Municipal wastewater reclamation: where do we stand?
An overview of treatment technology and management practice

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Abstract Water reclamation implementation and management practices at municipal wastewater treatment plants throughout the world are reviewed and some implementation and operational issues are defined. The information is based on a conventional literature survey, on an in depth survey study of European, Israeli and Australian medium and large-scale water reclamation utilities and on the findings of a dedicated international workshop.

The review identified over 3,300 water reclamation projects and designed the map of the main process technologies and their fields of product water application. The main conclusion of the enquiry is that the technological risks no longer represent a major concern for the development of water reclamation projects, rather issues such as the financing, failure management and social acceptance have become more critical.

Keywords Case studies; full-scale; mapping; municipal wastewater; review; water reclamation and reuse

Introduction

The water sector in Europe as well as in many other parts of the world is in a transitional phase with unique opportunities for water reclamation to be implemented on a larger scale as a sustainable practice within a framework of integrated water management.

The promotion of best practices for the implementation and operation of water reclamation schemes is more than ever needed. A sub-optimally managed project may result in adverse health, environmental or financial outcomes that may quickly shade away enthusiasm for water reclamation, hindering its development in the region.

Best practices should be firmly anchored to reality. Many municipal water reclamation facilities (MWRFs) already exist throughout the world yet, the information available is very dispersed or open to misinterpretation. Even information for a straightforward mapping of such basic indicators as facility location, treatment train and capacity, is difficult to collect, not to mention of basic management practices attached to the scheme including financing and community consultation as well as the technical aspects of operation, maintenance and monitoring.

An international survey was conducted to identify and evaluate the status of implementation and operational practice of municipal projects. The survey was carried out with the aim of preparing a single source of comprehensive information on implementation and operation of water reclamation schemes.

The purpose of this paper is to provide a synthesis of the survey. In-depth analysis will be provided in separate forthcoming publications.
Methodology
A database of municipal reuse schemes containing basic system data such as field(s) of application, process train, size and relevant public documentation of full-scale municipal water reclamation experiences was compiled. Data were collected from regional databases, national experts and literature. Seven geographical regions were analyzed: 1) North and 2) Latin America, 3) Europe, 4) Mediterranean Region and Middle East, 5) Sub-Saharan Africa, 6) Oceania and 7) Japan.

Best practices of management of water reclamation systems in the implementation/operation phase and challenges and constraints preventing implementation of best practice were reviewed through a literature survey. The survey addressed aspects such as type of ownership and financing, social and ecological impact assessment, quality control, failure and risk management, cost optimisation, process operation and maintenance of distribution and purification systems. The survey identified areas that need further investigation.

Responses from a self-compile questionnaire were solicited from identifiable European, Israeli and Australian projects producing a minimum of 0.5 Mm$^3$/y reclaimed water for unrestricted reuse or 2.5 Mm$^3$/y reclaimed water for restricted reuse. The questionnaire was compiled to determine the range of management practices implemented by each organisation and their efficiency and effectiveness. Participation of additional projects is possible and encouraged to enhance the content of the management guidelines.

Specific data gaps were also filled by the findings of a dedicated international workshop on operation of municipal wastewater reuse plants (www.aquarec.org), conducted in Thessaloniki, Greece earlier this year.

Status of municipal water reclamation facilities in the world
The review identified over 3,000 water reclamation sites, mostly in Japan (over 1,800) and the USA (over 800). In the EU and Australia the past decade has witnessed a faster growth with now an abundance of over 200 and 450 projects, respectively. Almost 100 sites were identifiable in the Mediterranean and Middle East area, with more than 50 in Latin America and 20 in Sub-Saharan Africa. Those numbers are destined to become quickly outdated. Many projects were identified in an advanced planning phase.

It is worth mentioning that other large water-stressed regions such as for instance China are also in the process of developing regional water reclamation programs (Pinjing et al., 2001), although they were not included in the survey.

The USA is by far the largest producer, with a volume of reused water estimated at close to 6.5 million cubic metres per day. While the USA have many medium to large scale schemes, most of the Japanese reuse projects are of small scale (Ogoshi et al., 2001). The statistics of the size distribution of the identified municipal water reclamation facilities (MWRF’s) in the different regions of the world is summarised in Figure 1. N.B.: The exact sizes of the Japanese applications were not available but were calculated by the figures provided by Ogoshi et al. (2001): the total reclaimed water delivered to a certain application divided by the number of facilities for that type of application.

With the exception of South Africa, reclaimed water produced by large-scale facilities is most commonly reused for agricultural and landscape irrigation. Small scale applications are mostly for urban, recreational and environmental uses.

The number of municipal water reclamation facilities identified throughout the world – sorted per field of reclaimed water application – is shown in Figure 2. The fields of application are split in five categories: 1) agricultural irrigation; 2) urban, recreational and environmental uses, including aquifer recharge; 3) process water for industry; 4) direct and indirect potable water production; 5) combinations of the above (mixed).

