NATIONAL PROGRAM FOR
Sustainable Irrigation

Research Bulletin

Estimating water use efficiency for a whole catchment

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Water lost is gained somewhere else

Catchment managers have a responsibility to ensure equitable use of water, balancing water requirements from the upper catchment all the way downstream to the end of the valley. On farms, efficient use of water is a goal which everybody shares to avoid plant stress from drought or waterlogging and to avoid paying for too much water.

However, water use efficiency depends upon where along the river you measure the water, and whether you are interpreting 'efficiency' for the paddock, the diversion channel or the whole of the valley. For example, a farm-scale water balance will correctly represent any deep drainage as a loss but cannot represent how these losses may become gains at the catchment scale (e.g. groundwater recharge). Similarly, seepage from a delivery channel may be a loss to the water authority but a bonus to the adjoining farmer, or the catchment as a whole.

Work commissioned by the National Program for Sustainable Irrigation has developed a method to assess the water balance at a range of scales for a particular valley. The method can use data from various sources and qualities (e.g. dam releases, rainfall, groundwater bores, crop yields) to provide insight into how irrigation can affect the water balance at different scales. Probabilities are used when making estimates of the various components of the water balance, and in this way the variability of the water balance elements is recognised.

Calculating the water balance

A project, managed by the NSW Department of Primary Industries, entitled 'Determining whole-of-system water use efficiency', has determined the whole-of-system and delivery-scheme water use efficiencies for the Macquarie valley in central western NSW (see map, Page 2). The starting point for the project was to determine the components of the water balance defined in Equation 1.

$$P + SW_{in} + CR = SW_{out} + DD + ET + \Delta S \qquad \textit{Equation 1}$$

where:

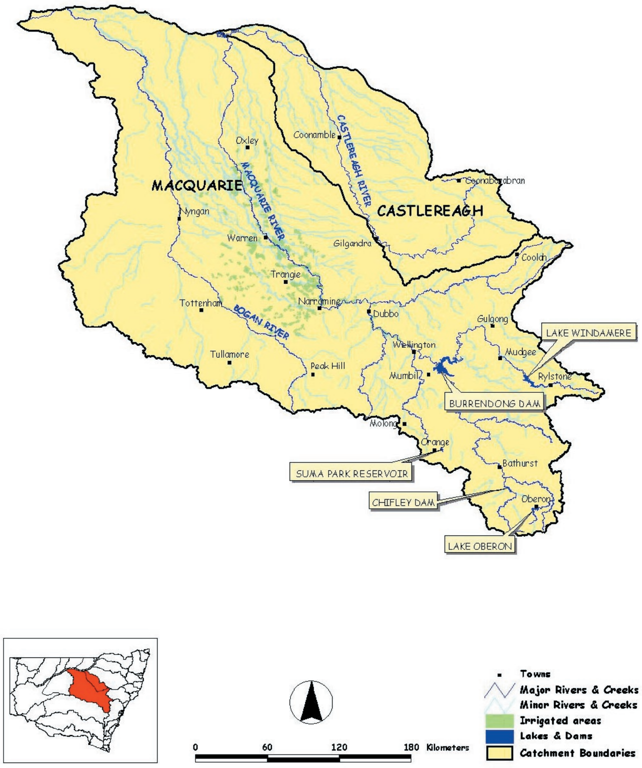
P is precipitation; SW_{in} is surface water flowing into the system (including pumped groundwater); CR is capillary rise; SW_{out} is surface water flowing out of the system; DD is deep drainage; ET is evapotranspiration; and ΔS is the change in storage.

To construct the water balances, three levels of confidence were assigned to measurements relating to:

- accounted-for water (able to be measured or predicted with reasonable accuracy and error estimates),
- partially-accounted-for water (volume or flow rate information is partially known, larger errors), and
- unaccounted-for water (volumes or flow rates are unknown).

This uncertainty is an important part of characterising a water balance as this unaccounted-for water in the water balance can be used to make an assessment of the potential water savings.

Managing uncertainty



Prepared by the Resource Information Unit, NSW Agriculture.
Catchment boundaries from data provided by DLWC, topographic features from AUSLIG Topo 250K Geodata.
August 2001

The seemingly simple task of constructing a water balance is very complex when the vagaries of climate change and the uncertain nature of some of the estimates (e.g. surface water flows, deep drainage) are considered.

