ONSITE AND DECENTRALISED WASTEWATER SYSTEMS
Advances from a decade of research and educational efforts
RL Siegrist, JE McCray, KS Lowe, TY Cath, J Munakata-Marr

ABSTRACT
Throughout the United States and worldwide, solutions to wastewater infrastructure need to be effective in protecting public health and preserving water quality while also being acceptable, affordable and sustainable. Onsite and decentralised systems have the potential to achieve these goals in rural areas, peri-urban developments, small towns and urban centres in larger cities.

These systems have evolved to include an array of devices and technologies that can be assembled to achieve varied discharge or resource recovery and recycling objectives. New mathematical models and decision support tools enable proper system selection and design for a particular application. To achieve needed advances in the science and engineering of onsite and decentralised systems and help assure integration of the outcomes into practice, research and educational efforts have been essential.

INTRODUCTION
In the US today, most people have ready access to safe drinking water and adequate sanitation as a result of major investments during the 20th century. The situation is similar in many other industrialised nations around the world. As we entered the 21st century, centralised water treatment plants and piping networks produced and distributed drinking water while sewers collected wastewater for treatment at remote plants.

In the US, centralised water and wastewater systems were serving about 85% and 75% of the population, respectively. However, there were growing concerns about the sustainability of large centralised systems. In the US, many of the components of large centralised systems were at or approaching the end of their design life spans and rehabilitation options were often limited and extremely costly. In addition, some of the potential flaws in centralised systems were becoming more apparent. For example, nearly 50% of the safe drinking water produced is typically wasted as a result of water distribution losses (~20%) and clean water use for flushing toilets (~30%).

Centralised systems can also lead to unplanned urban sprawl, localised water resource depletion, excess consumption of chemicals and energy, release of untreated sewage through leaking sewers and sewer overflows, and barriers to beneficial recycling and reuse. As evidenced by recent events in the US and abroad, centralised systems are also subject to upsets during natural disasters and may be targets of terrorist activities.

In contrast to the larger centralised systems established in urban areas, private wells and septic systems were commonly used in rural and suburban areas. During much of the 20th century, many viewed these systems as temporary with a vision that, sooner or later, they would be replaced by connection to centralised systems as these systems were expanded across the US. During this period, onsite and decentralised wastewater systems were not designed or implemented to achieve explicit treatment and reuse objectives over long-term permanent use. Not surprisingly, such systems suffered performance deficiencies ranging from hydraulic failures to localised contamination of groundwaters and surface waters.

These deficiencies were attributed to varied causes including poor system siting, improper design, faulty installation, and/or inadequate operation and maintenance. To support a growing vision that onsite and decentralised systems were not temporary, but rather were a permanent component of a sustainable wastewater infrastructure, research and educational initiatives, along with changes in regulatory requirements, sought to improve the standard of practice and mitigate many of the past performance deficiencies (eg, USEPA, 1997; Siegrist, 2001).

Based on research and development efforts over the past decade or more, modern onsite and decentralised systems have evolved to include a growing array of approaches, devices and technologies that can be applied at the development level up to watershed scale. Ultra low-demand fixtures or source separation plumbing can enhance water infrastructure by minimising water demands and maximising reuse in buildings and developments spanning rural, peri-urban and urban areas. Treatment can be achieved using anaerobic and aerobic bioreactors, porous media biofilters, sorbent filters, membrane separation units, constructed wetlands, soil treatment units, UV disinfection units and other technologies. Reuse of reclaimed water can occur through toilet flushing, landscape irrigation and other applications.

The vision of onsite and decentralised systems is still unfolding and the possibilities for the future are open-ended. One vision is that as planning and design of sustainable water and wastewater infrastructure occurs, onsite and decentralised systems will be universally and equitably considered across all scales of development (e.g., individual buildings, cluster developments, communities, watersheds). Any automatic predisposition towards more centralised infrastructure will have vanished. Modern infrastructure will be characterised by low-demand plumbing systems, treatment of wastewater at or near the point of generation, reclamation and reuse of wastewater resources, use of sensors and monitoring devices to verify and enhance performance, and remote process control and system management to monitor and automatically correct any system malfunction. Systems will commonly mimic natural processes to achieve performance objectives while minimising water, energy and chemical use, and enabling beneficial reuse.

