WaterWorks

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WATERWORKS
OFFICIAL JOURNAL OF THE WATER INDUSTRY OPERATORS ASSOCIATION OF AUSTRALIA

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OPTIMISATION OF SINGLETON IDEA STP

ASM Mohiuddin

Singleton (population 22,694) is the Local Government Area of Hunter New South Wales, with 15,100 people connected to council sewerage services.

Singleton Sewage Treatment Plant (STP) has two Intermittent Decant Extended Aeration (IDEA) tanks with a capacity of 10000 EP each. Sewage delivered to the treatment plant flows into a balance tank and is then distributed equally by two parallel flumes to two aeration tanks. There are three surface aerators in each tank. The plant was commissioned in 1998.

Each aeration tank runs aeration for 60 minutes, settling for 60 minutes, followed by 30 minutes decant. After decanting from the aeration tank effluent flows to one-day retention catch ponds and then to nine-day retention tertiary ponds before finally being discharged to Whittingham Swamp.

Waste Activated Sludge (WAS) is pumped into sludge lagoons during the aeration phase. Supernatant water from sludge lagoons is returned in one of two ways. From two of the lagoons it gravitates back directly to the aeration tanks. The third lagoon has a supernatant pump station, which was programmed to run at night during the off-peak of sewage inflow. The pumped flow is also returned directly to the aeration tanks.

Optimisation Steps

Supernatant Water Quality

During optimisation of the process in 2011, it was noticed that the supernatant water returning to the process was black in colour. After inspection it was found that the three sludge lagoons were full of sludge (Figure 1) and were continuously returning black sludge to the process.

So the first action in the process optimisation was to stop the supernatant return. Two sludge lagoons were then isolated, completely desludged into the drying beds and the lagoons were cleaned and repaired. The third sludge lagoon was desludged enough (1.0–1.5m) to accommodate more WAS and produce clear supernatant water after sludge settling in the lagoon.

Sludge Blanket Depth

Before optimisation, the sludge blanket level prior to decanting was much higher than the design of 1000mm. As a result, when the decanters were lowered sludge was drawn into the final effluent. This high level was due to sludge being continuously returned from the sludge lagoon.

Even with the WAS pumps running for 85–90% of the aeration time the sludge

Figure 1. Sludge can be seen breaking the surface in one of the sludge lagoons near the point of supernatant return.

OUR COVER

Technical Officer Paul Grogan operates a newly developed portable disinfection unit for disinfecting mains after mains breaks and newly installed mains.

blanket level could not be reduced. As a result effluent water was carrying sludge while decanting. When the sludge lagoons were isolated and the supernatant water quality improved, the WAS pumps were easily adjusted to waste enough sludge, and the sludge blanket was maintained at around 1000mm before decant. With maintaining the sludge blanket level at 1000±50mm before decant, it was observed that effluent decanted is very clear and no sludge carry-over occurred.

Mixed Liquor Suspended Solids (MLSS)

During process optimisation in 2011, the optimum mixed liquor suspended solids (MLSS) concentration was found to be 3500 ±100mg/L in the aeration tanks. Maintaining this solids level helps to maintain the optimum sludge blanket depth of 1000±50mm and results in a clear effluent.

Before the optimisation, the target MLSS value could not be maintained for the same reason as that described for having a higher sludge blanket level (< 1000mm), i.e. sludge was being returned with the sludge lagoon supernatant. After cleaning the sludge lagoons, sludge wasting was easily adjusted to maintain the optimum MLSS value of 3500±100 mg/L.

WAS Pump Run Time Adjustment

Since wasting occurs during the aeration stage of the IDEA cycle, the maximum run time available for the WAS pump was the total aeration time of 60 minutes. Prior to the desludging of the sludge lagoons, this wasting time was not enough to achieve the target sludge blanket level or the optimum MLSS. But after cleaning the sludge lagoons, the WAS pumps were adjusted to run for 50–60% of aeration cycle time or even less, which resulted in easily maintaining the required sludge blanket depth and MLSS. It was decided to adjust the WAS pump run time every day to maintain exactly the optimum sludge blanket level of 1000 ±50 mm and optimum MLSS of 3500±100mg/L.

Solid Retention Time (SRT)

Each aeration tank has the volume of 4432m^3 at Bottom Water Level (BWL). After process optimisation, 200±20m^3 of mixed liquor was wasted each day, giving a solids retention time (SRT) of 20 to 25 days. The WAS pumps operate at 10L/s and there are 10 operation cycles per day (60 minutes aeration, 60 minutes settling and 30 minutes decanting), and the pumps now run for 50–60% of the aeration stage to achieve the required SRT.

Decant Float Water Adjustment

The decanters were designed for a maximum loading rate of 21L/s.m. Each aeration tank has three decanters, two with a weir length of about 9m and one of 6m (total length is 24m). Each decant unit incorporates a weir plate and full-length stainless steel floats. When the decanters are lowered, as soon as the floats hit the water surface, travel of the weirs is arrested and the whole unit floats in the water. From then the water level of the tank will be lowered slowly according to the flow rate over the weirs.

In the case of too low water ballast, flow over the weir was minimal resulting in a higher load on the rest of the weirs eventually causing sludge carry over. Alternatively, if the water ballast was too high, the decanters sank into the water resulting in higher loading rates and sludge carry over.

The water ballast of all the decant floats were, therefore, adjusted to have the top surface of the floats about 25–30mm above the water surface while decanting.

Figure 2. The clean decant water after optimisation.

Adjustment of the water ballast of decant floats resulted in uniform and clear effluent flow while decanting.

Figure 2 shows the outcome of the optimisation, which indicates clean decanted water with uniformly floating decant floats and no sludge carry-over.

Aerator Cleaning

Three floating surface aerators are provided in each aeration tank. The standard oxygen transfer rate (SOTR) to each tank is 143kg O_2/h. The Singleton STP does not have any inlet screen to remove the rags in the wastewater. Inspection of the system in 2011 revealed the aerators had an accumulation of rags, which significantly reduced the efficiency of the aerators. Excessive vibration of the aerators was also noticed during operation. A program was established to clean the aerators every week, which significantly improved their performance and provided sufficient oxygen for nitrification and oxidising carbonaceous materials, thereby reducing effluent BOD.

Figure 3. The pump station lime dosing system – SSC operators Gary (L) and Keith(R) manually placing lime in baskets.

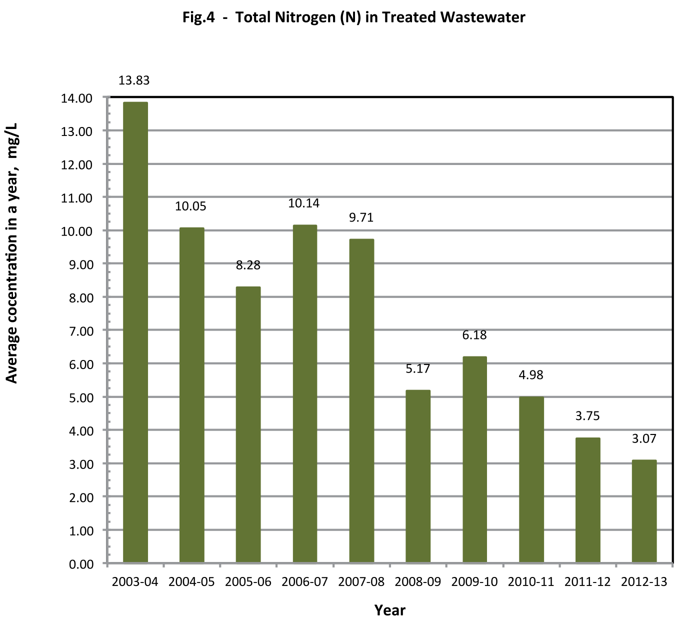

Figure 4. Total Nitrogen results for the Singleton STP from 2003 to 2013.

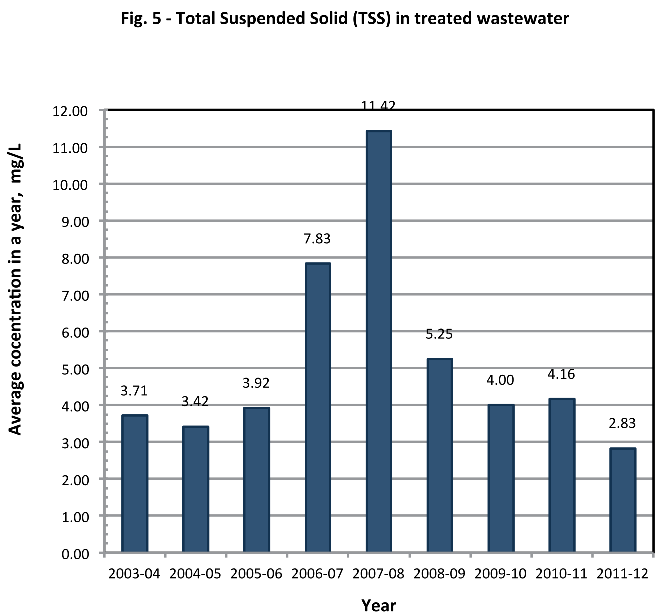

Figure 5. Total Suspended Solids (TSS) results for the Singleton STP from 2003 to 2012.

pH Adjustment

Testing of the raw sewage showed that pH is sometimes below 7.0. As pH below 7 adversely affects nitrification, a decision was made to manually put 5 x 25 kg bags of lime in three pump stations baskets twice a week (Figure 3).

Based on the average flow of 3ML per day, the lime dosing rate is approximately 11–12mg/L. The average pH over the last nine months has averaged 7.1 (range 7.0 to 7.3). In addition to aiding the nitrification process, lime dosing has improved sludge settleability in the aeration tanks.

