WATER WORKS

W-I-O-A Australia
EXCELLENCE IN OPERATIONS

OFFICIAL JOURNAL OF THE WATER INDUSTRY OPERATORS ASSOCIATION OF AUSTRALIA

November 2014

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WaterWorks is the publication of the Water Industry Operators Association of Australia (WIOA). It is published twice yearly and distributed with AWA *Water Journal*. Neither WIOA nor AWA assume responsibility for opinions or statements of facts expressed by contributors or advertisers.

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WaterWorks welcomes the submission of articles relating to any operations area associated with the water industry. Articles can include brief accounts of one-off experiences or longer articles describing detailed studies or events. Submissions may be emailed to peter.mosse@gmail.com or info@wioa.org.au

CONTENTS

OUR COVER

Engineer Stuart Bourne and plumber Brent Krause inspect the cooling tube array in Bedourie in far western Queensland. The basin would normally be full of water but has been drained to allow inspection of the impermeable clay base.

IMPROVING OPERATIONAL KNOWLEDGE

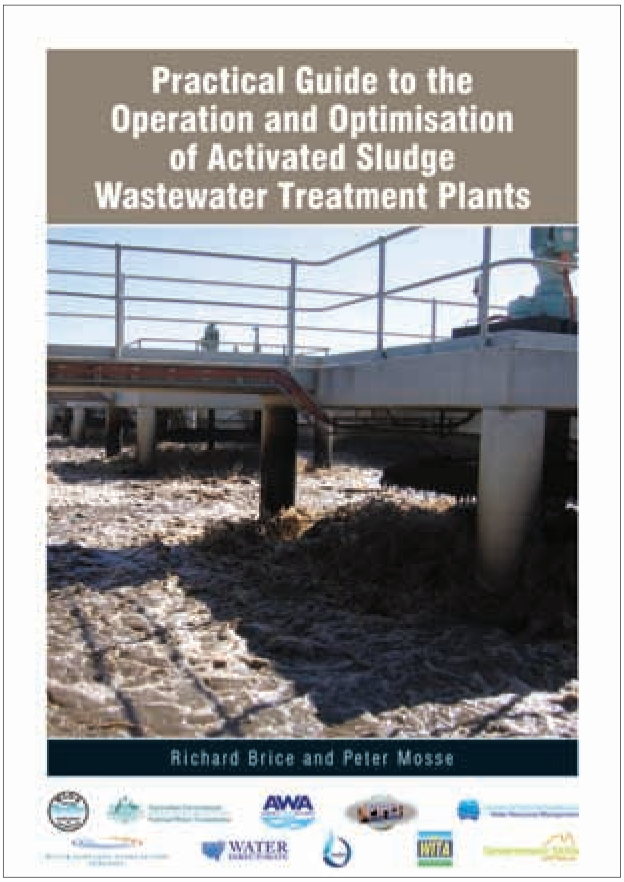
The collection and transfer of skills and knowledge is a challenge for all segments of society. When dealing with a food-grade product like drinking water, where consumers rely on the operators to provide them with safe drinking water every time they turn a tap on, the transfer of skills and knowledge takes on a much deeper and more important meaning.

Some years ago, WIOA recognised that water system operators were unable to access quality, accurate, user-friendly and practically focused resource materials, written to suit Australian conditions. From 2006 to 2009, in conjunction with a number of supporting organisations, WIOA embarked on an ambitious project utilising Australian water industry experts as authors, to develop a series of five *Practical Guide* books covering a range of water supply and treatment processes from catchment to the customer's tap.

These books have been well received by the industry and are being used as a reference text by a number of training organisations. Additionally, WIOA is using the content of the books as the backbone of a suite of one-day, non-accredited training seminars that are being staged in various parts of the country based on demand.

Following the success of the water books, it was a logical step forward to develop a corresponding set of practical resource books for the wastewater side of the industry. Work commenced in 2011 on a set of four wastewater books, with the *Practical Guide to Odour Control in Sewage Transport Systems* released in 2011. The second book in the series – the *Practical Guide to the Operation and Optimisation of Activated Sludge Wastewater Treatment Plants* – was launched at the WIOA Victorian Conference in September 2014. This 188-page book is jam-packed with all the information an operator of an activated sludge treatment plant would need to fine-tune their process. At just $44 per copy (plus postage), this is an essential and affordable item for all plant operators to have in their toolkit. An order form for any of the books in the water or wastewater series is available on the WIOA website.

WIOA is now working on the two remaining titles, *Operating and Optimising Wastewater Lagoons* and *Use of Reclaimed Water*, both planned for completion in 2015. In accordance with our mission and goals, WIOA will continue to seek out opportunities and implement solutions that will continually improve the knowledge of water industry operational practitioners.



The *Practical Guide to the Operation and Optimisation of Activated Sludge Wastewater Treatment Plants* is the second in the wastewater series.

REDCLIFFE STP ROAD TO RECOVERY

James Castle, King Intrapaiboon & Robin Cherry
Winner of Best Operator Paper and Best Paper Overall at the 2014 WIOA Qld Conference

Hydrogen sulphide generation associated with the operation of Redcliffe Sewage Treatment Plant (STP) in South-East Queensland had been a major issue for several years. There was severe damage to structures and equipment at the plant due to sulfuric acid attack (Figures 1 and 2), as well as complaints from the public. Over the years steps were taken to resolve the issue, but with little success in mitigating odour impacts on the community.

As part of the Queensland Government's water reform program, Unitywater began operations on 1 July 2010, including "inheriting" a Design, Build and Operate contract for the Redcliffe Sewage Treatment Plant (STP). The contractor went into receivership in May 2012. Within days, Unitywater took over operation of the plant. There were a number of health and safety deficiencies, but also significant effluent quality issues that needed to be addressed:

Figure 1. Existing primary clarifier flow splitter with covers removed.

- The primary sedimentation tank, the grit removal system and a secondary clarifier were all offline;
- A very high chlorine level of 14mg/L was present in the microbiological samples of 12 January 2011 (the licence limit being 0.7mg/L) and 19 January 2011. What makes this situation worse is that the majority of the flow is disinfected by UV disinfection. Only excess wet weather flows are normally chlorinated;
- A lack of biosolids records and questionable monthly quantities begged the question: where were the biosolids stored?
- The plant is required to achieve an effluent quality of 5mg/L total nitrogen (TN) and 1mg/L total phosphorus (TP) as a long-term median. The plant recorded some 20 instances of licence non-compliance during the period January 2010 to June 2012. On some occasions, the plant failed to meet licence conditions on more than one parameter. Since a failure of the single centrifuge (which was used for both sludge thickening and dewatering) in June 2011, the effluent TN results for the plant were generally much higher than 5mg/L and resulted in the continuous exceedance of the plant's short- and long-term 50th percentile limits and, at times, the maximum allowable TN limit. In addition, during this time the effluent TP results were generally above 1mg/L, which resulted in the continuous exceedance of the plant's short- and long-term 50th percentile limits and, at times, the maximum allowable TP concentration. Also, during this period there were a number of non-compliances for faecal coliforms and suspended solids.

In terms of operations, Unitywater quickly developed a prioritised Redcliffe STP Operations Transition Plan.

The major tasks identified and undertaken were:

- A general site safety audit and, in particular, engage qualified experts to determine if there were any non-

Figure 2. Inlet works with deteriorated walkways removed (left); and after making the area safe (right).

compliant electrical installations and check site chemical storage and dosing facilities for safety and regulatory compliance;

- Train staff and implement Unitywater safety systems, including organising PPE for staff and Permit to Work/Isolation Procedures;
- Investigate cost-effective means to decrease the bioreactor mixed liquor suspended solids (MLSS) inventory (until new centrifuges could be purchased and installed) to assist with effluent quality improvement;
- Ensure SCADA setup is adequate with appropriate alarms, security and software backup;
- Audit of O&M manuals, drawings, operating logs, SCADA functional specification, asset list and maintenance records;
- Establish cost tracking system to ensure Opex and Capex meets Queensland Competition Authority prudency and efficiency test.

