Community scale non-potable reuse in London using an MBR

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Abstract: Due to increasing pressure on water resources in southeast England, Thames Water are currently installing the first membrane bioreactor (MBR) plant for reuse (toilet flushing and irrigation) in the UK, at Beddington Zero Energy Development (BedZED), a prestigious sustainable development in south London. Thames Water will operate and evaluate the system via an in depth research programme for a 3 year period. A case study, the Solaire in New York (US), informed the BedZED Wastewater Reclamation Plant (BWRP) design and is presented. The BWRP process stream comprises 3mm screens, MBR, granular activated carbon and chlorination. Research will include process optimisation, water quality and water saving studies, post treatment efficiency and effectiveness, energy usage, studies of biofilm regrowth potential and household perception studies. A comprehensive metering system consisting of hardwired pulse, electromagnetic and radio meters will monitor reclaimed and potable water throughout the site. The metering data will be used to calculate water balances and water savings at various scales. Research using the radio meters (AMR) will cover areas such as customer side leakage and usage patterns. This research will allow a holistic and complete understanding of water use and recycling in a sustainable community.

Keywords: Membrane bioreactor; metering; non-potable; reuse

INTRODUCTION

Increasing pressure on water resources in the southeast of England require consideration of various new supply options. As well as the planned increase in population in London and the surrounding areas and changes in demographics (e.g. more single person households) other drivers include climate change, drought potential, regulators’ views and London’s 2012 Olympics. As a water provider in this region, Thames Water is considering various “novel” water provision options including water recycling to effectively manage and maintain future water supplies (Birks et al., 2004; Hills et al. 2003; Smith et al., 2001). As an additional driver for the consideration of recycling, planning requirements dictating more “sustainable” developments are motivating developers to consider more innovative solutions to utility provision and this often includes supplying water from unconventional sources or non-potable recycling.

BedZED (Beddington Zero Energy Development) is a UK “real life” example of a sustainable development in South London of over 100 residences (see Figure 1a) pioneered by the Peabody Trust. It was constructed in 2002 with the aim of embodying innovative approaches to planning, thermal demand, electrical demand, water demand, transport and renewable energy. The site included onsite wastewater treatment and recycling for non-potable uses, however, the original technology installed for recycling, the Green Water Treatment Plant, has had ongoing operational and maintenance issues, and is currently not functioning.

Thames Water has since agreed with the Peabody Trust to provide a new option for on-site non-potable recycling and is currently installing a membrane bioreactor (MBR) reclamation plant (see Figure 1b). The ‘BedZED Wastewater Reclamation Plant’ (BWRP) will be the first MBR reuse plant in the UK and provide reclaimed water for toilet flushing and garden irrigation for the properties. Thames Water is to operate and evaluate the BWRP as part of a three year detailed research project on site. The aim of the trial is to significantly reduce the potable requirements on
site and promote sustainable water options, whilst establishing good practice guidelines for reuse using MBR technology.

**Figure 1.** a. BedZED (Beddington Zero Energy Development), London, UK; b. The BedZED Wastewater Reclamation Plant (BWRP) membrane bioreactor (MBR).

This paper will present an overview of the research project at BedZED, looking at areas such as process optimisation and efficiency, novel metering techniques and householders perceptions of recycling. In addition, lessons learnt from a presented case study of urban reuse using MBRs in New York City (US) considers the various issues in the US, and how they influenced and informed the BWRP design in the UK.

**CASE STUDY: NON-POTABLE REUSE MBR AT THE SOLAIRE, NYC, US**

The US plays a leading role in the development of decentralised MBR systems for urban reuse. A fact finding period working in the US with Applied Water Management (AWM), a MBR design and operation company and previous sister company to Thames Water, provided expertise from MBR operations in New York City (NYC). This expertise was used to feed into the UK context, specifically the BedZED project.

AWM own and operate 20 MBRs for reuse throughout the east coast of the US, in New Jersey, Connecticut, Massachusetts and NYC. AWM operate in a number of prestigious apartment blocks in NYC, where wastewater is collected, treated and reused within the building primarily for toilet flushing, make-up water for cooling towers, and irrigation of roof gardens and parks. One of the sites, “the Solaire” (see Figure 2a) was built in Battery Park City, NYC in 2003 and a MBR housed in the basement recycles 95 m$^3$/d of wastewater for use within the building (see Figure 2b). At the Solaire wastewater is collected, via a 53m$^3$ “trash trap” for settlement of solids, and is treated via a MBR containing a 40m$^3$ anoxic zone and 75m$^3$ aerobic zone followed by a 55m$^3$ membrane tank housing two Zenon ZW500a cassettes. Post treatment consists of an ozone system for colour removal and disinfection followed by a UV system functioning as a secondary disinfection process. The Solaire has been used as a case study, with the technical design and operation data, water quality and water saving information, and cost data gathered and presented below, to support design and operation of the BWRP in the UK.
Lessons learnt from the US to aid BedZED MBR design and operation

The following sections present information gathered from the US and discuss how this relates to both a UK and global context.

