A Framework for Modelling the Energy and Greenhouse Implications of Water Demand and Supply Scenarios

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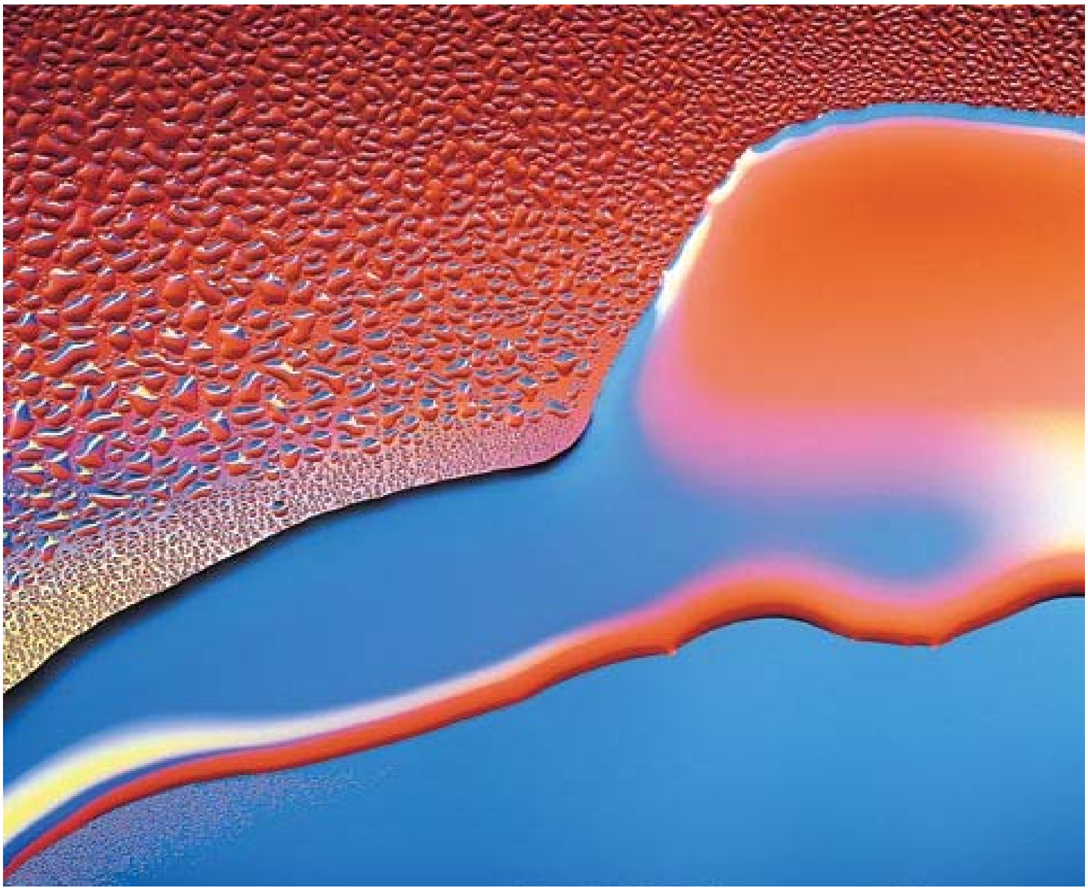
August 2009



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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South-East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South-East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South-East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

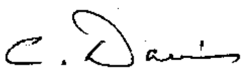
As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.



Chris Davis
Chair, Urban Water Security Research Alliance

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EXECUTIVE SUMMARY

The aim of this work was to provide a method for using water balance and demand models to calculate energy and greenhouse gas (GHG) emissions for future versions of the South East Queensland (SEQ) Water Strategy. Energy and GHG costs provide another way to differentiate between alternative water strategies and may be of financial significance in the event of a nationally implemented emissions trading scheme.

A framework was developed which identifies how existing and planned SEQ models can be used in this process. In the absence of the End Use Model (EUM) currently under development by the Queensland Water Commission (QWC), a for-research-only EUM was created to illustrate the calculation procedure for when the new model becomes available. In the case of existing models, modifications were made to the SEQ WathNet model to incorporate energy and GHG data. The report illustrates the framework, work to date and demonstration results for energy and GHG emissions for the SEQ urban water sector.

The framework is a robust and flexible platform for assessing alternative scenarios for the SEQ Water Strategy. As more refined data or models become available they can replace existing components and improve the accuracy of the results. In particular, the framework is demonstrated using energy data for water supply cognisant of three savings plans. Further work is required to properly incorporate energy and GHG emissions from urban water reservoirs and wastewater treatment and handling.

The figures below illustrate the framework components and demonstration results that represent the type of analysis possible by linking energy and GHG to the water balance. The demonstration results show that the:

- different water savings plans of the SEQ Water Strategy have different energy savings as a result of the reduced supply of water required (Figure ES 2a).
- seasonality of water supply creates a seasonality in energy use (Figure ES 2b and 2c).
- relatively even distribution around the average (50th percentile) in the monthly time series for SEQ can be qualitatively different from the more skewed distributions of energy cost in individual sub-catchments (Figure ES 2b compared to Figure ES 2c).

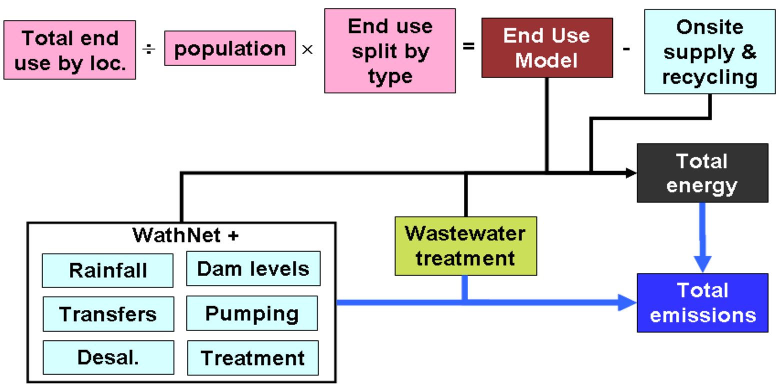
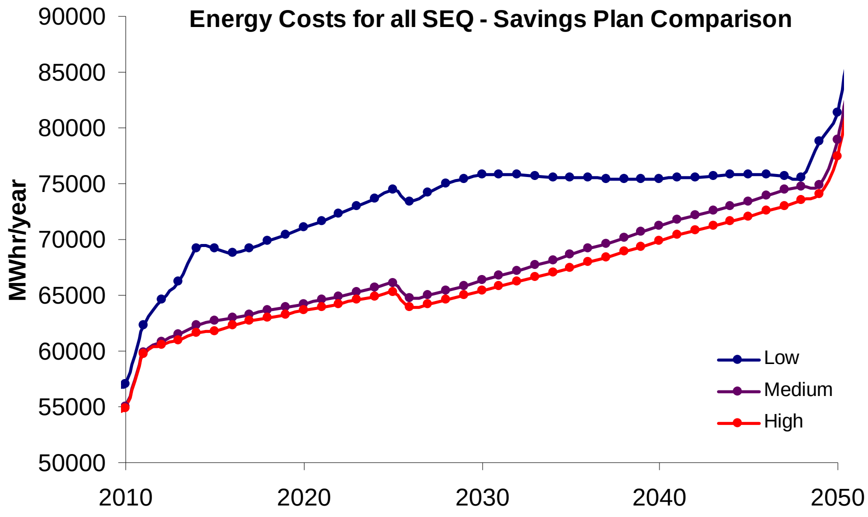


Figure ES 1: The framework for integrating energy and emissions modelling and data



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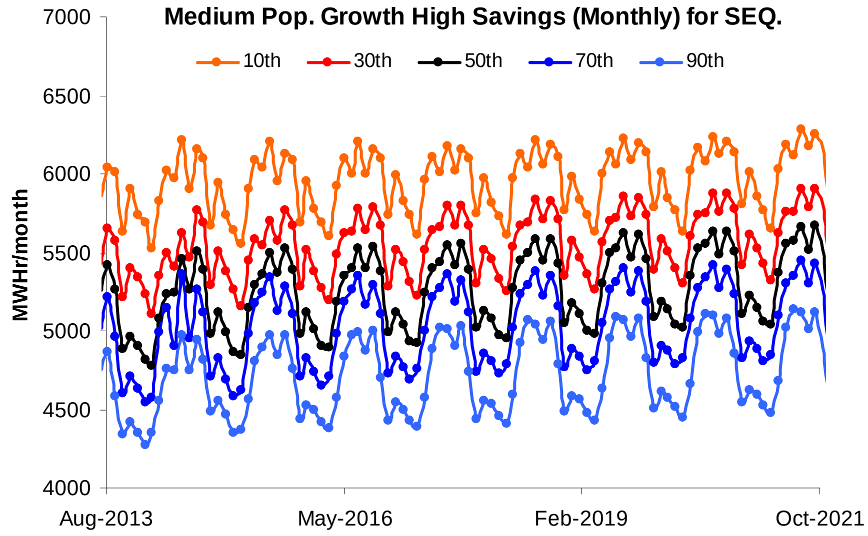

