COVER STORY

# Global milestones in water reuse: *keys to success and trends in development*

● Interest in water reuse is growing as more reliable water resources are sought to meet increasing demand and mitigate the impact of climate change on traditional sources. **VALENTINA LAZAROVA** provides a global overview of the advances that have taken place in water reuse, the wide range of successful projects that show its efficacy, and the challenges that need to be overcome if water reuse is to play a greater role in cities of the future.


**Cover image: Gippsland Water's Vortex Centre is an exciting and innovative community educational facility based at the Gippsland Water Factory (GWF) – a wastewater treatment and recycling system located at Maryvale in south-east Victoria, Australia.**

**Featuring interactive displays, touch-screens and engaging videos, the Vortex Centre focuses on water conservation and sustainable water management; highlighting water as a precious resource at a local, state, national and global level.**

**Visitors to the centre also learn about the treatment process at GWF, which treats 35 million litres of wastewater from nine towns in central Gippsland, and can recycle water for industrial reuse. The plant can potentially generate up to three billion litres of high quality recycled water each year, saving an equivalent volume of fresh water for potable supply. Credit: Gippsland Water.**

**Water reuse is increasingly being considered a quintessential component of sustainable and integrated water resources management (Asano, 2002; Asano et al., 2007; USEPA, 2012; Lazarova et al., 2013). Due to the pressure of an unprecedented increase in water scarcity the water supply planning paradigm is evolving from reliance on traditional fresh water resources towards building an environmentally sustainable diversified water portfolio, where low-cost conventional water sources are balanced with more costly but also more reliable and sustainable water supply alternatives. In this context, water recycling appears to be the most valuable and a compelling solution for the future preservation of human life and Earth's natural habitats.**

Over the past three decades, several thousand successful water reuse projects with diverse applications around the world have demonstrated that water recycling is a proven water scarcity solution and an essential tool for the mitigation of the impacts of climate change on the diminishing availability of fresh water resources. It is also of extreme importance for the protection of the planet's biosphere and for the achievement of the Millennium Development Goals.

Despite successful worldwide experience of water reuse projects over many years, the practical implementation and operation of new water reuse projects still faces numerous challenges and administrative barriers. The benefits of water reuse and its role in integrated resource management remain little-known and not well understood. Furthermore, the economic merits and financial performance of water reuse projects are difficult to assess and demonstrate. To better explain the role of water reuse for sustainable development and urban water cycle management, the IWA Specialist Group on Water Reuse has published a comprehensive compendium of worldwide practices (Lazarova et al., 2013). Cornerstone water reuse projects and little-known case studies have been selected from different countries and for different water reuse applications to illustrate the keys to success and lessons learned from their operation.

These projects are providing awareness of the tremendous challenges associated with securing a reliable water supply and environmental protection in the future worldwide and are illustrating the benefits of well designed, integrated and fit-to-purpose water reuse practices, as demonstrated below.

## Water reuse applications and the 'fit-to-purpose' approach

An important new concept in water reuse is the 'fit-to-purpose' approach, which entails the production of recycled water of a quality that meets the needs of end-users. As a consequence, the intended water reuse applications govern the degree of wastewater treatment required and the reliability of the wastewater reclamation processes and operation.

Even when polluted, wastewater is more than 99.98% pure water. A conceptual comparison of the extent to which water quality changes through municipal applications is shown schematically in Figure 1 (Asano, 2002; Lazarova et al., 2013). Today, technically proven water reclamation and purification technologies exist to produce pure water of almost any quality desired, including purified water of quality equal to or higher than drinking water.

The main categories of municipal wastewater reuse applications, related issues and constrains, as well as the most important lessons learned, are shown in Table 1. The dominant applications for the use of recycled water include: agricultural irrigation, landscape irrigation, industrial reuse and groundwater recharge.

Among traditional wastewater applications, agricultural and landscape irrigation are widely practiced throughout the world with well-established health protection guidelines and agronomic practices (Lazarova and Bahri, 2005; Asano et al., 2007). Agricultural irrigation was, is and will remain the largest recycled water consumer with recognised benefits and contribution to food security. Urban water recycling, in particular landscape irrigation, is characterised by fast development and will play a crucial role for the sustainability of cities in the future, including energy footprint reduction, human wellbeing and environmental restoration. Other relevant and cost efficient applications are also emerging, such as environmental enhancement, in-building recycling and industrial uses of reclaimed urban wastewater.

Indirect potable reuse, in particular groundwater (aquifer) recharge, after complementary polishing and storage of recycled water in an environmental buffer, has been implemented in many countries as an efficient response to the need to increase water supply. Finally, direct potable reuse, practiced for over 40 years in Namibia and recently implemented in the USA, is emerging as a solution to the challenges which some countries will face in the next 20 years.

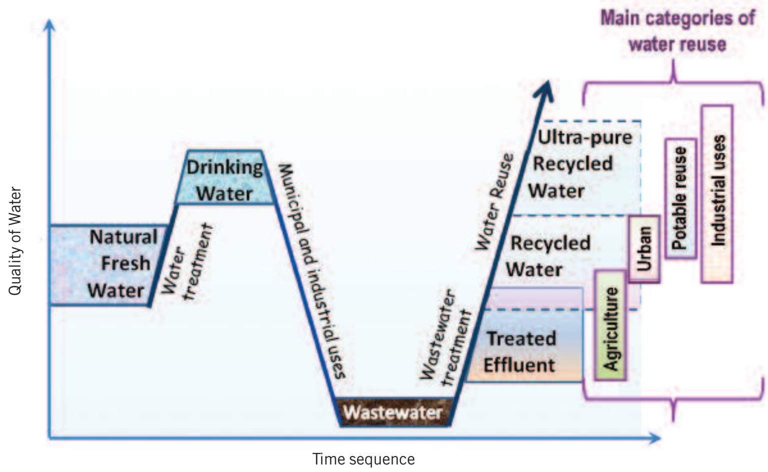
While there has been a clear preference for non-potable and indirect potable reuse applications, a number of factors are making it less feasible to further increase water reuse in these applications. It is inevitable that purified water will be used as a source of potable water supply in the future. Direct potable reuse offers the opportunity to significantly reduce the distance at which reclaimed water would need to be pumped and to significantly reduce the head against which it must be pumped, thereby reducing costs. The other significant advantage of direct potable reuse is that it has the potential to allow for the full reuse of available purified water in metropolitan areas, using the existing water distribution infrastructure (Drewes and Khan, 2011; Tchobanoglous et al., 2011). Implementation of direct potable reuse will require, however, a confidence in, and reliance on, the applied technology to always produce water that is safe and acceptable to consume.