Figure 2 also shows the level of treatment – secondary, tertiary or quaternary – in the dif-
ferent regions. Secondary treatment – also including nutrient removal – is characteristic of restricted agricultural irrigation (i.e. for food crops not consumed uncooked) and for some industrial applications such as industrial cooling (except for the food industry). Additional filtration/disinfection steps are applied for unrestricted agricultural or landscape irrigation as well as for process water in some industrial applications (tertiary treatment). Quaternary treatment – indicative of production for quality comparable to drinking water – involves a “double membrane” step to meet unrestricted residential uses and industrial applications requiring ultrapure water.

Figure 2 shows that the main fields of application and the level of treatment differ significantly between regions:

Figure 1  Size distribution of the identified MWRF in the different regions of the world

Figure 2  Number of identified MWRF per field of application (bar-charts) and level of treatment (pie-charts with attached bar for main tertiary treatment processes) in different regions of the world
Secondary treatment prevails in Latin America (over 80% of the facilities) and in the Mediterranean and Middle East region (over 50%), with (restricted) agricultural irrigation as the main final use. In the latter, however, this high percentage stems mainly from the Maghreb’s facilities. The other countries have a higher degree of tertiary treatment.

Secondary treatment in Latin America is mainly achieved with stabilization ponds, technology common also to the Mediterranean region and to the Southern US states. Stabilization ponds are generally applied for small to medium scale projects; however some large-scale facilities have been also identified (Angelakis et al., 1999). Secondary stabilization ponds are considered as being able to produce an effluent quality suitable for restricted irrigation. Stabilization ponds may also be suitable for unrestricted irrigation (Mara and Pearson, 1998) in which case the land area required must be greatly increased (maturation ponds must be added, in some cases followed by disinfection).

Small-scale tertiary treatment constructed wetlands sites are quite common in Europe (especially in France and Spain), compared to other temperate regions. Larger applications are also found, especially in The Netherlands, where oxidation ditches are applied as secondary (pre)treatment (Claasen and Kampf, 2004). Kampf (2004) indicated that those systems would need a retention time longer than 4 days to deliver an effluent quality suitable for unrestricted irrigation.

Only few cases of soil aquifer treatment (SAT) could be identified, although large operational experience is available. For instance, the Dan region scheme in Israel, a very large-scale SAT scheme (120–140 Mm³/y), has been operational for more than 25 years. SAT is particularly suitable for unrestricted agricultural irrigation as it provides storage as well as treatment to a level comparable to drinking water quality (Icekson-Tal et al., 2003).

A traditional water reclamation tertiary process is the coagulation/flocculation, sedimentation, filtration and disinfection train, also known as Title 22 technology as it was introduced with the homonymous Californian regulation, the first water reclamation regulation in the world (and therefore possibly applying a more precautionary approach). Full Title 22 facilities are more common in the USA than in Europe or Australia who started later in the development of water reclamation and could benefit of the US experience. In Europe one third of the tertiary treatment technology is developed somehow based on that concept, whereas the full Californian Title 22 treatment is carried out only at a limited number of installations. Some European examples applying the full Title 22 requirements (0 FC/100 ml limit) can be found in Costa Brava, Spain (Sala et al., 2002). In the EU-Mediterranean countries, aiming at the 10 FC/100 ml limit (Spain, Greece, Italy, Portugal, Cyprus and also Israel) the most common process is coagulation – flocculation and direct (or contact) filtration followed by disinfection.

Different types of disinfection technology were identified. Despite the potentially toxic by-products formed, the main disinfection technique is chlorination (applied in almost 85% of the cases). We also identified 15 UV systems, 7 ozone systems and 13 combined technology systems (the most common being ozone plus chlorination or UV plus chlorination) out of more than 400 disinfection systems surveyed. Other disinfection technologies such as PAA are often proposed in scientific journals; only one full-scale application of PAA could be identified (in Milan, Italy), for indirect agricultural reuse.

It is worth noting that the effluent of a well designed and operated activated sludge plant may already reach turbidity levels lower than 3 NTU and therefore several unrestricted reuse applications require only filtration (no flocculation) and disinfection step. It is worth remarking that Title 22 allows filtration without flocculation if the effluent turbidity before filtration is less than 5 NTU.