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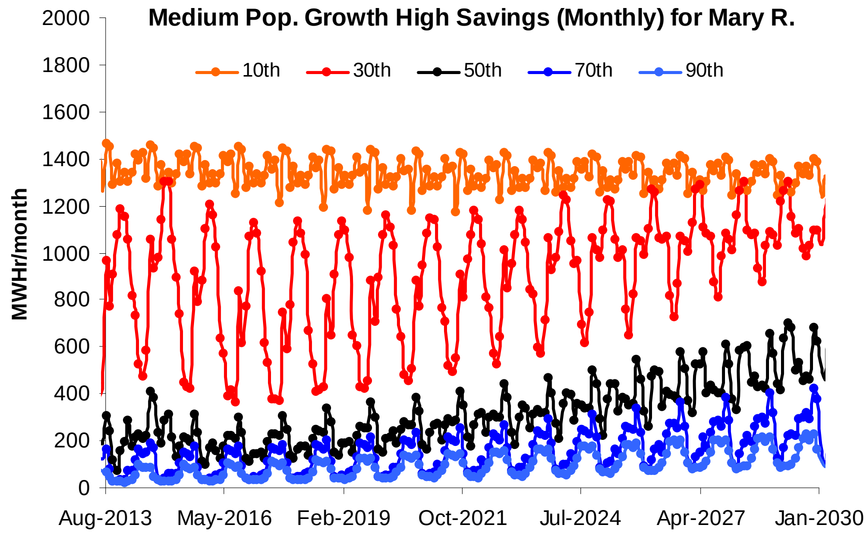


c)

Figure ES 2: a) Annual energy cost for all of SEQ assuming a medium population growth forecast comparing the 50th percentile results for low, medium and high water savings plans. (b and c) Sections of the time series monthly energy cost for all of SEQ (b) and the Mary River System(c) assuming the same scenario: a medium population growth forecast and a high savings plan. For each time point the analysis generates a distribution, the 10th, 30th, 50th, 70th and 90th percentiles are shown.

1. INTRODUCTION

Various models, tools, data and information have been assembled as part of the Life Cycle Analysis (LCA) and Integrated Modelling Project. The considerable work that has been done requires a conceptual and practical framework of coordination to assess the long term (50 year) energy and GHG implications of water demand and supply scenarios for SEQ. In the following, a framework for this purpose is described and its operation is demonstrated (refer to Figure 1 on page 4).

Previous work on this topic commissioned from consultancy companies has produced useful data but not a re-useable system that could, for example, respond to alternative population forecasts or new end use models. KBR's *Energy Consumption Discussion Paper* (2008) contained a preliminary assessment of the energy implications of the water balance but it also made some assumptions such as: all water pumping was from the source to the furthest destination. Marsden Jacob Associates (MJA) produced a more comprehensive report (*Energy Intensity of the Draft SEQ Water Strategy* (2008)) but the data and results in that work used a model which is no longer available to the Alliance.

The LCA and Integrated Modelling team has considered energy and GHG emissions for the SEQ Water Strategy (Hall et al. 2009) but has not previously linked this with models of the SEQ Water Grid (i.e. WathNet). Other research in the LCA and Integrated Modelling Project focuses on a specific case study catchment, namely, the Logan Basin.

There is a need for a SEQ wide framework for developing long term scenarios for energy and GHG gas emissions from water and wastewater services. This report outlines a simple and flexible framework for organising data, research and existing available models to produce energy and GHG metrics relating to scenarios of water supply and demand for all of SEQ.

The framework provides a robust methodology for updating existing data, forecasts and models to generate more accurate results. This report identifies and describes current components in the framework and how they may be updated in the future.

We stress that this is a demonstration of the practical operation of the framework and not an attempt to produce actual results. The numbers and graphs in the example results are indicative of the kind of output that could be expected from the framework in its ultimate form.

The EUM is described in some detail as this was constructed in lieu of another EUM being developed by the Queensland Water Commission (QWC). The interim EUM is accurate enough for the purpose of demonstrating the framework and informing the energy and GHG calculations of population forecasts and savings plan policy options. Detailed attention was also given to the integration of the SEQ WathNet Model into the framework. This component integrates energy and GHG data into existing demand-supply models in SEQ and provides immediate results for new demand-supply balances.

An important capacity that has been developed here is the flexibility to compare different scenarios in terms of energy and GHG impacts relatively quickly. If different plans for supplying water to SEQ over the next 50 years compare equitably in terms of the water balance, this framework may be used to differentiate them in energy and GHG terms using the same projections, forecasts and assumptions.

The full implementation of this framework requires more refined input to and from the various models and it also awaits the outputs from other research, for example, emissions from dams. However, example results demonstrate a first order calculation of the energy and GHG emissions cost of water demand and supply scenarios is readily achievable.

What follows is a brief description of the whole framework and, in separate sections, some discussion of the more developed components that comprise it. Example results are presented at the end of the report and are indicative of the outputs from the framework.

2. AIMS

This study aimed to develop a framework for calculating energy and GHG emissions for long term scenarios for SEQ water and wastewater services.

The framework aims to provide a pragmatic and robust methodology for using the best available data and models to generate and assess alternative scenarios. In particular it sought to:

- Use existing models and data for SEQ including the water balance model used by the SEQ Water Grid Manager;
- Incorporate population and demand projections and end use characteristics;
- Use SEQ Water Strategy projections, demand management and supply plans;
- Develop simplified models where none are currently available to demonstrate the calculation process; and
- Identify data and models that are planned for development that can be used in the framework in the future.

3. THE FRAMEWORK AND ITS COMPONENTS

This section presents the overall plan of the framework outlining the various components and their interconnections - see also Figure 1. The framework is a sensible and robust schema for combining the data, scenarios and modelling outputs from different efforts in the Urban Water Security Research Alliance (UWSRA). It is general enough that this map of integration can be used even with future revisions to forecasts or scenarios and irrespective of the final choice of models of water demand or supply.

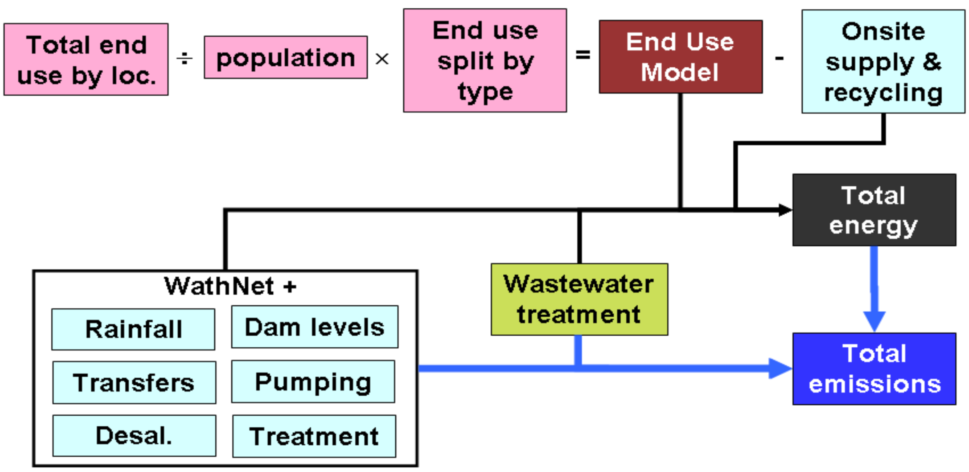


Figure 1: The framework for integrating energy and emissions modelling and data

This report is mostly about the framework itself and some proof-of-principle exercises that have been run to test its efficacy. It is important to re-iterate that not every component of the framework is in place and the final implementation relies on the completion of other research and modelling.

The basic calculation is linear and initiated from two starting points (refer to Figure 1). One is the demands of people and their environment (the End Use Model) and the other is the supply of water from the environment (including climate) mediated by major infrastructure or decentralised water supply options (WathNet +). From both of these are flows of information about energy use (black lines) and, separately, there are direct emissions from dams and wastewater treatment (blue lines).

