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Estimating unmetered stock and domestic water use

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Abstract: Water accounts present information on the stores and movement of water, including the volume of water diverted for consumptive use. Water extracted directly by water users to meet their stock and domestic water requirements is not metered in Australia and as a result, estimates are used to quantify this component in the water accounts and for other purposes.

Two approaches to estimate the water extracted for stock and domestic purposes are identified:

1. An estimate of the number of households and stock that rely on self extracted water is multiplied by their expected water requirements.
2. The number and volume of stock and domestic licenses issued by the water authorities to divert water from waterways or groundwater is combined with information on the use of farm dams to estimate the stock and domestic water use.

This paper compares directly estimates of stock and domestic water use generated by each of these two approaches for the Werribee River catchment (Victoria, Australia) for 2005/06. The two approaches are not expected to generate identical estimates due to the uncertainties associated with each of the estimates. Therefore, the uncertainty surrounding each of the estimates is also quantified and represented with a probability distribution. Ideally these two probability distributions would overlap and thereby show that the two approaches provide consistent results.

Data collected by the Australian Bureau of Statistics is used to estimate the number of households (2006 Population census) and stock (2005-06 Agricultural Census) in the catchment. These data are reported by the ABS according to statistical boundaries that do not correspond to the Werribee River catchment, and so had to be adjusted for use in the study, which provides an additional level of uncertainty. The uncertainty associated with expected water requirements of individual households and stock is also considered. The best estimate of the total stock and domestic water use using this first approach is 690 ML, and the 95% confidence interval is equivalent to ±63% of the best estimate. The source of uncertainty that has the largest influence on the results is the number of stock in the catchment, followed by the estimate of the expected water use per head of stock.

Using the second approach, extractions from waterways and groundwater sources are assumed to be related to license conditions and be within the limits set by these conditions. As extractions from farm dams are not licensed, estimates are based on simulation modelling. The estimate of stock and domestic water use generated by this second approach is higher, and is 810 ML. The 95% confidence interval surrounding this estimate is equivalent to ±55% of the best estimate. The uncertainty surrounding the volume of groundwater extractions has the largest influence on the overall uncertainty.

The estimates of stock and domestic water use generated by the two approaches diverge by 119 ML (or 15% of the upper value), but there is substantial overlap of the 95% confidence intervals associated with each estimate. Which is the better estimate of D&S water use is unclear as the uncertainty surrounding each of the two estimates is similar. As the data needed for the first approach are available for all of Australia on an on-going basis from the ABS, then the demand approach is probably the most practical approach at present for deriving standardised and comparable estimates of domestic and stock water use across Australia.

Keywords: *Water Accounting, Water Use, Uncertainty*

1. INTRODUCTION

The volume of water extracted by landholders from waterways, groundwater or from farm dams to meet their stock and domestic (D&S) water requirements is largely unmetered in Australia. Estimates of this water use are required as inputs to a variety of water resource studies, including investigations of the yield of water supply systems or the generation of a 'pre-development' time series of flows used as an input to environmental flow recommendations. Recently estimates of this water use have also been included in water accounts (e.g. Australian Bureau of Statistics 2006a; Department of Sustainability and Environment 2008).

There are at least two general approaches to estimate the water used for D&S purposes. In the first approach the estimate of water use is derived by estimating the demand for the resource. Estimates are first made of the number of households and the number of stock that require water, and these numbers are multiplied by a water use coefficient. This approach is similar to the methods used by the Australian Bureau of Statistics (ABS) (2006b; 2006c) to estimate regional water use. Throughout this paper this approach will be referred to as demand based estimates.

The second approach uses the information available from water authorities who issue licenses to landholders for extracting groundwater or diverting from waterways to meet D&S water requirements. This information can be used to provide an estimate of the D&S water use, and water accounts that adopt this approach tend to assume the entire licensed volume is used (e.g. DSE 2008; National Water Commission 2007). Although water authorities do not issue licenses to extract D&S water from farm dams, information on the number of farm dams in the catchment can be obtained, and combined with information on system behaviour, to estimate the volume of these extractions. There is no immediately obvious term for this second approach. The term 'supply' is easily confused with water provided through a reticulated system. Another option, 'licensed', is not entirely appropriate either as farm dams are not commonly licensed. This second approach will be referred to as the source based estimates throughout the paper as it estimates extractions from three sources of water.