A DECADE OF RESEARCH AND EDUCATIONAL EFFORTS
Among the research and educational efforts initiated in the US during the 1990s, the Small Flows Program was established at the Colorado School of Mines (CSM) in Golden, Colorado. Highlights of some of the research and educational activities carried out over the past decade are presented here.
**Research Highlights**

Several areas have been the focus of sustained research activities, including projects to: 1) determine the flow and composition of modern onsite wastewater streams; 2) evaluate the performance dynamics of bioreactors and biofilters, including their integration with soil-based unit operations; 3) evaluate the performance of decentralised systems utilising membrane bioreactors; and 4) develop mathematical models and decision support tools. A short discussion also highlights considerations important to achieving performance potential when systems are implemented under normal field conditions.

**Characterising Flow and Composition of Onsite Wastewaters**

Quantitative understanding of water use and wastewater characteristics is important for proper system selection and design. Until recently much of the available characterisation data were from studies completed more than 20 years ago. Recent and ongoing CSM research projects have been focused on advanced characterisation of modern waste streams. For example, in one recent CSM project, over 150 literature sources were analysed to obtain characterisation data for conventional constituents, microorganisms and trace organic compounds in raw wastewater and septic tank effluent (STE) from domestic (single and multiple), food, medical and non-medical sources (Lowe et al., 2006). Field monitoring was then completed at 17 domestic sites in three regions of the US (Lowe et al., 2009). A specialised apparatus was fabricated to collect 24-hour composite samples of raw wastewater and STE during each season of the year. Analyses were made for a suite of wastewater parameters (e.g., flow, temperature, pH, cBOD₅, nutrients, microorganisms, and trace organic compounds). Example results are presented in Tables 1 and 2 and in Figure 1.

Characterisation data for trace organic compounds have also been obtained through field monitoring at 30 sites in Colorado (Conn et al., 2006) in addition to the 17 sites studied by Lowe et al. (2009). This research revealed that many organic compounds could be present in wastewaters at relatively low but potentially important concentrations. Organic compounds associated with consumer product chemicals (e.g., caffeine, nonylphenols, Triclosan) routinely occur at low to high levels depending on the source (e.g., residential dwellings, restaurants, vs. convenience stores, etc.) (Conn et al., 2006, Lowe et al., 2009, Conn et al., 2010a) (Table 3).

Pharmaceuticals, pesticides, and flame retardants can also occur, but much less pervasively and typically at much lower levels (Conn et al., 2010a).

**Evaluating Performance of Onsite Unit Operations and Systems**

Onsite and decentralised systems involve unit operations that can be combined to achieve up to tertiary treatment levels with disinfection. Different types of systems can enable different discharge and reuse options. For onsite and decentralised applications, flow and composition can vary widely, usage can be discontinuous, and the design life can be undefined but often decades long. As a result, the dynamics of performance as affected by design, operation and environment can be quite complex. Research carried out at CSM has investigated the performance of contrasting systems through laboratory experiments, field-testing at the Mines Park Test Site located on the CSM campus, and full-scale systems monitoring. This work has focused in part on optimising the level of treatment to be carried out in a confined unit (e.g., a bioreactor) versus a natural system operation (e.g., a network of soil infiltration trenches) (Figure 2).

---

### Table 1. Average daily wastewater flow rates from residential dwellings based on field monitoring by Lowe et al. (2009) compared to overall averages of two earlier studies.

<table>
<thead>
<tr>
<th>Reference and study characteristics</th>
<th>Study average flow (L/day/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>Lowe et al. (2009) – Building sewer flows measured at each of 17 houses in Colorado, Minnesota and Florida, US, in 2008–09</td>
<td>207</td>
</tr>
<tr>
<td>Mayer et al. (1999) – Indoor water usage measured at each of 1,188 houses in 12 cities in Colorado, California, Oregon, Washington, Arizona, Florida, US and Ontario, Canada in the 1990s</td>
<td>262</td>
</tr>
<tr>
<td>USEPA (1980) – Based on multiple studies of water use or wastewater flows conducted by different investigators during the 1960s and 1970s</td>
<td>172</td>
</tr>
</tbody>
</table>