Table 1: Summary of current and possible future components of the framework

Component	Description of current component	Possible Future Component
Total end use by location	Aggregate residential water use by pre-reformed local government area boundaries.	Possible revised projections of total water use according to SEQ Water Strategy details.
Population	Medium forecast by LGA from *Queensland's future population 2008 Edition*, *Appendix F* generated by PIFU (Department of Infrastructure and Planning 2008).	Low and high population forecasts by LGA, consistent with associated demand fore-casts.
End use split by type	Information from Brisbane Water and the Gold Coast Waterfuture Project.	More information from Systematic Social Research and the SEQ Residential End Use Study.
End use model	For-research-only EUM.	QWC End Use Model.
Onsite supply & recycling	Data reported by the UWSRA LCA-IM team (Hall et al. 2009) and linked to WathNet by subtracting from centralised water demand.	Could be expanded to include on-site re-use and greywater.
WathNet +	Energy and GHG intensities reported by the UWSRA LCA-IM team (Hall et al. 2009) used in SEQ WathNet for demonstration.	Hydroplanner for SEQ developed by LCA-IM UWSRA team.
Wastewater treatment	Data reported by the UWSRA LCA-IM team (Hall et al. 2009).	Further analysis on the energy and fugitive emissions associated with specific treatment plants and their catchment.

Referring to Figure 1, population data and forecasts were obtained from The Planning Information and Forecasting Unit (PIFU) (Department of Infrastructure and Planning 2008). The data we have used for the 'Total end use by location' were the same as those used in the draft version of the SEQ Water Strategy (Queensland Water Commission 2008) and, as with the population data, they pertain to each of the pre-reformed local government areas (LGA) in SEQ. The quotient of 'Total end use' with population provides a per capita daily requirement by LGA location.

This information on the located, aggregate water consumption per capita was given yet more detail by using some (limited) information about how that water was actually used ('End use split by type'). These data combined are the essence of the EUM. However, to better represent the ultimate impost on the water grid, it is also necessary to consider some calculation of the up-take and use of rainwater tanks, greywater recycling and re-use and the ability of these alternatives to provide water on-site. While alternative supply modes are clearly important in the full framework, scenarios of their penetration and the subsequent calculation of their effect has not yet been fully developed.

Accompanying the information on flows and end use of water there are associated information flows used to calculate the 'Total energy' requirements of the system (shown in black in Figure 1). These can be about the energy associated with a particular type of end use e.g. the energy intensity and use of hot water; the bulk quantity of water needed from the grid in particular locations; and the energy required by alternative supply systems.

Information about how water is supplied is embedded in a model of the SEQ water grid, WathNet (hosted and maintained by the Department of the Environment and Resource Management). The WathNet model includes a stochastic representation of climate, stream flow and reservoir levels. It also represents demand at particular locations, distribution at major junctions, major existing and planned pumping and pipeline infrastructure and desalination plants. However, it should be mentioned that WathNet is not a complete representation of the SEQ water grid as it does not include detail such as the smaller distribution pipelines to end–users which have associated energy costs.

The water supply simulations of WathNet were informed by the water demand outputs of the EUM. By attaching energy intensities to the WathNet calculations the framework can estimate the 'supply side' contribution to the water system's 'Total energy' needs.

Subsequently, it was assumed that all of the energy for the system (including that used in households) ultimately comes from black coal-fired electricity. Thus, an emissions intensity factor of 1.04t CO_2-e / MWh has been applied to every joule of energy used in order to derive an initial figure for 'Total Emissions'. It will be readily conceded that this is a contestable assumption for a 50 year future scenario. However, the primary question here is: how much energy is required in the provision and consumption of water. The secondary question of how that energy is supplied is important but beyond the scope of the report.

Three further contributions to energy or emissions need to be considered to complete the framework. Energy used in 'Wastewater treatment' needs to be absorbed into the 'Total energy' account. Separately, the fugitive emissions from wastewater treatment and handling need to be added to the 'Total emissions' as do any emissions from urban water reservoirs.

The following section expands on the content of the framework's components and describes in some detail the EUM developed by the project. The EUM is the locus of much of the data that has been collated and several features of the framework are expressed in its calculations. It is envisaged that a similar analysis of scenarios for rainwater tanks could be performed in linked Excel™ spreadsheets.

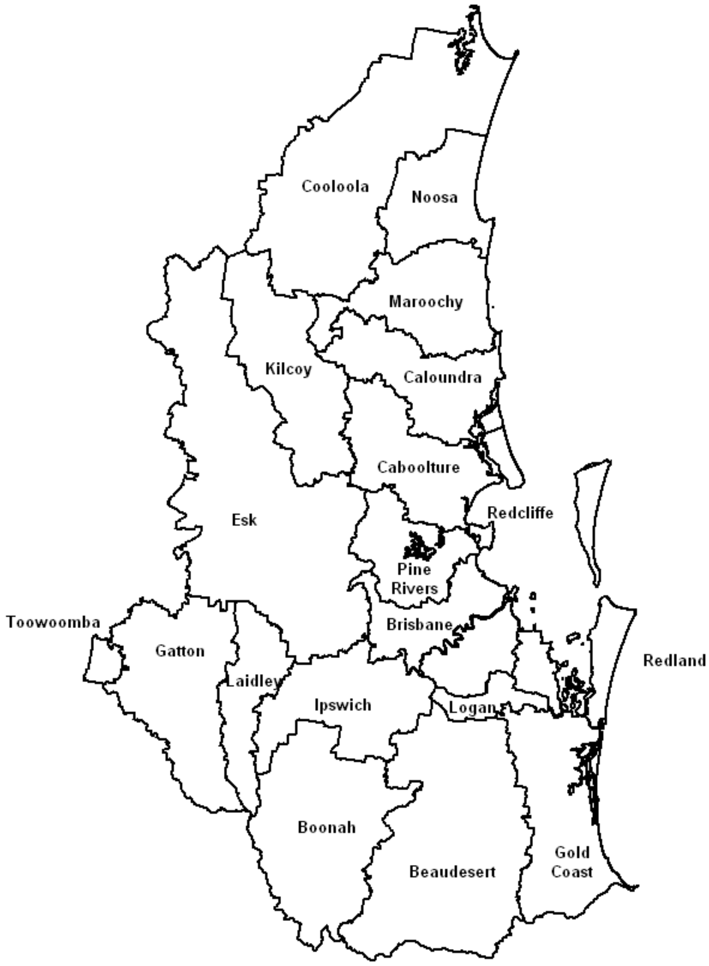
3.1. Population

Population forecasts were sourced from *Queensland's future population 2008 Edition, Appendix F* generated by the PIFU (Department of Infrastructure and Planning 2008) and located in the EUM.

In the EUM we have generally allowed for 3 possible population forecasts (i.e. a low, medium and high). Only a 'medium' was available for pre-reformed LGA boundaries in the aforementioned reference but a 'low' forecast is also available in an earlier report (Department of Local Government 2006).

The EUM scenarios of per capita water use by location extend to the year 2056. However, the PIFU population forecasts, by LGA, end at 2031. The projection for the population of all of Queensland at 2056 was used to estimate the SEQ population at 2056 by multiplying the relative change in the State population (between 2026 and 2056) by the SEQ population at 2026. The fraction of SEQ's population in 2026, in a given LGA, was then used to estimate the same LGA's population in 2056. The population for each LGA between 2031 and 2056 estimation was calculated by linear interpolation.

Population forecasts, by LGA, have been incorporated into the EUM for the following LGAs (see also Figure 2).



Beaudesert
Boonah
Brisbane
Caboolture
Caloundra
Cooloola
Esk
Gatton
Gold Coast
Ipswich
Kilcoy
Laidley
Logan
Maroochy
Noosa
Pine Rivers
Redcliffe
Redland
Toowoomba

Figure 2: Pre-reformed Local Government Area boundaries used in this work

3.2. Total Water Use – Incorporating Supply Substitution

Data for four savings programs were developed for business as usual (BAU), low, medium and high forecasts for personal consumption and disaggregated by LGA boundaries as described above. The assumptions behind the savings programs used in the EUM are outlined below. We understand that these are based directly on Table 12-1 of Report 4: *Regional Water Needs and Integrated Urban Water Management Opportunities Report*, a report prepared by MWH for the SEQ Regional Water Supply Strategy Integrated Urban Water Management and Accounting Task Group (MWH 2007).

