018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

D3.2.1 - D3.2.3 Summary Report of WP 3.2 Safe Water Reuse

Due date of deliverable: April 2011
Actual submission date: April 2011

Start date of project: 1 February 2006 Duration: 60 months

Organisation name of lead contractor for this deliverable

Revision [draft, 1, 2, …]

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

EU SWITCH Project

Summary Report of

WP3.2 Safe Water Reuse

1. INTRODUCTION

Water reuse is a necessity and an opportunity to meet the increasing water needs of growing world population. Water reuse has now been accepted as an integral component of sustainable urban water management strategy. At the same time, it is important that several technologies available for water reclamation and reuse are applied effectively and efficiency ensuring that quality of the water produced from such reuse system meet the respective water quality standards.

In this context WP 3.2 Safe Water Reuse of EU SWITCH Project focused on innovative ways to promote safe wastewater reclamation/reuse including indirect potable reuse through use of appropriate environmental buffers. It aimed at promoting an integrated urban water management approach involving a semi-closed urban water cycle that includes subsurface and surface buffers that provide both storage as well as a sustainable natural-systems treatment barrier. The main objective of WP3.2 was to develop and demonstrate sustainable treatment (and storage) technologies for the promotion of safe waste water reuse. The specific technologies analyzed in this WP are (i) soil aquifer treatment, (ii) engineered environmental buffer, and (iii) aquifer storage and recovery.

2. COMPLETED RESEARCH AND MAIN FINDINGS

2.1 Soil Aquifer Treatment

In the area of soil aquifer treatment (SAT) six MSc studies (contributing to Deliverable 3.2.1), have been completed evaluating different aspects of SAT and pre-treatment technologies.

- Harun (2007) analyzed the removal of several contaminants (DOC, trace organics, nitrogen-species, and microbes) during SAT of primary, secondary and tertiary effluents, using extensive literature data and statistical techniques. Based on this study a guideline for the assessment and prediction of performance of SAT system was proposed.

- Al-Sakkaf (2008) investigated feasibility of SAT as pre-treatment of MF/UF membrane system. This study showed that SAT pre-treatment of wastewater effluents not only improves the DOC removal by MF/UF membranes but also reduces the fouling potential of these membranes. Furthermore, combination of SAT and UF removes different organic matter fractions substantially thus increasing the potential for water reuse.

- Fernando (2009) investigated the effectiveness of SAT and ozonation as pre-treatment of NF membranes by measuring removal of bulk organic matter and its fractions, and flux decline of NF membranes. The study showed that flux decline of NF membranes could be reduced by 6% to 19% by SAT pre-treatment. Ozonation of secondary effluent before SAT further improved DOC removal in subsequent NF membrane process.

- Caballero (2010) analysed the effect of SAT pre-treatment on the removal of organic micropollutants during nanofiltration (NF). It was found that majority of the OMPs tested were removed more than 70% during soil passage of 5 m while some compounds were persistent. Ozonation pre-treatment of SAT enhanced the removal of OMPs during soil passage and majority of OMPs were below the detection level in hybrid SAT system using Ozonaton + SAT + NF.

- Malolo (2010) studied the effect of temperature and redox conditions on removal of contaminants during soil aquifer treatment. For both primary and secondary wastewater effluent DOC and nitrogen removal increased with increasing temperature. DOC removal was higher at aerobic conditions than at anoxic conditions. Furthermore, it was observed that removal of phosphorus in the SAT system (from primary as well as secondary effluent) was relatively low (< 32%)

- Bernstein (2009) examined the use of electrofloculation to remove humic acids from water as a pre-treatment for membrane filtration using laboratory-scale jar test and ultrafiltration system and at pilot scale using ZW-10 Zenon membranes. It was observed that there was enhancement of TOC and UV254 removal with electrocoagulation pre-treatment .This implies that electrocoagulation could be used to remove humic acids (with similar character like Leonardit) and could serve as a pre-treatment method for membrane filtration systems.

These MSc studies showed that SAT is a low-cost, robust and multi-contaminant removal technology which is effective for removal of bulk organic matter, nitrogen, pathogens and selected organic micropollutants. It was found that performance of membrane systems could be improved by using SAT as a pre-treatment for membrane filtration. In general, it can be concluded that SAT could be used for further polishing of both primary and secondary effluent treatment and SAT +NF hybrid system is an attractive technology for water reuse.

In addition to the above Mekorot Water (Israel) have analyzed the effectiveness of short-term SAT-NF hybrid system in a study at the pilot-scale for comparison against the conventional long-term SAT treatment at the full-scale. A further comparison was made in terms of a UF-short-term SAT hybrid system and short term SAT - NF process studied as part of another EU project (RECLAIM WATER).

