# Ozone In The Water Reclamation Process
# At South Caboolture, Queensland, Australia

Extracted by: S.Halliday, Watertec Engineering (2006)

## Abstract

The 10 ML/d South Caboolture Water Reclamation Plant treats secondary effluent to Australian Drinking Water Guidelines standard to allow unrestricted substitution of recycled water for town water. It was designed to reduce riverine pollution and to provide recycled water to industrial and community consumers for non-potable uses. The unique physical-chemical/biological treatment process incorporates biological denitrification, preozonation, coagulation/ flocculation, dissolved air flotation/ sand filtration, ozonation and biological activated carbon treatment. Some problems have been experienced due to the presence of iron and manganese in the feedwater and biofilm growth in the service water system. Operation of the plant has highlighted the need to recognize water-recycling water, as the production of a commodity rather than effluent disposal.

## Keywords

Water reclamation, ozonation, biological activated carbon, denitrification, potable reuse

## Introduction

Our resources are finite and should be used more effectively. The vast human populations are extremely demanding on the environment, particularly towards water resources. Land animals of about human mass manage quite well on about two litres of water per day. Humans require a hundred times as much; Australians even 250 times as much. Humans deposit their wastes into water, polluting freshwater resources and the oceans. Large quantities of water are used to flush away our wastes, but as always, dilution is not the solution to pollution - it only spreads it wider and further. This pollution is destructive to the environment, as is the need to store large quantities of water by damming up rivers - interfering with the natural flow of water. The urban human approach to sanitation: dilution of bodily waste with water and subsequent, not totally successful efforts to purify this wastewater must appear absurd to an uninvolved observer, say from another planet.

Six billion people and their pollution of water resources impede provision of potable water. To provide water with a quality suitable for drinking, extensive additional treatment is required. About one-third of the Earth’s population cannot afford suitable drinking water treatment or the luxury of safe sanitation. As a consequence, millions of people worldwide die annually after contracting waterborne diseases. Even in the most developed countries, people die from waterborne diseases and are at risk from toxicity contained in water. This may be natural toxicity from cyanobacteria – these really thrive as a result of pollution – and synthetic toxicants. Some of these may be accumulating substances that may, in a lifetime of exposure, increase the risk of such diseases as cancer, birth abnormalities and long-term genetic degeneration.

Improved wastewater treatment is one solution to pollution. Carried to full consequence, wastewater could be purified to a quality suitable for drinking and then not just dumped into the nearest river, but gainfully reused. Recycling water is not a new concept by any means. It is Earth's own method to ensure that the limited supply of water is made available over and over again. All water supplies on land originate from rainfall and find their way back to the oceans from where they re-evaporate at some time to be recycled onto the land. The unnatural activities of humans such as overpopulation, agriculture and industry pose a threat to the stability of this cycle and only by creating smaller reuse cycles within Nature's bigger water cycle can we to some extent reduce our devastating effect on the natural environment.

Water is a scarce resource in most parts of the developed world. Regardless of the scarcity of water in Australia, this country has been slow to embrace the principles of water conservation. Too little has been done on the preservation of water resources and avoiding ecological disasters. Drinking water supply has been endangered in the Murray-Darling Basin by the rampant increase in blooms of toxic cyanobacteria, caused by the increasing eutrophication of this river system. Many cities have water quality problems. Most major cities have water supply problems, needing interbasin transfer schemes of considerable magnitude.

Southern Africa, on the other side of the Indian Ocean, has a similar climate than Australia, and there was an early realization that water has to be recovered to make it go further. Research into water reclamation was started in the sixties and led to the building of the experimental Stander Water Reclamation plant in Pretoria and the Goreangab Water Reclamation Plant in Windhoek, Namibia. These plants presented an opportunity to further develop water reclamation technology and particularly to using the concept of using ozonation followed by biological activated carbon (van Leeuwen, 1980 and van Leeuwen et al., 1981 & 1983). Unfortunately, due to political changes and other urgent funding priorities, not much use of this technology has been made in South Africa, but it has been embraced in Namibia, where the Windhoek plant is being upgraded and extended to 21 ML/d (Burmeister et al., 1992) using the preozonation/BAC technology developed in South Africa. The technology has also been transplanted to Australia, improved upon, given a distinctive Australian flavor and now operating successfully on the banks of the Caboolture River, north of Brisbane as described in this paper.