Both the demand and source based approaches rely on a series of assumptions and there is considerable uncertainty associated with the results. The purpose of this paper is to assess and compare the uncertainties associated with each approach. A framework to quantify these uncertainties is presented and applied in a case study. Section 2 provides a general overview of the approach used to quantify and combine uncertainties. The demand based estimates are made in Section 3 and availability based estimates are presented in Section 4. A comparison of these estimates is presented in Section 5, along with a discussion of the implication of the results. The results provide an indication of the reliability of estimates of self-extracted D&S water use and can be used to efficiently allocate resources to improve these estimates.

2. OVERALL APPROACH

Walker et al.(2003) describes uncertainty as "…any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system." The total uncertainties in estimates of D&S water use are a combination of the uncertainties introduced by each step in the calculations (Figure 1 and Figure 4). The uncertainties associated with each step of the method are described using a probability distribution, which assigns a probability to each possible value of the model input. The type of probability distribution selected depends on the nature of the model input and uncertainty. For example, if there is no bias in the uncertainty, the use of a normal distribution is appropriate. Similarly, if the model input must be within an upper and lower bound, the use of a beta distribution is more appropriate. Once the uncertainties associated with each of the dominant model inputs are quantified they are combined using Monte Carlo simulations to assess the overall uncertainty associated with the estimates of D&S water use.

The Werribee River catchment was selected for the case study. It is located in central Victoria, Australia and has a catchment area of approximately 1,400 km², some of which covers metropolitan Melbourne. Estimates of D&S water use were made for 2005/06 to coincide with both the 2006 Population census and the 2005-06 Agricultural Census.

3. DEMAND BASED ESTIMATES

There are two steps involved in generating demand based estimates. Firstly, the number of households and stock relying on self-extracted water (i.e. water that is not supplied through mains) within the catchment is estimated. Secondly, the water use is calculated by multiplying these by a water use coefficient. Uncertainty is introduced in both steps. Data collected by the ABS on household and stock numbers are available for statistical spatial areas that do not necessarily coincide with other geographical areas, such as a river catchment. In the preparation of regional water accounts several methods have been used to transform data from one boundary to another (Edens et al. 2007). An area weight disaggregation method is adopted in this study which assumes that the data under consideration is correlated with area. The ABS (2006b; 2006c) also used this method and found that large errors are introduced by this assumption. The water use coefficients are calculated using the state based averages of water use. As there is variability in water use rates within the state, this assumption also introduces uncertainty. Each of these dominant sources of uncertainty are discussed in the following sub-sections before they are combined in Section 3.3.

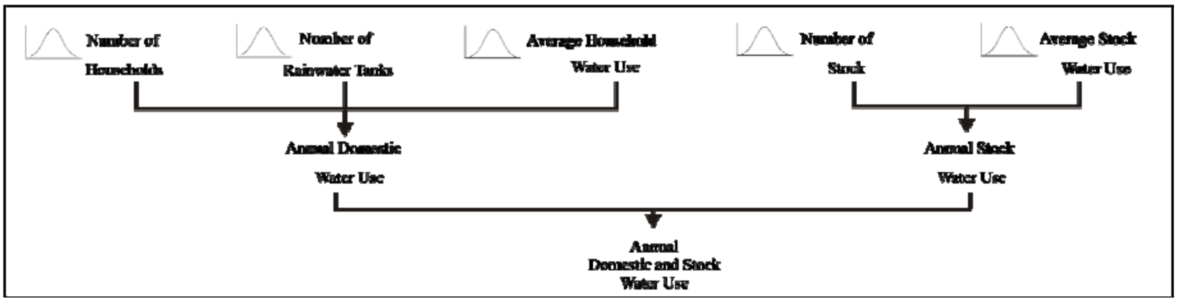

Figure 1. Method to estimate the demand for stock and domestic water

3.1. Annual Domestic Water Use

Each census the ABS collects information on the **number of households** across Australia and the last census year was 2006 (ABS 2006d). This information is aggregated to, and reported for, predefined statistical regions called statistical local areas (SLA). The steps in Figure 2 are used to estimate the number of

