Best practices for Sustainable Urban Water Cycle Systems

AN OVERVIEW OF AND ENABLING AND CONSTRAINING FACTORS FOR A TRANSITION TO SUSTAINABLE UWCSs

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TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW

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An overview of and enabling and constraining factors for a transition to sustainable UWCSs

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1. INTRODUCTION

Climate change, population growth and migration, increasing urbanization and ageing infrastructure are all expected to impose significant strains on urban water cycle systems (UWCS) in Europe and elsewhere over the coming decades. Cities across the continent will experience increasingly frequent shortfalls in the supply and demand balance, particularly during the summer months. More intense rainfall events will lead to local flooding of properties and transport systems and to pollution of receiving waters. Sustainable solutions to these challenges need to be sensitive to long-term investment needs, but also to increasing energy prices, demands for low carbon intensity solutions, and the need to reduce gas emissions from urban activities.

The TRUST project aims to create co-produced knowledge that urban water utilities can use for planning and justifying transitions to a sustainable UWCS. In D12.1 of the TRUST project, the various steps in such a planning process are presented (for details, see D12.1). At a certain stage in this process utilities will define their strategic options and design and select a strategy. The current Deliverable 11.1a presents an overview of best practices that might support water professionals and other urban stakeholders in identifying possibilities for strategic options. A best practice in this deliverable refers to an on-the-ground practice where an approach, technology or technique has been implemented successfully.

Practices in four different themes are addressed. These are demand management, reuse and recycling, water and energy, and leakage and loss reduction. For the description of best practices, policy documents, strategic plans, research reports and scientific articles were collected for every theme. Whenever these sources allowed for, transferable lessons are presented. These lessons are derived from the identification of enabling and constraining factors for the successful on-the-ground implementation. Factors that are taken into account involve four different levels (drawn from Brown et al., 2006):

- the individual level referring to technical knowledge, skills, expertise, the way in which individuals operate within the workplace and personal characteristics;
- the intra-organizational level referring to key processes, systems, cultures and resources within organizations;
- the inter-organizational level referring to agreements, relationships and consultative networks between organizations;
- the administrative and regulatory level referring to the overall approach of underlying principles, national and international regulations and policies and incentive schemes.

This report presents best practices in separate chapters: demand management in chapter 2, reuse and recycling in chapter 3, water and energy in chapter 4, and leakage and loss reduction in chapter 5. Each chapter contains (1) a description of best practices and (2) – as far as the sources enabled – factors enabling or constraining the transition to sustainable UWCSs.

2. DEMAND MANAGEMENT

2.1. Introduction

Water Demand Management (WDM) is the implementation of policies or measures that serve to control or influence the amount of water used (UKWIR/EA, 1996). A more comprehensive definition is given by the Department of Water Affairs and Forestry, South Africa (DWAF, 1999): "water demand management is the adaptation and implementation of a strategy (policies and initiatives) by a water institution to influence the water demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services and political acceptability". A definition from a social perspective is that WDM is a practical strategy that improves the equitable, efficient and sustainable use of water. This is achieved by: (i) stressing equitable access to water, reflected in a strategy that is specifically designed to improve service delivery to the poor; (ii) treating water as both an economic as well as a social good, and managing and pricing it accordingly; (iii) balancing the management of losses and consumption with new or augmented supplies; (iv) and managing the change from a supply driven to a demand responsive culture (Derevill, 2001).

This report includes examples that fall into one or more of the five categories of actions given in the definition of WDM by Brooks (2006). The five categories are: (i) reducing the quantity or quality of water required to accomplish a specific task (e.g. install water efficient household appliances); (ii) adjusting the nature of the task so it can be accomplished with less water or lower quality water (e.g. use of rainwater or seawater for toilet flushing, increase public awareness, introduce techniques of low water gardening); (iii) reducing losses in movement from source through use to disposal (e.g. pressure control, leakage control); (iv) shifting time of use to off-peak periods; and (v) increasing the ability of the system to operate during droughts (e.g. town-scale integrated management).

2.2. Best practices

2.2.1. Case 1: Public awareness in Jordan

In Jordan, the water demand exceeds the available renewable water resources which have been overexploited to bridge the gap. The adoption of a new strategy for water planning is crucial because this situation cannot be maintained without endangering sustainable development. For this reason, a National Water Master Plan has been developed for Jordan in 2004 while a National Water Strategy was developed and approved in 1997. A Water Demand Management Unit (WDMU) was established at the Ministry of Water and Irrigation by the end of 2002 to undertake the responsibility of Water Demand Management Programs for all sectors in Jordan. The plan examined the water resources in the country and its management issues, as well as institutional and regulatory issues. The level of water awareness among the public in the Middle East and North African countries is not consistent. However, in Jordan awareness is judged to be high. The Ministry of Water and Irrigation through the Water Demand Management Unit supports initiatives to increase awareness of water issues in the country. A major part of those activities were implemented under a five year program known as Water Efficiency and Public Information for Action Program (WEPIA). A second program has started with the title Instituting Water Demand Management in Jordan (IDARA). This nationwide program is focusing on instituting sustainable water demand management by helping to establish the required institutional and regulatory framework in the country.

Under the WEPIA project, the Royal Society for the Conservation of Nature (RSCN) and the Ministry of Education pioneered the process of bringing critical water issues to the centre of public discourse in Jordan. It was a five-year program, started in 2000, that sought the creation of a water conservation ethic in the general population of Jordan, implemented water-saving technologies to achieve significant savings, and institutionalized the processes it used. WEPIA sought to improve the knowledge, attitudes, and behavior of Jordanians regarding water issues. This project included: NGO capacity building, community grants, water audits and building retrofits, media campaigns, and training workshops. Thanks to this program and to the collaboration with the Ministry of Education, interactive water education programs are today widely available and accessible to teachers, students in public and private schools, religious leaders, and NGOs. As part of the educational strategy (Hussein, 2010):

- a water conservation curriculum has been integrated into school textbooks grades 1–11 in five subject areas since December 2002.
- an interactive CD for Children on Water Demand Management concepts, to support school curriculum concepts has been developed.
- steps have been taken to establish a master's degree program in Water Demand Management at Jordan University for Science and Technology in Irbid. This master program is a pioneering program that includes a series of highly specialized courses in Water Demand Management such as Best Management Practices, Demand Forecasting and Analysis, Strategic Planning for Water Demand Management; Planning Urban Demand Management Programs, Alternative Water Supply; and Water Demand Management in Agriculture. This program is designed to create a pool of specialized professionals to institutionalize domestic demand management. As part of the WEPIA program, more than 50% of religious leaders received training and materials on water issues and conservation techniques.
- WEPIA conducted a widespread media campaign to disseminate its message through television, radio, newspaper and magazines, to explain the water situation and how to participate in efforts in conserving water or using water more efficiently. Within each theme, issues such as scarce water resources, sector consumption of water, misuse of groundwater,

water-saving devices, water cost, and importance of water to industry were included.

Another relevant recent project in this field is the Awareness Project in Water (APW), implemented since 1994 by the Jordan Environment Society in cooperation with the Ministry of Water and Irrigation and USAID for about five years. Over 5,000 people throughout the Kingdom in different targets have attended workshops, lectures, seminars and special events to learn about water conservation and discuss local needs. The aims of the APW were: the creation of general awareness through mass media campaigns and development of local human resources by training selected leaders from voluntary organizations.

The role of the NGOs was also very important in the effort to raise public awareness over water issues in Jordan. Some of these projects are launched with the cooperation or input of the Ministry of Water and Irrigation. However, the majority are implemented fairly unilaterally from NGOs or international organizations such as the United Nations. Friends of the Earth Middle East (FoEME)/EcoPeace and the Royal Society for Conservation of Nature are just a few examples of groups who work in Jordan to promote awareness over water issues through many different ways such as: eco-tourism, activities in schools, technical training courses, recreational community events, various forms of media and instructional pilot projects.

However, probably more could be done. For example, existing public awareness campaigns could be adapted to include more specific information on Jordanian water conservation success stories. Along with the general water awareness themes, existing public campaigns could examine recent customer success in saving water (Hussein, 2010).

2.2.2. Case 2: Water Budget Rate Structure in California

Being in a semi-arid climate, California has faced frequent and prolonged droughts. In a typical policy intervention, state agencies and water utilities responded (in the urban sector) by either cutting water allocations to users or by dramatically increasing water tariffs, or both. The prolonged drought of 1986-1991 has resulted in many cases where water utilities went bankrupt, due to the fact that the conservation impact of their water pricing decreased dramatically the demand for water and the stream of revenue to cover their fixed costs. Motivated by the previous, water utilities in Southern California have pioneered since 1991 the Water Budget Rate Structure (WBRS). WBRS implements the four basic targets of a successful pricing scheme that according to Whittington (2003) are:

- **Revenue sufficiency**. From the water supplier's point of view, the main purpose of the tariff is often cost recovery. The revenue from water users should be sufficient to pay the operation and maintenance costs of the water utility's operations, repay loans undertaken to replace and expand the capital stock, provide a return on capital at risk and maintain a cash reserve for unforeseen events. The revenue stream must thus be adequate to attract both equity capital and debt financing. Ideally the revenue stream should be relatively stable and not cause cash flow or financing difficulties for the utility.

- **Economic efficiency**. Economic efficiency requires that prices be set to signal to consumers the financial and other costs that their decisions to use water impose on the rest of the society. From an economic efficiency perspective, a tariff should create incentives that ensure, for a given water supply cost, that users obtain the largest possible aggregate benefits. This means that volumetric water charges should be set equal to the marginal cost of supplying water. When capacity is constrained and water is scarce, it is commonly assumed that the marginal cost of supplying water can be approximated by the average incremental cost (AIC), i.e. the average cost of water from the next water capacity expansion project. Alternatively, the AIC of additional water may be the unit cost of reducing unaccounted-for-water.
- **Equity**. Equity means that the water tariff treats similar customers equally, and that customers in different situations are not treated the same. This would usually be interpreted as requiring users to pay monthly water bills that are proportionate to the costs they impose on the utility by their water use.
- **Poverty alleviation**. Many people feel that water services are a "basic right" and should be provided to people regardless of whether or not they can pay. This objective leads many people to recommend that water services be provided free, at least to the poor. Providing water free, through private connections, conflicts with the objectives of cost recovery and efficient water use.

WBRS is a tiered pricing scheme, but it differs from the traditional increased tier pricing schemes in that it is designed to provide revenue security to the water utility and at the same time guarantee fairness to the customers. Fixed costs of service are handled, mainly by political compromise. Of the amount calculated as fixed cost of service, utilities distribute certain percentage as fixed (irrespective of water use by the customer) and the remaining percentage as variable, assigned to the amount of water used. Utilities are aware of the trade-off between risk of low cost recovery of the fixed share and customer dissatisfaction from higher rates. Common practice among water utilities is to set the ratio off fixed cost distribution between the fixed and the variable portion of the bill to 20-30 and 80-70% respectively.

The WBRS is comprised of fixed costs and variable cost components. The fixed cost part is kept at a both a reasonable level for the customers and the water utility. The variable costs are comprised of several increasing tiers (between 4-6), depending on the water utility. The first and second tiers represent reasonable use of water by about 75% of the customers. The first tier in each WBRS refers to indoor water use and the second tier refers to outdoor water use.

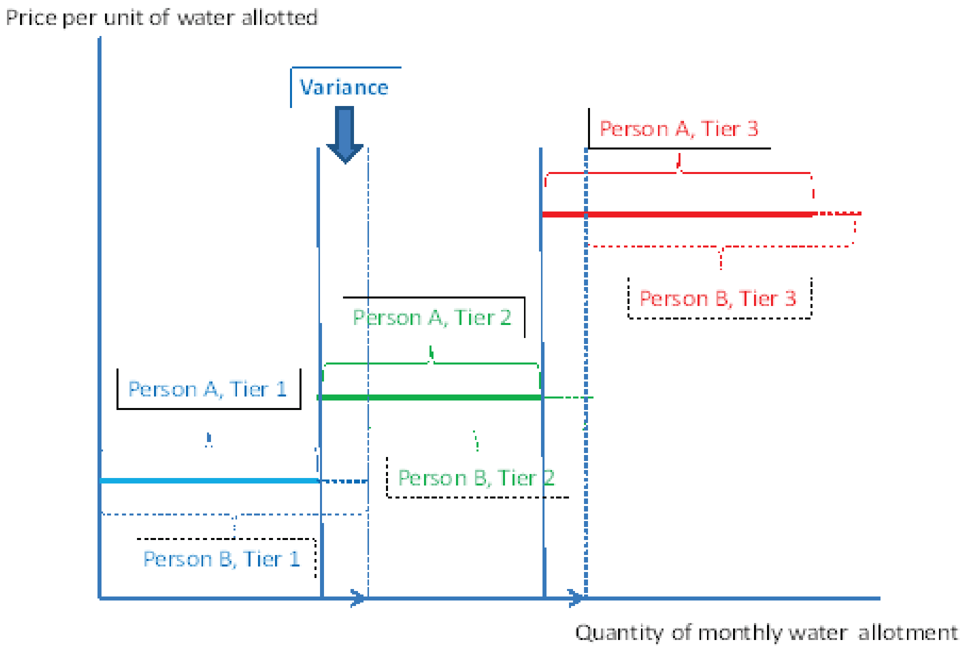

Figure 1: Tariffs of customers A and B, where B requested to adjust tier 1 to his specific conditions (Dinar, 2011).

Customers that exceed the first two tiers are considered not-efficient and face a significantly higher prices per unit of water consumed, compared to the second tier. Many water utilities compute the prices of the tiers following the second tier, by using the next alternative for water (the opportunity cost approach), such as imported water or water that are associated with much higher cost of provision. The WBRS is applied to the service area of the utility, using normative parameters. Customers are given then the option of requesting to adjust the tiers (Variance) to their own parameters. A simple scheme of the WBRS with two customers, A and B (where customer B requested to adjust tier 1 to her specific conditions is provided in the figure above. Customers can request variance in tier 1 and/or 2 only (Dinar, 2011).

The agencies that adopted WBRS succeeded in stabilizing revenues, reducing risk of revenue loss when customers use less water, increasing water efficiency, improving customer services and even reducing urban runoff.

2.2.3. Case 3: Progressive water tariff structure in Singapore

The Public Utilities Board of Singapore (PUBS) is using a progressive water tariff structure that penalizes the inefficient water usage. Effective from July 2000, domestic consumption of up to 40 m^3/month and non-domestic uses are charged at a uniform rate of €0.71/m^3 (S$ to € conversion at 7/2/2012). For domestic consumption of more than 40 m^3/month, the tariff becomes €0.85/m^3, which is higher than non-domestic consumption. In addition, the water conservation tax (WCT) that is levied by the Government to reinforce the water conservation message is 30% of the tariff for the first 40 m^3/month for domestic consumers and all consumption for non-domestic consumers. However, domestic consumers pay 45% WCT, when their water consumption exceeds 40 m^3/month. In other words, there is a financial disincentive for higher water consumption by the households. Similarly, water-borne fee (WBF), a statutory charge prescribed to offset the cost of treating used water and for maintenance and extension of public sewerage system, is €0.18/m^3 for all domestic consumption (Tortajada, 2006).

The impact of this pricing policy was that the consumption in 2004 was 11% less than in 1995. During the same period, the average monthly bill has more than doubled. These figures indicate that the new tariffs had a notable impact on the behavior of the consumers, and have turned out to be an effective instrument for demand management. This is a positive development since the annual water demands in Singapore increased steadily, from 403 hm^3 in 1995 to 454 hm^3 in 2000. The demand management policies introduced have resulted in lowering of this demand, which declined to 440 million hm^3 in 2004.

This tariff has several distinct advantages, among which are the following (Tortajada, 2006):

There is no "lifeline" tariff which is used in many countries with the rational that water for the poor should be subsidized since they cannot afford to pay high tariffs for an essential requirement for human survival. The main disadvantage of such a lifeline tariff is that it also subsidizes water consumers who can afford to pay for the quantity of water they actually consume.

The poor who cannot afford to pay for the current water tariffs receive a targeted subsidy. This was considered a more efficient policy in socio-economic terms, instead of providing subsidized water to all for the first 20-30 m^3 of water consumed by all households, irrespective of their economic conditions.

The current domestic tariff of water consumption up to 40 m^3/month/household is identical to the non-domestic tariff. Both are set at €0.71/m^3. In other words, commercial and industrial users do not subsidize domestic users, which is often the case for numerous countries.

The tariff structure penalizes all those households who use more than 40 m^3 of water per month. They pay the highest rates, €0.86 m^3, for consumption above this level. This rate is higher than the commercial and the industrial rates, and is a somewhat unusual feature compared to the existing norm.

Water conservation tax (WCT) is 30% of the tariff for all consumers, except for domestic households who use more than 40 m^3/month. The WCT on consumption of each unit higher than 40 m^3/month goes up by 50%, from 30% to 45%, which must be having perceptible impacts on household behavior in terms of water conservation and overall demand management.

Water-borne fee (WBF) is used to offset the cost for treating wastewater and for the maintenance and extension of the public sewerage system. It is set at €0.18 m^3 for all domestic consumption. For non-domestic consumption, this fee is doubled, €0.37/m^3, presumably because it is more difficult and expensive to treat non-domestic wastewater.

A Sanitary Appliance Fee (SAF) is also levied per sanitary fitting per month. It is currently set at €1.8 per fitting.

There are two components to water tariff. A major component of the overall revenue collected through water tariffs accrue to the PUBS recovering all operation and for considering maintenance costs and new investments. However, revenue from WCT accrues to the government and not to PUBS.

This pricing scheme is combined with a proactive management of the company installations. PUBS, through a program of leakages and losses minimization and elimination of illegal connections, has achieved a remarkably low unaccounted for water (UFW), which is 5%. This is a level which no other country has matched at present. In comparison, in England and Wales the best any private sector companies have managed to achieve is almost twice the level of Singapore. Similarly, UFW in most Asian urban centers now range between 40 and 60%.

2.2.4. Case 4: Metering in Ontario and Sofia

Although installed meters do not conserve water directly, they do help in determining the effectiveness of conservation measures. Metering also serves to implement conservation measures such as pricing and mandatory rationing of water and these cannot be implemented without meters. In addition, meters are also necessary to determine system losses. Excessively leaky portions of a distribution system and leaks inside buildings are more easily identified if the system is completely metered. Many water supply companies print a message on the water bill to alert the customer to high consumption. It advises the customer to check whether there are leakages in the plumbing system and to take appropriate follow-up actions if the consumption of this period is significantly higher than the consumptions of previous periods. Moreover, it is argued that metering, and hence cost is a direct incentive to reduce household consumption. Thus, metering perhaps is more than an indirect conservation measure.

There are examples of the effectiveness of water metering for water conservation from several countries. According to an Environmental Canada's study (Gan, 2000) on average an unmetered household used about 50% more water than a metered households in Calgary and in Edmonton. Also, the metering improvement programmes implemented in the latter part of last decade in four cities in Ontario reduced the water consumption by 15–27% on a long-term basis. A meter installation policy was also implemented in Sofia, Bulgaria when the water supply situation became critical (Dimitrov and Alitchkov, 1992). By the end of 1995, all consumers had to install individual water meters for measuring their consumption. The cost of meters repair is included in the price of water. Studies of water consumption in

Sofia showed that users who installed individual meters consumed about 10% less water than those with common meters.

2.2.5. Case 5: Examples of efficient household appliances

Washing machines

The THELMA project (The High Efficiency Laundry Metering & Marketing Analysis; THELMA, 1997) consisted of lab and field testing of washing machines. The field testing included 26 machines in different locations in the Pacific Northwest and California. The project included focus groups, which were conducted in Bellevue, Washington and Concord California in February 1995. The average saving per week was 370 lt (with 90% confidence intervals is 332 to 412 lt/week).

Self-closing faucets

A joint initiative between Southern Water, the Environment Agency and West Sussex County Council in the UK aimed to demonstrate the water and cost savings achievable in a practical school environment and to provide information and know-how that could be applied more widely. The project was conducted in Chesswood Middle School, Worthing (Styles and Keating, 2000). Options considered included retrofit push taps, spray taps and spray inserts. Ease of use, costs and likely misuse by pupils were discussed and finally, the self-closing push taps were chosen over the other options. The chosen model was the "Plush" tap, which retrofits to an existing tap. The "Plush" tap has an in-built flow restricting device which provides the means to further reduce consumption. The timing was adjusted to allow a flow of six seconds duration and the flow rate was restricted to 6 lt/min.

The reduction achieved by changing the taps was of the order of 508 lt/day, or 13% of the pre-installation consumption. In terms of the daily water use patterns, the majority of the reduction was from peak use and late afternoon, (possibly by cleaning staff) use. However, there were no complaints from the cleaners regarding the ease of use of the taps. The quality of the cleaning was not affected, indicating that prior to the push taps fitting the use of water for cleaning may have been unnecessarily high. There was also a slight reduction in night use, possibly because push taps cannot be left turned on.

Toilets

In a series of studies in the US Aquacraft (1999) calculated that net water savings between homes with low-flush-toilets and other homes was 38 lt per capita per day. Water consumption for toilets at the low-flush-toilets homes was 91 lt per household per day while water consumption for toilets at all other homes was 179 lt per household per day.

