Reconstructing the History of the Victorian Water Sector

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EXTENDED ABSTRACT

Government and institutional initiatives concerning scarce water resources should be considered in perspective with historical water supply and use. Historical records in Australia, however, are discontinuous, incomplete and often disaggregated by different categories of water supply and use. We present a method to produce a coherent reconstruction of the historical provision and consumption of water in the major Victorian catchments. This has been done using the Victorian Water Account: an accounting and simulation tool that tracks the stocks and flows of physical quantities relating to the water system. Two examples of the application of this method in the Victorian Water Account are given.

The Water Account is also part of, and informed by, an integrated framework of similar calculators: The Victorian Region Stocks and Flows Framework (VRSFF) for simulating long-term interactions between the many other sectors of the physical economy. Both the Water Account and VRSFF consider a wide scope of input data including population, land use, energy and water information. Victoria's water history is reconstructed by integrating the limited water data with these information sources using a process that resolves data conflicts and deduces missing information. That process is referred to here as 'calibration'.

The Water Account, in connection with VRSFF, also has the facility to explore many alternative future scenarios of water sourcing, treatment, delivery and end use cognisant of the historical record. The end product is an information tool capable of producing catchment level outputs for strategic decision support such as the operational and embodied consumption of water, flow in river networks and the energy cost of transporting and treating water.

1. INTRODUCTION

Australia is urgently seeking solutions to problems of water security in the context of climate change and capacity constraints. According to DSE (2004), "if Melburnians continue to use water at the same rate as in recent years, the city may approach its supply capacity within 15 years".

In attempting to construct and calculate scenarios of the future, it is important to have a historical perspective: to see the characteristics of past water supply and use in times of water stress; to see the bounds of past extremes in drought and flood and to capture some of the stock dynamics of the components of water systems.

However, the historical record is discontinuous and sometimes fraught with inconsistent information. The Australian Bureau of Statistics (ABS) water accounts are published occasionally (ABS (1998), ABS (2004), ABS (2006)) but they give only a static report of water use and not much detail on the different ways water is sourced.

A complementary form of water accounting is being undertaken by the National Water Commission (NWC) that focuses more on the sources of water. This will be a useful resource for the *future* to match with the ABS Water Accounts but to get a detailed historical picture it is the experience of the authors that you must derive it from numerous disparate data sources. For example, Victorian State of the Environment reports such as DWR (1989), the Victorian Water Review (Victorian Water Industry Association Inc., 2004) or the Victorian State Water Report (DSE, 2005)

The Water Account draws on these data but it is also part of, and informed by, an integrated framework of other accounts and calculators in The Victorian Region Stocks and Flows Framework (VRSFF). Each calculator is an account of some aspect of the physical economy of Victoria e.g. residential land use or energy supply.

In producing the Water Account and other stocks and flows frameworks that are its companions, a great deal of effort has gone into the construction of a *complete and consistent* historical database.

The emphasis on completeness stems from the integrated nature of our approach. What we are presenting in this paper mostly concerns water but water is an important part of many sectors of the physical economy. These sectors, in turn depend on others and it will be seen very quickly that it is difficult to reconstruct a history or produce scenarios of water supply or use unless you begin with the intention of being complete.

It is not sufficient to develop accounting models that simply include or represent the many sectors that involve water. Where relevant, the calculations of these accounts should be connected and self-consistent. Consistency is important from a basic accounting perspective: totals and other macro-state variables should be consistent with the sums and combinations of outputs from connected sectoral calculators.

2. METHODS

In practice, the noble principles of completeness and consistency meet with the problems of historical data often being disparate and fragmented.

The methods by which we overcome these issues may be remembered as the "Four Cs": 1) Collecting and cleaning data, 2) Categorising, 3) Conflict resolution and harmonisation 4) Consolidation. Note that these are not necessarily all used, or used in sequence, but collectively, we will refer to their application in stocks and flows frameworks as 'calibration'.