### The role of water reuse in integrated water management and Cities of the Future

Many water authorities around the world are moving to an integrated water planning approach to maintain the balance between demand and supply, and to reduce the risk of supply failures. Common elements of the integrated water planning approach include water conservation measures to control the growth in demand and the diversification of supplies to reduce supply risks. Supply diversification by water portfolios often includes the development of non-traditional water sources such as water reuse (treating used water and recycling it for use again), decentralised supplies from rain water and stormwater, or desalination of seawater or brackish groundwater. For water managers, the principle of building a water portfolio consists of combining low cost but unreliable supplies (e.g. river supplies) with higher cost but more reliable supplies (e.g. recycled water and desalination) to create a water supply portfolio, which is not too costly but is sufficiently reliable and has little risk of supply failure.

The concept of water portfolios has been applied since 1995 in West

**Figure 1: Water quality changes during municipal uses of water in a time sequence. Source: Asano, 2002; Lazarova et al., 2013.**




Basin, California, US, with the main objective being to reduce dependence on imported water and satisfy the increasing water demand. Nowadays, water recycling is becoming the key component of the West Basin water portfolio, accounting for 7% of the water supply in 2005, with projections to be increased to 41% in 2025. The outstanding feature of this case study is the production of five distinct types of 'designer' recycled water suited to specific use, thereby customizing the treatment and cost to the required use: tertiary disinfected water for irrigation and other urban uses, nitrified water for cooling towers, reverse osmosis followed by advanced oxidation water for direct aquifer recharge into a salt intrusion barrier, and single and double pass reverse osmosis for low and high pressure boiler water. In this region, where normal supplies are uncertain in drought times, the recycled water has proven to be a reliable source of water for customers, which is less expensive than new fresh water supplies, enabling the avoidance of industry loss in the region, alongside other well recognised economic, environmental and social benefits.

Another relevant example of an integrated water management approach is the Metropolitan Water Plan process of the Australian city of Sydney. Since 2006, this city has developed a more robust, diversified portfolio of water sources less dependent on rainfall and less prone to drought security risks, including water conservation, deep storage, water reuse and desalination. Water recycling accounted for 6.6% of the water supply in 2010 and will be doubled by 2015. The major benefits are increased drought security, improved environmental flows and river water quality, and a deferred need for new water storage.

It is important to stress that water reuse can play an important role for integrated management of water resources also in regions with abundant rainfall. Singapore is a good example of such a water-stressed country because of its limited and densely populated water catchment area with high domestic, commercial and industrial water demands. With innovation and use of advanced technologies, Singapore has turned used water (traditionally named wastewater in other countries) into a strategic resource to effectively attain its water supply sustainability, satisfying 30% of water needs. The main keys to success of the NEWater schemes are strong government support, effective public education and communication, and the existence of a single agency (PUB) managing wastewater and drinking water and taking a holistic approach to total water resource management, including water reuse.

For densely populated urban areas and megacities, water reuse will play a crucial role in the urban water cycle management, transforming the cities of the future into water-saving and 'leisure-paradise' settlements, as demonstrated by the cities of Tianjin and Beijing (Figure 2). The governments of these two megacities included water reclamation in the general planning of the cities. In 2011 in Beijing, water reclamation satisfied nearly 20% of total water supply (710Mm$^3$/yr). A new recreational environment has been built in the Olympic park using advanced and natural wastewater reclamation technologies.

The largest water reuse plan for urban uses in Europe was developed by the Autonomous Community of Madrid with as objective to satisfy 10% of the water demand by the production of 70Mm$^3$/yr of recycled water that will be distributed by 1200km of dual distribution pipelines. The most important lessons learned through these case studies is that with integrated water planning authorities in water-stressed regions have been able to cater for growing demands in the face of declining supplies due to droughts, population growth and climate change through water recycling.