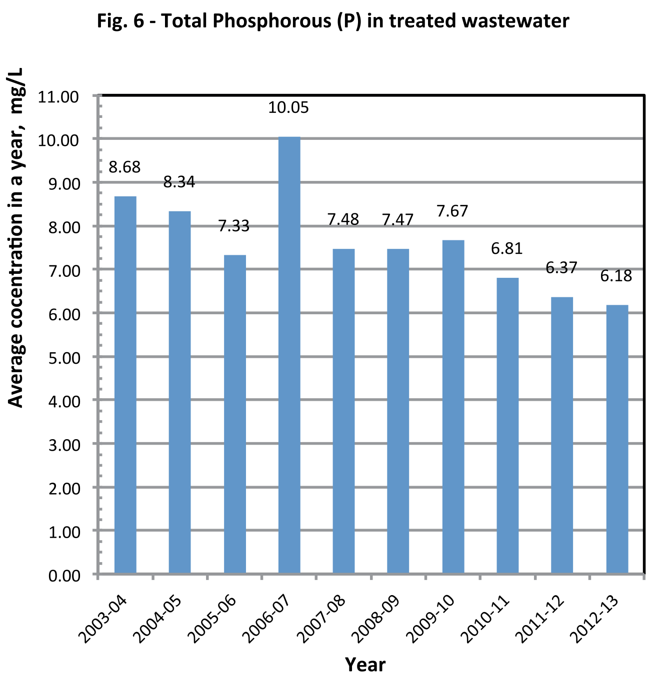

Figure 6. Total Phosphorus in the treated wastewater.

Plant Performance After Optimisation

Total Nitrogen

Before the optimisation, the average Total Nitrogen concentration was above 5mg/L and from 2003 to 2008 it was, in fact, above 10mg/L. The Total Nitrogen in the effluent has significantly improved since optimisation with an average concentration of 3.75mg/L in 2012–2012 and 3.07mg/L in 2012–13 (up to February 2013) (Figure 4).

Biochemical Oxygen Demand (BOD)

The average BOD in 2012–2013 (up to February 2013) was 2.0mg/L. This contrasted to an average BOD before optimisation of 4.0mg/L.

Total Suspended Solid (TSS)

Similarly TSS in the effluent improved, from above 4.0mg/L to 2.8mg/L (Figure 5). Maintaining optimum sludge blanket level, improving sludge settleability by adding lime bags, and water ballast adjustment of decant floats directly affected effluent TSS reduction.

Total Phosphorus

After process optimisation, in 2011–12 the average concentration of total phosphorus was 6.4mg/L (Figure 6) and in 2012–13 (up to February 2013) the average phosphorus concentration is 6.2mg/L, whereas in previous years it was in the range 7.5–10.0mg/L. The EPA licence limit for this treatment facility for phosphorus discharge in effluent is 15mg/L.

Higher phosphorus removal has been achieved by optimised lime dosing at the pump stations. Lime increases the pH of the inflow and helps biological phosphorus removal process. Stopping the sludge return from sludge lagoons also helped to reduce the phosphorus emission with effluent.

Singleton IDEA has not been designed for phosphorus removal. Higher phosphorus removal has been achieved by above process optimisation, as an additional benefit of reducing Total N, BOD and TSS.

The results of the optimisation program have been clearly demonstrated in the clarity of the final effluent and the improved nutrient and solids removal.

The Author

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PERISHER BLUE IMPROVES WASTEWATER TREATMENT

Michael O'Rance

Every winter thousands of holiday-makers visit the snowfields in New South Wales. Many skiers choose to park at the Perisher Ski Tube terminal and catch the train up to their favourite ski resort such as Perisher Blue or Blue Cow. Then every afternoon they return on the train back to the Ski Tube car park.

Oblivious to the excited skiers are the Perisher staff working behind the scenes to treat the sudden inflows of wastewater from the various toilet amenities and keep their sewage plants (Figure 1) operating at maximum efficiency.

Our intermittently decanted extended aeration (IDEA) treatment plant is unusual in that we have to feed the plant in summer, as we only have a handful of maintenance staff on-site. As we enter the ski season, we receive peak flows and loadings just as our temperature drops in our aeration tank. It's not uncommon to go for 12–14 weeks with temperatures of 7°C or below.

The plant has a small sludge digester of only 12kL capacity, and this used to require pumping out and disposal off-site every two to three weeks during the ski season and a couple of times in the summer as well. The cost of this was constantly rising, and it was becoming increasingly difficult to find someone to accept the waste, usually being tanker-trucked from Jindabyne up to Goulburn.

An opportunity arose to trial *For Earth Bio* additive to help break down the sludge in our digester. This proved to be very successful and we now pump out once per year, and only in summer, when we schedule in routine maintenance and drop all the tanks for annual cleaning and inspections. Based on this success we have continued to use the product now for three years.

The supernatant from the digester is pumped back to an inlet well and then into the aerated balance tank. While most is clear liquor, there is some light, thin sludge that does get returned to the head of the works. This has actually worked out to be a benefit, as it seeds the influent with fresh bacteria, which in turn has kept ammonia levels in the balance tank to around 40mg/L, compared to readings prior to dosing the additive of 60+mg/L, and peaks of over 80mg/L. This has reduced the ammonia loading on the aeration tank.

Another way the *For Earth Bio* product is utilised is for seeding the plant in the lead-in to the ski season. Previously, two loads of sludge from another treatment plant in the area would be brought in. This incurred the cost of having a tanker truck pick up and deliver the sludge. We now wait until the opening weekend of the ski season and dose up the aeration tank with the additive. This has worked very well, and it is cheaper and safer than relying on an outside contractor.

The vast majority of our influent comes from toilet blocks and there is very little domestic waste flowing to the plant. This, combined with extreme cold temperatures in the aeration tank, has meant that in the past there have been problems with ammonia levels not reducing sufficiently. Dosing with *For Earth Bio* over the aeration tank during the air-on period has been of great benefit. If there are spikes in the ammonia levels, usually 1–2L dosed over the treatment tank is enough, and on testing the next day there is normally a significant drop in the reading. Sometimes it may require ongoing dosing over a few days, or an increase in the amount dosed to get the level right down to satisfactory levels.

Figure 1. Perisher Blue STP in summer.

The Author

Michael O'Rance was a Waste Water Treatment Plant Supervisor at Ski Tube, Perisher Blue, at the time of the trial.

FULL WASTEWATER RECYCLING INSIDE ANZ BUILDING

Glen Millott & Peter Zauner

Four years ago an 80kL/d wastewater recycling plant (Figure 1) was commissioned in the new global headquarters building for ANZ Bank at Melbourne's Docklands precinct. The plant captures, treats and recycles all sewage and greywater generated daily by the building's approximately 6000-strong workforce and provides the recycled water for flushing and cooling tower top-up.

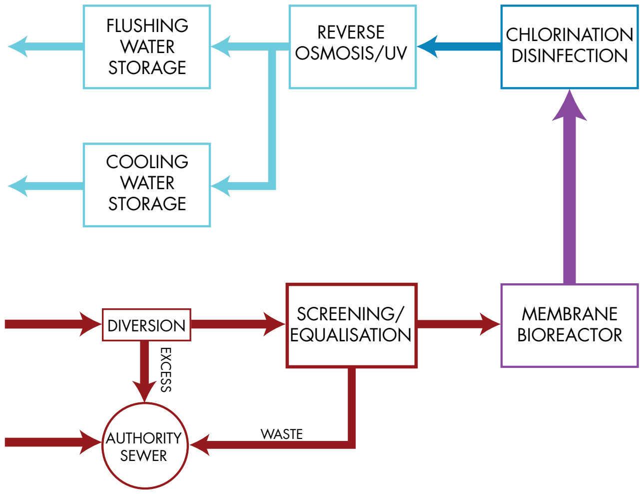

Figure1. Process Flow Diagram.

Wastewater collected from inside a building differs considerably from normal domestic sewage received at an STP. Typically the influent has concentration levels three to four times higher for most constituents. Additionally, designing a waste treatment plant inside a city building poses space and access constraints.

The plant is installed over two basement levels located directly under the expansive atrium of the building (Figure 2).

Figure 2. The ANZ building atrium.

The limited height of the plant room required a membrane tank with side access to the membrane modules (Figure 3).

In addition, the membrane tank is sealed at the top to prevent potential release of odours. To allow visual checks of the tank level, Perspex panels were installed. These require sprays to maintain visibility (Figure 4).

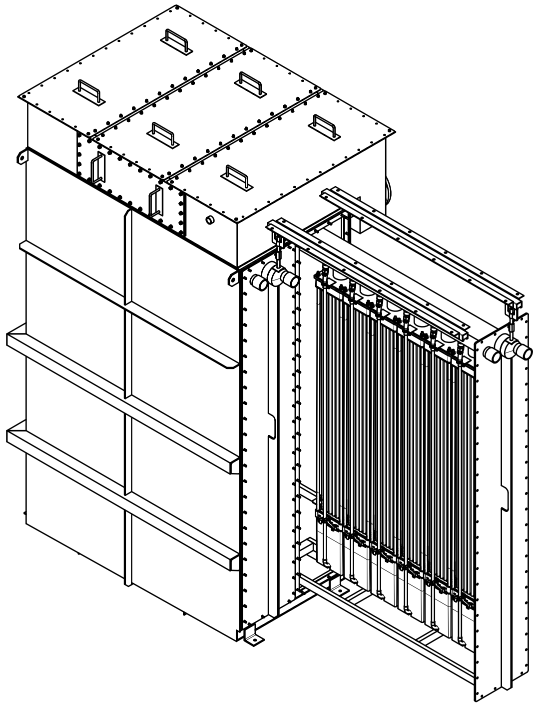

Figure 3. The membrane tank.

Figure 4. Membrane tank covers and sprays.

Chlorine contact time to achieve log-4 removal by chlorine disinfection is provided in a plug-flow contactor using several lengths of pipe snaking along the plant room wall (Figure 5).

Magnesium Hydroxide is used for pH adjustment in the bioreactor simply because it is safer to deliver and use at such a site.

WAS and screenings are automatically removed to the authority sewer.

Figure 5. The space-saving snake chlorine contactor.

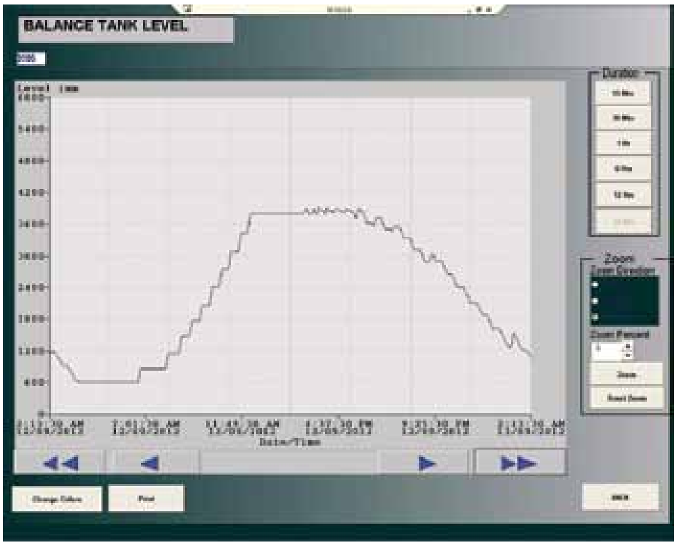

Figure 6. Level trend of the balance tank over a typical 24-hour period.