## Reclamation Plant Philosophy and Aims

Ten water recycling plants to industry have recently been built or are being planned in the greater Brisbane area (South East Queensland) ranging from 1 to 14 ML/d (Lehmann, 2000). The only one using ozonation and biological activated carbon, however, is the one in Caboolture. What also makes this plant unique is that it is able to produce potable quality water, but not for drinking use.

## History

The Caboolture Shire (local authority) operates a 40,000 equivalent person wastewater treatment plant, just south of the Caboolture River, 50 km north of Brisbane. It was decided in 1996 to get KME Engineers, now the Kinhill Group within Brown and Root Services Asia Pacific, a Halliburton company, to plan and design a water reclamation plant of 10 ML/d (2.6 mgd). The local Authority's intention was to minimize environmental impacts of discharge to the river, while producing water suitable for non-potable uses. However, the design brief included that the product water was to meet the National Health &Medical Research Council’s Australian Drinking Water Guidelines for potable water. It was also intended that total nitrogen levels were to be reduced to <1mg/L and total P to <0.1

mg/L in order to protect the middle Caboolture River. The design and construction of the water reclamation plant was carried out as a design and construct contract with Anglian Water International Pty Ltd being awarded the contract. The plant was completed early in 1999 and cost Aus $8 million (US $4.5 million). The Caboolture Shire Council has recently commissioned the design of a recycled water main to supply an ultimate capacity of about 10 ML/d to the nearby Narangba Industrial Estate.

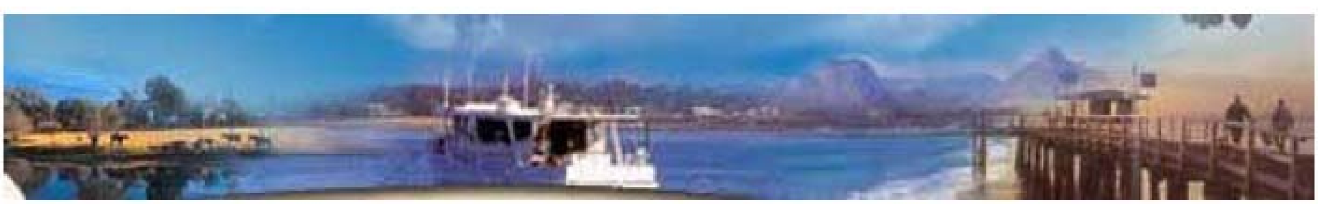
In March 1999 CabWater, a business unit of Caboolture Shire Council officially opened the South Caboolture Water Reclamation Plant (SCWRP)(See Figure 1). This plant was intended to provide high quality water for unrestricted non-potable use by large volume users such as local industry, sporting associations and schools via a dedicated recycled water distribution system. Treated water from the SCWRP meets the Queensland Department of Natural Resources Class A irrigation standard The intention is to eventually make the water available for unrestricted use. Consumers committed to using recycled water include industries such as tanneries, schools and local government

**Figure 1: South Caboolture Water Reclamation Plant**

## Environmental protection

A weir on the scenic Caboolture River (Figure 2) provides an impoundment for the Caboolture Water Treatment Plant. The section of the river below the weir receives little fresh water flow apart from high rainfall events. Tidal flushing of this section is poor. Consequently the middle section of the river is very sensitive to nutrient inputs. Water from the SCWRP is returned to the river if not recycled.

**Figure 2: The Caboolture River**



The two-stage process of Biological Nutrient Reduction wastewater treatment (BNR)(Figure 3) followed by the SCWRP ensures protection of the riverine environment from wastewater nutrients. Mean nitrogen and phosphorus levels of water discharged to the Caboolture River from January to July 2000 are found in Table 1 (Pipe-Martin, 2000). The reduction in nutrient load to the river has led to a measurable improvement in river water quality and an observable decrease in algal growth.

