

The environmental benefits of water recycling and reuse

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Abstract The world's supply of fresh water is finite and is threatened by pollution. Rising demands for water to supply agriculture, industry and cities are leading to competition over the allocation of limited fresh water resources. This paper examines how water reuse increases the available supply of water and enables human needs to be met with less fresh water. The paper is illustrated with water reuse case studies in agriculture, urban areas, industry and water resource supplementation in Australia and other countries. The links between water reuse and sustainable water management are examined. Water conservation and water reuse produce substantial environmental benefits, arising from reductions in water diversions, and reductions in the impacts of wastewater discharges on environmental water quality. Some examples are presented demonstrating the environmental benefits in quantitative terms. The paper also describes the economic and environmental benefits identified in a number of recent integrated water cycle planning studies in Australia.

Keywords Economics; effluent reuse; environmental benefits; water conservation

Introduction

The natural water cycle

In nature, water (like energy) is neither created nor destroyed but is converted from one form to another. In the natural water cycle, rain falling on the land is mostly transpired by the vegetation. But some percolates to groundwater and some runs off to the rivers and flows to the oceans to evaporate and return as rain. Almost all of the world's water (97%) occurs as salt water. Of the remaining 3%, two-thirds occurs as snow and ice in the polar and alpine regions. So only about 1% of global water occurs as liquid freshwater. More than 98% of the freshwater occurs as groundwater, while less than 2% is available in streams and lakes. So the liquid freshwater is a finite and limited resource (Bouwer, 2000).

The modified water cycle

Mankind has significantly altered the natural water cycle by overlaying new water cycle elements including: (a) extractions from rivers and groundwater for urban, industrial and agricultural use, (b) urban and agricultural runoff, and (c) return of treated or untreated wastewaters to streams. In many areas of the world, groundwater is the main water resource and often rates of extraction greatly exceed the rates of recharge, so groundwater levels are declining. An extreme example of the impacts of surface water diversion for irrigation has been the decline of the Aral Sea in Central Asia. Once the home of thriving fisheries employing 60,000 people, the Aral Sea has shrunk to a fraction of its former size. Former foreshore towns are now many kilometres from the sea. The economic, social and environmental impacts have been disastrous.

Urban development also has had a significant impact on the water cycle. Water drawn for urban water supply reduces streamflows in rivers. At the same time, stormwater runoff and wastewater discharges, which often carry high levels of pollution, cause a decline in the water quality of rivers. Serious degradation has been observed in some rivers, which have high levels of urban development in their catchments.

Emerging water shortages

The world's supply of fresh water is finite and is threatened by pollution. Rising demands for water to supply agriculture, industry and cities are leading to competition over the allocation of limited fresh water resources. In many countries, the available fresh water resources are already heavily committed and in some cases perhaps already over-committed. To avoid a water crisis, many countries must conserve water, manage supply and demand, pollute less and reduce the environmental impacts of growing population (Hinichsen *et al.*, 1999). Two examples are:

- (a) in the Nile Valley below Aswan, current water demands exceed the yield of the Aswan High Dam by a considerable margin; the shortfall is being made up by reuse of wastewater and irrigation drainage water discharges (Croce, 1998)
- (b) indications are that a lack of sufficient water supplies will become the single most important factor limiting South Africa's socio-economic growth in the twenty-first century; current projections indicate that water demand will exceed available supplies soon after the year 2020 (Odendaal *et al.*, 1998).

Water recycling in action

The mission of water suppliers is to provide reliable high quality services that meet customer needs and protect the environment. In recent years they have implemented successful water recycling projects in many countries. This experience has demonstrated the feasibility of water reuse on a large scale and its role in the sustainable management of the world's water. The examples are following as a small sample of the projects, which have been implemented. These are referred to reuse of agriculture, urban reuse, industrial reuse, and recycling to supplement water resources.

Reuse for agriculture

Monterey, California. The Monterey Regional Water Pollution Control Agency has constructed a scheme to use up to 20 Mm³/yr of recycled water from the Monterey and adjoining towns to irrigate 5000 ha of vegetable crops in the Lower Salinas Valley. Previously, excessive use of local groundwater for irrigation had led to seawater intrusion into the aquifers.