Unitywater knew from the onset that effluent quality would not be fixed overnight, so submitted an application to the Department of Environment and Heritage Protection (DEHP) to operate the plant under a Transitional Environmental Program (TEP) in December 2012. The TEP was approved by DEHP in January 2013. The TEP covered two specific compliance issues – namely odour and effluent quality.

The TEP included:

Inlet Works

- Refurbishment and reinstatement of normal operation of the step screen.
- Reinstatement of grit vortex mixer and operational improvements to the grit removal system.

Secondary Treatment

- Stabilisation of MLSS.
- Inspection and cleaning of bioreactors, with replacement of parts where warranted.
- Improve aeration controls.
- Perform a condition assessment of the secondary clarifiers and refurbish where warranted.

Sludge Treatment and Handling

- Replace fermenter sludge pumps and repair pipework with the aim to improve the operation and performance of the digesters and sludge handling systems, and reduce the solids and nutrient loading on the bioreactors due to the return stream (i.e. centrate) flows.

- Refurbish and reinstate the existing centrifuges to enable duty/duty operation for sludge thickening and dewatering and procure and install a new centrifuge or rotary drum thickener to act as common standby to reduce MLSS concentrations within the process. This will improve the aeration efficiency and nutrient removal within the bioreactors and reduce the loading on the secondary clarifiers.

Effluent Disinfection

- Refurbishment of the UV disinfection system.

Odour Control

- Refurbish the existing ferric storage and dosing system and reinstate ferric dosing to the inlet works.
- Reinstate odour covers and ductwork at the inlet works and repair ductwork around the site.
- Carry out a condition and capacity assessment of the existing Odour Control Facility (OCF) and reinstate effective operation of the current treatment facility.
- Refurbish the sodium hypochlorite storage and dosing system and reinstate sodium hypochlorite dosing to the OCF.

Improving effluent quality proved to be a challenge, in particular the lack of nitrification. The investigation included:

- Ammonia profiling of the reactor. This demonstrated that nitrification was occurring in the bioreactor, but ammonia levels would suddenly increase within a particular cell;
- Lifting of an a-recycle pump for an electrical check. The electrician found no issues and verified the pump was rotating correctly;
- Dye testing in the reactor. The test identified short-circuiting;
- Lifting the a-recycle pump again. Electricians were puzzled because the pump VSD indicated full healthy status;
- Thinking that the pump must not be sitting properly and, therefore, pumping down the bioreactor and identifying that despite the a-recycle pump impeller rotating, flow was going in the opposite direction;
- Lifting the pump for a third time and identifying that the VSD was intermittently faulting.
- Checking the other a-recycle pumps – and finding three of four pumps with the same issue.

While it would have been easy to have said “there is something wrong with the design” and maintained the status quo of poor effluent quality, dedication by the operations and maintenance staff paid off and the real problems were identified.

As of January 2014, the treatment plant has been meeting its effluent quality requirements. To reach this stage, including addressing safety matters, Unitywater’s capital expenditure on the plant has totalled $3.2M. However, there are still many matters and operational improvements to be addressed (including a new inlet works). The Unitywater Board has approved a project to rehabilitate, renew, operate and maintain the STP for the period to 2022.

The Authors

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PUBLIC HEALTH DEPENDS ON PROPER WATER MAIN REPAIR AND DISINFECTION

Everett Baker

Some experts estimate that only about 20 per cent of waterborne disease outbreaks are reported and documented, so the problem may be much more widespread. Failure to properly disinfect new or repaired water distribution mains and finished water storage facilities and wells violates regulations and can result in enforcement action.

Many small water systems contract backhoe or plumbing contractors to repair water mains. Still, water system officials are responsible for work done in their water systems. Each system's chief operator is responsible for and must oversee any repair work to ensure contractors use approved methods.

Leak Location

The first step is to locate the leak or repair area. Before work begins, the area must be isolated to the fewest customers and the least number of water mains by locating and operating the appropriate main valves.

Water pressure of less than 20 psi presents a health hazard, because it can result in contamination of water mains and customer plumbing. The larger the area affected, the higher the probability of contamination. Shutting off a well or water tower and putting the entire system out of service creates a health hazard for the entire community. This approach isn't recommended even if a boil-water notice is issued.

Repair

No amount of flushing, disinfecting or sampling of a main after repair can make up for unsanitary handling of materials or unsanitary practices during the repair.

Trenching The repair process starts with digging a repair trench, which must be dug on both sides of the main and be wide and long enough to accommodate a trench box and access ladder. Because soil around a leaking main is water soaked and unstable, trench boxes should be used. In addition, most operators aren't willing to slope trench walls at a 45-degree angle, especially when digging is required in yards or streets. Ladders should be used to safely access and exit trenches.

The repair trench must be sized to allow an operator to safely work on the problem area with enough room to clean the area and handle repair materials in a sanitary manner. The trench must be deep enough below the main for a repair clamp or other fittings to be installed, without coming into contact with trench water or soil.

Trench Water Proper handling of trench water is essential to repairing a main break in a sanitary manner. Studies on water main breaks reveal trench water and soil are contaminated with total coliform, *E. coli* and other bacteria. Therefore, trench water must be removed from the pipe area to be repaired. Installers must ensure repair materials don't come in contact with trench water or soil during installation. This requires that trenches be deep enough to keep water below the pipe, and trench pumps must be available to control the trench water. It may be necessary to place gravel in the bottom of a trench to control mud and water splashing. If the trench pump's capacity is inadequate, work should stop until additional or larger pumps are provided to control the trench water.

Flushing Repairing water mains requires flushing large amounts of water and disposing of strongly chlorinated water. If the chlorinated water infiltrates a stream, river, lake, pond or other water body, it can lead to fish kills and regulatory violations resulting in enforcement action. In addition, strong chlorine solutions can kill vegetation and make property owners unhappy. System operators must know where the flushed water will flow and have the means to dechlorinate and properly dispose of the water.

Repair Clamps and Parts Before a repair clamp is installed on a pipe, the pipe must be cleaned of any soil and washed, using clean rags and a 1–5 per cent bleach solution. When handling strong chlorine solutions, always follow appropriate safety practices. A large plastic orchard sprayer filled with a bleach solution is the best way to provide an adequate amount of bleach for this purpose.

Just before the repair clamp is installed on the pipe, the interior of both sides of the clamp should also be cleaned and thoroughly sprayed with the bleach solution. Cleaning is easier if the repair clamp has been stored, hauled and handled in a sanitary manner before installation. In addition, it's helpful to handle the clamp with clean hands or gloves, avoid setting it in dirt or mud, and prepare it in a clean area before taking it into the trench for installation. The same procedures must be followed when installing a tapping tee or saddle, including the tapping valve, pipe, fittings and tapping equipment.

Pressurised Repair These procedures must be followed even if the main is repaired while it remains full of water pressurised at 20 psi or more. For systems that provide continuous disinfection and maintain adequate disinfection residuals in the distribution system, leaks repaired under pressure present little danger of contamination and may not require disinfection after the repair. However, if a system doesn't provide continuous disinfection or if the main isn't repaired under pressure, disinfection is required.

Open-Cut Repair If a main must be cut open for repair, surrounding dirt must be removed to allow cleaning of all areas that may come into contact with repair fittings. The interior and exterior of each end must be cleaned of soil and washed with clean rags and a 1–5 per cent bleach solution. If a strong chlorine solution can be safely flushed from the affected area, calcium hypochlorite tablets should be placed in the ends of the pipe. Before doing so, all service lines in the affected area should be turned off to prevent strongly chlorinated water from entering customer plumbing. Use a food-grade adhesive to keep the tablets in place. The required number of tablets varies based on pipe diameter and length.

