Energy consumption and greenhouse gases emissions from the use of alternative water sources in South East Queensland

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ABSTRACT

Between 1999 and 2007, several successive years of severe drought put South East Queensland’s water supply under immense pressure. The decision was taken in 2005 to build a seawater desalination plant and three water recycling advanced treatment plants as part of a large investment plan to secure the region’s potable water supply. The infrastructure built and commissioned in the past 3 years has a combined capacity producing more than 350,000 m³ per day of very high quality water that can be used either directly (seawater desalination) or indirectly (recycled water) for supplying drinking water. All the plants primarily rely on reverse osmosis membranes for water purification which is an effective and reliable barrier to contaminants, but also requires high energy consumption and a high level of pre-treatment and chemicals. In this paper, the actual energy consumption of two of the plants (the seawater desalination plant and one water recycling plant) was investigated with the perspective of drinking water production over the July 2009–June 2010 period. Eolia™ Potable Water, a Life Cycle Analysis tool developed by Veolia Environnement Research & Innovation, was used to model the processes and estimate the greenhouse gases (GHG) emissions from both plants. As expected, the energy requirement of the desalination was higher (approximately 2.2 times) than the water recycling plant. The plants were found to be significantly more energy efficient when operated at higher flow. In both cases, the purchase of electrical energy represented by far the major contribution to GHG emissions. Indirect GHG emissions from chemical consumption could be reduced at the water recycling plant by optimising the dose of ferric chloride used at the plant and sourcing the chemical from a less distant supplier.

Key words | desalination, energy, greenhouse gases, life cycle analysis, water recycling

INTRODUCTION

With a growing population and the worst drought in recorded history, unprecedented pressure has been placed on South East Queensland’s (SEQ) water supplies. Water levels in the dams which supply the region with drinking water fell to historically low levels in September 2007 with less than 17% of the total storage capacity full.

The State Government of Queensland initiated a Regional Drought Strategy in 2005 to secure water supply for SEQ in the present and future. A water grid was created that involved the construction of major strategic assets to drought proof the area, which included 4 non-conventional source water treatment plants: a 125 ML/day seawater desalination plant on the Gold Coast, and 3 tertiary advanced water treatment plants (AWTP) in the Brisbane area, capable of producing up to 252 ML/day of purified recycled water for industrial use (predominantly cooling for power stations), and potentially indirect potable reuse (IPR) and irrigation (Traves & Davies 2008). These plants are operated by Veolia Water Australia under long term contract with the Queensland Manufactured Water Authority, WaterSecure, which owns the assets.
Reverse osmosis (RO) filtration is the main separation process used for water purification in all the plants, which is very effective in achieving high water quality but also often regarded as an energy intensive process, which could raise concerns, especially within a GHG mitigation perspective. Indeed Australia ratified the Kyoto Protocol in December 2007 and is striving to reduce its GHG emissions. The introduction of the National Greenhouse and Energy Reporting Act 2007 (Department of Climate Change and Energy Efficiency 2007) makes registration and reporting of energy use and production mandatory for corporations whose energy production, use, or GHG emissions meet specific thresholds.

Although numerous carbon footprinting studies have been conducted on desalination plants (Raluy et al. 2004; Peters & Rouse 2005), information is more limited on advanced water recycling schemes. Stokes & Horvath (2006) compared desalination, wastewater treatment plant effluent reclamation and water import using aqueducts in two case studies. In both site studies, desalination carried the highest impacts in comparison with water reclamation and water import.

Building upon the 2009–2010 operational data available, the present study aims at assessing and comparing in detail the energy consumption and carbon footprint of the seawater desalination plant and one of the AWTPs operated in SEQ and to propose practical operational improvement levers.

SCOPE OF STUDY AND METHODS

South East Queensland’s water grid and WaterSecure assets

The Gold Coast desalination plant is located in Tugun, about 90 km south of Brisbane. Seawater is drawn from an underground intake tunnel 1.5 km from the shore line. The water is shock chlorinated once per day to avoid mussels and other shell development on the intake structure. From there, the water is treated with:

- pre-treatment – coagulation with ferric sulphate, pH adjustment with sulphuric acid, dual media filtration and sodium bi-sulphite dechlorination;
- 2 pass RO filtration – this step includes cartridge filters, DWEER energy recovery devices, antiscalant and sodium hydroxide (2nd pass) dosing;
- remineralisation with lime water and CO₂ addition and final chlorination.

Drinking water is pumped from the plant to the distribution system where it is blended with other drinking water produced from conventional surface water (dam) treatment. Solids are removed from liquid waste streams that are then blended with the reverse osmosis concentrate stream and pumped back to sea where it is dispersed through diffusers.