In the stocks and flows approach, two frameworks of sectoral models are used. A calibration framework digests a wide variety of information to initialise the smaller number of variables in the simulator framework. The simulator then uses parameters and age profiles derived from calibration to explore possible future scenarios but it can also use the time series outputs of the calibrator to 'simulate over the historical period' i.e. reproduce history. Indeed, part of the calibration exercise is to check that the historical record can be completely and consistently reproduced.

2.1. Collecting and cleaning data

All raw data are read into the calibration framework and reviewed. Graphs and tables are inspected to detect gross errors in the raw data, e.g. the volume of water used by mining or agriculture should be less than the reported total water used. Where such errors exist, the source data are not edited, rather a correction is coded within the calibration framework leaving a clearly documented "audit trail".

Following this stage there may remain duplicate or conflicting data or there may be no direct information whatsoever. Even when there is patchy or no actual data for a variable it is rare that nothing at all is known. Aggregate statistics, State totals and related data provide bounds on variables. The procedures described next outline how to resolve these data issues and use related information to help fill the gaps in what we know about a variable.

2.2. Categorising

To identify discontinuities or any conflicts between data sets we first categorise the fields of different data into a common set of descriptors. Even at this early stage there may be a need for other input. For example, in deriving values for water required by industry in Victorian catchments, we used (1) a State total industrial water use, (2) a (normalized) split of industrial land use in local government areas (LGA) and (3) a mapping of LGAs to catchment area boundaries.

2.3. Conflict resolution - harmonisation

When we are able to compare overlapping and contiguous datasets, we can then choose the best combination to describe history. Where datasets conflict, it may be necessary to use information from many sources to judge the best way to assimilate information from either set.

Resolving or harmonising data conflicts may involve excluding information, averaging or finding the max/ min values along a time series and there may be implications on the calculated outputs within a calculator that need to be taken into account. As a general rule, harmonising is usually applied to more aggregated data (such as national and State totals) because there is little overlap of data at the disaggregated level. In particular, national and State totals are more likely to be available over longer periods.

2.4. Consolidation

Most data do not cover the entire historical period of the calibration. Consequently it is necessary to fill in the gaps in the time series, which may involve: using aggregate totals to deduce the disaggregate detail; using indirectly related data or even recursive algorithms. When there is an absence of good data or other information, interpolation or extrapolation may be used. Consolidating to a single data set for a given variable then allows us to look at the implications of this variable in other, dependent sectoral calculators. Again, in comparison with other information, this may require a further revision of the calibration process

At the conclusion of calibration we have a complete representation of the physical history of the system (here that is the Victorian water sector) that is consistent across all the sectors involved. A concomitant result is that we also will have developed values for a subset of variables (often these are intensive variables or the age structure of stocks) whose historical trajectories provide a sensible place from which to launch scenarios of the future.

3. RESULTS

To illustrate how the historical database of the Victorian Water Account was constructed, this section describes the calibration of two important components: residential water use and energy used for treating and transporting water and waste water.

3.1. Residential water use

Collection

The reconstruction of historical residential water use considered data from the ABS (1998, 2004), the Bureau of Rural Sciences (BRS, 1985) and the Victorian Department of Water Resources (DWR, 1989) and census data on population and dwellings from 1966 to 2001.

Categorisation

The process by which these data were combined into a single time series demonstrates the categorisation of: ABS "household water use" data; BRS "total domestic"; and DWR's information about "metered residential" for Melbourne 1972-1984, into a single "residential" category used in the Water Account (see **Figure 1**). This mostly involved a one-to-one mapping.

Conflict resolution and harmonisation

In Figure 1, the BRS datum for 1985 appears suspiciously low and, while there was a drought in effect at that time, it was also at odds with other information on Melbourne's historical residential water use in Victorian Government documents DSE (2005a). In this case, the harmonisation of the data proceeded through the exclusion of this outlier.

