Decentralised Wastewater Systems: Robustness and Carbon Footprint

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Decentralised Systems

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1. Study Background
2. Case Study on Decentralised Wastewater Systems
   - Capo di Monte (CDM)
   - Currumbin Ecovillage (CEV)
3. Research Methodologies & Results
   - System robustness
   - Water – energy nexus
   - GHG emissions
4. Conclusion
Decentralised systems are those systems that provide water and wastewater services at allotment, cluster and development scale utilising alternative water resources based on ‘fit for use’ concept.” (Cook et al, 2011)

- Application of fresh water resources reduced
- Waste streams reused - close to the point of generation
- Local distribution networks
Types of Decentralised Systems

Decentralised Systems

- Rainwater harvesting and reuse
- Greywater treatment and reuse
- Wastewater treatment and reuse
- Stormwater harvesting and reuse

Allotment scale
Communal scale
Cluster of houses
High-rise
Greenfield development
Needs of Decentralisation in Wastewater Infrastructure

Population Growth

754,000 new homes by 2031

1.5 million people by 2031

Ever Increasing Loads on Existing Centralised Wastewater Service Infrastructure!
Urban Water Systems Challenges

• Population growth
• Climate variability
• Aging infrastructure
• Resource constraints
• Wastewater disposal limitations
• Huge investments to upgrade systems
Benefits of Decentralisation in Wastewater Infrastructure

1. Integrated water systems planning
2. Conserve and recycle water to meet local needs
3. Being less resource intensive
4. More environmentally benign and precautionary, to protect receiving environments and manage pollution
5. Provide “fit-for-purpose” treatment solution
6. Targeting costly augmentation to centralised systems
7. Avoiding the financial risks inherent for new or expansion of centralised wastewater infrastructure
Current Available Decentralised Wastewater Treatment Technologies

- Total permutations for technological “mix-n-match” (in above Figure) are 1716!
- How to select an appropriate combination of decentralised wastewater treatment train?
- What is the key selection criteria?
- At present, there is a lack of real plant performance data on various decentralised wastewater technologies
Research Aims

• Our research aim is to develop a sound understanding and key selection protocol for decentralised wastewater technologies, in terms of:

1. Treatment performance and system robustness to various perturbations in wastewater quantity and quality
2. Water energy implications of different decentralised wastewater technologies
3. Sustainability in terms of fugitive and total greenhouse gas (GHG) emissions
Case Study (I) – Capo di Monte

Retirement village – 46 houses for over-50s community at Mt Tamborine

- Communal rainwater tanks
- Irrigation with recycled water
- Toilet flushing and external irrigation using recycled water
Capo di Monte – Schematic Diagram

**Design**
- **Capacity:** 100 EP; **ADWF:** 11 kL/day
- **BOD**₅: 10 mg/L; **TSS:** 10 mg/L
- **TN:** 10 mg/L; **TP:** 5 mg/L
- **E.coli:** 10 colony /100 mL;
- **Protozoa/ virus:** 10 col/100 mL
- **Min Cl₂ residue:** 1 mg/L
Capo di Monte – Decentralised Wastewater System

- Plant room for decentralised wastewater technologies
- Primary wet-well for raw sewage pumped from the 46 houses
- Immersed membrane bioreactor with anoxic/aerobic column
- UV disinfection and chlorination before reticulated to local households
Case Study (II) – Currumbin Ecovillage

The Currumbin Ecovillage at Currumbin Valley, Gold Coast

Acreage living with 110 houses (400 – 1600 m²)
Design
Capacity: 310 EP; ADWF: 51 kL/day
BOD₅: 10 mg/L; TSS: 10 mg/L
TN: 15 mg/L; TP: 10 mg/L
E. coli: 10 colony /100 mL;
Protozoa/ virus: 10 col/100 mL
Min Cl₂ residue: 1 mg/L
Currumbin Ecovillage – Decentralised Wastewater System

- Decentralised wastewater plant room at Currumbin Ecovillage
- Communal septic tanks
- Textile bio-filters
- Microfiltration unit
- UV disinfection and chlorination
Research Methodologies

• Treatment performance and system robustness to various perturbations in wastewater quantity and quality
  ➢ Diurnal wastewater quality sampling, water flow meters and BioWin® modelling

• Water energy implications of different decentralised wastewater technologies (in kWh/kL)
  ➢ Water flow meters and energy meters (single and three phase), data logger and telemetry system

• Sustainable in terms of fugitive and total greenhouse gas (GHG) emissions
  ➢ First principle mass balance approach using literature available GHG fluxes models
Influent Wastewater Quality Characteristics