Redundancy requirements for each piece of equipment were examined during the design process. In many cases, a practical decision was made to utilise the system diversion and backup systems. As a result, there is no redundancy for MBR membranes. However, critical items such as aeration blowers and bioreactor pH controls have backup. The balance tank can store 14 to 16 hours of wastewater volume.

Modifications to the plant design were necessary after the process tanks were constructed to accommodate an increase in water to be treated due to an increased population to be served. Fine-tuning of the influent balancing system was undertaken with the result that now the entire treatment train typically starts up around 10am and runs continuously until the late evening. The absence of repeated stops/starts is beneficial as it minimises the number of required flush cycles of the RO system and, therefore, increases the plant's overall recycled water production, improves the operation of the UV system, and extends lamp and ballast life.

In the absence of suitable validation guidance in Victoria at the time, in 2010 a 12-week validation period was carried out in accordance with *Interim NSW Guidelines for Management of Private Recycled Water Schemes*. During this period, the plant was shown to conform to requirements for removal of viruses and protozoa. BOD, TKN and TP removal efficiencies were all greater than 99%. The UF MBR membrane had been independently validated at LRV 4.0 for bacteria and LRV 3.0 for viruses.

This performance, and the fact that black water is being recycled, contributes to the building reaching a Six-Green-Star-Certified Rating, as certified by the Green Building Council of Australia (GBCA).

Operational Experiences

The plant operates automatically with remote monitoring and regular visits by operators for routine maintenance.

Plant access for operators is via a defined access procedure that initially might appear onerous. The building's Facilities Management and Security have access control requirements to ensure only appropriate personnel access site plant rooms. For example, all inductions, Safety Management Plans, Work Permits and current insurance certificates have to be in place before access is granted. Security's role includes identity confirmation and accountability for building keys.

Site management has specifically re-organised the car park spaces to enable ute access to the upper level plant room. This allows operators to deliver chemicals and carry necessary tools and equipment on-site during the maintenance activities.

There are strict controls on noise or odour emissions. Any activities likely to disrupt the tenants have to be undertaken outside working hours. As the plant room is located in the building's basement car park level, tenants or contractors might be driving or walking past the plant room doors at any time. The release of odours would be a major event in this building.

The building's facility management staff perform daily basic checks on pump flows, reagent levels on water chemistry instruments, DO, RO system faults and UV system faults and complete a checklist. In addition, facility management staff monitor alarms 24/7 with clear protocols on how to respond to each alarm.

Via a fully replicated HMI, WJP Solutions (WJPS) have full remote access to the plant's control system in their office where a total of eight (soon nine) similar plants are monitored, some in Melbourne, some interstate.

Operators attend the plant for an average of four hours a week, typically during two separate visits, for routine operation.

During routine visits, they carry out the following tasks:

- Deliver chemicals;
- Check critical equipment such as flow switches, look for leaks, unusual noises, etc;
- Check the operation of the drum screen;
- Review trends on HMI;
- Document all findings in a weekly checklist.

One of the most important chemical deliveries to the plant room is Magnesium Hydroxide for pH control. This chemical is typically delivered in large batches and there is no truck access to the plant room. To make this procedure more efficient, one of the service utes was modified to include a bulk chemical delivery tank and a pump to transfer the chemical directly to the on-site storage tanks. The service vehicle is now able to be positioned very close to the plant room entrance to reduce risks associated with chemical handling and transfer.

Chemical cleans of membrane equipment: Maintenance cleans and CIPs are automated sequences but are performed when operators are on-site. For CIPs, operators bring the required chemicals to site for the day.

Calibration of water chemistry instruments and Membrane Integrity Tests: These specific tasks are carried out in dedicated visits once a month.

Should routine integrity tests on the hollow fibre MBR membranes detect higher than allowable pressure decay rates, a "pinning" process would be used. In four years of operation this has never been required. However, equipment is in place to perform this task out on-site. For this, the membrane tank will be drained and rinsed, and access to membrane modules will be gained via an access hatch on the membrane tank's front. Either of the racks, holding five membrane modules each, can then slide out of the tank on a rail giving access to the membrane modules and allowing their removal (refer to Figure 3). A pinning vessel – brought to site for this purpose – will then be used to identify any broken hollow fibres and isolate individual fibres permanently by forcing a pin into the fibre's lumen.

Breakdown maintenance

WJPS have a call-out facility to physically respond to critical alarms if required. During planned or unplanned plant shutdowns, the balance tank can store 14 to 16 hours of wastewater volume. If the shutdown were to exceed that, the building's greywater and wastewater would automatically be diverted to the authority sewer.

Figure 7. Site Supervisor Rob Zukowski.

Lessons learned

During design, commissioning and four years of operation a number of lessons have been learned:

- Operating a wastewater plant in the basement of a building differs from operating an above-ground plant. Advantages include the fact that operators and equipment are sheltered from the environment and operate at constant temperature. The compact arrangement of all process units means that everything is in close reach for the operator. Some pieces of equipment, such as the membrane tank and the plug-flow chlorinator, had to be specifically designed for the space, but all these modifications have proven effective.
- An intimate knowledge of commercial building operations and dynamics is required for the successful design and implementation of such a recycling plant.
- Great importance should be placed on system tuning to maximise water efficiency.
- The chosen multiple-barrier approach, including the removal of salt and hardness, is considered best practice for cooling water.

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OPTIMISE CHLORINE CONTACT TANK PERFORMANCE

Jonathan Church & Jason Colton

When water flows through a chlorine contact tank or reservoir the theoretical detention time (TDT) can be calculated by dividing the volume by the flow rate:

$$\text{TDT [min]} = \frac{\text{Volume [m}^3\text{]}}{\text{Flowrate [m}^3\text{/min]}}$$

The TDT calculated in this way is a gross simplification because it assumes perfect plug flow conditions and that every bit of space in the tank is used equally. In reality this is far from the case. Short-circuiting and dead zones in the tank result in the actual contact time being significantly less than the TDT. Reduced contact time can have a big effect on the efficacy of the disinfection process. This is addressed in the *New Zealand Drinking Water Standards* (DWSNZ2008) by the requirement that a contact time of not less than 30 minutes *taking into account short-circuiting* is provided. There are no such provisions in the *Australian Drinking Water Guidelines*.

The widely accepted method for quantifying reduced contact time is by determining the T_{10} contact time. The T_{10} contact time is defined in the *USEPA Guidance Manual for Disinfection Profiling and Benchmarking* (2003), as the minimum detention time experienced by 90% of the water passing through the tank. Another way of looking at it is that only 10% of the water experiences a detention time of less than the T_{10} contact time, while 90% experiences more.

There are three methods available to water suppliers to determine the T_{10}. The first is by using a baffle factor, which is a gross simplification. The second is by using tracer testing, which is laborious; and the third is by using computational fluid dynamic (CFD) modelling.

Baffle Factors

The T_{10} can be estimated by using a baffle factor. This factor is the ratio between the T_{10} for a particular tank and the theoretical maximum detention time of that tank.

$$T_{10} = \text{Theoretical Detention Time (TDT)} \times \text{Baffle Factor}$$

A list of baffle factors and the corresponding baffle design is provided in Table 1.

So for a tank with no baffles and a single inlet and outlet, the baffle factor would be 0.3. If the TDT were, for example, 40 minutes the T_{10} would be 40 x 0.3 = 12 minutes.

Table 1. Baffle factor definitions (taken from *USEPA Guidance Manual for Disinfection Profiling and Benchmarking*).

Contact Tank Type	Tank Description	Baffle Factor
Un-baffled (mixed flow)	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities. Can be approximately achieved in flash mix tank.	0.1
Poor	Single or multiple un-baffled inlets and outlets, no intra-basin baffles.	0.3
Average	Baffled inlet or outlet with some intra-basin baffles.	0.5
Superior	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders.	0.7
Perfect (plug flow)	Very high length to width ratio (pipeline flow), perforated inlet, outlet and intra-basin baffles.	1.0

Tracer Testing

Tracer testing can be used to determine a T_{10} experimentally. Tracer testing is where a chemical is added to the water entering the chlorine contact tank and the change in concentration at the exit of the tank is measured over time. The shape of the resulting concentration versus time graph provides insight into the amount of short-circuiting and dead zones within the tanks and actual T_{10} and baffle factors can be determined.

There are two methods of tracer testing: the slug-dose method and the step-dose method. The easiest method to use is usually the step-dose method, since chemicals that are already in use on the plant, for example fluoride, can be used as the tracer. In the step-dose method a tracer chemical is dosed at a fixed dose until the concentration at the exit of the tank reaches a steady-state level (the concentration dosed).

Note that if fluoride is used as the tracer it will need to be turned off for a number of hours prior to initiating the step dose. A graph of the ratio tracer concentration at the exit of the tank (C)/dosed tracer concentration (C_0) vs time is plotted and from this the T_{10} can be identified (Figure 1). So when the tracer first appears, the concentration will be much lower than the dosed concentration – i.e. the ratio will be very much <1. As time passes and the concentration measured at the exit point increases, the ratio will gradually increase and approach 1.0. When the measured concentration is the same as the dosed tracer concentration, the value of the ratio will be 1.0. This type of graph is also known as cumulative distribution function curve.