Low Savings Program: Top 5 Water use efficiency measures ranked by annualised costs, rainwater tanks only used for outdoor, no rainwater tanks in new development unless there's an existing policy, no rainwater tanks assumed for existing dwellings unless a rebate scheme is in place and penetration of existing accounts varies with rebate level, no residential recycling unless it is an existing project, 5% of new non-residential water use from recycling, Western Corridor Recycling Scheme assumed to be implemented in 2009.

Medium Savings Program: Top 10 Water use efficiency measures ranked by annualised costs. Rainwater tanks to be used for outdoor, toilet and cold water laundry and mandatory in all new developments. Rainwater tanks in existing dwellings to be used for outdoor use only, a 25% rainwater tank cost rebate scheme is in place and 5% ultimate penetration of existing accounts assumed. Residential recycling for green field developments with > 1000 equivalent tenants in high priority river catchment or if > 10000 equivalent tenants, 10% of new non-residential water use from recycling, Western Corridor Recycling Scheme assumed to be implemented in 2009.

High Savings Program: Top 15 Water use efficiency measures ranked by annualised costs, rainwater tanks used for outdoor, toilet and cold water laundry, all new developments to have rainwater tank, for existing dwellings outdoor use only and 50% rainwater tank cost rebate scheme is in place and 10% ultimate penetration of existing accounts assumed, if rainwater tank in recycling areas assume tank used for all laundry and bathroom, residential recycling for green field developments with > 1000 equivalent tenants, 25% of new non-residential water use from recycling, Western Corridor Recycling Scheme assumed to be implemented in 2009.

3.3. End Use Characteristic Information

Characteristic information on the end use of water by households was obtained from several sources depending on the location in question. For Brisbane City Council (BCC), we used *Water for today and tomorrow – An Integrated Water Strategy for Brisbane* (BCC 2007). For Gold Coast City Council (GCC), the *Gold Coast Waterfuture Project Newsletter Autumn 2005* (GCC 2005). As no specific end use information was available for other LGAs, population weighted average values were taken from the characteristic % BCC and GCC.

Table 2: Characteristics of end use of water in the EUM and values for BCC and GCC at 2005. Data from WSAA (2005) and information available from Brisbane and Gold Coast City Councils (BCC 2007; GCC 2005).

	Brisbane City Council	Gold Coast City
Residential Indoor %	54%	65%
Garden & Outdoor %	46%	35%
Shower & Bathroom %	9%	16%
Toilet %	25%	20%
Clothes Washer %	13%	13%
Other Residential %	7%	16%
Residential Indoor (kL/property/year)	142.56	128.7
Garden & Outdoor (kL/property/year)	121.44	69.3
Shower & Bathroom (kL/property/year)	23.76	31.68
Toilet (kL/property/year)	66	39.6
Clothes Washer (kL/property/year)	34.32	25.74
Other Residential (kL/property/year)	18.48	31.68
Residential Indoor (ML/year)	54,885.6	24,967.8
Garden & Outdoor (ML/year)	46,754.4	13,444.2
Shower & Bathroom (ML/year)	9,147.6	6,145.92
Toilet (ML/year)	25,410	7,682.4
Clothes Washer (ML/year)	13,213.2	4,993.56
Other Residential (ML/year)	7,114.8	6,145.92

3.4. The End Use Model Implementation

The EUM is implemented in spreadsheets of Microsoft Excel™. The model contains values for population and total water use corresponding to SEQ LGAs defined by savings programs. These time series are multiplied by a split of end use for residential water derived from information about Brisbane City Council and Gold Coast City local government areas. A copy of the demonstration software can be obtained from the project team.

There are 12 possible 'base scenarios' founded on combinations of population forecasts and savings programs. These base scenarios are always retained in the spreadsheets but it is also possible for a user to start with one of these combinations and create a customised scenario using the scroll bars and other controls of the interface (see Figure 3). Scroll bars indicate the % change in the user-defined water end use at the end of the scenario period (2056) compared to the base scenario. Values for garden and outdoor, shower and bathroom, laundry, toilet and other end uses are displayed in the graphs on the same worksheet (not shown in Figure 3).

The user interface's scroll bars and buttons allow the user to dynamically explore scenarios defined by the start and end point of water consumption, by different end uses, for any LGA in SEQ (as selected from a drop down menu).

There is also a function to export customised scenarios, scroll bar settings and the output of the EUM to a separate workbook.

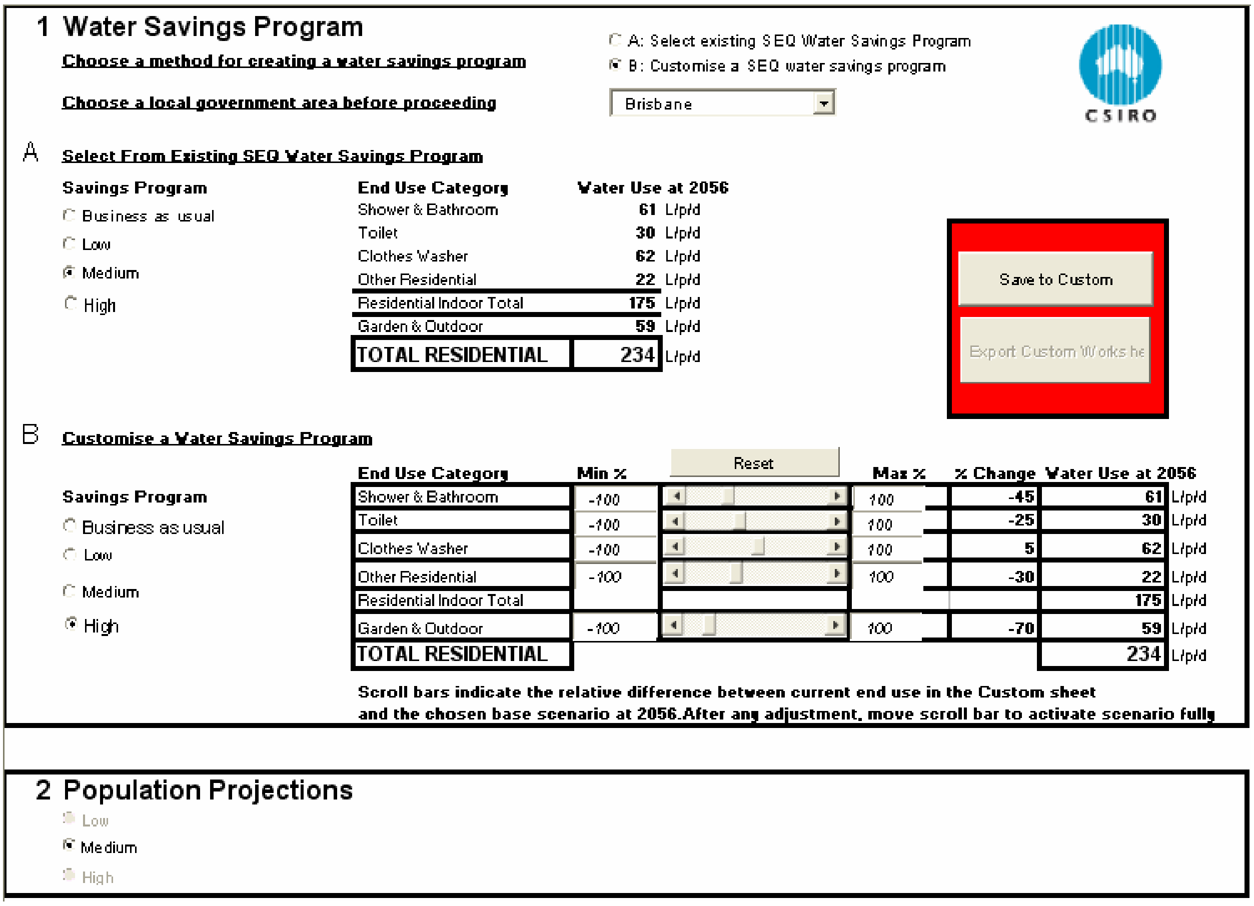


Figure 3: The EUM user interface – numbers displayed are indicative examples only.

3.5. Wastewater Treatment and Emissions from Dams

The energy and GHG implications of wastewater treatment and diffuse emissions from urban reservoirs have not been included in this demonstration. However, the data reported by the LCA-IM team (Hall et al. 2009) could be included in a similar way to energy and GHG emissions for water treatment and distribution. While these items will clearly be an important part of the final calculation, it may be premature to ascribe values to their salient parameters. However, from recent investigations by David De Haas of the University of Queensland it can be said that the energy intensity (Megawatt hours per Megalitre) of wastewater treatment lies between 0.4 and 1.0 MWh/ML. According to Kenway, Preistley and McMahon (2007), a total of 113,382 ML of wastewater was collected in Brisbane in 2004-05 and the electrical energy needed to treat and transport that was 47,617 MWh.