Consolidation

The data from DWR (1989) referred only to Melbourne. From this we needed to obtain an estimate of Victorian residential water use by first assuming that it is associated with residential dwellings. In another calculator concerning demography, ABS census information on population and housing had already been calibrated. This was used to derive a ratio of Victorian dwellings to those in Melbourne over history (see **Figure 2**).

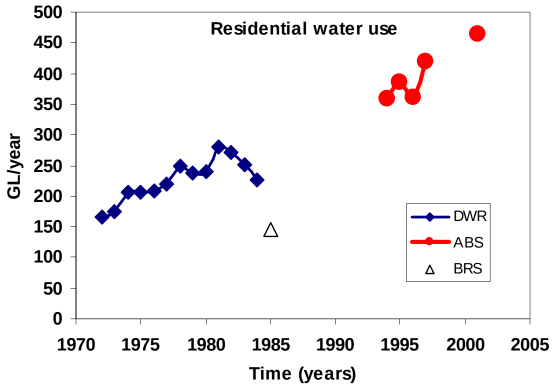

Figure 1. The three main sources of data on residential water use in Victoria: Department of Water Resources (DWR), Bureau of Rural Sciences (BRS) and ABS Water Accounts (ABS)

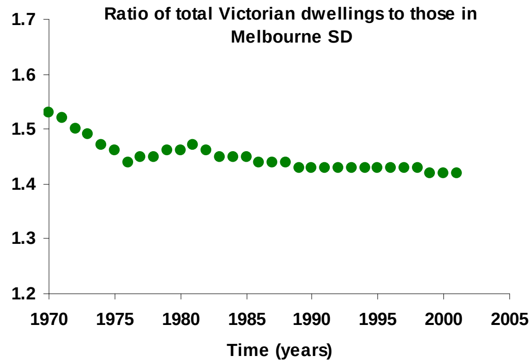

Figure 2. Ratio of total dwellings in Victoria to those in the Melbourne Statistical Division (SD).

The residential water consumption data for Melbourne was adjusted upwards by this ratio to get estimated values for all of Victoria. Estimates for the intervening (unknown) years between 1984 and 1993 were deduced through linear interpolation. For years preceding 1972, a linear trend was extrapolated based on water use in the years immediately following 1972. The final historical time series of residential water use in Victoria can be seen as the black line in **Figure 3**.

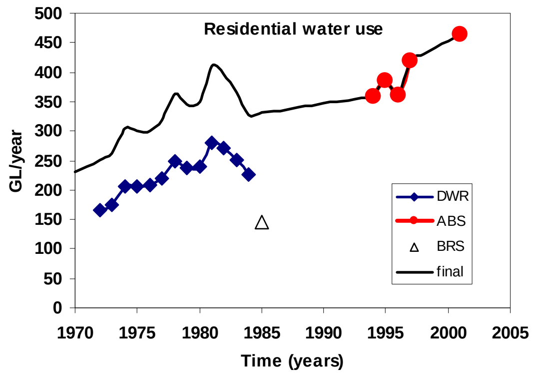

Figure 3. The final historical time series of residential water use in Victoria.

Note that there is no attempt to represent the variability of water use between 1984 and 1993. This might have been calculated through some sort of sampling of variation in the data outside that interval. However, any variability superimposed on the linear trend would have to model both meteorological variation and the subsequent response of households. This is not a trivial task and it is our opinion that calculating variability in residential water use for all years would add little for the amount of extra modelling that would be required.

This compromise in precision has implications about what the final time series can be used for. Our objective of producing long-term scenarios for strategic decision support means that we are willing to forgo yearly variations considering a higher priority on capturing changes over decades.

