. having mean application rates for cotton grown in the Gwydir Valley and cotton grown in the Macquarie Valley. Such region specific application rates may begin to account for factors that may influence the application rates such as climate, irrigation technologies and soil type.

Small area methods allow for more detailed estimates to be derived for more regions than is currently possible from direct collection. The potential for model specification error increases as the size of the small area decreases.

The river basin estimates, as calculated in Step 3, are subject to the problems of area-weighting. Area-weighting introduces a level of error not easily measured. The primary advantage of this method is its simplicity, its repeatability and applicability to any boundary of interest. It performs better when starting with SLA level data and going to larger non-ASGC boundaries, such as drainage divisions. The disadvantage, though, is that it assumes that agricultural water use (or crop area irrigated) is evenly distributed across a SLA. This assumption does not hold in reality as a number of factors affect where particular crops are grown such as topography, climate (particularly rainfall) and soil type.

The drainage division estimates could be calculated in a number of ways. Creating a SLA to drainage division concordance is an obvious option. Alternatively, the river basin estimates from Step 3 could be summed to the drainage division level. Cursory investigations into this method revealed minimal differences in the estimates. As such, the latter method was used in this paper.

4. EMPIRICAL RESULTS

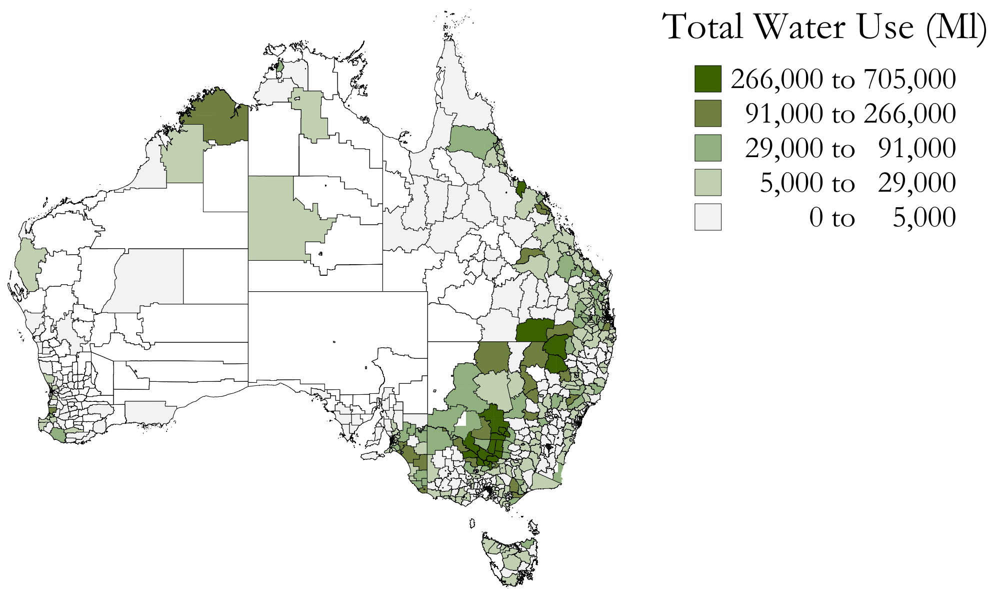
This section presents results of applying the small area estimation method to produce regional agricultural water use estimates.

4.1 Total agricultural water use maps

Maps of total agricultural water use at the SLA and river basin level were created using MapInfo©. Like a histogram, choropleth maps can show different distributions by simply altering the ranges width and anchor point (i.e. start point of the ranges). The natural break methodology (Caspall and Jenks, 1971) is a range option in MapInfo© and gives the best representation of the data. Percentile intervals (0 to 25, 25 to 50, 50 to 75, 75 to 95 and 95 to 100) and inter-quartile ranges were investigated and found to give poorer presentations of the data. However, such intervals can be better used for isolating the SLAs in the top 5% of total agricultural water use.

Map 4.1 displays the estimated total agricultural water use at SLA level. The dark green areas indicate areas of highest estimated agricultural water use; the light grey/green areas indicate less agricultural water use.

