TITLE OF PAPER: ENERGY WATER RELATIONSHIPS IN RETICULATED WATER SYSTEMS

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ABSTRACT

The relationship between the reticulated urban water cycle and the energy used in those processes are considered to highlight the operational energy component of urban water systems and suggest that this factor should be given more weight in the design of reticulated water systems, as energy costs rise. The study was undertaken to provide one aspect of why and how the urban water infrastructure could be modified to be more resource efficient and resilient now and in the future.

In New Zealand, data on energy used through various sectors of the water network have been captured by some councils, as part of monitoring their energy use and in reporting to the International Council for Local Environmental Initiatives (ICLEI) on greenhouse gas emissions. Data from four council-managed water supply and wastewater systems, with a diversity of local conditions, have been analysed for their relative energy use and energy efficiency of the various water supply and wastewater processes. Energy data from the councils at Nelson, Waitakere, Kapiti Coast and Palmerston North were consolidated into four sectors of the reticulated water system being: water supply pumping, water supply treatment, wastewater pumping and wastewater treatment.

All councils involved in this study had put in place systems to best meet required health standards and protect the immediate environment. The downside of such systems is the operational requirements and energy costs in a time when those costs will most likely increase. The question thus, is what can be done to bring down the costs of current infrastructure and what design changes could be made to make future water infrastructure more energy efficient, while still achieving the effectiveness and health standards that are required. These initial results showed some variations in energy efficiency between the systems and a consideration of relative energy use between sectors. For example, the degree of water supply treatment required and the degree to which gravity-fed systems are available were key factors in the energy operating cost of the water supply systems.

The investigation revealed that while the connection between energy use and urban water systems was being made increasingly, both overseas and in New Zealand, there is a scope for further innovations or alternative solutions to be considered when designing systems or considering what sort of solutions to use.

KEYWORDS

Energy; water; infrastructure; efficiency

INTRODUCTION

Access to clean water and the removal of wastewater is a hallmark of civilized urban living, delivering health and comfort benefits. Over the last 150 years, sophisticated reticulated systems have been developed to supply those services. Traditionally, reticulated water infrastructure has developed in conjunction with population growth although in some parts of the country, Wellington included, raw sewage was pumped directly into the harbour in recent history. This infrastructure is not just water intensive but also energy intensive, especially where significant levels of treatment and pumping are concerned. With both water and energy supplies undergoing more pressure and populations predicted to continue to grow, it is sensible to consider how our water related services can be met in a way that reduces the consumption of, not just water, but also associated energy. Critical to the design consideration is recognizing that hydrocarbon based energy supply will become substantially restricted and therefore more expensive in the next few decades. In addition, environmental externalities associated with energy generation, even our main renewable energy source through hydro dams, will add to that pressure and hence energy efficiency should be a key consideration in any infrastructure investment decision.

Previous research (Lawton et al, 2008a) has considered the benefits of a demand management approach to water, which in turn reduces associated energy requirements. While leakage reduction and demand management interventions are the most effective means of conserving both water and energy, there is also scope to focus on the design of current and future water systems to limit energy requirements. Understanding where energy requirements are highest is necessary to be able to design energy efficiency into reticulated water systems and ensure that the on-going operational costs of these services to communities are minimized. The design could consider water services based on ecological principles and closed systems that move towards being self-sustaining. The recovery of energy from wastewater treatment is but a step in that direction.

Some overseas studies have already highlighted the need to consider the use of energy in water infrastructure. The California Institute for Economic Efficiency (CIEE, 2000) notes: *"Critical elements of California's water infrastructure are highly energy intensive. Moving large quantities of water long distances and over significant elevations in California, treating and distributing it within the state's communities and rural areas, using it for various purposes, and treating the resulting wastewater, accounts for one of the largest uses of electrical energy in the state. Significant potential economic as well as environmental benefits can be cost-effectively achieved in the energy sector through efficiency improvements in the State's water systems."* New Zealand is generally fortunate in not having to pump water significant distances, the exception being the Waikato pipeline with a second pipeline anticipated in 2026, unless the demand is reduced.