**Figure 3: The South Caboolture Biological Nutrient Removal Plant feeding the South Caboolture Water Reclamation Plant**

**Table I** Physical-chemical and microbiological parameters of treated water January to July 2000

ND - not detected

| Parameter | Mean | Max | Min |
|---|---|---|---|
| pH | 7.0 | 7.5 | 6.6 |
| Conductivity uS/cm | 823 | 914 | 519 |
| TDS mg/L | 576 | 640 | 363 |
| Turbidity mg/L | 1 | 10 | 0 |
| BOD5 mg/L | <3 | 3.6 | <3 |
| COD mg/L | 14 | 20 | 5 |
| Suspended Solids mg/L | <2 | 2.4 | <2 |
| Ammonia N mg/L | 0.05 | 0.26 | <0.01 |
| Nox-N mg/L | 1.25 | 2.38 | 0.57 |
| Total N mg/L | 1.8 | 3.5 | 0.7 |
| Total P mg/L | <0.3 | <1.5 | <0.2 |
| Coliforms cfu/100mL | 1 | 10 | ND |
| Faecal coliform cfu/100mL | ND | 6 | ND |
| *E.coli* cfu/mL | ND | 3 | ND |

## The Reclamation Process

The reclamation process uses effluent from the biological nutrient removal South Caboolture wastewater treatment plant as feed. The wastewater itself is mainly of domestic origin. The integrated physical-chemical/biological SCWRP process scheme is depicted in Figure 4.