This translates to an energy intensity of 0.42 MWh/ML. Again, using a GHG intensity of 1.04t CO_2-e /MWh of electrical energy, this translates to 0.437 t CO_2-e /ML or approximately 50,000 t CO_2-e /year.

The above figures could be coarsely applied within the framework but they are essentially an aggregate and static snapshot. To be consistent with the rest of the framework, it would be more useful to determine detail on the location of the wastewater generation and treatment, and the particular wastewater transport task for that area. It would also be necessary to consider the effect of forecast population changes to each area. The determination and incorporation of this information has been left for future work and so wastewater treatment and emissions from dams do not figure in the example results.

3.6. WathNet and Water Supply Options

WathNet is a water balance modelling tool that is used by the SEQ Water Grid Manager (SEQWGM). It is generally used for water supply simulation using network linear programming. The model uses stochastic climate data input and produces probabilistic results. The model is run in a “forecast” mode from an initial (known) system state (e.g. initial storage volumes, flows, etc.) and future system behaviour is given by a probability distribution.

The WathNet SEQ grid model is a simplified representation of the SEQ system operation and does not go into detail such as pipes to households or treatment plants in small towns. As such, WathNet outputs represent approximate behaviour for all of SEQ. WathNet resolves down to monthly time steps in accordance with the following hierarchy of objectives (from McAlister et al. (2004)):

1. Satisfy water demand at all demand nodes;
2. Satisfy all in-stream flow requirements;
3. Ensure that reservoirs are at their end-of-season target volumes;
4. Minimise water delivery costs; and
5. Avoid unnecessary spills from the system.

A network file forms the basis for all the SEQ WathNet simulations and this has already been established to represent the SEQ Water Grid. In the WathNet network, nodes represent the demand for both potable water and wastewater in aggregated urban areas, and wastewater generation nodes represent the wastewater generated in the same areas. Reservoir nodes include potable water storage, sewage treatment plant storage, stormwater collection ponds and external wastewater supplies (where appropriate). Nodes are connected via links, which represent either stream flow or piped conduit flow. Particular rules may be attached to linkages to prioritise water distribution throughout the network.

A proof-of-principle test was undertaken to demonstrate the connections between the scenarios of water demand and the infrastructure by which that water would be supplied. This explored to what extent the existing data, EUM outputs and other information could be presented to WathNet with minimal modifications.

Time-series EUM outputs for low, medium and high savings programs assuming a medium population forecast were generated and accompanying these we constructed a schedule of supply infrastructure changes loosely related to that proposed in the SEQ Water Strategy (SEQWS) – refer to Table 3 in the Appendices.

Energy intensities for the treatment and transport of water were derived from multiple sources including the two consultancy reports, KBR (2008) and Marsden Jacob Associates (2008). Values and assumptions about how these energy intensities were derived are in Table 4 in the Appendices. Generally, pumping energy intensities were the total of raw, bulk, and retail pumping and these have been further combined with treatment energy intensities to produce the numbers in Table 4.

A number of modifications to WathNet were required for this exercise. WathNet was adapted to:

- read a 50 year demand projection for SEQ (based on local government areas), and
- calculate the long term (50 year) water balance, and
- use energy intensity factors for pumping and water/wastewater treatment to,
- produce a 50 year time series of energy costs (and indirectly emissions impact).

Some water supply options that might be considered in the SEQWS were not able to be simulated with WathNet:

- Bribie Island Stage 2.
- WCRSS Stage 2.
- Hinze and North Pine PRW.
- Mt. Crosby weir raising.
- Brisbane aquifers.

4. DEMONSTRATION RESULTS

As mentioned earlier, the purpose of this study was to describe the framework and report on a proof-of-principle exercise to demonstrate the coordination of existing models and data. As such, **it should be emphasised that the following are for demonstration and are not actual results of analysis**.

The example results represent the combined effect of a medium population growth forecast and three water demand scenarios from the EUM while also considering how existing supply infrastructure, a schedule of new infrastructure, major treatment plants, pumping from each sub-catchment to the grid, and major source augmentation (e.g., desalination, WCRSS, etc.) will provide water.

Each component of the water supply system has attached to it a ‘cost’ in terms of megawatt hours of energy required per megalitre, as shown in Table 4. Energy requirements for the end use of water (e.g. for hot water heating) were not included although this might be deduced from ABS reports (such as *Environmental Issues: People's views and practices Cat. 4602.0* (2005)), Kenway et al. (2008) or measured directly in future surveys.

The outputs all derive from WathNet which typically produces a distribution of likely results for each month simulated. With the extensions to WathNet described above we can produce results for the following over a 50 year period:

- storage volume;
- subsystem transfers;
- extraction forecasts; and
- energy forecasts.

We have chosen to demonstrate just the energy forecasts and aggregated the raw output into monthly and yearly distributions. We have extracted the 10th, 30th, 50th, 70th and 90th percentiles. The projections may be presented at the level of a sub-catchment as well as for the entire SEQ region.

Note that even in these example results, some features are clear. For example, comparing the annual (Figure 4) with the monthly (Figure 7) graphs of energy cost it can be seen that the seasonality of water supply has an effect on the seasonality of energy cost. The energy savings of *not* having to supply water through the grid can be seen in the comparison between different savings plans for SEQ (Figure 5). The relatively even distribution around the average (50th percentile) found in the monthly time series for all of SEQ (Figure 7) can be qualitatively different from the more skewed distributions of energy cost in individual sub-catchments (Figure 8) even when using the same assumptions.

GHG emissions associated with energy flows are not shown below but they are a simple multiplier of 1.04t CO_2-e / MWh. Thus the left hand scale in each graph may also be approximately interpreted as tons of CO_2-e.

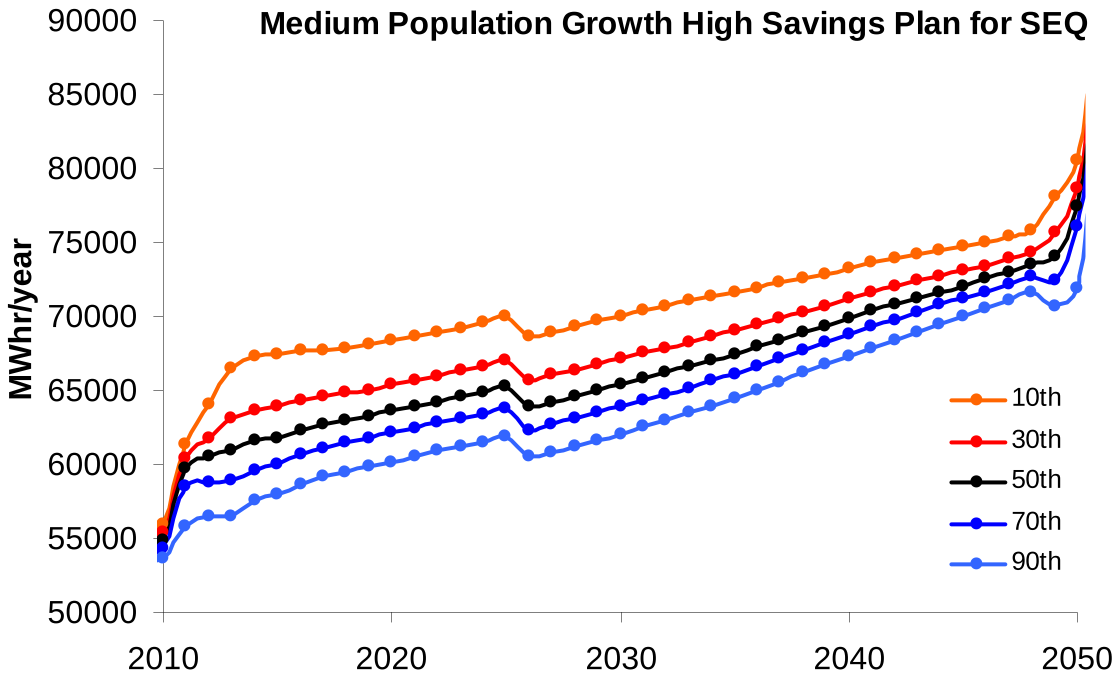


Figure 4: Annual energy cost for all of SEQ assuming a medium population growth forecast and a high savings plan. For each time point WathNet generates a distribution, the 10th, 30th, 50th, 70th and 90th percentiles are shown.