## Table 1: Categories of water reuse applications and related issues or constraints

| Category | | Potential application | Issues/constraints | Lessons learned |
|---|---|---|---|---|
| Agricultural irrigation | Unrestricted or restricted | Food crop, eaten raw, processed or cooked<br>Pastures for milk production<br>Orchards, vineyards with or without contact with edible fruits<br>Fodder and industrial crops<br>Ornamental plant nurseries | Water quality impacts on soils, crops, and groundwater<br>Runoff and aerosol control<br>Health concerns<br>Farmers acceptance and marketing of crops<br>Buffer zone requirements | Good practices available to mitigate adverse health and agronomic impacts<br>Storage design and irrigation technique are important elements<br>Numerous reported benefits |
| Landscape irrigation | Unrestricted or restricted | Golf courses and landscape<br>Public parks, school yards, playgrounds, private gardens<br>Roadway medians, roadside plantings, greenbelts, cemeteries | Water quality impacts on ornamental plants<br>Runoff and aerosol control<br>Health concerns<br>Public acceptance | Successful long-term experience<br>Good practices and on-line water quality control can ensure health safety |
| Non-potable urban uses | | In-building recycling, Toilet flushing<br>Landscaping (see irrigation)<br>Air conditioning, Fire protection<br>Commercial car/truck washing<br>Sewer flushing<br>Driveway and tennis court washdown<br>Snow melting | Health concerns<br>Scaling, corrosion, fouling, and biological growths<br>Cross-connection with potable water<br>Pollution of receiving waters | Dual distribution systems require efficient maintenance and cross-connection control<br>No health problems reported even in the case of cross-connections (for tertiary disinfected reclaimed water) |
| Environmental / Recreation uses | Unrestricted or restricted | Recreational impoundments<br>Environmental enhancement (freshwater or seawater protection)<br>Wetlands or biodiversity restoration<br>Fisheries<br>Artificial lakes and ponds<br>Snowmaking | Public health concerns<br>Eutrophication (algae growth) due to nutrients<br>Toxicity to aquatic life | Emerging application with numerous benefits for the cities of the future: improving living environment, human wellbeing, biodiversity, etc.<br>Online water quality control can ensure health safety |
| Industrial reuse | | Cooling water<br>Boiler feed water<br>Process water<br>Heavy construction (dust control, concrete curing, fill compaction, and clean-up) | Scaling, corrosion, fouling, and biological growths<br>Cooling tower aerosols<br>Blowdown disposal<br>Cross-connection with potable water | Water quality to be adapted to the specific requirements of each industry / process<br>Request for high reliability of operation, cost and energy efficiency |
| Indirect potable reuse with replenishment of: | Aquifers | Groundwater replenishment by means of infiltration basins or direct recharge by injection wells<br>Barrier against brackish or seawater intrusion (direct recharge)<br>Ground subsidence control | Groundwater contamination<br>Toxicological effects of organic chemicals<br>Salt and mineral build-up<br>Public acceptance | Successful practice since 1970s<br>Multiple barrier treatment ensures safe potable water production<br>Efficient control by means of advanced modelling tools |
| | Reservoirs | Surface reservoir augmentation<br>Blending in public water supply reservoirs before further water treatment | Health concerns<br>Public acceptance | Successful practice since 1970s<br>Multiple barrier treatment ensures safe potable water production<br>Improvement of water quality |
| Direct potable reuse | | Pipe-to-pipe blending of purified water and potable water<br>Purified water is a source of drinking water supply blended with source water for further water treatment | Health concerns and issues of unknown chemicals<br>Public acceptance<br>Economically attractive in large scale reuse | Multiple barrier treatment ensures safe potable water production<br>No health problems related to recycled water in Namibia since 1968 |

Source: Lazarova et al., 2013 adapted from Asano et al., 2007

**Milestones in urban water reuse**

As shown in Table 1, water reuse in urban areas includes a wide variety of applications and schemes with the common characteristic that all these purposes do not require potable water quality, but need an adequate infrastructure. Additional reticulation systems have been used in water short regions to supply non-potable water for various purposes for more than 80 years, with intensive large-scale development in the 1970s in the United States and in-building recycling in Japan, followed by an increasing interest since the 2000s in eco-cities in Australia, China and other countries. Dual distribution and plumbing systems are relatively easy to install in new urban areas or buildings with relatively low initial cost. For this reason, semi-centralised urban water management is a new concept considered to be a prerequisite for water reuse.

Because of the high risk of direct contact with recycled water, the water reuse requirements are very stringent (total disinfection and on-line control), as well as the rules for cross-connection control. Relatively few cross connection incidents with backflow from recycled water systems have been


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Figure 2: View of the Olympic park in Beijing, China where water reuse is practiced

reported in the literature, with no reported illness. The major causes of cross connections between recycled and potable water systems reported in Australia, United States and United Kingdom are illegal connection of private residences, inadequate construction, records and pipe identification, and higher pressure in the recycled water system.

The implementation of dual distribution systems is becoming one of the key elements of eco-cities with reduced potable water demand. In Australia, on the basis of the operational experience of the first large residential project in Rouse Hill in Sydney, a new project in Pimpana Gomera in Queensland is aiming to cover 45% of the water demand of 45,000 residential homes through using recycled water; lowering the drinking water demand to about 16% of its baseline typical level.

Another proven concept of integrated urban water cycle management is water recycling in buildings. In Japan, about 2500 individual buildings have on-site wastewater reclamation / rainwater harvesting systems. In these buildings, reclaimed water is used for a variety of purposes, including toilet flushing, garden watering, cooling water, car cleaning, and fire protection. The 40+ years of Japanese experience has demonstrated that on-site wastewater reclamation / rainwater harvesting systems have numerous benefits, such as a reduction in the volume of potable water supply, lower loads to the sewer system and reduced risk to public / economic activities in disaster situations. In-building water recycling has been promoted mainly by local regulations and favourable taxes. Relevant technological know-how has been accumulated and membrane bioreactors were identified as being highly suitable for on-site wastewater reclamation.

Financial incentives are one of the most important keys to success of urban reuse, and in particular in-building water recycling. A good example is the first high-rise green building in the US – the Solaire Apartments in Battery Park City in lower Manhattan, an area adjacent to the Wall Street financial district of New York City. This building was also the first LEED (Leadership in Energy and Environmental Design) certified residential high-rise building in North America with an integrated design for the site, facility, landscape, and water management. The water reuse incentive programme of this project offsets water reuse operational costs by providing a 25% reduction in rates for water and sewage services from the city when at least 25% reuse is provided onsite. The Solaire building also received state tax incentives for providing affordable housing and for offsetting the cost of some of the green building features in the design. The Solaire wastewater reclamation system is located in the building's basement and the recycled water is used for toilet flushing, cooling water, and landscape irrigation. This approach reduces the water taken from the city's water supply by over 50% and significantly decreases energy costs.

The win-win relationship between the building owners, decision makers and water reuse operators is also crucial for the success of urban water recycling, as demonstrated by the experience of the Japanese capital of Tokyo. In the case of the Shinjuku area the principle of semi-decentralized wastewater reclamation enabled a significant reduction in the costs of treatment, transportation and distribution. Over 30 high-rise buildings are supplied with recycled water for toilet flushing, which is cheaper than tap water by about 23%. The remaining volume of purified water is used for river flow restoration. This project was the first milestone of area-wide water reuse in Japan. In this project, the capital cost of in-building dual piping was relatively low due to its inclusion at an early planning stage.