The report, *"Energy Down the Drain: The Hidden Costs of California's Water Supply",* (NRDC, 2004), highlights a generally accepted approach to utility development where the cost or value placed on utilities relates only to the utility provided by that utility company, hence:

"Water utilities value only the cost of treating and delivering water. Wastewater utilities value only the cost of collection, treatment and disposal. Electric utilities value only saved electricity. Natural gas utilities value only saved natural gas. This causes underinvestment in programmes that would increase the energy efficiency of the water use cycle and increase agricultural and urban water use efficiency."

Studies have proposed that by assessing water on its total value, energy and water demand management programmes that could not meet the earlier cost-effectiveness threshold become attractive (CEC, 2005).

Water scarcity has become a critical and defining issue for Australia with climate change and related policy taking centre stage as an already very dry continent attempts to innovate and greatly extend the useful life of its already overstressed, and in many cases, over-allocated water resources. The relationship between water and energy is especially pertinent in Australia because it is likely that additional new future supply will come from energy-intensive desalination and "black water" treatment plants in order to meet future demand. In New Zealand according to the CEO of the Sustainable Energy Association of New Zealand, "New Zealand's current centralised electricity system means that power has to travel relatively long distances, which results in New Zealand having one of the highest power loss rates in the developed world" (SEANZ. 2008). So while much of that energy is generated through hydro-dams, considered to be renewable, the use of that energy is still inefficient compared with local renewable sources.

In response to the wider issue of water scarcity, greenhouse gas (GHG) mitigation and water conservation, measures have been implemented country-wide. Australia's Commonwealth

Scientific and Industrial Research Organisation (CSIRO) have carried out a study considering the missing connection between these critical efforts (Kenway et al, 2008). In addition, studies on pumping and water treatment efficiency have been explored to better understand the available opportunities of energy and water conservation, (ibid).

CSIRO has considered the water-energy relationship for seven major cities, six in Australia and Auckland City in New Zealand. To explore further the energy intensive areas of the water cycle, studies were undertaken to provide guidance on how to implement more energy efficient measures within the water supply and wastewater systems. The outcome of the research has shown that the large variance in energy intensity associated with urban water systems for each city was mainly due to differences in topography, water source and treatment systems.

METHODOLOGY

To arrive at an initial understanding of New Zealand's reticulated energy and water relationship, energy use was analysed for four councils operating in differing water infrastructure contexts.

Previous Beacon water-related research indicated that the consistency and method of water-related data collection between councils was highly variable, (Lawton *et al*, 2008b). To overcome this problem and collect a consistent data set, only councils with a commitment to assessing and managing carbon emissions through the International Council for Local Environmental Initiatives (ICLEI) were considered for the study. However, even though ICLEI requires collection of energy/water supply and treatment data, it was evident from the initial data inspection that there was no consistent method of recording the information. This, and the time required for council officers to collect and collate the information, excluded many councils from the study.

A range of water infrastructure features and configurations was considered to investigate the individual and relative energy intensities they contributed to water infrastructure. The four councils selected are shown in Table 1, along with their key water infrastructure features.

Council	**Supply Type**	**Wastewater Treatment standard**
Waitakere City Council (WCC)	Five dams: mainly gravity fed plus the pipeline from the Waikato	Tertiary –Mangere plant (Tertiary treatment reduces the nutrient concentration in the wastewater)
Palmerston North City Council (PNCC)	Turitea Stream and artesian well (at peak times)	Tertiary
Kapiti Coast District Council (KCDC)	Four systems, largest system supply from Waikanai River, bore water at peak times during dry weather	Predominantly tertiary, some secondary (Secondary treatment uses bacterial action to degrade organic matter)
Nelson City Council (NCC)	Maitai Dam and the Roding River	Predominantly tertiary

Table 1: Case study councils with key water infrastructure features

The energy examined in this study reflects direct inputs to water cycle operational requirements (i.e. electricity for pumping and operations of the treatment facilities) and makes no consideration of embodied energy in plant construction.

The water cycles were broken down into the following four sectors based on the study, (NRDC, 2004).

Water Pumping: The energy required to extract the water from its source, the conveyance of water to the treatment site, and pumping required to supply the end-user.