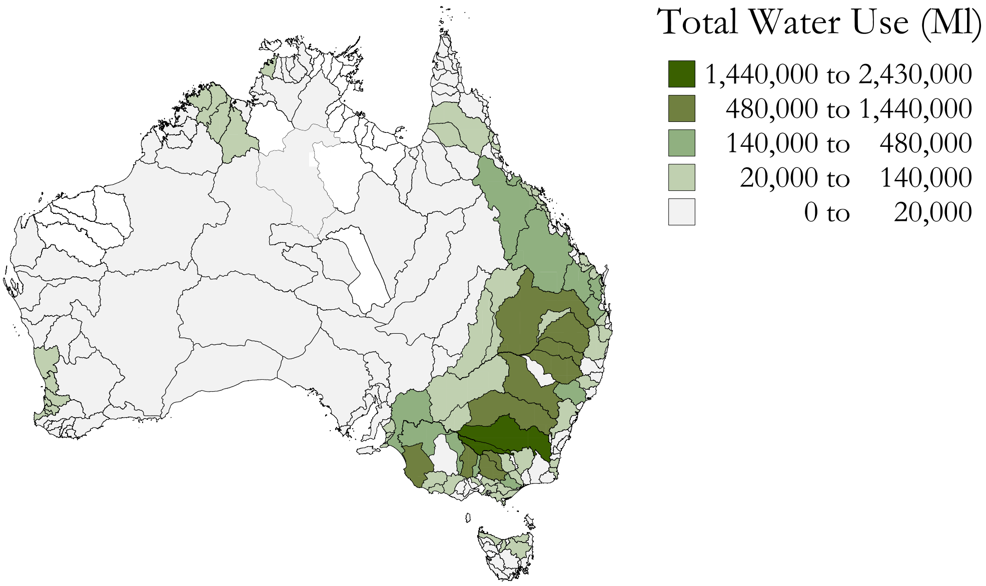
4.1 Estimated total agricultural water use at the SLA level, 2000–01



The results presented in map 4.1 are generally consistent with other research and reports (e.g. NLWRA, 2001a). The SLAs of highest agricultural water use are clearly highlighted, such as water used for cotton around the Queensland/New South Wales border and water used for the dairy and rice regions near the Victorian/New South Wales border. Other areas of interest, such as the Ord River scheme in Western Australia, are also highlighted on the map.

Map 4.2 displays the estimated total agricultural water use at river basin level. The cotton growing areas around the Queensland/NSW borders no longer appear in the highest water use range. This is attributable to the way the river basin layer and SLA layers concord in the region and the ranges used by MapInfo. The map reveals the Murrumbidgee (IV10) and Murray–Riverina (IV09) river basins (that are the dairy and rice areas of the Murray Darling Basin) as the river basins of highest agricultural water use.

4.2 Estimated total agricultural water use at the river basin level, 2000–01



The river basin map provides a good picture of agricultural water use at the river basin level; however it is less informative than the SLA map. This is due to the problem of area-weighting and also that the river basins are generally larger than SLAs, especially away from the coastline. The SLA map shows agricultural water use, predominantly for sugar, as being located closely along the Queensland coastline. Due to the concordance of river basins and SLA boundaries in Queensland, the river basin map shows agricultural water use further inland of the Queensland coast, especially towards northern Queensland. Although the maps may suggest homogenous water use throughout the river basin boundary, it is important for the reader to appreciate that agricultural water use is most likely concentrated in the eastern most parts of these river basins (cf. map 4.1).

4.2 Drainage division estimates

Table 4.3 displays the results of applying our small area estimation method and then aggregating to drainage divisions as outlined in Step 4. The estimates of agricultural water use are for six of the 12 drainage divisions in Australia (Appendix A). These divisions were selected as they are the basins of most interest due to the size of their agricultural production and the fact that they service the majority of the Australian population. The estimates were calculated by summing the river basin estimates that make up a drainage division. River basin crop breakdowns would most certainly be subject to higher levels of error than the drainage division breakdowns as a result of the area-weighting methodology. As such it was decided to present drainage division crop breakdowns.