The interior of couplings, repair pipe and other fittings must be cleaned and washed with a bleach solution just before installation. Depending on the repair pipe length, a cloth swab soaked in bleach may be needed to clean and disinfect the pipe's interior. Both exterior ends of the repair pipe must be cleaned and disinfected in the same manner as the water main ends. Ensure couplings and repair pipe aren't contaminated with soil or trench water during installation. The same procedures must be followed when replacing or installing a new valve, elbow, hydrant or flushing device.

Disinfection

When repair is completed, the affected section of the main should be slowly filled with water to displace any air. If chlorine tablets are placed in the main, they should remain in place for several hours to allow the chlorine to dissolve and the repair area to be disinfected.

The amount of time required to disinfect a main depends on the strength of the chlorine dose. For example, if a 100-mg/L dose is used, the tablets must remain for three hours. Next, the chlorinated water should be flushed from the main and properly handled. Provisions to remove the strong chlorine from the water may be necessary.

If chlorine tablets aren't used, the affected section of main should be flushed at scouring velocities to remove dirt or colored water, and disinfected. Table 1 shows the velocities that must be reached in water mains of different sizes to provide adequate flushing.

Table 1. Required Flow to Maintain Residual Pressure.

Pipe Diameter (in.)	Flow (gpm)	Number of 2.5-in Hydrant Openings
2	26	1
2.5	38	1
3	60	1
4	105	1
6	225	1
8	400	1
10	600	1
12	900	2
16	1,600	2

These velocities must be reached to provide adequate flushing.

The affected section of the main should be flushed and chlorinated in the same way as a new water main. AWWA Standard C651, 'Disinfecting Water Mains', recommends flushing and chlorination where practical; a situation isn't impractical just because a system or its contractor doesn't have the necessary equipment or doesn't want to make the effort. Three chlorination methods are presented, but two of the methods – using calcium hypochlorite tablets or granules – work only if the main is cut open for repair. The third method is continuous feed.

To use the continuous-feed method, the system or its contractor must have the necessary equipment to feed a chlorine solution into the water main. Basic equipment consists of a tank to hold the chlorine solution and a pump to force the solution into the water main. The solution tank should be polyethylene with a tight-fitting lid and valved fittings to connect the pump and tank.

Tank size depends on the length of water line to be disinfected, but tanks larger than 50 gal are difficult to move by hand. Pump size also depends on the amount of line to be disinfected, but a 5-gpm pump should be adequate for most repair jobs. If an electric pump is used, a portable power source must be available. The pump must include hoses and fittings to connect it to the solution tank and to the water main.

A valve should be provided on the discharge side of the pump to control pump output. The volume of chlorine solution to disinfect a water main is small if it's injected directly into the water main as shown in Table 2.

Table 2. Chlorine Required to Produce Desired Concentration.

Pipe Diameter (in.)	1% Chlorine Solution (gal)
4	0.16
6	0.36
8	0.65
10	1.02
12	1.44
16	2.60

Inject chlorine solution directly into a water main to minimise required volume.

However, if an existing service line is used to inject chlorine into the main, the service line's entire volume must be displaced to get chlorine to the main. For example, 100ft of 3/4-in. diameter pipe contains 2.77 gal of water, and 100ft of 1-in. diameter pipe contains 4.04 gal of water. If solution is pumped through a fire hydrant, the entire volume of the fire hydrant and its leg line must be displaced to get chlorine to the main.

No amount of flushing, disinfecting or sampling of a main after repair can make up for unsanitary handling of materials or unsanitary practices during the repair. For example, it's helpful to handle a repair clamp with clean hands or gloves, avoid setting it in dirt or mud, and prepare it in a clean area before taking it into the trench for installation.

In addition, 10ft of 6-in. diameter pipe contains 14.7 gal of water. If a service line or hydrant isn't available, a tap should be made to the water main near the isolating valve upstream of the line break.

Before starting the chlorination process, all service lines in the affected area should be turned off to prevent strongly chlorinated water from entering customer plumbing. After a chlorine source is connected to the water line, a hydrant or flushing device downstream of the repair site should be opened, and the isolating valve upstream from the repair should be opened partially to provide a low flow of water through the main.

At the same time, chlorine solution is pumped into the main until at least a 25mg/L residual is obtained at each hydrant or flushing device in the affected area. If there are multiple hydrants or flushing devices, they should be opened in succession until at least a 25-mg/L residual is measured at each.

Hydrants or flushing devices and the isolating valve are shut off after the desired residual is obtained. After 24 hours, the chlorine residual in the main should be at least 10mg/L. If it's less than 10mg/L, the chlorination process should be repeated.

Most water system operators don't want to wait 24 hours before restoring service to customers. Fortunately, the contact time required to disinfect a main can be reduced if the chlorine residual is increased. If the chlorine concentration is increased to 100mg/L, the contact time can be reduced to three hours. During the process, the chlorine residual shouldn't drop below 50mg/L. If the dose is increased to 300mg/L, contact time can be reduced to 15 minutes. However, you must safely dispose of the strongly chlorinated water.

Flushing And Advisories

After disinfection, the affected area must be flushed to remove air, contamination, or coloured water and until chlorine residuals are less than 4 mg/L. Service to customers can then be turned on and the main returned to service. Most homes are higher than the water mains. If pressures are low in a main, they will be even lower in household plumbing. Therefore, it's important to notify each customer that a main repair involving possible low water pressures has occurred.

The notice should advise each customer to flush all plumbing on their premises to remove any contamination, air or coloured water before they use the water. The notice must also advise residents to boil water for drinking or culinary purposes and ask them to notify the water system if they notice any colour or odour (other than chlorine) in the water. These advisories can be hand delivered using doorknob hangers or door stuffers or distributed electronically.

Advisories shouldn't be lifted until special water samples are collected upstream and downstream of the main repair and are negative for coliform bacteria. If a large area of the system was affected, more than two water samples may be required. The system operator should contact the appropriate regulatory authority for guidance. If any sample is positive for coliform bacteria, an advisory must continue, additional disinfection and flushing are required, and system operators should contact the appropriate authority for guidance.

The Author

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TUNING BNR PLANTS

Ken Hartley

In yacht racing, the competitors may use seemingly identical craft, but only a few are consistent winners. The winners have developed a deeper understanding of their operating environment (wind and water), of the behavioural characteristics of their vessels, and of the tuning techniques and sailing strategies that achieve optimum results over a wide range of racing conditions.

STP operators have the same challenge to tune their plants to achieve and maintain peak performance, or achieve maximum capacity. Tuning increases performance, highlights bottlenecks limiting capacity, and reduces operating costs.

Plant process behaviour is subject to climatic influences and the natural performance variability of all biological systems. The process loading (sewage flow and organic loading) is also variable because of seasonal, diurnal, social and statistical influences. Treatment plants, therefore, need to be continuously optimised to maintain best performance under variable loading conditions.

Conscious effort applied to any area of human activity, including sporting pursuits, results in improvement in performance. Such improvements have been demonstrated repeatedly in construction, manufacturing and chemical processing operations and the curves of gradually increasing production rate, improving performance and decreasing cost are called learning curves.

Figure 1 shows the improvement in effluent quality after startup of a new BNR plant. Nitrogen improvement was rapid because it relied only on optimum tuning of the DO. However, improvement of P removal was slower as it depended on the tuning of an activated primary tank pre-fermenter to enhance the feed VFA level and associated development of a population of phosphate-accumulating organisms.

Evolutionary Operation (EVOP)

The actual capacity and performance capabilities of an operating plant are nearly always different from the original design values. This arises because of design and construction margins, influent flow and quality characteristics differing from design, and the accumulation of specific operational know-how on the plant, which improves performance and enables bottlenecks to be identified and overcome.