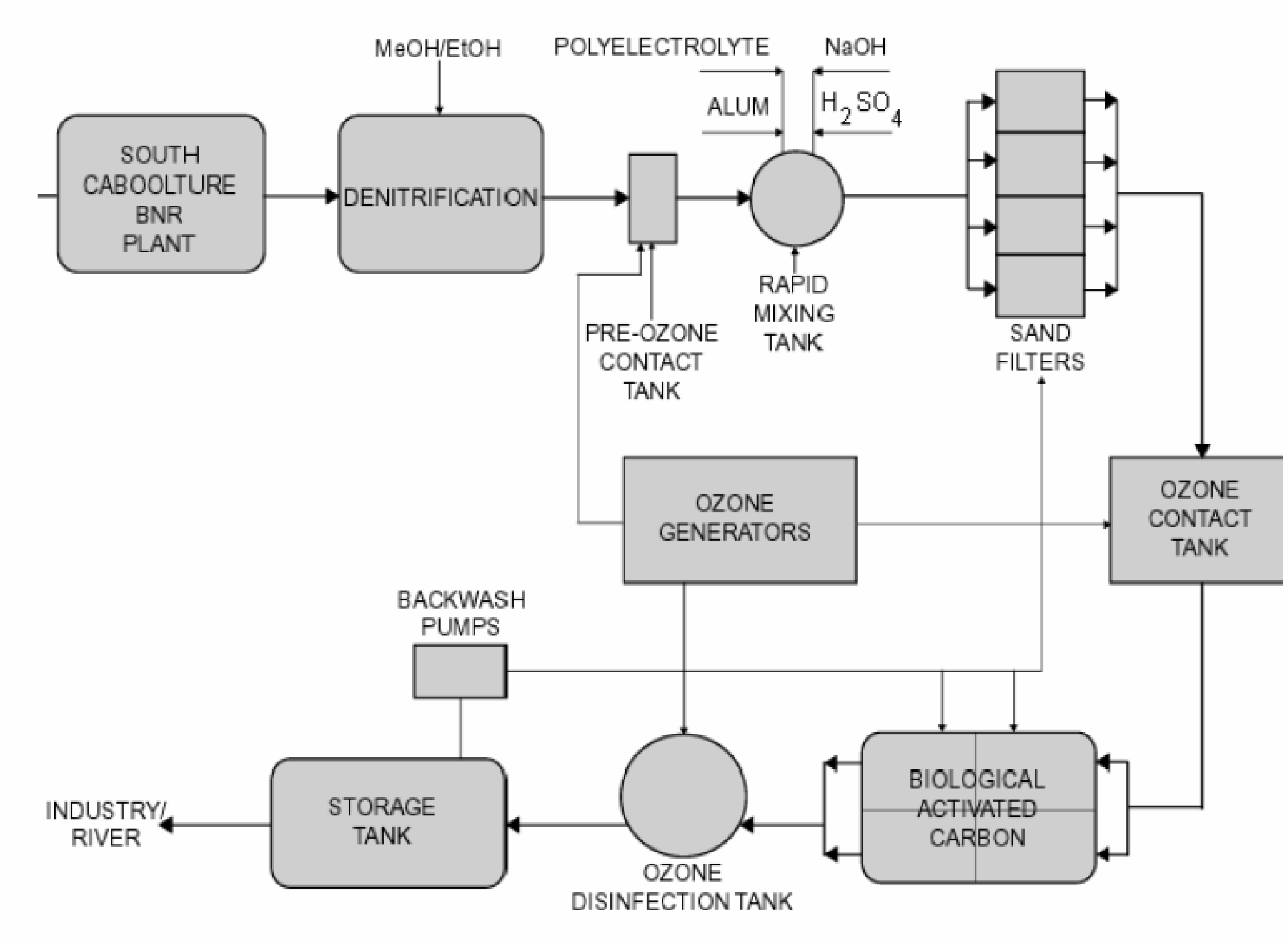



**Figure 4: The South Caboolture Water Reclamation Process**

### Denitrification

Most nitrogen enters the plant as nitrate as the activated sludge plant is a fully aerobic process. An anoxic suspended media biofilm reactor, with a retention time of 30 min is used for denitrification (Figure 5). Methanol was intended as a carbon source for the denitrifying organisms. The methanol dosage was automated linked to the nitrate concentration and averaged about 8 mg/L. Currently a waste ethanol product is used, diluted to 62% to give an equivalent C to methanol at lower cost.

### Coagulation/ Flocculation

Microflocculation of the denitrified water occurs after low level dosing with ozone, c. 2 mg/L. This aids subsequent aluminum sulfate coagulation and flocculation at an average dosage of 80 mg/L. Provision has been made for pH correction with either sodium hydroxide or sulfuric acid. Given that the water has a low alkalinity, it is normally required to dose 5-10 mg/L (as $CaCO_3$) of sodium hydroxide.


**Figure 5: Denitrification Process Unit**

## Flotation/ Filtration

Dissolved air flotation is used to remove the bulk of the alum flocs to the surface where the float is removed by periodic decanting (Figure 6). The clarified water flows down through a sand bed, at a rate of 6 $m^3 m^{-2} h^{-1}$ which removes the remaining flocs. The operator reports less effective flocculation when the ozone system has been off line. No evidence of heavy biological activity on the sand filters has been detected. Air-binding of the sand has not been reported. This unit has operated relatively trouble-free.

**Figure 6: Flotation-Filtration Process Unit**

## Ozonation

Ionics Watertec, now known again as Watertec Engineering, manufactured the Ozgen ozone generators. The feed to these three ozone generators, each of 3.0 kg/h is 90% oxygen from Oxygen Concentrators constructed with molecular sieve – activated alumina/zeolite columns (Figure 7). The alumina ensures a dewpoint for this mixture of -60C. Water driven Venturi type injectors have been used in all cases to introduce the 6% w/wozone. Ozone is applied at three points: before coagulation at c. 2 mg/L, ahead of the BAC columns at 9 mg/L, and finally at 2 mg/L for final disinfection after BAC. The larger dosage is applied for organic oxidation as well as disinfection. The residual ozone concentration at the exit of this contactor, with a residence time of 15 min, is approximately 1 mg/L. The ozone transfer efficiency of these units varies from 80 - 90%. Thermal-catalytic Ozgen units from Watertec Engineering are used for off-gas destruction.


**Figure 7: Detail photos of the ozone generation cells and the PSA oxygen concentrators**

Iron and manganese in the water are oxidized, causing their precipitation. Start-up issues with the ozonation occurred when a slug of water came into the plant with a very high dissolved manganese concentration. Lesser slugs occur when the plant has been shut down and restarted. These could be due to the feed water to the plant becoming anaerobic during shutdowns and subsequent reduction and dissolution of manganese from the influent pipework and suspended solids. The soluble manganese is oxidized and precipitated mainly as colloidal $MnO_2$ in the main ozonation tank. The BAC filters then remove the colloidal manganese. Biofilm growth in the cell cooling water jackets was an initial concern although it did not appear to cause any complications with the generation cells. Chlorination of service water to the ozone cells was installed as a precaution and found to be effective.