4.3 Estimated total agricultural water use ('000 ML) for selected drainage divisions, 2000–01

	Drainage division					
Crop	*Murray–Darling*	*North-East Coast*	*South Aust. Gulf*	*South-East Coast*	*South-West Coast*	*Tasmania*
Vegetables	171	88	15	119	73	49
Sugar	0	1 140	0	0	0	0
Fruit	488	78	31	79	55	10
Grapes	492	3	94	111	22	1
Cotton	2 680	215	0	1	0	0
Rice	1 950	0	0	8	0	0
Dairy	1 760	254	30	647	64	76
Other	3 800	523	28	904	155	85

From table 4.3 it is apparent why the Murray–Darling Drainage Division is referred to as "Australia's food basket", having the largest water use for almost all the listed crops. The total agricultural water use estimates for the Murray–Darling Basin are similar to that in the report by Bryan and Marvanek (2004). The North-East Coast Division, which runs along the Queensland coastline, produces all of the country's sugar. Fresh produce from the fruit, vegetable and dairy industries is prominent throughout all the listed drainage divisions. The 'Other' category is defined as livestock, pasture, grains and other agriculture; this covers a broad spectrum of agricultural activities. As such 'Other' is generally the largest user of water throughout most of the divisions.

4.3 Cursory assessment of area-weighted concordance

The purpose of this cursory investigation was twofold. One was to assess if area-weighted concordance could be used in non-census years. The other was to compare area-weighted concordance estimates to direct survey estimates for river basins within Victoria.

4.3.1 Area-weighted concordance in non-census years

The ABS conducts a sample survey of the Agriculture sector in the years between the agricultural censuses. The sample surveys produce estimates of the area irrigated (and since 2002–03 volume applied, in ML) at the SD level. As mentioned, the

Agricultural Census produced SLA area irrigated estimates. This area-weighting investigation allows for a determination as to the value of area-weighting when only SD level information is available. The investigation involved an empirical comparison of the difference between river basin estimates when area-weighting using SLA data and area-weighting when using SD data.

4.4 SLA area-weighted river basin estimates vs SD area-weighted river basin estimates for selected river basins, 2000–01 (River basin codes in Appendix A)

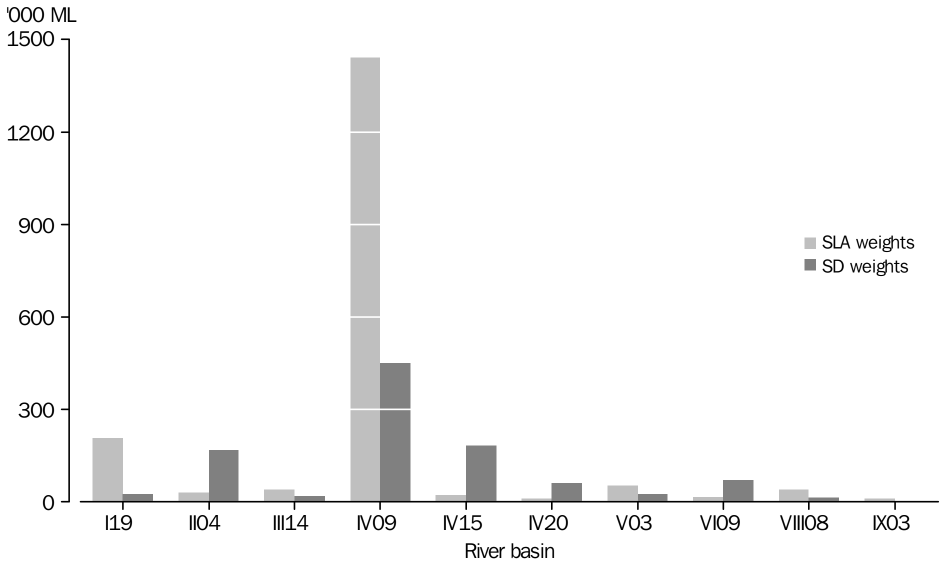


Figure 4.4 shows the differences that can arise when using area-weighted concordance to ascertain estimates for the river basin spatial boundaries. The graph shows the SLA concorded to river basin estimate and the matching river basin estimate when undertaking area-weighted concordance starting with SD information (See Appendix A for the x-axis codes). The Murray–Riverina (IV09) was estimated to use 1,440,000 ML of water using SLA area-weighting. SD area-weighting estimated 450,000 ML of water for agricultural purposes. The difference is almost one million ML. For the Houghton River (I19), the SLA estimate is 205,000 ML, while the SD estimate is 25,000 ML: over eight times the amount of the SLA area-weighted estimate.

The results suggest that the area-weighting methodology is dependent on the building blocks used. When only SD level information is available, other methods should be explored and utilised for producing alternative geographical outputs.