Mexico City. In Mexico, 90% of the wastewater from Mexico City is used for irrigation in the Valley of Mexico and the adjoining Mezquital Valley, an area with low rainfall and poor soils. About 45 m³/s is transferred to the Mezquital Valley where it is used to irrigate an area of about 90,000 ha. The use of wastewater for irrigation has greatly increased crop yields. A second benefit of this irrigation has been an increase in groundwater recharge in the Mezquital Valley including the creation of a new shallow aquifer and an increase in the base flow of local streams (Jimenez *et al.*, 1998).

Dan Region, Israel. Israel's total water needs exceed the available water resources which total about 1,800 Mm³/yr. To help meet water needs, recycled water is used extensively for agricultural irrigation. More than 60% of wastewater is reused. The wastewater discharge from Tel Aviv (about 130 Mm³/yr) is treated then percolated into an aquifer which provides further treatment. The water is then extracted from recovery wells and pumped through the Dan Region pipeline to meet agricultural water needs in the Dan Region and the Negev Desert.

Virginia, Australia. In South Australia, a major scheme has been constructed to supply up to 30 Mm³/yr of recycled water, from the Bolivar sewage treatment plant in Adelaide, to the

Virginia area north of Adelaide for irrigation of horticultural crops. The scheme includes a 120,000 m³/d water reclamation plant that incorporates dissolved air flotation and filtration processes (Marks, 1998).

Urban reuse

St Petersburg, Florida. The City of St Petersburg in Florida has constructed an extensive urban water reuse scheme which has been in operation since 1977 and which now supplies approximately 10,000 properties including 9,300 residential properties. Reclaimed water uses include urban and residential landscape uses, industrial uses, air conditioner chiller water and a backup source for fire protection. The scheme supplies an average of about 80,000 m³/d of recycled water. The quantity used depends on weather conditions. In 1993, more than 100,000 m³/d of recycled water were supplied to consumers. A further 70,000 m³/d is used for deep well injection to prevent saline intrusion into the City's drinking water aquifers (RWCC, 1993).

Irvine Ranch, California. The Irvine Ranch Water District (IRWD) commenced construction of a dual reticulation recycled water scheme in 1977. Recycled water is used for landscape irrigation including residential gardens (2,000 ha), irrigation of food crops (400 ha), ornamental lakes, car washes and industrial uses including a carpet mill. IRWD has mandated the use of recycled water for toilet flushing in new high rise office buildings. The IRWD dual reticulation system supplies 57,000 m³/d to 1,750 customers and delivers more than 15 Mm³ of recycled water per year.

South Bay, California. In California's Silicon valley, the San Jose and Santa Clara County authorities were directed to limit fresh water discharges to the south end of San Francisco Bay to not more than 450,000 m³/d to reduce damage to an environmentally sensitive salt marsh environment. Rather than construct an ocean outfall, they have built the South Bay Water Recycling Scheme to deliver recycled water for urban, industrial and agricultural users. The 60,000 m³/d first stage has been in service since 1998 (Rosenblum, 1999).

Rouse Hill, Australia. In Australia water will be recycled for residential uses at Rouse hill, a new housing development area in the north-western sector of Sydney. The area is ultimately planned to have 300,000 people with the first stage of the development catering for 100,000 people in 35,000 houses. A second reticulation system has been installed to supply recycled water for toilet flushing and garden watering. The first section of the scheme commenced operation in August 2001 and will supply 10,000 houses.

Homebush Bay, Australia. A water recycling scheme has been installed at Homebush Bay in Sydney, Australia where the Sydney Olympic Games were staged. Up to 7,000 m³/d of recycled water from stormwater and treated wastewater sources is used for toilet flushing in sporting venues, irrigation of open space areas, and to 2,000 residential houses for gardens and toilet flushing. Microfiltration and reverse osmosis treatment processes are used to achieve the required water quality. The scheme will reduce demands on Sydney's fresh-water supplies by about 850,000 m³/yr (Cooney, 2001).

Mawson Lakes, Adelaide. The Mawson Lakes housing development in Adelaide Australia will house 10,000 people in 3,700 houses and also serves a university and a commercial and industrial estate. Wastewater from the estate will be treated and recycled for toilet flushing and landscape irrigation. Stormwater from the site is collected, treated and recycled to provide lakes and water features within the estate and supplementary water for landscape

irrigation. Aquifer storage and recovery will be used to store surplus winter flows of recycled water and stormwater and supply peak irrigation needs during summer (Marks, 1998).