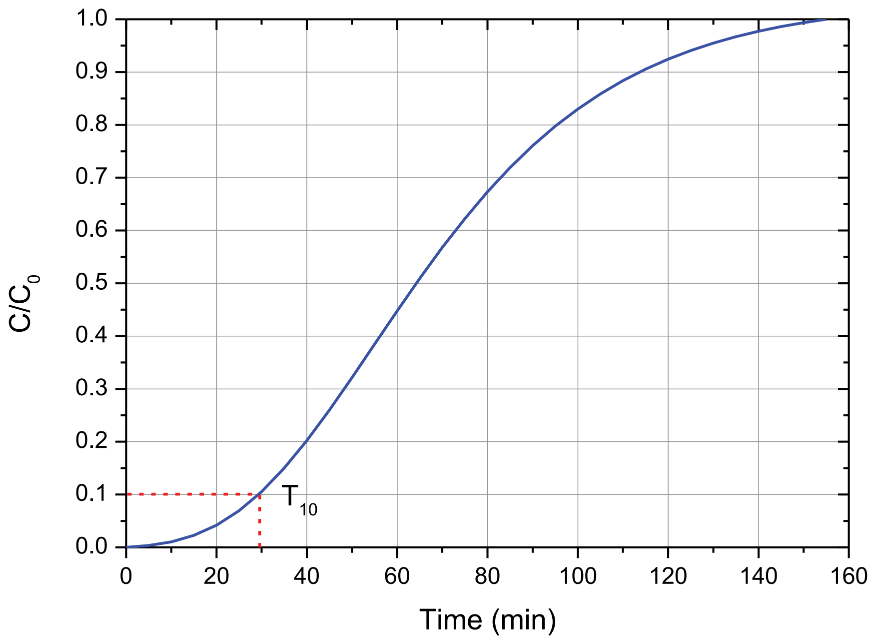


Figure 1. Step-dose tracer test – cumulative distribution curve.

Tracer testing is a proven technique for demonstrating T_{10} contact times. However, it is time consuming and can be expensive, since a minimum of four tests is recommended to cover different flow and level conditions. It can also have a significant impact on plant operations. Flow and level need to be fixed for each test, which can often mean inhibiting filter backwashing where the backwash water is drawn from the tank itself or upstream of the tank. Furthermore, there may be some situations where a tracer is not readily available – e.g. the fluoride dosing point may be after the chlorine contact tank, in which case an alternative tracer has to be used, increasing the cost.

Computational Fluid Dynamics (CFD) Modelling

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses computer models to solve and analyse problems that involve fluid flow. CFD is used widely overseas in a range of industries, but its use in Australia and New Zealand, particularly in the water industry, has been limited. The reason for this is both cost and resources. Up until recently CFD software had extremely high licensing costs, which meant engineering and consulting companies were reluctant to invest in it. This in turn meant that there were very few people capable of running CFD simulations. The recent release of an open source CFD software package (CAE-Linux) combined with advances in computing power has changed this, making CFD very price-competitive compared to tracer testing (30–40% cheaper than tracer testing).

In order to use CFD to determine T_{10} contact times a number of steps have to be followed. A real-world example to demonstrate the steps is provided.

The Wainuiomata WTP chlorine contact tank (Figure 2) is a circular tank, 16.9m in diameter and 6m tall with a volume of 5170m³. The reservoir is baffled by two parallel membrane curtains, 25m long, running from opposing walls. These curtains are fixed to the floor using a full-length skirt which was factory-welded to the main membrane curtain. Water enters on the right of the reservoir through a 1200mm CLS pipe angled at 45 degrees from underground towards the floor. The pipes are flush with the floor of the reservoir, providing an elliptical exit.

Figure 2. The Wainuiomata WTP chlorine contact tank.

A simple wire-frame model is then built (Figure 3). The wire-frame represents the edges of an available volume for the water to flow through. Different geometries need to be created for each different reservoir level.

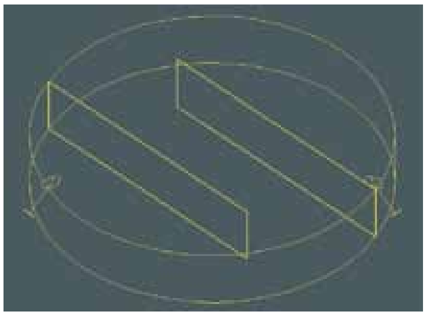


Figure 3.

Using the computer model, the total volume is divided into lots of little individual volumes called "bubbles". These bubbles completely fill the tank. (Figure 4). For the Wainuiomata WTP chlorine contact tank in the 96% full scenario 299,434 bubbles were created. Note that the bubble density increases automatically around features such as baffles. This can be clearly seen in Figure 3. Each bubble of volume is a cell in which the CFD mathematics are performed. The software then evaluates each steady state condition using the inlet velocity as the only starting condition.

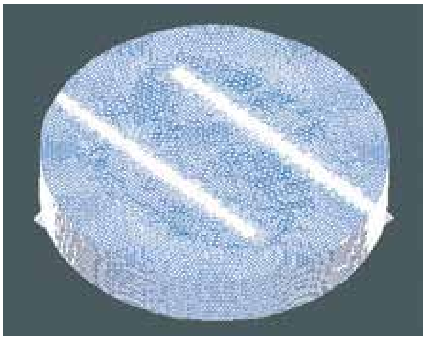
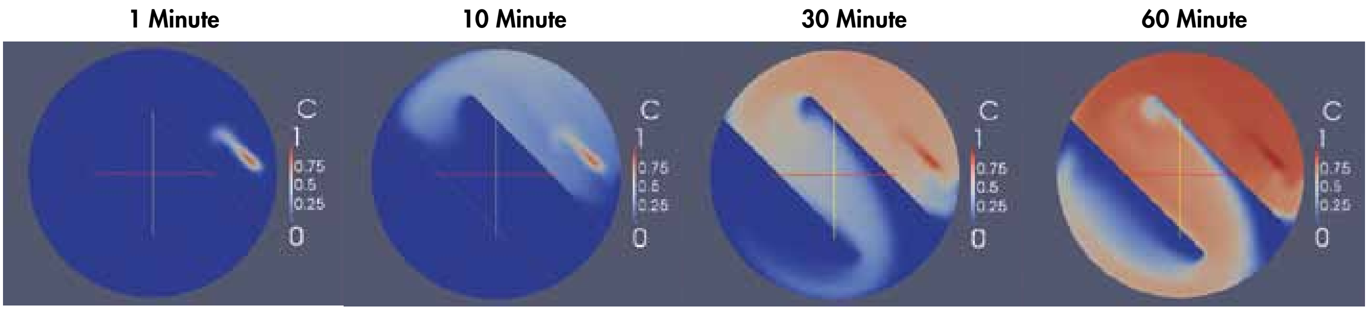


Figure 4.

A tracer test was simulated by adding 1mg/L of an inert tracer to the inlet of the tank. The simulation was run until the tank



outlet reached steady state i.e. 1mg/L.

A time sequence of the tracer concentration in the Wainuiomata chlorine contact tank for 60ML/d and 96% level is shown. Note that the tracer first appears at the exit of the tank sometime after 30 minutes and before 60 minutes.

The simulated tracer concentration at the exit of the tank was used to plot a cumulative distribution function curve (C/Co vs time) as described above and shown in Figure 1. The output of the tracer test simulations for a range of scenarios are shown as cumulative distribution function curves in Figure 5. The T_{10} for each case can then be calculated from the curves. A baffle factor was then calculated by dividing the calculated T_{10} contact time by the theoretical contact time. The calculated T_{10} contact times are shown in Table 2.

Table 2. Wainuiomata WTP CCT T_{10} contact times for all scenarios.

Level (%)	T10 Contact Time (mins)		
	60 ML/d	40 ML/d	20 ML/d
96	49	75	159
76	37	57	127
51	28	43	100

It can be seen from Figure 5 and Table 2 that when the reservoir is operated at maximum flow (60ML/d) and minimum operating level (51%) that the T_{10} contact time is less than 30 minutes. The calculated baffle factors for each of the scenarios (Table 3) show a range from 0.34 to 0.46.

Table 3. Wainuiomata WTP CCT baffle factors for each of the scenarios tested.

Level (%)	Baffle Factor		
	60 ML/d	40 ML/d	20 ML/d
96	0.34	0.36	0.40
76	0.35	0.37	0.41
51	0.39	0.42	0.46

This data highlights two issues with using the standard baffle factor definitions shown in Table 1.

1. The first is that when a baffle factor is selected it is applied to all flow and level scenarios. In reality the baffle factor varies with both flow and level.
2. The second issue is that given the range in actual baffle factors it is quite difficult to select a baffle factor that will cover all scenarios. For example, the baffle factor that has been selected for the Wainuiomata WTP chlorine contact tank was 0.4. This was selected because it was felt that the tank fell between the 0.3 and 0.5 definitions. It can be seen from Table 3 that under many operating scenarios the baffle factor was underestimating short-circuiting.

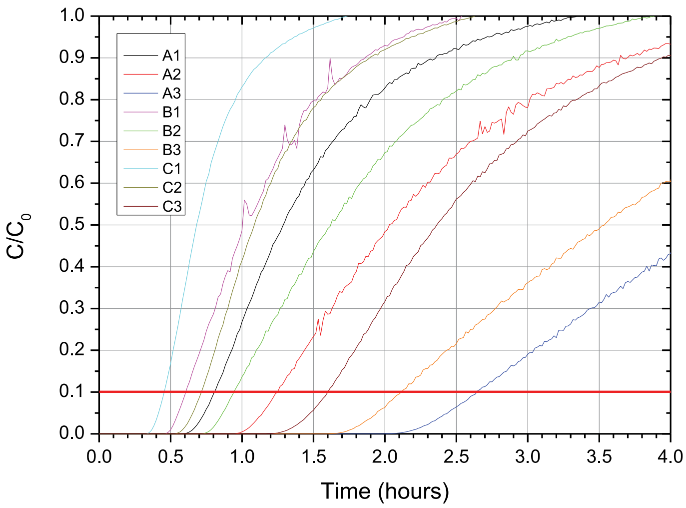


Figure 5. Cumulative distribution functions for each of the scenarios tested for the Wainuiomata WTP.

CFD modelling can be used to provide additional value over and above the determination of T_{10} contact times.

- **Identification of dead zones.** CFD clearly identifies dead zones in any flow scenarios.
- **Locating sample points.** One area where dead zone identification is important for existing tanks is in locating of sample points. If the tank is being sampled from a dead zone then the sample will not be representative under changing conditions. If the sample is being used for pH and/or chlorine measurement and control then the process control will be very difficult to tune effectively. In order to achieve good process control, a homogenous sample is required. Using CFD an optimum sample location can be selected.
- **Evaluating tank modifications.** Modifications to inlets/outlets and baffles can be evaluated offline. Sometimes a simple fix can be provided to an existing problem. For example, in the examples provided the T_{10} was less than 30 minutes in one scenario. A number of inlet modifications were evaluated and it was found that a simple deflector plate at the inlet would increase the T_{10} to greater than 30 minutes.