3.2. Energy needs of water

Deducing the energy consumption by the water sector required a more elaborate process with a much wider collection of data inputs (refer to **Figure 4**). In this case both extensive and intensive variables were calibrated so that the total calculated electricity use for water treatment and transport matched or exceeded the reported total by ABARE (2007). Note that the majority of energy provided to the Victorian water sector is in the form of electricity. Hence, in variable names we have used the terms “energy” and “electricity” interchangeably.

Potable water data

The *quantity* of potable water treated and delivered was calculated from ‘upstream’ population, industry and land use calculators in the VRSFF – see **Figure 4**. Kenway et al. (2007) have collated statistics from the water utilities of four major Australian cities and, from their figures, the electricity needed per litre had a system wide average of 470J/L for treatment and distribution of potable water in Melbourne in 2004-05. This intensive variable has been taken to be representative of all of Victoria. More detail can also be found in Melbourne Water (2006).

Discharged water data

As with potable water, the flows of discharged water used as inputs are the outputs of preceding calculators. The calibration of these calculators is outside the scope of this example but it is important to note the connections (see **Figure 4**). Kenway et al. (2007) calculates an intensity of 3400 J/L for discharged water treatment and pumping in Melbourne for 2004-05. This has been taken to be representative for the state as, according to the Victorian Water Industry Association Inc., (2004), the vast majority of Victoria’s waste water discharge occurs in or around Melbourne

Re-used water

In the process of collecting information on water supply and discharge, extensive data on the re-use of water were found in ABS (1998, 2001) and used to estimate the electricity required for water re-use. This re-use mainly occurs in mining, processing and assembly and heavy industries. Where the energy intensity of the treatment of re-used water was unknown, we estimated this to be half that for potable water treatment. This estimation comes from the simple reasoning that water *is* treated to be re-used but not to the same degree as potable water.

Desalination

Information on the energy intensity of reverse osmosis desalination can be found in various places such as Ahmad and Schmid, (2002). For the proposed Sydney desalination plant, The Australia Institute (2005) estimate a figure of 17750 J/L which is the current value used in the Water Account. However, no water was supplied through desalination over the historical period, so the associated electricity requirement was zero.

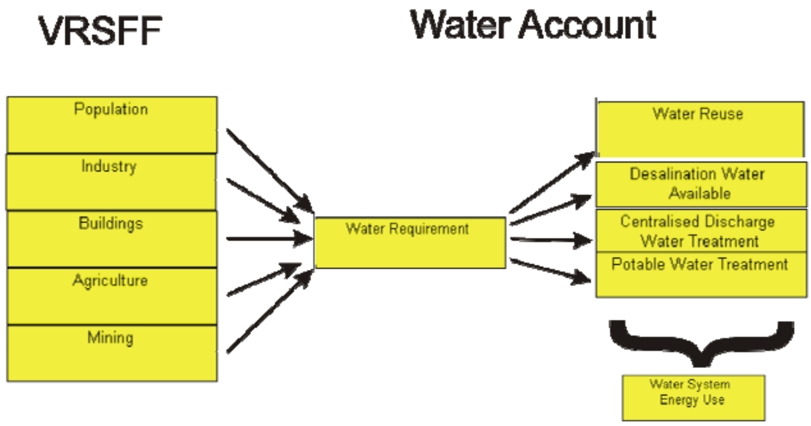

Figure 4. Outputs from VRSFF sectoral models drive water requirements. This subsequently determines activity for different water services. The electricity consumed by these water services is calculated in the "Water System Energy Use" account.

Transferred water and totals

Having obtained reasonable figures for the intensive and extensive variables concerning potable water supply, re-use and wastewater discharge, the remaining calibration task focussed on the electricity required for transfers of water between surface water management areas (SWMA) e.g. for irrigation. The preceding intensive variables could be reasonably assumed to apply across history and geography, but the variation in flows between SWMAs and differences in geography, did not allow such flexibility with assumptions about the energy intensity of water transfers. This situation was exacerbated by the paucity of time series data on water transfer flows.