In the SWITCH pilot and demonstration-scale study, the SAT-NF hybrid work involved two pilot tests to effectively remove all organic matter including micropollutants and use minimum infiltration area:

(i) In first system, the short-term SAT is accomplished through infiltration secondary effluent by sand filtration and surface spreading at high velocity and water recovery at short-term (30 days retention time, 15 m. distance from infiltration)

and use of a relatively "open" Nanofiltration (NF) membrane (NF 270, 1000 Dalton) to remove most of the organic matter and micropollutants without removing salts. The operation of the NF is performed at 2-3 atm. at 90% recovery.

(ii) In the second system, short-term SAT is accomplished by dug-well infiltration of filtered secondary effluents followed by a tighter NF membrane (NF-90) for the complete organic and almost complete salt removal (DOC <0.2 mg/l, chlorides <50 mg/L, Ca <3 mg/L, sulfate <1 mg/L). The NF process is performed at 6 atm. working pressure and 70% recovery. This process is comparable to the UF-RO process for effluent desalination but at lower energy use.

Based on the findings of these studies, a "Guideline for design, operation and maintenance of SAT and Hybrid SAT system" has been prepared.

2.2 Engineered Environmental Buffer

In the area focusing an Environmental Buffer, five MSc studies were completed (contributing to Deliverable 3.2.2) and two PhD studies have been completed. The research conducted focused on selective phosphorus adsorption as a post treatment of membrane brines for environmental safe disposal and recycling and the performance of pre-biofiltration (artificial bank filtration) to remove fouling active compounds prior to membrane filtration.

- Wegmann (2007) investigated the removal of phosphate from membrane concentrates. The removal capacity of the adsorbent GFH was determined depending on pH and the concentration of competing water constituents.

- Riechel (2008) studied the regeneration and reloading capacity of the adsorbents GFH and FerroSorp along with an economic use of the regenerant. Precipitation of the desorbed phosphate and recovery of a highly plant-available P-fertilizer was also investigated.

- Warschke (2008) investigated appropriate treatment techniques to 1) increase the recovery of the membrane filtration to more than 98 % thus minimizing the volume of the concentrate stream, and 2) increase the concentrate quality to enable discharge into surface water bodies.

- The three MSc studies mentioned above were done in close collaboration with the ongoing PhD study of Alexander Sperlich on “Phosphate adsorption onto granular ferric hydroxide (GFH) for wastewater reuse”.

- González Tomaskovich (2008) investigated the influence of operational conditions and filter materials of bio-filtration on the removal of organic foulants prior to UF. The results show that the filtration rate (0.25 m/h and 0.5 m/h) have minor influence on the removal of organic foulants like biopolymer compounds at chosen experimental conditions. The influence of temperature (seasonal variation) on fouling content and UF operational conditions and cleaning strategies on flux recovery were investigated.

- Liang (2008) investigated the influence of operational conditions on the performance of UF filtering slow sand filtrate. Different chemicals are tested to identify the effect

on permeability recovery of fouled membranes. Based on these results, a technical and economical evaluation of the combination of slow sand filtration and UF for water reuse is conducted.

- Closely connected to the two MSc studies mentioned above, the PhD study of Xing Zheng (2010) investigated the role of major organic foulants in ultrafiltration of treated domestic wastewater and their removal by bio-filtration as pre-treatment.

2.3 Aquifer Storage and Recovery

The main activities of this task dealt with the injection of waste water into aquifers, and in particular analysis of the potential threats to groundwaters posed by viruses. The specific objective was (i) to determine the mechanisms controlling the natural attenuation of virus particles in an example matrix-flow–dominated aquifer and (ii) to develop a method for evaluating the likely mobility of virus particles in a given system. To achieve the research objectives of this study two approaches have been adopted (a) field experimentation and (b) field sampling and monitoring.

The main activities conducted in this task included:

- Modelling of the tracer redistribution in the field experiment to confirm the flow regime and the nature of the flow paths between the injection and withdrawal boreholes.
- Analysis of the uncertainties in the quantification of viral counts in the receiving boreholes through supplementary experimental work in the laboratory. Detailed experimental work has been undertaken to quantify the limitations of the experimental methods.
- Preliminary assessment of the viral re-distribution and breakthrough in the field experiment.
- Interpretation of the field, laboratory and modeling to determine the potential risks attributable to viral migration in sandstones.
- Monitoring of viral signatures in the Nottingham Borehole to confirm the association (or otherwise) of the link between deep groundwater viral populations and leakage from sewers in the vicinity of the borehole.