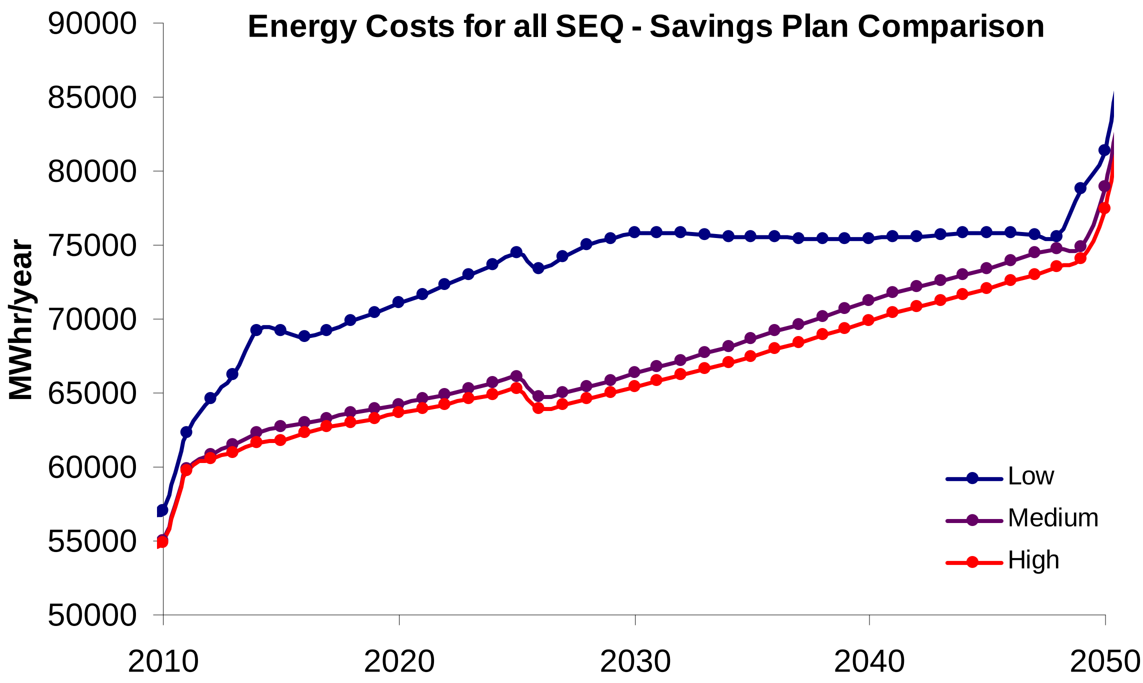


Figure 5: Annual energy cost for all of SEQ assuming a medium population growth forecast comparing the 50th percentile results for low, medium and high water savings plans. The coarse features are strongly coupled to the implementation and use of desalinated water from Tugun and Kawana.

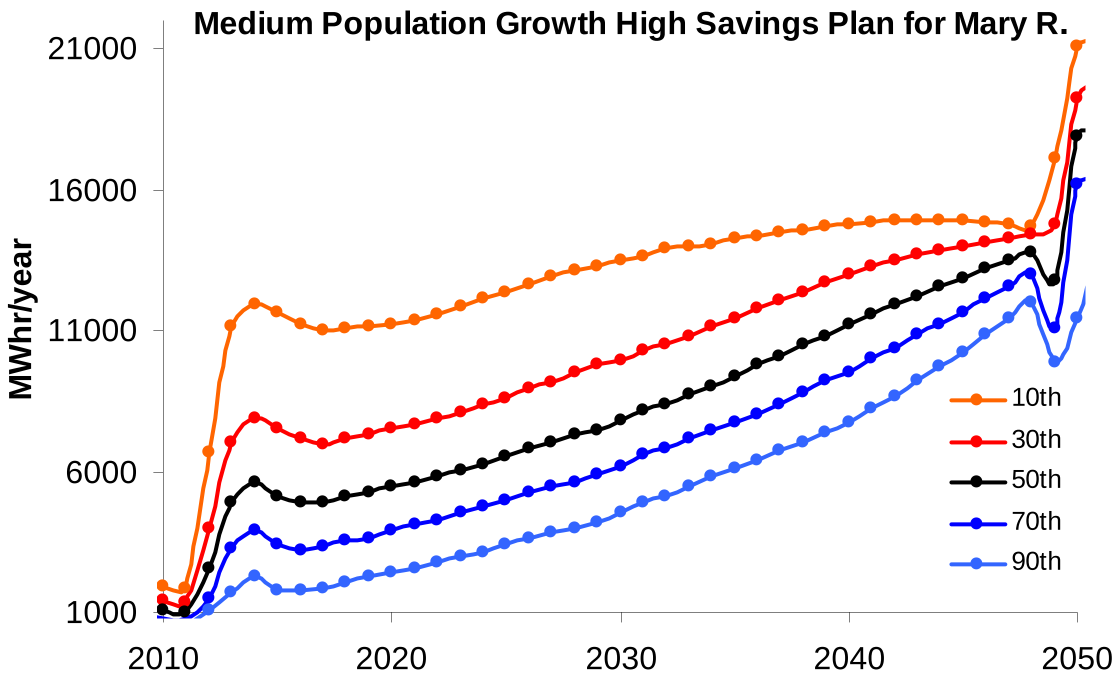


Figure 6: **Annual energy cost for Mary R. system (Baroon Pocket Dam, Lake MacDonald, Traveston Crossing Dam) assuming a medium population growth forecast and a high savings plan. For each time point WathNet generates a distribution, the 10th, 30th, 50th, 70th and 90th percentiles are shown.**

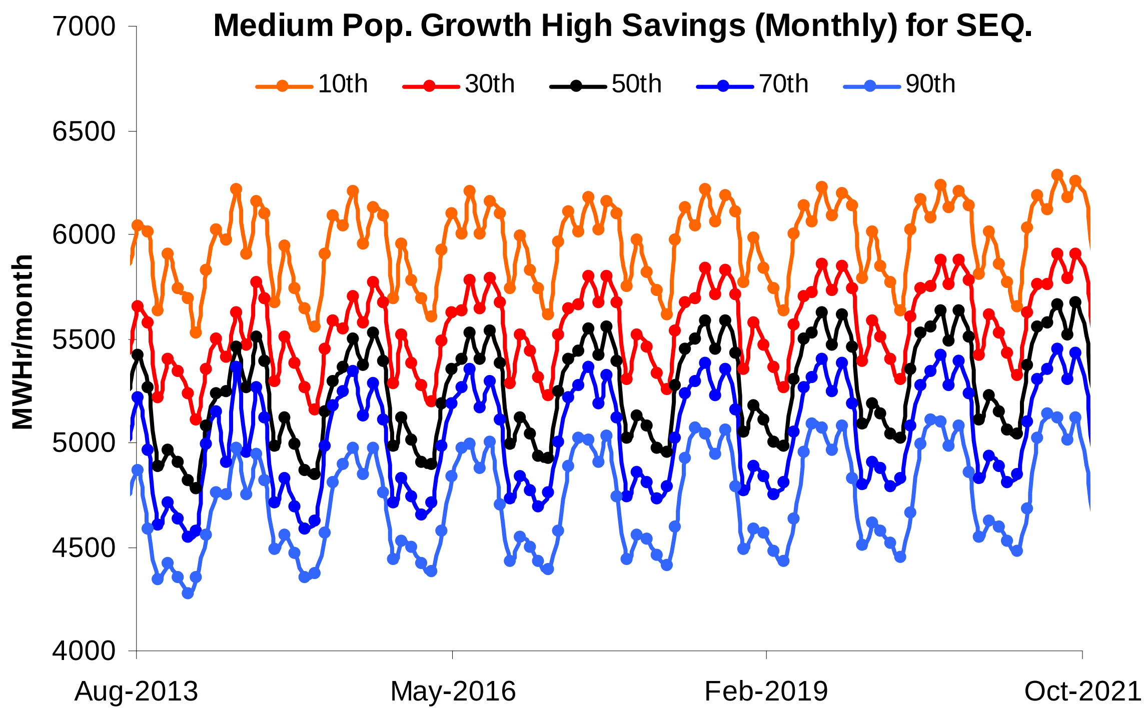


Figure 7: **Section of time series monthly energy cost for all of SEQ assuming a medium population growth forecast and a medium savings plan. For each time point WathNet generates a distribution, the 10th, 30th, 50th, 70th and 90th percentiles are shown.**