The major highlights and lesson learned from the selected case studies on urban water reuse, including decentralised systems and in-building recycling, are summarised in Table 2. The common themes running through these case studies are that urban reuse has offset pressures from growing demands and water shortages due to drought and climate change by producing large savings in drinking water needs. There have been worthwhile economic and environmental benefits. Keys to success have included strong government and regulatory support, stakeholder involvement, development of community support through effective public education programmes, effective treatment, careful monitoring and quality control, and recycled water priced lower than drinking water. Major challenges include ensuring a high water quality to protect human health by disinfection and the required high reliability of supply, interruptible in many cases (fire protection, toilet flushing, cooling) with a backup water system and storage capacity for irrigation purposes to meet peak demand. The high cost of dual distribution is one of the major constraints (can be prohibitive for transportation distances over 15-25km), followed by the requirement for cross connection measures and control. Dual plumbing was shown to be affordable for new buildings.

It is important to underline the increasing interest in urban planning for environmental and recreational water reuse, practiced for years in the United States with specific regulations and well recognised benefits. This application is only just now emerging in Europe, despite the existence of environmental protection policies such as the European Union Water Framework Directive and Blueprint to Safeguard Europe's Water Resources. Only the new Spanish water reuse regulation includes a definition and water quality requirements for environmental and recreational uses of reclaimed water. Nevertheless, some recent successful projects in the Costa Brava and Barcelona (Spain), Bora Bora (French Polynesia) and Milan (Italy) could unlock and promote these very important water reuse applications not only in Europe, but in all countries.

The successful case studies of the Olympic park in Beijing, the restoration of river flows in Tokyo and lake restoration in Mexico City illustrate well the benefits of water reuse, not only for the urban environment, but also for the preservation of historic heritage, aquatic and wildlife habitat, and human health and wellbeing. Keys to success have included government and regulatory support, stakeholder involvement, production of good quality recycled water, detailed project planning, development of community support through education, and recognition of the economic and environmental benefits delivered by these projects (Table 2).

## Milestones in indirect and direct potable water reuse

The success story of potable water reuse started in early 1960s with water augmentation by means of groundwater (aquifer) recharge in Montebello Forebay, California (1962) and direct potable reuse in Windhoek, Namibia (1968). Over 43 years of operational experience of direct 'pipe-to-pipe' reuse in Windhoek has demonstrated the feasibility and lack of adverse health impacts of this practice. However, public opposition and concerns around unknown micro-

## Table 2: Highlights and lessons learned from the selected water reuse case studies (continued p19)

| Category / Type of uses | Case studies | Drivers and Opportunities | Benefits | Challenges | Keys to Success |
|---|---|---|---|---|---|
| ***Integrated water resource management*** Urban uses, Water supply augmentation, Industrial uses, Agriculture | Sydney (Australia), West Basin (California), NEWater (Singapore), Costa Brava (Spain), Cyprus Tianjin (China) Others: Beijing (China) | Water scarcity, Drought security, Develop local water supply, High energy cost, Availability of large users | Increased diversity, reliability and security of water supply, Deferred new water supplies, Reduced dependence on imported water, Avoided loss of industry, Independent of climate change and extreme weather condition Simultaneous water and energy savings Environmental improvement | Developing costly separate facilities and infrastructure (dual distribution) Management of competing sources, Meeting water quality requirements and secure water quality control, Contractual agreements and need of regulations refining | Government commitments, Recycled water provides assured water supply and is less expensive than comparable potable water, even after the users' investment in retrofitting costs, Multi-barrier approach to ensure good water quality (source control, high proportion of domestic wastewater, comprehensive secondary wastewater treatment, use of proven advanced technologies, comprehensive water quality monitoring, adhering to strict operating procedures), Public outreach and education achieve acceptance |
| ***Urban water reuse*** Landscape irrigation, Garden watering, Fire protection, Toilet flushing, Cleaning | Knittlingen (Germany) Madrid (Spain), Honolulu (Hawaii), Bora Bora (Polynesia), Australian experience Others: West Basin (California) | Political and institutional commitment, Climate change with severe droughts, Limits on new drinking water sources, Higher standards for discharges to the environment | Saving of high quality freshwater water for potable water supply, Cheaper price than drinking water and cost saving, Prevention of revenue loss for industries and tourist activities during droughts, Environmental benefits such as increasing water reserves in the region's reservoirs and restoration of biodiversity | Construction and operation of dual distribution systems, Controlling operational costs with unpredictable energy prices, Manage reliable operation and recycled water supply without interruptions, Define the most adequate pricing strategy of water services, Quality controls to prevent cross-connections. Community education | Awareness and commitment of the regional authorities, municipalities and citizens, Customized local solution that is demand-based to match customer needs, Connected technology and design with local industrial, commercial, residential, environmental and recreational needs. Simultaneous production of superior quality ultra-pure process water for industry helping to ensure the economic viability, Development of clear guidelines for urban and residential use, Support from health authorities, Public-private partnerships |
| ***Decentralised urban water reuse and in-building recycling*** Toilet flushing, Garden watering, Cooling water make-up, Cleaning | Shinjuku area, Tokyo (Japan), The Solaire building, New York (US), In-building recycling in Japan Others: Knittlingen (Germany) | Government commitment, Regulatory requirements, Favourable incentives and taxes | Saving of potable water to avoid the expansion of the capacity of potable water supply and sewer systems in congested urban areas, Cost saving for building owners, Reduction of water demand and water fee for citizens, Maintenance of public/economic activities in disaster situations | Reliable recycled water supply despite the high water demand variations, Good aesthetic quality of recycled water (colour), The amount of lightly contaminated grey water cannot cover the amount needed for toilet flushing, Relatively high energy demand for the membrane bioreactors | Regulatory mandate for sustainable development and financial support through grants and incentives, Win-win relationship between the building owners and the metropolitan government, Reliable water supply in terms of quality and quantity with cheaper cost, Relatively low initial cost for the dual pipe distribution due to early planning since the building design, Water reuse regulations and guidelines, Technological know-how of design and operation of wastewater reclamation systems |

pollutants were the main constraints around the development of this water reuse practice. Nevertheless, unplanned indirect potable reuse is a common situation in which inherent water quality issues are not fully addressed because of the divided responsibilities for wastewater discharge and downstream water supplies.