CFD is a viable alternative to tracer testing in order to determine actual chlorine contact times. In fact, CFD has many advantages over tracer testing. It is now cheaper than tracer testing due to the availability of open source software, it has no operational impact and can be used to provide additional value over and above the determination of T_{10} contact times and baffle factors.

The use of standard baffle factors is a gross simplification and their use can result in an underestimate of short-circuiting in chlorine contact tanks.

The Authors

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CHLORINE TRAINING IN REMOTE WA

Ron Levett, Tony Bohdan & Rob Namestnik

The Water Corporation of Western Australia has always invested in the ongoing development of its employees, and chlorine training is no exception. All chlorine training is provided through the in-house HR Learning and Development section, and all the courses are aligned to relevant legislation, in particular the National Water Package (NWP07).

One of the problems is providing practical training in remote areas. There are over 300 chlorine sites throughout Western Australia and trainers often travel vast distances to deliver the training.

A challenge that faces all training providers who cover such vast areas as the Water Corporation is being able to provide training on location, rather than only offering city-based training to participants. Training equipment such as empty chlorine drums and cylinders are impossible to transport on a regular basis, which has called for some innovative ways to simulate training for use in regional and remote areas of our business.

The HR Learning and Development team has developed a range of lightweight portable training aids to allow candidates to simulate chlorine drum and cylinder connection and disconnection as used for container changeovers.

The drum simulation equipment consists of a folding panel drum-end complete with two valves. There is also a separate chlorine manifold connection for liquid-draw systems. The equipment transforms into a lightweight, portable package and can be assembled in minutes (Figures 1 and 2).

Figure 1. Lightweight portable chlorine drum training equipment.

The drum end (Figure 2) has a cover over the valves, and the candidate must use the correct procedure to prepare the drum for either gas or liquid draw and connect the vacuum regulator or auxiliary valve with pigtail (Figure 3) and the emergency shut-off device.

Figure 2. Training drum end with cover (top) and after connection to vacuum regulator (bottom).

The portable equipment also allows candidates to experience the conditions related to drum changeovers, to repeat and gain confidence in the correct sequence of connecting and disconnecting drums. The candidate is placed in the same physical position, kneeling on the ground, wearing correct PPE and using correct tools while following standard operating procedures (Figures 4 and 5).

For operators at sites with cylinders, the team uses a number of boxed training kits. Each kit contains the top of a cylinder, yoke and vacuum regulator (Figure 5).

These practical training aids have allowed meaningful training to be carried out throughout the vast state of WA.

Figure 3. Pigtail connected between training drum and manifold connector.

Figure 4. Trainee operator simulating a drum connect/disconnect.

Figure 5. Portable boxed chlorine gas cylinder training kit.

The Authors

Ron Levett, **Tony Bohdan** and **Rob Namestnik** are Technical Trainers at the Water Corporation and travel throughout WA to deliver water industry and compliance courses. For more information, email training@watercorporation.com.au attention one of the above-mentioned authors.

NEW VIDEO HEALTH AND SAFETY SOPS

Michael Clewes
Winner of the Ecolab Prize for Best Operator Paper at the 2012 WIOA Victorian Conference

Generally, the world over, there are only three main questions that a court or a regulator will ask in the event of an incident:

- Was a safe workplace provided?
- Was the person trained?
- Was the person supervised?

These questions naturally form the base principles of the North East Water incident investigation methodology and, in truth, it was recognised that, especially in the more long-term workers, there was very little evidence of training.

During my work as a health and safety manager in the United Kingdom I was once asked by the Health and Safety Executive (HSE) the equivalent of WorkSafe: *"Can you prove this employee knows what you claim they know?"*. Having duly provided copies of training files and sign-offs for procedures the HSE challenged me, stating: *"This proves they have it, but can you prove they know it?"*.

At North East Water this same issue was apparent; however we are fortunate that our staff are very skilled at their work and our opportunity to conduct investigations was, thankfully, very limited. The few investigations we did embark on, however, showed a gap in our management of training for health and safety, especially for long-term employees.

The injury statistics for North East Water are improving year on year; this year saw a reduction in lost time injuries from four down to one, while the frequency rate fell from 12 to four (Figure 1). However, this still shows there is work to be done and improvements to be made.

We asked our staff a key question: *"Given the current level of training, would you be happy to let your son or daughter perform this task?"*.

For North East Water this was a critical question that ensured all staff saw value and perspective of the holistic health and safety training program. North East Water recognised that the key to any change and effective management was to engage employees at the earliest opportunity. Accordingly they began by consulting with the Health and Safety Committee, Executive Management and the Human Resources Department, as well as key employees.

The consultative process included:

- A review of five years' worth of incident and injury statistics;
- A gap analysis of current training files was performed; this task required a detailed audit of over 150 folders, some spanning over 30 years;
- A training needs analysis was developed;
- An electronic database, CRIS 21, was implemented to capture training and personnel records;
- North East Water joined the North East Regional Development Scheme, NERDS, an electronic training platform using a system called E-Learning.

NEW Video SOPs

North East Water needed to overcome the issue of not making experienced workers feel they were being treated like children with the training that was required. The issue was to find methods of continually providing information, instruction and training that did not make staff feel they were being made to "suck eggs", and that was seen as a value-added addition to their careers.

There was also the issue, thankfully not often heard at North East Water, where we needed to get away from the mantra: *"We've never had to do it that way before"*.

North East Water seized on the phrase: *"Tell me and I'll do it, show me and I'll understand"*. This, of course, was the result we wanted to get from our training to staff; understanding leads to valuing and ultimately leads to compliance. If you have compliance then incidents should not occur.

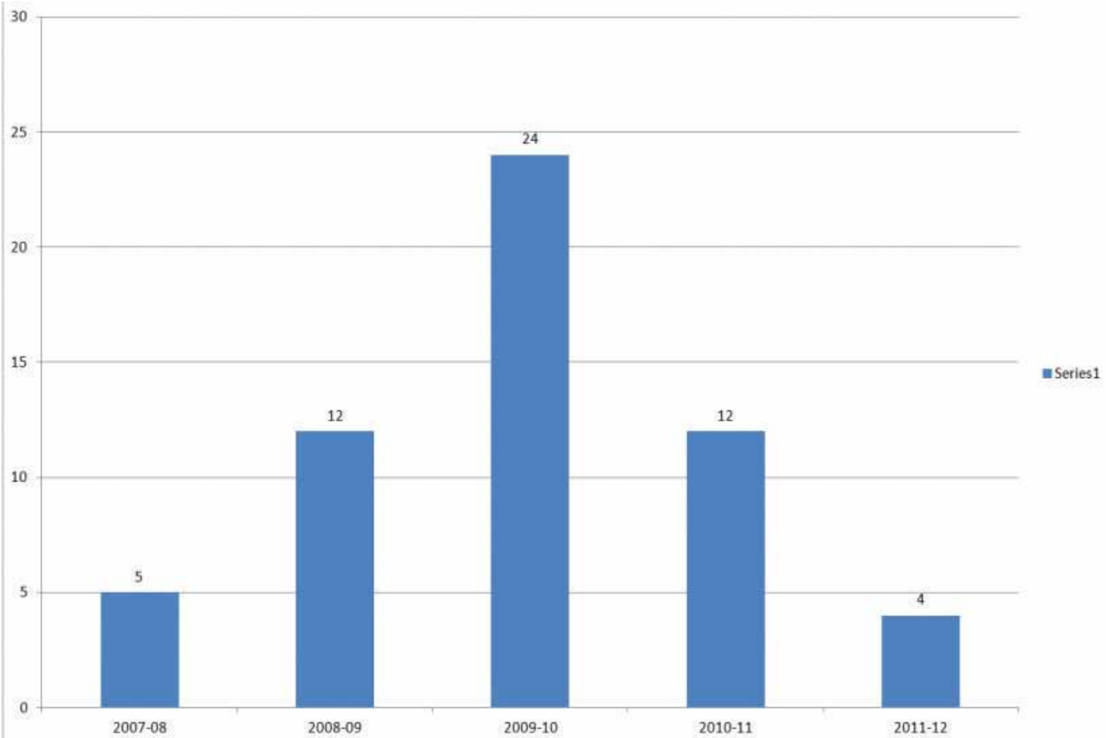

Figure 1. Extract from the Annual Report 2011–12 – Lost Time Injury Frequency Rates.

Video Standard Operating Procedures (SOPs) were seen as the way forward and it was determined that the videos would have the most effect if they starred our own people.

North East Water also recognised that the people who had the information we wanted in the SOPs were also, ironically, the same people whose training files were lacking in information.

This was the key to obtaining buy-in and engaging these long-term employees in the process without them feeling that they were being treated in an inferior manner. Moreover, the guys felt a sense of purpose in transferring their acquired skills into a format that would benefit younger and less experienced members of staff.

We engaged with experienced employees to write our scripts and to lay out the scenes required, and staff volunteered to be in the videos.

Delivery of the Training

Training of all new employees is planned and agreed with their supervisor prior to their first day. This includes, among other training, receiving the video SOPs. The video is presented though the E-Learning platform, which the employee logs into via an enrolment sent from HR. Following the viewing of the SOP video and reading the supporting written SOP, the employee is navigated to a questions screen to sit a formal test.

Feedback is provided for wrong answers and for answers where we might like to enhance and re-enforce the message of the training throughout the questions screens.

On successful completion of the module, the employee is able to print a certificate and the employee's electronic training file is automatically updated.

The video SOP format has been widely accepted as a suitable means of conducting initial and refresher training for all employees, including more experienced staff.

The success of the initiative may be masked by other projects being embraced by staff; health and safety can often be an unseen gain and a very visible loss when an organisation looks backwards at performance.

The key for North East Water was to take the three main investigation questions that are asked retrospectively and ask them proactively to prevent injury harm and damage.

The training aspect is certainly satisfied using the approach that North East Water has taken: training is determined, planned, delivered, verified and refreshed in a format that is acceptable to new and long-term staff.

The video SOP does not remove the need for on-the-job shadow training and does not make a new person a process expert overnight.

However, in response to the question: "*Would you allow your son, daughter or respected other to perform a given task with this type of training?*" the answer has come back as a resounding "YES".

The Author

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STANDARD REQUIREMENTS NEEDED FOR WTPS

Bruce Murray & Christian Sanders

The United Nations Human Rights Council made headlines in 2010 by affirming that access to safe drinking water was not a privilege, but an essential human right. This is sadly far from reality in many parts of the world. Most Australians would be surprised to know that their own water supplies are not always totally safe and potable. We take steps in the direction of safe drinking water, but levels of risk are allowed to vary across Australia. The tough truth is that larger cities and towns tend to have better water than many towns in regional areas. Many water supplies, big and small, are also often at greater risk after heavy rainfall in the catchment and with the associated rapid changes in raw water quality.