4.3.2 Area-weighted concordance vs. Direct estimation

In 2004, as part of a geocoding test exercise, all Victorian units on the Agriculture Frame were coded to collection districts. Collection districts were, at the time, the finest spatial unit available in the ASGC. This work allowed for estimates of the area irrigated for river basins in Victoria to be calculated via direct estimation. These direct estimates, which were calculated via post-stratification, were then compared to the river basin estimates that were derived using area-weighting.

4.5 Direct river basin estimates vs area-weighted river basin estimates of the area irrigated (ha) of fruit in Victoria, 2000–01

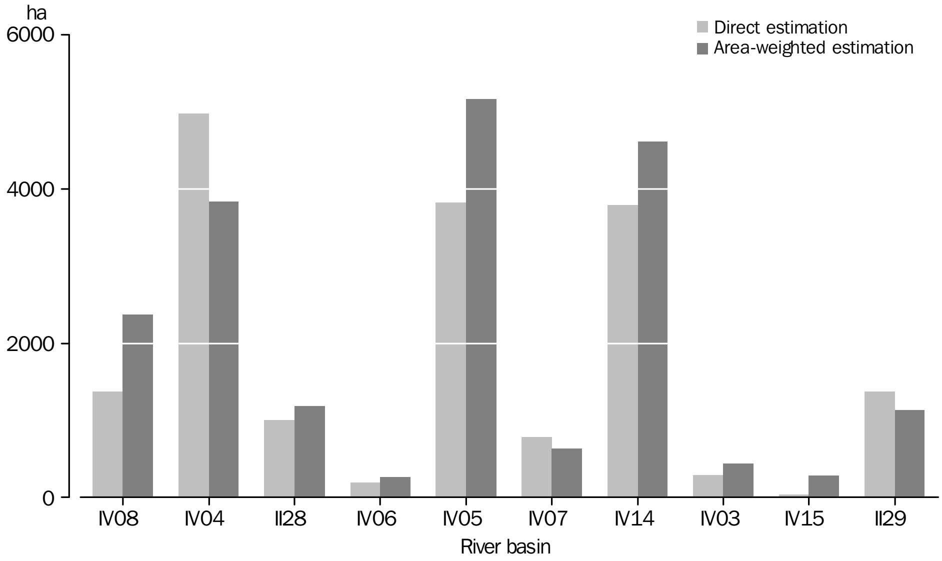


Figure 4.5 shows the differences between the two estimation methodologies. Post-stratification is a superior methodology to area-weighting when the units are accurately coded. The differences between the two methodologies suggest that area-weighting should be used with caution, even at the SLA level, as it can lead to both over and under estimation.

Area-weighting is a simple methodology that can provide an approximate estimate quickly, such as agricultural water use at the river basin level (cf. map 4.2). To present more detailed and accurate figures for non-ASGC boundaries, other more robust methodologies should be considered and used.

5. CONCLUSIONS AND FURTHER WORK

5.1 Further work

Availability and access to good auxiliary data on factors that influence agricultural water use will be necessary to further improve the regional estimates. There is a range of auxiliary data that is held by government agencies and research bodies. This will require further collaboration with these agencies and allow for small area estimation techniques that draw upon relationships between survey data and auxiliary data. There are four main areas where these relationships can be found and need to be explored in the future:

1. Between the survey based estimate and auxiliary information from administrative data sources, censuses or other surveys. Survey based information that will be explored more extensively are the questions relating to water use volumes (ML) on future agricultural surveys and censuses. This information was first collected on the Water Survey – Agriculture of 2002–03 and was also collected in the 2006 Agricultural Census. The data from 2006 will be coded to meshblocks.

2. In correlations between direct estimates observed over time. This approach may be implemented using ABS agricultural census and survey information. Correlations between SLA estimates between censuses or the correlations of SD/State area irrigated estimates from annual Agricultural Surveys are some possibilities.

3. In cross-sectional relationships between units with similar characteristics observed in different small areas within some broader region. For example units growing cotton within the northern cotton growing region of Emerald and Dawson could be expected to have some similar characteristics to the units growing cotton within the southern inland regions around the Macquarie Valley and Bourke.

4. Spatial relationships between neighbouring small areas. It is reasonable to expect agricultural water use to be spatially related as agricultural industries are generally clustered together. These spatial relationships may be investigated further in the future.