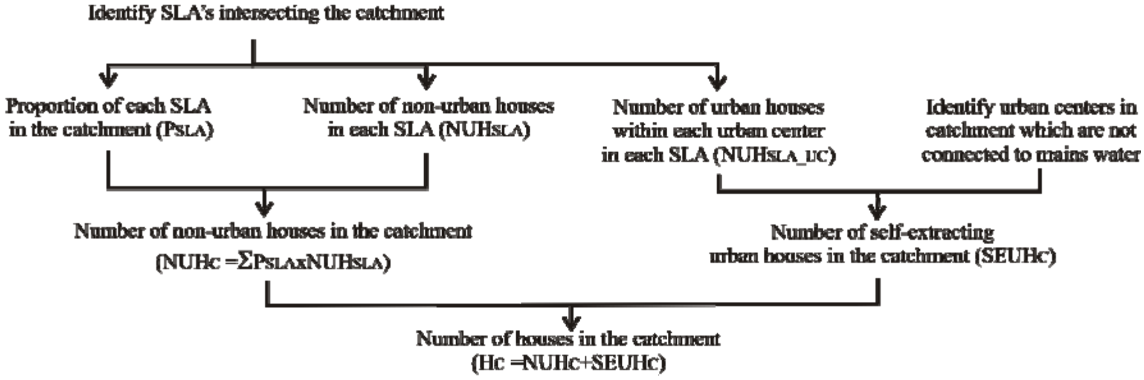

Figure 2 Method to estimate number of houses in a catchment.

occupied households in a catchment, that are not connected to an urban water supply system.

Using the census information and the steps in Figure 2, the Werribee River catchment was estimated to contain 20,300 households. Of these, only 2,300 are estimated to not be connected to an urban water supply system.

The allocation of non-urban households to the catchment based on area is a dominant source of uncertainty. This uncertainty can be approximated by using the steps above to estimate the number of occupied households in a SLA from the larger statistical division (SD) and comparing to the reported number for the SLA. In order to estimate this uncertainty for the Werribee River catchment, the number of households located within the Central Highlands Statistical Division is allocated to the nine SLAs based on their relative areas. The calculations exclude the SLAs in Ballarat, a large urban centre. These estimates are then compared to the recorded numbers for each SLA. The estimates based on disaggregation range between - 63% and +141% of the recorded values. This source of uncertainty is represented with a beta distribution that is bounded by -63% and +141%.

A large proportion of houses that are not connected to an urban water supply system source their water from rainwater tanks. This supply of water is not considered by either approach presented in this paper. Of Victorian households, 78% of the households that are not connected to an urban water supply use **rain water tanks** for washing clothes (ABS 2007). This is used as a surrogate for the percentage of houses that use rainwater tanks for their domestic supply, leaving only 500 houses which rely on self-extracted water from groundwater, waterways or farm dams in the Werribee River catchment. The ABS (2007) publishes the standard errors associated with their estimates and these were used to estimate the uncertainty associated with the percentage of households that rely on a rainwater tank. The uncertainty is represented by a normal distribution with a standard deviation of 5%.

The **household water coefficient** is assumed to equal the average Victorian household water use. Urban water authorities publish the average household water use of their customers (Water Services Association of Australia 2007a, 2007b) and these are used to estimate the average household water use across Victoria. Excluding the urban water authorities who extract water from large irrigation supply systems, the average household water use in 2005/06 was 195 kl/household/year. The variation between the volumes reported by each urban water authorities is used to characterise the uncertainty associated with the household water coefficient. It is represented by a normal distribution with a standard deviation of 36 kl/household/year.

3.2. Annual Stock Water Use

An agricultural census was undertaken by the ABS in 2006 and it provided information on the number of different types of stock for each SLA (ABS 2008). The steps in Figure 3 are used to estimate the **number of stock** in a catchment from the information reported for SLAs. In the Werribee River catchment it is estimated that there are 128,600 sheep, 17,400 cattle, 4,600 pigs, 341,700 chickens and 500 horses.

