WATER REUSE OPTIONS TO EXPAND WATER SUPPLY PORTFOLIOS

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Water scarcity issues are affecting communities across the globe. Our water supplies for the most part are fixed; what we had yesterday and what we have tomorrow on our planet does not change significantly. Our challenges for effectively managing our water are plentiful, unlike the water supply. One key challenge is that while water quantity is fixed, changes in climate have resulted in shifts in water patterns and, consequently, many communities which were water-rich in the past are facing a new challenge as water supply and water demand no longer balance. To complicate matters, many communities with already limited water resources continue to experience high growth which only exacerbates their water supply problem. Economic development also is resulting in consumption of the water resources at an increasing rate and is creating conveniences which are shifting growing populations to coastal and urban locations. Also, the largest growth of people is occurring in countries that have the most potential to improve economically (India, China, Africa, South America). Together, population growth, economic development and climate change are changing the water balance in many communities.

To deal with water scarcity issues, the hunt for water must reach beyond the traditional means of new water supplies, i.e. rivers, aquifers, lakes. A holistic water review is required to examine conservation, non-potable reuse, indirect potable reuse, impaired waters (brackish or contaminated waters), desalination and water sharing between adjacent communities. Of the options listed above which involve water supply, water reuse is a universal solution that is not limited by climate, geographical location or water supply situation. The critical factor for reuse is the end use, which dictates the water quality requirements and drives the required level of treatment.

NON-POTABLE REUSE

Non-potable reuse is a large category which encompasses various types of irrigation, industrial reuse, recharge of non-potable water aquifers and any other method of reusing wastewater effluent in a way that is disconnected from potable water supplies.

REUSE FOR IRRIGATION

Irrigation is probably the most predominant type of non-potable reuse implemented world-wide. Irrigation opportunities can be categorised as crop irrigation or turf irrigation with further differentiation based on opportunity for human consumption of crops irrigated or human contact with the irrigation water. Each of these categories of irrigation can relate to different levels of treatment. For example, treated water used to irrigate crops that are not used for human consumption–such as grasses, alfalfa, hay and biofuel crops–may not require additional treatment steps beyond that associated with secondary treatment. However, crops that may be consumed by humans will require additional treatment, which in some parts of the world means secondary treatment and in other parts of the world the addition of

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filtration and improved disinfection processes. Similarly, irrigation applications with potential human contact–such as irrigation of golf courses, highway medians, parkways and school yards–also typically require filtration and disinfection to eliminate viruses and other emerging pathogenic micro-organisms. The challenge with crop and turf irrigation is the seasonal water requirements as well as the co-dependence on climate. Wet-weather events as well as low-temperature periods outside of the growing season, directly impact the opportunity for irrigation and force discharge to surface waters. Consequently, the level of reuse may be limited in some regions. EPA (2004) indicates in Table 1 a number of constituents that treatment technologies should address in order to produce an adequate water quality for irrigation along with triggering potential concern if not controlled. The ANZECC & ARMCANZ (2000) long- and short-term trigger values generally agree with Table 1, differing where shown in parenthesis.

Table 1. Recommended Limits for Constituents in Reclaimed Water for Irrigation

Constituent	Long-Term Use (mg/l)	Short-Term Use (mg/l)	Remarks
Aluminum	5.0	20	Can cause non-productiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron	0.75 (0.5)	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/L. Usually sufficient quantities in reclaimed water to correct soil deficiencies. Most grasses are relatively tolerant at 2.0 to 10 mg/L.
Cadmium	0.01	0.05	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.
Chromium	0.1	1.0	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt	0.05	5.0 (0.1)	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride	1.0	15.0 (2)	Inactivated by neutral and alkaline soils.
Iron	5.0 (0.2)	20.0 (10)	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead	5.0 (2)	10.0 (5)	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5 (0.075 on citrus)	2.5 (0.075 on citrus)	Tolerated by most crops at concentrations up to 5 mg/L; mobile in soil. Toxic to citrus at low doses. Recommended limit is 0.075 mg/L.
Manganese	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/L in acidic soils.
Molybdenum	0.01	0.05	Non-toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium	0.02	0.02 (0.05)	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium.
Tin, Tungsten and Titanium	-	-	Effectively excluded by plants; specific tolerance levels unknown
Vanadium	0.1	1.0 (0.5)	Toxic to many plants at relatively low concentrations.
Zinc	2.0	10.0 (5)	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.

