Performance of the full-scale biological nutrient removal plant at Noosa in Queensland, Australia: nutrient removal and disinfection

V. Urbain*, P. Wright and M. Thomas***

* ASTRAN – Lyonnaise des Eaux, C/- Australian Water Services, Level 14, 9 Hunter Street, Sydney NSW 2000, Australia

** Australian Water Services, Noosa Wastewater Treatment Plant, Off Noosa Springs Drive, Noosa Head 4567 QLD, Australia

Abstract Stringent effluent quality guidelines are progressively implemented in coastal and sensitive areas in Australia. Biological Nutrient Removal (BNR) plants are becoming a standard often including a tertiary treatment for disinfection. The BNR plant in Noosa – Queensland is designed to produce a treated effluent with less than 5 mg/l of BOD_5, 5 mg/l of total nitrogen, 1 mg/l of total phosphorus, 5 mg/l of suspended solids and total coliforms of less than 10/100 ml. A flexible multi-stage biological process with a pre-fermentation stage, followed by sand filtration and UV disinfection was implemented to achieve this level of treatment. Acetic acid is added for phosphorus removal because: i) the volatile fatty acids (VFA) concentration in raw wastewater varies a lot, and ii) the prefermenter had to be turned off due to odor problems on the primary sedimentation tanks. An endogenous anoxic zone was added to the process to further reduce the nitrate concentration. This resulted in some secondary P-release events, a situation that happens when low nitrate and low phosphorus objectives are targeted. Long-term performance data and specific results on nitrogen removal and disinfection are presented in this paper.

Keywords Biological treatment; municipal sewage; nitrogen; phosphorus; prefermenter, UV disinfection

Introduction

Noosa is located two hours' drive north of Brisbane. It's one of Australia's premier holiday destinations. The population increases from 30,000 to 50,000 in the summer holiday period. In 1994, the Noosa Council decided to replace the "old" and overloaded trickling filter coastal sewage treatment plant. The objective was to implement a new "state of the art" facility that would give to the community the world's best practice technology in order to protect the quality of the receiving water. A 25-year DBO contract was awarded to Australian Water Services in 1996. The plant design was provided by AWWT (a subsidiary of Queensland Consulting Engineering Cardno & Davis) working in association with Stanley Consulting from Canada. The whole design, build, and commissioning phases were performed in an 18-month period of time. The first stage of the project was to construct a Biological Nutrient Removal (BNR) plant with an average dry weather flow (ADWF) capacity of 12,000 m^3/d (i.e. 48,000 EP) and 60,000 m^3/d peak wet weather flow. Although the sewer is defined as a separate system, over 900 mm of rainfall has been recorded in a 24 hour period. As a result stormwater ingression and groundwater infiltration is likely to occur. Stage two, to be constructed at some point in the future, is to treat influent flows up to 18,000 m^3/d ADWF and 90,000 m^3/d peak WWF. The objective of this paper is to present the nutrient removal performance of the BNR process and the efficiency of the tertiary treatment that consists of rapid sand filters followed by UV disinfection.

Effluent criteria

The effluent discharged from the plant has to meet the criteria presented in Table 1. The contractual requirement is based on a $50\%^{ile}$ of the results from a set of 46 rolling 8 day control tests.

Water Science and Technology **Vol 44 No 2–3 pp 57–62**

Table 1 Treated effluent (24 hour "composite" sample) contract criteria required at the outlet of the UV disinfection treatment (* in a grab sample)

Criteria	Total P	Total N	Fecal Coliforms*	TSS	BOD_5	DO	pH
50%ile	1	5	10/100 ml	5	5	–	6.5
Absolute maximum	4.5	15	600/100 ml	44	44	> 2	to 8.5

Description of the sewage treatment plant

Primary treatment. The actual 8,000 m^3/d of raw sewage arrive at the plant *via* 85 pumping stations at flows varying from 30 l/s at night up to 300 l/s during morning peaks (note: peak flows of up to 600 l/s have been measured during storm events). Some liquid wastes (digested sludge, septage, landfill leachate) are handled at the plant as well. They are added directly at the inlet of the works. The preliminary treatment process consists of five different steps:

1. two 3 mm step screens controlled by the water level in the upstream channel
2. a vortex separation system for grit removal
3. two parallel primary sedimentation tanks (PST) of 346 and 227 m^2 respectively
4. an anaerobic prefermenter of 770 m^3 (H = 4.3 m; S = 227 m^2; SRT = 10 d; HRT = 24 h)
5. two biofilters to treat the air from the inlet works and the prefermenter.

Due to odour problems the whole "PST + prefermentation" process was shut down in November 1998. The low and variable concentration of Volatile Fatty Acids (VFA) in raw sewage forced the operator to install an acetic acid dosing system during the commissioning period in 1997. This unique operating system has been since used to balance the VFA concentration in raw sewage and recently to replace the VFA supply from the prefermenter, too.