Industrial reuse

Power station cooling. Recycled water from the City Phoenix is supplied to meet the cooling water needs of the Palo Verde Power Station, which is located in the Sonoran Desert, 55 km west of Phoenix. Average rainfall in the area is about 175 mm/yr. The power station has an installed of 3,810 MW. The water recycling scheme supplies has a capacity of approximately 250,000 m³/d as cooling system make-up water.

Power station boiler feed. In Australia, recycled water from the Dora Creek sewage treatment works is pumped to the 2,640 megawatt Eraring Power Station at Lake Macquarie, about 100 km north of Sydney. There it is further treated by microfiltration and reverse osmosis to produce a water of potable grade which is then further treated in the existing demineralisation plant to produce purified water which is used as boiler feed to provide steam for the power station turbines. This recycled water replaces 1.2 Mm³/yr of potable water previously supplied from the town water supply system (Cole and Deans, 1994).

Steel production. Recycled water is supplied to steelworks for a variety of process water uses including cooling water, quenching of the blast furnace slag and quenching at the coke ovens. It is currently planned to expand the water recycling system at the Port Kembla steelworks in Australia to at least 35,000 m³/d and possibly to 50,000 m³/d.

Oil refining. In Australia, a 14,000 m³/d dual membrane water reclamation plant has been installed at the Luggage Point sewage treatment plant in Brisbane to supply process water to the BP oil refinery (Don, 2001; Barr, 2002).

Semi-conductor manufacture. The Singapore Public Utilities Board has been conducting the Singapore NEW Water project, a 10,000 m³/d demonstration project to demonstrate the suitability of recycled water, which has received advanced treatment to supply high purity water for high technology and semiconductor industries. The demonstration project, which was commissioned in May 2000, includes extensive health studies. A dual membrane process using microfiltration and reverse osmosis followed by ultraviolet light filtration has been used. Following the success of the demonstration project, a further 72,000 m³/d capacity is now under construction and is expected to be in service by December 2002.

Recycling to supplement water resources

Incidental or unplanned supplementation of water resources is widespread where treated wastewater is discharged to rivers, lakes that are subsequently used for drinking water supplies. Commonly quoted cases include the Thames and Rhine Rivers where multiple uses occur between source and the ocean. In the USA, a 1980 study by the US.EPA reviewed 1,246 water supply systems serving 80 million people in towns over 25,000 population and found that 26 million people were served from sources which contain between 5% and 100% treated wastewater during low flow periods.

South Africa. Water reuse has played a major role in matching demands and available raw water supplies. The 1956 Water Act required treated wastewater flows to be returned to stream of origin unless applied to beneficial reuse, a requirement that encouraged the introduction of high standards of treatment. As a result, recycled water constitutes a substantial

proportion of the base flow in many rivers. For example, recycled water is now about 50% of the inflow into Hartbeespoort Dam which supplies water to Pretoria and Johannesburg (Odendaal *et al.*, 1998).

Los Angeles, California. Since 1962, the Los Angeles County Sanitation District has been using recycled water to recharge a groundwater potable water supply through surface spreading basins at Whittier Narrows. The recycled water was initially disinfected secondary effluent and was upgraded by addition of tertiary filtration in 1978. The amount of recycled water recharged annually averages 16% of the total inflow to the groundwater basin. Depending on location and aquifer characteristics, the proportion of recycled water in the potable water wells ranges from 0 to 23%. After extensive data acquisition and analysis, an independent scientific panel to the State of California concluded that the Whittier Narrows groundwater recharge was as safe as commonly used surface water supplies (State of California, 1978).

Orange County, California. Since 1976, Orange county in California has operated Water Factory 21, a 57,000 m³/d water reclamation plant producing recycled water of drinking water standard which is injected under pressure into a heavily used potable aquifer to prevent salt water intrusion. After more than 15 years of intensive groundwater monitoring, Orange County has observed no change in groundwater quality that would cause a public health concern. The plant is currently being expanded to 200,000 m³/d using a dual membrane process.

Upper Occaquan, Virginia. In Virginia, recycled water from the Upper Occaquan water reclamation plant is discharged to the 42 Mm³ Upper Occaquan reservoir, which supplies drinking water to about 1 million people in North Virginia. Typically recycled water represents 10% to 15% of the reservoir inflows and the average detention time in the reservoir is 26 days. The water reclamation plant was initially 55,000 m³/d capacity and has been enlarged to 100,000 m³/d. Further enlargement to 200,000 m³/d is planned.