Flows of water transferred were based on DWR (1989) information for 1986 and the estimated distance that water travelled was based on known canal or pipeline lengths or (using MapInfo GIS) centroid to centroid distances between SWMAs.

One aggregate reference, to calibrate to, was ABARE's (2007) historical time series total energy requirement for Victoria's water sector (1974 to present). However, there remained conflicts between that top-down total and a bottom up sum of the components mentioned above. What follows is the 3-stage process by which we arrived at the energy intensities and quantities of water transport while attempting to be consistent with the aggregate statistics.

Conflict resolution and harmonisation

Data from Kenway et al. (2007) and known transfers between Thompson and Yarra SWMAs, DWR (1989 p64) were used to get an initial value for the energy intensity of water transfer, 3.3 GJ/GL/km. This was then used to derive a first estimate of energy for water transport which was added to the energy required in potable, re-used and discharged water to produce a calculated total. This was to be compared to the reported total in ABARE's historical time series (T_{ABARE}).

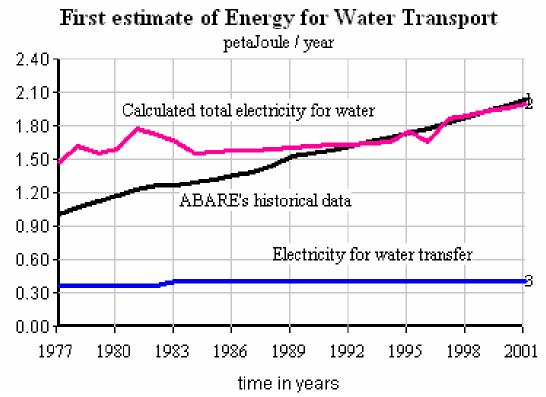

Figure 5. The first estimate of energy intensity for water transfer used to generate the total electricity for water transfer (blue line). This was added to all other water related energy needs to produce the calculated total (pink) to be compared with ABARE's historical data (black).

The only comprehensive data we had for transfer flows was from DWR (1989) for 1986. This was used in conjunction with the 1986 ABARE total as summarised in (1). This adjusted the energy intensity of water transfer downwards so that the calculation of aggregate electricity needs for the Victorian water sector matched ABARE at 1986 (see **Figure 6**).

$$(1)\quad I_{\text{int}} = \frac{(T_{ABARE} - pot - dis - reuse)_{1986}}{flow_{1986}}$$

Where I_{int} is the intermediate energy intensity for water transfer, $(T_{ABARE} - pot - dis - reuse)_{1986}$ is the residual after subtracting the potable, discharge and reused water energy requirements from the ABARE total for 1986 and $flow_{1986}$ is the water transfer flow datum for 1986 multiplied by the distances over which that water flows.

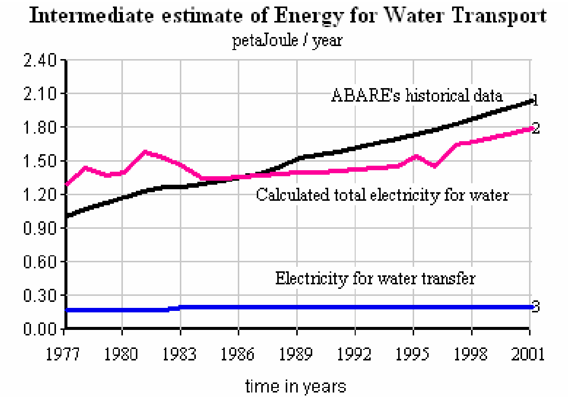

Figure 6. Intermediate estimate of electricity for water transfer (blue line) using data for transfer flows in 1986. The small change at 1983 is due to the Thompson-Yarra pipeline coming online

