ENERGY AND CARBON FOOTPRINT: A COMPARISON OF NON-POTABLE WATER AND WASTEWATER SERVICING APPROACHES

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ABSTRACT

Energy use and carbon footprint have financial, environmental and social implications that affect the sustainability of water and wastewater servicing approaches. Data availability has and continues to limit the measurement of life-cycle costs and impacts of energy and carbon.

This paper analyses the relative energy and carbon impacts of four different water and wastewater servicing approaches designed to serve a theoretical 15,000 lot residential development. Sydney Water has used its Energy and Carbon Estimator (ECE) tool to estimate energy use and carbon footprint for each approach.

Conceptual design of each servicing option and sizing of each infrastructure component was required in order to build each project in the ECE tool. This included pipe networks, pumping stations, storage tanks, treatment systems and any other asset within the assessment boundary. The analysis measures the long term differences between each servicing option and discusses why these differences exist.

INTRODUCTION

The dependence of water management on energy (often referred to as the energy water nexus), means that water utilities have a significant influence on the long term sustainability of urban communities. The choice of water and wastewater infrastructure, once made can fix the energy intensity of water services for 20 to 30 years or more. The infrastructure choice also determines the quantity and type of materials that are used and the quantity of associated embodied carbon emissions.

Sustainably servicing greenfield growth is a complex challenge of which energy and carbon is only one part. Cost, technical challenges, social / customer acceptance, impact on urban form and liveability as well as ecological impacts all need to be considered. A range of factors will influence the choices around decentralised and centralised approaches and decisions about how non potable water demands are met. Many of these will be specific to local conditions, the nature and condition of existing infrastructure, when and how development will occur and so on. The purpose of this paper then is not to advocate any specific approach, but rather to illustrate the application of the ECE tool and provide insights into one of the key issues around water service provision - energy use, carbon emissions and their associated costs.

ANALYSIS

The purpose of this analysis was to demonstrate the relative difference in energy and carbon footprint of different servicing approaches. This can be achieved by analysing quite idealised system layouts, the level of detail being sufficient to understand the broad level of carbon and energy impact associated with each approach.

The key planning assumptions on which each option is based are described below:

Key assumptions

- 15,000 low density residential lots.
- Occupancy rate of 3 persons per lot.
- Wastewater production of 150 litres per person per day.
- Potable water supply is available.
- Discharge of excess treated effluent to waterways permitted.
- Land is available for effluent disposal via subsurface irrigation.
- Alternative water supply is mandatory (to meet 40% potable savings as per BASIX).
- Linear development uptake over 15 years (1000 lots per year).
- Assessment period of 30 years.
- Fugitive emissions from wastewater networks were not included due to lack of data, (treatment plant fugitives were included).
**Option design**

Traditional approaches to water network planning involve the engineering of options to meet a set performance standard, typically using computerised hydraulic modelling techniques. To rapidly investigate different service configuration options such as those required for decentralised systems, a model was prepared to size the infrastructure elements in each of the idealised infrastructure layouts. The model uses hydraulic performance standards and a typical system configuration for each option (as shown in Figure 1, Figure 3, Figure 5 and Figure 7). The sizes of the assets that make up each option are automatically calculated from assumed hydraulic performance and service standards (such as minimum pressure or hours of reserve storage). The asset characteristics and assumptions can be adjusted to simulate a wide range of options. The new urban development area is idealised with specific user defined assumptions about layout, lot spacing, density, ground slope, water demands and other characteristics.

**Option 1: Conventional wastewater treatment and recycling with dual reticulation**

This servicing option represents a conventional dual reticulation approach to greenfield servicing with centralised wastewater treatment, recycled water production, and a third pipe network to distribute the recycled water to each property.

It comprises a gravity sewer network, sewer pumping where required, a single intermittent decanted aeration lagoon (IDAL) wastewater treatment plant with additional sand filtration, a recycled water balance tank, transfer pumping station, transfer main, surface reservoir, elevated reservoir, elevated pumping station, delivery main and pressure reticulation network. The trunk assets (main carriers, pumping stations, treatment, reservoirs etc.) are all constructed up-front with reticulation being delivered in pockets as development occurs.