## Biological activated carbon

The four open gravity biological activated carbon beds used in parallel have a depth of 2.2m and an empty bed contact time of 18 min (Figure 8). The total surface area of the beds is $13m^2$. The activated carbon used is coal based provided by James Cummings & Sons Pty Ltd in Sydney, Australia, type MWD4050CB with a specific surface area of >1000 $m^2$/g. This carbon was chosen for its high proportion of mesoto micro-pores, density and abrasion resistance (hardness >85%). It has a mesh size of 8/30 ASTM, with a uniformity coefficient of 1.6.

The backwash frequency was 12 to 24 hours and backwashing is performed at a rate of 130L/s resulting in an upflow velocity of 0.01m/s or 36 m/h following 60 seconds air scour. Extending the air scour to 120 s has been found to allow backwash intervals to be increased to 36 hours. This reduces losses resulting from abrasion.


**Figure 8: BAC Unit Process**

The activated carbon filters host bacteria, which remove oxidized organic compounds. After two years of operation, this process is still working well, with minimal losses due to attrition. Projections are that topping up by around 10% will be required after 3 to 5 years. While the COD seems to have stabilized around a mean of 12.8 mg/L in the effluent, this is higher than the value at start-up of around 5 mg/L. This is probably due to gradual GAC exhaustion. A criterion of 25% COD removal by the combined action of ozone and BAC was used on the Stander water reclamation plant in South Africa as an indication of GAC exhaustion.

While operating under this criterion, no substance of concern (such as pesticides or high disinfection by-products) was ever detected during an intensive sampling program. Table II shows COD removal data throughout the process. The mean filter effluent COD is 20 mg/L and this is decreased on average to 12.8 mg/L, i.e. a 36% removal, indicating an acceptable COD removal and probably no need for GAC regeneration.

## Disinfection

Final disinfection is achieved by ozonation at 2 mg/L, leaving a residual of 0.5 mg/L. This has been shown to be effective against protozoa, bacteria and viruses (See Table III). No viruses or protozoa have been detected in treated water. There have been occasional low-level breakthroughs of indicator bacteria associated with particular events on the plant. The design brief included that the product water was to meet the National Health &Medical Research Council's Australian Drinking Water Guidelines for potable water. This objective has been met with the exception of some *E. coli* counts resulting from too high an ozone demand due to manganese build-up during periods of non-operation for maintenance. This can be overcome with stand-by ozone generators.

**Table II** COD removal throughout the process

| Date in 2000 | Influent | MBBR Effluent | Flofilter Effluent | Final treated water |
|---|---|---|---|---|
| 10 July | 55 | 60 | 25 | 10 |
| 17 July | 34 | 39 | 24 | 10 |
| 25 July | 29 | 38 | 34 | 14 |
| 01 August | 29 | 39 | 20 | 15 |
| 08 August | 29 | 33 | 19 | 14 |
| 15 August | 38 | 33 | 29 | 10 |
| 22 August | 28 | 37 | 14 | 9 |
| 05 September | 24 | 29 | 19 | 10 |
| 12 September | 30 | 50 | 15 | 15 |
| 19 September | 23 | 33 | 9 | 9 |
| 26 September | 38 | 43 | 24 | 14 |
| 03 October | 19 | 33 | 19 | 14 |
| 10 October | 34 | 39 | 20 | 24 |
| 24 October | 44 | 34 | 20 | 15 |
| 31 October | 44 | 39 | 15 | 15 |
| 07 November | 29 | 34 | 15 | 10 |
| 14 November | 29 | 34 | 20 | |
| 21 November | 60 | 35 | 20 | 10 |

Sodium metabisulfite is dosed at 3mg/L prior to storage to avoid corrosion of the reservoir roof. When reuse of treated water commences, chlorine will be dosed to provide residual action against bacterial re-growth. Chlorination facilities are being installed on the outlet of reservoir.