“Sustainability” drivers. As with BedZED, the Solaire building was built with a key driver to be sustainable. In the US, this was as a response to “green” building initiatives, such as the Leadership in Energy and Environmental Design (LEED) rating (US Green Building Council LEED guidelines, 2005) and the Battery Park City Environmental Guidelines (Battery Park City Residential Environmental Guidelines, 2005) which require new buildings in the city to demonstrate significant water savings (i.e. >25% compared to a typical “base” buildings water usage). If savings are demonstrated, the building service provider can receive significant reductions in water and wastewater charges. In addition, constructions conforming to the LEED standards can also attract more clients and potential tenants can be willing to pay more rent.

In the UK, developers are faced with similar design objectives, with the recently produced Government Code for Sustainable Homes (Department for Communities and Local Government: London, 2006) advising all new developments to reduce design consumption to a minimum standard of 120 litres/person/day (l/p/d) (compared to typical Thames Water average of 164 l/p/d, OFWAT, 2006) by water conservation initiatives. In addition, the UK public are becoming far more aware of sustainability issues such as energy and water efficiency, and are demanding more in terms of sustainability when purchasing a new home.

Achievable water savings. Research carried out at the Solaire by AWM (see Table 1, Clerico, 2007) over a period of three years shows that a 48% reduction in potable water consumption can be achieved when compared to usage in a typical “base” building (average usage, 246 m³/d, Clerico, 2007) by a combination of wastewater recycling and installation of water efficient appliances (e.g. low flush toilets, efficient dishwashers etc). At the Solaire, on average 33% of the total water consumption is met by reclaimed water (see Table 1). This “real life” saving from MBR recycling has been shown to be achievable in the US for domestic dwellings, and it is therefore a minimum target to be achieved in the UK at BedZED.
Table 1. Water usage at the Solaire, NYC over 3 years compared to usage in a “base” building*

<table>
<thead>
<tr>
<th></th>
<th>Potable Water, m³/d</th>
<th>Reclaimed Water, m³/d</th>
<th>Total Water, m³/d</th>
<th>% Reduction in potable water (calculated from ‘base’ usage)</th>
<th>% reclaimed water</th>
<th>% potable water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical “base” building usage</td>
<td>246</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>112</td>
<td>67</td>
<td>179</td>
<td>55%</td>
<td>38%</td>
<td>62%</td>
</tr>
<tr>
<td>2005</td>
<td>142</td>
<td>62</td>
<td>204</td>
<td>42%</td>
<td>30%</td>
<td>70%</td>
</tr>
<tr>
<td>2006</td>
<td>128</td>
<td>60</td>
<td>188</td>
<td>48%</td>
<td>32%</td>
<td>68%</td>
</tr>
<tr>
<td>Average</td>
<td>129</td>
<td>63</td>
<td>192</td>
<td>48%</td>
<td>33%</td>
<td>67%</td>
</tr>
</tbody>
</table>

* Table adapted from Clerico, 2007

Compliance to regulatory targets. The recycling plant at the Solaire is operated to achieve the quality parameters specified by the NYC Department of Health Regulations (see Table 2, Clerico, 2007) which is comparable to the US Environmental Protection Agency (EPA) recommendations for unrestricted urban reuse (EPA, 2004). Over four years of operation, the recycling plant at the Solaire has near consistently met these water quality goals (see Table 2). In the UK, there are currently no guidelines for water recycling, and therefore the aim is to meet and exceed, if possible, the US EPA regulations (EPA, 2004) in the BWRP, as has been demonstrated at the Solaire.

Table 2. NYC regulations and EPA suggested guidelines for urban reuse

<table>
<thead>
<tr>
<th></th>
<th>EPA recommendations for unrestricted urban reuse*</th>
<th>NYC specified guidelines for the Solaire**</th>
<th>Average product water at the Solaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>≤ 10 mg/l</td>
<td>&lt; 10 mg/l</td>
<td>&lt;4 mg/l</td>
</tr>
<tr>
<td>SS</td>
<td>No suggestion</td>
<td>&lt; 10 mg/l</td>
<td>&lt;1 mg/l</td>
</tr>
<tr>
<td>Faecal coliforms</td>
<td>No detectable /100ml</td>
<td>&lt;100/100 ml</td>
<td>&lt;1 cfu/100ml</td>
</tr>
<tr>
<td>PH</td>
<td>6-9</td>
<td>6.5-8.0</td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>≤ 2 NTU</td>
<td>&lt; 0.5 NTU</td>
<td>&lt;0.1 NTU</td>
</tr>
<tr>
<td>Cl₂ residual</td>
<td>1 mg/l (minimum)</td>
<td>No regulation</td>
<td></td>
</tr>
</tbody>
</table>