Urinals

In a project conducted in the Chesswood Middle School, Worthing (Styles and Keating, 2000), two options were examined, passive infra red controls (battery or mains operated) and waterless urinals. After considering the patterns of urinal use, cleaning regimes at the school and maintenance costs, the battery operated Passive Infra Red (PIR) controls were chosen as the preferred option. Following the installation of the PIR controls, the school's daily water consumption reduced from an average of 8746 lt over the 34 day base period (school days) to 4006 lt/day over the following 14 day period. This is a reduction of some 55% of the pre-installation levels. The savings arise mainly from the drastically reduced background night levels. However, it is unlikely that this entire reduction is due to the installation of the urinal controls because during the long summer holiday, the average daily consumption, probably due to the free flowing urinals, was reasonably constant at around 3600 lt/day.

During term time, consumption within the school starts to rise around 8:00am and returns to the base flow some 12 hours later. Outside of this period, a consumption of some 1800 lt was typical before the installation of the urinal controls and arguably 1800 lt were also used during school hours. Following the introduction of the controls however, outside hours use effectively reduces to zero, whilst daytime use continues at around 1800 lt. This gives a saving of some 1800 lt/day. During weekends and holidays, the picture is somewhat different. The average weekend consumption, which is likely to comprise the regular hygiene flushes only, is approximately 360 lt/day. Therefore, assuming a 40-week school year, the introduction of the urinal controls is estimated to save some 895 m^3, or 68% of the pre-installation consumption in a full 12-month period.

2.2.6. Case 6: Residential Water Conservation in Miami-Dade, USA

In response to increasing water demand, Miami-Dade County, FL, USA implemented water conservation incentives for the residential customers. These incentives include rebates and unit exchange programs for showerheads, toilets and clothes washers.

Water conservation practices promoted by Miami-Dade Water and Sewer Department (MDWASD) assist end-users to implement efficiency measures to reduce water demand. Water conservation practices promoted by MDWASD include projects such as senior and low income family full retrofit program, high efficiency showerhead (SH) exchange program, high efficiency toilet (HET) rebate program, and high efficiency clothes washer (HEW) rebate program. For the rebate programs (HET and HEW), consumers have purchased the high efficiency appliances approved by either the EPA Water Sense program (for SH and HET) or the Energy Star program (for HEW). The certified Water Sense or Energy Star products must be at least 20 percent more efficient than the other conventional products. For the HET rebate program, the qualified toilets have flow rates less than 6 lt per flush (GPF), which is lower than that for a conventional toilet (13 lt). For the SH exchange program, MDWASD offers low flow showerheads (5.7 lt per min) and equipped with on/off valve and swivel head for user comfort and convenience. A retrofit kit with two high efficiency aerators is included in the SH exchange package. With respect to HEW rebate program, the certified HEW products are usually front-loader designs which can reduce the total water volume during washing. These programs were promoted in different years, starting in 2005 for SH, 2006 for HET and 2007 for HEW.

Water savings and water use trend shifts of the customers were evaluated during the first four years after the implementation of water conservation practices. About 6–14% reduction in water demand has been observed during the first and second years. The water savings continued during the third and fourth years at a lower percentage. Water savings for water use efficiency measures were about 10.9%, 13.3% and 14.5% for the showerhead, toilet, and clothes washer programs; respectively. Adoption of more than one type of water efficiency appliance contributed to additional saving in residential water use.

The following table demonstrates the reduction of the potable water demand achieved (as %) with the implementation of each one of the programs (Lee et al., 2011).

Table 1. Reduction of potable water demand achieved by the implementation of three programs (HET: High Efficiency Toilet; HEW: High Efficiency clothes Washer; SH: high efficiency Shower Head) for Mean, High user and Low user water demand (Lee et al., 2011)

	HET	HEW	SH
Mean	19	18.0	14.7
High user	23.6	17.0	14.3
Low user	22.1	20.6	0.1

2.2.7. Case 7: Pressure control in Sao Paulo, Brazil

Pressure management has been around for many years in its basic form as a means of hydraulic system control and more recently has been very successfully introduced in many countries to combat leakage. Pressure management, as a means of combating leakage, can be used in most systems whether they are pumped or gravity fed, although the design of the scheme will change dramatically due to different hydraulic patterns. Often the reduction of pressure from one level to another can be a controversial subject, and one which sometimes utility managers prefer to ignore as there is a potential for customer dissatisfaction.

Sao Paulo, Brazil, utilized demand-based dynamic, time-based and fixed traditional methods to control the pressure in the distribution network. Various types of control were deployed and tested, including (Burn et al., 1999):

Flow-based dynamic modulation of a hydraulic valve: This is the best type of control for areas with changing conditions, head loss, fire flow requirements and the need for advanced control. This type of control is affected by controlling outlet pressure in relation to demand by connecting the controller to a metered signal output. Modulation of outlet pressure is achieved by altering the force against the pilot spring. The controller is normally supplied with a local data logger and optional remote communications. Control can be affected with a preset profile which shows the changing relationship of demand and head loss in the sector. Alternatively a direct communications link can be made between the controller and the critical point. Obviously the second option involves communications and therefore higher costs, which are not always necessary or cost effective. In general, installation costs are higher for this type of control; however, additional savings and guaranteed fire flows due to more intelligent control usually make this type of control more desirable.

Time-based modulation of a hydraulic valve: This can be affected by using a controller with an internal timer. Control is affected in time-bands in accordance with demand profiles. This methodology is very effective for areas with stable demand profiles and head losses and is usually used where cost is an issue, but advanced pressure management is desired. Time-based modulation controllers can be supplied with or without data loggers and/or remote links. Some manufacturers connect the controller to the pilot valve and alter the set point of the pilot valve by introducing a force against the existing force of the pilot spring.

Fixed outlet hydraulic control: This is the traditional method of control and uses a basic hydraulically operated control valve. This method is effective for areas with low head losses, demands which do not vary greatly due to seasonal changes, and areas with uniform supply characteristics.

The figure below shows how pressure control can significantly flatten the pressure profile across a system, even though the actual pressure reductions are very small, being in the order of only 10 m. It should be noted that the pressure after control shown by the bottom area is much more stable than the top area, which is uncontrolled and subject to wide variation. This smoothing of the pressure cycle also reduces the number of bursts within the system.

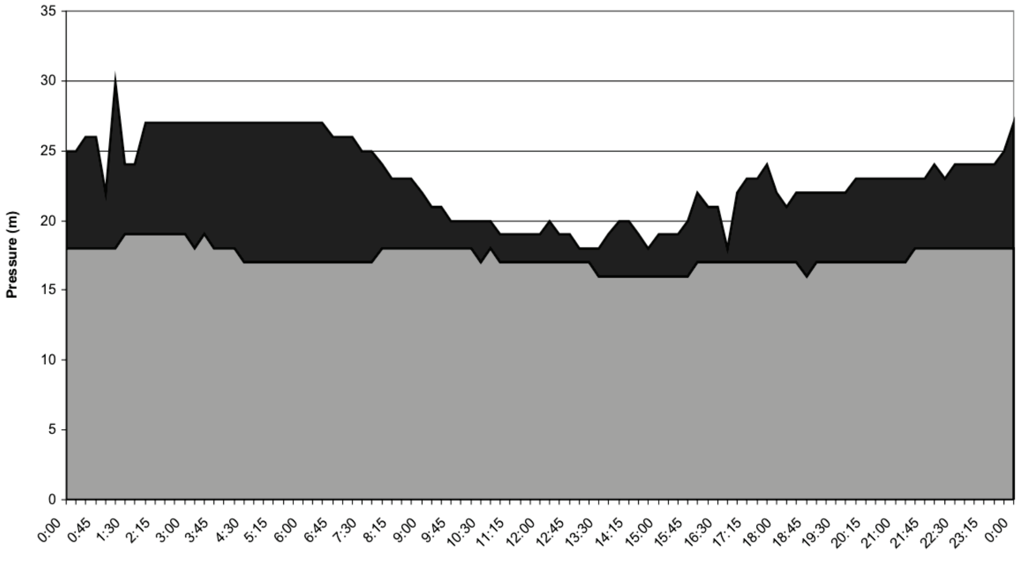

Figure 2: Diurnal variation of pressure of sites in the metropolitan area of Sao Paulo before and after pressure control (Burn et al., 1999).

Even though the amount of pressure reduction was small, the savings in water loss were very significant, as can be seen in the next figure.

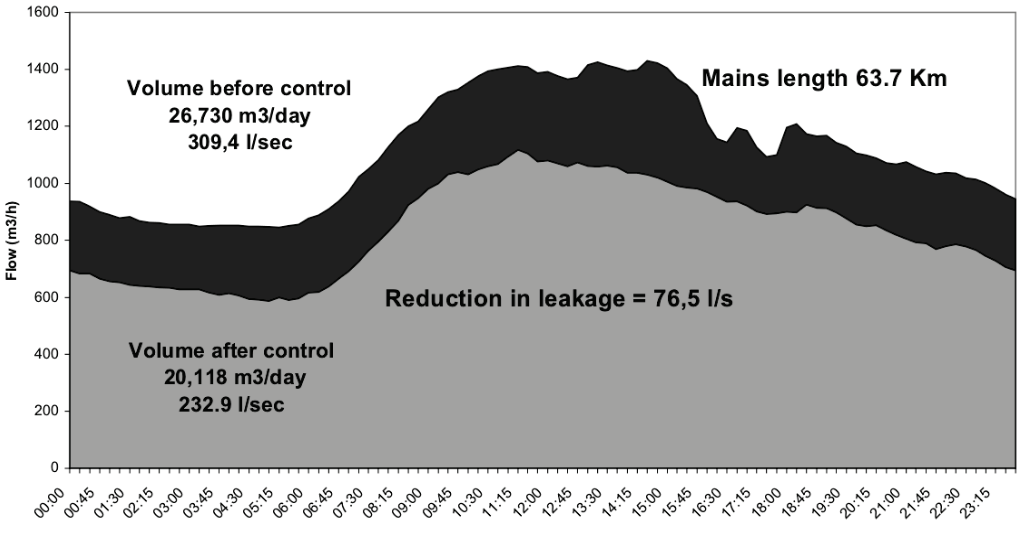

Figure 3: Diurnal variation of leakages of sites in the metropolitan area of Sao Paulo before and after pressure control (Burn et al., 1999).

2.2.8. Case 8: Integrated management in Melbourne

The City of Melbourne has practiced total water-cycle management since 2002, supported by its adoption of the Total Watermark policy in 2004 and the Water Sensitive Urban Design (WSUD) Guidelines in 2005 (City of Melbourne, 2005). Total water-cycle management is the integrated management of all components of the hydrological cycle within urban areas and landscapes – including water consumption, stormwater, wastewater and groundwater to secure a range of benefits for the wider catchment. The city has recently revised Total Watermark to place it within a 'city as a catchment' context. Within this context Melbourne implemented the following interventions across the public and private sectors (City of Melbourne, 2009):

Table 2. Implemented interventions in terms of actions and reduction percentages in the 'city as a catchment' approach within the Total Watermark policy of the City of Melbourne (City of Melbourne, 2009)

	ACTIONS	REDUCTION
Parks	Irrigation efficiencies (subsurface, soil moisture sensitive, technological improvements, limited time). Understanding of soil types and subsequent soil moisture needs. Mulching to prevent evaporation. Planting climate responsive, drought tolerant species. Staff training programs and contract provisions.	40%
Council buildings	Efficient fittings – flow restrictors on taps, showerheads. Efficient toilets – dual flush, reduced header tank flow. Fire-sprinkler testing (reduced from weekly to monthly, or recirculating). Cooling tower efficiencies. Staff training, contract provisions, education and behavior change programs.	40%
Business	Fire sprinkler testing (reduced from weekly to monthly, or recirculating). Cooling tower efficiencies. Appliances – efficient washing machines and dishwashers. Reduction in water use up to 50% per employee achieved through alternate water sourcing.	50%

	Efficient fittings – flow restrictors on taps, showerheads. Gardens – efficient species, layout and irrigation (to be maintained when water restrictions are not in place). Property management and tenant behavior change programs. Proceed with the rollout of water conservation projects currently being trialed including installation of waterless woks, cooling tower program, fire sprinkler testing program, green hotels and sustainable office building program.	
Residences	Efficient fittings – flow restrictors on taps, showerheads. Appliances – efficient washing machines and dishwashers. Gardens – efficient species, layout and irrigation (to be maintained when water restrictions are not in place). Swimming pools – pool covers, re-use of backwash. Householder behavior change through education. Balance ring mains, fire sprinkler and cooling tower efficiencies. Efficient fittings and appliances. Householder behavior change through education.	40%

2.2.9. Case 9: Water efficiency in Sydney

Sydney Water's water efficiency initiatives in 2010-11 included residential, business and school programs. These programs are supported by community education and research and development activities (Sydney Water, 2011).

Residential water efficiency

During 2010-11, indoor water efficiency programs provided an opportunity for households to replace inefficient fittings such as showerheads, tap flow regulators and toilets. Specifically:

- WaterFix provided households with an opportunity to have a qualified plumber: to install a new water efficient showerhead; to install tap flow regulators; to install toilet cistern flush arrestor for single-flush toilets; to repair minor leaks. Each WaterFix service was estimated to save 20.9 thousand lt a year. Since the program started in 1999, a total of 485211 properties, including Department of Housing properties, have taken up a WaterFix service.

- The DIY Water Saving Kits were developed as an alternative to the full WaterFix service. The kits provided simple devices customers could install to make existing showerheads and taps more water efficient. Each DIY kit was estimated to save about 6.7 thousand lt a year. Since the program began in 2004, 211,623 DIY kits have been distributed.

- Replacing a single-flush toilet with a 4 star dual-flush toilet can save about 23 thousand lt a year. Since it started in July 2008, 28,224 toilets have been replaced as part of this program.
- Sydney Water offered customers a $150 rebate for purchasing a water efficient washing machine. Since 2006, 186,634 rebate applications have been paid, saving each household on average 18 thousand lt a year.
- As part of the New South Wales (NSW) Government's Climate Change Fund, a $150 rebate was offered for installing a hot water circulator with instantaneous gas hot water systems. A hot water circulator sends the cold water back into the hot water system to be reheated or used later. The NSW Government estimated that each hot water circulator would save up to 17 thousand lt a year.
- Sydney Water offered customers a rebate for installing and connecting a new rainwater tank to existing homes. It is estimated that each rainwater tank installed saves between 35 to 60 thousand lt a year on average depending on how it is installed.
- A program that helped customers identify and repair concealed leaks in their homes. Meter reading data was used to identify long and short term leaks. Once notified of this consumption anomaly, if a targeted customer could not find their leak an expert contractor was provided to detect the leak using specialist leak detection equipment. Since 2008, over 230 leaks have been detected and repaired. It is estimated that this service saved each participating household 50 thousand lt a year.

In total, these programs saved 17,556 million lt of water in 2010-11.

Non-residential water efficiency

Sydney Water helped businesses and government save water by identifying opportunities and management improvements to reduce water use through a series of programs. These programs are:

BizFix helped business customers by offering 50:50 co-funding for retrofitting water efficient fittings in bathrooms and kitchenettes. The program helped 327 business sites to identify potential water saving opportunities. From its commencement in 2009, at the end of 2010-11 a total of 203 businesses had implemented water savings identified by the program, with each saving on average 1,800 lt a year.

Smart Rinse offered a free replacement of inefficient pre-rinse spray valves with efficient ones in commercial kitchens and retail food shops. The program provided 4,707 spray valves to business customers, each saving on average 253 thousand lt a year.

Top 100 online monitoring offered online monitoring of water use to customers using more than 100 thousand lt a day to better manage their water use and identify leaks. The program monitored 162 sites each saving just over 300 thousand lt a year on average.

HiRise pilot targeted 30 commercial/retail high-rise buildings over three years to learn about these buildings and identify water efficiency opportunities and develop key performance indicators for the sector.

School water efficiency

High water using schools or schools that have identified water efficiency as a priority, have participated in the Every Drop Counts (EDC) in Schools Program or the School Amenities Program. EDC in Schools focused on helping schools track water use and identify potential leaks through education materials, teacher training courses, dedicated education officers and online water use monitoring. The Amenities program fitted 26 high schools with water efficient amenities. These two programs and the Rainwater tanks in Schools Program have saved around 502 million lt of water a year.

2.2.10. Case 10: Use of seawater for toilet flushing in Hong Kong

The growth in population and of the economy of Hong Kong has caused a significant increase in the demand for fresh water. To secure sufficient water supply and to reduce reliance on imported water from Dongjiang (East River) in Mainland China, the Hong Kong Special Administration Region (HKSAR) government has implemented a wide range of water conservation measures which include the use of seawater for toilet flushing.

During 2007, about 0.74 hm^3 of seawater was used for toilet flushing every day, equivalent to some 28% of the daily fresh water consumption. The seawater is firstly screened by strainers to remove solid particles. It is then disinfected with chlorine or hypochlorite before being pumped to service reservoirs for distribution to consumers. Nearly 80% of the population is now supplied with seawater for flushing. This practice saves energy as seawater is extracted near the consumer centers, whereas most fresh water supplies in Hong Kong are pumped through long distances and go through sophisticated treatment processes. Currently, the supply of seawater for flushing is a free service to the community.

![trust logo]

Figure 4: Seawater supply zone in Hong Kong (Yue and Tang, 2011).

For areas outside the seawater supply zone, fresh water is used for toilet flushing. It is usually billed at 4-monthly intervals according to meter readings. Only one meter is installed in each building to record the total consumption of fresh water used for toilet flushing by all flats in the same building. The charges payable are calculated on a two-tier tariff structure. The first tier of 30 m^3/flat is free of charge; and the second tier of any consumption above the level of 30 m^3/flat is charged at HK$4.58 per cubic meter (US$1= HK$7.8). In 2006, about 82 million cubic meters of the fresh water was supplied for toilet flushing, which was equal to about 9% of the total fresh water consumption.

2.2.11. Case 11: Centralized rainwater harvesting in Germany

Rainwater utilization in Germany is widespread since the 1980s (Nolde, 2007). Typically, the water is collected from the roof and is filtered, stored and primarily used for toilet flushing, garden watering and household laundry. Nolde presents a novel approach: instead of using only the water from the roofs, he suggests that that rainwater draining from the streets and courtyard surfaces could also be reused. This could be a viable option for densely populated urban areas and reduces drinking water consumption and wastewater production. It also minimizes the entry of pollutants into the surface waters, without the need for a sewer connection. He found that 70% of the toilet-flush demand can be replaced by treated stormwater without any comfort loss.

In one pilot application about 11,770 m^2 of sealed surface area are connected to a rainwater reservoir situated in the cellar of the pilot building. 63% of the collected surfaces originate from the roof, 35% from courtyards and sidewalks and 12% from traffic surfaces. Rainwater is first discharged into the existing rainwater sewer of the Berlin water company, and from there it drains into the rainwater reservoir until the reservoir reaches its full capacity. The 190 m^3 rainwater reservoir is filled with rainwater until the water level in the reservoir reaches the sewer level. Excess water is discharged into surface water. Biological treatment of the rainwater takes place in a "planted" substrate filter which has been installed in the building.

Figure 5: Rainwater plant site in Berlin-Lankwitz (Nolde, 2007).

About 10 m^3 of rainwater are treated daily followed by disinfection with UV (28 Watt). The service water reservoir (6 m^3) serves as a storage tank for the treated rainwater and acts as a system buffer during consumption peaks. The rainwater harvesting plant supplies 80 apartments and 6 small trade units (a total of 200 persons) with high-quality service water for toilet flushing and garden watering.

The selected substrate filter consists of two layers each is 2.2 m long, 1.1 m wide and 0.7 m deep. The above layer consists of expanded clay particles (8–16 mm grain size) while the lower layer is filled with gravel (4–8 mm). The two layers are placed 1 m apart. Rainwater percolates from above continuously and uniformly over the whole substrate bed. The rainwater plant has been operating since 2000 without clogging or other technical problems.

2.2.12. Case 12: Rainwater harvesting in Southampton University

A rainwater harvesting scheme is installed in the Administration and Student Services Building of the University of Southampton. Rainwater falling on all of the flat roof and the atrium glazed roof is filtered then collected in an underground tank, and pumped to a header tank serving all of the WC flushing cisterns. For use in time of drought there is a mains standby connection to the header tank.

The system comprises of a 15 m^3 underground tank, 3 vortex filters, a single pump and a 450 lt header tank. The rainwater harvesting area is 1000 m^2. The building occupancy is 150 people. Average annual rainfall is 800 mm and the scheme is expected to provide 1690 lt/d. The capital cost was 4 325 pounds and the payback time is estimated at 5.3 years.

Figure 6: Administration and Student Services Building, University of Southampton (Rainharvesting systems, 2012).

2.2.13. Case 13: Low water gardening in Cyprus

Smart gardening techniques can be used to reduce significantly the water demand for garden irrigation. The following figure demonstrates the development of a garden in Cyprus. The garden was planted with xeriscape shrubs. A spaghetti tube water system was installed and the ground was covered with a landscaping fabric (prevent the growth of most weeds). Afterwards the area was mulched with white gravel. Mulching trees and shrubs is a good method to reduce landscape maintenance and keep plants healthy. Mulch helps conserve moisture by achieving a 10 to 25 percent reduction in soil moisture loss from evaporation. Mulches help keep the soil well aerated by reducing soil compaction that results when raindrops hit the soil. They also reduce water runoff and soil erosion (Evans, 2000).