The Western Corridor Recycled Water scheme encompasses 3 AWTPs that receive secondary treated effluent from 6 wastewater treatment plants, and about 200 km of large diameter pipeline connecting the AWTPs with end users. Two of the AWTPs are located close to the Brisbane River mouth while the third one (Bundamba) is located near Ipswich, about 50 km south west of Brisbane. Processes used at each AWTP are similar with minor variations from one plant to another. These are:

- pre-treatment – coagulation/settling with ferric chloride for phosphate precipitation and chloramination;
- Micro- or Ultra-Filtration;
- 3-stage RO filtration – this step includes antiscalant dosing and is designed for an overall 85% recovery;
- advanced oxidation by hydrogen peroxide dosing and UV light irradiation;
- remineralisation with lime water and CO₂ addition and final chlorination.

So far the AWTPs have been providing purified recycled water (PRW) to two power stations in the region primarily as a supply to cooling towers. When the region’s combined dam levels drop below 40 per cent, PRW may be used to supplement Wivenhoe Dam which is the main water reservoir from where Brisbane draws its drinking water supply.

RO concentrate waste from the plants close to the Brisbane River mouth is discharged through diffusers. Further treatment is applied at the Bundamba AWTP to remove inorganic nutrients before discharge in the brackish part of the Brisbane River. As a result the load of nutrients discharged to the lower Brisbane River and to Moreton Bay has been greatly reduced, in particular the phosphorous load.
Life cycle assessment (LCA)

LCA is a ‘cradle-to-grave’ approach for assessing industrial systems during their entire life cycle. It begins with the extraction of raw materials from the earth to create the product through the use and finally the disposal of the product, when all materials are returned to the earth. It enables the estimation of cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses, such as raw material extraction, material transportation and ultimate product disposal (Figure 1).

Following the LCA methodology, Veolia Environment Research & Innovation has developed Eolia™ Potable Water, a decision support tool dedicated to the environmental evaluation of potable water supply systems. Developed using the LCA software GaBi® from PE International, Eolia™ Potable Water follows the 4 phases of the ISO 14040 LCA standardized procedure (Figure 2).

Goals definition and scope

The primary goal of LCA is to choose the best product/process with the least effect on human health and the environment. However the US Environment Protection Agency listed several secondary goals achievable by LCA depending on the type of project (EPA 2006). This study specifically focused on the following objectives:

- Support of a broad environmental assessment of Water-Secure’s operations which could help in identifying relative environmental burdens of specific plants or processes.
- Establish baseline information for processes and plants operated at an early stage in asset life which may later be used in the decision making process for asset renewal or upgrade.
- Rank the relative contribution of individual processes within single water treatment plants.

While designed for the augmentation of drinking water supply in SEQ, the 3 AWTPs producing PRW have not yet introduced water into the region’s main reservoir. This study has been performed using actual data from operation at the Gold Coast desalination plant and the Bundamba AWTP from 1 July 2009 to 30 June 2010. The two other AWTPs were not included here as final commissioning works had not been completed at the time of the study.

For the desalination plant, the system boundaries included the intake pumping of seawater, the water treatment plant, pumping of drinking water to the first main reservoir, and return of concentrate back to sea. For the AWTPs, the system boundaries included the intake pumping of secondary treated effluent from 4 different wastewater treatment plants, treatment at the AWTP, treated water pumping to a balance tank above Wivenhoe Dam, and discharge of treated effluent to the Brisbane River.

This paper specifically focuses on these two plants and their respective distribution systems, including construction, consumption of energy and chemicals, transport and maintenance (limited to the replacement of the RO...
membranes) and associated GHG emissions. Based on literature review, the following hypotheses have been defined in Eolia™ Potable Water (Vince et al. 2008):

- The decommissioning phase at end of plant life is considered to be negligible;
- The potable water production plant is estimated to have a lifetime of 30 years;
- An expected membrane life of 5 years.

Life cycle inventory

A Life Cycle Inventory (LCI) quantifies the energy and materials usage (inputs flows) and releases (output flows) generated by the processes carried out during the life-cycle of potable water supply. These processes are divided into two types:

- Foreground processes: these are the processes performed by the water industry and include plant construction and plant operation. Eolia™ Potable Water proposes a database of elementary water treatment modules that quantify the inputs and outputs of each treatment process. These modules may easily be interconnected in the graphic interface of GaBi to model a treatment process.
- Background processes: these are the processes that are not performed by the water industry but nevertheless belong to the life-cycle of potable water supply. They represent the production and the supply of the commercial products purchased by the water industry (e.g. concrete, chemicals or electricity). These processes have been modeled using the Ecoinvent database (Frischknecht et al. 2004).

The electrical energy supplied by the grid in SEQ is generated 88% from hard coal, 10% from natural gas, and 2% from renewable energy (State of Queensland 2009) and was modelled within the Gabi LCA software using datasets from Ecoinvent.

Impact assessment

Eolia™ Potable Water uses IMPACT 2002© to convert LCI inputs and outputs into environmental impacts. These impacts can be assessed against 14 midpoint impact categories, 4 endpoint damage categories (biodiversity, natural resources, human health, and global warming), or as a single score. This study specifically focuses on global warming by calculating the GHG emissions generated directly and indirectly by WaterSecure’s operations.