El Paso, Texas. Since 1985, El Paso in Texas has used recycled water from the 38,000 m³/d Fred Harvey water reclamation plant to recharge the Hueco Bolson drinking water aquifer. Detention time is approximately 2 years before water is drawn for supply from the El Paso potable water wells. No negative effects on health related water quality parameters have been observed but there has been some increase in total dissolved solids content in the aquifer.

Windhoek, Namibia. Windhoek, the capital city of Namibia, is situated in the central highlands of Namibia between the Kalahari Desert to the east and the Namib Desert to the west. The nearest perennial river is the Kavango, 750 km away. As a result of severe water shortages during drought, the world's first potable water reclamation plant of 4,800 m³/d capacity was constructed in 1968. The plant has consistently produced water of acceptable potable quality for 30 years. It has been upgraded on several occasions and is currently being enlarged to 21,000 m³/d using dual membrane technologies. Overall since 1968, recycled water has contributed 4% of the total water supply in Windhoek but has been up to 31% of the total supply during severe drought periods. The recycled water is blended with treated water from the Goreangab water treatment plant before distribution, with the maximum blend being 1:1 during drought periods. The average blend since 1968 has been 1:3.5. The blend from Goreangab is mixed with water from other sources in the service reservoirs so that normally there is a maximum proportion of 25% recycled water in any zone in any period (van der Merwe and Menge, 1996).

Drinking water supply sources are subject to close monitoring to ensure that the supply is safe. As an overall goal, water reuse projects should provide at least the same degree of public health protection as conventional water supplies. Water quality issues for resource supplementation reuse projects are the same as with any potable water supply project. Parameters to be addressed include pathogens, organics and inorganics. Due to the wastewater origin of recycled water, treatment technologies must address the potential higher levels of microbiological and chemical contamination. In the absence of specific standards covering potable reuse applications, the industry has developed a “multiple barriers” approach to ensure the appropriate levels of safety and reliability. In this concept, multiple unit processes or other mechanisms are provided to remove or inactivate each quality parameter of concern, particularly the microbiological parameters.

Water reuse and integrated urban water planning

Traditionally, water authorities have managed their water supply, sewerage and stormwater drainage systems as separate entities. Integrated urban water planning is a structured planning process to evaluate concurrently the opportunities to improve the management of water, sewerage and drainage services within an urban area in ways which are consistent with broader catchment and river management objectives. As discussed by Davison *et al.* (2001) catchment management impacts directly and indirectly on all three components of the urban water cycle, having effects on drinking water quality, wastewater treatment and stormwater management. A simple framework of hazard identification, assessment and management underpins the management of both catchments and urban water cycle elements.

The New South Wales Department of Land and Water Conservation (DLWC, 2001) has developed an integrated urban water planning process through a number of recent pilot studies conducted in partnership with local authorities in studies in the New South Wales towns of Finley, Goulburn and Bombala. The process links urban water management objectives to overall catchment and river management objectives. As a prelude to the integrated urban water planning process, DLWC undertakes an assessment of water quality and flow conditions, with particular focus on the sources of nutrients in catchment discharges. This data assists in shaping appropriate urban planning responses, particularly when urban discharges are a significant proportion of total nutrient discharges.

The pilot studies have shown that an integrated approach to urban water, sewerage and stormwater planning can identify opportunities that are not apparent when separate strategies are developed for each service. The pilot studies have shown that both water conservation measures and water reuse are important contributors to environmental water quality improvements, and can also reduce water supply costs. The result is better-integrated, more sustainable solutions, and substantial cost savings for local communities. Savings of up to 50% of capital costs have been identified in the pilot studies, but this may be exceptional. It is probably more practical to set a modest target of 15% to 20% savings and to see if this can be bettered.

The conduct of an integrated urban water planning study is often a less costly process than traditional separate water and sewerage strategy studies. The integrated urban water planning produces a rapid screening and shortlisting of potential opportunities in partnership with the community. The process can lead to significant savings in project investigation and development costs, as well as the sorts of capital and operating costs savings which have been identified in the pilot studies (Anderson and Iyadurai, 2003).

Environmental benefits of water reuse

Water reuse to meet the world's water needs

Felicia Marcus, former USEPA's Regional Administrator for the dry western region of the USA, has said: “Water recycling is a critical element for managing our water resources.