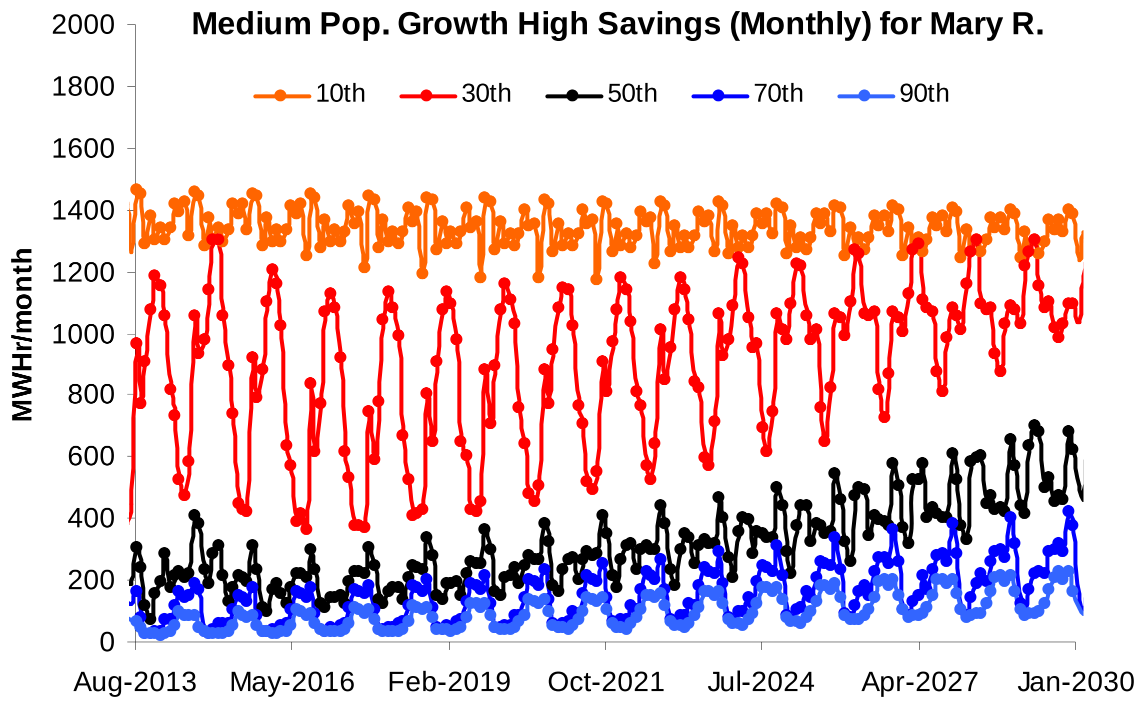


Figure 8: Section of time series monthly energy cost for Mary R. system (Baroon Pocket Dam, Lake MacDonald, Traveston Crossing Dam) assuming a medium population growth forecast and a high savings plan. For each time point WathNet generates a distribution, the 10th, 30th, 50th, 70th and 90th percentiles are shown.

5. DISCUSSION

5.1. Advantages

The framework presented here is simple and flexible and does not rely on a complicated piece of integrating software and, because of this, it allows for substitution with other tools. There is no reason why another EUM model could not be used instead of the one shown in Section 1.4. If another model of the SEQ supply grid were available then this might also be inserted in the place of WathNet. The main task is ensuring compatibility (enabled here through the common Excel^{TM} format of shared data) and consistency in the definitions of shared parameters.

An equally important point demonstrated here is that existing data and models can be used effectively in this framework to produce sub-catchment or system level outputs about the energy costs of water demand and supply. The effort for developing the components of the framework was minimized to permit greater attention on coordinating the components to produce results (albeit example results at this stage).

Lastly, this work has extended the existing models and data to produce outputs that neither could have generated alone. The prior ability of WathNet to generate projections of dam levels, extractions and transfers is now enhanced with energy costs (and indirectly GHG emissions) that are consistent with population forecasts, end use information and energy intensities from parallel research.

5.2. Limitations

The modules of the (current) framework are not high-precision instruments and their accuracy is limited by whichever is the least detailed or accurate element in the calculation. Yet, even at this level, the framework is still useful to get a self-consistent, high-level picture of the energy costs of the SEQ water system.

Several aspects of the framework did not feature in the final calculations though this is not a problem inherent in the framework, merely an issue with the lack of data and the resolution and limits of the framework's constituents. Energy associated with end use (hot water) and internal energy costs in the sub-catchments are absent. Small town water treatment costs and the distribution costs between the main grid and end users have not been represented either. It might be useful to determine the energy costs below the sub-catchment level but this is at a resolution greater than most of the data available. With further research it may be possible to absorb these smaller costs in the energy intensities or to utilise other more detailed water balance models that operate at the sub-catchment level.

For completeness, we might include the energy embedded in the new infrastructure both at the water grid level and in the off-grid alternative supply technologies. It is likely this will be less than the energy impost of the operation of the water system but it is currently missing from the framework.

5.3. Extensions

Apart from addressing the limitations mentioned above there are several potential enhancements to the framework components.

The source of initial data on total water use (by LGA) belongs to savings plans and population projections that are not automatically mutually consistent. It would be tremendously useful to have access to spatially specific water consumption data and population projections with the same underlying assumptions or to be able to generate total water consumption forecasts as a function of demographic data.

End use characteristics were applied to each LGA based on limited information about BCC and GCC. Where there are spatial differences in water end use and total water use, this heterogeneity may interact with the operation of the water grid and produce significantly different results, for example, about pumping needs. Further research on the end use of water around SEQ is being undertaken in the Systematic Social Analysis and the SEQ Residential End Use Study projects being undertaken by the Urban Water Security Research Alliance.

The structure of EUM developed is simple enough for this exercise but more value may be gained from an EUM with greater detail. It is understood that such an EUM is being constructed by the QWC and, if it were compatible, it would immediately extend and refine the framework.

Undoubtedly, the energy efficiency by which water is supplied will change in the future and the carbon intensity of the form of that energy may also improve. Presently, the energy intensities used for the projections remain constant though they are input as a time series. If valid scenarios of future energy intensities of water demand and supply became available, these could be easily incorporated into the WathNet calculations.

6. CONCLUSIONS

A framework for integrating existing data and models to simulate the energy and GHG implications of water supply and demand scenarios has been developed and trialled. The full implementation of this framework requires more refined input to the various models and other components and it also awaits the outputs from other research for example, emissions from urban reservoirs. However, example results demonstrate a first order calculation of the energy cost of water demand and supply scenarios is readily achievable.

The framework also offers a robust methodology to incorporate new developments in data and models in the future.

APPENDICES

Table 3: Assumptions on the supply infrastructure schedule used as input to WathNet

Location	Year Available	Yield* (ML/a)
North Coast Region		
Existing Sources		
Borumba Dam	2006	10,940
Lake MacDonald	2006	3,500
Maroochy System (Cooloolabin and Wappa)	2006	7,000
Baroon Pocket Dam	2006	33,000
Caboolture Weir	2006	1,240
Bribie Island GW (stage 1)	2006	1,400
New Source Options		
Traveston Crossing Dam Stage 1	2013	59,060
Borumba Dam Stage 3		40,000
Mary System (Fully Developed)	2050	40,000
Ewen Maddock Dam	2010	2,500
Bribie Island GW (stage 2)	2008	5,000
Kawana Desalination Plant	2052	25,000
Toowoomba Region		
Existing Sources		
Cressbrook, Cooby and Perseverance	2006	9,000
Toowoomba GW - Basalts	2006	4,000
New Source Options		
Wivenhoe - Toowoomba Pipeline	2012	
Boonah Region		
Existing Sources		
Moogerah Dam	2006	500
South Coast Region		
Existing Sources		
Nerang River System	2006	52,000
Maroon Dam	2006	6,000
Leslie Harrison Dam	2006	5,300
Nth Stradbroke Island GW (Stage 1)	2006	9,000
Brisbane River System	2006	258,550
Lake Kurwongbah	2006	4,750
North Pine Dam	2006	37,310
Enoggera Dam	2006	1,100
New Source Options		
SEQ Desal Plant (Tugun)	2009	45,600
Hinze Dam Stage 3	2015	6,200
Logan System Fully Developed	2016	29,500
WCWR Scheme Stage 1	2008	28,656
WCWR Scheme Stage 2	2009	84,700
North Pine PRW Scheme	2044	25,000

* Considers hydrological yield, reliability and priority of supply, environmental flow objectives, water treatment plant and pipeline capacities and legislative extraction limits.