### Table 2. Typical domestic wastewater composition determined by Lowe et al. (2009) and reported in two other published sources that are commonly used for onsite system design.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>Range</td>
<td>Range</td>
</tr>
<tr>
<td>TSS</td>
<td>mg/L</td>
<td>232</td>
<td>22–1690</td>
<td>155–330</td>
</tr>
<tr>
<td>Oil &amp; grease</td>
<td>mg/L</td>
<td>50</td>
<td>10–109</td>
<td>–</td>
</tr>
<tr>
<td>cBOD₅</td>
<td>mg/L</td>
<td>420</td>
<td>112–1101</td>
<td>155–286</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>849</td>
<td>139–4584</td>
<td>500–660</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/L</td>
<td>184</td>
<td>35–738</td>
<td>Not rept.</td>
</tr>
<tr>
<td>Total N</td>
<td>mg-N/L</td>
<td>60</td>
<td>9–240</td>
<td>26–75</td>
</tr>
<tr>
<td>Total P</td>
<td>mg-P/L</td>
<td>10.4</td>
<td>0.2–32</td>
<td>6–12</td>
</tr>
</tbody>
</table>

---

**Figure 1.** Cumulative frequency distribution of total phosphorus loading rates based on wastewater monitoring at 17 residential dwellings in Colorado, Florida, and Minnesota, which included 24-hour flow-weighted composite sampling during each season (2008–2009) (Lowe et al., 2009).
Table 3. Concentrations of trace organic compounds associated with consumer product chemicals in wastewaters from 30 small residential, commercial and institutional sources (Conn et al., 2006).

<table>
<thead>
<tr>
<th>Trace organic compound</th>
<th>Use</th>
<th>Detection frequency</th>
<th>Concentration range (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caffeine</td>
<td>Stimulant</td>
<td>100%</td>
<td>0.5–E 9,300</td>
</tr>
<tr>
<td>Coprostanol</td>
<td>Animal sterol</td>
<td>100%</td>
<td>0.5–E 7,100</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>Animal sterol</td>
<td>100%</td>
<td>0.5–E 2,200</td>
</tr>
<tr>
<td>Ethylenediaminetetraacetic acid (EDTA)</td>
<td>Metal chelation</td>
<td>100%</td>
<td>0.5–1,700</td>
</tr>
<tr>
<td>4-Methylphenol</td>
<td>Disinfectant</td>
<td>98%</td>
<td>0.5–E 4,500</td>
</tr>
<tr>
<td>4-Nonylphenolethoxycarboxylates (NPEC)</td>
<td>Surf. metabolite</td>
<td>95%</td>
<td>2–320</td>
</tr>
<tr>
<td>Nitritriacetic acid (NTA)</td>
<td>Metal chelation</td>
<td>82%</td>
<td>0.5–130</td>
</tr>
<tr>
<td>4-Nonylphenol (NP)</td>
<td>Surf. metabolite</td>
<td>77%</td>
<td>2–340</td>
</tr>
<tr>
<td>4-Nonylphenolethoxylates (NPEO)</td>
<td>Surf. metabolite</td>
<td>75%</td>
<td>2–170</td>
</tr>
<tr>
<td>5-chloro-2-(2,4-dichlorophenoxy) phenol (Triclosan)</td>
<td>Antimicrobial agent</td>
<td>68%</td>
<td>0.5–82</td>
</tr>
</tbody>
</table>

1 E = estimated value (concentration exceeded maximum value on standard curve).

Onsite Treatment in Septic Tanks, Textile Biofilters and Membrane Bioreactors. In one CSM project, a septic tank, textile biofilter unit (TFU), and membrane bioreactor (MBR) were established at the Mines Park Test Site and used to treat wastewater from an 8-unit apartment building. Based on 16–28 months of monitoring, the overall effluent quality produced followed this relative ranking (higher to lower quality): ST-MBR > ST-TFU > ST (Figure 3). The TFU achieved an average removal efficiency (mg/L) of 90% for carbonaceous BOD (cBOD), 30% for nitrogen, and >95% for fecal coliform bacteria. The removal efficiency of the MBR was 99% for cBOD, 61% for nitrogen, and 100% for fecal coliform bacteria. The dissolved organic carbon in the effluents averaged 34, 11, and 6 mg/L for the ST, TFU and MBR, respectively. Organic carbon characterisation studies revealed that in addition to reducing the total concentration of organic matter in the STE, the TFU and MBR transformed the organic matter. The STE contained saturated organic compounds of low to high molecular weight. The TFU effluent had a buildup of humic and fulvic acid material that was more aromatic in character. The organic matter in the MBR effluent was similar to TFU effluent, but with more developed humic and fulvic acid substances. Directly related to the treatment efficiency achieved, the operational complexity, maintenance requirements, energy use and cost were higher for the MBR compared to the TFU, which was somewhat higher compared to a ST.