Water Treatment: The energy required for the processes of treating water that meets potable water health standards. Some localities then exasperate the energy used in pumping and treatment through significant pipe leakage rates which vary between a low c.11% in Waitakere to a reported over 50% in one part of the country.

Wastewater Pumping: The energy required for any pressurisation or pumping that occurs within the wastewater's collection, conveyance to treatment site and disposal.

Wastewater Treatment: The energy required for the operations occurring in the wastewater treatment plant.

The energy data collected for this study for all but Waitakere City Council (WCC) is derived from the ICLEI Councils for Climate Protection (CCP) Programme milestone 1 data. The milestone 1 data is an inventory of city councils' greenhouse gas emissions for council services and operations and provides an analysis of sources of these emissions from the municipality as a whole.

Although WCC contributed to ICLE, much of its water cycle is managed by the regional water wholesaler - Watercare Services Ltd., so the data was sourced from the Auckland Water Industry's Annual Performance Review (Auckland Water Industry, 2006/2007) and WCC's 2007 to 2008 annual water pumping figures (Ecowater, 2008). Total energy used for each area (i.e. water pumping, wastewater treatment, etc.) of the entire Auckland region was collated from the Watercare Annual Report (Watercare 2008) and the percentage of water (13%) and wastewater (11%) allocation for WCC was attained from the Auckland Water Industry report. There may therefore be some minor discrepancies in the calculated amounts for WCC, due to the differing years from which the information has been collected; being what was available at the time of the research.

The information from each council was analysed to provide the following efficiency equations:

- Water Energy Efficiency (kWh/Cubic Metres) = Annual Water Supply Energy (kWh)/ Annual Water Supply (Cubic Metres);
- Wastewater Energy Efficiency (kWh/Cubic Metres) = Annual Wastewater Energy (kWh)/ Annual Wastewater Supply (Cubic Metres).

These results were then compiled to deliver the total water-energy intensity relationship as annual kWh/per person that provide a snapshot of the relative intensities of the various systems.

RESULTS

Waitakere City Council (WCC)

The total energy figures for WCC in Table 2 were derived from their percentage of Watercare's energy figures, plus the contribution managed directly by WCC.

Waitakere's water supply source is located close to where it is consumed and 98% of the supply is gravity fed due to the height of its dams in the Waitakere Range. Domestic and other water uses average 220litre/pp/pd.

The total energy figures for WCC were derived from their percentage of Watercare's energy figures, plus the contribution managed directly by WCC.

Stage	Energy (KWh)	Energy %
Water Pumping	853,578	6.31

Water Treatment	3,180,600	23.50	
Wastewater Pumping	1,439,948	10.64	
Wastewater Treatment	8,060,030	59.55	
Total Electricity (kWh)	**13,534,155**		
	Energy (kWh)	**Volume (m^3)**	**Energy Water Ratio (kWh/m^3)**
Water Cycle	4,034,178	17,054,177	0.24
Wastewater Cycle	9,499,978	15,159,110	0.63
Population	**193,400**	Notes: Pop expected to grow to 257,200 by 2026	
kWh per capita	**69.98**		

Table 2: Summary of WCC's Energy/Water Use Relationship

On an annual per capita basis, the energy use for the total reticulated water system was 69.98 kWh. On a per capita basis, WCC's energy efficiency is the best of the four councils studied. As can be seen in Table 2, the highest energy use occurs with wastewater treatment (59.55%), followed by water treatment (23.50%) and wastewater pumping (10.64%) and then water pumping (6.31%). In terms of energy intensity, WCC's wastewater treatment is nearly three times that of supply. However, wastewater treatment also involves anaerobic digesters, which provide biogas for on-site power generation providing 51% of the energy required for the wastewater treatment process, significantly increasing the energy efficiency of that system.

Palmerston North City Council (PNCC)

The population of Palmerston North is 67K and is expected to grow by another third by 2026. Water use, domestic and all other uses for the city, is estimated at 423 litres/pp/pd. The Council has a demand management programme focused on reducing outdoor water use over summer and a leak reduction study. The water supply to the main urban area of Palmerston North is sourced from the Turitea Stream as well as by four artesian bores at times of high demand. There are two storage dams at Turitea to help manage supply from the Turitea Stream. The analysis of data is summarised in Table 3.