The milestones in the development of safe water reuse practices for indirect potable reuse are illustrated in Figure 3. The proposed two categories are based on the advances in wastewater treatment with the technological breakthrough of membrane filtration. Two subcategories, covering both aquifer recharge and reservoir replenishment, are dissociated according to the water quality requirement:

- Surface spreading in aquifers and surface reservoir replenishment
- Direct injection in aquifers, mostly as seawater intrusion barrier

The significance and the lessons learned from aquifer recharge in the unconfined aquifer of Montebello Forebay in eastern Los Angeles County are of crucial importance for the success of indirect potable reuse. A five-year epidemiological and toxicological study (1978-1983) and a follow-up epidemiological study (1996-1999) did not demonstrate any measurable adverse effects on groundwater quality or the health of the population drinking this water.

The Groundwater Replenishment System (GWRS) in Orange County, California is the world's largest wastewater purification system for indirect potable reuse. Beginning in 1975 with the successful implementation of Water Factory 21, this project was upgraded and expanded to GWRS in 2008. Recycled water has been used to prevent saline intrusion (direct injection) and to maintain water level (by spreading basins and river beds) in aquifers that supply drinking water to Orange County. The treatment capacity of 265,000$m^3$/d provides enough water for 600,000 people, with on-going expansion to 378,000$m^3$/d. Despite advanced treatment by microfiltration, reverse osmosis and advanced oxidation, the operating costs are relatively low at 0.35 US$/$m^3$, taking advantage of the large scale and the optimized energy consumption of 0.53kWh/$m^3$.

For comparison, the operating costs of small water reuse projects can be more than doubled for the same water reclamation treatment. Nevertheless,

## Table 2: Highlights and lessons learned from the selected water reuse case studies (continued p20)

| Category / Type of uses | Case studies | Drivers and Opportunities | Benefits | Challenges | Keys to Success |
|---|---|---|---|---|---|
| ***Environmental and recreational uses of recycled water*** Restoration of urban streams, recreational water bodies, leisure activities, Improvement of air quality, dust control | River restoration in Tokyo (Japan), Olympic Park, Beijing (China), Mexico City (Mexico) Others: Milan (Italy), Bora Bora (Polinesia) | Political willingness to improve urban infrastructure, People expectations for a better environment, Need for management of urban floods and dust storms, Dried up urban steams | Restoration of flowing water and water bodies is improving living environment and biodiversity, Creation of recreational areas and improvement of leisure quality, Reduction of respiratory illness, Halting the growth of slums in risky urban areas | Water quality management in artificial water bodies, Good aesthetically pleasing quality of reclaimed water, Maintain the water quality of artificial water bodies in a long-term through water ecology regulation, Establish stable ecosystems in the artificial water bodies with good self-purification, Restoring the original environmental conditions | Government commitments, Strong political support, Strong public support for restoration of urban environment and preservation of historic heritage, Positive economic development and national pride, International co-operation, A sound technical background, Recognition that by reusing wastewater to restore the lake, dust storms, urban floods and soil erosion in Mexico City could be controlled, Utilization of reuse projects as a tool to educate citizens on city's history |
| ***Potable water reuse*** Indirect potable reuse by aquifer recharge: direct injection as salt intrusion barrier, surface spreading and reservoir replenishment Direct potable reuse | GWRS Orange County, (California), Torreele (Belgium), Occoquan (US), Western Corridor (Australia), Windhoek, (Namibia) Others: West Basin (California), NEWater (Singapore) | Unsecure water supply, declining aquifer water table, severe droughts and increasing water demand, Insurance policy for variable climate, Federal construction grants | Enhanced safe yield of the drinking water system, Increased water supply security, Safe potable water produced by an advanced multiple barriers approach, Sustainable production using less power than imported water, Improved drinking water quality, Enhanced water quality of both watershed and drinking water reservoir Secured social and economic development | Stringent recycled water quality requirements, High costs and needs of funding, Emerging issue of micro-pollutants, Managing the recycling facilities at low production rates, Public acceptance and regulatory approval, RO concentrate should be treated / reused, Increased emphasis on controlling pollution from urban runoff | Strong political and community support and collaboration, Excellent information policy and education practice, Multiple barrier approach, state-of-the-art technology, pilot tests and continued demonstration of improvements to water quality over project life, Locally-controlled, drought-proof and reliable supply of high-quality water in an environmentally sensitive and economical manner, Independent monitoring to provide unbiased information to stakeholders, Reliable operation and on-line process and water quality control, Public-private partnership |

even at relatively small scale, the economic feasibility and health safety can be demonstrated as shown by the project of dune aquifer recharge in Torreele, Belgium (capacity 7000m$^3$/d). The produced recycled water of excellent quality enables sustainable groundwater management in an area with high ecological interest and intense tourist activity in summer.

The pioneer in indirect potable reuse for replenishment of drinking water surface reservoirs is the Upper Occoquan Service Authority (UOSA) in Virginia, United States. Their long-term operational experience since 1978 has clearly demonstrated that water quality can be improved by water recycling using multi-barrier conventional treatment and polishing. One of the major benefits is the improvement of drinking water quality and the secured supply of more than 1.3 million people (204,000m$^3$/d). It is estimated that full development of the scheme will double the water supply yield of the Occoquan reservoir system.