Studies of full-scale operating systems have also been insightful regarding system design and performance. For example, performance data were available for 30 onsite wastewater treatment systems installed at homes in Colorado (Wren et al., 2004). These data were evaluated and a subset of eight systems employing textile biofilter units was selected for additional investigation. Field monitoring revealed a wide variation in the effluent quality produced for BOD$_5$ (4 to 45 mg/L), TSS (1 to 83 mg/L), and total N (12 to 136 mg/L). A virus tracer using bacteriophages revealed a potential to achieve 99.9% virus removal. While unit operations and systems can have potential to produce high quality effluents, achieving this under field conditions requires proper design and routine operation and maintenance.

In another CSM project where trace organic compounds were characterised in wastewaters at 30 sites (see Table 3), additional monitoring was completed to assess removal in septic tanks, biofilters and constructed wetlands (Conn et al., 2006). Removal efficiencies ranged from <1% to >99%, with the efficiency dependent on treatment unit removal mechanisms and the properties of the trace organic compounds. For example, compared to anaerobic treatment in a septic tank, aerobic treatment in a textile biofilter enhanced the removal of trace organic compounds that could be aerobically biodegraded. In a companion project completed at the Mines Park Test Site, this relationship was further revealed, as the removal efficiency in a textile biofilter was generally greater than in a septic tank (Table 4) (Conn et al., 2010b).
Table 4. Concentrations of trace organic compounds in the effluents from a septic tank versus a textile biofilter used to treat wastewater from an 8-unit apartment building (Conn et al., 2010b).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Septic tank effluent</th>
<th>Textile biofilter effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOC</td>
<td>mg/L</td>
<td>30 (8.4)</td>
<td>16 (4.2)</td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>mg-N/L</td>
<td>34 (7.5)</td>
<td>3.8 (1.1)</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>mg-N/L</td>
<td>0.85 (0.48)</td>
<td>19 (3.8)</td>
</tr>
<tr>
<td>Caffeine</td>
<td>µg/L</td>
<td>34 (8.7)</td>
<td>0.87 (0.49)</td>
</tr>
<tr>
<td>Ethylenediaminetetraacetic acid (EDTA)</td>
<td>µg/L</td>
<td>24 (1.0)</td>
<td>33 (13)</td>
</tr>
<tr>
<td>Nitrilotriacetic acid (NTA)</td>
<td>µg/L</td>
<td>3.7 (2.3)</td>
<td>4.0 (1.9)</td>
</tr>
<tr>
<td>4-Nonylphenol</td>
<td>µg/L</td>
<td>3.3 (1.4)</td>
<td>&lt;RL of 2</td>
</tr>
<tr>
<td>4-Nonylphenolethoxycarboxylates (NPEC)</td>
<td>µg/L</td>
<td>63 (23)</td>
<td>7.3 (3.6)</td>
</tr>
<tr>
<td>4-Nonylphenolethoxylates (NPEO)</td>
<td>µg/L</td>
<td>1.6 (0.97)</td>
<td>&lt;RL of 1</td>
</tr>
<tr>
<td>5-chloro-2-(2,4-dichlorophenoxy)phenol (Triclosan)</td>
<td>µg/L</td>
<td>9 (3.3)</td>
<td>&lt;RL of 0.2</td>
</tr>
</tbody>
</table>

<RL = result was less than the reporting limit based on the methodology used.

In another project, a replicated factorial design was employed to evaluate three soil infiltrative surface architectures (ISA, open, gravel-laden or synthetic-stone laden) with domestic STE applied at two daily hydraulic loading rates (HLR) (4 or 8 cm/d) (Siegrist et al., 2005; Lowe and Siegrist, 2008). Pilot-scale infiltration trenches were established in Ascalon sandy loam soils at the Mines Park Test Site located on the CSM campus. Based on two years of monitoring, the effluent infiltration rate declined to very low levels due to soil clogging at the infiltrative surface with a time-dependent behaviour that was consistent with model simulations (Figure 4). After this period of decline, an open ISA maintained an infiltration capacity that was 40% to 80% higher than the other ISAs tested. Purification of STE in the soil was very high; the cumulative mass removal for dissolved organic carbon (DOC), total N and total P averaged 94%, 42% and 99%, respectively, while removal of bacteria and viruses exceeded 99.9%. While there was no significant difference in purification based on ISA or HLR, a slight increase in purification was associated with an increase in the soil vadose zone depth (e.g., 120 cm vs. 90 cm below the soil infiltrative surface).