Stage	**Energy (KWh)**	**Energy %**	
Water Pumping	1,123,556	21.26	
Water Treatment	413,056	7.80	
Wastewater Pumping	478,056	9.03	
Wastewater Treatment	3,278,056	61.91	
Total Electricity	**5,294,724**		
	Energy (kWh)	**Volume (m^3)**	**Energy-Water Ratio (kwh/m^3)**
Water Cycle	1,538,612	10,391,426	0.15
Wastewater Cycle	3,756,112	11,567,000	0.32

Population	**67,300**	Note: Expected to grow by 33% in the next 18 years (2026)
kWh per-capita	**78.67**	

Table 3: Summary of the Palmerston North Energy/Water Use Relationship

PNCC's water supply shows a kWh per capita figure of 78.67. This is the annual energy requirement per capita for PNCC's water infrastructure. The highest energy use occurs with wastewater treatment (61.91%), followed by water pumping (21.26%), wastewater pumping (9.03%) and water treatment (7.8%). Energy requirements for the total amount of electricity used annually is 5,294,724 kWh's. The energy/water ratio for supply was at 0.15kWh/m3 while wastewater treatment was at 0.32kWh/m3.

The most energy intensive part of the system was for wastewater treatment. The plant recently had a $15.5 million upgrade, which included a phosphorous treatment system in order to improve the standard of wastewater being disposed of into the Manawatu River.

Kapiti Coast District Council (KCDC)

Located on the lower West Coast of the North Island, KCDC has a focus on reducing water demand. The current high water usage of 650 litres/pp/pd is significantly due to the sandy soils and dry summer climate and hence high outdoor use for domestic and some market gardens. The population of 46K is likely to grow as Kapiti is a popular retirement area and a commuter town for Wellington.

Kapiti's future supply is a critical issue for the council with the expected capacity likely to be met within the next two to three years. Restrictions on water-take from the Waikanae river supply require a shift to bore water extraction during dry periods of the year. The energy required to extract this bore water is higher than from the river. The wastewater treatment in the District is to tertiary standard, with some secondary treatment. A number of properties also use septic tanks.

Stage	**Energy (kWh)**	**Energy %**	
Water Pumping	118,590	1.69	
Water Treatment	3,353,589	47.69	
Wastewater Pumping	777,493	11.06	
Wastewater Treatment	2,782,749	39.57	
Total Electricity	**7,032,412**		
	Energy (kWh)	**Volume (m^3)**	**Energy-Water Ratio (kWh/m^3)**
Water Cycle	3,472,179	7,817,730	0.44
Wastewater Cycle	3,560,233	4,025,000	0.88
Population	**46,200**	Has a rapidly growing population	
kWh per capita	**152.22**		

Table 4: Summary of Kapiti Coast Energy/Water Use Relationship

KCDC's highest energy use is in water treatment and reflects the poor drinking quality standard of the base water sources. Kapiti's total water system shows a kWh per capita figure of 152.22, the highest of the four council case studies. This is the amount of energy per person required annually for water infrastructure. The highest sector of energy use occurs in treating water (47.69%), followed by wastewater treatment (39.57%), then wastewater pumping (11.06%) and water pumping (1.69%). The energy/water ratio for supply was 0.44kWh/m^3 while wastewater treatment was 0.88kWh/m^3.

Nelson City Council (NCC)

Nelson has long dry summers with limited access to further future water supply sources. The population base is 46K but is substantially exceeded in the summer months as Nelson is a popular tourist destination. Through use of regular summer water restrictions, resulting in a low yearly average level of domestic water use of 160 l/pp/pd, the Maitai and Roding Rivers can provide sufficient water to meet the City's needs until 2060.

Nelson has two main wastewater treatment systems: Nelson North Treatment Plant, nine kilometers out of Nelson (will reach treatment load capacity in 2020) and Bells Island Treatment Plant (of which only 45% of plant wastewater is from Nelson). These systems use 360km of wastewater pipes with 27 pumping stations.