Figure 7 Low water gardening in Cyprus (Rural Cyprus, 2012).

2.3. Transferable lessons for Sustainable UWCS

This section identifies enabling and constraining factors which can be identified from the cases in section 2.2.

The public awareness program in Jordan was successful because it combined direct benefits from demand reduction with long-term benefits from the creation of water education programs (interactive CDs for children, master's degree program, etc.). The enabling factor seems to be the creation of an institutional structure (enabling factor at the administrative level), and the cooperative relationships between several ministries at national level and between governmental and non-governmental organizations (inter-organizational factor).

The success and innovation of Melbourne's approach stems not from the individual interventions, which in themselves are new but not novel, but rather from their deployment as a bundle of measures, focusing on distributed solutions and interventions, within a coherent long-term strategy and vision. The fact that the strategy spans traditional stakeholder boundaries and cuts across the public and private sector (inter-organizational level) implies that part of the innovation and value is in how different parties were brought together, solutions implemented and correction were made as the program progressed.

The Sydney Water's water efficiency initiatives demonstrate a factor at the administrative level. Since the pay-back period of installing water saving appliances may be quite long to attract public interest, Sydney Water used a more proactive method. The utility created a framework in which it provided substantial and direct economical benefits to the consumers to motivate: (i) the installation of water efficient household appliances, (ii) the installation of simple rainwater harvesting schemes, and (iii) the minimization of the in-house leakages. The result of this program was a significant reduction of the potable water demand, which exempted the need to increase the capacity of the water-supply infrastructure with costly interventions.

Another example of an enabling factor at the administrative level is the framework of promotion and pricing policy used by the Hong Kong Special Administration Region (HKSAR) government for the use of seawater for toilet flushing. The seawater is supplied for free inside a zone close to the sea front. The customers inside this free-of-charge zone constituted the critical mass to attract more customers to join the scheme. The seawater charges to the customers outside this zone are based on a two-tier tariff structure of which the first 7.5 m^3/flat/month are free of charge.

The pilot application of centralized rainwater harvesting in Germany demonstrated enabling factors at the individual and administrative level. At the individual level, the simplicity of the innovation allowed the inexpensive and smooth operation of the recycling scheme. A further advantage of this simplicity is the low energy requirements for cleaning and distributing the stormwater. At the administrative level, an enabling factor is the German regulation concerning the rainwater utilization (DIN 1989), which is preferentially in favor of rainwater harvesting from roof surfaces.

The low water gardening in Cyprus is an example of an individual level enabling factor that could be combined with an administrative level enabling factor. In this example a house owner shared online his experience about the use of modern materials and latest gardening knowledge to reduce water demand. Most certainly his actions will encourage other users to mimic his achievement. However, a much higher success and penetration of this good practice could be accomplished if the dissemination of the knowledge was implemented systematically at the administrative level. Then, more self-motivated DIY enthusiasts could easily find support to their ambitious plans. This would ensure that good ideas of individuals would benefit the whole society to the highest possible degree.

3. REUSE AND RECYCLING

3.1. Introduction

Urban water recycle is the procedure where the greywater or the wastewater from showers, baths and washbasins (in some cases washing machines) is treated appropriately in order to cover non-potable demands (Butler et al, 2009; EA, 2011). This chapter focuses on the technologies that can be used for: (i) reducing domestic (in-house and outdoor) and non-domestic (industry, tourism, public uses, etc.) urban water consumption; (ii) covering non-urban water demand (agriculture, environment protection, etc.) with used urban water. The examples of this chapter concern systems that are characterized by a simple link (from management point of view) between the first use of water and consumption of the recycled/reused water. The locations of these two can be either at the same place (e.g. local grey water recycling scheme) or can be distant (e.g. use of treated waste water for irrigation). Examples of recycling systems that include complex network of connections between different demands and sources, flow interactions and/or combination of recycling schemes are not included in this chapter, but in the Water Demand Management chapter.

3.2. Best practices

This section presents both cases for non-domestic use and domestic use in sections 3.2.1 and 3.2.2 respectively.

3.2.1. Non-domestic use

3.2.1.1. Case 1: Wastewater reclamation in Barcelona

Water is a scarce resource of vital importance in the Mediterranean Spanish coast and also specifically in the Barcelona metropolitan area, where 4 million people and the main Catalonian industrial activity are concentrated. Reuse is part of the criteria of a new environmental policy in Catalonia and Spain that promotes a new water culture, trying to increase the non-conventional resources and guaranteeing at the same time the physical, chemical and bacteriological water quality. To cope with water scarcity, reclaimed water generated in a wastewater treatment plant serving part of the Greater Barcelona are reused for maintaining ecological flow in a neighboring river, irrigating farm areas, supplying additional water to wetlands in the river delta area and perform a barrier against seawater intrusion.

Specifically, almost 50 Glt/y of reclaimed water can be used for supplying the ecological flow in the lower part of the Llobregat River, irrigation of farm areas and supplying water to wetlands in the river deltaic areas.

Wastewater reclamation in this scheme can also be used for the control of the salt-intrusion problem in the Llobregat lower delta aquifer through the implementation of a hydraulic barrier. For obtaining water with the quality required for all the reuse purposes, it is necessary to modify the existing biological treatment to remove nutrients (nitrogen and phosphorus) and the construction of a tertiary reclamation facility, which for recharge purposes includes a reverse osmosis plant. The project improved ecological conditions in the lower part of the Llobregat River basin, contributed to reduce the scarcity of water resources in the Barcelona metropolitan area and helped to avoid seawater intrusion into Baix Llobregat delta aquifer. In order to obtain the required water quality for reuse, two different tertiary treatments were built. This is probably the most important water reuse project on the Mediterranean coast and it is the first time that a barrier against seawater intrusion has been built in Spain. The budget of the project was appr. € 100 million, including the construction and starting of operational phase. The operational costs were estimated at 0.07 €/m^3 of reclaimed water for tertiary treatment including lamellar clarifier, filtration and UV disinfection, and at 0.30 €/m^3 for the tertiary treatment using microfiltration and reverse osmosis (Cazurra, 2008).

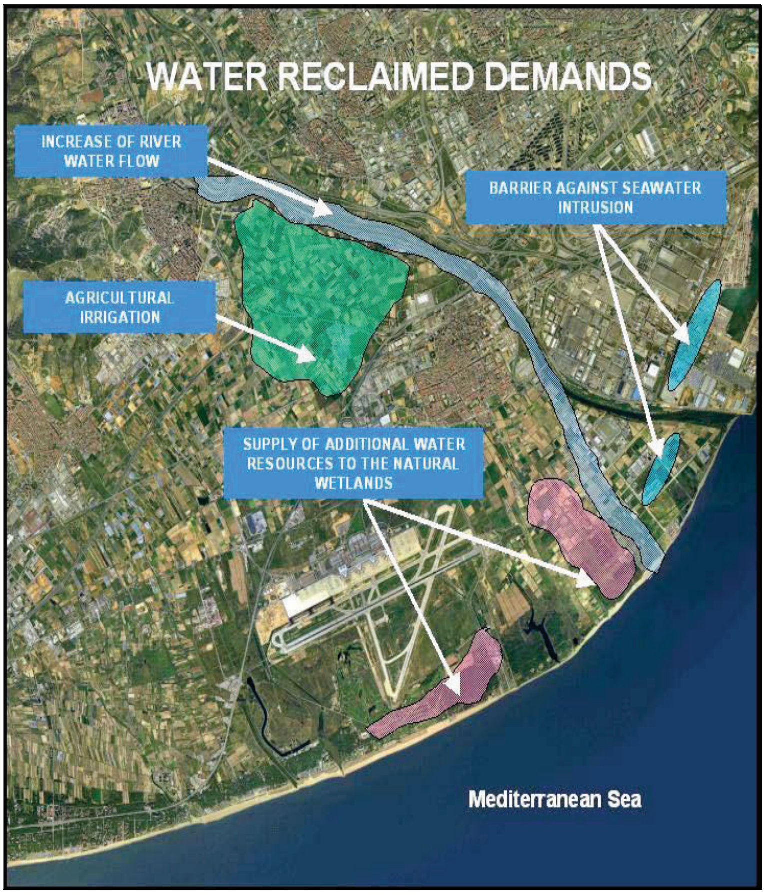

Figure 8: Llobregat River lower delta (Cazurra, 2008).

3.2.1.2. Case 2: Wastewater reuse in Mexico City

Mexico City has 21.4 million inhabitants and is located 2240 m above sea level in a closed basin. Since 1789 Mexico City's wastewater has been sent north to the Tula Valley, through three sewage pipelines. The wastewater is used to irrigate 76 000–90 000 ha, divided into four irrigation districts (No. 03 Tula, No. 100 Alfajayucan, No. 25 Ixmiquilpan and No. 88 Chiconautla), benefiting 73 372 farmers (Jiminez, 2005).

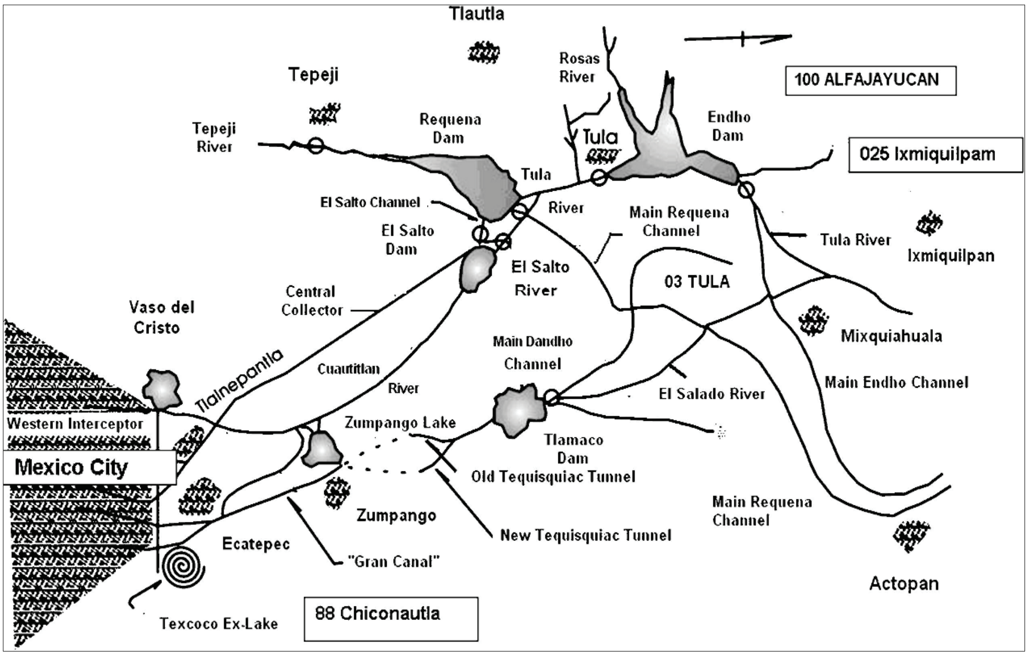

Figure 9: Irrigation districts using wastewater from Mexico City (Jiminez, 2005).

Wastewater is distributed in the valley by a complex hydraulic system composed of nine dams (three of which are small reservoirs storing fresh water from a neighboring valley and six larger dams with wastewater) and more than 858 km of open unlined channels. Irrigation methods are flood and furrow. The use of wastewater for agriculture began in 1896, in the poorest and most remote areas. Over time, the benefits of its application were evident and in the 1990s the President of Mexico, at the request of the farmers, granted them an entitlement to use the wastewater which, according to the legislation (as all waters in the country) is property of the state. In 1994 the farmers actually opposed the project to treat Mexico City's wastewater with conventional technology. They requested that: (a) should wastewater be treated they should continue receiving the same volume to which they were entitled (Mexico City's government intended to treat the city's effluent and reuse it within the urban area); and (b) treated wastewater should still contain the "substance" that fertilizes their soils. Farmers were aware that besides increasing yields, wastewater increases land prices (1 ha of land where wastewater is available can be rented at USD 455/yr instead of USD 183/yr for rain-fed agriculture land). It also improves income: related to crops produced in rain-fed plots, income for crops irrigated with untreated wastewater is

92, 678, 55 and 41% higher for maize, beans, barley and wheat respectively. Even when compared to crops irrigated with surface "first use" water, those irrigated with untreated wastewater provide higher income: 40, 63, 15 and 6%, respectively. On the other hand, health conditions are seriously affected: the helminthiasis morbidity rate in the region is 16 times greater in children than that of regions with similar social and economic conditions (Jiminez, 2005).

3.2.1.3. Case 3: Managed aquifer recharge in Salisbury, South Australia

The project in Salisbury South Australia was conducted by the Australian National Water Commission with the objective of gaining a sound scientific understanding of the processes affecting water quality; and to develop management strategies for reliable, sustainable production of water of potable quality sourced from stormwater.

Aquifer Storage, Transfer and Recovery (ASTR) is similar to traditional aquifer storage and recovery (ASR), but the difference lies in the use of separate wells for injection to and recovery from a confined aquifer, rather than the same well for both. This type of managed aquifer recharge ensures a longer minimum residence time for recharged water than for simple aquifer storage and recovery, to provide a more consistent treatment barrier in water recycling.

The Salisbury ASTR project is located on the Parafield Airport and Parafield Gardens Oval, on the Northern Adelaide Plains, South Australia. This ASTR site is internationally unique because the aquifer was initially brackish and needed to be flushed with fresh stormwater. The scheme receives urban stormwater from the Parafield and Ayfield catchments which contain residential, retail business and mixed industrial areas. The Parafield catchment yields on average 1100 Mlt of urban stormwater per year.

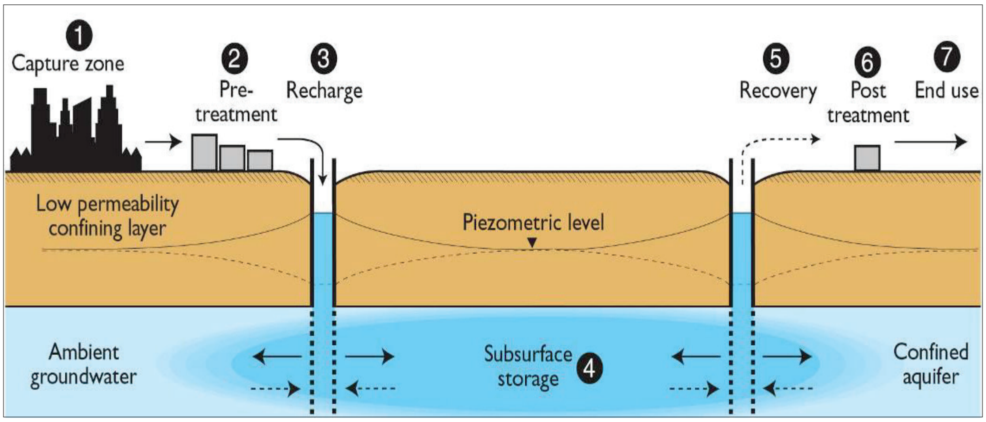

Figure 10: The system schematic of Salisbury ASTR (CSIRO, 2010).

The Parafield stormwater harvesting system consists of a weir which diverts water from the Parafield Drain into the 47 Mlt in-stream basin, the first of three stages of the system, and which serves as an initial settling basin for the stormwater. Excess stormwater flow overtops the diversion weir and continues to flow down the Parafield Drain during a storm event. Water flows into the in-stream basin and is pumped at 3 Mlt/hour to the 48 Mlt holding storage until capacity of the holding storage is reached or the in-stream basin is drained. Water in the holding storage then flows by gravity into the cleansing reedbed. The cleansing reedbed is vegetated with seven different species of reeds, planted in parallel rows that are perpendicular to flow through the wetland. The capacity of the reedbed is approximately 25 Mlt, and it has a surface area of 2 ha. The cleansing reedbed and holding storage are designed to achieve a minimum holding time of 7 days; however, the actual holding time varies with use. Water is pumped from the reedbed outlet to two storage tanks, and from there it is pumped to the ASTR well field.

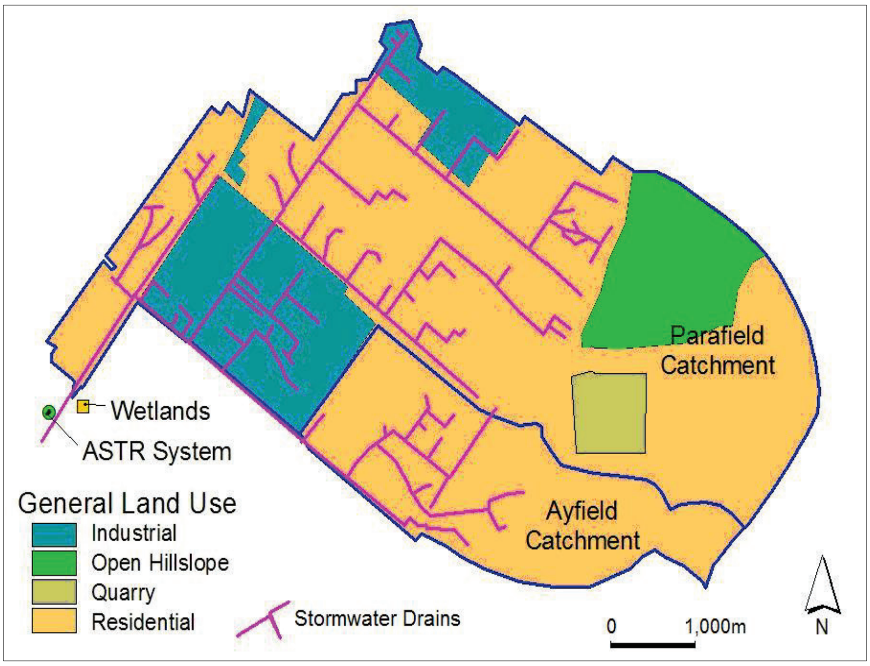

Figure 11: Parafield and Ayfield stormwater catchments showing main stormwater drains (CSIRO, 2010).

The ASTR system comprises four injection wells surrounding two recovery wells and a series of three piezometers. The rhombic well configuration and 50 m inter-well spacing was designed to produce a mean residence time in the aquifer of 6 months. The ASTR system operates in conjunction with a two-well ASR system at Parafield Airport for storage of excess stormwater. When operating at capacity, the ASR system processes water at a maximum rate of 3.6 Mlt/day, which meets the needs of the Michell Australia wool processing plant and is also the maximum injection rate into the aquifer from the current wells.

3.2.1.4. Case 4: Cooling Water Recirculation in Wyoming, USA

The use of water for cooling in industrial applications represents one of the largest water uses in the United States. Water is typically used to cool heat-generating equipment or to condense gases in a thermodynamic cycle. The most water-intensive cooling method used in industrial applications is once-through cooling, in which water contacts and lowers the temperature of a heat source and then is discharged.

Recycling water with a recirculating cooling system can greatly reduce water use by using the same water to perform several cooling operations. The water savings are sufficiently substantial to result in overall cost savings to the industry. Three cooling water conservation approaches that can be used to reduce water use are evaporative cooling, ozonation, and air heat exchange (Brown and Caldwell, 1990).

In industrial/commercial evaporative cooling systems, water loses heat when a portion of it is evaporated. Water is lost from evaporative cooling towers as the result of evaporation, drift, and blowdown (a process in which some of the poor-quality recirculating water is discharged from the tower in order to reduce the total dissolved solids). Water savings associated with the use of evaporative cooling towers can be increased by reducing blowdown or water discharges from cooling towers.

The use of ozone to treat cooling water (ozonation) can result in a five-fold reduction in blowdown when compared to traditional chemical treatments and should be considered as an option for increasing water savings in a cooling tower (Brown and Caldwell, 1990).

On the other hand, air heat exchange works on the same principle as a car's radiator. In an air heat exchanger, a fan blows air past finned tubes carrying the recirculating cooling water. Air heat exchangers involve no water loss, but they can be relatively expensive when compared with cooling towers (Brown and Caldwell, 1990).

The Pacific Power and Light Company's Wyodak Generating Station in Wyoming decided to use dry cooling to eliminate water losses from cooling-water blowdown, evaporation, and drift. The station was equipped with the first air-cooled condenser in the western hemisphere. Steam from the turbine is distributed through overhead pipes to finned carbon steel tubes. These are grouped in rectangular bundles and installed in A-frame modules above 69 circulating fans. The fans force some 1.3 million cubic meters per minute of air through 74.3 hectares of finned-tube surface, condensing the steam (Strauss, 1991).

The payback comes from the water savings. Compared to about 15.14 m^3/min of make-up (replacement water) for equivalent evaporative cooling, the technique reduces the station's water requirement to about 1.14 m^3/min (Strauss, 1991).

3.2.1.5. Case 5: Rinsing in Singapore

Another common use of water by industry is the application of deionized water for removing contaminants from products and equipment. Deionized water contains no ions (such as salts), which tend to corrode or deposit onto metals. Historically, industries have used deionized water excessively to provide maximum assurance against contaminated products. The use of deionized water can be reduced without affecting production quality by eliminating some plenum flushes (a rinsing procedure that discharges deionized water from the rim of a flowing bath to remove contaminants from the sides and bottom of the bath), converting from a continuous-flow to an intermittent-flow system, and improving control of the use of deionized water (Brown and Caldwell, 1990).