Where the calculated total electricity required ($T_{calculated}$ shown as the pink line in **Figure 6**) deviates below the ABARE historical data, the water transfer energy intensity and transfer flows were both adjusted proportionally so that the ABARE data is matched - refer to (2) and (3). At any time where $T_{ABARE} > T_{calculated}$:

$$(2)\quad I_{final} = \sqrt{\frac{T_{ABARE} - T_{calculated}}{I_{int} \times flow_{1986}}} \times I_{int}$$

$$(3)\quad flow_{final} = \sqrt{\frac{T_{ABARE} - T_{calculated}}{I_{int} \times flow_{1986}}} \times flow_{1986}$$

In (3), $flow_{final}$ is the final estimate of water transfers multiplied by the distances over which that water flows. Where $T_{calculated} > T_{ABARE}$, those variables remain unchanged from their values at 1986. We assume the same relative uncertainty to $flow_{final}$ and I_{final}. Both variables are equally unreliable, deriving from single measurements where no absolute uncertainties were known.

The final total calculated energy requirement (pink line in **Figure 7**.) for water transfers = $I_{final} \times flow_{final}$. This is summed with the energy needed for all other water services and the total matches ABARE's historical data exactly after 1986. This is due, in part, to an increasing energy requirement for water transfers (blue line in Figure 7).

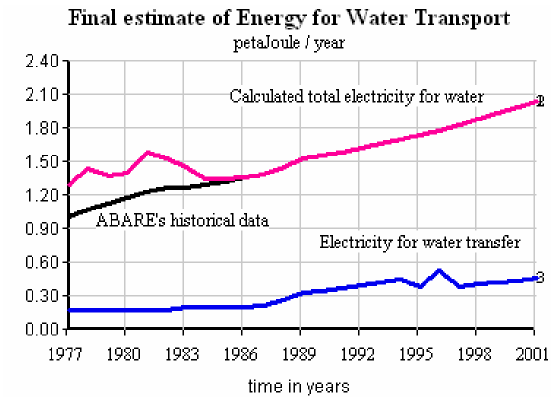

Figure 7. Final step in the calibration of energy required for water transfers.

The allowance to exceed ABARE's historical statistics is based on the fact that data was collected from surveys which are, if anything, more likely to produce underestimates than otherwise, Baynes (2007).

4. DISCUSSION

We have presented two examples of a method for reproducing the physical history of the Victorian water sector. We used available data in concert with a framework of models that simultaneously re-constructs the history of other sectors of the physical economy of Victoria (VRSFF). The basic method comprises four processes: 1) Collecting and cleaning data, 2) Categorising, 3) Conflict resolution and harmonisation and 4) Consolidation.

One of the merits of this approach is that it's a tractable, consistent and systematic way of 'bringing it all together'. Another way of congregating information might be through relational databases but this would not present a user with the same clarity about the processes of data conflict resolution and consolidation.

By being broad in scope we have relinquished some precision. We could be more detailed or disaggregated in our categories or use more detailed time series or time steps. But this raises the question of how much precision do you need to be accurate?

For example, it might be preferable to have detailed time series of intensities for waste water treatment. This might represent the changing technology and standards applied. In the absence of more information, we have used values from a single time point (2005) which are at least based on current knowledge and represent a reasonable estimate until more historical data comes to hand.

5. CONCLUSIONS

For developing scenarios of the future of water in Victoria there is a need to consider the physical history:

- To ascertain how the present situation has arisen, what is the current status and what are the likely trajectories for the future.
- To determine the age structure of infrastructure which might influence future dynamics and limit/open options.
- To get an idea of what variables (or entire sectors) have been/are; important to the whole; which are stable or not stable.

This paper presents an efficient way to congregate many, often disparate data sets to build a coherent picture of the physical history of water in Victoria. This information also connects to other stocks and flows frameworks to enable long term, cross-scale simulations based on a topically broad and temporally deep historical 'calibration'.

6. ACKNOWLEDGMENTS

This work inherits much from the data, methods, and results of the Australian Stocks and Flows Framework (ASFF) and we are grateful to the creators of ASFF for their continuing support.

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