Addition of a treatment unit to produce effluent of higher quality than typical STE has the potential to retard soil clogging and enable application of higher HLRs, resulting in smaller soil treatment units. Associated with the treatment unit study described (e.g., see Figure 3), the three effluents were applied to replicate pilot-scale infiltration trenches installed at the Mines Park Test Site (Van Cuyk et al., 2005). The results of bromide tracer tests and infiltration rate measurements made periodically during operation revealed that some degree of soil clogging occurred at the soil infiltrative surface in the sandy loam soil, even with application of the much higher quality TFU or MBR effluents (Figure 5).

When comparing system-wide purification (i.e., ST-soil vs. ST-TFU-soil vs. ST-MBR-soil), pollutant and pathogen removal efficiencies were very high. Moreover, soil pore water concentrations of pollutants (e.g., DOC, N, P) were consistent across different treatment systems and soil depths, even although the applied water qualities were quite different (Figure 6). The ability of a sandy loam soil to remove viruses was quite high (e.g., >99.99%
by 60 cm soil depth), and insensitive to whether STE, TFU effluent or MBR effluent had been applied at either 2 or 8 cm/d.

To understand the fate of trace organic compounds in a soil treatment unit, a controlled field experiment was completed at the Mines Park Test Site. The effluents from a septic tank or a textile biofilter (Table 4) were applied to the sandy loam soil and the soil pore water was periodically sampled at 60, 120, and 240 cm below the soil infiltrative surface.

Purification of trace organic compounds (e.g., caffeine, nonylphenols, Triclosan) in a soil treatment unit principally occurs by sorption and biodegradation processes. Achieving high removal efficiency for a particular organic compound thus depends on the properties of the compound as well as the process conditions present in the soil treatment unit (Conn et al., 2010b). For example, caffeine and Triclosan in septic tank or textile filter unit effluents were completely removed by 60 cm depth through aerobic biotransformation (Conn et al., 2010b).

Decentralised Treatment in Membrane Bioreactors
Membrane bioreactors can be a viable option for wastewater treatment and water reuse in applications such as neighbourhoods, high-rise apartment buildings or commercial developments. At CSM, a sequencing batch reactor–membrane bioreactor hybrid system (SBR-MBR) has been in operation for four years (Henkel et al., 2011; Cath, 2012; Vuono et al., 2012). The SBR-MBR was established through the Advanced Water Technology Center at CSM (www.aqwaterc.com) and is being used in a demonstration of tailored water reuse for a complex of apartment buildings on the CSM campus in Golden, Colorado (Figures 7 and 8).

For the purposes of this demonstration, tailored water reuse involves generation of water with different concentrations of nitrogen and phosphorus that can be used directly for plant irrigation. Research is investigating the effects of tailored water operations on system performance, including optimised approaches to control biological performance, sustain membrane performance, reduce energy requirements, and ensure robustness of the system.

As part of the demonstration, several operational strategies have been examined to determine their effects on effluent quality and energy consumption. Findings to date have revealed that by altering operations, tailored water reuse is possible by controlling the level of N and P removal.

Mathematical Models and Decision Support Tools
Models and Decision Support Tools can facilitate proper planning and design of onsite and decentralised systems. In one area of emphasis at CSM, analytical and numerical models of varying scope and complexity have been developed or refined to aid design of an isolated system or clusters of soil treatment units, as well as for assessment of onsite system impacts at the local, development and watershed scale (e.g., Beach and McCray, 2003; McCray et al., 2005; Poeter et al., 2005; Siegrist et al., 2005; Bumgarner and McCray, 2007; Heatwole and McCray, 2007; McCray et al., 2009, 2010; Geza et al., 2009, 2010, 2012).

A prime example of a model that can be used to predict purification performance of a soil treatment unit is STUMOD (Soil Treatment Unit Model) (Geza et al., 2009). STUMOD was originally developed to predict the fate and transport of nitrogen in a soil treatment unit. STUMOD calculates nitrogen species concentrations with depth in the soil profile (Figure 9a) and the fraction of nitrogen remaining with depth (Figure 9b). By repeatedly running STUMOD using randomly selected values from ranges of potential input values, the probability that a certain fraction of the total nitrogen in the effluent infiltrated will reach a specified soil depth can be estimated (Figure 9c).