How do we define safe water and how do we ensure that our water treatment plants (WTPs) and supply systems provide it as closely as possible to 100% of the time? In the absence of a clearly defined set of regulations, the answer to these questions in many towns depends on many factors. The NHMRC *Australian Drinking Water Guidelines* (ADWG) 'Framework for Drinking Water Quality Management' is a huge step in the right direction, but it is implemented to various degrees by different water authorities.

In addition, there are few tools as yet to guide and define how to achieve the intent of the Framework. The areas of concern that we come across in how one *effectively* operates and maintains a WTP include: defining acceptable levels of monitoring; instrumentation; equipment redundancy; staffing; training and competency; and reporting and documentation.

We must minimise the risk of pathogens getting through from the catchment to the consumer in all our water supply systems. Further refinement of the ADWG will no doubt follow and health-based targets may be included. However, in the interim it would useful to establish a WTP evaluation system.

The purpose of this system would be to define minimum and best practice requirement levels for all aspects of a WTP based on the level of pathogen risk posed by the catchment.

The Situation

Over the last 30 years, we have seen the Australian water industry undergo a period of significant change with respect to treatment technologies, instrumentation capabilities and customer expectations. Customers in many towns and cities across the country can now expect levels of water quality that were not even considered a few decades ago.

In our experience, the following factors have contributed to the limited development in some smaller supplies.

- Insufficient guidance on what is acceptable in terms of WTP infrastructure, operation and reporting;
- Operators are mostly only required to report problems rather than report detailed monitoring of performance;
- Limited sampling and monitoring often occur at the discretion of operations (i.e. when the plant has *recovered* from any hiccup);
- Limited capacity within the managing authority to address all of the technical issues that occur;
- Limited engagement with water treatment staff;
- Water treatment assets operated by insufficient numbers of staff, sometimes under-trained and sometimes of limited experience;
- Limited customer understanding of the quality of water supplied to them; and
- Insufficient population numbers and low water rates to recoup infrastructure and operations investments.

Without incentive to meet minimum, let alone high, standards of operation, we see little likelihood of significant improvement coming to our regional towns. So let's develop a set of acceptable standard requirements for WTPs.

Water Supply Objectives

We believe that the basic objectives for a water supply system include:

- Provision of safe drinking water;
- Flexibility of design to allow satisfactory water treatment under all raw water feed conditions;
- Sufficient equipment to ensure reliable operation at all times;
- Equipment is well-maintained and instruments are regularly calibrated;
- Alarms provide timely warning that a control point may be failing;
- Operations staff are trained and experienced to match the requirements of the system and are provided with operational refresher training;
- Adequate staff (technical or otherwise) are available, especially during poor raw water quality events;
- Operations environment is safe and satisfying to work within;
- Monitoring and reporting on real water treatment performance enables continual improvement;
- Operations & Maintenance (O&M) Manuals, Standard Operating Procedures (SOPs) and Work Instructions (WIs) are provided to ensure consistent plant operations;
- Management systems are in place including Water Quality Management System, Quality Assurance and Incident and Emergency Management.

System Management

The efficient operation of a WTP involves a set of systems. Rather than a series of stand-alone actions, processes or setups, all of these systems are interrelated.

To illustrate this, take the case of an individual issue such as high filtered water turbidity. It may be a once-off event, or something that occurs frequently. It is possible to view the issue of high filtered water turbidity as a potential cascade of consequences arising from each quality area. For example:

Management Systems: Critical control points (CCPs) are unidentified or poorly defined, as are operational procedures, and process alarm set-points may be improperly set resulting in insufficient time to address an issue before it becomes a problem.

Operations and Maintenance: Lacking a clear set of objectives that should be encapsulated in the management system, the plant is frequently stopped and started, leading to unstable process conditions, chemical dosing not being optimised with routine jar testing, plant operation being frequently unsupervised, routine maintenance not being performed on plant equipment, and/or instruments not being calibrated on a regular basis.

Information Management: No documentation system has been developed for the operators to refer to and plant performance data may not be recorded.

Control/ Automation: Insufficient automatic supervisory control (SCADA) leads to inconsistencies in performance.

Equipment/ Infrastructure: Sub-optimum coagulation as a result of inadequate mixing of chemicals in the process stream, insufficient flocculation time, sub-optimum polyacrylamide dosing, and no mechanism for dealing with poor water produced during the filter ripening period.

Obviously this might just be scratching the surface with such a common issue (sadly) as high filtered water turbidity, but we believe it illustrates our point: linkages exist starting with the overall management system, moving down through the day-to-day operational work, until you reach the actual equipment comprising the WTP.

Management Systems

Let's start from the top then – the management systems level. To be useful, functional and comprehensive, a Drinking Water Quality Management System (DWQMS) must define the objectives of each WTP or system and detail how they will be achieved *at each site*. This document is *the* key risk management tool for a water authority and directly informs how a water supply will be managed from catchment to tap. The DWQMS defines how the water authority will meet its obligations.

The DWQMS must consider the level of catchment risk of the water supply system and particularly in regard to pathogens. The higher the risk the more measures and treatment are required. The DWQMS must also relate to the actual WTP; the limits set for the Critical Control Points (CCPs) must be measurable and practical for the operators to keep a close eye on.

WTP operations and maintenance, information management and WTP design are all informed and shaped by the DWQMS. Its purpose is to identify risk and then nominate controls for that risk, define how to ensure the controls are implemented and, lastly, provide the mechanism for verifying and recording the implementation of the controls. The DWQMS is a living process and it must be reviewed, updated and developed regularly to ensure it stays relevant, effective and comprehensive.

Operations and Maintenance

Once you have set your quality objectives, identified the risks to those objectives, and developed mechanisms for mitigating those risks, it is time to implement controls – operations and maintenance. Operations and maintenance are, at their core, a large-scale exercise in risk mitigation. It's the DWQMS converted from words into action.

The operations team needs to be focused on their water supply and treatment system with adequate resources and all infrastructure tuned and ready to go, and with all the tools they need at their fingertips.

Information Management

So, our water is 100% safe. OK, prove it. Could you? How would you answer any of the following questions?

- What did you do today, and where is the record that you carried out your daily checks and noted any problems or issues? Did you follow them up?
- Where are you supposed to take samples from? How frequently? Where do you record the results?
- How do you troubleshoot that pump you only use occasionally?
- What are you required to do before you can enter the filter? Where do you keep that procedure?
- What are you required to wear before you handle that chemical?
- How often is that instrument calibrated? What is the procedure? Where is the result of the last calibration located?
- What training sessions have you attended in the last three years? Where is this information recorded?
- How has the plant operated over the last week? Don't tell me – let me see the data.

If you struggle to answer any of the above, chances are your information management system is a bit too informal. To carry out our duties and comply with the obligations of the DWQMS, we need a set of defined procedures and tasks to follow, the skill and knowledge to carry them out appropriately, and a means for recording that they have been completed (e.g. measurement value, check mark, signature, data entry or handwritten notes). These are achieved through:

- Operations & Maintenance (O&M) Manuals;
- Templates, Logbooks and Checksheets;
- Job Safety and Environmental Analyses (JSEAs)/Safe Work Method Statements (SWMSs);
- Work Instructions (WIs) and Standard Operating Procedures (SOPs);
- Maintenance and Calibration Schedules;
- Weekly/Monthly Performance Reports; and
- Training Records.

Control/Automation

OK, so there are only so many hours in a day… how do we control and watch over such a complicated bit of kit that is our WTP? The answer, of course, lies with well-programmed SCADA (Supervisory Control and Data Acquisition), and PLC (Programmable Logic Controller).

These days, these two systems do the bulk of the control and monitoring work in a well-operated WTP. They are the brains of our plants. Set up correctly, they:

- Start/stop the WTP based on downstream storage levels and other conditions;
- Control flow rates and manage smooth, near-continuous operation;
- Batch and dose chemicals;
- Blowdown clarifiers and backwash filters;
- Manage recycling water back to the head of the works smoothly and evenly;
- Switch between duty and standby equipment;
- Monitor and trend water quality parameters and plant equipment;
- Warn operations staff to sub-optimum performance;
- Shut down the WTP on failures.

Without attending the plant continuously, it is nearly impossible to consistently meet current standards for drinking water quality without a functioning SCADA and PLC. However, simply having them is no guarantee of quality – they are only as good as we program them to be! To be effective, they must be configured based on a solid understanding of the water treatment process, what control inputs should be operator adjustable, and what alarms are required. In addition, trending capabilities should facilitate troubleshooting as well as enable the performance monitoring and reporting obligations of the operations team to be met.

Infrastructure and Equipment

Is all of the infrastructure and equipment necessary to achieve satisfactory water quality, under all raw water conditions, available for operation with sufficient level of redundancy? Old equipment needs to be replaced. New technologies may need to be considered or evaluated. Sufficient levels of equipment redundancy should allow uninterrupted operation under all scenarios.

Proposed WTP Requirements

Detailed requirements for a WTP in each of the areas described above are being developed. There is some debate to be had on these before finalisation.

It is proposed that the following is in place for a best practice WTP:

1. Management Systems
   - A WQMS regularly reviewed
   - A QA system
   - Incident and Emergency management
2. Operations and Maintenance
   - Sound operations philosophy
   - Continuous operation
   - Flow-change ramping
   - Continuous plant optimisation
   - Regular inspections
   - Well-cleaned tanks
   - Maintenance program
   - Instrumentation calibration program
   - Frequent jar testing
   - Rapid response to problems
   - Operator training and improvement program
3. Information Management
   - Up to date O&M manual and SOPs/WIs
   - Reporting and communication protocols
   - Job Safety and Environment Analyses (JSEAs)/Safe Work Method Statements (SWMSs) and Risk Assessments
   - Chemical Risk Assessments
   - Material Safety Data Sheets (MSDSs)
   - Manual Handling Risk Assessments
   - Chemical Analysis Certificates
   - Calibration Logsheets/Schedules
   - Operation Logsheets
   - Sampling Records/Schedule
   - Daily/weekly/monthly checksheets and reports
4. Control and Automation
   - Online instrumentation with priority alarms
   - Alarm history
   - Remote monitoring
   - Flow pacing where necessary
   - Feedback control where practicable
   - Automatic changeover on equipment failure
   - Monitoring of all CCPs
   - Trending
5. Infrastructure and Equipment
   - Adequate infrastructure to cover all raw water conditions
   - Sufficient flexibility of design and redundancy
   - Managed water recycling
   - Multiple barriers
   - Well-used laboratory
   - Adequate safety
   - Asset management.