Constituent	Recommended Limit	Remarks
pH	6.0	Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals' toxicity described above).
TDS	500 - 2,000 mg/l	Below 500 mg/L, no detrimental effects are usually noticed. Between 500 and 1,000 mg/L, TDS in irrigation water can affect sensitive plants. At 1,000 to 2,000 mg/L, TDS levels can affect many crops and careful management practices should be followed. Above 2,000 mg/L, water can be used regularly only for tolerant plants on permeable soils.
Free Chlorine Residual	<1 mg/l	Concentrations > 5 mg/l causes severe damage to most plants. Some sensitive plants may be damaged at levels as low as 0.05 mg/l.

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REUSE FOR INDUSTRIAL APPLICATIONS

Industrial reuse opportunities can provide a more sustainable solution for reuse as the demand is typically more consistent. In fact, the inverse of the wet-weather concerns noted for irrigation are true for industrial reuse: a defined amount of reuse water must be guaranteed. While the industrial applications can include manufacturing related usage, one of the most synergistic reuse opportunities is to reuse wastewater effluent for cooling tower makeup water or process water in power plants, oil refineries or other similar industrial plants. It should be noted that whilst cooling water application concerns are similar to those for irrigation applications, they include closer scrutiny of those water quality parameters indicative of potential corrosion and fouling as well as microbiological concerns if used in cooling towers, particularly Legionella. As the air temperature increases, industrial cooling uses will also increase. During cooler times of the year, the amount of reuse water used in this application will decrease. The optimum condition would be the ability to provide high quality reuse water, which can serve as process water and cooling water within the industrial plant, in combination with discharge of the process water/cooling water back to the wastewater treatment plant for treatment and purification prior to returning to the industry as process water. An example schematic is provided in Figure 1. Within the water reclamation facility, flow could be removed at various points within the treatment train based on the required level of treatment.

Three of the key constituents of concern with the above schemes are phosphorus, nitrogen and total dissolved solids. In the forward process to provide reuse water, nutrients can traditionally be removed cost-effectively via the biological processes at the wastewater reclamation facility; however, some additional polishing using breakpoint chlorination for ammonia removal or high-rate chemical polishing may be required for phosphorus removal.

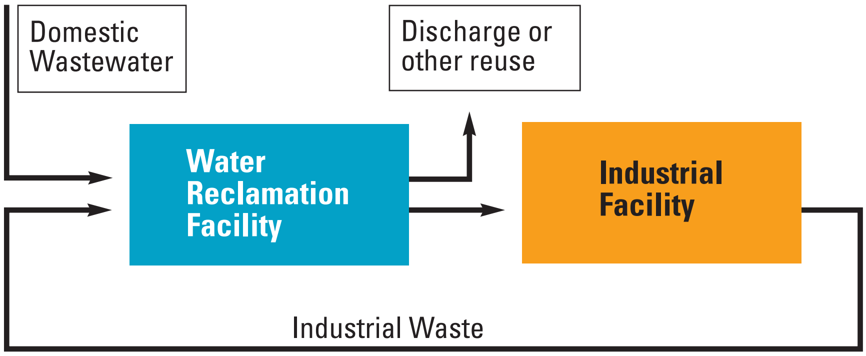

Figure 1. **Industrial reuse scheme.**

In Singapore, PUB, Singapore's national water agency, has identified an opportunity to further expand their water supply for industrial reuse. PUB's Jurong WRP is located in an industrialised area in southwestern Singapore. The plant currently uses a conventional activated sludge process with surface aerators to produce secondary effluent for ocean discharge. As part of Singapore's sustainable water management strategy, PUB is retrofitting part of the plant to an MBR process with a capacity of 68 MLD. The MBR will supply high-quality industrial water to a new refinery and other industries on nearby Jurong Island, freeing up potable water to meet water demand for domestic use.