Quaternary treatment: there is a growing trend for new larger scale plants to use double membrane processes such as microfiltration and reverse osmosis in addition to tertiary
treatment for reaching drinking water standards. In Australia examples are the Sydney Olympic Park and Rouse Hill near Sydney for reticulation through a “third pipe” for non-potable urban applications. The new plant about to be commissioned at Port Kembla will supply process water for an integrated steel mill and the plant at Luggage Point near Brisbane will supply an oil refinery. These applications are all replacing water from sources for potable use although in all cases the reuse water is used for non-potable applications. In Europe, a relevant example is the Wulpen aquifer recharge facility in Belgium preventing salt intrusion and serving as indirect drinking water production (medium-scale application). A similar but large-scale scheme has been operating for some years in Orange County California (Deshmukh, 2004). Examples of direct drinking water production are found in Windhoek, Namibia (Haarhoof and Van der Merve, 1996) and in Singapore (Leslie et al., 2003). So far very few agricultural applications could be identified on full-scale. An example is the Gerringong scheme in NSW Australia for effluent applied to dairy pasture.

MBR technology is increasingly applied for small-scale reuse facilities such as “in building” schemes and for community facilities (Hills and Malfeito, 2004). There are also significant expectations for the use of membrane bioreactors (MBR) for larger scale projects, from which the effluent might be reclaimed directly, for unrestricted irrigation, or as a pretreatment of reverse osmosis to produce drinking water quality. Some examples: the Empoli’s MWRF’s for industrial water supply (Lubello et al., 2003) and the Villafranque MWRF’s for agricultural irrigation (Angelakis et al., 1999).

Management issues: findings summary
Several implementation and operational problems have been inventoried, some of which are particular to water reclamation whereas others are common to all projects in the water and wastewater sector. This section will emphasizes the most relevant issues specific to reclamation projects.

The major bottlenecks for the implementation of efficient and effective management practices of water reclamation projects vary between regions. In several European regions most of them originate from the fact that water supply and wastewater treatment have historically developed separately and are often managed by different corporate entities. By contrast in Australia and Israel where water and sewerage management is normally the responsibility of a single corporate entity, the opportunities for reuse have been exploited to a much greater extent.

Financial issues
Most of the surveyed projects were financed accounting for cost-benefits without consideration of non-water supply benefits. Externalities such as for instance the scarcity of water and the marginal cost of new sustainable sources of water where existing sources are at – or beyond – their sustainable limit were rarely accounted for. Similarly the financial, social and environmental burdens of effluent disposal to the environment were rarely considered in the economic analysis.

Most of the projects benefited of financial incentives, especially direct grants to cover part of the initial investment. Water supply benefits alone are insufficient to carry the investment costs of improving the effluent, as market distortions of the water supply services are still significant. The price users pay for conventional water is rarely based on full cost recovery pricing principles and in some cases, such as Australia, this is politically not yet possible.

The current transitional phase of the European water management represents a unique opportunity to correct market distortions while providing, with water reclamation,
cheaper alternative to applications not requiring drinking water quality. EU Member States will have to promote cost recovery policies ensuring adequate incentives for users to use water resources efficiently by 2010 (EC 2000/60). For some productive applications this would be a politically tough task . . . unless (large amounts of) cheaper alternative water could be delivered, as the Israeli experience demonstrates.

Water reclamation projects have also benefited from several types of specific financial incentives, although to a lesser extent. Some examples include a recent regulation allowing exemption of the user tax for reclaimed water in Costa Brava (Mujeriego et al., 2000) or accelerated depreciation of financial interest of the initial investment in the USA (US Executive Order 12803/1992).

Economic disincentives to discharge of secondary effluent seem also important to encourage water recycling and water conservation. In Australia increased environmental standards or community expectations for effluent discharges have meant in some cases that the cost of treating wastewater to standards required to recycle water for some applications is less than the cost of treatment and/or effluent transfer required to meet the more stringent discharge regulatory requirements. This may become true in some European regions where the quality of the surface water is far from reaching a good status, the discharge of secondary-treated sewage is still a major concern and/or groundwater over-extraction is now a major problem.

Inadequate education, training, understanding

With exception of industrial and institutional projects the public acceptance of reclaimed water was often a critical factor for the financial sustainability of the project. Several projects did not meet the economic promises because they were delayed or running at a lower yield, as a result of the reluctance of the end user to use treated wastewater (most of the surveyed projects relied on voluntary participation of customers). Often despite pro-active public outreach efforts since the planning phase.

It is important noting that the perception revealed by the European survey is that, in the view of some public administrations and of the civil population, treated wastewater still remains basically wastewater. It is not widely known on the other hand that in many urban and semi-urban areas in Europe surface or ground waters have (still) a bacterial quality worse than that of a secondary-treated wastewater. In many existing urbanized catchments the water cycles actually include indirect, unplanned and uncontrolled (!) reuse of – sometimes even untreated – wastewater.

But facts and figures might inflame rather than convince. The acceptance of water recycling is a social factor with high emotive content. In some cases the involvement of local NGO’s and environmental associations was a critical success factor, as the Empuriabrava project, Spain clearly demonstrates (Sala and Serra, 2004). Their involvement in building up credibility, trust and confidence is often underestimated.