This work is directly linked to research activities on Hyporheic Zone (HZ) under WP5.3 Natural Treatment Systems.

3. KEYOUTPUTS AND PUBLICATIONS

Several MSc and PhD studies covering different aspects of Safe Water Reuse have been completed and some results of these studies have been published in peer-reviewed journal and international conference proceedings.

All the MSc and PhD studies related to WP3.2 are available at SWITCH project website: **http://www.switch.watsan.net/page/4941**

The results of the research activities in WP3.2 were published in several peer reviewed journals and presented in several international conferences. A list of WP3.2 publications are provided at the end of this report. All the publications in journals and conference

proceedings related to WP3.2 are available at SWITCH project website. **http://www.switch.watsan.net/page/5261**

One of the key output of this work package is ***Guidelines for design, operation and maintenance of SAT and hybrid SAT systems***: This guideline will assist the design engineers and planners in feasibility assessment, planning, design and operation and maintenance of different types of Soil Aquifer Treatment (SAT) systems depending on water quality and hydrogeological conditions.

4. TRAINING and DISSEMINATION

Two training workshops were conducted to disseminate the findings of the studies in this WP, together with that of WP5.3 on Natural Systems for Drinking Water Treatment.

- *Soil/Aquifer-Based Natural Systems for Drinking Water and Wastewater Treatment Training Workshop Tel Aviv, Israel (November 28 – 29, 2007).* Topics covered in this training included (i) Soil Aquifer Treatment (SAT): General Concepts; SAT as Practiced Historically in Israel; New Concepts Envisioned for SAT in Israel; SAT Hybrids with Pretreatment and/or Post-Treatment, (ii) River (and Lake) Bank Filtration (RBF): General Concepts; RBF as Practiced in Berlin as Semi-closed Urban Water Cycle; Framework for Feasibility Assessment of RBF; Appropriate Technology and Technology Transfer to LA Demo-Cities.

- *Natural Systems for Drinking Water and Wastewater Treatment, Training Workshop Accra, Ghana (February 26 – 27, 2009).* Topics covered in this training included (i) Soil Aquifer Treatment (SAT): General Concepts; SAT as Practiced Historically in Israel; New Concepts Envisioned for SAT in Israel; (ii) River (and Lake) Bank Filtration (RBF): General concepts; RBF as Practiced in Berlin as Semi-closed Urban Water Cycle; (iii) Framework for Feasibility Assessment of SAT and RBF; (iv) Constructed Wetlands: General Concepts; (v) Relevance/Application of Soil-Based Natural Systems in Ghana.

In addition to paper presentations in internal conferences and training sessions, the results of WP3.2 Safe Water Reuse were also disseminated to LA members and other stakeholder in different forums, some of them are listed below:

(i) Dr. Haim Cikurel (Mekorot Water) made a presentation on "Future scenario's for Soil Aquifer Treatment: Responding to change" during SWITCH Project Workshop on Learning Alliance in Tel Aviv Israel (10-11 December 2006)

(ii) Dr. Cikurel was invited by the Spanish representative of IWRA (International Water Resources Association) for an International workshop on: Artificial Recharge of Groundwater Management in Palma de Mallorca (20-23 October 2009). In this workshop, he made a presentation titled "New concepts envisioned for SAT in Israel", which was focused on the hybrid –SAT systems that was developed under WP3.2 of SWITCH project.

(iii)Dr. Cikurel also gave a presentation on "Soil Aquifer Treatment: Basic concepts, operability, troubleshhoting and new improvement" during Fecal Sludge Management Conference (5-9 July 2010), Accra, Ghana.

(iv) Dr. Cikurel has recently received other invitation for making presentation on Hybrid SAT Systems in "International Seminar on Water Reuse and Artificial Recharge" in UNAM (Universidad Nacional Autonimica de Mexico) on the 9-10th of June 2011 in Mexico City.

LIST OF PUBLICATIONS FROM SWITCH WP3.2 SAFE WATER REUSE

Publications in Journals/Books:

Aharoni A., Guttman Y, Tal N., Kreitzer T. and Cikurel H. (2010) SWITCH project Tel-Aviv Demo City, Mekorot's case: hybrid natural and membranal processes to up-grade effluent quality. *Rev Environ Sci Biotechnol*, 9:193–198

Joyce, E., Charles, K., Rahman, H., Aller, M. F., Durand, V., Riley, M. S., Greswell, R. B., Renshaw, J. C., Mackay, R., Rivett, M. O., Hart, A., Pedley, S. and J. H. Tellam (2008) Assessing the hazard from viruses in wastewater recharge of urban sandstone aquifers. In: Michael G. Trefry (ed), *Securing Groundwater Quality in Urban and Industrial Environments*, IAHS Publ. 324, ISBN 978-1-901502-79-4 566.