For removal of many of the key pollutants of concern, (i.e. nutrients, metals, volatile organics, organics, salinity, etc.), electrodialysis, nano-filtration or reverse osmosis may be required. Additional pollutants may need to be removed based on the requirements of the industrial facility. Removal of these pollutants is site-specific and will need to be discussed with respect to the industrial facility. Additional solids removal processes will need to be considered at the water reclamation facility if TDS removal is required by the industrial facility.

INDIRECT POTABLE REUSE

The most contentious, though accepted in some regions, level of reuse is indirect potable reuse (IPR). IPR can be defined as discharging a high quality reclaimed water into a surface water or groundwater that is used as a drinking water supply. The reality is that IPR can be planned or unplanned. Planned IPR is the dedicated discharge to a reservoir or an aquifer which serves as the drinking water supply for a community. For example, in the U.S. treated effluent from Las Vegas, Nevada, is discharged to Lake Mead, which serves as the city's water supply. In Scottsdale, Arizona, the city implemented aquifer recharge of its treated effluent 10 years ago to extend its water supply and eliminate water mining. Unplanned IPR is the discharge to a river, such as the Thames in the UK or the Mississippi or Ohio Rivers in the U.S., which serve simultaneous roles as discharge receivers from wastewater plants and water supply sources for drinking water plants. It appears that the free flow of water minimises the apprehension of discharge and supply within a given water body compared to the planned IPR, which occurs with what is envisioned as a confined water.

In Australia, large amounts of treated effluent is generally not discharged to a water body that serves as a drinking water supply. There are, however, cases of IPR, such as in SE Queensland and in NSW in Sydney, where a portion of the water taken from the Hawkesbury River for the North Richmond WFP originates from STP dis-

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charge, as does a small portion of the flow that enters Warragamba Dam. Many fresh water rivers and streams cannot serve as a discharge point for treatment plants in a protected catchment. Discharging to a water supply would require significantly higher levels of treatment to meet reuse standards.

IPR, both planned and unplanned, is practiced in numerous locations around the world – some acknowledged as such and others surreptitiously performed. Treatment requirements for unplanned IPR are a function of the stream water quality and vary from secondary treatment without disinfection to high levels of nutrient reduction in combination with filtration and disinfection. Planned IPR currently demands the most stringent level of treatment prior to discharge. Water quality requirements can be as stringent as those of drinking water with the additional charge of removing micro-constituents (EDCs, PPCPs). Currently, the predominant drivers for IPR discharge are salinity and micro-constituents for aquifer discharge, and the addition of nutrient constituents for reservoir discharge. Depending on the discharge location, technologies such as GAC, BAC, ozone, UV, micro-filtration, nano-filtration, reverse osmosis, electrodialysis and advanced oxidation have been applied in various configurations.

Recently, Melbourne Water in Melbourne, Victoria, invested in an extensive pilot plant program to investigate the benefits of multiple combinations of many of the above technologies for various reuse opportunities as it seeks to improve its discharge quality to the bay and evaluate future reuse opportunities that would extend their water supply portfolio. An example of the IPR treatment scheme provided for the Bundamba Advanced Water Treatment Plant (AWTP) in Brisbane, Queensland, is provided in Figure 2. A somewhat similar treatment scheme using micro-filtration, reverse osmosis and UV is being trialed by Water Corporation in Perth, Western Australia, for aquifer recharge at Beenyup.

Investigations of newer technologies which accomplish micro-filtration, disinfection and micro-constituent removal have the opportunity to reduce the advanced water treatment plant (AWTP) footprint as well as expand the options for advanced treatment for non IPR discharges to effectively address micro-constituents.