Three key factors have been identified as the basis for learning and improvement in complex activities.

1. Deliberate effort is needed.
2. You have to believe that improvement is truly possible before you will seriously look for it.
3. Delays or interruptions to the improvement process result in "forgetting", and progress is inhibited or regresses.

As applied to STPs, the fundamental philosophy of EVOP is that the plant should always be *operated* and *monitored* so as to deliberately improve the operators' understanding of its behavioural characteristics and allow its performance and/or capacity to be continually improved.

The basic tuning strategy is as follows:

1. Define goals and set targets.
2. Adjust the plant control variables.
3. Measure the outcomes.
4. Interpret the data and develop ideas for improvement.
5. Re-adjust the process.
6. Conduct trials and tests on specific processes or the whole plant.

In simple terms the three basic steps to EVOP are Measure, Interpret, Act.

EVOP applies to improvement in plant capacity as well as performance. Capacity can be increased by overcoming plant bottlenecks. A good example is the distribution of load to parallel process trains. With optimum flow distribution all parallel trains will fail at the same time; one train failing before the others wastes unused capacity in the non-failing trains. As a rule of thumb, if one train in a plant receives 10% more than its optimum share of the load, the total plant capacity is reduced by 9%; or putting it another way, the plant capacity can be increased by 10% simply by redistributing the load.

Most performance improvements are slow. For example, the full effect of a change in the biological solids retention time is not seen for three times the change in SRT. The improvement process is ongoing. The EVOP program should be integrated with the regular plant monitoring and control program. Plant data are collated, analysed and reported at regular intervals (typically monthly) and when specific test programs have been undertaken. The operational

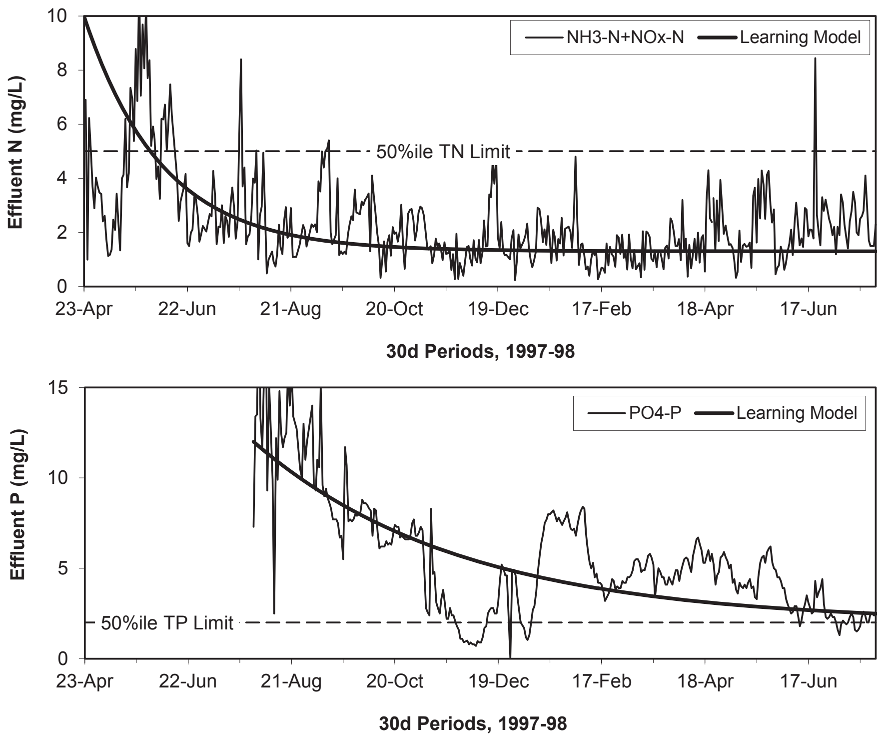

Figure 1. Effluent N and P during the startup phase of the new Thorneside BNR plant – an oxidation ditch with online activated primary tank (APT) prefermenter and anaerobic pre-reactor.

group meets at regular intervals to review the process data, provide helpful analysis and stimulate a flow of new ideas to be incorporated in the investigation. Current progress is openly shared to facilitate input and feedback from all plant personnel.

Tuning a BNR plant can be complex, with many interactions between process variables. To achieve good performance it is essential to collect operating data and review performance on a regular basis. Some general principles are as follows:

1. Biological processes are susceptible to rapid upset but are very slow to recover. It is therefore essential to monitor plant performance closely in order to identify any upsets and initiate recovery action as early as possible.
2. It is difficult to have too much data. Do not skimp on analytical effort and ensure that plant instruments are regularly calibrated and maintained.
3. Maintain trend plots of key parameters and examine all results regularly to catch problems early.
4. Look for interactions between and within processes so that understanding of the plant's operating characteristics can be actively enhanced. When opportunities present, conduct special tests to improve understanding and quantify operating characteristics.
5. Be aware of interactions between processes and the likely effects that changes to one process may have on others.
6. Best results are achieved if process operating conditions are maintained as constant as possible. Keep process operating adjustments to the necessary minimum. Ensure process equipment is reliable.
7. Be patient. The full effects of many operating adjustments are not evident for 2–3 solids residence times, even for changes seemingly governed by hydraulic residence time. This is because associated changes in biomass composition are often involved.
8. With statistical licence limits a good operating strategy is to operate routinely as far below the limits as is practicable or economic. This provides a statistical buffer against periods of upset.

A typical suite of plant trend plots may incorporate 25–30 plots displaying 80 or so individual parameter trends. They can most conveniently be displayed five to an A4 page, facilitating comparison of trends.

Figure 2 shows two example plots developed over the first two years or so of plant operation, both highlighting useful plant operating characteristics.

Figure 2(a) shows clearly that alum and ferric dosing (ferric for sulfide precipitation at the plant inlet, alum direct to the oxidation ditch to further supplement bio-P removal) increase effluent SS by reducing the floc size distribution. The 60-day (3SRT) moving average chemical dose rate tracks the effluent SS concentration quite well. The parameter scales are selected to match the trends and highlight the relationships.

Figure 2(b) highlights the inverse relationship between sludge SVI and belt press cake TS concentration. The two y-axis scales are chosen to match up the plotted parameters – in this case the scales are reversed. This plot shows clearly that operation of the bioreactor to minimise the SVI can increase the dewatered cake TS from 13% to 15%, significantly reducing disposal cost.

Many such operating characteristics can be discerned, and taken advantage of, using this trend plotting technique.

The table overleaf summarises potential tuning methods to:

1. Meet environmental quality standards in the effluent;
2. Meet environmental quality standards in the biosolids;
3. Meet environmental quality standards in the atmosphere;
4. Reduce plant operations and maintenance expenditure;
5. Maximise plant operating capacity.

The Author

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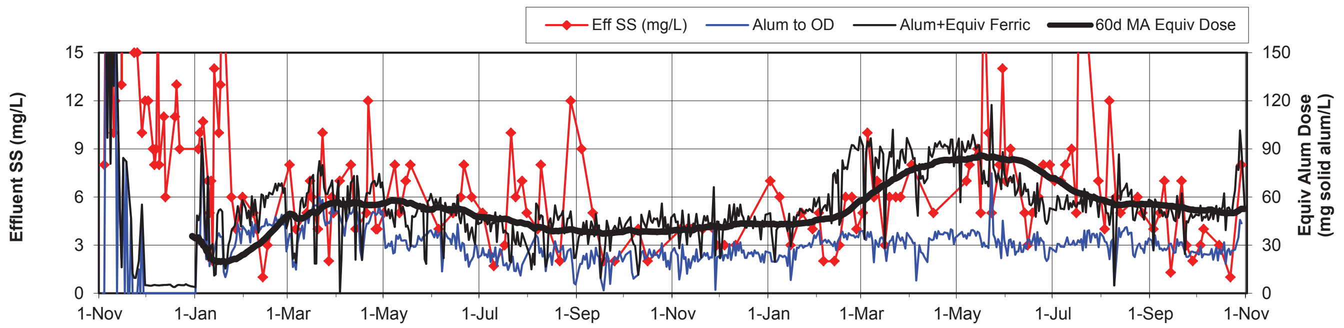
a) Two-year trends from startup of an oxidation ditch plant in Nov-05. Correlation between effluent SS and 3SRT moving average precipitant dose. Median MLSS and unstirred SVI were 3.2 g/L and 80 mL/g respectively.



b) The first eighteen months operation of another oxidation ditch plant, starting Feb-11. Effect of sludge SVI on BFP cake TS.