Through water conservation and recycling, we can meet environmental needs and still have sustainable development and a viable economy.” Tom Hannigan, CEO of California’s Department of Water Resources, has described water recycling as “the brightest star” in meeting future water needs in California.

Given the water shortages which are now occurring, it is increasingly difficult to justify the old wasteful “use once and throwaway” approach which has traditionally been used by urban societies. Water conservation, reuse and recycling can greatly increase the benefits obtained from limited supplies of freshwater. This is shown in the following two diagrams in Figures 1 and 2 which show the water balance in a river basin where 50% of the average flow is used for agriculture and 25% for urban and industrial needs. The “status quo” case of a “throw-away” city which diverts, uses water once and then discharges it is shown in Figure 1.

The improvement in downstream river flows resulting from a 20% reduction in water demands through water conservation and water efficiency measures in both agricultural and urban use, coupled with beneficial reuse of 90% of reclaimed water flows for non-potable uses is shown in Figure 2.

Many rivers are experiencing declines in water quality due to high discharges of pollutants. It can be shown with simple modelling that downstream water quality is a function not only of the amount of pollutants being discharged, but also a function of the amount of freshwater being extracted from the river. It can be demonstrated that water reuse reduces the amount of fresh water diverted and reduces the amount of pollutants being discharged and therefore results in improvements in downstream water quality.

The corresponding improvements in downstream water quality as a result of the reduced diversions and reduced discharges of treated wastewater in a hypothetical 120 km length of a river containing two large cities are shown in Figure 3.

Recycled water is a valuable resource. Instead of being thrown away, appropriately treated water can be recycled – used a second time – to reduce the demand on high quality freshwater sources and improve environmental water quality. Water recycling increases

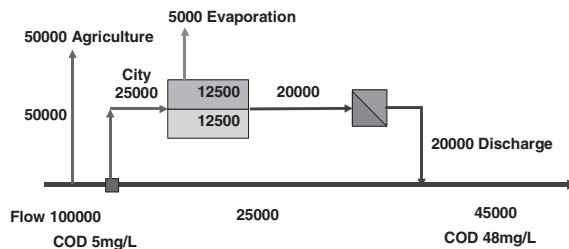


Figure 1 Status quo – use and discharge. 75,000 m³ water use needs 75,000 m³ fresh water; net use 55,000 m³

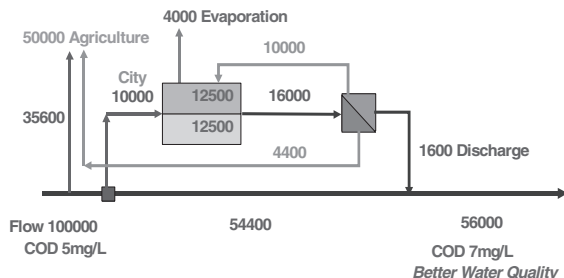


Figure 2 Benefits of water conservation, reuse and recycling. Conserve and 90% reuse: 75,000 m³ water use needs 45,600 m³ fresh water; net flow reduction 44,000 m³

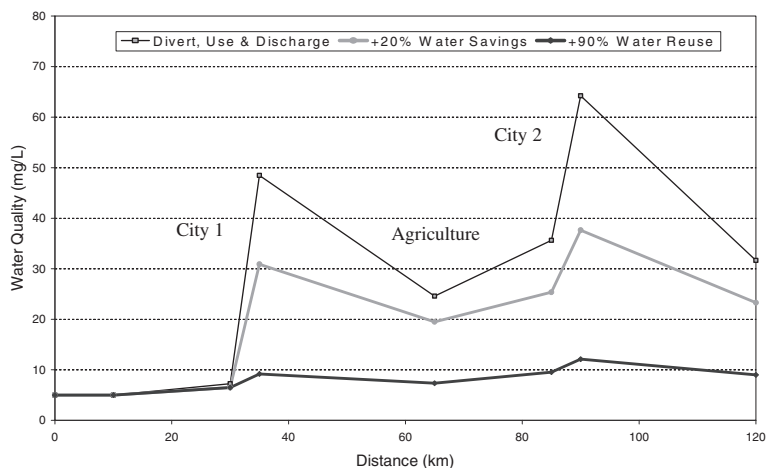


Figure 3 Water quality benefits of water conservation and beneficial reuse

the available supply of water and enables greater human benefit to be achieved with less freshwater. Therefore, water recycling can make a substantial contribution to meeting the world's water needs and to lessening mankind's impact on the world's water environment (Anderson, 2001a; Anderson, 2001b).