* EPA, 2004; ** adapted from Clerico, 2007

Technical design and operation. Design of the BWRP has been, in part, based on technical recommendations from the US operations. Lessons learnt from the US which have been used for the design at BedZED include; the use of a pre screen or settlement prior to the MBR, the use of separate adjustable blowers for aeration and membrane scouring to maintain efficient levels of dissolved oxygen in all zones whilst increasing energy efficiency, and the use of fully automated backwashing GAC filters for post treatment to prevent biofouling in the GAC unit. In addition, previous work carried out on the identification and characterisation of biological regrowth in reclaimed water pipework systems of MBR reuse plants (Karim et al., 2005) will be further progressed in the UK scenario at BedZED.

Cost efficiency. A major drawback for the further emergence of this technology found in the US is that small systems such as the Solaire focusing on one apartment block only (housing ~250 apartments) lead to relatively high capital costs and low operational efficiency. The UK trial will explore this issue, developing work carried out by Thames Water on the cost efficiency of an advanced membrane recycling system at the Millennium Dome, London (Brewer et al., 2001; Smith et al, 2001).

BEDZED (BEDDINGTON ZERO ENERGY DEVELOPMENT) – CURRENT OVERVIEW

Utilising lessons learnt from the US case study, the following sections look at the BedZED project in the UK and how the US work informed on design of the project. Beddington Zero Energy Development (BedZED) in Sutton, south London, was constructed in 2002 and consists of over
100 properties split into 8 housing blocks and a community centre (see Figure 3). The residential properties range from 3 bedroom townhouses to one bedroom flats, with a mixture of tenures (e.g. full and shared ownership, key workers and affordable housing etc). The site also houses several offices, including the architects who designed BedZED, a nursery, an exhibition centre and a show home for visitors (Peabody Trust, 2006). All BedZED buildings are fitted with water efficient appliances (Bioregional, 2007), and the original concept was to include onsite wastewater treatment and recycling via the ‘Green Water Treatment Plant’ (GWTP). However, this plant has had ongoing operational and maintenance issues and currently does not function.

**Figure 3.** Plan of BedZED site, south London, UK.

The site has an existing dual pipe network to accommodate both the reclaimed and potable water supply to the houses. Seven reclaimed water storage tanks located under each of the eight housing blocks (with one tank feeding two housing blocks, 1 and 2 – see Figure 3) hold the reclaimed water and are used as required for toilet flushing and irrigation in the houses above. As the original onsite wastewater treatment, the ‘Green Water Treatment Plant’, is no longer in operation, non-potable demand in the houses is currently met with a combination of rainwater and potable water.

**SUSTAINABILITY RESEARCH BY THAMES WATER AT BEDZED**

**Installation of the UK’s first reuse MBR: BedZED Wastewater Reclamation Plant (BWRP)**

*Overview.* Thames Water is currently installing the BedZED Wastewater Reclamation Plant, which will treat and recycle the wastewater that has currently been going to the sewer. Domestic wastewater from the residences is collected via 2 underground septic tanks and piped to the BWRP, where it passes through 3mm screens and onto the MBR. The MBR contains a 9.1m$^3$ anoxic and 12.3m$^3$ aerobic zone for nitrification and denitrification, and six Zenon ZW500c membrane modules (total membrane surface area, 120m$^2$) for removal of contaminants by filtration. The MBR plant maximum capacity is 60m$^3$/d. Post treatment consists of automatic backwashing granular activated carbon (GAC) filtration for adsorption of organic compounds and to remove residual colour, followed by chlorination to maintain a target 0.5mg/l chlorine residual in the reclaimed water pipe network going to supply (see Figure 4). Real time data from all plant equipment will be read from a versatile SCADA (Supervisory Control and Data Acquisition) system which will monitor functioning of the BWRP and associated metering system via mimics and trend graphs, and have the ability for remote access and data logging.
Evaluating technology efficiency. Following commissioning, research will commence on various aspects of the BWRP technology. Optimisation of the process stream for this particular use is a key area, and the research will include screening efficiency, flux and mixed liquor suspended solids (MLSS) range achievable, and membrane fouling propensity (including extracellular polymeric substances (EPS) and Sludge Volume Index (SVI) methods). Evaluating the post treatment technologies is key and research will include GAC backwash efficiency, chlorine dosing requirements and the potential for trihalomethane (THM) formation from reclaimed water disinfection. Water quality will be regularly monitored after each stage of the process stream, in the reclaimed water tanks and at key points around the pipe network, notably the furthest point from chlorination and in cisterns in domestic houses. In addition to standard water quality parameters, the fate of EDCs (endocrine disrupting compounds) throughout the process will be investigated, as they are seen as emerging compounds of concern and can be concentrated in reuse systems. Energy usage will be carefully monitored as part of a process whole life cost evaluation, and will be optimised by checking the influence of flux, and aeration rate and frequency on the permeability. Biofilm regrowth throughout the pipe network will be investigated and mitigation techniques developed as necessary.