The first large water recycling scheme in Australia for dam replenishment and industrial use was implemented in 2007 near Brisbane, known as the Western Corridor Recycled Water Scheme. This project consists of three Advanced Water Treatment Plants using a combination of microfiltration, reverse osmosis and advanced oxidation to produce 236,000m$^3$/d of highly purified recycled water to meet the stringent requirements of Australian Drinking Water Guidelines and even more stringent recycled water regulations. In this case, water recycling is a part of a water portfolio to secure water supply if necessary during severe drought in addition to water desalination.

The feasibility and safety of direct potable reuse is demonstrated by the more than 44 years of operation of the Goreangab Water Reclamation Plant in Windhoek, Namibia (21,000m$^3$/d). The recycling plant was upgraded in 2002 with new more efficient and reliable treatment technologies and additional non treatment and operational barriers. Recycled water now supplies about 30% of drinking water needs, with a maximum allowed blending ratio of 35%. The main reasons for public acceptance of potable reclamation are the lack of other affordable choices and the fact that since the beginning of potable reuse, no reclaimed water related health problems have been experienced.

The common themes running through these case studies are that potable water reuse has offset pressures from growing demands and water shortages due to drought and climate change by producing high-purity alternatives and drought-proof resources to cover drinking water needs. There have been worthwhile economic and environmental benefits (Table 2). Keys to success have included the use of state-of-the-art multi-barrier treatment technologies to produce purified recycled water meeting drinking water requirements, detailed preparation and pilot plant testing, detailed independent monitoring, strong government and regulatory support, development of community support through effective public education programmes, a demonstrated need for new reliable drought-proof supplies and a clear demonstration of the economic and environmental benefits.

### Milestones in industrial water reuse

One of the greatest opportunities for water reuse is to supplement or replace the potable and / or freshwater demands of industries. Industry is the second largest market for water supply after agriculture, accounting for around 25% of global demand. Industrial reuse and internal recycling

## Table 2: Highlights and lessons learned from the selected water reuse case studies

| Category / Type of uses | Case studies | Drivers and Opportunities | Benefits | Challenges | Keys to Success |
|---|---|---|---|---|---|
| ***Industrial reuse*** Industrial uses of municipal recycled water | San Luis Potosi (Mexico), RARE Project (California)<br><br>Others: West Basin (California), Honolulu (Hawaii) | Water scarcity and droughts, Conflicts for water between sectors, Willingness to diversify the water supply portfolio, Government Policy | Long-term sustainable water management to secure water supply and protect the environment, Conservation of potable water and energy savings, Reduction of the threat of severe rationing during droughts, Reduction of wastewater and pollutant discharges | Infrastructure to secure distribution and continuous supply, Fluctuating raw water quality, High level of reliability in the treatment process, Disposal of the RO brines, Flow equalization | Federal and State policies, water reuse regulation and political support, Consistent water quality, adapted to customer's requirements and high reliability of operation, Creative project funding (public-private partnerships) |
| Industrial water recycling | Panipat (India), Closed loops (Germany) | Environmental protection targets, Water supply security, Reduction of costs, 'Green' image | Boost in industrial water supply security, Environmental protection, Lower energy, water consumption and wastewater discharge, Lower costs, Improved material utilization, Economic and social development | High variations of raw wastewater quality, Stringent reclaimed water quality targets, Economic benefits from water recycling have to outbalance investment and operating costs, Needs for efficient and reliable wastewater treatment and reclamation processes, Zero liquid discharge targets. | Demonstrated economic benefits from closing loops, Technical and economic feasibility and high efficiency and reliability of water recycling schemes, Economic growth and success of the industry, Environmental awareness, Experienced plant operators (public-private partnerships) |
| ***Agricultural irrigation*** Irrigation of rice, corn, wheat, pastures, potatoes and horticulture | Milan (Italy), Noirmoutier (France), Australian experience<br><br>Others: San Luis Potosi (Mexico) | Water shortages and drought, Policies for water resource management and water reuse regulations, Existing supplies fully allocated or polluted | Increased crop production, Improvement of health safety, crop's yields and farmer's revenues, Diversification of agricultural production with implementation of horticulture, Fertilising value and reduction of the quantity of chemical fertilizers, Conservation and preservation of sensitive environment, biodiversity and economic and leisure activities | Seasonal demand for irrigation and high storage needs, Very stringent water reuse standards, Funding for the construction and operation of wastewater reclamation facilities, Supply of high-quality irrigation water to farmers free or at low charge, Increased salinity due to seawater intrusion in sewers in coastal areas | Unfailing commitment of farmers and local stakeholders, Development of national and state guidelines and guidance manuals for use of recycled water and water saving, Financial equilibrium, high treatment efficiency and reliability of operation, Valorisation of historical heritage and peri-urban agriculture, Public education programmes and collaborations with non-profit organisations, Public-private partnerships |

are becoming current practices in many countries and industries with increasing water demand, closing loop cycles and zero liquid discharge as a long-term goal (Table 2). Inter-sector water reuse, and in particular the use of recycled urban wastewater for industrial purposes, is characterised by fast growth in many countries, as shown by experiences in California, Mexico and Hawaii. The potential for industrial reuse of treated municipal wastewater will increase in the future as raw potable water supplies become more limited, the cost of potable water increases due to more stringent standards and discharge regulations become more stringent.

The major factors that influence the potential for industrial water reuse include the availability of water, the industry's discharge requirements, water quality, volume, economics and reliability.

Although there is a wide range of industrial water uses, the major uses are cooling system make-up water, boiler feedwater, process water, washdown water and miscellaneous uses, including site irrigation, fire protection, road cleaning, etc. The first three categories are of particular interest because they are high-volume and high-quality applications with excellent prospects for using recycled municipal wastewater.

The water quality requirements and fields of application of water recycling in industry differ across the types of industry, particular industrial process, and the target performance. For this reason it is not possible to generalise water quality requirements for industrial process water. The greatest concern around the use of recycled water in cooling towers is the risk posed by inhalation of pathogens in the aerosols. Moreover, corrosion, scaling and biofouling of equipment and distribution systems are a common issue. The quality requirements increase as operating pressure and temperature increase. The control or removal of hardness is required. Insoluble salts of calcium and magnesium are the main contributors to scale formation in boilers and are removed by processes such as ion exchange and reverse osmosis. Successful water reuse practices are implemented in the petroleum industry, oil refineries, thermoelectric power generation plants, pulp and paper facilities, the textile industry and even the microprocessor, electronics and food industries.