Discussion

Identifying the benefits

In the past there has been a focus on the cost of implementing water reuse schemes, but less consideration of the benefits side of the Equation. Often the indirect benefits and the environmental benefits have not been accounted for in the evaluation of the merits of a project.

Using reclaimed water in place of fresh water for existing uses can free up existing water supply system capacity to cater for new water needs. This results in savings in the cost of developing new water sources, water transfers, treatment and distribution systems. It can also result in significant improvements in downstream river water quality. From an examination of the hypothetical case presented in Figures 1, 2 and 3, it is possible to identify a wide range of benefits that result from water conservation and reuse. The benefits include:

- (a) agriculture benefits such as: (i) reduced diversion costs, (ii) value of a secure "drought-proof" supply of reclaimed water, (iii) increased farm production, and (iv) value of reclaimed water nutrients = savings in fertiliser applications;
- (b) urban water supply benefits such as: (i) savings in the capital cost of diversion structures, drought storage, transfer systems and water treatment and (ii) savings in operation and maintenance costs including pumping energy and treatment chemicals;
- (c) urban wastewater benefits such as: (i) savings in discharge pump stations and pipelines and (ii) savings in treatment and nutrient removal costs required for discharge to sensitive waters;
- (d) environmental water quality benefits such as:
 - (i) reduction in freshwater diversions
= more river flow for downstream users
= better downstream water quality
 - (ii) reduction in pollutant discharges
= better downstream water quality
 - (iii) better downstream water quality
= reduced environmental impact and improved river aesthetics

- = reduced impacts on fisheries and aquatic life
- = improved public health for downstream users
- = lower water treatment costs for downstream users
- = improved recreational values of waterways.

Economics and sustainability

In most coastal locations in Australia, the costs of developing new fresh water supplies often exceeds US 0.5 \$/m³, and in drier inland areas the cost is often much higher. A considerable amount of work is being done to evaluate water recycling projects in terms of their economics and sustainability. A recent example is the Sydney Water Corporation's Water Recycling Strategy (SWC, 1999) which evaluates potential water recycling projects in terms of levelised annual costs in \$/m³ and Greenhouse gas impacts expressed in equivalent kWh/m³ energy use. White and Howe (1998) have described the levelised annual cost approach. The results of these analyses suggest the following.

- (a) Selected large industrial reuse projects and urban landscaping projects which are located close to the treatment plant are more economic than dual reticulation residential schemes.
- (b) Indirect reuse by supplementation of water resources would be more cost effective than many non-potable reuse options but may have higher greenhouse gas impacts.
- (c) Decentralised treatment and recycling systems may warrant further examination.
- (d) The implementation of low cost water conservation measures can provide a 10 to 20 year window of opportunity in which to make informed decisions about implementing advanced water recycling applications and to improve further the technology.

Conclusions

Successful water recycling projects have been implemented in many countries. This experience has demonstrated the feasibility of water reuse on a large scale and its role in the sustainable management of the world's water. Both project experience and comprehensive health studies have demonstrated the potential to use recycled water to supplement drinking water supplies. An integrated approach to urban water, sewerage and stormwater planning can identify opportunities that are not apparent when separate strategies are developed for each service. The result is better-integrated, more sustainable solutions, and substantial cost savings for local communities. Water conservation and water recycling measures are key elements in integrated urban water planning.

Water conservation and beneficial reuse can reduce freshwater diversions from streams and improve downstream water quality. There are many direct and indirect benefits which result from reduced diversions and improved downstream water quality. These benefits should be evaluated and taken into account when assessing the merits of implementing new water reuse projects. Water reuse increases the available supply of water and enables greater human needs to be achieved with less fresh water, thus lessening mankind's impact on the world's water environment. A move from the old "use once and throw away" approach, to a new sustainable "conserve, use wisely and recycle" water economy will benefit the whole world. There is still much to do to improve water recycling technologies and improve the evaluation of project economics and sustainability. While the World's water problems may seem great, we have seen enormous progress in water conservation and recycling in the last 20 years. There is cause for optimism that, with focussed effort, mankind can reverse the degradation of the planet's water environment and meet the world's water needs in a sustainable way.

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