5.2 Conclusions

The broad area ratio estimator and area-weighted concordance methods used in this paper were straightforward to apply. The broad area ratio estimator with auxiliary information worked well as it is reasonable to expect that different agricultural industries (or crops) have different water requirements. The main problem was the assumption of using state level averages for crop application rates. Further collaboration and access to auxiliary data may diminish this problem as will the additional data collected in ABS surveys since 2002–03.

Area-weighting is a methodology that can quickly provide a snapshot of particular activities for non-ASGC boundaries. The main problem with area-weighting in the case of agricultural water use was the assumption of homogenous water use across SLAs or other regions. As such the area-weighting methodology could not, in this case, provide reliable agricultural water use statistics for small areas and the data presented in this paper should be used with great caution by policy makers and others.

Small area estimation techniques are being more fully explored by the ABS in a variety of subject matters. In addition new sampling techniques, such as land parcel survey methodologies (ABS, 2005) and the coding of the 2006 Agricultural Census data to meshblocks, are being investigated. For water, our immediate attention is on investigating options for estimating total water use as a possible addition to the *Water Account, Australia 2004–05*.

Regional water statistics will continue to be a research focus for the ABS Centre of Environment and Energy Statistics. This project was only the first step towards producing small area estimates of water use. Importantly, there are non-ABS data sources that were not integrated into this project. A more detailed investigation of these sources, combined with the development of the land parcel survey methodology and the meshblock coding of the 2006 Agricultural Census, should lead to better regional water use statistics for Australia.

ACKNOWLEDGMENTS

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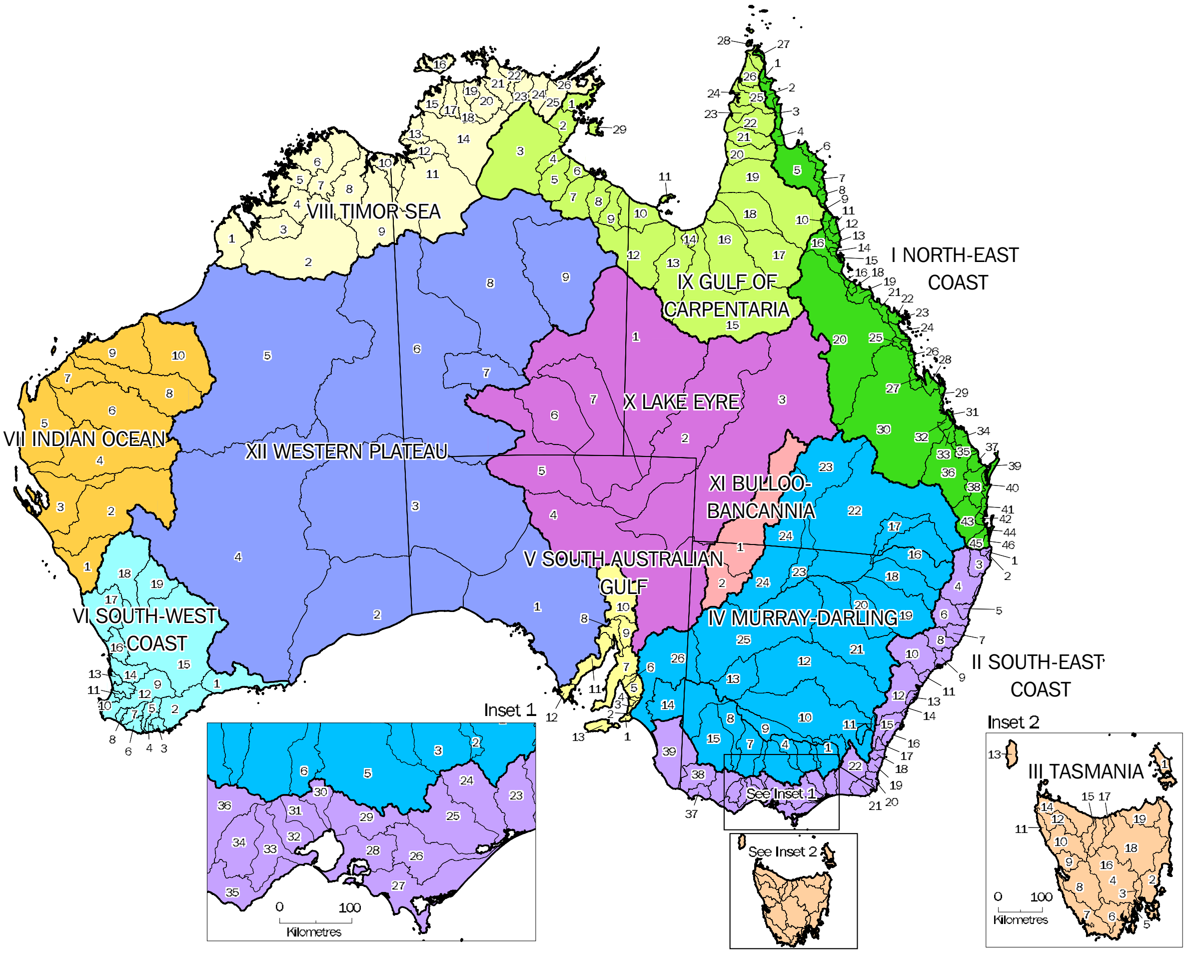
APPENDIXES