Deionized water can be recycled after its first use, but the treatment for recycling can include many of the processes required to produce deionized water from municipal water. The reuse of once-used deionized water for a different application should also be considered by industry, where applicable, because deionized water is often more pure after its initial use than municipal water (Brown and Caldwell, 1990).

A pilot study at Duraco Industries Pte Ltd in Singapore verified the potential of saving water by recycling spent rinse water from the process lines. The recycling process comprises four steps: (1) wastewater stream segregation, in which spent final rinses are segregated from other more heavily contaminated rinses and are combined to form a raw feed water stream for treatment; (2) pretreatment, in which the raw feed water stream is treated to remove particulates, microorganisms and free chlorine, and to reduce TOC; (3) heavy metal removal, in which the pretreated water is separated into a concentrate stream (containing salts) and a permeate stream (clean water) using a nanofiltration membrane; (4) polishing step, in which the permeate is further deionised using a mixed bed. The polished permeate stream is then recycled back to the plating operation rinsing system. The results of a pilot study showed that high quality product water (heavy metals free and < 5 mS/cm in conductivity) is being consistently produced using a NF membrane system with an overall water recovery of 90%.

The product water treated using this hybrid process is being recycled for use in the plant operation with no detrimental effects. The design data for a full scale NF plant with a treatment capacity of 25 m^3/h has been obtained and the estimated payback period is between 13 and 18 months. The process is more applicable for reclaiming wastewater containing mainly heavy metals but low in monovalent ions (Wong et al., 2002).

3.2.1.6. Case 6: Recycling water for industry in Sydney

According to Sydney Water (2009), more than seven billion lt of recycled water a year is used for industrial processes in Sydney and the Illawarra. Sydney Water operates one of the biggest industrial water recycling schemes in Australia. It supplies BlueScope Steel in Port Kembla up to 20 million lt of high quality recycled water per day. This replaces up to 7.3 billion lt of drinking water per year previously drawn from the local Avon Dam, a 57% reduction of drinking water consumption by Sydney Water's largest customer.

The water recycling plant, located at Wollongong, has been operating since 2006, uses micro-filtration and reverse-osmosis membrane processes to produce very high quality recycled water, suitable for a range of industrial purposes. The wastewater is screened and settled to remove large solids and grit. Biological treatment uses micro-organisms to reduce nutrients such as nitrogen and phosphorous. The treated wastewater is clarified to further improve quality. Microfiltration uses hollow fibres to remove some fine particles, bacteria and viruses. Reverse osmosis improves the quality of the water by removing viruses, nutrients and dissolved salts at high pressure, using fine barrier membranes. The recycled water is then disinfected before it is pumped to BlueScope Steel's Port Kembla Steelworks. This project alone reduced the use of drinking water across the total Illawarra region by 17%.

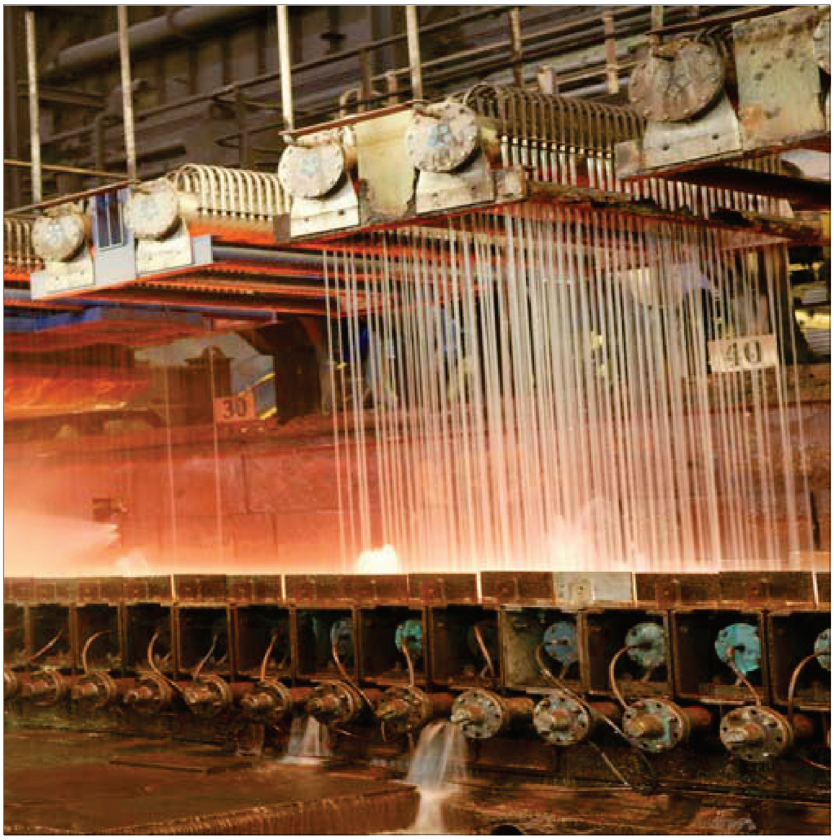

Figure 12: Recycled water is used for cooling the hot strip before it is cooled (Sydney Water, 2009).

3.2.2. Domestic use

3.2.2.1. Case 1: Indirect wastewater reuse through dune infiltration in Belgium

In July 2002, the Inter-municipal Water Company of the Veurne region in Belgium (IWVA) has started producing infiltration water. The source is wastewater effluent; the techniques are a combination of membrane filtration. The water is used for groundwater recharge of the dune water catchment 'St-André' (IWVA, 2012). This resulted in groundwater levels increase and reduction of the risk of seawater.

Figure 13: St-André infiltration pond (IWVA, 2012).

The indirect potable reuse scheme of Torreele/St André is based on a multiple barrier approach. Secondary treated effluent from the municipal WWTP of Wulpen (83.000 PE) is treated by ultrafiltration, followed by reverse osmosis. The highly treated water is introduced in the aquifer through an infiltration pond and recharges the unconfined aquifer in St-André. Due to varying distances between the wells and the pond, residence times vary between 30 days and almost 5 year, whereby 50% of the recharged water reaches the extraction wells after 55 days. The groundwater is extracted by pumps and treated with the existing water treatment plant in St. André. The plant comprises aeration and rapid sand filtration. The final product is then supplied to the potable water distribution system.

Potable reuse schemes obviously need to be designed to assure that potential risks are carefully controlled and managed. For the Torreele facility, a risk assessment analysis has been performed, identifying the critical control points, the key monitoring strategies and preventive and corrective measures, resulting in a water safety plan as promoted by the WHO. The plan addresses hazardous pathogens, as well as other key factors that govern safety in artificial groundwater recharge, including health risks resulting from oxidized nitrogen and toxic trace chemicals such as pharmaceutical compounds (Weemaes, 2011).

The unusual aspect of this project is their high level of communication and involvement with the community prior to, throughout the project and during the three years of operation. This has reinforced a high level of trust and acceptance of indirect potable reuse within the community. IWVA also have a commitment to search out international experience and share their experience at leading conferences in most parts of the world (Angelakis, 2008).

3.2.2.2. Case 2: Local greywater recycling in Vietnam

The so called HUBER GreyUse® plant for treatment of greywater has been adapting Membrane Bio-Reactor (MBR) systems for greywater treatment to the specific conditions in Vietnam in a small city in the Mekong delta, South Vietnam. Wastewater from kitchen sinks and bathrooms of a dormitory on the campus of Can Tho University was clarified in the HUBER GreyUse® plant. The treated water was used for toilet flushing.

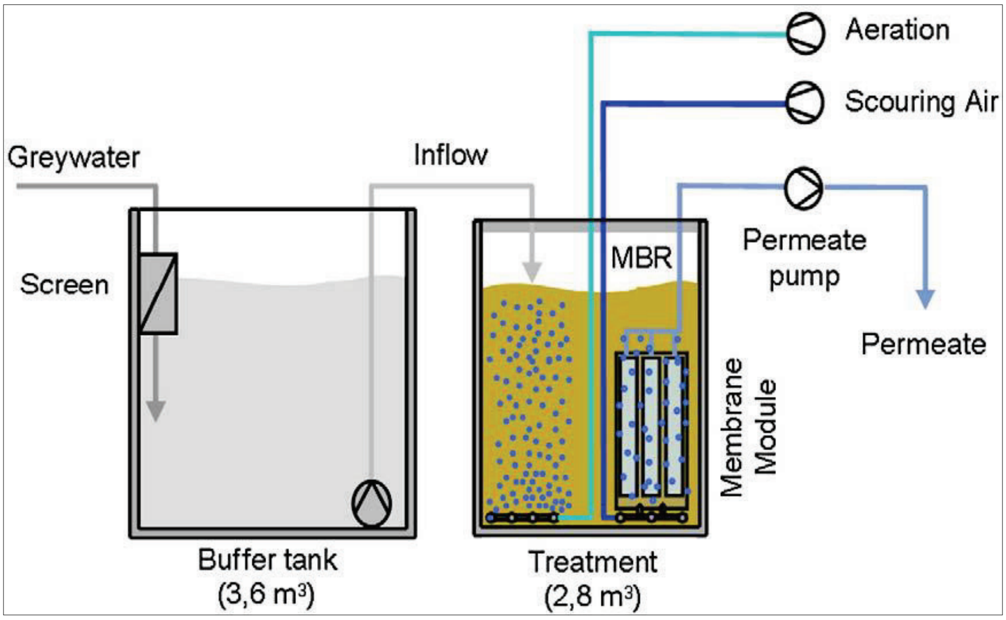

Figure 14: Schematic representation HUBER GreyUse (Paris and Schlapp, 2010).

The system operation was stable throughout the whole test period and showed very high COD elimination rates of on average 92.2%. All effluent values met the German standards specified for the reuse of treated water for toilet flushing, laundry washing and irrigation. The treated greywater has also bathing water quality according to the EU directive 76/160/EEC.

Even under difficult local conditions, such as varying inlet concentrations, the quality requirements for reuse of treated wastewater in households and for outdoor applications could be met throughout the whole test period. The fresh water demand can be reduced significantly if this service water is used for toilet flushing, cleaning and irrigation. Greywater recycling involves therefore also economic benefits in addition to ecological advantages. Interesting saving potentials exist particularly in the industrial sector for hotels, camping sites or sports facilities where the water consumption is very high. Particularly in densely populated cities greywater recycling could be an appropriate method to save water.

3.2.2.3. Case 3: Integrated water recycling in Brisbane, Australia

The Payne Road development is located in Brisbane's western suburbs. The development area is situated on the urban fringe and is bordered to the west by the Brisbane State Forest and Enoggera Reservoir Reserve, and to the north-east by the Enoggera Creek. Aimed at the high-end of the property market, the 3.75ha subdivision is divided into 22 lots, with homes ranging from 800m^2 to 1800m^2 in size.

The project aimed to demonstrate an integrated water cycle approach to household water supply, including both individual and communal rainwater tanks for potable water supply, a household-scale greywater recycling system for garden watering and bioretention basins for stormwater treatment and discharge (Davis and Farrely, 2009).

Each household is equipped with an 18 m^3 to 22 m^3 rainwater tank to supply all household uses. Two 75 m^3 communal tanks are also located at the bottom of the development to store excess flow from household tanks, and to provide emergency supply for extra household and fire-fighting needs. A float valve and trickle feed from water mains ensures supply security. All tank water is treated through a 1mm mesh screen, a geotextile filter sock (to prevent leaves and sediment entering the tank), a 1μm carbon filter, and a UV disinfection unit for treatment to potable standards (Gardner et al., 2006). Water supply is pressurised by a 0.45/0.75kW submersible pump, triggered automatically when pressure drops below 350kPa (Diaper et al., 2007).

Greywater is treated by an aerobic composting system. The systems are installed on individual lots and they deliver treated water to gardens via subsurface irrigation. Moisture sensors detect saturation levels, and excess treated greywater is discharged into the sewer (Gardner et al., 2006). A 22kW diesel pump attached to the communal tanks ensures compliance with fire-fighting regulation for flow and pressure (Diaper, et al., 2007).

Although not included in the integrated water cycle approach, council limitations on sewerage connection for the development meant that an innovative approach to sewage conveyance was required. Wastewater from kitchens and toilets is conveyed via low-infiltration, reticulated gravity sewerage to a communal sewer pump well. As the sewer main already operates at peak flow capacity, sewage from the development is withheld in a pump well until it can be discharged during off-peak (between 12am-6am) into the main sewerage trunk (Gardner et al., 2006).

Each rainwater tank is divided into 3 zones: the bottom zone provides for household water supply (1/5 of the tank), the middle part of the tank provides the working storage volume for the communal tanks (3/5 of the tank), while the top 1/5 of the tank is used as a stormwater surge detention zone (Hamlyn-Harris, 2006; Gardner et al., 2006). The bulk of the stormwater runoff not captured by rainwater tanks is captured in swales and treated in a bio-retention system at the bottom of the development. Stormwater sensitive landscape and road design ensures that runoff drains to an 80m long by 25m wide swale, including a 0.6m deep by 1m wide bio-retention system filled with sandy loam to treat water before it is discharged to the Enoggera Creek via a stormwater pipe. In addition, two 0.5m rock weirs assist flood management for flows during a 2 year storm event (Gardner et al, 2006).

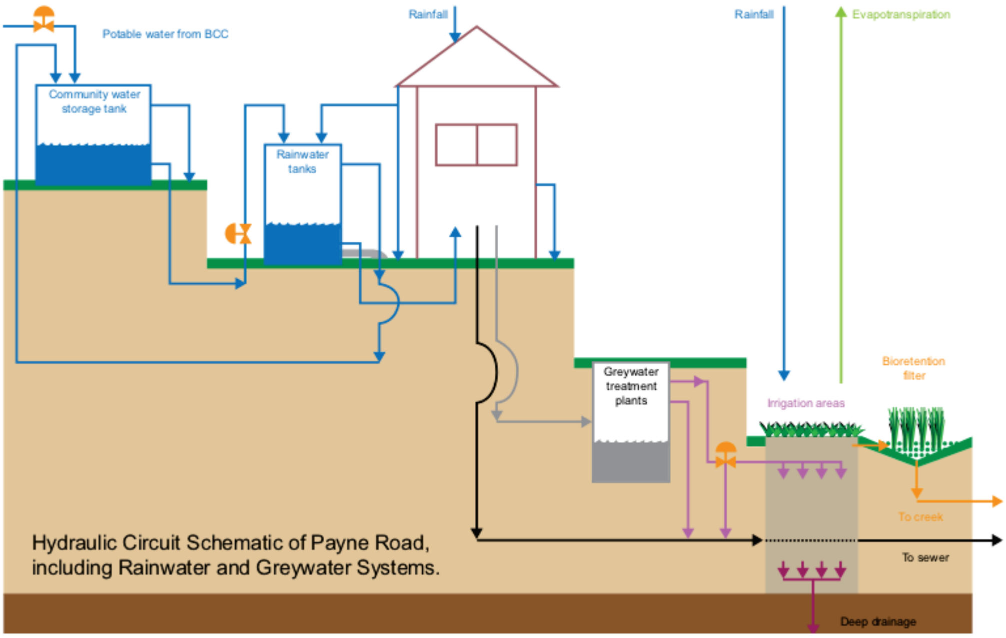

Figure 15: Water schematic for Payne Road (Source: Payne Road Project, n.d., www.payneroad.com.au).

3.2.2.4. Case 4: Wastewater use for garden irrigation in Cyprus

Subsidies for drinking water conservation initiated in Cyprus in 1997 by the Water Development Department (WDD). The subsidies encouraged the construction of domestic boreholes for garden irrigation and the connection of a borehole to toilet cisterns for flushing. These were followed in 1999 by additional subsidies to install domestic grey water recycling systems, and hot water recirculators. During the same period (1997) public water supply of desalinated water has been introduced as a source for domestic water to meet the deficit resulting from the growing demand. The rationale and underlining policy objective of the WDD was to reduce demand for distributed drinking water in households (part of which is coming from desalination) that is too expensive to be used for gardens and toilet flashing, especially during drought periods.

The WDD offered a subsidy of €700 for the construction of boreholes for the irrigation of private household gardens. The aim of this policy was to reduce potable water consumption from the distribution networks. To be eligible for the subsidy, applicants' households should be within the jurisdiction of a water supply board, either a Water Board or a community board, and connected to the water supply system of a Water Board or of a municipality or community board of the Republic of Cyprus (Charalambous et al., 2011).

From 1997-2010 a total of 13,172 subsidies have been granted (of which 59% for new boreholes, 34% for connection of boreholes to toilets, 6% for recirculators and 1% for grey water recycling systems installation). The total amount paid in subsidies from 1997-2010 is about 5.5 million € (of which 59% for new boreholes, 34% for connection of boreholes to toilets, 3% for recirculators and 4% for grey water recycling systems installation). The overall average cost of saved water from all the subsidies during the whole 1997-2010 period is 0.43€/ m^3 (Kossida and Tekidou, 2011).

3.2.2.5. Case 5: Beddington zero fossil energy development: key lessons

The Beddington zero fossil energy development (BedZED) in London, UK, is something of a modern icon in terms of assembling simultaneously on the same site new construction methods, the best of available 'green' technology and social engineering combined with new peri-urban lifestyles. Completed in 2002, BedZED is the first large scale eco-community in the UK. The project was led by Peabody (London's largest housing association) in partnership with Bill Dunster Architects and environmental consultants BioRegional. As with many innovative and exploratory departures, however, not everything went according to plan (Shirley-Smith and Butler, 2008).

The water management strategy for BedZED, as originally developed by Arup, Bill Dunster Associates (BDA) and BioRegional, was based on a four-fold approach. (a) To reduce the overall consumption of potable water by the installation as standard, of water efficient appliances. (b) To make occupants aware of and take responsibility for their own water consumption and to be able to monitor it. (c) To install a rainwater harvesting (RWH) system by draining surplus water from the slightly arched green roofs. (d) To install a 'Living Machine' (LM) (designed by Living Technologies) in a greenhouse located in the BedZED services building for the purpose of full on-site waste water treatment.

The next figure shows how the water management system (as built) at BedZED is arranged. The mains water supply enters the site via a bulk meter and is distributed in a conventional way directly off the pressurized main to all dwellings. Likewise waste water is initially collected in a conventional way and flows under gravity to a sump from where it is pumped to into a pair of large, compartmentalized primary settlement tanks arranged in series beneath the football field. The liquor from the settlement tanks is then pumped to the GWTP on the first floor in the green house where it flows through the treatment train. The treated effluent is passed through a ultraviolet (UV) unit for disinfection, dyed green and distributed through a return spinal pipe back to the green water storage tanks under each of the blocks. From here it is pumped on demand directly to the toilet cisterns of the dwellings, or used to irrigate the sky gardens. Surplus treated effluent is drained by gravity to a watercourse (ditch) at the boundary without being UV irradiated. Emergency connection to the main sewer was available as fallback position in case of system malfunction.

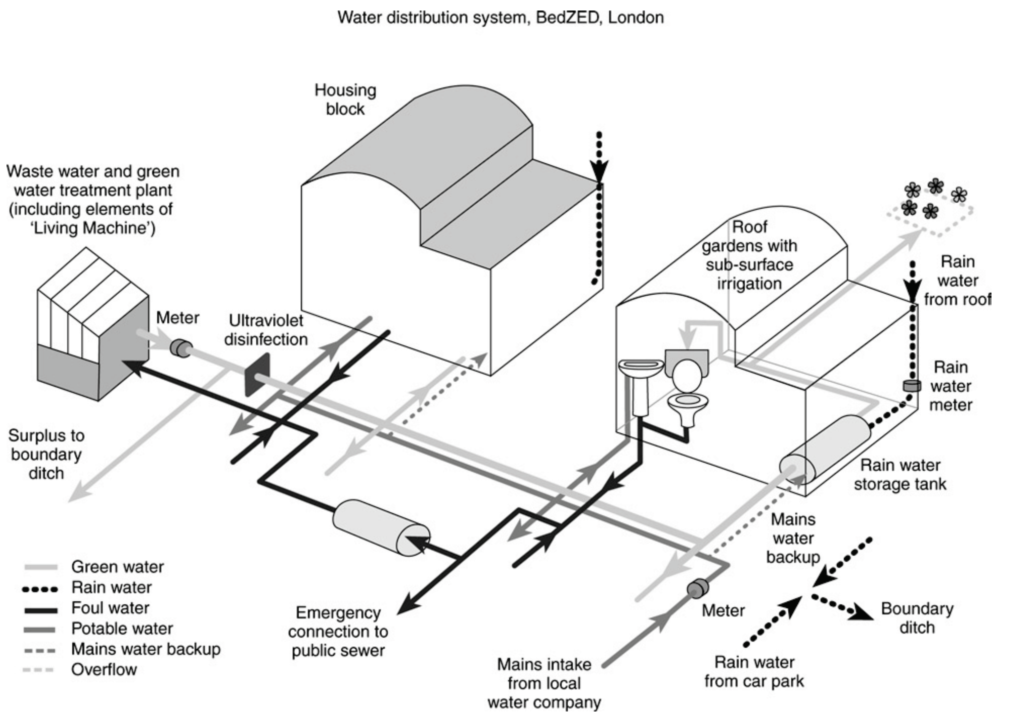

Figure 16: Essentials of the water system for BedZED (Living Technologies, 2000)

Albion Water Ltd (AWL) became involved with the scheme in July 2000. Albion Water was the sole Ofwat-licensed water company in England and Wales at the time other than the major incumbent suppliers of water and wastewater services. It was agreed with The Peabody Trust that AWL would become the licensed water and wastewater services provider for BedZED, in conjunction with AWL's joint venture partner South West Water plc.