Stage	**Energy (KWh)**	**Energy %**	
Water Pumping	1,247,058	21.02	
Water Treatment	1,884,634	31.77	
Wastewater Pumping	643,940	10.85	
Wastewater Treatment	2,157,313	36.36	
Total Electricity	5,932,945		
	Energy (kWh)	**Volume (m^3)**	**Energy-Water Ratio (kWh/m^3)**
Water Cycle	3,131,692	8,115,000	0.39
Wastewater Cycle	2,801,253	6,082,550	0.46
Population	**41,000**	Note: Expected to grow from 46,000 to 53,000 in the next 15 years (2023)	
kWh Per Capita	**114.71**		

Table 5: Summary of NCC Energy/Water Use Relationship

Nelson's water supply shows a kWh per capita figure of 114.71. This is the amount of energy used per capita per annum for the water infrastructure. As with two of the other case studies, the highest energy use occurs with wastewater treatment (36.36%), followed by water treatment (31.77%), then water pumping (21.02%) and wastewater pumping (10.85%). The energy/water ratio for supply was 0.39 kWh/m^3 while wastewater treatment was 0.46 kWh/m3. Like Kapiti, Nelson's water treatment energy requirements were relatively high at 31.77%, reflecting the high level of treatment required from the rivers. NCC's energy profile is more evenly distributed than the other councils although again, probably because of the river-fed supply, water treatment is relatively high.

From the collated data, the energy efficiency of the water and wastewater systems of the four councils and the total kWh/ per capita for each overall system can be compared. Their relative overall efficiency is highlighted as kWh/capita per annum. The relative energy efficiency is depicted in Figure 1.

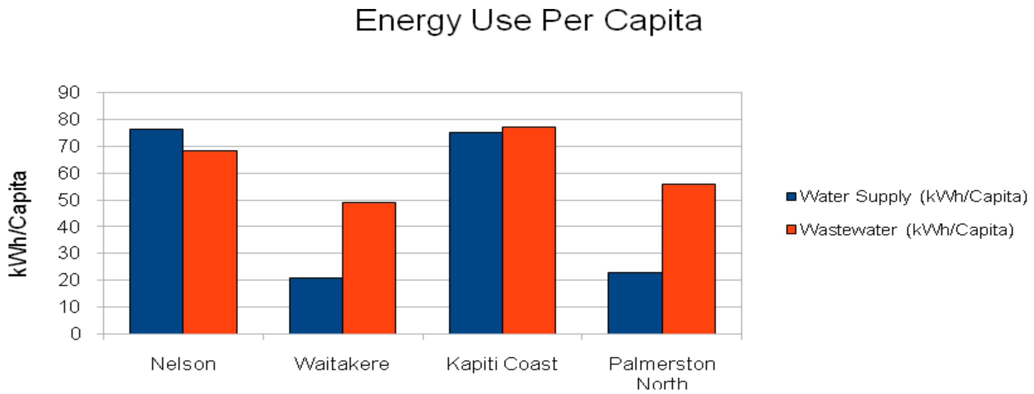

Figure 1: Figure demonstrating the kWh per capita figure for water supply and wastewater from the four case study areas.

Overall, WCC has the most efficient per capita system with PNCC not far behind, given its significantly higher per capita water use. However, if the energy generated through Watercare's wastewater treatment is included in the calculation then WCC's overall water infrastructure would be even further ahead in terms of energy efficiency. As wastewater treatment was the highest segment for three of the four councils it demonstrates the value in capturing waste gas, primarily methane, for alternative uses. As WCC and PNCC had the larger populations, it could be extrapolated that systems serving larger populations are more energy efficient, but given the low sample number, further study would be needed to substantiate that claim.

Energy associated with water treatment was a major contributor to KCDC's energy profile and does re-affirm the policy approach they are taking, trying to introduce rainwater tanks to provide water for non-potable uses and supplement reticulated supply, especially as much of the potable water is used to irrigate their dry sandy soils. Nelson's water supply, also from rivers, also needed considerable treatment but the supply issue was aggravated by the city's topography, requiring water supplies to be pumped from considerable distances. Of interest was the low level of energy used by PNCC for water treatment, despite being taken from the Turitea Stream and being subjected to alum-flocculation gravity filtration.