A. AUSTRALIA'S DRAINAGE AND RIVER BASINS



I North-East Coast

1 Jacky Jacky Creek
2 Olive–Pascoe Rivers
3 Lockhart River
4 Stewart River
5 Normanby River
6 Jeannie River
7 Endeavour River
8 Daintree River
9 Mossman River
10 Barron River
11 Mulgrave–Russell Rivers
12 Johnstone River
13 Tully River
14 Murray River (Qld)
15 Hinchinbrook Island
16 Herbert River
17 Black River
18 Ross River
19 Haughton River
20 Burdekin River
21 Don River
22 Proserpine River
23 Whitsunday Island
24 O'Connell River
25 Pioneer River
26 Plane Creek
27 Styx River
28 Shoalhaven Creek
29 Water Park Creek
30 Fitzroy River (Qld)
31 Curtis Island
32 Calliope River
33 Boyne River
34 Baffle Creek
35 Kolan River
36 Burnett River
37 Burrum River
38 Mary River (Qld)
39 Fraser Island
40 Noosa River
41 Maroochy River
42 Pine River
43 Brisbane River
44 Stradbroke Island
45 Logan–Albert Rivers
46 South Coast

II South-East Coast

1 Tweed River
2 Brunswick River
3 Richmond River
4 Clarence River
5 Bellinger River
6 Macleay River
7 Hastings River
8 Manning River
9 Karuah River
10 Hunter River
11 Macquarie–Tuggerah Lakes
12 Hawkesbury River
13 Sydney Coast–Georges River
14 Wollongong Coast
15 Shoalhaven River
16 Clyde River–Jervis Bay
17 Moruya River
18 Tuross River
19 Bega River
20 Towamba River
21 East Gippsland
22 Snowy River
23 Tambo River
24 Mitchell River (Vic.)
25 Thomson River
26 Latrobe River
27 South Gippsland
28 Bunyip River
29 Yarra River
30 Maribyrnong River
31 Werribee River
32 Moorabool River
33 Barwon River
34 Lake Corangamite
35 Otway Coast
36 Hopkins River
37 Portland Coast
38 Glenelg River
39 Millicent Coast

III Tasmania

1 Flinders–Cape Barren Islands
2 East Coast
3 Coal River
4 Derwent River
5 Kingston Coast
6 Huon River
7 South-West Coast
8 Gordon River
9 King–Henty Rivers
10 Pieman River
11 Sandy Cape Coast
12 Arthur River
13 King Island
14 Smithton–Burnie Coast
15 Forth River
16 Mersey River
17 Rubicon River
18 Tamar River
19 Piper–Ringarooma Rivers

IV Murray–Darling

1 Upper Murray River
2 Kiewa River
3 Ovens River
4 Broken River
5 Goulburn River
6 Campaspe River
7 Loddon River
8 Avoca River
9 Murray–Riverina
10 Murrumbidgee River
11 Lake George
12 Lachlan River
13 Benanee
14 Mallee
15 Wimmera–Avon Rivers
16 Border Rivers
17 Moonie River
18 Gwydir River
19 Namoi River
20 Castlereagh River
21 Macquarie–Bogan Rivers
22 Condamine–Culgoa Rivers
23 Warrega River
24 Paroo River
25 Darling River
26 Lower Murray River