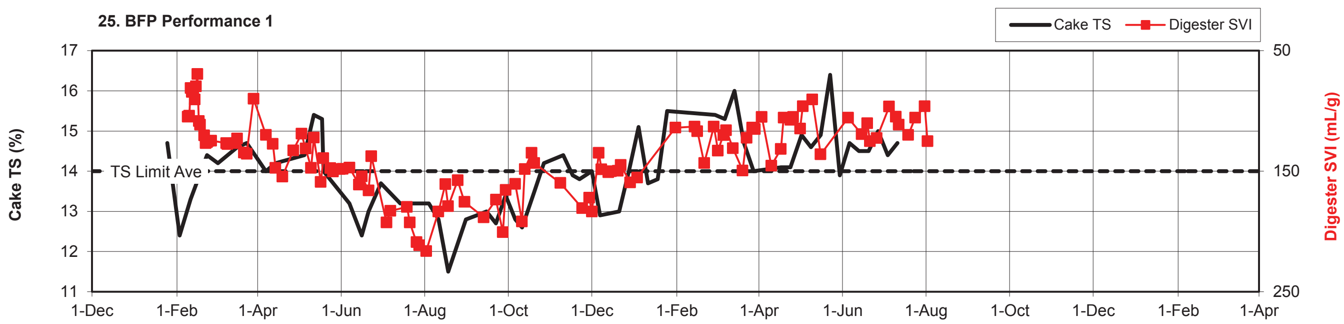


Figure 2. Examples of useful plant operating characteristics developed during the early operating period.

POTENTIAL TUNING METHODS	1. Meet Environmental Quality Standards – Effluent		
Parameter	**Typical Standard/ Performance**		**Potential Tuning Methods for a Continuous Flow Process**
	Median Limit (mg/L UNO)	**90:50%ile**	
BOD	5	2	Increase SRT to minimise soluble carbonaceous BOD
			Minimise SS to minimise particulate carbonaceous BOD (refer parameter SS)
			Minimise NH_3-N to minimise nitrogenous BOD (refer parameter NH_3-N)
SS	5	2.5	Operate all secondary clarifiers to minimise overflow rate
			Reduce effluent nitrate level to avoid clarifier rising sludge
			Reduce clarifier scraper speed to avoid blanket disturbance
			Reduce turbulence levels ahead of clarifiers to minimise floc breakup
			Reduce Al or Fe dose ahead of clarifiers to minimise floc size reduction
			Operate at SRT above 8 days
			Operate at MLSS above 3 g/L
			Operate at unstirred SVI above 200 mL/g
			Operate at sufficient RAS recycle ratio during high flows
Nitrogen			
NH_3-N	0.5	4	Increase DO concentration (reduce effluent NH_3-N)
			Increase SRT
			Increase pH
			Dose alum
			Increase aerated mass fraction of biomass/decrease unaerated fraction
			Optimise biological P removal
			Increase plug flow character of bioreactor
			Increase temperature (not generally applicable)
			Reduce influent variability
			Reduce influent salinity
			Reduce industrial wastewater inputs
			Minimise recycle from sludge system
NOx-N	–		Increase anoxic mass fraction of biomass (increases effluent NH_3-N)
			Reduce DO in recycle streams
			Reduce aerobic zone DO to stimulate simultaneous N/DN (reduces nitrification)
			Reduce RAS ratio to denitrify RAS flow (reduces clarifier capacity; may cause rising sludge)
			Dose organic carbon Minimise recycle from sludge system
Soluble organic N	–		Dose alum or ferric
Particulate organic N	–		See SS item above
TN	5	2	See four Items NH_3-N to Particulate organic N above
Phosphorus			
PO_4-P	–		Eliminate DO input to anaerobic zone
			Eliminate nitrate recycle to anaerobic zone
			Eliminate sulfide input to anaerobic zone
			Increase influent RBCOD by:
			Sewage holdup/fermentation in influent sewer system
			Enhancement of pre-fermenter performance
			Recycling from an anaerobic digestion/sludge dewatering system
			Dose VFA – propionic in preference to acetic
			Increase process anaerobic mass fraction
			Shorten process SRT
			Increase ML pH – by increased denitrification or chemical dosing
			Dose alum or ferric
			Minimise recycle from sludge system
Soluble organic P	–		Dose alum or ferric (organic P conc is generally low)
Particulate organic P	–		See SS item above
TP	1	2.5	See three items PO4-P to particulate organic P above
pH (units)	6.5–8.5 range		Maximise denitrification in bioreactor and aerobic digester (for low pH – high pH is unusual)
			Enhance bio-P removal; reduce alum dosing
			Dose alkali
Faecal coliforms (cfu/100 mL)	10	10 (1 log)	Process alum dosing increases UV transmissivity, reduces chlorine demand and reduces F. cols in contactor influent

2. Meet Environmental Quality Standards – Biosolids		
	Min/Max Limits	
Anaerobic digestion VS reduction/gas production	38% min reduction	Increase process SRT – thicken feed
		Arrange process as cells in series
		Increase process temperature
		Increase process pH – dose alkali as necessary
Aerobic digestion SOUR	1.5 mgO2/h/gTS max	Increase process SRT – thicken feed
		Arrange process as cells in series
		Maintain process pH>6.0 – aerate intermittently to dentrify; dose alkali as necessary
3. Meet Environmental Quality Standards – Atmospheric		
Odour		Quantify/address sources
		Reduce influent sulfide
Nitrous oxide		Quantify/address sources
4. Reduce Plant O&M Expenditure		
Reduce electricity consumption	Off-peak operations; operate equipment only when necessary	
Flow-dependent power	Appropriate pump size, variable speed control	
Load-dependent power	Variable load control	
Fixed power	Operate equipment only when necessary	
Reduce chemical consumption		
Metal salt	Enhance biological performance to minimise chemical supplementation; optimise pH; alternative chemical	
Alkali	Maximise denitrification	
Carbon source	Increase influent COD:TKN ratio	Vary primary effluent quality
Disinfectant	Increase contact time; reduce disinfectant demand	
Polymer	Optimise sludge dewatering	
Substitute cheaper chemical	Compare relative quantities required and commercial prices	
Reduce biosolids disposal/reuse cost	Maximise dewatered sludge TS	
	Reduce TS production:	
	Optimise PST performance	
	Increase SRT	
	Minimise precipitant dosing, liquid &/or solids stream	
	Increase bioreactor SRT	
	Increase digester SRT	Thicken feed
	Optimise digester operation – temperature, pH, mixing regime	
	Increase beneficial return from sale of biosolids:	
	Increase sludge stability	
	Reduce sludge chemical content; modify chemical content	
Minimise total expenditure	Define minimum total cost (sum of interacting components)	Minimum total may not be the sum of individual minima
Minimise N & P recycles from sludge system	Denitrify aerobic digesters by intermittent aeration	Also reduces alkali requirement
	Precipitate P released in digester – alum or ferric	Chemical consumption less than in liquid stream due to higher P concentration
5. Maximise Plant Operating Capacity in order to Maximise Operational Robustness & Defer/Minimise Further Capital Expenditure		
Flow distribution	Distribute load to parallel modules in proportion to their individual capacities	For maximum operating capacity, all parallel modules should fail at the same time
Effluent quality variability	Minimise effluent quality variability to maximise the average load at which the effluent quality standards can be met. Determine the reasons for performance excursions and implement preventive action	Assuming the licence has percentile limits
Sludge settleability	Minimise SVI to maximise biological process capacity	Clarifier capacity is often a bottleneck
SRT	Operate at the shortest practicable SRT to meet the effluent standards	Maximises hardware capacity
RAS ratio	Operate at maximum practicable RAS ratio	Maximises clarifier wet weather capacity
Process controls	Set up and tune process controls to enable all process parameters to be reliably maintained at the desired set points	Good control minimises effluent quality variability and maximises capacity
Plant operating characteristics	Use the EVOP mode of operation to increase understanding of the plant operating characteristics and facilitate ongoing improvement of capacity and performance	Low-cost enhancements of performance and capacity can be achieved by overcoming defined bottlenecks