Figure 7. Sequencing Batch Reactor-Membrane Bioreactor system established on the CSM campus and used for neighbourhood-scale wastewater treatment and water reuse at Mines Park (Cath, 2012).

![Figure 7. Sequencing Batch Reactor-Membrane Bioreactor system established on the CSM campus and used for neighbourhood-scale wastewater treatment and water reuse at Mines Park (Cath, 2012).](image)

Initial operation: SBR-MBR treatment efficiency:
- 97% COD removal (15.0 mg/L)
- 40% PO4 removal (3.4 mg/L PO4)
- 70% N removal (8.8 mg/L NO3-N) (expected N removal = 90%)

Optimised operation: SBR-MBR treatment efficiency:
- 97% COD removal (15.0 mg/L)
- 90% PO4 removal (< 1 mg/L PO4)
- 95% N removal (< 2.0 mg/L NO3-N)

![Figure 8. Illustration of the effluent quality from the SBR-MBR at Mines Park as affected by operational strategy (Henkel et al., 2011; Vuono, 2012).](image)
During the past 2 decades or more, research — such as highlighted in this paper — has advanced the science and technology of onsite and decentralised systems. However, research findings do not automatically yield improvements in practices. Clear and compelling research findings can certainly help foster improvements. But improved practices and advances in applications also require translation of research findings so they convey knowledge and know-how to designers, contractors, regulators, policy makers and others. This helps ensure that findings can be adopted into modern regulations and requirements.

It is also critical that research findings be incorporated into curriculum for the education of students who can help catalyse improvements and advances. Concerning this latter point, a semester-long course for seniors and graduate students has been developed at CSM and routinely delivered during the past five years. “ESGN460. Onsite Water Reclamation and Reuse” is a 15-week long course focused on the selection, design and implementation of onsite and decentralised wastewater systems. A textbook is being prepared to support delivery of this type of course and Springer will publish it by early 2014.

**ACKNOWLEDGEMENTS**

Numerous individuals and organisations have contributed to the research highlighted in this paper. The efforts of past and current students at CSM are gratefully acknowledged, including: John Albert, Jennifer Bagdol, Debbi Huntinger-Beach, Kathy Conn, Charlotte Dimick, Sarah Doyle, Kirk Heatwole, Shiloh Kirkland, Paula Lemonds, Andy Logan, Jim McKinley, Rebecca Parzen, Tanja Rauch, Nate Rothe, Kyle Tackett, Mia Tucholke, Dave Vuono, Ryan Walsh and Abigail Wren.

Current and former research staff and post-doctoral fellows include: Drs Sheila Van Cuyk, Mengistu Geza and Jochen Henkel. Contributing faculty have included the authors of this paper as well as Drs Jörg Drewes, Eileen Poeter, John Spear and Geoffrey Thyne.

Program funding has been acquired through CSM and its Research Foundation, the USEPA National Decentralised Water Resources Capacity Development Project, USGS National Institutes of Water Research, National Science Foundation, Water Environment Research Foundation and Department of Education, along with contracts and philanthropic grants from private industry.
unconventional sources.

bioremediation and methanogenesis from wastewater treatment and for desalination.

field of research is membrane processes for engineering and a PhD in Civil and a Bachelor's Degree in Mechanical concerning environmental remediation and natural systems for wastewater reclamation. She is Manager of the Mines Park Test Site.

Kathryn Lowe (email: klowe@mines.edu) is a Senior Research Associate at the Colorado School of Mines with over 20 years’ experience leading field investigations concerning environmental remediation and natural systems for wastewater reclamation.

Tzahi Y Cath (email: tcath@mines.edu) is an Associate Professor of Environmental Engineering at the Colorado School of Mines. He holds a Bachelor's Degree in Mechanical Engineering and a PhD in Civil and Environmental Engineering. Dr. Cath’s main field of research is membrane processes for wastewater treatment and for desalination.

Junko Munakata-Marr (email: junko@mines.edu) is an Associate Professor in Civil and Environmental Engineering at Colorado School of Mines. Her research and teaching interests centre on microorganisms in engineered environmental systems, including biological wastewater treatment, bioremediation and methanogenesis from unconventional sources.

REFERENCES


