ENERGY AND GREENHOUSE FOOTPRINTS OF WASTEWATER TREATMENT PLANTS IN SOUTH-EAST QUEENSLAND

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LCA project

17 or 18 August 2009
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   - Scopes 1, 2 & 3
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Introduction
Why calculate WWTP greenhouse gas?

- Use ~ 5 to 10 W/EP (~500 to 1000 kWh/ML) electricity
- Can be a significant part of local government total GHG footprint (~40 to 50%)
- Potential emissions up to:
  - ~0.8 kg CO\textsubscript{2}-e per day per EP as methane
  - ~0.3 kg CO\textsubscript{2}-e per day per EP as nitrous oxide
  - ?? kg CO\textsubscript{2}-e per day per EP as carbon dioxide (non-biogenic)

- **NGERS (2007)** – Australian Federal govt. requires reporting (effective July 2008) when exceeding certain thresholds
NGERS Thresholds

WWTP ~200,000 to 300,000 EP
Life Cycle Assessment

• **Research alliance objective**: LCA model of SEQLD water grid
  - Dams
  - Water Treatment & Distribution
  - Wastewater Collection
  - Wastewater Treatment & Disposal (effluent & biosolids)
  - Water recycling/ Advanced treatment
  - Desalination

• **Use LCA as a tool to inform decision makers**
  - Energy/ greenhouse & secure water supply
  - Environmental impacts / burden
Previous LCA studies

• WWTP impacts dominated by operational inputs & outputs (power, chemicals, biosolids etc.)

• Embodied energy (construction/demolition) relatively minor

• Examples: Lundie et al. 2004 for Sydney
Lundie et al. (2004) – Sydney Water


TABLE 5. Comparison of Scenarios against the Base Case for Each Environmental Indicator and Impact Category

<table>
<thead>
<tr>
<th>Scenario</th>
<th>total energy (%)</th>
<th>water usage (%)</th>
<th>climate change (%)</th>
<th>eutrophication potential (%)</th>
<th>photochemical oxidant formation potential (%)</th>
<th>human toxicity potential (%)</th>
<th>freshwater aquatic ecotoxicity potential (%)</th>
<th>marine aquatic ecotoxicity potential (%)</th>
<th>terrestrial ecotoxicity potential (%)</th>
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</thead>
<tbody>
<tr>
<td>desalination</td>
<td>27</td>
<td>0</td>
<td>23</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>3</td>
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<tr>
<td>demand management</td>
<td>−4</td>
<td>−6</td>
<td>−4</td>
<td>−6</td>
<td>−6</td>
<td>−6</td>
<td>−6</td>
<td>−6</td>
<td>−6</td>
</tr>
<tr>
<td>energy efficiency</td>
<td>−12</td>
<td>0</td>
<td>−11</td>
<td>−1</td>
<td>−6</td>
<td>−1</td>
<td>0</td>
<td>0</td>
<td>−2</td>
</tr>
<tr>
<td>energy generation</td>
<td>−8</td>
<td>0</td>
<td>−7</td>
<td>0</td>
<td>−1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>−1</td>
</tr>
<tr>
<td>energy recovery from 50% biosolids</td>
<td>−4</td>
<td>0</td>
<td>−2</td>
<td>0</td>
<td>−2</td>
<td>−9</td>
<td>−29</td>
<td>0</td>
<td>−39</td>
</tr>
<tr>
<td>population +7%</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>population +16%</td>
<td>8</td>
<td>16</td>
<td>10</td>
<td>16</td>
<td>15</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>population −7%</td>
<td>−4</td>
<td>−6</td>
<td>−5</td>
<td>−6</td>
<td>−6</td>
<td>−6</td>
<td>−6</td>
<td>−6</td>
<td>−6</td>
</tr>
<tr>
<td>population −16%</td>
<td>−8</td>
<td>−12</td>
<td>−8</td>
<td>−12</td>
<td>−11</td>
<td>−12</td>
<td>−12</td>
<td>−12</td>
<td>−11</td>
</tr>
<tr>
<td>secondary upgrade of major coastal STPs</td>
<td>23</td>
<td>0</td>
<td>21</td>
<td>−8</td>
<td>16</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>51</td>
</tr>
<tr>
<td>secondary &amp; tertiary upgrade of major coastal STPs</td>
<td>26</td>
<td>0</td>
<td>23</td>
<td>−10</td>
<td>17</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>60</td>
</tr>
</tbody>
</table>
Methodology
Inventory data - WWTPs