Albion Water undertook to deliver BedZED's water supplies and waste water recycling plant in the knowledge that it would be commercially marginal, but that the BedZED GWTP would be an important and valuable demonstration project of sustainable technology for further development on new sites in different parts of the UK. The demise of the company (AWL), however, left BedZED residents and The Peabody Trust in a difficult position. SWW continued to provide basic statutory services for residents, but had little incentive to carry the GWTP through to a successful outcome. Thames Water has now undertaken a limited responsibility to restore the GWTP to specification standards while currently removing waste water through its own network. It also intends to install a membrane bioreactor as the principal treatment system.

Site management during the construction period had some inherent weaknesses and apparently difficulty was experienced in the simultaneous handling of the full range of new, 'sustainable' technologies being rolled out on the BedZED development. That such a task was daunting is no exaggeration. The difficulties were, however exacerbated by poor communication, delayed decision making, ill-timed construction programming, and some redundancies and closures of small companies engaged on the site owing to the ensuing delays.

3.3. Transferable lessons for Sustainable UWCS

This section identifies enabling and constraining factors from the cases in section 3.2.

The use of Mexico City's waste water for irrigation is an example with inter-organization enabling factors. The Mexico City authority has been cooperating successfully with the farmer's association for decades. This cooperation appears to be quite harmonious, to the extent that the farmers requested from the Government to grant them an entitlement to use the wastewater, which according to the legislation (as all waters in the country) is property of the state.

The success of the indirect wastewater reuse in Belgium is attributed to the high level of communication with the community and its involvement prior to, during the project and throughout the three years of its operation. This has reinforced a high level of trust and acceptance of indirect potable reuse within the community.

The BedZed pilot project on the other hand is an example of several constraining factors: at the local (design) level it appears that the concepts of demand management, rainwater harvesting, stormwater management, green water recycling and thermal heat storage, which were supposed to be combined within the same system, were never really integrated into the same design concept – exploiting interactions and avoiding duplications. This led to oversized underground tanks, wasted treated effluent, large amounts of mains water top-up and uncertainty about the quality of water supplied for various purposes. At the organization level, the project was handled by a series of different parties which were sequentially tasked with designing and making the system work. This proved to be inefficient and error-prone. Ideally a single competent organization should have been rendered responsible for all aspects of integrated water management in the site.

4. WATER AND ENERGY

4.1. Introduction

Water utilities face the challenge of being more energy efficient. After manpower, energy is the highest operating cost item for most water and wastewater companies. High energy consumption will affect the water industry worldwide and is inextricably linked to the issue of climate change. Climate change confronts the water sector with the need to optimize the energy use and limit greenhouse gas emissions of their operations (Smith et al, 2009). By doing so, water utilities contribute to the target of the European and national governments for substantial energy reductions in the coming years of up to 20%.

In the European water industry, building and managing its infrastructure in a cost-effective, energy efficient manner is nowadays seen as an important responsibility. The number of examples of energy measures in water production and treatment is growing rapidly. In 2010, the Global Water Research Coalition devised a global compendium of "Best practices in the energy efficient design and operation of water industry assets" (UKWIR and GWRC, 2010).

The European case studies described in this compendium show significant energy savings in all parts of the water cycle. Overall energy efficiency gains of between 5 and 25% seem realistic. Both incremental improvements in energy efficiency through optimization of existing assets and operations and more substantial improvements in energy efficiency from the adoption of novel technologies can be distinguished. There are two areas with most potential; pumps of most types and functions, and aerobic wastewater treatment systems. Examples with potential include the improved operational set up of pumping design, on line aeration control, and energy efficient bubble aerators and sludge belt thickeners. Next to optimizing energy efficiency across the water cycle, there are also opportunities for energy generation. Appealing practices include biogas production from sludge (co)digestion and hydraulic energy generation from micro-turbines (Frijns et al., 2012).

In this section some of the European best practices, from drinking water to wastewater treatment and sludge processing, are presented. For detailed information and other best practices, see Frijns and Uijterlinde (2010) and the TRUST Internal Deliverable, entitled 'The interconnection potential of enhanced water-energy flow synergies' (Frijns and De Graaf, 2012).

4.2. Best practices

4.2.1. Case 1: Variable frequency drives at a water collection well in Grobbendonk, Belgium (Pidpa)

The application of variable frequency drives at the pumps of the water collection well Grobbendonk resulted in about 15-20% energy saving, i.e. ca. 100.000 kWh/y.

Pidpa, the Provincial and Interurban Drinking Water Company in the province of Antwerp, provides water to 65 municipalities in the province of Antwerp. At Grobbendonk, drinking water is produced from 30 wells that collect groundwater.

The water collection wells of Grobbendonk are sensible for clogging, increasing the pumping head with up to 10 meters over the years. Moreover, the groundwater level has a 2 meter seasonal variation, and mutual influence on collection between wells can have an effect on the level of about 5 meter. Thus, originally the wells were equipped with oversized pumps that had to be strangled, so that sufficient head would remain available.

To overcome the related energy loss, variable frequency drives have been installed at the low pressure pumps of 11 new wells (of the 30). Variable frequency drives, or variable speed drives (VSD) alter the frequency and voltage of the electrical supply to a motor, and allow speed and torque control without wasting power. Main incentive was cost saving from energy saving.

On average 5 m pumping head was gained, or 9,600 kWh/y energy gain per pump, a 15-20% energy efficiency improvement. Total savings are about 100,000 kWh/y. The payback time is 2.5 years.

Figure 17: Pump with variable frequency drives at water collection well

4.2.2. Case 2: New drinking water pumps and operational control in Nindorf, Germany (Süderdithmarschen)

At waterwork Odderade new drinking water pumps and operational control were installed. The specific energy consumption [kWh/m↖] of the new frequency driven pumps was about 15.7 % lower.

The water utility Süderdithmarschen supplies southern Dithmarschen with drinking water. The waterwork Odderade produces approximately 6 Mio. m↖ drinking water per year. New drinking water pumps and operational control were installed.

Before modernization six pumps with different dimensions generated the required pressure of 5.4 bar. Two of the pumps had a frequency control, the other four pumps were operated with only one speed. In the course of the modernization the six old pumps were replaced by four frequency driven pumps. The specific energy consumption [kWh/m↖] of the new pumps was about 15.7 % lower. In 11 to 12 years the modernization is amortized.

Figure 18: Frequency driven pump

4.2.3. Case 3: Micro-turbines on drinking water treatment plant in France (SIEVI & Veolia)

Installation of 4 micro-turbines on drinking water supply network: 4.5 million kWh/y generated.

The drinking water treatment plant of SUPER RIMIEZ is located higher than the customers leading to an excess pressure (>17 bars) at domestic network inlets. Microturbines installed on drinking water supply network allow converting the hydraulic potential energy loss resulting from this hydraulic design into electrical energy.

3 Francis microturbines were installed:

- 1 turbine on DW supply network (installed power: 120 kW, average flow= 0,5 m^3/s, height differential: 40 meters)
- 1 turbine on DW supply network (installed power: 291 kW, average flow= 0,3 m^3/s, height differential: 120 meters)
- 1 turbine on DW supply network (installed power: 171 kW, average flow= 0,4 m^3/s, height differential: 52 meters)

The investment costs was 1,3 M€ and the total energy generated was 4,5 million kWh/y. The payback time is 6 years (because of preferential feed-in tariffs).

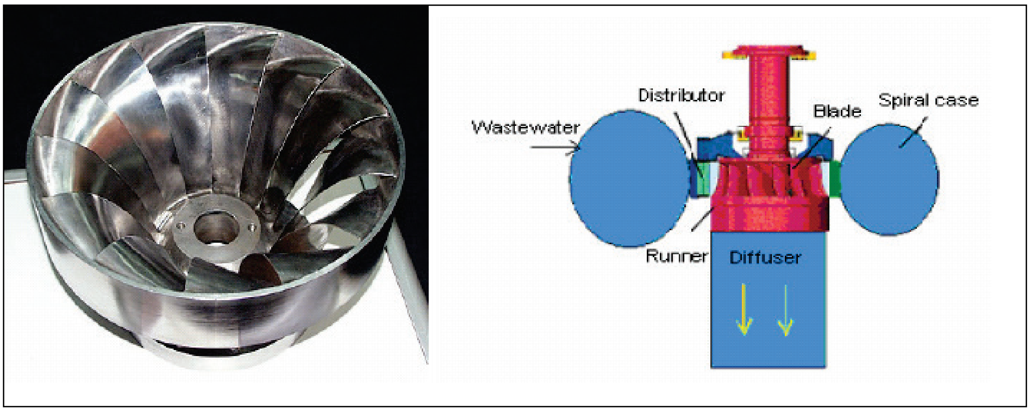

Figure 19: Schematic diagram of micro-turbine

4.2.4. Case 4: Energy efficient plate aerators in Sliedrecht, Netherlands (Waterboard Hollandse Delta)

Plate aerators have a higher efficiency compared with conventional fine bubble aeration, resulting in a 25% decrease of energy demand.

The WWTP Sliedrecht is a treatment plant based on the activated sludge process with a capacity of 40.000 p.e. and 16.500 m^3/h. Aeration was carried out by conventional fine bubble aerators fed by two blowers.

Due to an increase of the load and stricter effluent standards the aeration capacity had to be extended approximately 25% (from 281 to 354 kg O2/h). At first it was planned to extend the aeration by supplemental conventional fine bubble aerators, a third blower piping and installing extra energy power.

In the advanced design the extension of aeration was carried out by installing supplemental plate aerators with a high specific OC capacity. Due to this high specific capacity the supplemental aeration could be reached by only installing the plate aerators without extension of the blower capacity and extra piping.

Compared to the conventional fine bubble aerators, plate aerators have a much higher efficiency:

- Conventional fine bubble aerator: 17-20 g/Nm^3,m; 3,0-3,5 kg O2/kWh
- Plate aerators: 25-30 g/Nm^3,m; 4,0-5,0 kg O2/kWh

Compared with surface aerators (1,8-2,0 kg O2/kWh) the energy efficiency is even higher, however, this type of aeration has lower maintenance costs.

The high efficiency of the plate aerators is mainly caused by the smaller diameter of the produced air bubbles, which cause a much higher oxygen transfer to the water than by bigger bubbles. A second reason of the higher efficiency is that distance between the plate aerators and the bottom of the aeration tank is less than with conventional fine bubble aerator. Therefore the aerators have more depth, more contact time and more oxygen transfer to the water.

Figure 20: Plate aerators at bottom of wastewater treatment aeration tank

4.2.5. Case 5: Sludge age depending on temperature in Hoensbroek, Netherlands (Waterboard Limburg)

Lowering MLSS during summer operation decreases the energy demand with 10-15%.

Design of activated sludge plants is mainly based on waste water characteristics, effluent standards and temperature of the waste water. Especially lowest temperatures during winter operation are leading in the volume of the aeration tank. Low winter temperatures result in a low sludge load and therefore high aeration volumes in order to achieve effluent standards also during winter periods. Low sludge load during at low temperatures is the result of the low growing rates of especially nitrifying bacteria. Sludge age in the aeration tank has to be corresponding with the growing rate of these bacteria. Sludge ages lower than the growing rate will results in a wash out of nitrifying bacteria out of the activated sludge and therefore an increase of N-concentration in the effluent.

Growing rates of the nitrifyers very much depend on temperature. This implies that (many) more nitrifyers can be present in the activated sludge at operation temperature above the design temperature. Therefore the total sludge volume in the aeration e.g. the MLSS concentration might be reduced during summer operation.

Important driver to reduce the sludge volume is the reduction of the oxygen demand. The total oxygen demand very much depends on the total sludge volume and the temperature. Therefore oxygen demand in the WWTP is higher during summer as equal MLSS concentration during winter operations.This implies that MLSS reduction during summer will lead to a reduction of oxygen demand and therefore energy demand without impact on the effluent quality. Depending on temperature differences during summer and winter, a 10-15% energy reduction is achievable. This is tested and verified at WWTPs of Waterboard Roer en Overmaas, Waterboard Hollandse Delta and Waterboard Vallei en Eem. Results showed that a 5-20% reduction of the energy demand was achieved.

Increasing the sludge age during summer periods has impact on the sludge mineralization. Sludge production might increase compared with the situation of one whole year MLSS concentration. This results in supplemental costs for sludge treatment and disposal. Test results showed that based on calculations, a 3-5% increase of sludge production might be expected, however, in practice no significant differences were measured. In case this would appear, digestion of the sludge can compensate the increase.

A severe risk in too much focusing on the reduction of energy demand is that increasing the sludge concentrations at autumn when temperature drops, might be too late, which will have a negative impact on the effluent quality.

4.2.6. Case 6: Sharon/Anammox in N-rich sludge water from dewatered digested sludge in Rotterdam, Netherlands (Waterboard Hollandse Delta)

The oxygen demand and therefore the energy consumption of the Sharon/Anammox process is very low, due to the partial oxidation. Introduction of this process at the digester effluent resulted in an extra 500 kg N/d removal at an equal energy consumption.

The WWTP Rotterdam-Dokhaven is a municipal wastewater treatment plant with a capacity of 620.000 p.e. and 19.000 m^3/h. The treatment is based on biological AB-process. The excess sludge is thickened, digested and dewatered in the nearby location of Sluisjesdijk. The digester effluent, which is high N-concentrated (approx. 1,0-1,2 gN/l), is recycled to the WWTP and contributes for about 15-20% in the total N-load (4.000-4.500 kg N/d) of the plant. The N-removal in the activated sludge system was based on conventional nitrification and denitrification.

In this project the SHARON/ANAMMOX-process was introduced as a separated treatment for the digester effluent. The SHARON-process is based on a partial ammonium oxidation. Partial in two ways: oxidation from ammonium to nitrite (no nitrate) and only 50% of the ammonium is oxidized. Therefore the SHARON-effluent is a 50%/50% mixture of ammonium and nitrite.

Due to the partial oxidation, the oxygen demand (and therefore the energy consumption) is very low.

The SHARON-effluent is treated in the ANAMMOX–reactor where the ammonium and nitrite is reduced in one step by special anammox bacteria to nitrogen gas. Oxygen is toxic, therefore no aeration, only a limited energy demand for mixing.

Although a 50-60% energy reduction might be reached in the treatment of the N-rich digester effluent, this was not achieved in the Dokhaven-project. However, the SHARON-ANAMMOX-process resulted in an extra 500 kg N/d removal at an equal energy consumption.

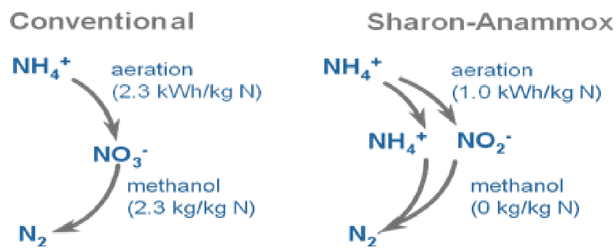

Figure 21: Conventional and autotrophic N-conversion routes

For other projects, where the N-removal is already optimal/maximal, the introduction of the SHARON/ANAMMOX can achieve a significant reduction of the energy demand.

Other advantage of the process is that no carbon source is needed/used for denitrification. Also the small excess sludge production is an advantage, however, this is at the same time a risk factor: after a disturbance of the anammox bacteria population it takes a long time to regrow in the system. Although this has happened several times during the start up period, much knowledge of the process has been gained and the process is reliable now for implementation.

The SHARON/ANAMMOX-process is also successfully used for several N-rich industrial waste water (tannery, food-processing). In one case the process has been optimized in the one reactor CANON-process with lower investment costs.

4.2.7. Case 7: Energy and economic savings using biogas for electricity and heat generation in Spain (Agbar)

Fossil fuel energy required for the sewage and sludge processing was reduced significantly by using the biogas generated during anaerobic digestion of sewage sludge instead of natural gas (around 25%). Furthermore, and according to the Spanish legislation, 200 k €/year are saved by selling the electricity to the grid instead of using it in the plant.

Using advanced sludge treatment technologies in order to decrease sludge's disposal requirements and reduce the energy consumption may seem controversial, but a project in Spain shows that it can be easily achieved by using biogas as fuel in the process.

The WWTP is a relatively new treatment plant designed in 1997 which treats around 260.000 m^3/day (600.000 population equivalent). The facility could be expanded in the future to 715.000 PE (25% increase) if necessary. The sewage treatment consists of pre-treatment (screening, fats and grits removal), lamellar primary settling, activated sludge (with anaerobic, anoxic and aerobic chambers, for simultaneous C, N and P removal) and secondary settling. The effluent is discharged into a river.

Primary sludge is first sieved and then mixed with the biological sludge. The mixed sludge is then thickened to 3-4% TS by centrifugation and anaerobically digested under two-stage mesophilic conditions (38ºC). Finally, it is mechanically dewatered by a centrifuge (23% TS) and thermally dried with air in a direct dryer (upto 93% TS). The benefits of sludge drying are well-known, namely (1) volume reduction (which facilitates storage or final disposal), (2) possibility of dried sludge valorization (cement industry, gasification…) and (3) improvement of the sludge properties (sludge energy content increase, enhanced biological stability…). However, sludge drying has a high energy requirements (thermal), thus it is an interesting disposal solution if a heat source is available.

Around 9.000 Nm^3/day of biogas are produced during the anaerobic digestion of sewage sludge in this plant. The utilization of this methane-rich gas (with an energy content between 6,2 and 6,7 KWh/Nm^3) in an internal combustion engine was considered as a very interesting option in order to reduce the plant's overall fossil fuel consumption. One biogas and two natural gas engines (nominal electric power 1.358 KW each) were installed when the plant was built. There is an additional boiler powered with natural gas to cope with the overall heat demands on the plant. The total gas consumption on the plant is about 63.300 MWh/year.

Until 2008, the electricity produced in the three engines (24.756 MWh/year) was mainly used in the plant for sewage aeration and pumping and only a modest amount was sold to the grid (6.662 MWh/year), thus the plant could have been working without connection into the power grid. This action was economically improved in 2009 with the implementation of incentives for green energy production. In fact, according to the Spanish legislation (Orden ITC/3801/2008 and Orden ITC/1723/2009), electricity from the biogas and natural gas engines are sold at 10.335 and 8,795 c€/kWh respectively. With the application of these fees, the plant's total savings can be estimated to be 200 k€/year.

The engines' heat is used for two basic operations in the sludge line: sludge drying and digester's heating. Exhaust gases from the three engines and the auxiliary boiler are mixed together and directed to the adjacent sludge drying plant for heat recovery: a gas/gas heat exchanger heats air for the dryer. These gases are then discharged into the atmosphere at around 200ºC. In addition, cooling water circulates through the engines and its heat is used for digester heating. In total, engines' heat stands for around 13.000 MWh/year (thermal), of which 9.276 MWh correspond to more than a third of the sludge drying requirements (the rest is supplied by the exhaust gases from the auxiliary burner) and to 100% of digester's heating (i.e: 3.720 MWh/year).

This case study shows how energy from sewage sludge allows WWTPs to save energy and therefore contribute to climate change mitigation. Biogas utilization in internal combustion engines saves up to 19.200 MWh/year (around 25% of the total gas consumption) and can be easily coupled to a sludge drying facility, showing that its energy content can not be underestimated.

4.2.8. Case 8: Energy savings using sludge combustion exhaust gases for thermal drying in France (Lyonnaise de Eaux)

Energy required for the sludge processing drops radically after the implementation of the proposed heat recovery step. In fact nowadays the process saves up to 90% of the fossil fuels that used to be consumed.

Upgrading a wastewater treatment plant with advanced processes to achieve new, strict water quality regulations and save energy may seem paradoxical, but a project in France, illustrates how these facilities can improve their overall energy balance by using sludge and other organic waste as fuel in the process.

Since 2006 the upgraded facility has treated wastewater for 400,000 persons equivalent (pe), a substantial increase from its original capacity of 140,000 pe when it was constructed in 1955. By 1975, a new independent branch increased capacity to 240,000 pe. These two facilities were designed to treat exclusively the carbon pollution to comply with regulations. The original structure treated sludge in two different lines. The first treated sludge using a sequential order consisting of digestion, solar drying, and storage. Biogas was flared and most of the produced heat warmed the digester. In the new treatment branch, sludge was first gravitationally thickened, then mechanically dewatered, and finally burned in a fluidized bed. The sludge was chemically conditioned prior to its mechanical dewatering in a press filter. Exhaust gases were allowed to pre-heat the combustion air, and the combustion ashes were disposed into a controlled landfill.

The new facility was upgraded to meet European directives, which were non-existent during the previous expansion in 1975, and to handle wastewater from a larger population. Its design aims to reduce not only carbon, but also nitrogen and phosphorous pollution.