Because of problems with the different data sources (e.g. different time ranges and measurement intervals), the project developed a new approach to defining the water balance. By adopting a statistical method called Bayesian Networks, the project was able to use irregular datasets and parameters that are not dimensionally equivalent (e.g. groundwater depth in metres and surface water in megalitres).

Where the exact values for a component are not known a probability of the component being High, Medium or Low is calculated from available data. In essence, Bayesian Networks provide a method to represent relationships between variables even if relationships involve uncertainty, unpredictability or imprecision. Links between variables can be established with certainty or based on a probability set by observation or expert opinion.

Software developed by the project allows for the aggregation of the collected data for various spatial and temporal scales (e.g. for the Narromine Irrigation Scheme, on an annual basis). The software interrogates each of the aggregated elements in the water balance and categorises the data into Low, Medium and High ranges (or assigns an Unknown value). Groundwater is classified into rising, falling or static levels. From this point, the software is then able to construct the Bayesian Network and associated conditional probability tables (an example is shown in Figure 1).

Results

Looking first at the delivery-scheme scale, the water use efficiency was calculated for two irrigation schemes within the Macquarie Valley (Narromine and Tenandra) for six and eight years for each scheme, respectively (Table 1).

Table 1. Conveyance Efficiency for the Narromine Irrigation Scheme (Narromine Irrigation Board of Management 2001) and the Tenandra Irrigation Scheme (Lyn Davies, pers comm.)

Year	Diversion/River pump (ML)	Farm Deliveries (ML)	Conveyance Efficiency
Narromine Irrigation Scheme			
1994-5	50407	41362	82%
1995-6	17095	10614	62%
1996-7	35093	28093	80%
1997-8	24047	19850	83%
1998-9	33145	28150	85%
1999-00	43072	36900	86%
Median	34119	28122	82%
Tenandra Irrigation Scheme			
1995-6	12000	9840	82%
1996-7	24000	20400	85%
1997-8	31000	26350	85%
1998-9	21108	17731	84%
1999-00	28941	24021	83%
2000-01	40633	33725	83%
2001-02	42366	35164	83%
2002-03	22536	18480	82%
Median	26471	22211	83%

With the exception of one year for the Narromine Irrigation Scheme, the conveyance efficiency for both these schemes ranges between 80% and 86%. The exception occurred in 1995-96 water year, when the conveyance efficiency was calculated to be 62%. This corresponds with the year when a relatively high efficiency was calculated at the whole-of-system scale (Table 2), suggesting the losses from the scheme scale did not translate to a loss at the whole-of-system scale.

Looking at the catchment as a whole, figures for the annual whole-of-system water use efficiency are shown in Table 2.

Table 2. Assessment of whole-of-system efficiency for Macquarie Valley.

Year	Dam releases and gauged tributaries (GL)	Irrigation and end of system flows (GL)	Whole-of-system efficiency
1993-94	941	636	68%
1994-95	820	537	65%
1995-96	338	281	83%
1996-97	687	390	57%
1997-98	626	409	65%
1998-99	1987	1876	94%
1999-00	1094	736	67%
2000-01	1784	1084	61%
Median	880	587	67%

This assessment demonstrates the great variation in the calculated whole-of-system efficiencies, which range from 57% to 94% (Table 2). The year in which the high efficiency of 94% was calculated coincided with a relatively high rainfall year (considered in the same eight-year period) and the lowest evapotranspiration (ETo) and evaporation (averaged from the SILO datadrill on a 5 km grid (BoM 2005). The next highest whole-of-system efficiency occurs in a year when the dam releases and gauged tributary inflows were the lowest in the eight years of record (Table 2). The climate data averaged over the catchment for the entire record (rainfall = 524 mm; evapotranspiration = 1396 mm; evaporation = 1802 mm) suggest this was an average year. Without these two relatively high values, for the rest of the record the whole-of-system efficiency ranges between 57% and 68%.