The milestones in industrial water reuse can be categorised into two groups, similar to indirect potable reuse, with the cornerstones being the implementation of membrane technologies and in particular reverse osmosis. The West Basin Municipal Water District in California is a pioneer in the production of 'designer' recycled water from municipal wastewater, from which three qualities are produced for industrial purposes. Since its start-up in 1995 of the combined MF/RO treatment of municipal wastewater, the long-term operational experience has demonstrated that recycled water provides a reliable source of water for industry when potable water supply is uncertain, and at a lower cost. Several other similar recycling facilities have been constructed in Singapore, Mexico (San Luis Potosi), India (Panipat), northern California (RARE project) and Hawaii (Honolulu).

The pioneer in closing the water cycle in industry is Germany, where rainwater and industrial water recycling have been practiced since the beginning of the 20th century. The German experience in industrial water recycling has demonstrated that there are technical possibilities for water recycling for almost any application. Water recycling schemes have reduced wastewater volume by 78-92% in textile, paper and food and beverage industries. Key factors for the success of industrial water recycling are treatment efficiency and reliability, as well as technical and economic feasibility. The closing of the industrial water cycle with the objective of 'zero liquid discharge' can be achieved by means of three strategies involving water saving and wastewater minimisation:

- Cascading reuse, involving direct reuse with no or little treatment
- Wastewater recycling after appropriate treatment
- Source reduction by decreasing the need of water of a given industrial process

## Milestones in water reuse for agriculture

The majority of water reuse projects worldwide are implemented for agricultural irrigation and are driven by increasing water scarcity and ever increasing agricultural water demand. As a rule, agriculture is the greatest water user in a region, but is often the 'poor man' of water supply, least able to afford the development of new water resources. The need for alternative water resources has been accelerated over the past few years by severe droughts, which occur not only in traditionally arid areas in the United States, the Mediterranean region, the Middle East and South Asia, but also in a number of temperate states and countries in Europe and North America. For example, according to a United Nations Food and Agriculture Organization (FAO) study (FAO, 1999), the drought of 1999 in the Near East resulted in a relative decline of food production of 51% and the economic impact of the 2003 drought in Europe exceeded €13 billion ($17.4 billion). In this context, water reuse is becoming more valued, and certain countries are already using a large proportion of their treated wastewater for irrigation (Argentina, China, Cyprus, Egypt, Israel, Jordan, Kuwait, Libya, Mexico, Saudi Arabia, Spain, Syria, Tunisia and United Arab Emirates).

The largest scheme in the world is in the Mezquital valley in Mexico, which commenced around 1890 with the drainage canals of raw wastewater from Mexico City used for irrigation of agricultural lands. The scheme now irrigates up to 90,000ha of agricultural crops but still without adequate wastewater treatment.

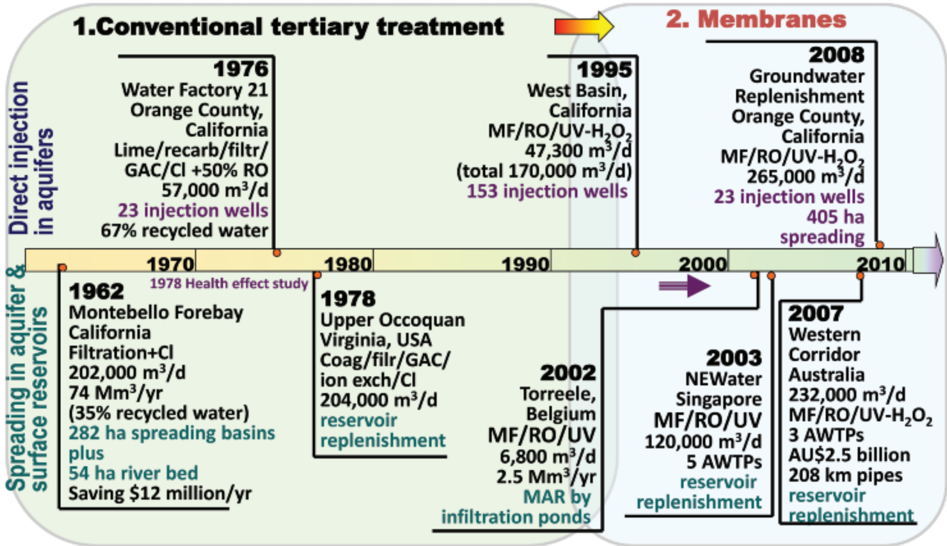


**Figure 3: Milestones in indirect potable water reuse with selected cornerstone projects. Source: Lazarova, 2011, 2013.**

The milestones in development of safe water reuse practices for agricultural irrigation are illustrated in Figure 4. The proposed three categories of water reuse projects are based on the advance in wastewater treatment and scientific knowledge and include:

- Irrigation of industrial crops, fodders and seed crops, orchards, forests, etc. irrigated with secondary effluent often after storage and polishing in open lagoons such as maturation ponds. Implementation of large projects in the Unites States and Tunisia in the 1960s, in Argentina in the 1970s, in France and Spain in the 1980s.
- Irrigation of food crops (eaten cooked or processed) with tertiary effluents. In the 1980s, two large projects in Florida (e.g. Water Conserv II) and in Israel (Dan Region) demonstrated the safety and benefits of water reuse by means of extensive scientific studies.
- Unrestricted irrigation of crops consumed raw with well treated and disinfected recycled water (tertiary filtered and disinfected effluent or ultrafiltration-treated secondary effluent). Long-term extensive research completed as a part of the implementation of water reuse projects in California (Monterey) and Australia (Virginia pipeline) has demonstrated the safety of recycled water and has convinced all stakeholders of the benefits of water reuse.