DIRECT POTABLE REUSE

Currently, direct potable reuse is practiced in only one city in the world, Windhoek, Namibia. This city uses direct potable reuse on an intermittent basis only to a maximum of 25% of their supply. In 2006, the Toowoomba City Council launched the Toowoomba Water Futures Project that proposed the closing of the water cycle for drought relief, such that highly treated sewage would eventually be discharged to the inlet of Mt Kynoch WTP after 30 days of detention. The proposal was ultimately defeated by the electorate. In the U.S., the most extensive research focusing on direct potable reuse has been conducted in Denver, Colorado; Tampa, Florida; and San Diego, California. In San Diego, the following unit processes after secondary treatment were piloted:

- Coagulation with ferric chloride
- Multimedia filtration
- Ultraviolet disinfection
- pH adjustment with sulfuric acid
- Cartridge filter
- GAC
- Reverse Osmosis

Since that time, concern has developed over micro-constituents; therefore ozone, advanced oxidation and PAC would need to be added to assure compliance with direct reuse requirements.

AWTP FLOW SCHEMATIC

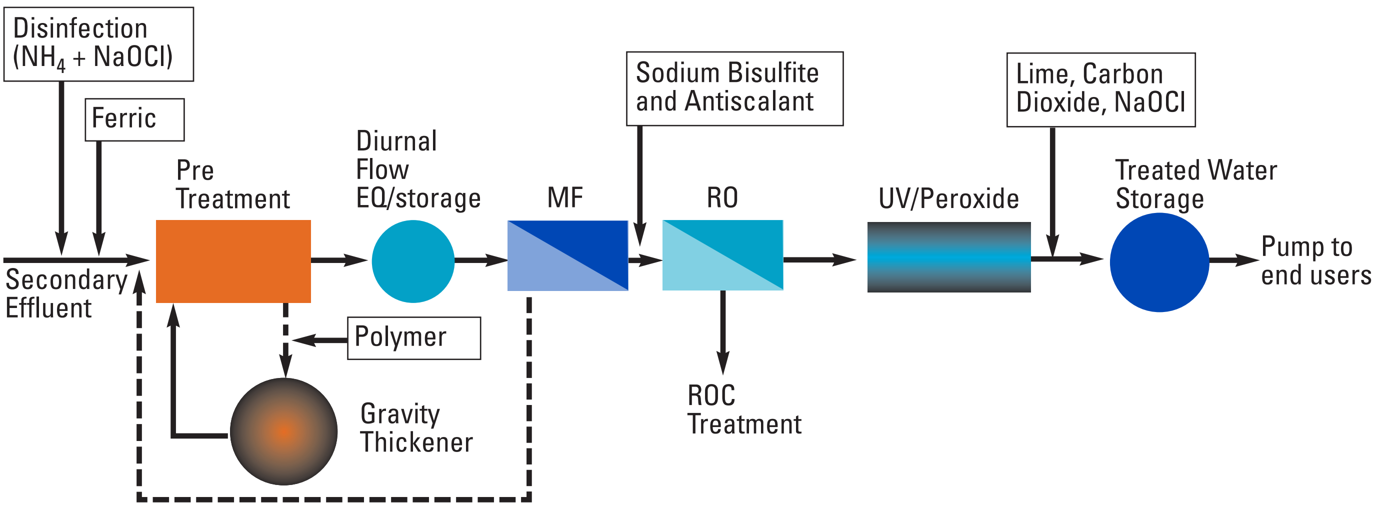

Figure 2. **Bundamba AWTP Process Schematic**

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CONCLUSIONS

To address water scarcity issues, a holistic water review is required to examine conservation, non-potable reuse, indirect potable reuse, impaired waters (brackish or contaminated waters), desalination and water sharing between adjacent communities. Water reuse is an effective solution that is not impaired by climate, geographical location or water supply situation. There are a host of reuse opportunities for any given community; however, there is no one-size-fits-all solution. Each community must effectively evaluate the options and select the most sustainable solution for its given situation, both in the present as well as forecasted for the future. The appropriate solution will vary by region and degree of water scarcity.

REFERENCES

EPA, Guidelines for Water Reuse, August 2004, EPA Number 625C04108

ANZECC & ARMCANZ 2000, 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality', Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

http://www.toowoombawater.com.au/who-else-is-doing-this-/index.php?option=com_content&task=view&id=214&Itemid=1

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