- South-East Queensland
- Approx. total 40 no. WWTPs
- Surveyed 35 no. WWTPs
- Beaudesert, Esk, Laidley, Gatton, Kilcoy etc. not included in study area
## Two types of WWTP

<table>
<thead>
<tr>
<th>TYPE 1</th>
<th>TYPE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Primary sedimentation</td>
<td>• Extended aeration BNR activated sludge</td>
</tr>
<tr>
<td>• BNR activated sludge</td>
<td>• Some with aerobic digestion of waste activated sludge</td>
</tr>
<tr>
<td>• Anaerobic co-digestion of (primary + waste activated sludges)</td>
<td>• No biogas/ collection</td>
</tr>
<tr>
<td>• Biogas collection → <em>some</em> with on-site co-generation (electrical power &amp; heat)</td>
<td>• No co-generation</td>
</tr>
<tr>
<td>• <em>Most</em> with chemical supplementation for nutrient removal (N&amp;P)</td>
<td>• <em>Many</em> with chemical supplementation for nutrient removal (N&amp;P)</td>
</tr>
</tbody>
</table>

*Some with biogas collection.*
## WWTPs surveyed – size summary

<table>
<thead>
<tr>
<th>TYPE OF PLANT &amp; DESCRIPTION</th>
<th>No. of plants surveyed of this Type</th>
<th>% of TOTAL ADWF treated for WWTP in survey</th>
<th>% of Effluent TOTAL N LOAD (50%ILE) for WWTP surveyed</th>
<th>Approximate % of effluent TOTAL P LOAD (50%ILE) for WWTP surveyed</th>
<th>Current ADWF (ML/d)</th>
<th>Indicative EP from ADWF, assuming 200 L/EP.d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Average</td>
<td>Min</td>
<td>Max</td>
<td>Average</td>
</tr>
<tr>
<td>Type 1 – No Cogen</td>
<td>3</td>
<td>8%</td>
<td>7%</td>
<td>5%</td>
<td>5.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Type 1 – Cogen</td>
<td>3</td>
<td>38%</td>
<td>44%</td>
<td>60%</td>
<td>15.1</td>
<td>123.7</td>
</tr>
<tr>
<td>Type 2 - Small</td>
<td>5</td>
<td>0.3%</td>
<td>0.6%</td>
<td>0.4%</td>
<td>0.075</td>
<td>0.46</td>
</tr>
<tr>
<td>Type 2 - Medium</td>
<td>17</td>
<td>19%</td>
<td>20%</td>
<td>8%</td>
<td>1.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Type 2 - Large:</td>
<td>7</td>
<td>35%</td>
<td>28%</td>
<td>27%</td>
<td>10.4</td>
<td>54.0</td>
</tr>
<tr>
<td>TOTAL no. of plants surveyed</td>
<td>35</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>0.1</td>
<td>123.7</td>
</tr>
</tbody>
</table>

Two biggest plants – no advanced P removal
Effluent N & P

**Type 1**

- Proportion of plants in survey

<table>
<thead>
<tr>
<th>Value</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td></td>
</tr>
<tr>
<td>&gt;10</td>
<td></td>
</tr>
<tr>
<td>5 to 10</td>
<td></td>
</tr>
<tr>
<td>3 to 5</td>
<td></td>
</tr>
</tbody>
</table>

**Total N**

- mgN/L

<table>
<thead>
<tr>
<th>Value</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td></td>
</tr>
<tr>
<td>&gt;5</td>
<td></td>
</tr>
<tr>
<td>3 to 5</td>
<td></td>
</tr>
<tr>
<td>1 to 2</td>
<td></td>
</tr>
</tbody>
</table>

**Type 2**

<table>
<thead>
<tr>
<th>Value</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td></td>
</tr>
<tr>
<td>&gt;10</td>
<td></td>
</tr>
<tr>
<td>5 to 10</td>
<td></td>
</tr>
<tr>
<td>3 to 5</td>
<td></td>
</tr>
</tbody>
</table>