Sharma, S.K., Harun, C.M. and Amy, G. (2008) Framework for assessment of performance of soil aquifer treatment systems. *Water Science and Technology*, **57** (6), 941-946.

Sperlich, A., Warschke, D., Wegmann, C., Ernst, M. and Jekel, M. (2010) Treatment of membrane concentrates: phosphate removal and reduction of scaling potential. *Water Science and Technology*, **61** (2), 301-306.

Sperlich A, Schimmelpfennig S,Baumgarten B, Genz A, Amy G, Worch E. and Jekel M (2008) Predicting anion breakthrough in granular ferric hydroxide (GFH) adsorption filters, *Water Research*, **42**, 2073-2082.

Sperlich A., Zheng X., Ernst M. & M. Jekel (2008) An integrated wastewater reuse concept combining natural reclamation techniques, membrane filtration and metal oxide adsorption, *Water Science and Technology*, **57**, 909-914

Zheng, X., Ernst, M. and Jekel, M. (2009) Identification and Quantification of Major Organic Foulants in Treated Domestic Wastewater Affecting Filterability in Dead-end Ultrafiltration. *Water Research*, **43**, 238-244.

Zheng, X., Ernst, M. and Jekel, M. (2009) Effect of Slow Sand Filtration of Treated Wastewater as Pre-treatment to UF. *Desalination, **249**, 591-595.* .

Zheng, X., Ernst M. and Jekel, M. (2010) Pilot-scale investigation on the removal of organic foulants in secondary effluent by slow sand filtration prior to ultrafiltration. *Water Research*, 44 (10), 3203-3213.

Zheng X., Ernst M., Huck P. and M. Jekel (2010) Biopolymer fouling in dead-end ultrafiltration of treated domestic wastewater. *Water Research*, **44**, 5212-5221.

Zheng X., Ernst M. and M. Jekel (2011) Stabilizing the performance of ultrafiltration in filtering tertiary effluent-Technical choices and economic comparisons. *Journal of Membrane Science*, **366,** 82-91.

Publications in International Conference Proceedings:

Adin, A., Chen, Y. and Berenstein, R. (2007) Electrocoagulation of humic acid and its effect on membrane fouling reduction. *Proceedings of the International Water Association Conference on Particle Separation*, Toulouse, France.

Cikurel, H., Sharma, S.K. Jekel, M., Kazner, C., Wintgens, T, Amy, G., Ernst, M., Guttman, Y., Tal, N., Kreitzer, T., Putschew, A., Vairavamoorthy, K. and Aharoni, A. (2010) Alternative hybrid SAT-membrane treatments: Short SAT-NF treatment to upgrade effluent quality. *Proceedings of the IWA Regional Conference and Exhibition on Membrane Technology and Water Reuse* (18- 22 October 2010), Istanbul, Turkey, 193-205.

Sharma, S.K., Al-Sakkaf and Amy, G. (2009) Effect of soil aquifer treatment (SAT) pre-treatment of wastewater effluent on the performance of MF/UF/NF membranes. *Proceedings of Reuse 2009 Conference, Brisbane, Australia*, (21-25 September 2009).

Sharma, S.K., Hirpa, H.I, Kahawita, K.I and Amy, G. (2010) Removal of bulk organic matter from different wastewater effluents during soil aquifer treatment. *Proceedings of the IWA World Water Congress 2010 (19-25 September 2010), Montreal, Canada*.

Sharma, S.K., Caballero, M., Maeng, S.K. and Amy. G. (2011) Removal of Organic Micropollutants in SAT and Hybrid SAT Systems. *IWA Water Reuse 2011 Conference* (15-20 September 2011), Barcelona, Spain.

Sperlich, A., Warschke, D., Wegmann, C., Ernst, M. and Jekel, M. (2008) Behandlung von Membrankonzentraten bei der Abwasserwiederverwendung durch induzierte Fällung. Conference *Proceedings of the Annual Meeting of the German Water Chemical Society*, Trier (in German).

Zheng, X., Ernst, M. and Jekel, M. (2008) Quantification of Biopolymers in Treated Domestic Wastewater as Major Organic Foulants Affecting Fouling Resistance in Dead-end Ultrafiltration. Conference *Proceedings of the Annual Meeting of the German Water Chemical Society*, Trier.

Zheng, X., Ernst, M. and Jekel, M. (2008) Slow Sand Filtration of Treated Domestic Wastewater as Pre-treatment to UF: Effects of Operational Conditions on the Performance of UF Pilot Plant. Conference *Proceedings of the IWA World Water Congress*, Vienna.