The upgraded wastewater treatment plant opted for a common line to treat all the produced sludge. The new sludge treatment was still organized around the combustor since it was the principal equipment in the previous configuration; however the design engineers instituted some major experimental changes. First, the static gravitational thickening was substituted for a dynamic drip grid. Then the former press filter was replaced for a new continuous centrifuge. Finally, although the combustor remained, a new belt dryer was installed in order to use the heat produced by means of a closed loop with the combustion exhaust gases. Thus, moisture is evaporated by direct contact between the wet sludge and combustion hot gases, which have low oxygen content. The resulting byproduct, dried and dewatered sludge, is used as agricultural fertilizer. Combustion ashes, another by-product, are disposed into landfills according to European sanitary policies.

The case study shows that it is possible to make a trade-off between installing more advanced treatment processes and saving energy. More advanced treatment processes produce the same amount of treated effluent, yet doubled the consumption of electricity compared to the first configuration. Most importantly, the major cost savings were achieved by the new design of the sludge line. The new sludge processing avoids completely the diesel consumption and significantly reduced gas use. The total energy consumed (electricity, diesel, and gas) in the two lines remains nearly the same with only a slight increase (13%) for the upgraded version.

The new sludge line configuration takes advantage of the sludge volatile matter potential as a tool to reduce overall energy consumption, whereas there was nearly no use of this potential in the first configuration. The new arrangement also provides operating advantages because it is much more flexible in terms of sludge disposal routes since it can accept external sludge from other wastewater treatment plants, industry, and also grease wastes. The final, dewatered product (90-95% dry content) can be used for agricultural needs, energy recovery, or landfill if no other possibility.

4.2.9. Case 9: Optimized use of sewage gas with microgasturbines in Switzerland

If a municipal sewage treatment plant (STP) carries out sludge digestion, sewage gas is produced which can be used as an energy source. The use of sewage gas for power and heat production has become more attractive, particularly since the introduction of guaranteed revenue for electricity fed into the grid within Switzerland in 2008. With microgas turbines, an additional technology is available alongside tried-and-tested thermal power stations. The individual constraints of an STP and its size determine which sewage gas usage concept generates the highest added value.

Since several decades, usage of sewage gas has been used for generation of electricity in Switzerland in cogeneration power plants (CPP). In these plants, electricity is generated and the excess heat is produced at a temperature of around 80° C which is very suitable to warm up the sludge to around 37° C for the sludge digestion.

In recent years, the 70 STP's which deliver electricity into the net have produced around 50 GWh per year. Since 2008, a regulation was introduced in Switzerland, which guaranteed the revenues for electricity into the net for a period of at least 20 years. This of course has provided a motivation for many STP's to consider the option of gas recovery and utilization.

This case study deals with an alternative process for the utilization of sewage gas, using microgasturbines (MGT). So far, MGT's have only been used in 8 different STP's in Switzerland, and the experiences with these installations and a comparison with CCP is reported.

The most important conclusions are:

- The electrical yield of MGT's is smaller than for CPP: For plants with a mid-range capacity (100- 150 kWel), 37% of the energy is converted into electricity with CPP, while 29% is generated with MGT.
- On the other hand, the rest heat generated by MGT has a much higher temperature and thus, a much higher exergy than that generated by CCP: The temperature is around 275-300° C compared to 80° C for CCP. This gives a much higher range of potential of high-value applications for this waste heat (see below).
- Also some more heat is generated in MGT (56% instead of 51%).
- MGT's are much more flexible in handling variations in methane content of the sewage gas than CPP's. MGT's can handle even gases with methane contents of 50% (the content in sewage gas is around 60-64%).
- In MGT, excess heat (summer) can be disposed of by a waste gas exhaust. The heat exchanger only comes into play when actually needed. This option is mostly not available in CCP's.

Because of the higher temperature of the heat released, MGT enables the use of fluid-bed sludge drying. This concept will be realised in a STP with the following key properties: capacity of the STP: 80,000 population equivalents; amount of sewage gas produced: 1 Mm^3/year (total energy content: 6400 MWh/a).

In the current situation, 84% of the sewage gas is used for sludge drying, also of sludge from other STP's. In future only the own sludge will be treated, so there will be a surplus of gas available. The application of CCP was compared with MGT combined with fluid-bed sludge drying.

In future, it is foreseen that additional substrates (from external providers) will be digested in the sludge digestion. The use of MGT results in a similar cost balance as CCP if no co-digestion is used. The reason lies mainly in the higher investment costs of MGT. The real advantage appears when co-digestion is applied. The higher electricity yield clearly outweighs the increased investment costs and thus, the net cost balance is better than in the case of CCP.

4.3. Transferable lessons for Sustainable UWCS

This section intends to identify enabling and constraining factors which can be distilled from the cases in section 4.2.

The previous section showed that large potentials exist in energy saving and generation in the water system. Although the previous section focused on the technological aspects of energy saving and generation in the water system, in this final section of the chapter emphasis is put on the opportunity that exists for the water sector in relation to other developments in cities. These opportunities point towards the *potential* enabling factor of a closer cooperation of water utilities with a diversity of stakeholders in cities (intra- and inter-organizational, individual enabling factor). In the documentation on the techniques themselves, there is no explicit reference to such factors. Below, however, and based on a few articles, some potential factors are discussed.

As most of the energy use in the urban water cycle comes from heating water by households, it is apparent that the participation of inhabitants and the housing sector is required. Such participation might be considered an *enabling inter-organizational factor*. Water conservation measures in households that are implemented due to a closer involvement by inhabitants and the housing sector, both through water saving devices (e.g. for washing machines) and behavioral changes (e.g. less water gardening) can have a substantial contribution to a reduced amount of water to be produced and treated and thus the energy use related. This is in particular the case for warm water conservation. It is thus important to address this issue with the construction and installation sector. Fortunately, in their efforts to lower the Energy Performance Coefficient of new houses, the building sector is already moving towards the implementation of warm water conservation (Nederlof and Frijns 2010). Examples of energy reduction in buildings and offices are the introduction of more efficient appliances such as better water heaters, and heat recovery from used water or extracted from the groundwater.

In fact, in the efforts of other sectors, such as building, energy, and urban planning, to become energy neutral, a large potential exist to incorporate energy efficient water initiatives as well. One can anticipate that the driving forces for change are stronger in these urban sectors than in the water sector itself. Collaboration of the water boards through the contribution of water measures as part of the carbon neutral effort of cities could well be a successful strategy. Novotny (2010) emphasizes the substantial contribution water conservation can have in minimizing the carbon footprint of cities.

Future city planners have to consider water, energy and nutrient flows together rather than separately and will have to design with flexibility for future changes. These flows interact, therefore the water sector should interact with other sectors to discuss common challenges and develop shared solutions. For example, Kenway et al (2011) note the opportunities for co-managing water and energy in cities through their temporal variations. Involvement of both sectors simultaneously may help identify interdependencies as well as help address peak load issues (e.g. making use of biogas or hydropower energy produced by the water sector) which are critical to both sectors.

As such, the efforts to improve the energy efficiency of the water sector and integrate water and energy in urban areas, contributes to the overall objective of TRUST towards sustainable urban water systems.

5. LEAKAGE AND LOSS REDUCTION

5.1. Introduction

Some of the information in these chapters is taken directly from deliverable 5.5.1, *Exploration of existing technologies for maintenance*, in the EU project PREPARED. This is done with permission of the authors (Bruaset et al., 2012).

In the last years, the changing climatic conditions, in which the extreme events of floods and droughts have been increasingly more frequent, lead to water shortages in many countries of the world. The importance of water losses in the overall total distributed water is well known. The amount of water leaked in water distribution systems varies widely between different countries, regions and systems, from as low as 3–7% of distribution input in the well maintained systems to 50 percent and even more in some undeveloped countries and less well maintained systems (Covas and Ramos, 1999).

Water leaks can be expected to increase because of climate change in some climate regions, due to:

- Dehydration and settling of the ground in hot climates, causing pipes to break.
- Colder climates during winter in already cold climates, increasing the break rate due to thaw. This is already observed in European and North American cities.
- Higher number of frost/defrost periods annually (in some climates), increasing the strain on pipes, causing them to break (Vevatne et al., 2007).
- Increased corrosiveness of the ground (Vevatne et al., 2007).

The expected increase in break rates due to climate change will enhance the problem of water leakage and only confirms the need to control and reduce leakages in the drinking water networks. A range of equipment and techniques have been developed to assist water engineers in reducing the losses and control the rate of leakage.

The main methodology of leak detection is the establishment of Distict Metered Areas (DMAs) and a following detailed localization of leaks. This is mostly done by searching for leaks with listening equipment or with an acoustic correlator. These are acoustic techniques. All of the technologies which are being presented in the cases below are being used and applied in municipalities and water companies today. Thus, they have been proven to work in actual practice.

At the same time, it is vital to introduce performance indicators for the strategic target setting. Rizzo (2012) explains that Malta Water Services Corporation has joined up with a growing number of water utilities worldwide that are adopting the use of the Infrastructure Leakage Index (ILI) as a means of measuring and benchmarking water leakage. The ILI is a high level performance indicator advocated by the *International Water Association* (IWA) and already adopted by various countries across the globe. The ILI is computed as the ratio of the total national leakage (Current Annual Real Losses) to the minimum technically achievable leakage value (Unavoidable Annual Real Losses). Hence an ILI of 1 implies that the national value of leakage will have been reduced to its minimum technically achievable value (for a given pressure regime), a feat that can only be achieved by an organization that is highly competent and that boasts a water network that is in good infrastructural condition.

5.2. Best practices

5.2.1. Case 1: Brescia

The information in this section is taken from Fantozzi (2000). ASM is the Municipal Services Board of Brescia, which is a town of 200,000 inhabitants situated in the North of Italy. Since 1988, ASM BRESCIA has been engaged in an active program of leakage reduction. Various methods of leakage monitoring and detection have been employed by ASM, which include:

- District metering technique and step testing
- Leak detection and location using leak noise correlators
- Area surveys using acoustic loggers
- Analysis of the results by the Company's Maintenance Database

ASM's commitment to leakage reduction is demonstrated by the reduced level of leakage achieved in many of the managed water networks. In order to reduce pumping and hence operating costs to a minimum, an intensive leakage location program was initiated in the late 1980's, with the aim of systematically checking the network at regular intervals using correlators. ASM decided to divide the network into a number of small zones called districts that was proved by experience in different parts of the world, to be the most efficient method of controlling leakage. Then, permanently closing the boundary valves and installing flow meters on the few supplying mains is a way to continuously monitor the level of leakage. If an increase is registered in the night consumption, a team is sent in to locate the leaks. In this way, leakage is under permanent control, but intervention occurs only at the optimum moment.

The leak inspection on water pipelines using the cross-correlation method were standardized in 1991 by a work group of the CNR (Italian National Research Council). The method is based on the analysis of casual continuous acoustic noise generated by the water escaping from the pipeline and carried out by using the cross-correlation technique. The target is to standardize the method of leak detection by using the cross-correlation technique in order to detect and locate the leaks themselves yet not their amount. The method of testing requires the use of non intrusive sensing devices (accelerometers) or intrusive devices (hydrophones) placed on existing pipeline fittings as well as conditioning, acquisition and signal analysis instrumentation in order to detect and locate leaks.

On site inspection results

The results obtained over a sample of 4820 km of water distribution network in different Italian cities that have been surveyed using the cross-correlation technique in the last ten years are now outlined. During the systematic survey concerning the above mentioned networks - about half consisting of cast and ductile iron pipes and the other half of steel pipes and asbestos cement pipes (only 33 km of plastic pipes have been inspected) - a total of 3450 water leakages have been detected. Out of the detected leaks, 3312 (96%) have been located exactly and have undergone repair. Some of the remaining 174 leaks have been located during the repair excavation at distances greater than 3-4 meters from first indicated location. The location errors are essentially due to the uncertainty of the used distance between sensors.

In the last few years other acoustic techniques have been developed to optimize water leakage management in identifying leakage areas prior to directing leak detection operators to pinpoint the leak. Thus it have been developed systems for acoustic noise monitoring and recording that can be permanently or time limited installed at hydrants, valves or house connections. These "noise loggers" record typical noises in the network during low consumption hours at night and identify areas of potential leakage for further investigation. The ultimate advance consists in transmission of leak presence from the noise loggers to a receiver module, which may be hand carried or vehicle-mounted.

Noise Logger

This logger is installed at fittings via a simple magnetic coupling, and is battery powered with no maintenance requirement, and no problems for being immersed in water.

The separation distance between loggers depend mainly on the pipe material, with plastic pipes requiring closer spacing than metallic pipes. Each unit is intelligent and adapts itself to the environment. If no leak is present, a radio signal is transmitted to indicate normal background conditions. However, as soon as a leak is detected, the unit enters an alarm state and transmits a radio signal to indicate a "leak condition". Signals are received by a module that can be mounted in a patrolling vehicle, or can be easily hand-held. The receiving module analyses and "homes in" on signals to identify the location of units indicating a "leak condition", and thus the approximate position of a likely leak.

The reading of an area meter could easily include the monitoring of the loggers within it, so that new leaks are localized at exactly the same time as increases in the night flow are noticed. This should mean a prescribed leakage level can be easily maintained, because the detection time is greatly reduced. This innovative technology offers the possibility of continuous, permanent monitoring for leakage for the entire distribution system or just for those parts that are known problem areas.

The next step will probably be the automatic cross-correlation analysis between permanently installed loggers. The noise logger will be enabled to correlate a leak position with an adjacent logger and transmit the exact position by interfacing through SCADA with a GIS system. This process would enhance the leakage control process significantly.

District Metered Areas monitoring (DMA)

DMAs are often applied in leakage reduction strategies, as shown in case studies Brescia, Trondheim and Molde. When using DMAs to monitor the network, the water distribution system is divided in several zones - District Metered Areas (DMA) - according to the topology and topography of the system, and the number of consumers, each supplied by a single (or more) pipe(s) on which is installed a flow meter (Covas and Ramos, 1999; Algaard et al., 2007; Morrison et al., 2007). The DMAs are created by closing valves.

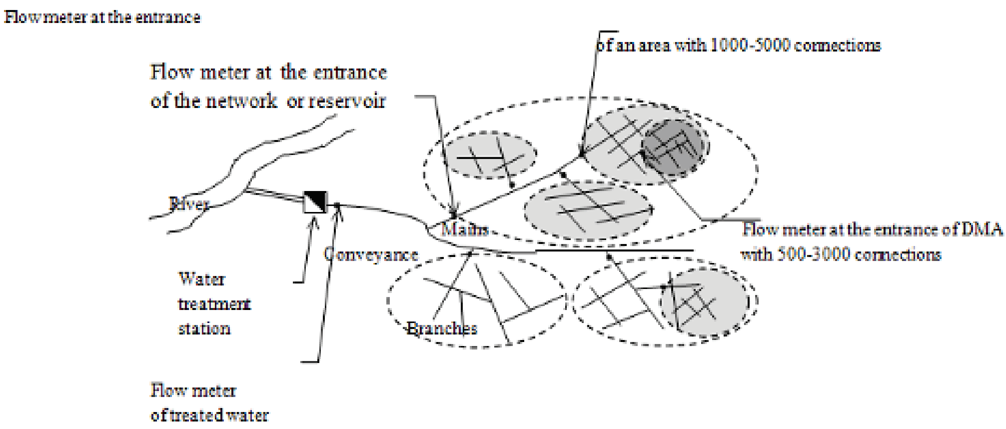

Figure 22: An example of District metered areas (Covas and Ramos, 1999)

The important tasks of DMA establishment are to control all the inflows and outflows in the area, as well as pressure variation during the day, using volumetric methods or the minimum night flow. Only this way it is possible to control the hydraulic performance of the network and to estimate leakage volume, eventually, determining leaks' positions by step testing or any other method. The leakage level in each area will allow the definition of priorities and adequate strategies for action. Each DMA should have up to 500 (1500) to 3000 connections. Sometimes DMAs are small autonomous networks supplied directly by elevated reservoirs.

An important condition of DMAs is subdividing of the distribution system into areas that can be isolated from each other and whose flows can be measured with appropriate metering (USEPA, 2010). Once a DMA has been identified, the flow is metered with an installed or portable water meter to measure the total volume of water supplied to the area. Reading the DMA master meter during late night periods (2:00 am – 5:00 am) can provide indications of higher flows than would be expected during this early morning period. DMAs with suspiciously high flow levels can then be further refined through step-testing to better characterize the water loss in this area.

Step testing

This method consists in temporary division of the DMA in sub areas by valve closure inside the DMA, or by the installation of moveable flow meters (Covas and Ramos, 1999). This method consists in progressive valve closure in the direction of an installed flow meter and the measurement of the correspondent flow. The success of step testing requires a well organized plan for the valve closure and meters sensible to very low flows. It should be applied also during the night, so that any significant increase in flow with no apparent cause, points out to the presence of a leak or a rupture. Depending on the methodology used, step-testing may cause backsiphonage, the risk of infiltration of ground water and some parts of the network can be without water for a period of time.

The testing starts at the end of the system and successively works backwards towards the head of the area where the area meter is located. A comparison of the measured results, coupled with knowledge of the area, can flag laterals in the system showing a higher than expected flow rate and one where leak detection is most likely (USEPA, 2010).

Step-testing can use either permanent or temporary metering. Permanent meters have the advantage of already being in place, easily accessible with historical usage data based on past billing to verify their calibration. Key points in the distribution system, which will be needed for routine analysis of system flows, are good locations for permanent meter installation. Such meters can be routinely read either manually or via a supervisory control and data acquisition (SCADA) system. Frequently these meters are used to monitor flows throughout the system but can double as water loss meters when used as part of a water loss management program.

5.2.2. Case 2: Trondheim

The information in this section is taken from Ellefsen (2012).

Trondheim is a city in the middle of Norway, with about 180 000 inhabitants. They started in the early 90's with DMA's and a leak reduction strategy. At that time, they divided the city into leakage zones (DMA's) in which today has two flow meters each permanently installed. They have since installed software which is continually supervising the consumption. The consumption during night is controlled against set values. If these set values are exceeded, an alarm is set off. If this occurs several times or over a longer period, it will be looked into since something has obviously happened in the zone.

The relevant zone will then be divided into smaller zones, as part of "light" step testing. These zones can be divided for example on the basis of pipe materials. Experience shows that a leak behaves different in different kind of materials. In ductile iron or plastic pipes, a leak can increase slowly over time, while in cast iron pipes the leak will mostly increase fast and stay at that high value, meaning a larger crack/hole has appeared in the pipe.

A consultant has been hired to make suitable normal values for day and night consumption in the different DMA's. These values will be used to compare with the continually measured consumption and will help to identify when a leak occurs in a zone. When a zone with leak(s) has been located, they use two different methods of locating it:

- Listening rod and a geophone (explained further below)
- Correlating noise loggers

The first method is mostly used in areas with cast iron pipes. This type of material with cracks produces a higher and easier identifiable sound to the geophones. Dutcile iron and plastic pipes will not produce a sound during a leak which is easy to identify and the method is therefore not as suitable on these materials. When using the rod and the geophone they will go from manhole to manhole until the area of the leak is somewhat localized. For exact location of the leak between two manholes, noise leak correlators must be used.

The municipality has invested in sets of noise leak correlators which help them to reduce and keep the leakages low. When these are used in a DMA, one noise correlator is placed on each manhole in the zone over a night. This may take several days, depending on the size of the zone. When all measuring is finished, the data is imported to a computer where it is analyzed and leaks are located.

When leaks are localized they are as fast as possible repaired in order to reduce the amount of lost water. Repair orders are continuously being sent to the repair teams. The leakage reduction strategy that the municipality has been applying in the last decade has helped them to reduce and maintain the leakage levels. However, during the latest years the winters have been more harsh than normal with very cold temperatures which have resulted in increased break rates of the drinking water pipes and thus higher leakage rates. Due to the increase in breaks during winter, the municipality has also started to search for leaks during winter time, as opposed to earlier.

GIS Systems for registration of failures and water leaks

GIS (Geographic Information Systems) systems are used to store all system and operational and maintenance data about a water or sewer network. The GIS systems contain visual data and an overview of the networks with an integrated database for the whole system. Each pipe in the system is stored with metadata which describes the pipe. The pipes in the GIS database are connected to another database called "diary", which collects operational data. In the diary every single incident (like pipe break or repair) with all necessary information can be registered on the specific pipe it has occurred in, and tells the history of the pipe. The diary is therefore also called the failure data base.

The purposes of a system for registration of failures and other performance related incidents include:

- To store information to make statistics for future analysis
- To follow and document the performance of the network
- To assess the need for reactive or proactive interventions
- Register information collected at interventions about the system failure

Part of the registration is to record failures in the drinking water networks, which includes breaks on pies and leakages. In the municipality of Trondheim, such failures have been collected for many years and are used when managing their networks (Ellefsen, 2012)

Real-Time Monitoring Systems

Real time monitoring systems can be used both for the water and the wastewater networks. Monitoring within these systems is performed continuously where relevant parameters are measured and monitored while instruments can be accessed and controlled, for example through valve operation.