*Figure 1* shows the idealised layout modelled. It comprises the treatment plant at the bottom of the catchment, a central sewer carrier, and 5 development areas of 3000 lots feeding into the central carrier. *Figure 10* shows an idealised long-section of the system configuration.

**Option 2: Decentralised wastewater treatment and recycling with dual reticulation**

Option 2 (shown in *Figure 2* and *Figure 3*) comprises five separate development areas of 3000 lots that drain via gravity sewer reticulation to local membrane bioreactor (MBR) wastewater treatment and recycling plants, recycled water balancing tank, delivery pumping station and pressure reticulation network. This approach is well suited to staged investment, in part because it avoids large trunk mains and the direct pumping of recycled water avoids reservoirs and trunk delivery mains. MBR wastewater treatment is also well suited to staging in modules, however as with any treatment facility there is still a proportion of fixed cost. The avoidance of long sewer trunk mains combined with treatment units sized closer to loading, can also bring operational efficiency and prevent long term issues like odour and corrosion. The viability of this option depends on being able to discharge excess effluent to river/watercourse when needed.
Option 3: Decentralised wastewater treatment with local discharge and rainwater tanks

This option comprises a wastewater system identical to that described for Option 2. It differs in that non potable water needs are met with onsite domestic rainwater tanks (volume of 4000L) instead of dual reticulation. Effluent is discharged to the local waterway instead of being recycled to non-potable demands. Large discharges to the environment would typically require additional nutrient removal to meet environmental protection regulation. Figure 4 and Figure 5 below provide an idealised system and catchment configuration.

Figure 4: Local system configuration for Option 3 - decentralised wastewater treatment and rainwater tanks.

Option 4: Community scale wastewater treatment with sub-surface irrigation and rainwater tanks

Option 4 (shown in Figure 6 and Figure 7) represents a small community scale servicing approach, idealised over a large area. The servicing option comprises on-property septic style tanks with a pump, gravity sewer networks, 30 local treatment plants each servicing 500 lots with an effluent balancing tank and an effluent pumping station and approximately 450 hectares of sub-surface irrigation land (for the whole development).

Rural communities or fringe developments that cannot be economically connected to existing systems have historically opted for this type of community scale system. The approach has not had significant application in Australia to date, but is popular in the United States and New Zealand.

Community scale systems rely on a low-tech but robust wastewater treatment process and on having land available for sub-surface effluent disposal. Key strengths include their highly modular configuration and low energy use. While sub surface irrigation enables a lower level of treatment, the viability of this option depends on ongoing access to relatively large areas of land. This option therefore tends to be suited to semi-rural or fringe areas or as an interim measure while development occurs progressively or in stages in a growth area.
Modelling

Sydney Water’s Energy and Carbon Estimator (ECE) was used to assess the energy and carbon impacts of each servicing option. Each option was set up in the ECE tool using the asset information produced in the option design model described earlier.

The ECE is a Microsoft Excel based tool developed to let users quickly and consistently estimate the life-cycle greenhouse gas emissions and life-cycle energy cost of new water and wastewater assets. It analyses the embodied and operational energy associated with construction and operation of water assets. The tool is pre-loaded with data on raw materials and construction methods for water related assets and combines this with material emission factors to calculate embodied greenhouse gas emissions. It also combines energy consumption rates with the asset sizing information to determine the operational energy and carbon impacts. Further information on the ECE tool is available upon request to the authors.

Results

Community scale wastewater systems with rainwater tanks (Option 4) resulted in the lowest life cycle energy costs at about $5.6 million, as shown in Figure 8 below. This low energy cost is due to the low-tech secondary level wastewater treatment typically adopted where sub-surface irrigation is used to manage effluent. In contrast, this option also presented the largest carbon footprint at almost 300,000 tonnes over 30 years. The large footprint is driven by a) the high embodied carbon associated with installing both a septic tank and rainwater tank on every property and b) the large fugitive methane emissions from the on-property septic tanks (refer to Figure 14).

Decentralised MBR plants with rainwater tanks (Option 3), presented the highest energy cost at over $10 million across 30 years. This is driven by the relatively high energy demand of MBR treatment and by the energy demand of on-property rainwater tanks.