Further details will be provided in a subsequent article in the next edition of *WaterWorks.*

The Authors

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ARSENIC REMOVAL IN REMOTE COMMUNITIES

Mei-Leng Yau & Gary Thorne

Winner of the Hepburn and Iwaki Pumps Prize for Best Paper Overall at the 2012 WIOA Victorian Conference

In a remote Indigenous community in the Kimberley region of Western Australia the arsenic levels were up 0.02mg/L, double the 0.01mg/L ADWG health limit. The community has three production bores. Two low-yielding bores supply the community with potable water. The third, high-yielding bore was taken offline due to elevated levels of arsenic. The aim was to bring the third bore back online to satisfy the community's growing demand for water and to lower the arsenic levels.

Arsenic (As), a naturally occurring element, is introduced into water when minerals and ores are dissolved. When arsenic dissolves in water it forms oxyanions, trivalent arsenite As(III) under reducing conditions or pentavalent arsenate As(V) under oxidising conditions.

The requirements for the arsenic removal plant were identified:

- The plant must require minimal maintenance;
- The plant had to be simple to operate and maintain by the service provider on their existing six-week cycle;
- The plant had to be robust to withstand the outback conditions;
- It had to use minimal energy, minimal consumables and minimal physical labour for maintenance;
- The waste stream had to pose a negligible contamination risk to the environment.

Four options were considered:

1. Coagulation and precipitation

The process of coagulation and precipitation involves adding a coagulant to the drinking water, then clarifying and filtering it. When the source water has a pH of <7.5, arsenic can be removed with equal efficiency by both aluminium and iron coagulants. When the pH is >7.5, iron coagulant is more efficient than aluminium. The source water has a pH of approximately 8, making an iron-based coagulant more suitable.

Coagulation has been shown to be less efficient for removing arsenite than for removing arsenate. Chlorine, ozone, chlorine dioxide or potassium permanganate can be added before coagulation to oxidise arsenite and convert it to arsenate, creating another control point.

However, adding pH control, coagulant dosing control and redox control for oxidation would require an intensive control system. This would increase operating and maintenance costs and increase the potential for failure because the plant would be unmanned for six weeks at a time. Maintaining the system would be too complex and the plant would need a larger footprint. The process of removal of arsenic by coagulation and filtration was not explored further.

2. Reverse osmosis

Reverse osmosis (RO) membranes can remove arsenic and other impurities from drinking water. Although a valid treatment option, RO was quickly abandoned due to silica fouling issues and because 35% of the available water would become a waste stream containing much higher levels of arsenic (approximately 0.05mg/L). The waste stream would also need to be contained, complicating the design and creating an environmental sustainability problem.

3. Ion exchange

Pentavalent arsenic is present in drinking water as dihydrogen arsenate ($H_2AsO_4^-$) and monohydrogen arsenate ($HAsO_4^{2-}$), so it is possible to remove arsenic by anion exchange. When arsenic-laden water passes through a strong base anion resin, arsenate ions are exchanged for other anions on the resin. This process was thoroughly investigated, as it is much simpler than either coagulation or reverse osmosis.

Using ion exchange creates some problems. The resins require regeneration, they produce a waste stream, and arsenic

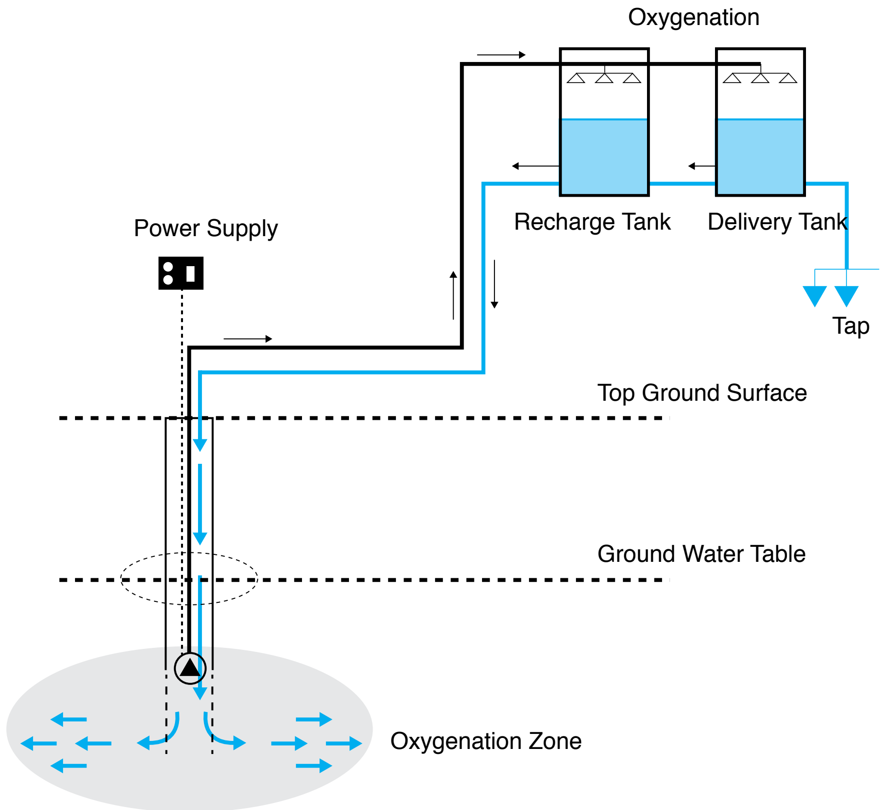

Figure 1. Schematic diagram of an SAR plant.

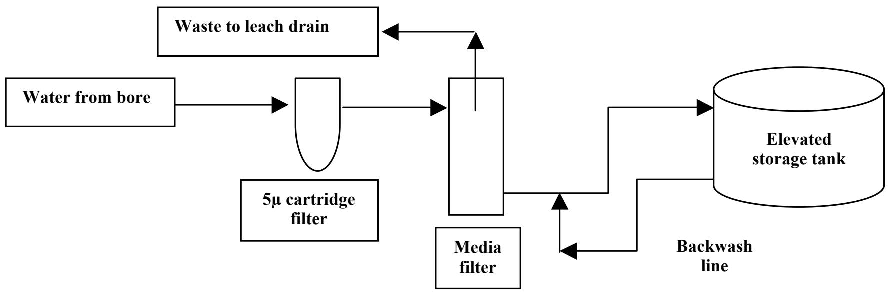

Figure 2. Arsenic-removal process flow diagram.

can be released back into the environment. The process would require pre-treatment to remove organics, suspended solids and other contaminants that would foul the resins and decrease their effectiveness. Ion exchange was also rejected.

4. In-situ groundwater plant

Investigations to find a more suitable treatment process revealed Dr Bhaskar Sen Gupta's subterranean arsenic removal (SAR) technology. The SAR process takes the oxidation and filtration process used in aboveground water treatment plants and transfers it underground into the aquifier.

Groundwater is extracted into a tank at ground level, aerated and re-injected into the bore underground (Figure 1). Aeration causes the oxidation of arsenite to arsenate, ferrous to ferric (Fe^{3+}) and manganese (II) (Mn^{2+}) to manganese (IV) (Mn^{4+}). This creates an arsenate co-precipitated with the Fe^{3+} and, to a lesser extent, Mn^{4+} precipitates, reducing the content of arsenic in the bore water. The water is then filtered by the surrounding sand, removing the contaminants. The oxidation process is enhanced by bacteria in the subsurface. The re-injection of aerated water into the bore creates an oxidation zone where physical, chemical and biological processes are intensified, increasing the effectiveness of the oxidation process and, ultimately, the removal of arsenic.

The main advantages of implementing this system in a remote community are that the process requires no chemical input, does not produce a waste stream, is a simple design and has a minimal footprint. Because the arsenic and iron flocs filter through the sand, sludge handling is not needed and the total volume of contaminants filtered into the sand is insignificant compared to the surrounding groundwater area. The simplicity of the design minimises operating and maintenance costs.

However, when Dr Gupta reviewed the quality of the water at the remote community, he advised that the combined levels of Fe^{3+} and Mn^{4+} were too low to create a stable reaction in the water supply. This process option was also eliminated.

5. Adsorption

In the adsorption process, arsenic ions adhere to a solid surface and are extracted from the water. The surface is typically a metal-based granulated media, held in a pressure vessel. Arsenic-laden water travels through the vessel and makes contact with the media. Arsenic is adsorbed onto the media, and effluent leaving the pressure vessel has considerably lower arsenic levels. The adsorption process, unlike the ion exchange process, does not release an anion in place of the arsenic, so there is no risk of increasing anion levels in the water.

The medium chosen must not require regeneration (thus avoiding problems associated with disposing of the waste stream). It must be able to be disposed of and replaced after exhaustion, achieve optimum process with a pH of 8, be able to adsorb arsenic ions, and, most importantly, arsenic must be its top removal priority, followed by other metals and ions.

Activated alumina and granulated ferric hydroxide are typically used for the adsorption of arsenic from drinking water. Activated alumina is more effective in removing arsenate than arsenite; therefore, an oxidation process would be necessary to convert As(III) to As(V). Activated alumina is highly pH-dependent, with an optimum removal range between pH 5.5 and 6.5. The community's water has a pH of approximately 8, so it would require a pH adjustment before it entered the pressure vessel, increasing the system's complexity and its operating and maintenance costs. Activated alumina was rejected.

Adsorbsia (DOW Chemicals) is a titanium oxide medium that has a strong affinity for arsenic, lead and other heavy metals. It is designed to be non-regenerative, needs less maintenance and is, therefore, ideal for a remote community. Once exhausted, the media is disposed of in landfill after they have been tested and passed the US Environmental Protection Agency's toxicity characteristic leaching procedure (TCLP) extraction protocol.

A process flow diagram of the system is shown in Figure 2.

Over time, head loss will occur across the media, due to compaction and the filtration of particulates. A 5 µm particulate cartridge filter is installed upstream of the media pressure vessel to extend the cycle

Figure 3. The arsenic removal plant installed in the clear water tank compound.