V South Australian Gulf

1 Fleurieu Peninsular
2 Myponga River
3 Onkaparinga River
4 Torrens River
5 Gawler River
6 Wakefield River
7 Broughton River
8 Mambray Coast
9 Willochra Creek
10 Lake Torrens
11 Spencer Gulf
12 Eyre Peninsular
13 Kangaroo Island

VI South-West Coast

1 Esperance Coast
2 Albany Coast
3 Denmark River
4 Kent River
5 Frankland River
6 Shannon River
7 Warren River
8 Donnelly River
9 Blackwood River
10 Busselton Coast
11 Preston River
12 Collie River
13 Harvey River
14 Murray River (WA)
15 Avon River
16 Swan Coast
17 Moore–Hill Rivers
18 Yarra Yarra Lakes
19 Ninghan

VII Indian Ocean

1 Greenough River
2 Murchison River
3 Wooramel River
4 Gascoyne River
5 Lyndon–Minilya Rivers
6 Ashburton River
7 Onslow Coast
8 Fortescue River
9 Port Hedland Coast
10 De Grey River

VIII Timor Sea

1 Cape Leveque Coast
2 Fitzroy River (WA)
3 Lennard River
4 Isdell River
5 Prince Regent River
6 King Edward River
7 Drysdale River
8 Pentecost River
9 Ord River
10 Keep River
11 Victoria River
12 Fitzmaurice River
13 Moyle River
14 Daly River
15 Finniss River
16 Bathurst & Melville Island
17 Adelaide River
18 Mary River (WA)
19 Wildman River
20 South Alligator River
21 East Alligator River
22 Goomadeer River
23 Liverpool River
24 Blyth River
25 Goyder River
26 Buckingham River

IX Gulf of Carpentaria

1 Koolatong River
2 Walker River
3 Roper River
4 Towns River
5 Limmen Bight River
6 Rosie River
7 McArthur River
8 Robinson River
9 Calvert River
10 Settlement Creek
11 Mornington Island
12 Nicholson River
13 Leichhardt River
14 Morning Inlet
15 Flinders River
16 Norman River
17 Gilbert River
18 Staaten River
19 Mitchell River (WA)
20 Coleman River
21 Holroyd River
22 Archer River
23 Watson River
24 Embley River
25 Wenlock River
26 Ducie River
27 Jardine River
28 Torres Strait Islands
29 Groote Eylandt

X Lake Eyre

1 Georgina River
2 Diamantina River
3 Cooper River
4 Lake Frome
5 Finke River
6 Todd River
7 Hay River

XI Bulloo–Bancannia

1 Bulloo River
2 Lake Bancannia

XII Western Plateau

1 Gairdner
2 Nullarbor
3 Warburton
4 Salt Lake
5 Sandy Desert
6 Mackay
7 Burt
8 Wiso
9 Barkly

B. BROAD AREA RATIO ESTIMATOR

The method used to calculate the SLA agricultural water use totals is known as a broad area ratio estimator. This gives an estimate of the total agricultural water use by applying the state mean application rates for different crops in the SLAs.

The model below contains no specified error component but obviously, with any modelling, there is error.

At the time this research was undertaken, SLA estimates of total agricultural water use within an SLA were not available.

$$\hat{y}_i = \sum_g \frac{\hat{x}_{i,g}\, Y_{r,g}}{\hat{X}_{r,g}}$$

$\hat{y}_i$ is the estimate of total agricultural water use in SLA i.

The water use information (ML) is from the *Water Account, Australia, 2000–01*.

$Y_{r,g}$ is the State total water use (ML) for crop g.

The area irrigated information (ha) is from the *Agricultural Census, 2000–01*.

$\hat{x}_{i,g}$ is the estimate of area irrigated (ha) for crop g in SLA i.

$\hat{X}_{r,g}$ is the estimate of the total area irrigated (ha) for crop g in State r.

C. AREA-WEIGHTING

The methodology used to calculate river basin estimates of water use (ML) and area irrigated (ha) is known as area-weighted concordance. The estimator is given by:

$$\hat{y}_j = \sum_i \hat{y}_i \times P_{ij}$$

$\hat{y}_j$ is the estimate of total agricultural water use (ML) for river basin *j*.

$\hat{y}_i$ is the estimate of total agricultural water use (ML) for SLA *i*.

P_{ij} is the proportion of area that SLA *i* overlaps river basin calculated in MapInfo.

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