The conventional wastewater system with dual reticulated recycled water (represented by Option 1), had the smallest overall carbon footprint. This option also had the second lowest energy cost. Economies of scale are the primary driver for this small carbon footprint. This means fewer materials per unit of treatment and water provided and larger more finely tuned process equipment that delivers less ongoing operational energy use. The centralised treatment also means that fugitive emissions from wastewater can be economically managed.

Comparing Options 2 and 3 in Figure 8 shows that choosing rainwater tanks over dual reticulation increases both the embodied and operational carbon impacts.
The year-by-year analysis presented in Figure 9 below shows the significance of embodied greenhouse gas emissions relative to operational emissions. In Option 1, the embodied equates to about 15 years of operational emissions. Options 2, 3 and 4 show the staging of embodied impacts that comes with a staged approach to capital infrastructure provision.

Figure 11, Figure 12, Figure 13 and Figure 14 show breakdowns of each asset and asset component for each option.

Discussion

All four servicing options analysed in this paper could be optimised to reduce both the energy costs and carbon impacts. While Option 1 represents the lowest carbon impact and second lowest energy cost, it would perform better if a) cogeneration facilities were installed to generate power and b) the development was delivered sequentially in a daisy chain arrangement that allowed both the trunk infrastructure and the treatment facility to be staged in smaller increments. Direct pumping to the recycled water system could further improve this option by eliminating capital intensive reservoirs and trunk infrastructure.

Option 2 has a lower embodied impact, but this is offset by higher energy consumption that comes with advanced membrane treatment. A more optimised solution might use an alternative treatment technology that requires less energy, such as a granular biomass process or an anaerobic MBR process that recovers biogas for energy generation. It might be further optimised by replacing gravity sewer system with a vacuum...
sewer system connected directly into houses. This would reduce the embodied impacts of the network and treatment plant.

Small scale community systems (represented by Option 4) serve the purpose of staging expenditure and minimising operational energy costs. However, this can be at the cost of a larger life-cycle carbon footprint and can bring other issues including worse effluent quality, large spatial footprint and an inability to recover resources such as energy and nutrients. The high embodied and fugitive greenhouse gas impact of this option could be substantially reduced by altering the configuration. This would involve replacement of the on-property tanks with semi-centralised septic tanks at the treatment plant or within the development. This would reduce the embodied emissions and enable control of the fugitives and odour via flaring or scrubbing.

While most infrastructure providers are primarily concerned with the direct financial costs of energy use and carbon emissions, the analysis presented highlights that embodied carbon emissions are a significant contributor to the carbon footprint. Polluters are not required to count embodied (scope 3) emissions under the legislated carbon pollution reduction scheme (CPRS); they are counted as the scope 1 or 2 emissions of the source product maker. Given this policy framework, it can be expected that some water service providers will confine their focus to the regulatory requirements and commercial aspects of the CPRS. Others may pursue a broader sustainability agenda, and deal more explicitly with embodied energy and emissions in their infrastructure choices for water servicing.

Fugitive emissions are a key point of difference between community scale systems and more conventional approaches. Fugitives are typically counted as scope 1 emissions and companies are liable under the CPRS. The primary source of these emissions is the on-property septic tanks. This raises questions around liability for the carbon impacts, as it will depend on who delivers the scheme and where the boundaries of operational responsibility lie.

CONCLUSION

This analysis demonstrated that the ECE tool is effective for rapidly assessing the energy and carbon impacts of different servicing approaches. It also provided some valuable insights into different aspects of energy and carbon that should greatly assist future selection of servicing approaches.
Figure 10: System configuration for Option 1 - conventional wastewater treatment and dual reticulated recycled water.

Figure 11: Shows the asset and component breakdown for Option 1, (in t CO2e over 30 years).

Figure 12: Shows the asset and component breakdown for Option 2, (in t CO2e over 30 years).
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<th>Asset Component</th>
<th>Option 3 (t CO2e over 30 years)</th>
<th>Option 4 (t CO2e over 30 years)</th>
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**Figure 13:** Shows the asset and component breakdown for Option 3, (in t CO2e over 30 years).

**Figure 14:** Shows the asset and component breakdown for Option 4, (in t CO2e over 30 years).