**Table III** Pathogens January to June 2000 (Pipe-Martin, 2000)

ND not detected

| Organism | No. of tests | Filtered Water | | Disinfected Water | |
|---|---|---|---|---|---|
| | | Mean | Max | Mean | Max |
| Faecal coliforms Cfu/100mL | 24 | 1142 | 7200 | ND | 6 |
| Giardia Cyst / 10L | 19 | 1.3 | 4.2 | ND | ND |
| Cryyptosporidium Cyst / 10L | 19 | 0.6 | 2.2 | ND | ND |
| Reovirus / L | 3 | ND | <0.05 | ND | ND |
| Adenovirus / L | 3 | 0.7 | 2 | ND | ND |
| Enterovirus / L | 3 | ND | ND | ND | ND |

## OPERATIONAL ISSUES

### Water Quality

An intensive three-year monitoring program is being conducted to assess the performance of the plant and its unit processes. Monitoring includes physical chemical determinants, heavy metals, indicator bacteria and specific pathogens such as the protozoa *Giardia* and *Cryptosporidium* and a suite of viruses. Figure 9 summarizes some of the more important quality indicators as the water passes through different key unit processes.

### Use of ozone

Occasional difficulties have been experienced operating a plant with ozone disinfection only, due to the lack of sufficient residual action at times. However, in all cases this has been found to be due to re-dissolution of manganese, which does not occur during continuous operation. Interruption of ozone generation results in clear water reservoir contamination, which persists until the contaminated water has been replaced. Chlorination will be provided in the reuse distribution system to control bacterial re-growth but cannot be dosed to service water.