SCADA systems: SCADA stands for *supervisory control and data acquisition* and refers to industrial control systems, computer systems that monitor and control industrial, infrastructure or facility based processes. Infrastructure processes may be public or private, and include water treatment and distribution, wastewater collection and wastewater treatment. Generally speaking, a SCADA system always refers to a system that coordinates, but does not control processes in real time.

Continuous measurement of water flow in DMAs (District Metering Areas) during night can reveal irregular increase in water flow which can be the cause of leaks. For example can the increase of water flow over a set value result in an alarm going off in the system. Leakages can thus be identified and localized quite fast for repair. The result is reduced overall leakages. This technique has for example been applied in the case studies of Brescia (Fantozzi, 2000) and Trondheim (Ellefsen, 2012), as described above.

Different Acoustic techniques for leak localization

Leak localization is an activity that identifies the spot of a leak between two manholes in a pipe system. The acoustic technologies (Covas and Ramos, 1999) are based on the fact that water discharge by the leak generates uncommon vibrations on the conduit with a certain band of dominant frequencies. The intensity and the frequency of the sound allow the location of the source, the leak. Two distinctive audible noises are produced as pressurized water breaches the water main (USEPA, 2010). The first noise is produced by a shockwave created when the water is forced through the opening. These sounds are normally in the 500 to 800 Hz range and are propagated through both the pipe and the water. These sonic waves travel substantial distances in the pipe and therefore can be detected for the distance near hundred meters from the actual break site. The second noise generated is typically in the 20 to 250 Hz range and is produced by the impact of the water stream on the surrounding pipe bedding materials, as well as water circulating through the cavity caused by the leak. These sound waves travel through the ground and are therefore restricted to a much shorter distance of travel before they are attenuated and can no longer be identified from the background noise. These lower frequency sound waves can be used to help spot the exact location of the break as the operator continues to listen along the pipe. There are many sounds carried by the pipes such as the noise of water moving through and around various appurtenances, to pumping sounds to street noises. Every distribution system has its own unique acoustic signature that changes from one point in the system to another. It takes time to recognize and understand the various noises that are part of normal system operation. Acoustical instruments are designed to assist the operator in detecting and identifying those sounds that are most characteristic of a main water loss. An experienced operator with distribution system operating knowledge is a key factor in effective leak detection.

Listening rods are among the simplest and oldest form of leak detectors in use (USEPA, 2010). A listening rod aids the user in hearing the noises that water makes as it is forced from a pipe. The listening rod in its simplest form is a steel rod, near one meter in length, with an earpiece at one end to help block out outside noises and to identify and pinpointing the leak by direct listening to the sound generated in sections of the network (usually used places with easy access, such as metal devices, fire hydrants and valves). Sounds from the water loss site are transmitted through the steel rod to the listener. If the user is in close enough proximity to the leak site, the lower frequency ground waves can also be detected. It takes operator practice and skill to successfully use a listening rod, but it is an effective and inexpensive tool.

The ground microphone or geophone is the indirect acoustic sounding alternative to the latter (direct acoustic sounding) used for surface sounding to pinpoint leakage. It is very useful for leak detection on plastic pipes under hard surface, losing its efficiency in grass and unmade surfaces (Covas and Ramos, 1999).

The *geophone* is a completely mechanical listening device that operates much like the physician's stethoscope (USEPA, 2010). A set of listening tubes extends from the operator's ears down to listening-heads placed directly on the ground above the pipe to be evaluated. An experienced operator, moving the heads along the pipe, can become adept at detecting leaks. The stereo-effect of the two listening heads permits the operator to accurately locate the site of the breach. While the simplicity of the device makes it very rugged and inexpensive to operate in the field, it can miss some sounds that are traveling in the pipe and water system. Leakage sounds for non-metallic pipe or the low-frequency sounds of water impacting the surrounding bedding do not travel well through the pipe but rather travels through the ground. Geophones are best used for detecting leak sounds that are propagated largely through the ground.

There are a wide variety of acoustic listening devices that use a *hydrophone* (piezoelectric crystal materials that produce an electric signal in response to acoustic impacts) to pick-up the sounds of leaking when placed on the piping system or in some cases on the ground above the pipe (USEPA, 2010). These instruments are enhanced versions of the listening rod coupled with a battery powered sound amplifier to enhance the sound being transmitted. Testing on the ground along the pipe must augment the static listening to the pipe leak sounds to accurately locate these leaks. Many devices are also equipped with frequency range filters to permit the operator to filter out non-leak causing noises and better concentrate on noises coming from the pipe in the frequency range most indicative of a leak. A number of more sophisticated acoustic leak detectors have added various degrees of digital processing to the amplification systems. These detectors aid the operator by providing digital and graphic readouts of sound strength to assist in identifying leak locations. Many instruments attempt to correlate the amplitude of the leak noise to leak flow rates to provide the operator with an indication of leak magnitudes.

Data loggers are a modification of acoustic leak noise detection recording (USEPA, 2010). Data loggers combine a listening head with a digital recorder into a single sensor that can be attached to the system and left in place to operate over an extended period of time. At the end of the testing period, the loggers are removed and their time-marked data downloaded to specialized leak characterization and detection software for analysis. The frequency of sampling and recording sound intensity information is preset by the operator and can range from once per millisecond to once per minute and can remain in place for several days, limited only by the data storage capacity of the unit. More sophisticated loggers can be set to turn on and turn off, sampling only during the quieter, low-flow hours. Some models of data loggers contain radios that will download their stored data when queried, resetting themselves for follow-on recording. This data transmission feature is useful for extended period measurements when the change in identified signals can be used to confirm and quantify water loss magnitudes. Data loggers can be an effective, low-cost method of taking continuous measurements, especially when nighttime logging is desired. Data loggers are most successful when used for leak detection on cast iron, ductile iron, steel, concrete and transit pipe. Leak detection in PVC needs longer run times.

Permalog + enables water suppliers to quickly and efficiently locate leaks in the water network (Fluid Conservation Systems). Loggers are deployed in areas of the distribution system to provide continuous monitoring of leakage. Easily installed on pipe fittings, they are retained in place by a strong magnet and are powered by low cost replaceable batteries. When a potential leak is detected, the logger enters an alarm state and transmits a radio signal to indicate a “leak” condition. The effectiveness of Permalog technology has been proven in some of the harshest conditions on earth. Loggers are immersion-tested to IP68 and will continue to operate even in flooded chambers. Water suppliers can monitor 100% of their distribution system confidently and effectively, enabling leakage to be reduced quickly, and easily maintained at a low level. The new Permalog+ includes logging functionality, where noise is recorded at preset intervals over an extended period of time. The logger can store up to twenty-nine days of level and spread history and the noise trends identified can then be presented in graph format, enabling the user to distinguish clearly between leak and non leak noise.

Leak noise correlators. It is not unusual for larger leaks to generate both lower frequency and lower noise intensities than recently formed, smaller leaks. Smaller pipe penetrations may result in higher discharge velocities that produce a louder, more characteristic sound for the same pressure differential across the pipe than older larger pipe breaches (USEPA, 2010). These larger leaks can therefore be even more difficult to detect and locate, especially in portions of a distribution system that are generating a wide range of noise profiles.

Leak noise correlators are portable computer-based devices, which can locate leaks automatically. They measure the acoustic wave in two (or more) different sections of the pipe with sensors, and the leak’s location is calculated by the time difference between the arrival of equal frequencies to each sensor (Covas and Ramos, 1999). Some leak noise correlators are wireless and provide the flexibility needed to accurately locate water loss sites along highly inaccessible routes (USEPA, 2010). The acoustic correlator is used to locate the leak with a couple of meters (Covas and Ramos, 1999). It is very efficient in quickly defining leak areas.

The leak noise correlators are more efficient, yield more accurate results and are less dependent on user experience than listening devices. Leak noise correlators consist of acoustic sensors such as accelerometers and hydrophones, wireless signal transmitters and receivers, and an electronic processing unit. As shown schematically below, the sensors are attached at two contact points with the pipe (normally fire hydrants) that bracket a suspected leak. The signals are transmitted from the sensors to the processing unit wirelessly. The processing unit computes the cross-correlation function of the two leak signals to determine the time lag between them. It then calculates the location of the leak based on a simple algebraic relationship between the time lag, sensor-to- sensor spacing, and sound propagation velocity in the pipe.

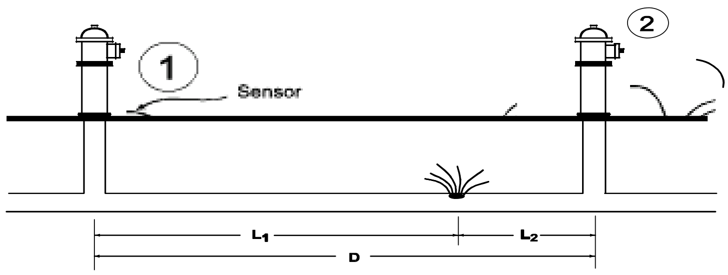

Figure 23: Schematic illustration of the cross-correlation method (Hunaidi and Wang, 2000)

5.2.3. Case 3: Molde

The information in this section is taken from Jacobsen and Mosevoll (1985).

The water supply system in Molde, a city in western Norway, supplies about 25 000 people. They started to rethink their leakage reduction strategy due to:

- A very high consumption at 6,35 mill m^3/year, which at that time exceeded the capacity of the source and translated into a consumption of about 1000 l/pe*day (when they started in 1983 the number of inhabitants was 17 000)
- A new water treatment facility was built. The source had a capacity of 4,4 mill m^3/year.
- Very high friction loss and many interruptions in the network.

What they first did was to divide the network into 7 DMA's which was each supplied through one pipeline. Flow meters were installed into all zones to measure flow. Then the average water pressure was reduced by adjusting the pressure zone lines and the establishment of a new pressure zone. Each of the DMA's was then divided into 7-10 smaller zones. What was further done was the following:

- Measuring of night consumption in the smaller zones. This was done by closing off one small zone at a time while measuring the flow to the rest of the small zones in the DMA. Around half of the small zones were then cut from further investigation due to low or no leakage.
- Coarse localization of leaks to stretches of pipes between two valves. This was done with mobile measuring equipment or with listening equipment where leaks were high (due to high noise).
- Detailed localization. Around 50 leaks were identified. To pinpoint the exact location of the leaks, listening equipment and noise correlators were used.
- Repair of the leaks. 48 of the identified leaks were dug up. It was found leaks in 46 of the 48 locations, and these were repaired. After this, the night consumption was reduced with 93 l/s, or 470 l/pe*day. This means that total production of water per year was reduced with 3,13 mill m^3/year, amounting to almost 50 % of the total production of water in 1982.

5.2.4. Case 4: Khayelitsha, City of Cape Town

Khayelitsha is one of the largest townships in South Africa and is located approximately 20 km from Cape Town on the Cape Flats which is a large flat sandy area at or near sea level. There are approximately 43 000 serviced sites with both internal water supply and water borne sewage while there are a further 27 000 low-cost housing units which are supplied from communal standpipes supporting a population of approximately 450 000.

At the beginning of 2000 the water supplied to Khayelitsha was measured to be almost 22 million m^3/a. The level of leakage was estimated from the night-time water use to be almost three-quarters of the water supplied to the area. The Minimum Night Flow (MNF) was measured to be in excess of 1 600 m^3/hr which is sufficient to fill an Olympic sized swimming pool every hour. The main source of the leakage was identified as the household plumbing fittings which have been badly damaged through constant exposure to a relatively high pressure of 80m. The Khayelitsha Pressure Management Project was commissioned in 2001 to improve the level of service to the Khayelitsha community by reducing the excessive water pressure and pressure fluctuations in the reticulation system.

The average daily flow was reduced from 2 500 m^3/hr to 1500 m^3/hr representing an annual saving of 9 million m^3/hr or approximately 40% of the original water use. The Minimum Night Flow was reduced from 1 600 m^3/hr to 750 m^3/hr.

Pressure management

Leakage is tightly coupled with network pressure. When overall pressure is reduced, the same happens to leakage. Pressure control reduces the frequency of sudden bursts and postpones leaks evolution. The investment in measures to reduce pressure in the network might be efficient to reduce leakage with the following financial savings in water treatment and pumping costs. In cases where it proves to be economically and technically appropriate, the leakage control policy can be complemented with pressure control measures applied to DMAs. Such measures can be pressure reducing valves (PRV) or micro-turbines, the definition of pumping schemes or the use of stage pumps or variable speed pumps.

Pressure in a water distribution systems can be controlled different ways, where dividing the system in different pressure zones according to their topography is the most used. Each zone is supplied with a controlled head maintained either by a reservoir or by pressure reducing valves (PRV) installed in all entrances of the zone. The use of pressure reducing valves is common to dissipate the excess energy, being one of the most efficient and easily applicable alternatives to control network pressure.

Micro-turbines have the advantage of, instead of dissipating the excessive flow energy, transforming it in electric power that can reinforce the base load energy. Micro-turbines are particularly adequate to water conveyance systems with significant difference in topographic levels.

As McKenzie and Wegelin (2010) indicate: "South Africa boasts several of the largest and most successful advanced pressure management installations in the world, some of which have received both national and international recognition. The scope for reducing leakage from water reticulation systems in the country is significant and many municipalities are now implementing new pressure management schemes in certain areas. While it is accepted that pressure management is not applicable in all areas, it does provide very significant savings under certain conditions and is often the most cost effective WDM (Water Demand Management) intervention in the South African environment. It is important to understand that pressure management does not involve repairing the actual leaks or addressing the underlying problems which cause the leakage and in this regard should always be considered as the first phase of a multi-phase strategy to drive down leakage."

South Africa was one of the first countries in the world to adopt the principles of advanced pressure control as developed in the UK for the UK water industry back in the early 1990's. The techniques used in the UK were first presented in South Africa in 1993 and following a series of small pilot projects, the full scale Johannesburg Pressure Management Project was completed in 1995 by two different teams involving the design and commissioning of almost 100 advanced pressure control installations (McKenzie, Wegelin and Rhoner, 2000). As with any new technology, there were teething problems and many lessons were learned, however, the benefits derived from the pressure management were significant and clearly apparent to the water supply managers who quickly supported the methodology.

Water supply systems worldwide are generally designed to provide water to consumers at some agreed level of service which is often defined as a minimum level of pressure at the critical point which is the point of lowest pressure in the system. In addition, there may be certain fire-flow requirements which can over-ride the normal consumer requirements. The systems are designed to accommodate these pressure and flow requirements during the period of peak demand which would normally occur at some specific time of the day. In other words, the systems are designed to provide the appropriate supply volumes and pressure during a short period and for the remainder of the time the systems tend to operate at pressures significantly higher than required. Even within the same system, there will be areas of high pressure due to topography and/or distance from the supply point with the result that many parts of a supply area will operate at pressures significantly higher than required in order to ensure that there is sufficient pressure at the one critical point. Managing water pressures in a supply area is not a simple issue and there are a great many items to consider. The common factor in every system is the fact that leakage is driven by pressure and if the pressure is increased, the leakage will also increase. Conversely, if the water pressure can be reduced, even for part of the day, the leakage will also decrease. No two systems react in the same manner to pressure and it is often very difficult to predict the reduction in leakage due to a decrease in pressure with confidence.

In order to reduce leakage through pressure management it is necessary to reduce the water pressure without compromising the level of service with regard to the consumers and fire-fighting. As mentioned previously, most systems are designed to provide a certain minimum level of service in the system during the peak demand period as shown in the figure below. In this example it is assumed that a minimum pressure of 20m is required.

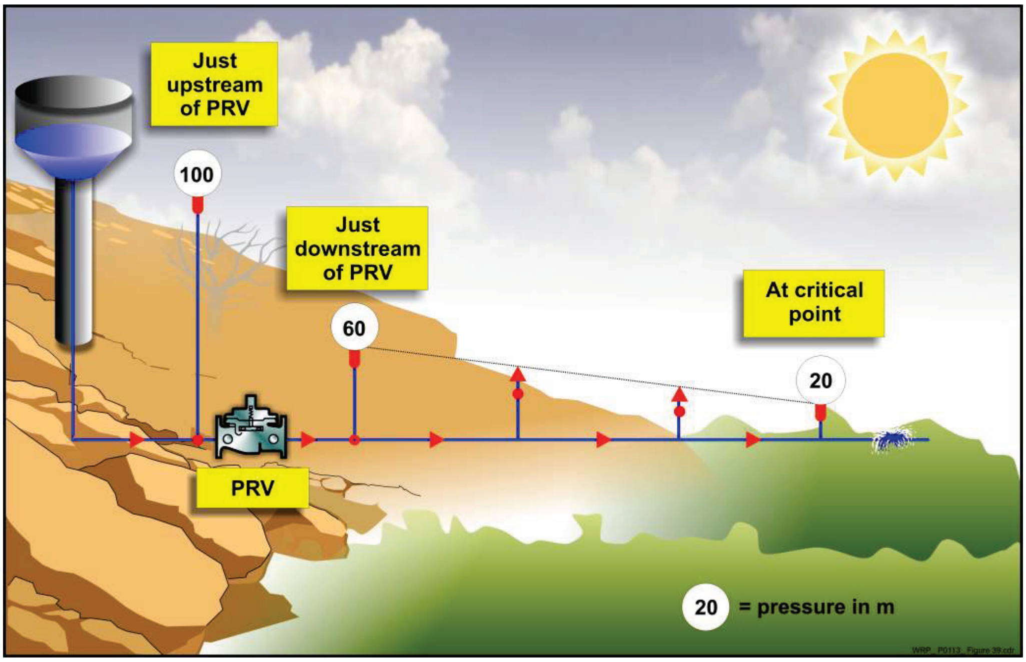

Figure 24: Typical pressure during peak demand periods (McKenzie and Wegelin, 2010)

During the off-peak periods the system operates at a water pressure which is significantly higher than necessary as shown in the figure below. In effect, there are long periods when there is significant scope for pressure reduction and this is the basis on which the pressure management interventions are designed.

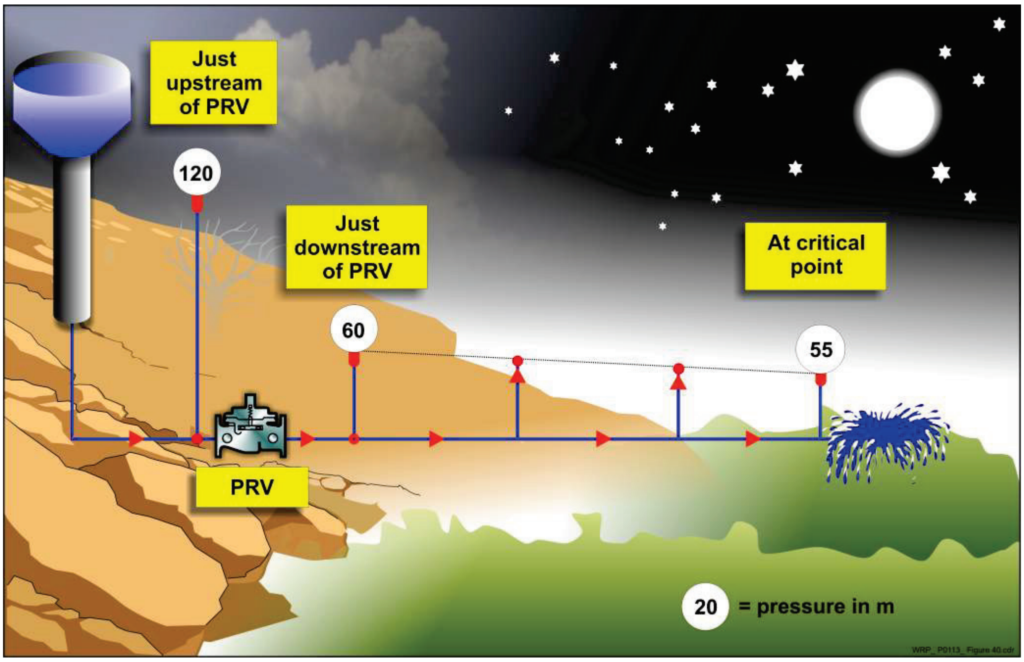

Figure 25: Typical pressure during off-peak periods (McKenzie and Wegelin, 2010)

Reducing the water pressure in a system can be achieved in a number of ways each of which has advantages and disadvantages. The following techniques are discussed in McKenzie and Wegelin (2010):

- Fixed outlet pressure control
- Time-modulated pressure control
- Flow modulated pressure control

5.2.5. Case 5: Sebokeng, Emfuleni Local Municipality

Emfuleni Local Municipality is located to the south of Johannesburg in the industrial heartland of South Africa. The municipality supplies water to approximately 1.2 million residents of which 450 000 are located in the Sebokeng and Evaton areas. The areas are predominantly low-income residential areas with approximately 70 000 household connections, each of which is supplied with an individual water supply as well as water borne sewage. The combination of low income coupled with high unemployment has resulted in a general deterioration of the internal plumbing fittings over a period of many years causing high levels of leakage which is characterized by a minimum night flow in the order of 2 800 m^3/hr. This is one of the highest minimum night flows recorded anywhere in the world and represents almost two Olympic sized swimming pools of water every hour during a period when demand for water should be minimal. It was estimated that the wastage in the area before the project was commissioned was in the order of 80% of the water supplied to the area which in turn represented an annual water bill of approximately R120 million per year (±$12 million). In 2004, the municipality commissioned one of the largest advanced pressure management installations in the world as the first phase of a long term strategy to reduce wastage in the area. The savings achieved exceeded all expectations of both the Project Team as well as the Municipality and are the most obvious benefits to accrue from the project. The figure below shows the savings in water demand from the beginning of the advanced pressure management.