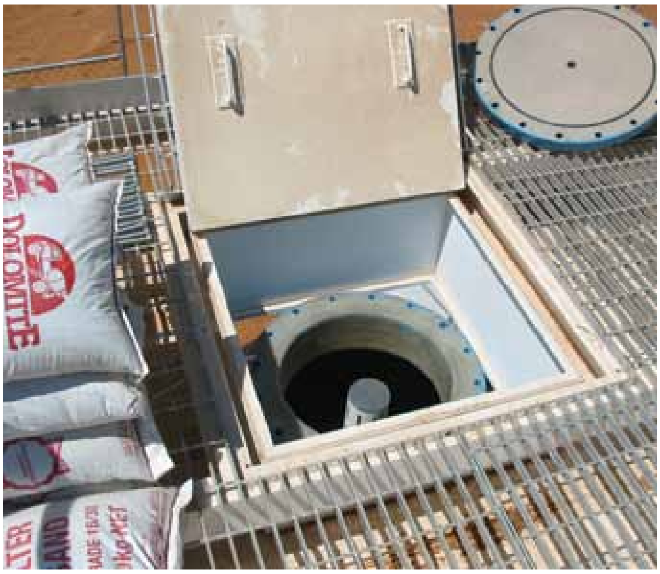

Figure 4. The media loading and unloading hatch in the container roof.

Figure 5. The remote telemetry unit on the outside of the container.

run time between backwashes. As a result, the backwash cycle can be undertaken during the routine six-week maintenance inspections, so it does not need to be automated. An adjustable differential pressure switch is installed over the arsenic media bed and the 5 µm particulate cartridge filter, set to warn service providers via a remote telemetry connection that they will need to wash/change media and cartridge filters on their next six-weekly visit.

Backwashing is initiated manually and needs to be carried out quarterly. Treated water drawn from the elevated storage tank will expand the media using a total of five bed volumes. The backwash water is suitable for disposal in leach drains as it contains few to no arsenic contaminants.

A magnetic dual-direction flow meter is installed downstream from the media filter vessel for monitoring the treated water and the backwash flow rate. The arsenic-removal system is installed in a 3m shipping container (Figure 3).

The top of the unit has been designed to allow for media removal and replacement (Figure 4).

The plant has been fitted with a remote telemetry unit (Figure 5), which provides the remote service provider details

Table 1. Early performance data.

Date	Pre-Filter mg/L	Post Filter mg/L
11/12/2012	0.003	<0.001
13/11/2012	0.001	<0.001
28/09/2012	0.001	<0.001

of the cartridge pre-filter and the arsenic unit differential pressure. This allows them to plan their routine service visit to the community because cartridge replacement and media backwash are manual operations. Typically a service visit is based around a six-week cycle and the plant operates unmanned between visits.

The plant was mechanically installed at the end of July 2012, however on inspection in August 2012 prior to media installation and commissioning, it was noticed that the gravel was the incorrect grade. Four weeks later, after lots of unsuccessful calls to swimming pool companies, the correct media grade arrived on-site.

The plant finally came on-line in September 2012. Samples are taken every six weeks or so and the results up to the end of 2012 are shown in Table 1.

Historically arsenic levels increase during long dry spells, which is the reason for the increase in December.

The Authors

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RETHINKING PAC HANDLING

John Knoblauch

Morgan WTP is located on the banks of the River Murray at Morgan in South Australia and provides filtered water to the "Iron Triangle" cities of Whyalla, Port Augusta and Port Pirie, and the Yorke and Eyre Peninsula as far west as Ceduna. The plant has a capacity of 200ML/Day.

The plant draws its raw water from the Murray River. Water quality can vary significantly depending on flows in the river. During the recent drought years it was unusually clear due to the very low flows. Turbidity was in the order of < 20 NTU, but then when the drought broke, it climbed to several hundred. Although these low turbidities were in many ways a blessing this does, of course, provide an environment conducive to algal blooms. And with algal blooms comes MIB and Geosmin.

PAC dosing was not included in the original design for the plant, but it was demonstrated that the filters at Morgan had the ability to remove a significant proportion of the MIB/Geosmin due to a biological colony on the media. An important part of this was the fact that we backwash with unchlorinated water, allowing the biology to thrive.

The biological system worked well with low levels of MIB and Geosmin; however as a result of an exceptionally high level of MIB/Geosmin in the river, it was decided to attempt to install a temporary Powdered Activated Carbon (PAC) dosing plant. Time did not allow for the usual procurement process and we were asked to "just get some into the water as best we could" and as quickly as we could. No-one was particularly happy with this decision, as we all knew what was to come – or at least those of us that had been there before knew, and we were not about to tell the new guys.

The idea was to lay a concrete slab near the rapid mix tank, and place on it a 50,000-litre poly tank to use as a slurry tank, and an 8-cubic metre steel hopper with a screw feeder to discharge PAC into the slurry tank. The intention was to add sufficient carbon and water to make a 10% solution of sufficient quantities to provide adequate dosing for a night's pumping, thus avoiding having to prepare a slurry out of hours. The volumes suggested would be adequate for this task. As there was no flow tracking facility provided, it was agreed that a flat line flow of 1400l/s would be maintained during this period. A mixer was placed in the slurry tank to provide continuous mixing, and a variable speed peristaltic pump was used to dose the slurry into the rapid mixer.

All of the equipment was in place within 10 days of the initial decision.

How hard could it be? All we had to do was hold the bag over the silo hatch and pull the string. Wrong!

Several problems raised their head.

- Seriously compacted PAC meant that when we tried to empty a bag into the hopper, we discovered that the carbon would not discharge. If I had not seen it with my own eyes I would not have believed that even with the entire bottom of the bag removed, we still had to poke and prod to get it to come out. When it finally did, it was over in a couple of seconds. All except the dust cloud of course.
- Although we fed some lime as an initial test for the screw feeder and this appeared to be OK, when operated with PAC the system would only deliver a very small amount of PAC, as it was so "liquid" most of it ran back down the auger. To add to this it tended to compact around the outside of the feed chute, and as a result overheated the drive motor.

So we converted the prototype system to one where air was injected at the base of the auger chute, and the PAC was then blown into the slurry tank.

This proved to be moderately successful, however due to the ease with which PAC becomes compacted, it failed to flow into the discharge cone of the silo. We tried to break up the PAC by using a long length of PVC pipe. This resulted in being able to deliver only small amounts of carbon, and created considerable risks due to the static electricity being built up on the PVC pipe in an explosive dust environment. This issue meant that even if we found a way to deliver the carbon to the slurry tank, this was not going to be of much help if it would not flow out of the hopper. It was suggested we might try a vibrator on the hopper, but I was worried that this may compact it even more.

To overcome these problems we bought a small tank and removed the top, filled it a third full with water and emptied a bag of PAC into it. The intention was to dissolve the PAC into a concentrated slurry and then pump it into the larger slurry tank. All we found was that the powder floated on the top like an iceberg, and needed to be broken up using a spade, air jet and high-pressure hose. All of this resulted once again in large amounts of black dust.

We tried using breathing apparatus but it was impossible to perform the work with a full BA on, and cartridge -type filters blocked within minutes, and we then could not breathe at all.

Our final attempt to transfer carbon to the slurry tank was with an air-operated diaphragm pump. This proved to be

moderately successful, even though it took 30 minutes to transfer less than 100kg of carbon and then it blew a diaphragm.

After a particularly harrowing few hours, while we were sitting at the smoko table and throwing around ideas (like footing the bill to provide the public with 100ML/day of bottled water) one of the guys made a comment along the lines of “why are we taking it out of the bag before we turn it into a slurry?”. Everyone sat quietly for a few seconds until we began to realise that this may well be a possibility. And so the real discussion began.

We went to the local hardware store and bought a small rainwater tank and immediately cut the top off. The fitters retired to the workshop and made the monster torture rack to go at the base of the tank. The idea was that we would drop a bag over the spikes and cutters to fill the bottom of the bag with holes, and the central spear would be connected to a high-pressure water supply and have a number of small holes drilled in it to create a 360 degree spray inside the bag.

The resultant slurry that drained from the bottom of the bag was then pumped into the large slurry tank.

It worked like a charm. We could empty a bag within minutes (providing it was not badly compacted) and produce very little dust. We had overcome the current difficulties, but a very determined approach from all of us to management suggested that this was not a permanent solution, and we needed to fund a properly designed dosing facility before we had another such event, and a more developed version of the unloading unit needed to be part of that system.

Nothing is ever as easy as it first appears and there were a number of minor issues that presented themselves:

Bags

- Bags that had been in storage for a long time, and especially if they had been stacked on top of one another, compacted so badly that it is almost impossible to empty them properly. We ended up having to return them for re-bagging.
- The original bags had a plastic liner in them and that created issues with the plastic blocking the exit holes. Current bags have no liner.
- Once a unit is produced to meet a given bag size, there is always the risk that the manufacturer may just decide to change the bag dimensions.

Crane

- We used the forklift to lower the bags onto the original spikes, and we noticed that the rate of lowering had to be at a minimum value or the bag would simply rest on the spikes (just like lying on a bed of nails).
- There was some concern regarding the explosive nature of carbon dust, and it was decided to go for an air-operated crane. This, however, did not have the required lowering speed and so it had to be modified.

Spears

- The configuration of the piercing spikes was critical, as it had to ensure sufficient destruction of the bottom of the bag to allow discharge, and also to hold the shape of the bag so it did not collapse in on itself due to the vacuum caused in the emptying process.

- Regular sharpening of the cutting edges provides a much more reliable piercing process.

Spray Nozzles

- The best internal pattern was found to be diagonally across the bag from the centre spike as well as along each side from the corner spears.

- A set of nozzles was directed at the tank discharge to the transfer pump, as this reduced the likelihood of any blockages at that location.
- Dust suppression nozzles over the top of the bag need to be adjustable and directed well above the top of the bag and pointing downwards.
- Nozzles that are specifically made for dust suppression should be used for this purpose.

As much as I would love to suggest our system is dust-free, that would be an exaggeration, but I am happy to say that it is an immeasurably better alternative to the nightmare of unloading PAC as a dry powder the old way. We still use disposable overalls and a breathing mask that simply blows fresh air over the operator’s face.

We can now prepare 40,000L of 10% solution with one operator in a normal day, and I would suggest the cost of this unloading system is no more than the alternatives (in fact, probably less) and is more acceptable to the operators.

The Author

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