The Bayesian Network constructed for the Macquarie valley based on ~100 years of annual data suggest that for a large proportion of the time the groundwater change and End-of-System (EOS) flows are unknown, due to a lack of data(52% and 44% respectively) (Figure 1). If these variables were considered without the influence of their 'parents' (independent variables) they would exhibit a uniform distribution for the remainder of their states (e.g. low, medium, high for EOS flows; rising, static, falling for groundwater change). It is the influence of all the variables that are linked (either directly or through an intermediate variable) that govern the prior probability distribution determined by the Netica® software (Norsys 1997).

The annual rain and evapotranspiration data at the catchment scale (catchrain and catcheto in Figure 1) were averaged from monthly data for 3303 points at 5 km intervals across the catchment. The behaviour of the constructed water balance can then be investigated by entering 'findings' for one or more variables. The probability distributions that are calculated after a 'finding' has been entered are the posterior distributions. Therefore with additional information, the End of System flows and groundwater change (gwchange) can be predicted with greater confidence.

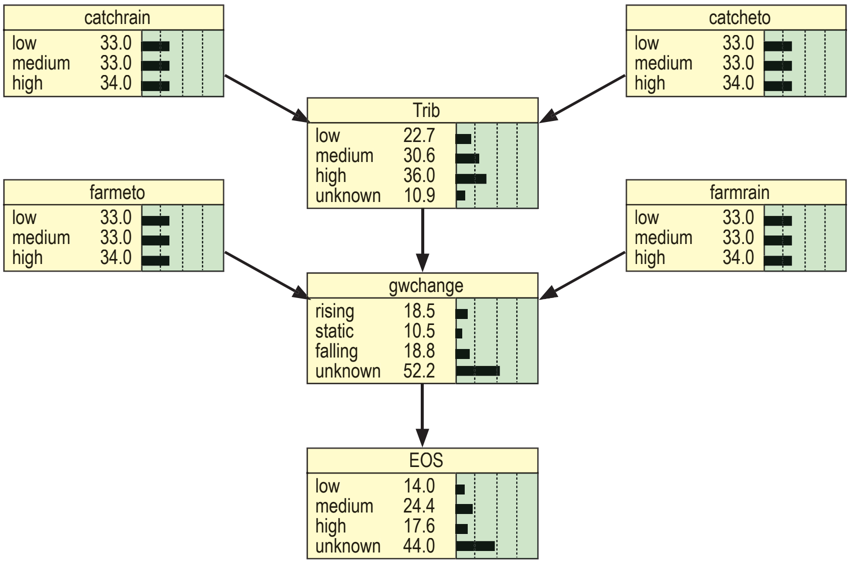


Figure 1. Whole-of-System Water Balance using Bayesian Networks showing the prior probability distributions. The prior probabilities for the variables believed to be influenced by these independent variables (i.e. Tributary inflows (Trib), groundwater change (gwchange) and end of system flows (EOS)) (Figure 1), are conditional on the behaviour of their parents (catchment and farm rain and ETo).

Further applications

The assessment of water use efficiency at any scale is a data-intensive exercise, which is generally difficult to obtain. Data that are available are generally held in different locations and there are different time steps associated with each dataset, making it difficult to align them. The method developed in this project provides a means of bringing these disparate datasets together, and adopts an assessment based on probabilities of outcomes in a qualitative sense.

The method is of benefit to any individual responsible for managing and understanding catchment-scale water flows. The ability to bring elements that indirectly influence the water balance (e.g. wheat yields) into the analyses provides considerable scope for developing Bayesian Networks that reflect individuals' understanding of their own farm and how it fits in the catchment.

This project has provided the foundations for further work in the area of assessing Water Use Efficiency at a Whole-of-System scale using a Bayesian Network technique.

Further reading

BoM (Bureau of Meteorology) (2005) Data Drill dataset. http://www.nrm.qld.gov.au/silo/datadrill/

Fairweather, H. (2005). Determining Whole-of-System Water Use Efficiency.NPSI Final Report DAN14. 38 pages, plus Appendices. http://www.lwa.gov.au/downloads/final_reports/DAN14_Final.pdf

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Norsys software corp. (1997) Netica – Application for belief networks and influence diagrams. http://www.norsys.com/

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