**Total P**

- mgP/L

<table>
<thead>
<tr>
<th>Value</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>&gt;5</td>
<td></td>
</tr>
<tr>
<td>2 to 5</td>
<td></td>
</tr>
<tr>
<td>1 to 2</td>
<td></td>
</tr>
</tbody>
</table>
Data collected

- **Flow** (dry weather average)
- **Influent** COD (or BOD), TKN and TP concentrations
- **Effluent** Total N and Total P concentrations
- **Power** consumption & Power generated (on site) from biogas (if any)
- **Chemicals** consumption
- **Biosolids**
- **Screenings & grit**
- **Biogas** produced (if any) & methane content (if measured)
- **Flow of sludge** stream(s) treated through anaerobic digestion
- **Method of effluent disposal** (ocean, estuary, river, wetlands or irrigation)
- Approx. % effluent volume disposed to **effluent reuse** (e.g. irrigation)
GHG calculations

- Former AGO workbook methodology inadequate (WSAA, 2007)
- IPCC ‘Tier 3’ or NGERS (2008) Technical Guidelines ‘higher order’
- First principles (mass balance approach)
- WWTP functional areas (C & N in/out)
- Fugitive emissions
  - Raw sewage dissolved CH₄
  - Denitrification N₂O
  - Anaerobic digestion CH₄ (not combusted)
  - Biosolids CH₄
  - Effluent N₂O (receiving water/ environment)
- Non-biogenic carbon (CO₂)
- Biosolids carbon sequestration (?)
- ALL SCOPES: 1, 2 & 3 included
Scopes 1, 2 & 3

**Scope 1: Direct**
Emissions from fossil fuels or other sources under direct control (e.g. own production process or vehicle fleet).

**Scope 2: Indirect**
Emissions from electricity consumed but generated elsewhere.

**Scope 3**
Other indirect emissions resulting from business but emission sources are not owned e.g. from supply chain of consumables or transport of goods purchased.
Emission factors

• **Sources**
  - NGERS (2008) Technical Guidelines (e.g. power, fuels)
  - Simapro® LCA software databases (e.g. chemicals)
  - Literature survey (WSAA, 2007) (fugitive emissions)
  - Other: literature or estimates (e.g. non-biogenic carbon)

• **Major uncertainties**
  - Fugitive emissions factors
    - DN process off-gas $N_2O$ : ~500-fold range
    - Biosolids disposal $N_2O$ or $CH_4$ : ~5 to 100-fold range
    - Effluent $N_2O$ : ~up to 1000-fold range
  - Non-biogenic organic carbon in wastewater (1% to 50%??)
  - Carbon sequestration in biosolids disposed (5 to 25%??)
Uncertainty analysis

Plant 1

- Monte Carlo simulation (Excel®-based Add-on)
- Input values for uncertain emission factors

- Minimum, Maximum and 'Best estimate' (or Median)
- Normal distribution simulated in the model from these estimates

Combined probability from multiple uncertainties

- Total GHG emissions, kg CO2-e/d

Graph showing the distribution of total GHG emissions with percentage values along the horizontal axis from 0% to 100%.
Results
GHG emissions results

**Assumptions**
- 8 mg/L raw influent dissolved methane
- 10% non-biogenic raw influent organics
- 1% denitrified N as nitrous oxide

**GHG emissions breakdown for example plants**

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>124 ML/d Type 1 + Cogen</td>
<td>54 ML/d Type 2</td>
<td>24 ML/d Type 1</td>
<td>6 ML/d Type 2</td>
<td>24 ML/d Type 1</td>
<td>54 ML/d Type 2</td>
<td>6 M L/d Type 2</td>
<td>6 ML/d Type 2</td>
</tr>
</tbody>
</table>
Emissions by Scope – Type 1

Plant I: Type 1 (with biogas + cogen.)
- Scope 1, N2O: 37%
- Scope 1, CH4: 20%
- Scope 1, CO2: 8%
- Scope 2, CH4: 20%

Plant II: Type 1 (with biogas but no cogen.)
- Scope 1, N2O: 17%
- Scope 1, CH4: 17%
- Scope 1, CO2: 14%
- Scope 2, CH4: 57%

125 tonnes/d CO₂-e
124 ML/d ADWF

43 tonnes/d CO₂-e
24 ML/d ADWF
Emissions by Scope – Type 2

**Plant III: Type 2 (Extended aeration, large)**

- **Scope 1, N2O**: 19%
- **Scope 1, CH4**: 17%
- **Scope 1, CO2**: 17%
- **Scope 2**: 5%
- **Scope 3**: 48%