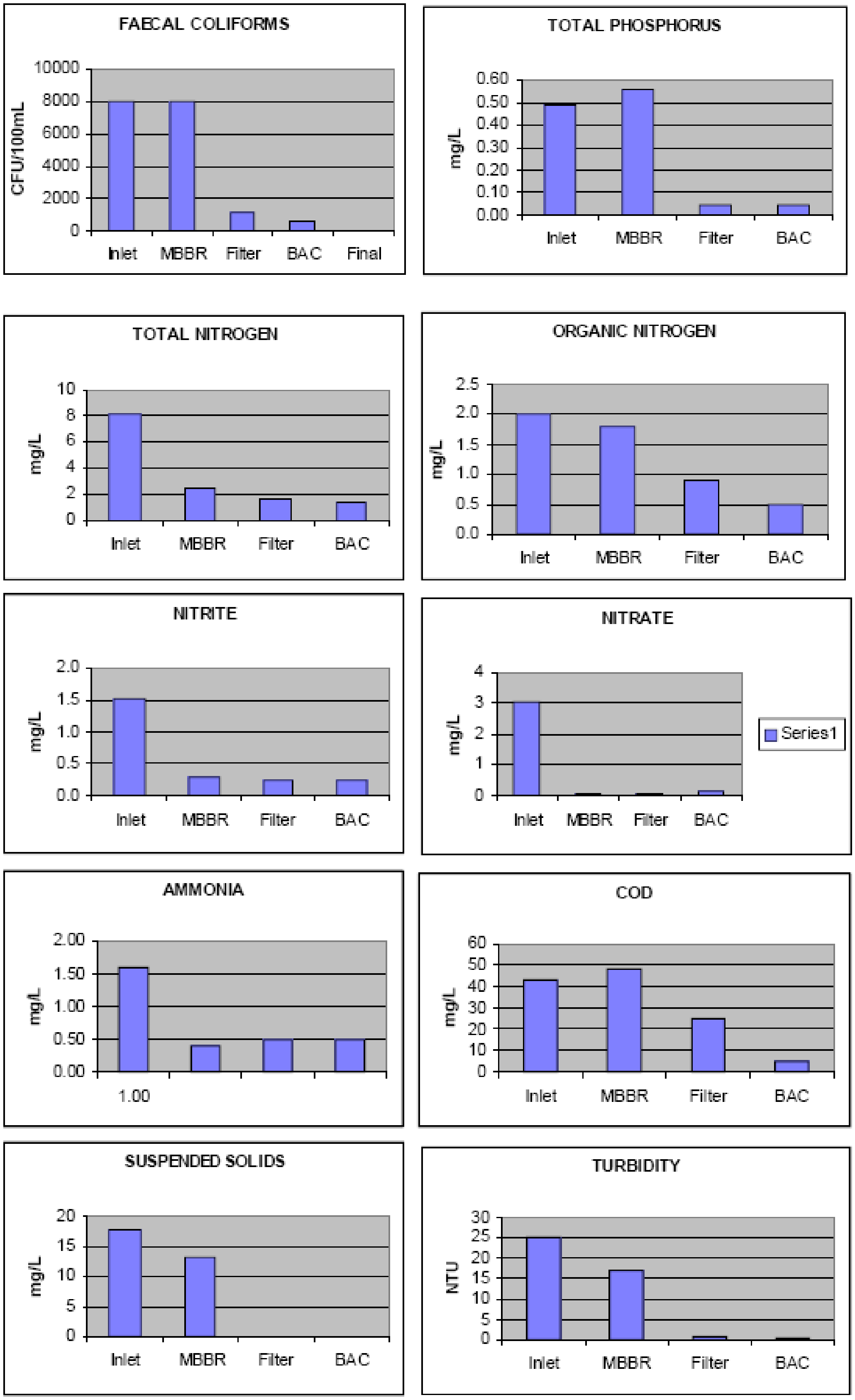



**Figure 9:** Typical treatment indicators through different unit processes during commissioning

Precipitation of iron and manganese after ozone contact has affected operation of the plant. Head loss and solids breakthrough in the BAC filters have occurred during high loadings. Breakthrough has contaminated service water causing deposition of solids in the ozone generation cells.

## Water aggressiveness

The plant was off line for seven months due to concrete corrosion problems. All wetted surfaces of the plant were showing softening or erosion of 2 - 5mm. This problem has also been noted on some of the other local wastewater and water treatment plants and does not appear to be specifically related to any of the reclamation plant operations (e.g. ozone). The water has been shown to be undersaturated with respect to calcium carbonate with the pH lower by around 0.8 units than the saturation pH. The shutdown was used to apply all wetted surfaces with a polymer coating.

## Attitudes

Despite all testing and a requirement that reclaimed water is used for non- potable purposes only, State EPA and Health dept. are still trying to apply restrictions to use. This appears to be a mindset, which will only change after some projects are in use and initial public reaction and litigation fears are overcome.

It has become apparent that a change in attitude is required when reclaiming water for reuse. During plant design, the emphasis was on removal of wastewater contaminants. Consequently, issues such as iron and manganese precipitation were not considered. These “water supply” issues are critical to efficient operation of the plant and consumer perception of the product. Designers, managers and operators must recognize that they are supplying water to consumers and not disposing effluent. Whilst quality might be suitable, the consumers may not want to purchase the water if it is recycled.

Community education will be required to make people aware of all the issues associated with using recycled water and to encourage its use. The design, operation and monitoring of the plant must address water quality issues as well as removal of traditional wastewater contaminants.

## Production costs

Operating cost of the recycling process is $Aus151/ML, i.e. Aus$ 0.15/m$^3$ or about US$0.33 per 1000 gal. Capital amortization over 20y at 7%/y interest, will amount to another Aus$200/ML or c. US$0.42/1000 gal. Consumers will be charged a two-part tariff equivalent to $300/ML, less than half the cost of potable water, on completion of the recycled water mains.

## Conclusions

The Caboolture process, with its unique integrated physical-chemical/biological treatment has proved to be cost-effective. The biological unit operations within the process ensure continuous sustainable production with low operational and chemical cost. Some demineralisation (denitrification) is achieved biologically and expensive activated carbon life is prolonged almost indefinitely also by biological means. Water can be supplied well below the cost of water from conventional sources. Minor operational problems have been overcome and the experience will be valuable for further implementation of this approach to water reclamation.

Industrial water recycling using effluent or effluent that has been provided with enhanced treatment is not widely practical in Queensland. Nevertheless, a number of significant projects have emerged over the last few years, whereby there has been some financial benefit gained by the use of recycled water. With the cost of source water increasing, and the cost of treatment reducing, it is expected that industrial reuse will increase. Increased industrial reuse would be encouraged if water-using industries were encouraged (through planning incentives) to locate in areas close to wastewater treatment plants.

Long established prejudices about the source of the water still need to be overcome, but the successful operation of the plant to date will go a long way in overcoming these cultural barriers.

**Figure 10: One of the researchers demonstrates his confidence in the SCWRP by consuming the end product**

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