Calculating water savings at BedZED in a pilot of novel metering methods

Overview. A comprehensive metering system of over 150 meters on both the potable and reclaimed water supplies will allow a full and detailed on site water balance to be carried out (see Table 3). Metering will be carried out at various scales of water usage; the bulk supply to site, the housing block scale and the individual house scale (see Table 3). Reclaimed water usage will be monitored separately for both toilet flushing and irrigation purposes, and also potable “top up” usage per housing block in the unlikely event of insufficient reclaimed water availability. The layout of the existing pipework on site meant that metering for both potable and reclaimed water at every scale was not possible (see Table 3) and, in the case where no metering is available, will be calculated or estimated in the SCADA system. Monitoring will be carried out using a combination of hardwired pulse meters, electromagnetic meters and also state-of-the-art automatic meter reading (AMR) radio meters all linked back to the SCADA. Figure 5 shows a schematic of the metering system.

Metering research. The metering system will be used to carry out an extensive and detailed water balance of the site at various different scales, including house, housing block and whole site scale. This will allow a holistic understanding of relative water usage of reclaimed and potable water to be understood, and water savings quantified. Detailed research will also be carried out on the AMR radio meters installed in the boundary boxes outside each of the 107 domestic residences to monitor
individual potable usage. During the research period, the AMR technology will be trialled, with performance and range investigated. The data received from the devices will be analysed for customer side leakage and usage patterns, including night usage, seasonal variations and impacts of external events (e.g. drought related restrictions such as hosepipe bans). In the future, there will be the potential for comparison of this site, a green, sustainable community, with a standard development. Promoting water efficiency and recycling initiatives to the householders has always been a key requirement of the BedZED project and the possibility of a web based customer interface will be investigated, which would allow residents to view their water usage online.

Table 3. Meters installed at BedZED: Type and water usage scale

<table>
<thead>
<tr>
<th>Site</th>
<th>Housing block</th>
<th>House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reclaimed water – WC</td>
<td>✓ (1)</td>
<td>x</td>
</tr>
<tr>
<td>Reclaimed water – Irrigation</td>
<td>✓ (7)</td>
<td>x</td>
</tr>
<tr>
<td>Potable water</td>
<td>✓ (1)</td>
<td>x</td>
</tr>
<tr>
<td>Potable water top up</td>
<td>x</td>
<td>✓ (8)</td>
</tr>
<tr>
<td>Wastewater</td>
<td>✓ (1)</td>
<td>x</td>
</tr>
</tbody>
</table>

✓ = meters installed (total number of meters in brackets)  x = unable to install meters due to pipework constrictions

Figure 5. Schematic of the metering system at BedZED

Gauging householders’ perceptions to the sustainability initiatives
Householder perception studies will also be undertaken during the three year evaluation to gauge attitudes to the sustainable water initiatives. BedZED has always offered a ‘green’ lifestyle and it may be a major reason for residents selecting it over other locations. This is similar to the Solaire in NYC, where the ‘green’ image of the building is a significant appeal to the tenants.

CONCLUSIONS
Increasing legislation from the Government and other regulatory groups, in addition to growing householder awareness and support of sustainability issues, means that the driver for planners, developers and water providers to consider and promote water conserving initiatives such as
recycling is becoming ever more apparent. In light of these issues, in addition to increasing pressure on water resources in the southeast of England, Thames Water is evaluating various novel water supply initiatives such as non-potable reuse. A key demonstration project for Thames Water is the installation; operation and evaluation of the first UK MBR reuse plant at BedZED, south London. This project will cover a wide range of topics, from assessing and optimising non-potable reuse technology efficiency to the development of a customer interface around the AMR radio metering system to allow householders to monitor their domestic water usage, allowing a holistic and complete understanding of water use and recycling in a sustainable community. A case study from NYC in the US provided Thames Water with invaluable information to feed into the BedZED scheme, and it is hoped that the project itself will become a blueprint for future sustainable developments such as the London Olympics 2012.

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