Wastewater pumping was consistently a low contributor to over-all energy use, being between 9% and 11% for the case study councils.

CONCLUSION

Energy and water are both resources that are coming under increased pressure, globally and locally. Efficiency of both design and operation is required to reduce environmental and financial costs from urban reticulated water systems. Monitoring and analysis is required to better understand where high costs occur and wherever practical design them out of the system with reference to international best practice studies. A design consideration for smaller communities should be how best to replicate or substitute for the advantages offered by larger populations and at what scale those amendments could best be achieved. Any system that offers co-generation will reduce the energy burden on the water infrastructure.

Energy expended in wastewater pumping was not a major component of the four case studies. Energy expended in the treatment of wastewater was relatively high for three of the four case studies. This reflects the fact that wastewater in these communities is treated to tertiary level with direct environmental benefits. However, the high energy associated with this level of treatment indicates the potential for design and operational improvements to be developed.

In this study, both the background research and local data analysis highlighted a number of ways that energy associated with water infrastructure could be reduced.

1. **Water Demand Management Options:** Managing down demand and ensuring the infrastructure is efficient, eg has low leakage rates, will always be top of the list for reducing energy requirements. A wide range of demand management options are available, from on-site supplementary supply to more efficient water fitments and fittings. Reduction in water requirements will have a “flow” on effect of reducing energy use.

2. **Utilising Energy Audits and Benchmarking Tools:** The lack of in-depth knowledge of the over-all energy utilisation of water infrastructure is of concern. Councils that are contributing to ICLE’s studies or organisations like Watercare who are making that information public are in the minority. Monitoring and benchmarking are considered useful tools in providing baseline performance data against which future strategic decisions are to be made.

3. **Maintenance of Pumps and Motors:** Once constructed, there are limited ways of maximising the efficiency of water supply and wastewater systems. A key approach is to ensure pumps are maintained at their optimal level of efficiency. Variable speed drivers to help monitor and manage energy use of the motors lets motors operate much more precisely and not over run unnecessarily.

4. **Reduce Peak Demand Times:** The National Resource Defense Council “Energy down the Drain” report (2004) notes that the energy costs for water systems depend heavily on whether energy is consumed during on-peak or off-peak periods.

5. **Co-Gen from Wastewater Biogas:** Wastewater biogas is an on-site energy resource that may be used instead of remotely sourced natural gas or electricity. The biogas methane is collected during the anaerobic digester stage of a wastewater treatment process.

6. **Other On-Site Renewable Energy Sources:** Other local renewable energy sources can be provided for energy intensive processes, an example being the provision of wind-power to the desalination plant in Perth. On-site renewable energy generation through wind or solar may become a common feature as energy prices rise. PNCC has implemented a closed loop system using a mini-hydro dam, providing a degree of energy self-sufficiency in water supply.

7. **Consideration of a secondary supply:** The energy required to treat water to potable standards is a significant cost to some communities such as Kapiti. It highlights a lack of logic in treating water to a high potable standard to use it for the majority of household uses, or in Kapiti’s case, mainly outdoor use, when untreated water will suffice. It suggests that for some communities, serious consideration should be given to the provision of a secondary water supply source that does not require treatment to that level. KCDC has recognized this approach in a proposed District Plan Change to require rainwater tanks installed in all future new homes.

8. **Re use of water, especially where wastewater is tertiary treated:** In general, New Zealand provides a high level of wastewater treatment, required for protecting our waterways, but which is energy intensive. Instead of being discharged to waterways, tertiary treated wastewater could be used for non-potable uses, in particular irrigation, instead of using treated potable water.

This study concludes that there is a growing awareness of energy requirements in water infrastructure both in New Zealand and overseas. Better monitoring and reporting systems will help focus on design and operational changes that improve efficiency. In particular, considering energy and water as one system will ensure future water infrastructure does not over-burden the environment or our finances.

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