Lack of national quality standards and the inadequate training of public administrations led in some cases to the setting of questionable permits. An extreme example is a project where the effluent complied to strict standards for unrestricted agricultural irrigation, but the public administration released a permit basically referring to WHO’s recommendations on irrigation with raw wastewater (and with that virtually terminated the project).

Lack of communication/collaboration between the water and wastewater sector

The enquiry covered four types of ownership structures: 1) where water and sewerage management is the responsibility of a single corporate entity (most prevalent), where 2) the water or 3) the wastewater company managed the water reclamation project, or 4) where ad hoc project-related structures were set up. The enquiry highlighted that in the way the water
and wastewater market in some European regions is structured today, collaboration between different entities is far from evident. Poor institutional agreements were in some cases the only reason for delaying the project.

On the other hand the importance of cooperation with the local water supplier (and with neighboring reclamation schemes) for project success cannot be overemphasized, as the international experience demonstrates (e.g. Hermanowicz et al., 2001). Examples of ad hoc types of synergies between the water and wastewater sector could be identified. Those experiences indicated that the question of ownership is not a problem per se rather it is tied to that of legal responsibility, access and above all financing and cost allocation (Maas, 2004).

**Operation and maintenance issues**

Management practices of process operation, quality control and failure management varied considerably from region to region and even from project to project. It is worth noting that acceptable risk is generally very location-specific which does not fit within international guidelines (Anderson et al., 2001), and that international agreement on standard practices on the assessment of risks is far from being reached.

Despite the fact that procedures such as Hazard Analysis and Critical Control Points (HACCP) are increasingly used to direct efforts in process control and monitoring to guarantee hygienically safe reclaimed water (Dewettinck et al., 2001; Salgot et al., 2003; Cunliffe and Stevens, 2003), very few surveyed projects have used them.

Liabilities and risks of the different management practices could not be compared. Only one project experienced a property damage claim and even in that case, the water was used for purposes not covered by the contractual agreement between the supplier and the customer. It is interesting to note that very few surveyed projects seem concerned about emerging issues such as trace organic contamination.

A common trait in process operation and risk management of the surveyed projects is the adoption of extensive quality control practices and in particular the widespread use of instrumentation, control and automation. Contrarily to the common perception that sensors are one of the weakest points in on-line monitoring and control, the respondents have expressed quite a high degree of satisfaction with the performance and reliability of many types of monitoring equipment. Most common types of reclamation-specific real time/remote control were related to on-line turbidity and conductivity measurements.

Many respondents gave particular importance to the management of reticulation systems especially where reclaimed water is reticulated in close proximity to potable supplies. Several types of contractual agreements were identified to limit the liability of the water supplier on the one hand, and to insure that operation and maintenance is practised in a safe and responsible manner, on the other. The experience in Australia, at Sydney Olympic Park (Listowski, 2004) and at Rouse Hill in Sydney (De Rooy and Engelbrecht, 2003) is to manage the system with comprehensive inspection during construction and with follow up inspections and certification. In Israel, in case of a pipe leakage the farmer is immediately notified and the water utility will have to repair the leakage in a time delay up to 24 hrs. Water supply interruptions of 24 hrs are already sufficient for some crops to deteriorate.

Detailed experience on preventive maintenance of distribution systems was gained. In Israel for instance, to prevent clogging problems in irrigation systems, main distribution lines, zooplankton and algal blooms in reservoirs, at the start of the irrigation season slug chlorination (50 mg/l) is applied as plug flow to clean the long standing lines and the lines are flushed with effluents. In high demand season, once a week for 4 hrs., 12–15 mg/l Cl₂ is applied to the main lines (usually at weekends), the end-user is notified and he has to flush his irrigation system with effluents before irrigation. At the exit of effluent reservoirs
80–120 mesh wire strainers are used, fish is used as biological control against zooplankton. Copper sulfate is used against algae or a natural product (Degilin) is used against zooplankton, in blooming seasons.

In SAT and the distribution systems, particular attention is paid to the optimisation of recovery wells operation to prevent high sand concentrations in pipes, biofilm and Mn and Fe depositions.

Recent full-scale experiences with double membrane systems provided promising results regarding process robustness and preventive maintenance practices (van Houtte and Verbauwhede, 2004; Deshmukh, 2004).

Conclusions
Many full-scale municipal water reclamation facilities exist throughout the world. This paper provides an overview on the type of treatment level and technology most commonly applied in different geographic areas, as well as universal challenges in implementation and operation of those schemes.

The review indicates that there is much we can learn from each other and that the need of uniform implementation and operational management guidelines is real and urgent. The survey set out in this paper is a first step towards the establishment of a single source of comprehensive information that takes in full account the needs of the water reclamation utilities.

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