Table 4. Energy intensities for treatment and pumping combined for use in the proof-of-principle exercise with WathNet. <u>These numbers are not finalised and represent indicative values at this stage</u>.

Supply Option	MWh/ML	Comment
Borumba Dam	0.85	Taken as equal to the Traveston Crossing figures outlined below, as there is no piping/pumping necessary above Traveston.
Lake MacDonald	0.39	Where specific data wasn't available, a volume weighted SEQ average for both treatment and bulk water distribution was used – see note (2) at bottom of table.
Maroochy System (Cooloolabin & Wappa)	0.40	MJA figure for treatment at Image Flat WTP and MJA's SEQ average bulk distribution energy intensity.
Baroon Pocket Dam	0.46	MJA figure for treatment at Landershute WTP, and MJA SEQ average bulk distribution energy intensity.
Caboolture Weir	0.39	Derived as for Lake McDonald.
Ewen Maddock Dam	0.48	Used treatment figure specific to this source from MJA, and average intensity of bulk water distribution for existing sources from MJA.
Kawana Desalination Plant	4.34	Used MJA Tugun figures for treatment and average intensity of bulk water distribution for existing sources from MJA for pumping energy.
Bribie Island Groundwater	1.18	From KBR figure for North Stradbroke Island Groundwater option (Groundwater Augmentation including Distribution energy), to Bribie Island Schemes.
Traveston Crossing Dam Stage 1	0.85	From MJA.
Mary System (Fully Developed)	1.19	Pumping Energy taken from ISF report for Traveston Dam stages 2 & 3, Treatment from MJA for Traveston Stage 1.
North Coast – Brisbane pipelines	1.27	Combined Northern Regional Water Pipeline (NRWP) plus Northern Pipeline Interconnector (NPI) pumping energy. The MJA report notes that this is an average figure for combined gravity and pumped supply of 70,000 ML/a. If the pipeline is operated below 32,120 ML/a, no pumping energy is required, whilst 3.2 MWh/ML is required for each unit above that.
Cressbrook, Cooby & Perseverance Dams	1.50	Raw, bulk and retail pumping energy assumed to be dominated by major lifts from Cooby (231m lift, 20km length), Perserverance (264m lift, 35km length), and Cressbrook (457m lift, 40km length) dams (see * at bottom). Assuming 450mm pipe and flow 1m/s approx.
Toowoomba Groundwater - Basalts	1.18	From KBR figure for North Stradbroke Island Groundwater option (Groundwater Augmentation including Distribution energy), to Bribie Island Schemes.
Wivenhoe - Toowoomba Pipeline	3.11	The path of the Wivenhoe-Cressbrook pipeline outlined at www.toowoombapipeline.com.au/index.php?id=128 indicates a high point of around 280m, with Cressbrook lake itself around 250m. Lift from Wivenhoe at 67m is taken as approximately 200m. The transfer distance and anticipated flow rates given at the URL above are 38km and 14,200 - 18,000 ML/a respectively, through a 675mm pipe. The pumping energy has been calculated to be1.06MWh/ML and Cressbrook to Toowoomba requires a further lift of 457m (from http://www.usc.edu.au/NR/rdonlyres/24D5012C-F91A-4C47-8459-CE8005B284E9/0/Dianne_Thorley_WW.pdf), and transfer of approx 40km. This stage requires a further 2.00 MWh/ML. This is added to the "WTP Treatment" energy intensity 0.051 = MWh/ML - see note (1).
Moogerah Dam	0.39	Derived as for Lake McDonald.
Nerang River System	0.24	Uses data from Survey Data for Gold Coast Water for 2006/07. Only a total pumping figure reported, which includes raw, bulk, and retail.

Supply Option	MWh/ML	Comment
Maroon Dam	0.39	Derived as for Lake McDonald.
Leslie Harrison Dam	0.40	MJA figure for treatment at Capalaba WTP plus MJA SEQ average bulk distribution energy.
Hinze Dam Stage 3	0.24	As for Nerang River System.
Logan System Fully Developed	0.78	This is for combined Cedar Creek Weir stages 1 & 2, with pumping energy for weir to WTP to SRWP inclusive. No transport along SRWP included. No attempt to consider alternative delivery than to SRWP.
Nth Stradbroke Island GW	1.18	From KBR figures for Groundwater Augmentation including Distribution.
Redlands PRW	1.78	Treatment energy uses MJA value for Bundamba. Pumping PRW water to dam uses MJA Gold Coast to Hinze Dam figure. For WTP treatment and post WTP treatment pumping, used Nerang River values.
SEQ Desal. Plant (Tugun)	4.50	MJA figure assumed correct for this spreadsheet. MJA give 4.3MWh/ML for all operations of desalination plant which presumably includes seawater/brine pumping and disposal, and delivery as far as Tarrant Drive. For RO treatment alone it is 4.0 MWh/ML and the extra 0.3 MWh/ML is added to 0.2 MWh/ML for Tarrant Drive pumping station.
Brisbane -- Gold Coast pipeline	1.11	Sum of pumping at Molendinar (0.34 MWh/ML), Coomera (0.28 MWh/ML), and Cambers Flat (0.49 MWh/ML).
Brisbane River System	0.49	Effectively Mt Crosby, taken from survey data for Brisbane Water for 2006/07, with 90% of the energy attributed to "treatment" then re-allocated to pumping as advised by Michael Gregg. This largely reflects lift to Camerons Hill clear water reservoir. MJA estimates not used here as they are based on only 3 months.
Lake Kurwongbah	0.32	Derived as for North Pine Dam.
North Pine Dam	0.32	Taken from Survey Data for Brisbane Water for 2006/07, with 60% of the energy attributed to "treatment" then re-allocated to pumping as advised by Michael Gregg. MJA estimates not used here as they are based on only 3 months.
Enoggera Dam	0.39	Derived as for Lake McDonald.
Mt Crosby Weir Raising	0.49	Derived as for Brisbane River system.
WCWR Scheme	2.45	RO Treatment Energy and pre-treatment pumping taken from flow weighted averages for all 3 WTPs, and pumping to 3 possible destinations, given in MJA. As this is effectively for production of raw water, further WTP treatment and end user delivery pumping energy equivalent to that for Brisbane River system is added (this is not from MJA report). Note that this will not be required for that delivered to Swanbank, but can't differentiate that detail so it incurs same additional energy.
North Pine PRW Scheme	1.69	Treatment Energy uses MJA value for Bundamba. Pumping PRW water to dam uses MJA Moreton to North Pine figure. For WTP treatment and post WTP treatment pumping, use North Pine values from survey.
Brisbane Aquifers	0.43	From KBR.

*http://www.usc.edu.au/NR/rdonlyres/24D5012C-F91A-4C47-8459-CE8005B284E9/0/Dianne_Thorley_WW.pdf

(1) A flow weighted average of energy intensities for a set of 12 WTPs in SEQ - from the MJA report.

(2) The default value for the energy intensity of "Raw, Bulk, and Retail Pumping" is 0.34 MWh/ML. which is a flow weighted average for the distribution of bulk water in SEQ - from the MJA report.

GLOSSARY

ABS	Australian Bureau of Statistics
BAU	Business as usual
BCC	Brisbane City Council
CO_2-e	Carbon dioxide equivalent – An index that integrates various greenhouse gases associated with a system by using the global warming potential of each to weight the contributions.
DERM	Department of Environment and Resource Management
DNRW	Department of Natural Resources and Water (now in DERM)
EUM	End Use Model
GCC	Gold Coast City Council
GHG	Greenhouse gas
KBR	Kellogg Brown and Root Incorporated
LCA	Life Cycle Analysis
MJA	Marsden Jacobs Associates Pty Ltd
ML	Megalitre (10^6 litres)
MWH	Montgomery Watson Harza
MWh	Megawatt hours (10^6 watts or 10^3 kilowatt hours)
NPI	Northern Pipeline Interconnector
NRWP	Northern Regional Water Pipeline
PIFU	Planning Information and Forecasting Unit
PRW	Purified recycled water (treatment plant)
RO	Reverse osmosis
SEQ	South East Queensland
SEQWGM	SEQ Water Grid Manager
SEQWS	SEQ Water Strategy
SRWP	Southern Region Water Pipeline
UWSRA	Urban Water Security Research Alliance
WCWRS	Western Corridor Water Recycling Scheme
WSAA	Water Services Association of Australia
WTP	Water treatment plant

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