Diurnal wastewater flow pattern during sampling period

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<table>
<thead>
<tr>
<th>Wastewater Parameters</th>
<th>Units</th>
<th>CDM-STP License Limits</th>
<th>CDM-STP Influent Values Range</th>
<th>CDM-STP Average Values</th>
<th>Common Values Range at centralised WWTPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD&lt;sub&gt;total&lt;/sub&gt;</td>
<td>mg/L</td>
<td>-</td>
<td>590 - 1060</td>
<td>825</td>
<td>314 - 438*</td>
</tr>
<tr>
<td>BOD&lt;sub&gt;total&lt;/sub&gt;</td>
<td>mg/L</td>
<td>10</td>
<td>240 - 430</td>
<td>335</td>
<td>120 - 190#</td>
</tr>
<tr>
<td>N&lt;sub&gt;total&lt;/sub&gt;</td>
<td>mg/L</td>
<td>10</td>
<td>69 - 140</td>
<td>105</td>
<td>87 - 94*</td>
</tr>
<tr>
<td>P&lt;sub&gt;total&lt;/sub&gt;</td>
<td>mg/L</td>
<td>5</td>
<td>14 - 27</td>
<td>21</td>
<td>-</td>
</tr>
<tr>
<td>Suspended solids (TSS)</td>
<td>mg/L</td>
<td>10</td>
<td>120 - 260</td>
<td>190</td>
<td>144 - 207*</td>
</tr>
<tr>
<td>Volatile Suspended solids (VSS)</td>
<td>mg/L</td>
<td>-</td>
<td>120 - 180</td>
<td>150</td>
<td>125 - 168*</td>
</tr>
</tbody>
</table>

From *Pollice et al. (2004) and #Freeman et al. (2009)
@RISK Modelling

Total Nitrogen

Total Phosphorus
### Summary table on EPA approved limits, mean and standard deviation of samples and the probability of exceedance of wastewater qualities

<table>
<thead>
<tr>
<th>Parameters</th>
<th>EPA Approved Limits</th>
<th>Sampled Effluent Quality</th>
<th>Quantitative Risk Model</th>
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<tr>
<td></td>
<td>50th percentile</td>
<td>80th percentile</td>
<td>Max</td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>-</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Total suspended solids (mg/L)</td>
<td>-</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Total nitrogen (mg/L)</td>
<td>10</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Total phosphorus (mg/L)</td>
<td>7</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Escherichia coli (cfu/100mL)</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
System Robustness – BioWin® Modelling

BioWin model setup for Capo di Monte

Parameters calibration from diurnal sampling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>ASM1 Default (at 20°C)</th>
<th>Calibrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of readily biodegradable COD</td>
<td>-</td>
<td>0.16</td>
<td>0.415</td>
</tr>
<tr>
<td>Fraction of unbiodegradable soluble COD</td>
<td>-</td>
<td>0.05</td>
<td>0.031</td>
</tr>
<tr>
<td>Fraction of unbiodegradable particulate COD</td>
<td>-</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Fraction of ammonia</td>
<td>-</td>
<td>0.66</td>
<td>0.716</td>
</tr>
<tr>
<td>Fraction of soluble unbiodegradable TKN</td>
<td>-</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Heterotrophic maximum growth rate</td>
<td>d⁻¹</td>
<td>6.00</td>
<td>4.62</td>
</tr>
<tr>
<td>Heterotrophic decay rate</td>
<td>d⁻¹</td>
<td>0.62</td>
<td>0.24</td>
</tr>
<tr>
<td>Heterotrophic yield</td>
<td>gVSS/gCOD/d</td>
<td>0.67</td>
<td>0.45</td>
</tr>
<tr>
<td>Half-saturation constant for readily biodegradable COD</td>
<td>gCOD/kL</td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Autotrophic maximum growth rate</td>
<td>d⁻¹</td>
<td>0.80</td>
<td>0.20</td>
</tr>
<tr>
<td>Autotrophic decay rate</td>
<td>d⁻¹</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Autotrophic yield</td>
<td>gNNO/gCOD/d</td>
<td>0.24</td>
<td>0.10</td>
</tr>
<tr>
<td>Half-saturation constant for ammonia nitrogen</td>
<td>gN/kL</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Half-saturation constant for dissolved oxygen</td>
<td>gO₂/kL</td>
<td>0.20</td>
<td>0.20</td>
</tr>
</tbody>
</table>
Perturbations in Wastewater Quantity & Quality on the Stability of Decentralised Systems: System Response

Applying simulated perturbations on BioWin® MBR system response curve to restore steady state operation

Results:

- No direct effects of increasing hydraulic & COD shock loads on process stability
- Nitrogen shock loads of greater than 30% will upset the nitrification process
- It took ~12 hr to restore the MBR operation to normal steady state conditions
Process Schematics with Water-Energy Smart Meters

Capo di Monte

Currumbin Ecovillage
Specific Energy Consumption of Decentralised Technologies

- At present, there is still lack of data on the water energy implications of decentralised wastewater technologies.
- Here, we monitored two different decentralised wastewater plants for its specific energy consumption (kWh/kL of treated effluent).
Specific Energy Consumption for Wastewater Treatment and Recycling – an Australian Context

- Here, we compared the specific energy consumption for recycled water scheme in Australia.
Sustainability in the Selection of Decentralised Wastewater Treatment Technologies

• What is the surrogate for sustainable performance criteria in wastewater treatment technologies?

• Carbon footprints – What is implicated within?
  ➢ Direct carbon footprints: derived from fuel and energy consumptions
  ➢ Indirect carbon footprints: from fugitive gases such as N₂O and CH₄

• At present, there is a deficient in the current national carbon accounting methodology for GHG emissions from decentralised wastewater systems.
  ➢ To date, virtually no information is available on GHG emissions.

• Energy-related GHG emissions are the predominant source but the non-energy related GHG, such as methane (CH₄) and nitrous oxide (N₂O), are also of significance owing to their high global warming potential.

• Both CH₄ and N₂O are reported to have a GWP of 25 and 298 times greater than that of carbon dioxide equivalent (CO₂-e) respectively, over a 100 year period.
Summary of current estimation models on fugitive GHG emissions

<table>
<thead>
<tr>
<th>Reference</th>
<th>Model assumption</th>
<th>CH\textsubscript{4} estimate (g CH\textsubscript{4}/capita.d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinnicutt et al. (1910)</td>
<td>*Measured value</td>
<td>10.1</td>
</tr>
<tr>
<td>Sasse (1988)</td>
<td>*Estimated value assuming 25% CH\textsubscript{4} dissolved</td>
<td>18</td>
</tr>
<tr>
<td>IPCC (2007)</td>
<td>*Estimated value based on 50% BOD is converted anaerobically</td>
<td>25.5</td>
</tr>
<tr>
<td>Foley et al. (2009)</td>
<td>*Estimated value based on that 40% of solids are removed as septage</td>
<td>11</td>
</tr>
<tr>
<td>Leverenz et al. (2010)</td>
<td>*Measured value</td>
<td>11</td>
</tr>
</tbody>
</table>

\[ Tr_{N2O,WWTP} = \sum Tr_{N2O,N,R} = \sum V k_L a \times \left\{ \left[ N_2O - N \right]_r - \left[ N_2O - N \right]_s \right\} \]

\[ k_L a = \left[ \frac{D_g}{D_i} \right]^{-0.49} \times 34,500 \nu_g^{0.86} \]
First-Principle Mass Balance Estimation

- We have estimated the possible fugitive GHG emissions at Capo di Monte and Currumbin Ecovillage respectively.

<table>
<thead>
<tr>
<th>Components</th>
<th>Estimated GHG emissions (kg CO₂-e per kL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CDM</td>
</tr>
<tr>
<td>Current average daily wastewater flows (kL/d)</td>
<td>9.3</td>
</tr>
<tr>
<td>Energy related GHG emissions from imported electrical power</td>
<td>5.59</td>
</tr>
<tr>
<td>CH₄ emissions from identified decentralised process</td>
<td>0</td>
</tr>
<tr>
<td>N₂O emissions from identified decentralised process</td>
<td>0.23</td>
</tr>
<tr>
<td>Landfill disposal of screens, grit and bio-solids</td>
<td>0.01</td>
</tr>
<tr>
<td>Effluent disposal for irrigation</td>
<td>0.02</td>
</tr>
<tr>
<td>Dissolved CH₄ in raw sewage</td>
<td>0.08</td>
</tr>
<tr>
<td>Chemical and fuel consumption</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>Total GHG emissions</strong></td>
<td><strong>5.96</strong></td>
</tr>
</tbody>
</table>

**Conclusion:** It was found that the high methane emission from the communal septic system can offset the energy-related MBR system at Capo di Monte.
Stochastic Variation in Fugitive GHG Emissions – Problem and Solution

- From the estimations of all the available methane fluxes models, which are based on different mass balance assumptions, we found that there is a high variation in the CH$_4$ generation from septic system (for instance)

- Assuming a log-normal distribution, the 90% emission range of the communal septic systems at CEV has a potential of 6.69 – 15.18 kg CO$_2$-e/kL.

Solution: Validate using a multi-component GHG analyser
Acknowledgements

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THANK YOU

www.urbanwateralliance.org.au