94 tonnes/d CO₂-e

54 ML/d ADWF

**Plant IV: Type 2 (Extended aeration, medium)**

- **Scope 1, N2O**: 19%
- **Scope 1, CH4**: 42%
- **Scope 1, CO2**: 17%
- **Scope 2**: 5%
- **Scope 3**: 4%

12 tonnes/d CO₂-e

7.9 ML/d ADWF
Snapshot of GHG from SE QLD WWTPs

GHG emissions per day
Total GHG, including lift pumps. Error bars denote combined uncertainties (5%ile & 95%ile) from Monte Carlo simulations

Uncertainties (Min - Max.) incl. in Monte Carlo Simulations:
- Raw influent dissolved CH4 (1 - 30 mg/L CH4)
- % Raw influent non-biogenic COD (0 - 30%)
- Secondary process off-gas N2O (0.01 to 5% of N-denitrified)

Potential biosolids C-sequestration
Total Greenhouse Gas emissions

Assuming 20% biosolids C sequestered (long term)

PLANT NAME
Data not available for some plants
GHG emissions per ML

Total GHG emissions per ML, including lift pumps. Error bars denote combined uncertainties (5%ile & 95%ile) from Monte Carlo simulations.

Uncertainties (Min - Max.) incl. in Monte Carlo Simulations:
- Raw influent dissolved CH4 (1 - 30 mg/L CH4)
- % Raw influent non-biogenic COD (0 - 30%)
- Secondary process off-gas N2O (0.01 to 5% of N-denitrified)

Graph showing the relationship between ADWF treated (ML/d) and GHG emissions per ML. The graph includes data points for different plant types and shows the potential for biosolids C sequestration.

Equations:
- \( y = 1.9773x^{-0.093} \) with \( R^2 = 0.3295 \)
- \( y = 4.177x^{0.278} \) with \( R^2 = 0.8951 \)

Assuming 20% biosolids C sequestered (long term).
GHG emissions per ML

Total GHG emissions per ML excluding lift pumps. Error bars denote combined uncertainties (5%ile & 95%ile) from Monte Carlo simulations.

Uncertainties (Min - Max.) incl. in Monte Carlo Simulations:
- Raw influent dissolved CH4 (1 - 30 mg/L CH4)
- Raw influent non-biogenic COD (0 - 30%)
- Secondary process off-gas N2O (0.01 to 5% of N-denitrified)

Three plants with power generation from biogas.

Data not available for some plants.
Power consumption per ML

Gross plant power consumption per ML ADWF excluding lift pumps.

Three plants with power generation

- Plant Power per ML for Plant Type: Extended aeration BNR-Act. Slg.
- Plant Power per ML for Plant Type: PST/An. Dig./BNR-Act. Sludge.
Power consumption vs. N removal

GHG emissions per ML
Total GHG, excluding lift pumps. Error bars denote combined uncertainties (5%ile & 95%ile) from Monte Carlo simulations

Uncertainties (Min - Max.) incl. in Monte Carlo Simulations:
- Raw influent dissolved CH4 (1 - 30 mg/L CH4)
- % Raw influent non-biogenic COD (0 - 30%)
- Secondary process off-gas N2O (0.01 to 5% of N-denitrified)

Three plants with power generation from biogas

"Best estimate" GHG emissions (tonnes CO2-e/ML ADWF)

Assuming 20% biosolids C sequestered (long term)
Conclusions

• Useful inventory of operating data from WWTPs in SEQLD
• Uncertainty in emission factors highlighted
  ➢ Fugitive emissions of CH₄ & N₂O
  ➢ Non-biogenic organics in raw sewage
  ➢ Carbon sequestration in biosolids
• Uncertainties appear to influence results in range: ~mean (±20%)
• Typical emissions, flow-specific basis ~1 - 2.5 tonnes CO₂-e /ML
• Economies-of-scale: lower emissions/ML with increasing plant size
• Type 1 plants: lower emissions only with power recovery from anaerobic digestion & biogas
• Trade off with advanced nutrient removal → LCA
• Need to extend study to full SEQ Water Cycle
Thank you

www.urbanwateralliance.org.au