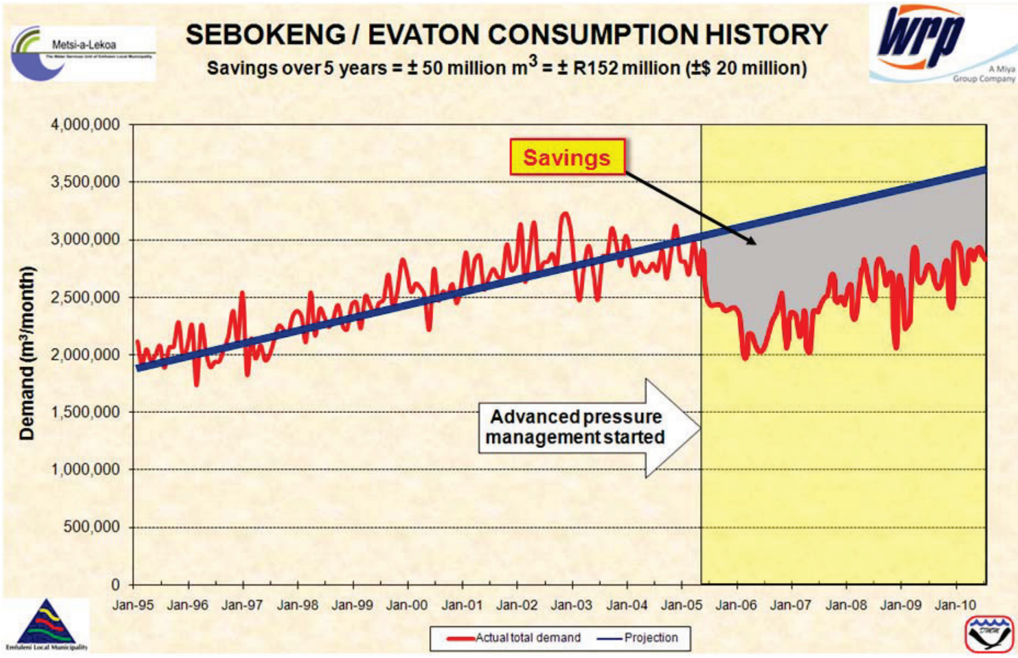

Figure 26: Historical water consumption in Sebokeng and Evaton areas for a 13 year period (McKenzie and Wegelin, 2010)

Control of valves

Optimized control of valves in water networks is another technique which can reduce leakages. As the complexity of a distribution network grows, the average overpressure (larger than necessary pressure) tends to increase. Minimization of the overpressures is possible by remote control of valves installed on the pipe network in accordance with the changing demand pattern (Sterling and Bargiela, 1984). Sterling and Bargiela (1984) used simulation to state that it was possible with a potential of 20 % reduction of the volume of leakages using optimized valve control. Later research Ulanicki *et al.* (2000) and Campisano *et al.* (2010) included case studies. Ulanicki *et al.* (2000) stated that leakage could be reduced to 53% of the original value, with cost savings being in the same region. Operational pressure control is a cost-effective method for reducing leakage over whole sub-networks, and for reducing the risk of further leaks by smoothing pressure variations.

5.2.6. Case 6: Enia, Italy

The information in this section is taken from (Fantozzi et al., 2012).

The advanced pressure management strategy applied by Enia utility (Italy) includes the installation of:

- an advanced system which continuously adjusts and controls the pressure of water going into a DMA so that under all demand levels, low to high, the average zone pressure is kept to the minimum required, consistent with good service;
- a micro-turbine which uses the pressure difference produced by the Pressure Reducing Valve (PRV) to produce electric energy and make all monitoring devices installed in the PRV chamber self sufficient in terms of electric supply;
- a monitoring system which allows pressure and flow data to be collected from each DMA or PMA;
- a decision support tool which allows Minimum Night Flow (MNF) profiles to be analyzed, in conjunction with pressure profiles recorded by other pressure loggers strategically placed inside the DMA at the average zone point (AZP) and at the critical point (CP), to identify where an intervention with active leakage control is economically justified.

The strategy selected by Enia Reggio Emilia in order to achieve an efficient management of Non Revenue Water was to complete the implementation of District Metered Areas (DMA), introduce calculation of IWA water balance and PIs, optimize Pressure Management, set up of a monitoring system and implement a methodology to analyze Minimum Night Flow (MNF) profiles and compare Real Losses calculated from Night Flows and Water Balance. In regards to advanced pressure management, various technologies have been introduced to optimize achievable benefits and to allow implementation even in places without availability of electric energy.

After high leakage areas are identified and leakage volume is quantified, the individual leaks are located by step tests and acoustic detectors (leak noise correlators, geophones and noise loggers). Once the DMA has been cleared of detectable leaks, a pressure-dependent baseline flow is determined and the area is monitored to identify when leakage starts to develop again.

Specialized software, introduced in 2005, has been progressively applied to all existing DMAs, enabling Enia to compare real losses calculated from night flows and water balance, to quickly identify deficiencies in management of real losses, and likely priorities for action. The software is now in use also in other Italian Utilities.

At Enia, there is now an automated process that determines the average flow rate for each DMA between 3,00 and 4,00 a.m. Each morning it is possible for each DMA to compare the average night flow rates with established benchmarks and calculate the difference between the benchmark and the most recent night flows.

Benefits gained

The benefits achieved to date with pressure management implementation include: reduction of leakage rate, reduction of bursts frequency, reduction of time of response in case of leakage, optimized reduction of pressure according to real live data, reduced energy consumption, etc..

In the city of Reggio Emilia, the PM program in the last four years (from 2004 to 2009) had a major role in obtaining:

- more than 13% reduction of the per capita daily inflow
- more than 28% reduction in the number of bursts
- more than 16% reduction in per capita consumption (from 113 to 94 mc per capita per year).

The case study demonstrates that through the implementation of advanced pressure management methodologies, a significant improvement in the efficiency of distribution systems is feasible.

5.3. Transferable lessons for Sustainable UWCS

For each of the successful case studies or technologies in the previous sections, the enabling and constraining factors (where these were described in literature) are identified and discussed.

Brescia

Individual and inter-organizational level (enabling):

As successful as the first approach proved to be in locating the leaks, it provided no guarantee that the reduction in leakage would be sustained. What was needed was a permanent leakage control system, able to reduce and maintain leaks at a low level over time.

In the last fifteen years the use of acoustic emission techniques has shown that leaks can be accurately identified and localized much faster than with any conventional method.

These experiences in leakage detection and location have proved that the application of acoustic techniques gives water industry the most effective tools of conserving precious water resources. In particular, the use of cross-correlation to detect and locate the leaks on underground pipelines has gained larger and larger approval within the water industry, because it offers a more accurate location of the leak and less dependence from operator interpretation and it can be used in very noisy conditions.

The obtainable benefits due to the application of the considered technique are dependent on the care and manner in which it is applied and the results are as good as the operators strictly observe the guideline. With the application of the "noise loggers" which record typical noises in the network during low consumption hours at night, it is now possible with permanent acoustic monitoring of the distribution network. This new technology will help to achieve further leakage reduction without increasing the costs for water leak detection.

District Meter Areas monitoring

Individual and intra-organizational level (constraining):

The implementation of DMAs depends on the complete knowledge of the network in terms of pipe characteristics, location of valves and reservoirs. For the efficient implementation and accomplishment of this task, it should be used a Geographical Information System where all the components of the water distribution network would be mapped and characterized. This could off course be a constraining factor, at least for small scale municipalities with limited resources.

The success of the leakage control policy depends strongly on the hydraulic simulation of the network before and after DMAs implementation. The simulation is of the utmost importance to assess the performance of the system under the new hydraulic conditions after the DMA zoning and, eventually, to redefine the DMAs in case of significant decrease of the level of service. The negligence on this step involving simulation of the network might put at stake the success of the all leakage control system. The delimitation of DMAs presupposes the definition of valves closure and location of flow meters and other measurement equipment.

Step testing

Individual and intra-organizational level (constraining):

The Accuflow valve flow meter can be easily operated by one technician, having been designed for ease of use. However, the situations where it is likely to be of most use, such as measuring night flow across the distribution system, will require staff with a high standard of training and experience to get the best results out of the device.

Intra-organizational level (enabling):

All experience to date has indicated that step testing using the Accuflow produces significantly better results than conventional step testing. The cost of setting-up, monitoring and maintaining a DMA has a high ongoing cost. The Accuflow offers the possibility of carrying out area monitoring at far lower cost, which may prove to be a satisfactory and cost effective approach to conventional leakage monitoring for many situations.

Trondheim

Individual and Intra-organizational level (enabling):

On the intra-organizational level, the leakage reduction strategy and the new equipment has helped to reduce the necessary number of crewmen working on leakage reduction. It has also helped to reduce working hours during night. Before the arrival of leak noise correlators, the crew used to bicycle around during night and listen to manholes with listening rods and geophones. With the noise correlators, this is no longer necessary, as they can be placed there during daytime and monitor the night consumption. The reduction of night time work is a positive aspect of the leakage reduction new equipment. The crew has also responded positive to increased challenges as they are not only responsible for placing out the noise correlators, but also for collecting and analyzing the data. The new leakage reduction strategy is thus responsible for increased motivation, increased capacity and increased efficiency in the company.

Inter-organizational level (constraining):

When the municipality first started talking about introducing DMA's, people in other parts of the country were negative and thought that the introduction of zones and closure of valves would represent a difficulty. However, this has been proven wrong as the leakage zones are working well and they have now very good control of what comes in and what goes out of every zone through two flow meters in each zone.

Administrative and regulatory level (enabling):

Another enabling factor in the new leakage reduction strategy is that good leakage routines and methods give increased financing from politicians. The politicians see the benefit of increased professionalism in the water company and have due to that increased the long term financing. Initially the cost is higher, but it will decrease and result in a long term low cost compared to the old leakage reduction methods.

Individual level (constraining):

In general, many utilities underestimate the importance of registering failures in a data base linked together with other data bases. Systems for such registration may lack the link between the asset inventory data base (i.e. the GIS) and the failure data base. It is important that this link is kept, and the failure data base/diary should include the asset ID. Without this link, it is difficult to couple the information in the GIS with the failures, for example in order to analyze pipe properties in relation to pipe failures. Relevant field information that should be registered about a water and wastewater failure is type of failure, a description of the failure, reasons for the failure etc. When all these data are in place and recorded over several years, failure data can be used to model future failures of drinking water pipes, which can be used to prevent leaks from occurring. Leakage levels can thus be reduced.

Intra-organizational (constraining):

Another mind-set present in some water companies and municipalities is that it is not important to register events and failures in the networks. This will constrain the work of operating and maintaining the networks and thus reduce the possibility of leakage reduction through the use of GIS systems, data and modeling.

Molde

Individual and administrative and regulatory level (enabling):

The leakage reduction strategy has, in addition to reducing the costs, helped to reduce the number of breaks on pipes and customer complaints. This is most probably due to:

- Reduced overall pressure
- The discovery and repair of leaks which would have developed into larger breaks
- The reduction of friction loss and the overall strain on the pipe network

This should enable the municipality further in implementing the leakage reduction strategy and to gain increased financing from politicians.

Khayelitsha : City of Cape Town – 2001

Intra-organizational and administrative and regulatory level (enabling):

The main source of the leakage was identified as the household plumbing fittings which have been badly damaged through constant exposure to a relatively high pressure of 80m. Such leakage resulted in very high water consumption in most properties and high levels of non-payment since the customers could not afford to pay for new taps and toilet fittings let alone the high water bills. The Khayelitsha Pressure Management Project was commissioned in 2001 to improve the level of service to the Khayelitsha community by reducing the excessive water pressure and pressure fluctuations in the reticulation system. An existing high level of leakage can in some instances be an enabling factor to start a pressure management strategy, especially where the non-payment is high and the profit of implementing leakage reduction will be great.

Local labor was used throughout the project and the community support was a key factor in the successful implementation of the project.

Pressure management

Inter-organizational (enabling):

Following the success of the Johannesburg project, one of the most ambitious pressure management projects undertaken anywhere in the world was designed and commissioned in 2001 in Khayelitsha for the City of Cape Town (McKenzie, 2002). The most recent large scale advanced pressure management installation in South Africa was commissioned in Mitchells Plain for the City of Cape Town in November 2008 and is now the 3rd largest scale pressure management installation of its type to be constructed in South Africa. An important enabling factor for the implementation of pressure management has therefore been success in former case studies, first and foremost in the same country.

Individual and administrative and regulatory level (enabling):

A lot of the enabling factors for pressure management are the success stories of the case studies where it has been applied. Stories of benefits in places where pressure management has been applied will enable the implementation of the method in other utilities. Lambert and Fantozzi (2010) discussed a series of benefits arising from the implementation of pressure management, including a reduction of burst frequencies of mains and service connections (see figures below), deferment of pipe renewals and increase of infrastructure life, reduced costs of active leakage control, reductions of components of consumption, and improved service to customers from fewer interruptions to supply. Pressure management is now being used not only for leakage control, but also for demand management, water conservation and asset management.

Figures below illustrate the benefit on pipe breaks from reducing the pressure in the network. The figures are based upon a data set of 112 examples from 10 countries collected by the IWA WLTF (Water Leak Task Force) pressure management team (Thornton and Lambert, 2006), for mains and service connection pipes.

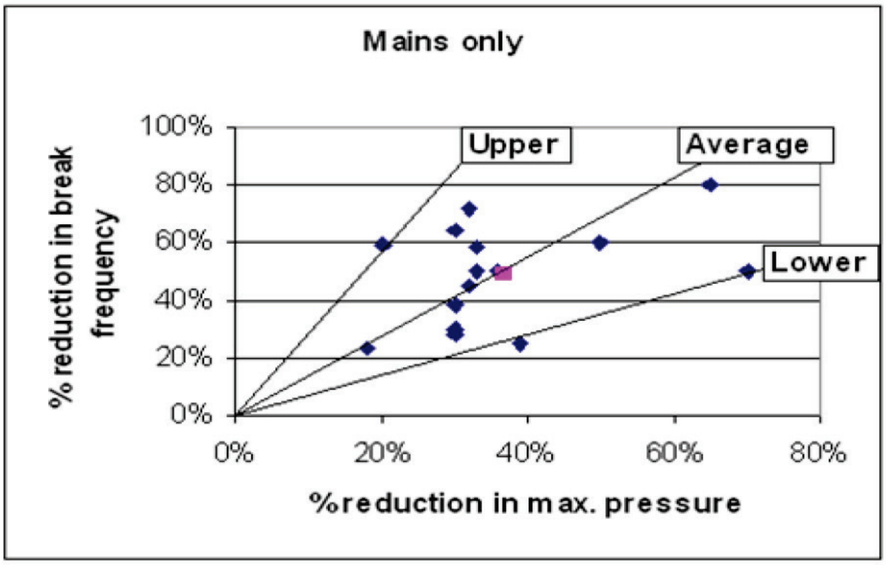

Figure 27: Influence of pressure management on break frequency of mains (Lambert and Fantozzi, 2010)

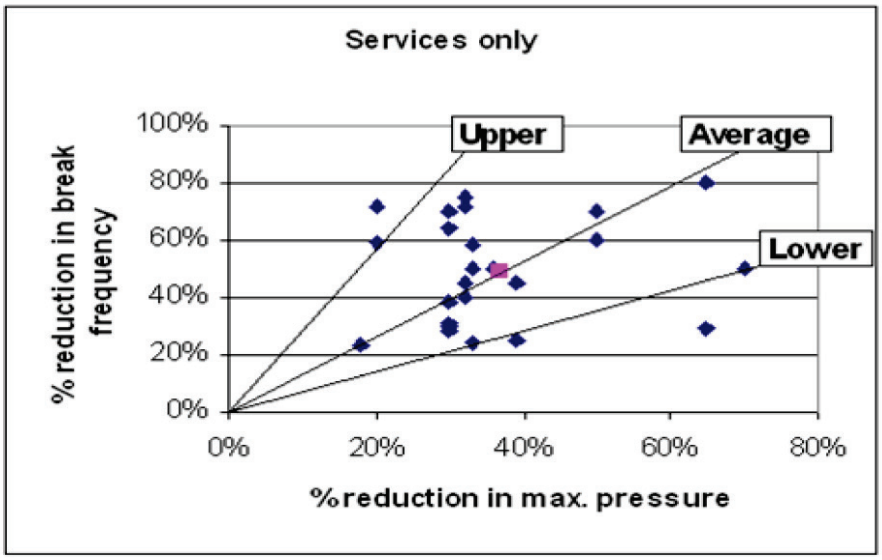

Figure 28: Influence of pressure management on break frequency of service connections (Lambert and Fantozzi, 2010)

Sebokeng: Emfuleni Local Municipality - 2005

Inter-organizational level (enabling):

It was estimated that the wastage in the area before the project was commissioned was in the order of 80% of the water supplied which in turn represented an annual water bill of approximately R120 million (±$12 million). In 2004, the municipality commissioned one of the largest advanced pressure management installations in the world as the first phase of a long term strategy to reduce wastage in the area. The project involved no financial input from the Municipality and even the initial capital costs were borne in total by the Project Team. The project was, effectively, a small scale Public Private Partnership (PPP).

The savings achieved exceeded all expectations of both the Project Team as well as the Municipality and are the most obvious benefits to accrue from the project. After operating and managing the installation for two years, several other benefits also became apparent which were not initially anticipated. In particular the following benefits have been achieved:

- Defer upgrading of infrastructure
- Identification of bottlenecks in the system and problem infrastructure;
- Identification of bulk meter errors;
- Catalyst for funding;
- Improved Municipality Status
- Creation of National WDM fund;
- Catalyst for other WDM interventions;
- Sustainability of Savings.

The project represents a significant advancement in Public-Private Partnerships (PPP's) and clearly demonstrates that small scale Public Private Partnerships can be viable despite the general view that this type of project is confined to large scale initiatives due to the effort and expense in developing the PPP type of contract. While the Sebokeng and Evaton Public Private Partnership is clearly one of the most successful small scale PPP's to be completed in South Africa, the real benefits of the project are only now materializing four years after the project was commissioned. While the financial savings generated exceed all initial expectations, the hidden and often less tangible benefits greatly outweigh the obvious and tangible benefits.

Individual and intra-organizational (constraining):

Before implementing an on-line pressure control scheme it is necessary to perform studies to investigate the economical aspects of such a scheme. Such analysis is normally based on the existing knowledge about a particular pipe network. A convenient form of such knowledge is a hydraulic model of the network. Unfortunately typical hydraulic models do not include important leakage information and instead the leakage flows are aggregated together with demands. Such hydraulic models cannot be properly calibrated and used for the planning of pressure control schemes. May (1994) proposed an approach to leakage modeling which has a direct physical interpretation and can be incorporated into a simulation algorithm comparatively easy. Ulanicki *et al.* (2000) adopted the May approach to building the leakage model.

Enia

Intra-organizational and inter-organizational level (enabling):

Results achieved are encouraging Enia to extend the analysis to all water systems and implementation of pressure management in all DMAs where it is proven to be effective. The example of Enia is like a champion in Italy, encouraging other utilities in the country to implement or further extend the use of IWA approach and application of advanced pressure management solutions.

As with other case studies, the success of the Enia case study is encouraging not only other municipalities in Italy to implement leakage reduction strategies such as pressure management, it is also encouraging Enia themselves to extend their own implementation of pressure management.

6. CONCLUSIONS

The previous chapters presented best practices on the themes demand management, reuse and recycling, water and energy and leakage and loss reduction. We have seen that for each of these themes, technologies and approaches are available. And, additionally, these can really increase the performance of current urban water services.

As far as possible, enabling and constraining factors in these practices for the implementation and use of technologies and approaches have been identified. We acknowledge that these factors might be different for each and every (future) practice. From that perspective it is not possible to draw general lessons. At the same time, the factors which were identified hint towards some key messages for urban water utilities and stakeholders who are envisioning a transfer to a sustainable UWCS.

At the *individual level* it appears that the simplicity of a technology contributes to its actual uptake in practice. At the same time, some technologies ask for well-trained water professionals who have years of experience.

At the *intra-organizational level* the mindset in utilities to actively work with new technologies and approaches is enabling or constraining the success of its uptake. Moreover, the availability of new equipment in the utility and encouraging results of its use contributes to the motivation of water professionals in the organization and herewith to the overall performance of the utility. Additionally, sufficient knowledge on key characteristics of the physical (and social) water network is an important factor contributing to successful sustainable practices.

At the *inter-organizational level* many practices in the previous chapters indicate that cooperation between utilities and stakeholders pays off. This starts with active engagement in discovering new relationships with stakeholders in cities within and outside the water sector and with citizens. That could be a fruitful basis to build a common understanding of the challenges and way forward in sustainable urban water management.

At the *administrative level* some of the practices showed that the use of new technologies or approaches needs to be supported by an institutional structure. Also the embeddedness in a long-term strategy and vision contributes to the success of sustainable practices.

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