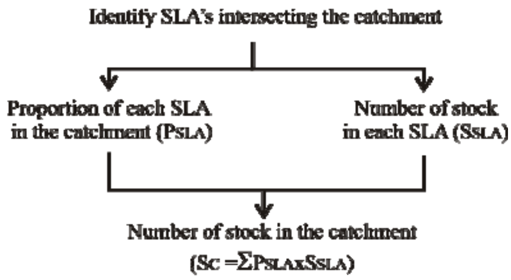

Figure 3 Method to estimate number of stock in a catchment

The allocation of stock numbers to a catchment based on area introduces uncertainty. It is likely that there will be an uneven or clumped distribution of livestock particularly if there are only a few farms that deal with a specific type of stock. As for the number of households, this uncertainty can be approximated by applying the steps above to estimate the number of stock in a SLA from the larger statistical division (SD). This time, the number of stock in all Victorian SDs are allocated to SLAs using the steps above, and compared to the recorded values for the SLA. Only SLAs that consist of more than 10% of the SD area are included to avoid major urban areas. While the uncertainties vary between stock types, they are in the order of ±100%. Again, these bounds are used to generate a beta probability distribution to represent this disaggregation uncertainty.

The **stock water coefficients** are based on the average stock water use rates published by the relevant government department. Victorian estimates are obtained from Cummings (2002). The volume of water consumed by stock depends on the breed, size and age of the animal, the weather and type of feed and a range of water requirements were included in Cummings (2002). For example, the water requirements of cattle range from 22 to 68 L/head/day. In this assessment dairy and beef cattle are lumped together, however, the results could be improved if they were considered separately. The uncertainty associated with the stock water coefficients is represented by a beta distribution and bounded by the maximum and minimum water requirements in Cummings (2002).

4. SOURCE BASED ESTIMATES

Three different sources of non-main water for stock and domestic water are considered. Water can be pumped from waterways, groundwater or collected in farm dams (Figure 4). Licenses are issued by the water authority to extract water from both waterways and groundwater and for these sources of water it is assumed that all such extractions are licensed and the water use does not exceed the licensed volume. However, a different approach is required for farm dams because at present they are not licensed. The estimate of water use is based on the number of farm dams, the average proportion of the dam volume used to meet D&S demands and also the net inflows into the farm dams. Water captured in rainwater tanks is not considered.

4.1. Groundwater

The volume of water diverted from groundwater to meet D&S demands is based on the number of groundwater bores registered for D&S use. Within the specified water supply protection areas in the Werribee River catchment there are 270 bores used for D&S purposes (DSE 2007). The number of groundwater bores located outside these areas is expected to be small and are not included in this analysis. An upper extraction limit of 2 ML/year each is associated with each D&S groundwater bore (DSE 2007).

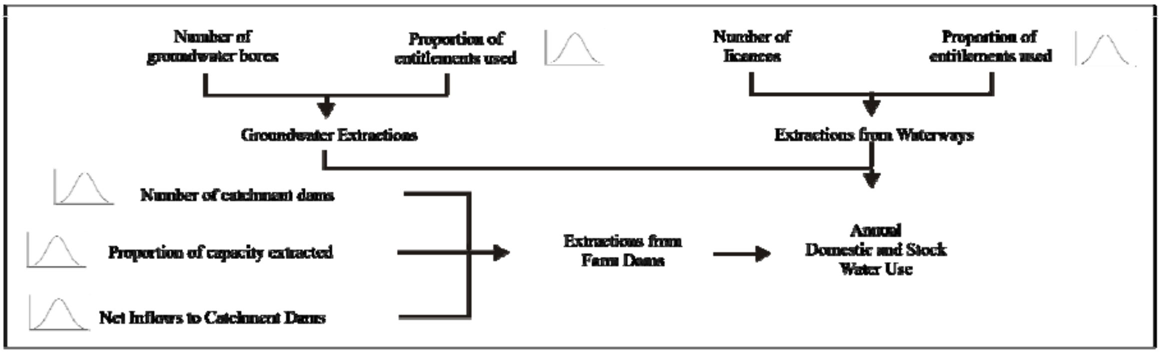

Figure 4. Method to estimate the availability of water to supply stock and domestic use

Therefore the maximum water use is 540 ML/year. During 2005/06 it is assumed that the water use could be anywhere in the range from 0 ML/year (representing a "sleeper license") to 540 ML/year and is represented by a uniform distribution.