TECHNICAL ASSESSMENT AND MENTORING PROJECT FOR REMOTE PLANTS

Michelle Hill & Dave Cameron

Queensland is a big state. There are many small to medium sized water Treatment Plants (WTPs) scattered across rural and outback areas with limited access to specialist technical expertise.

In May 2013, *qldwater* secured a grant from Skills Queensland (now the Department of Education, Training and Employment) to undertake a project trial in two stages, focused on support for drinking water operators in small and remote communities.

The project targeted two key regions: Longreach and Central West Queensland as well as South Burnett and Toowoomba regions and surrounds. The following Councils were participants in the project:

Longreach Region – Phase 1

- Longreach Regional Council
- Barcoo Shire Council
- Barcaldine Regional Council
- Diamantina Shire Council
- Boulia Shire Council

Burnett Region – Phase 2

- South Burnett Regional Council
- North Burnett Regional Council
- Banana Shire Council
- Cherbourg Aboriginal Shire Council
- Bundaberg Regional Council (training and mentoring)
- Toowoomba Regional Council (training and mentoring)

The main components of this project were:

- Water Treatment Plant/Systems technical assessment;
- Training needs analysis;
- Workforce planning analysis;
- Training workshop development and delivery (alignment with Drinking Water Quality Management Plans);
- Development and implementation of an industry mentoring program;
- Development of communication strategies and continuity plan to ensure the outcomes and learnings can be applied in other regions.

Bruce Murray gets a closer look at the Cherbourg Water Treatment Plant.

A total of 22 WTPs and five disinfection-only water supply systems were visited by the technical consultants (and *qldwater* staff). A full technical report for each treatment plant and water supply system, including suggested improvement actions, was provided to each council involved.

The site visits by the technical consultants uncovered some recurring issues at many of the treatment plants including:

- Limited operator knowledge of coagulation control and jar testing;
- Poor condition of many of the filters;
- Limited knowledge of filter operation;
- Poor process monitoring, limited reporting to management;
- Lack of suitable instrumentation for the plant, both online and laboratory instruments;
- General lack of critical alarms.

Peter Mosse (left) gets a rundown on the plant from the Biggenden Treatment Plant Operator.

A cheery training group at Mundubbera WTP.

The improvement reports developed from the initial visits focused on what could be done to optimise processes for existing plant, rather than what sort of plant should really be there, but in a number of instances significant repairs were necessary. In these circumstances, while up-skilling and training is essential, it is also important that operators have access to appropriate equipment for ensuring drinking water quality and safety. The project has provided a valuable opportunity for councils to consider how process improvements can be made through simple modifications and adequate training for staff on plant optimisation and troubleshooting. In addition, they now have important advice to support maintenance programs and future capital purchasing decisions.

A further outcome was the delivery of targeted training to overcome some of the deficiencies in knowledge identified during the technical visits. A two-day combined Coagulation, Flocculation, Jar Testing and Filter Operation course was developed. This has now been delivered in Longreach, Wondai, Mundubberra, Bundaberg and Gympie.

Operators from a broad area of Queensland have participated. These training workshops were very well received by the operators in attendance, and the practical nature of the workshops ensured that training could be easily transferred to on the job tasks. Each training workshop was attended by nine operators from the various Councils in the region (nine was the maximum due to the practical nature of the training) to allow the course to remain practically focused.

The training included a half-day theory followed by practical onsite training at the water treatment plant for the remaining 1.5 days. This training was very well received by the participants, and feedback on the value of the training from the employers was extremely positive. Participants were encouraged to take a systems view, investigate and trial, all the things that are critical to drinking water treatment processes but are not always practically covered through completion of Certificate III Water Operations.

Not only were these workshops an opportunity for operators to receive practical training at an actual WTP, they also provided a forum for operators from the different regions to initiate information sharing and collaborative opportunities. An example of the success of this approach is evident through the Supervisors at North and South Burnett Regional Councils now regularly contacting each other to discuss common issues.

The *Technical Assessment and Mentoring for Remote and Regional Drinking Water Services* project has been highly successful and well received by the industry. The project has provided an opportunity for water service providers to critically analyse the operation of their WTPs and water supply systems, and their approach to operator training and workforce development.

At the outset of the program, there was strong support from industry and enthusiasm for a new approach to workforce development and up-skilling for operators. Sourcing organisations to participate in the project was, therefore, an easy process. The WTP operators involved directly in the practical side of the project have been enthusiastic and welcoming of the project goals and have provided positive feedback on the technical support and training provided through the program, leading to more of this training being delivered in these and other regions. Further, many operators are keen to be involved in future mentoring and operator exchange opportunities that will inevitably result from the project.

The project links well with *qldwater*'s efforts to promote the uptake of operator certification in Queensland, providing some important skills and improving planning for learning and development. In addition, the regional collaborative approach has meant that participants in the technical assessment and mentoring program have been able to join with those in the certification pilot to create larger cohorts of trainees for Certificate III training, leading to more cost-effective, face-to-face training delivery. WIOA is acting as the certifying body for the pilot, and the strong linkage between WIOA and *qldwater* continues to provide new opportunities for operators in Queensland.

Other beneficial outcomes from the project include the trial of an equipment sharing process between water organisations. Arrangements have been made for larger water service providers to share their equipment no longer in use (e.g. from recently decommissioned plant) with smaller regional councils. These smaller councils often lack the required funding to purchase new equipment and the establishment of these processes will critically assist monitoring, giving operators and managers better data to inform decisions. The first of these trials currently underway is for online turbidity meters from Westernport Water in Victoria being installed at the Longreach WTP. Depending on whether this proves cost effective and successful, additional projects will be implemented. Seqwater has indicated its willingness to participate, with some considerable equipment potentially available.

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UNCOVERING THE SOURCE OF HYDROCARBONS IN DRINKING WATER

Steven Newham
Winner of Best Paper by an Operator at the 2014 WIOA Victorian Conference

In October 2013, Goulburn Valley Water (GVW) received a call from a business in Shepparton complaining that the water had a horrible chemical taste and was undrinkable. The initial sample obtained from the customer's sink confirmed the presence of a 'solvent' odour and the immediate response was to provide the customer with bottled water while some analysis was carried out. The customer was advised not to drink the tap water until further notice.

On investigation, it was noted that the property adjoining the business was an automotive paint shop. The initial thoughts were that the source of the contamination could be from a cross-connection between the premises, since there were no similar complaints from surrounding properties. Both properties were sampled for hydrocarbon analysis and an urgent turnaround requested from the laboratory. Results were received two days later and showed high levels of toluene and xylene and other monocyclic aromatic hydrocarbons, which were above the ADWG health guidelines. However, the contamination was only present in one of the samples.