Despite the proven benefits of water reuse for agriculture and the availability of good practices and new irrigation technologies, many new projects are hampered by a lack of funding or very stringent regulations.

The water reuse project in Milan is an important milestone for agricultural water reuse in Europe, first because the long history of agricultural reuse in this area and second because almost 30 years were necessary to approve the new scheme of wastewater treatment and reuse by local and government authorities. At present, this is the largest successful and beneficial water reuse project in Europe, producing high quality filtered and disinfected recycled water for agriculture and the restoration of polluted rivers in the Po valley. The recycled water is distributed through an existing network of canals and channels for the irrigation of rice, corn, wheat and pasture. New projects for the irrigation of horticultural crops are being developed. The benefits have included the revitalisation of peri-urban parklands, improved surface water quality and the restoration of biodiversity and freshwater fishing.

As illustrated by the experience of water reuse on the island of Nourmontier, low cost and easy to operate natural polishing in maturation ponds can achieve adequate disinfection, providing at the same time large storage capacity. Over 90% of irrigation demand for producing early crops, particularly potatoes, are covered by reclaimed water with additional benefits of conservation and preservation of sensitive environment, biodiversity, as well as economic and leisure activities in the coastal area. Despite this successful experience, the new regulations are introducing more stringent water quality requirements and additional restrictions that hinder the development of new projects.

The Australian experience is providing an excellent illustration of successful well designed and managed projects with well recognized

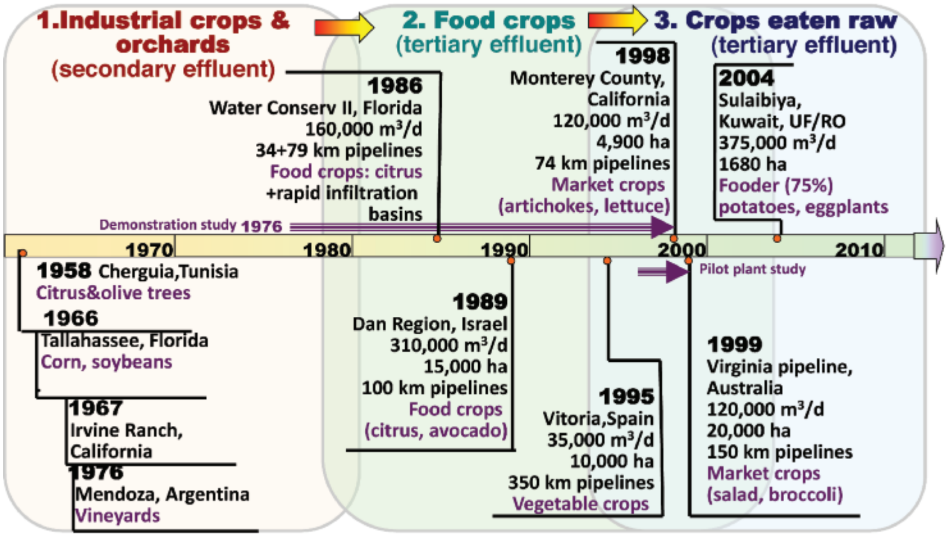


**Figure 4: Milestones in water reuse for agriculture with selected cornerstone projects. Source: Lazarova, 2011.**

benefits. The development of water recycling schemes for the irrigation of crops has enabled Australian farmers to increase production despite water shortages due to drought and increased competition for fully allocated river water supplies. A number of large recycled water irrigation schemes have been constructed in recent years, including the major irrigation scheme for horticultural crops in Virginia in South Australia. The growth in recycled water use has been supported by development of appropriate guidelines for management of health and environmental risks together with extensive guidance materials to help growers to establish successful farm practices. As with all forms of irrigation, care is required to ensure the recycled water irrigation is matched to crop needs, salinity is controlled, and both soil and groundwater conditions are kept sustainable.

## Conclusions and perspectives

Producing reclaimed water of a specified quality to fulfil multiple water use objectives is now a reality due to the progressive evolution of water reclamation technologies, regulations, and environmental and health risk protection. However, the ultimate decision to promote water reuse is dependent on economic, regulatory, public policy, and, more importantly, public acceptance factors reflecting the water demand, safety, and need for reliable water supply in local conditions.

Securing economic viability is an important challenge for the majority of water reuse projects. Unfortunately, water reuse is suffering from competition with undervalued and / or subsidized conventional water resources.

Full-cost recovery is a desirable objective but depends on ability to pay and many successful projects are only able to recover the operating cost. Financial incentives, grants, taxes and new pricing mechanisms can improve the economic viability of water reuse schemes. The evaluation of the benefits of water reuse at a large macro-scale (and its contribution to secure water supply and enhance urban environment and human wellbeing) also greatly contributes to the development of new water reuse projects, in particular in densely populated urban areas.

Independent of the type of reuse application and the country, the public's knowledge and understanding of the safety and suitability of recycled water is a key factor for the success of any water reuse programme. Consistent communication and easy to understand messages need to be developed for the public and politicians explaining the benefits of water reuse for long-term water security and sustainable urban water cycle management.

The technical challenges facing water reuse are not yet completely resolved. In particular for industrial, urban and potable water reuse applications, it is extremely important to improve the performance, efficiency, reliability and cost-effectiveness of treatment technologies. Water recycling facilities are facing tremendous challenges of high variations of raw water quality, peaks in salinity due to salt intrusion into sewers, and variation in water quantity due to extreme conditions of lower water demand, flooding or alternative disposal of recycled water.

Energy efficiency, carbon and environmental footprint are becoming important. The ambitious goals of sustainable development and achieving a zero net carbon and pollution emission footprint call for a new holistic approach to the management of the water cycle, with an increased role for water reuse. With the further growth of megacities and increasing efforts to optimise energy efficiency, water recycling is of growing interest and will take a leading role in the future. ●

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