4.2. Waterways

Just as for groundwater, the estimate is based on the number of landholders to which the water authority has issued a licence for extracting water for D&S purposes from a waterway. A total of 53 of these licences have been issued in the Werribee River catchment (Southern Rural Water 2006). These licensed are issued with an upper extraction limit of 2.2 ML/year. In the Werribee River catchment this equates to a total volume of 140 ML/year. It is assumed that the water use during 2005/06 could be anywhere between 0 ML/year and 140 ML/year and is also represented by a uniform distribution.

4.3. Farm Dams

A different approach is required to estimate the volume of water extracted from farm dams to meet D&S requirements and the simulations model, Tool for Estimating Dam Impacts (TEDI) was employed. TEDI undertakes a water balance for each farm dam in the catchment and calculates their cumulative impact on streamflows (Nathan et al. 2000). Inputs to the model include the number of farm dams, the demand factor and data to estimate the net inflows to each dam. There are substantial uncertainties associated with some of these inputs and a framework to assess these uncertainties was developed by Lowe and Nathan (2008; Submitted). The uncertainty associated with the **number of farm dams** and **net inflows** was estimated using the method presented by Lowe and Nathan (2008; Submitted). The **demand factor** is the average volume of water extracted from the dam, presented as a proportion of the total dam capacity. Southern Rural Water surveyed the owners of 36 D&S farm dams and the demand factor was estimated to be 0.08 with a standard deviation of 0.11 (Lowe 2009). The uncertainty associated with the demand factor was assumed to follow a normal distribution. The diversions that occur in a given year are limited by the volume of water held in the dam at the start of the year and the net inflows.

5. RESULTS

The estimates of stock and domestic water use generated by the two approaches diverge by 119 ML (or 15% of the upper value) (Table 1). There is substantial overlap of the 95% confidence intervals associated with each estimate, however, the 95% confidence interval obtained using the approach based on the water source is slightly narrower than obtained using the demand based approach (Figure 5).

Further analysis was undertaken to understand the relative contribution of each component of the D&S water use on the overall uncertainty. For each approach, the D&S water use was estimated using

Table 1 Summary of results.

	Best estimate of water use (ML)	95% confidence interval of water use (% of median)	
		Lower Limit	**Upper Limit**
Approach based on the demand for water			
- Domestic water use	100	-65%	+125%
- Stock water use	590	-70%	+86%
- Total	690	-63%	+63%
Approach based on the source of water			
- Waterways	70	-100%	+100%
- Groundwater	270	-100%	+100%
- Farm Dams	469	-65%	+65%
- Total	809	-55%	+55%

Monte Carlo simulations multiple times, each time the uncertainty associated with only one of the components of D&S water use was considered. The uncertainty in the estimate of D&S water use for each of the separate calculations is measured using a dimensionless term, the coefficient of variation (CV) (i.e. the standard deviation divided by the mean). The CV is a dimensionless term; higher values of CV imply higher uncertainty and vice versa. A comparison of the CVs shows the relative contribution of each source to the overall uncertainty. In Figure 6 and Figure 7 each source of uncertainty is represented by an axis and the shaded area crosses the axis at the value of the CV. For example, the CV of the water use estimated using the demand based approach when only the uncertainty in the number of stock was considered is equal to 0.19 (Figure 6).

The uncertainty in the number of stock is the biggest influence on the overall uncertainty of the demand based estimate, followed by the stock water use coefficient. For the source based estimate, the uncertainty associated with groundwater extractions was the greatest cause of uncertainty, followed by the net inflows to farm dams and the demand factor.