Life cycle interpretation

Life Cycle Interpretation analyses the impact assessment results, with a clear understanding of the uncertainty and the assumptions made during the LCI and the life cycle impact assessment (LCIA). Eolia™ Potable Water provides the opportunity to perform a sensitivity analysis on the computed parameters, in order to highlight the influence of a given variable (e.g. choice of chemical supplier or intake pumping height) on the overall performance of the supply system (Vince et al. 2008).

RESULTS AND DISCUSSION

Electricity usage

In 2009–2010, the average daily water production was 21,900 m³/d out of a 66,000 m³/d capacity at Bundamba AWTP, and 63,000 m³/d out of a 125,000 m³/d capacity at the Gold Coast desalination plant. Seawater desalination production and distribution required a total of 3.82 kWh/m³, while PRW production and distribution came to a total of 1.73 kWh/m³. When considering the treatment process alone, the electricity requirement was reduced to 3.50 and 1.14 kWh/m³ respectively for the production of desalination and water recycling. Figure 3 provides a breakdown of the electricity consumption per process step on the desalination plant (a) and recycling plant (b) relative to the total electricity used for production and distribution of water.

While the RO filtration step remained the process step with the highest single electricity demand at Bundamba AWTP (35%), the demand was much better distributed as compared to the desalination plant where RO filtration draws 84% of the total energy demand, indicating that the water recycling plant may present more opportunities for energy efficiency improvements.
to design capacity resulted in significantly lower specific electricity consumption per volume of produced water. Operating the desalination plant at 33% results in a 10% higher electricity consumption per m³ of treated water produced when compared to operating at 66% or 100%, which can be explained by the internal by-pass of seawater required for reaching the appropriate velocity in the discharge diffusers (Figure 4(a)).

Similarly, a clear correlation was made with the production flow at Bundamba AWTP (Figure 4(b)). In this case, the increase of specific electricity consumption at lower flows can be attributed to a loss of equipment efficiency and the increase of the relative consumption of non-flow dependant auxiliary equipment.

**GHG emissions – carbon footprint**

GHG emissions from Bundamba AWTP and the Gold Coast desalination plant are shown in Figure 5. Production and distribution of desalinated water generates just over twice the amount of GHG generated from water recycling (4.2 and 2.0 kg CO₂-eq/m³ respectively). In both cases, the production of electricity used by the plants represents a major contributor to GHG emissions, 85% and 95% respectively for water recycling and desalination. This is followed by chemicals production and plant and pipe network construction. During the first 18 months of operations, WaterSecure has purchased Renewable Energy Certificates (from solar energy) for its desalination plant in order to offset the emissions of GHG from the purchase of electrical energy as shown on Figure 5.

In depth analysis of the chemical consumption at Bundamba AWTP (Figure 6) highlights the predominance of GHG emissions from the production and freight of ferric chloride. This chemical is used in large quantity in the pre-treatment for phosphate precipitation and is delivered by truck from a supplier located more than 900 km away from the plant. Optimizing the dose and sourcing this
product (or a similar one) from a less distant supplier could result in a significant reduction of the GHG emissions from the plant.

CONCLUSIONS

Specific energy consumption (kWh/m³ of produced water) and greenhouse gas emissions from a seawater desalination plant and an advanced water recycling plant, both recently commissioned in South East Queensland, were assessed and compared by using the standardized Life Cycle Assessment methodology.

As expected, the electrical energy required for seawater desalination was higher than for water recycling, averaging 3.30 and 1.14 kWh/m³ respectively for treatment alone as measured over a 12 month period. The plants were found to be significantly less energy efficient when operated at low production flows. A 10% increase in specific energy consumption was measured on the desalination plant when operated at its lower capacity (33% of design flow). Even more notably, the specific energy requirement varied by up to 40% on the water recycling plant when the plant operated between 17 and 50% of its design production flow.

In both cases, the off-site production of electricity required for treatment plant needs represented by far the major contribution to GHG emissions, representing 85 and 95% of the GHG emissions respectively for water recycling and desalination. Purchase of Renewable Energy Certificates from photovoltaic electricity producers effectively allow for a major offset of GHG emissions from the desalination plant, bringing the emissions down from 4.2 to less than 0.3 kg CO₂-eq/m³. From an operational point of view, ferric chloride optimal dosing and local procurement have been identified as a simple and cost-effective improvement lever to reduce the GHG emissions of the recycling plant.

To conclude, one should note that this study focusing on carbon footprint does not currently take into account the environmental impacts generated by freshwater use and depletion. The lack of a proper water-related LCA indicator may induce strong biases in decision making, particularly when comparing potable water supply systems that use different water resources (e.g. desalination, groundwater extraction). A sound water footprinting methodology fitted for LCA has therefore been developed by Veolia Environment Research and Innovation and is currently being included within Eolia (Bayart et al. 2010). The combination of carbon and water footprinting within the robust LCA framework will surely take decision-making on water solutions to the next level.

REFERENCES


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