A property history check revealed that three lots had been created from the original property and that the owner was a plumber. Assuming the possibility that the plumber could have done something creative with the plumbing, the theory that the source of contamination may be a cross-connection was further supported.

A site inspection was promptly undertaken and it was again noted that the internal tap had a strong solvent odour. All three properties were inspected and the following observations made:

- There was no ring service from any of the properties;
- There was no evidence of tampering or illegal connection;
- Audio testing for meter noise and illegal bypass or leak revealed nothing abnormal;
- The properties were on separate service lines;
- When the meters were isolated there was no flow to the premises;
- None of the properties had a rainwater tank or pump;
- The meters had not been tampered with and check valves were correctly in place. Each service had two check valves in the meter, a jumper valve in the RA meter stop and potentially an additional jumper valve in the service ferrule;
- The property in question did not have a hot water service.

The entire paint shop premises were inspected with no area off limits. There were no signs of spills, spraying, industrial use of paints or large-scale batching at the paint store. The paint storage area was inspected and there were no vats or buckets with hoses in them, or evidence that there may have been siphoning occurring.

GVW Maintenenace Operations confirmed that there had been no mains bursts on the water main in question and none in the surrounding area recently. Property consumption was checked and found to be consistent with previous reads, indicating no major internal leaks.

This left only four plausible options for the source of contamination:

1. Syphoning from the toilet cistern. Unlikely, but yet to be checked;
2. Another cross-connection from a property to the south or west. Unlikely, given that the customer had no water when the stop tap was turned off. The property to the south was a Food Store/ Warehouse Distribution. The property to the west was residential;
3. GIS showed an old scrap caryard to the north where work had been undertaken recently. Unlikely, given the highly odorous contaminant, as this would have instigated widespread complaints. This was also supported by laboratory analysis of the water from the neighbouring paint shop. Additionally the customer with the contaminated water stated that the issue arose before the site was cleared for the construction of the new building;
4. An unknown issue with internal plumbing. An old repair on an internal property water pipe evidenced by the installation of an isolation valve within the property.

The site investigation was thorough and ruled out a cross-connection to the paint shop, but was ultimately inconclusive. Because of this a new sample point was installed immediately prior to the customer's water meter, and further sampling undertaken from the original sample point at the customer's sink and the new sample point at the water meter. Following this, the service was flushed as hard as possible through the customer's sink and the above samples repeated. The laboratory was also requested to undertake further testing of the original sample to provide a hydrocarbon fingerprint of the contamination.

The hydrocarbon fingerprint results from the laboratory for the original sample showed no exact match with any petroleum reference chromatograms. However, the laboratory stated that the fingerprint was consistent with contamination by light petroleum distillates such as mineral turpentine or petrol or petrol product.

The results confirmed that the contaminant was still present within the property *but not present* at the new sample point installed at the water meter. This confirmed that the issue was isolated to the single customer and did not originate from the GVW supply. Although GVW was no longer obligated to resolve the issue, the investigation to find and isolate the source of the contamination continued, as the levels of contamination were considered a health risk to the customer.

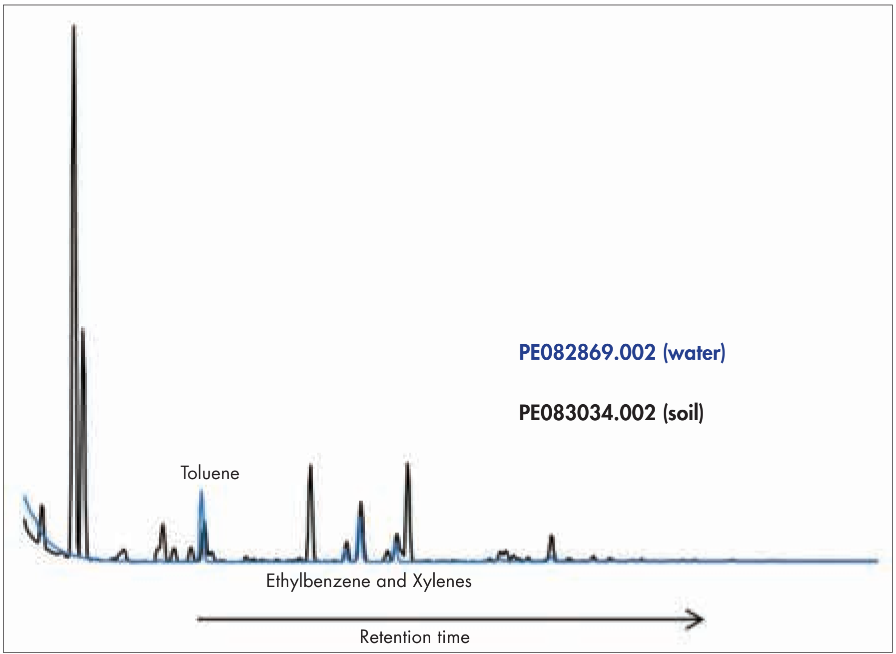

Figure 1. The fingerprint chromatogram comparison for the water and soil samples.

The site was attended once again and this time the toilet cistern was dye-marked with fluorescein, confirming no siphoning. It was found that the customer's sink still had a strong solvent smell and it was during this inspection that a small amount of oil was noticed between the buildings, which was in line with the internal plumbing and almost directly above the old repair identified by the tenant.

After returning to the office, the words "toluene leaching residential fittings" were entered into an internet search engine. The very first result returned was a US EPA paper on *Permeation and Leaching*, which included case studies of petroleum products permeating plastic piping. This led us to revisit the suspected contaminated area and take soil samples. Surface trash was removed and a first soil sample taken from the top 25mm of ground, comprising crushed rock and debris.

The pipe trench was then exposed to the same depth as the internal water pipe and a second soil sample taken from the sidewall of the trench. The area did not have an odour until the surface was disturbed. It was then noted that the soil was extremely odorous, with a strong smell of solvents. Despite warning the laboratory, the content was even higher than they were anticipating and they had to analyse again at an even higher dilution range to obtain reportable values.

The chromatogram comparison between the water and soil samples (Figure 1) had close matches for toluene, ethylbenzene and xylene, confirming the contaminated soil was the source of the drinking water contamination. A hydrocarbon fingerprint of the samples was unable to identify a unique match; rather, it appeared to be a cocktail of contaminants, similar to mineral turpentine, degreaser, high octane petrol, WD40, light distillates and possibly two-stroke engine oil – which indicates that the area could have been a dumping ground for petroleum products for quite some time.

Figure 2. The original repair; rural grade poly pipe.

The issuing of the formal letter advising both the owner and the tenant that the water contamination originated within the property – and that the water was not suitable for consumption – eventually led to the owner relocating the internal pipework to by-pass the contaminated soil.

After the owner relocated the pipe, the area of contamination was excavated to identify the pipe material and it was found to be Rural Grade Poly Pipe (Figure 2). This was significant as it confirmed the contamination was via permeation of plastic piping.

The type of contamination and location adjacent to a paint shop initially led the investigation in the wrong direction of a cross-connection. Future incidents of this type of contamination will lead to a search in the vicinity for contaminated soil.

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A LONG ROAD TO FLUORIDATION FOR PORT MACQUARIE AND HASTINGS

Terry Randall & Murray Thompson
Winner of the Best Operator Paper and Best Paper Overall at the 2014 WIOA NSW Conference

Fluoridation of the Port Macquarie-Hastings Water Supply Scheme was first addressed by the former Port Macquarie Municipal and Hastings Shire Councils prior to amalgamation in 1980. The Councils resolved to defer a decision on fluoridation for the newly constituted Hastings Municipal Council in 1981.