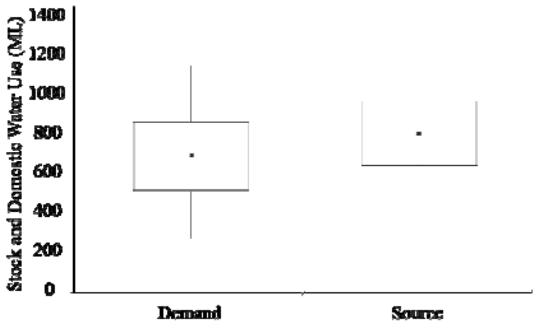

Figure 5 Comparison of the 2005/06 stock and domestic water use in the Werribee River catchment estimated using both approaches

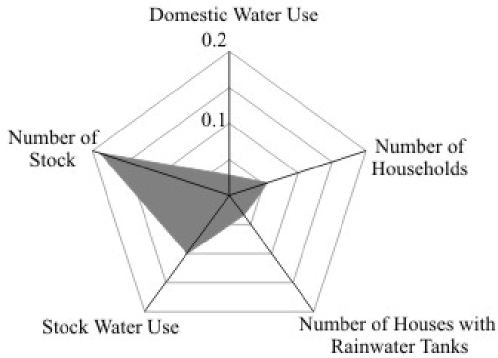

Figure 6 Spider plot showing the relative contribution of each model input to the uncertainty in the estimate of demand.

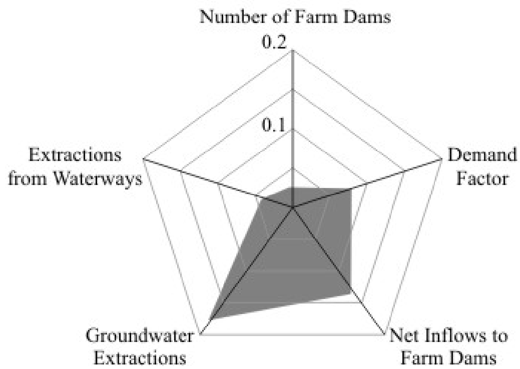

Figure 7 Spider plot showing the relative contribution of each model input to the uncertainty in the estimate of the sources of water.

6. DISCUSSION AND CONCLUSIONS

There are large uncertainties associated with the estimates of self extracted water to meet stock and domestic requirements. However, the considerable overlap of the probability distributions generated using the demand based and source based approaches shows that they give consistent results and provides some confidence in the results. Which is the better estimate of self-extracted D&S water use is unclear as the uncertainty surrounding each of the two estimates is similar. A simple unweighted average of the two approaches may be the best estimate but in many cases the data needed for the second approach may be absent and where available, the types of licenses used will vary from state-to-state.

The demand approach relies on data collected by the ABS. In the case study, census data was obtained and it was assumed that the uncertainty associated with the number of households and stock within a SLA was negligible. However, in years where data are collected via a survey this may not be the case. It was also assumed that the census information represents the stocking rates across the entire year. Furthermore, the number of stock may be underestimated as the ABS only includes agricultural enterprises with an estimated annual income from agricultural operations of at least $5000. In areas around urban centres, such as Ballarat, there may be a large number of small farms not covered by the ABS agricultural survey or census. While no data are available on the extent of the problem the ABS is developing alternative survey methods to assess the size of the problem (see ABS 2005). In the case study, the greatest reduction in uncertainty will be achieved by improving estimates of the number of stock in the catchment. One option is to consider auxiliary information when disaggregating stock numbers within an SLA, such as the address of agricultural enterprises with high stocking rates.

The approach based on the source of water requires information to be collected from the water authorities responsible for issuing water use licences and modelling of farm dam impacts. It may underestimate the water use if landholders either do not comply with, or have not registered for a D&S licence. In some catchments stock may have direct access to waterways, negating the requirement for a licence. In the case study catchment, the majority of D&S water was sourced from farm dams. However, in catchments where this is not the case the assumption that groundwater and waterway extractions can be any value up to the licensed volume will have a much greater influence on the overall uncertainty. Without metering of water use from these sources it is difficult to improve these estimates.

In conclusion there are considerable uncertainties associated with estimates of self-extracted water to meet stock and domestic requirements. However, there is similarity between the estimates generated using two independent approaches. A framework to assess the uncertainty associated with these estimates was applied to a case study catchment and this demonstrates how such an analysis can be used to identify the effective approaches to improve estimates of water use.

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