Fluoridation was not considered again until 1985 when a series of reports and discussions on the issue over several years resulted in the decision to hold a referendum on the issue at the September 1991 Local Government election exactly nine years after the initial deferral decision by the two former Councils. The poll results were 20,533 votes saying "No" to fluoridation and 8,198 saying "Yes". Based on these results, Council resolved not to fluoridate, but acknowledged the dental health benefits provided by fluoride and resolved to lobby NSW Health for an upgrade of dental services in the local area.

The issue of fluoridation remained dormant until 31 May 2004, when Council resolved to have the question of fluoridation of the water supply scheme determined by an expert committee appointed by NSW Health. Council also requested NSW Health to fund 50 per cent of all the recurrent costs associated with the operation of the fluoridation plant, which included chemicals, water testing, maintenance, repairs and future refurbishment costs.

The Fluoridation of Public Water Supplies Committee determined that fluoridation should be introduced to the Port Macquarie-Hastings Water Supply Scheme. Council was directed by the Director General of NSW to fluoridate the water supply scheme (NSW Government Gazette No, 131, 6 August 2004) in accordance with the requirements of the *Code of Practice for the Fluoridation of Public Water Supplies*, *Fluoridation of Public Water Supplies Act 1957*. The funding request was declined leaving Council with costs in the order of $250,000pa, plus the ongoing depreciation of the assets.

During the latter half of 2004 and early 2005, Council staff made contact with a number of water authorities that owned and operated large fluoridation plants to request information in relation to the design, construction and operation of these facilities. A number of site inspections were also arranged with staff travelling to Brisbane, Newcastle, Sydney and Melbourne to inspect these facilities and discuss related issues with management and operational staff members.

In November 2005, Council approved a development application of a centralised 120ML/day capacity fluoridation dosing plant located at the Rosewood Reservoir site.

Hunter Water Australia (HWA) was engaged by Council to develop and review suitable options and to provide a recommended concept design for the fluoridation dosing facilities to meet all the requirements of NSW Health's *Code of Practice for the Fluoridation of Public Water Supplies* and also ensure the "least operational cost" for Council of all future operational, maintenance, repair and asset refurbishment commitments.

The concept design prepared by HWA was then independently reviewed by the NSW Department of Public Works (PWD) and developed by PWD into detailed design plans and specifications.

In March 2006, Council submitted to NSW Health its 'Form 1 Application' for the fluoridation of the Hastings District Water Supply Scheme for review and also referral for approval to the Fluoridation of Public Water Supplies Advisory Committee. This application included detailed design drawings, contract specifications, procurement strategy and a preliminary capital cost estimate of $1.89M.

In July 2006, Council received a reply from NSW Health indicating that a maximum subsidy of $650,000 only would be approved for the construction of the Rosewood Fluoridation Plant. This maximum subsidy-funding amount was based on advice that NSW Health had received from NSW Office of Water.

In August 2006, Council requested both NSW Health and NSW Office of Water to provide a detailed response listing all the design points of concern and cost-effectiveness issues raised in relation to the submitted design and specifications. This was requested in order for Council to review this information and provide an informed response to these concerns and then be able to advance the project to construction.

While awaiting this advice from NSW Health and NSW Office of Water, Council re-engaged HWA to independently review both the detailed designs and cost estimates prepared by PWD.

Following a protracted period of discussions, meetings, design reviews and funding negotiations with both the NSW Office of Water and NSW Health, finally in 2010 approval was granted for Council to proceed with its adopted fluoridation plant design and project procurement plan. Funding to the amount of $1.78M would be provided by NSW Health for this project.

Construction of the fluoridation plant, funded by NSW Health, was completed in November 2011. Approval to commence fluoridation of the water supply was subsequently granted by NSW Health in January 2012.

Council's procurement plan included for all site and civil construction works to be completed under a detailed design contract, which had been prepared by both HWA and NSW Public Works. This civil construction works contract included site roadworks, drainage, dosing pit and building, chemical waste tank, bunded areas, bunded area shade structure and roofing, electrical switchroom, dosing room and all associated site facilities.

A separate electrical contract was used to procure a Type 3B electrical

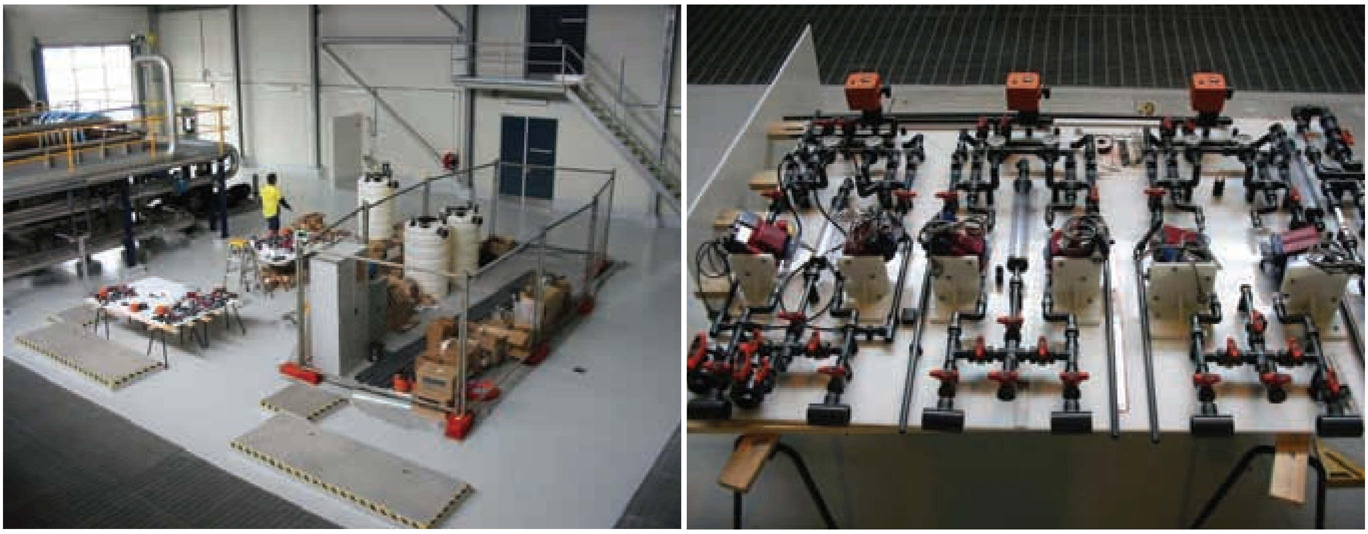

Figure 1. Wauchope WTP with the fluoridation dosing system work area (left) and final dosing system configuration (right).

control switchboard, based on a detailed design completed by Council and NSW Public Works. This contract included programming of the local PLC and OMI display screen, based upon a detailed design control philosophy that had been developed and documented by Council and PWD.

The supply and installation of all the dosing system plant, equipment, pipework and instrumentation would be completed by Council staff and selected local contractors who had previous experience in the construction of liquid chemical dosing systems.

To facilitate the completion of these complex dosing system works, a work area was established at the adjacent Wauchope Water Treatment Plant (WTP) (Figure 1). It was then possible for staff to work on this dosing system project in a clean and safe environment.

The detailed configuration of the required three independent dosing systems with associated pipework, fittings, valves, pumps and instrumentation required a great deal of thought and consideration. This included the selection of suitable

Figure 2. The completed fluoridation dosing system at Rosewood Reservoir.

materials and jointing arrangements to prevent possible chemical leaks, together with the positioning of these items to ensure reliable plant performance and also the need to be able to remove and replace equipment in the future. A lot of trial and error was used to develop the final dosing system configuration before the pipework and fittings were correctly positioned and constructed as shown in Figure 1.

The final fluoridation dosing plant arrangement (Figure 2) was installed onsite and successfully commissioned in February 2012.

It may have taken Council 31 years, from 1981 to 2012, to achieve the goal, but the outcome is now to provide ongoing benefits to the dental health of the local community.

The Authors

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