Secondary treatment. Nutrients (carbon, nitrogen and phosphorus) are removed in two parallel activated sludge bioreactors each consisting of 10 cells of 4.8 metres depth in series. The two bioreactors are not independent as the flow to the two 38 m diameter clarifiers is mixed. Excess sludge is extracted from the returned activated sludge (RAS). The BNR plant can be operated in different configurations thanks to a flexible piping, isolating valves and pumping system. The plant is currently operated according to a five-stage configuration. Each bioreactor is divided into an anaerobic (cell 1 and 2 = 380 m^3), anoxic (cells 3, 4 and 5 = 708 m^3), aerobic (cells 6, 7 and 8 = 1161 m^3), endogenous anoxic (cell 9 = 491 m^3) and a final aerobic zone (cell 10 = 500 m^3). The dissolved oxygen set points are controlled via a PLC system at 1.5, 1.25, 1.0 mg/l and 1.5 mg/l in cells 6, 7, 8 and 10 respectively. The activated sludge plant is operated at an average SRT of 8–15 days and a HRT of 15 to 18 hours.

Tertiary treatment. The clarified effluent is treated on rapid sand filters before UV disinfection.

1. The four sand filters (total surface = 166 m^2) are designed with a 1.8 m depth of sand over diffusers with provision for both air scour and backwash water (maximum head loss = 3 m, maximum backwash rate = 54 m/h). The maximum filtration rate (15 m/h) allows the 60,000 m^3/d peak wet weather flow to be treated
2. The Ultra-Violet light disinfection "4000" system supplied by Trojan Technologies is a gravity flow, medium pressure lamp system complete with automatic, self-cleaning mechanical/chemical sleeve units. The system consists of 2 banks in series each of them equipped with 5 modules of 6 lamps (3200 watts/lamp). The energy input to each module is processed *via* an electronic device called a "ballast". The design flow is 36,000

m^3/d (417 l/s) and the UV dose is maintained at 30 mW/cm^2.sec. A PLC system is used to control the energy input based on the flow and UV transmittance on-line measurements.

Sludge treatment. Excess activated sludge and primary/fermented sludge are digested in an aerobic/anoxic digester (25 days design sludge retention time). The average specific oxygen uptake rate is equal to 1.5 ± 0.4 mgO_2/gTSS.h (n = 96). Digested sludge is dewatered up to 16 ± 2% (n = 96) using a gravity drainage table – belt filter press supplied by TEMA. The filtrate is treated with lime slurry in order to precipitate the phosphates that are released in the aerobic digester, and then settled. The supernatant is pumped to the bioreactors providing some additional alkalinity to balance the loss during nitrification.

Results and discussion

Characteristics of the wastewater

The quality of composite raw wastewater (after screening) and effluent samples has been analyzed during intensive sampling periods as well as every 8 days (license requirements) between November 1997 and May 1999 (Table 2). As expected, large variations are observed from day to day and the average value is rather “virtual”. Unexpected events such as solvents ingression (detected by the smell) and high phosphate concentrations (discharge from laundry) have been experienced as well as high peak flows during rainfalls. Despite this intrinsic variability effluent characteristics are well within the 50%^{ile} required values. The high values in treated effluent indicative of problems such as secondary P-release were mainly experienced outside the 8 day test periods.

VFA production in the prefermenter

The fermenter was on-line from November 1997 until November 1998, when odour problems resulted in the primary sedimentation tanks and the fermenter being shutdown. Routine analysis of the VFA and COD in the influent sewage and the fermenter supernatant was performed using the Hach spectrophotometric test methods. The results are summarised in Table 3 with the minimum and maximum percentile values rather than the average in order to get rid of unreliable results.

Table 2 Chemical and biological characteristics of the influent and effluent of the Noosa BNR plant (average (standard deviation, minimum and maximum values)

	INFLUENT				EFFLUENT			
Parameters (in mg/L)	**Design**	**Actual**	**Min.**	**Max.**	**Guideline**	**Actual**	**Min.**	**Max.**
COD	–	520 ± 137	210	1100	–	39 ± 17	19	120
BOD_5	300	183 ± 69	40	440	5	1.6 ± 0.8	< 1	4
VFA (as acetic acid)	–	27 ± 16	0	66	–	–	–	–
TSS	270	239 ± 88	110	630	5	2.7 ± 1.8	2	10
Total Nitrogen	55	43 ± 12	15	95	5	4.7 ± 1.1	4.7	8.6
Ammonia-N	–	35 ± 12	24	37		0.4 ± 0.4	0.1	1.7
Nitrate-N	–	–	–	–	–	3.0 ± 0.8	1.1	4.6
Total phosphorus	11	9.3 ± 4.0	2	25	1	0.6 ± 0.7	0.1	4.0

Table 3 Chemical characteristics of the prefermenter input (primary settled effluent) and output (fermented sludge supernatant)

	Raw sewage (10%ile ; 90%ile)		Fermenter supernatant (10%ile ; 90%ile)	
	mg/L	**kg/d**	**mg/L**	**kg/d**
VFA (as acetic acid)	24 (10 ; 44)	184	117 (74 ; 162)	105
Total COD	522 (373 ; 713)	4003	1624 (819 ; 1800)	1462

The ratio of VFA to COD increased from 4.6% in the sewage to 7.2% in the fermenter supernatant. If it is assumed that COD is conserved, then the net production of VFA in the fermenter is 38 kg/d. Relative to the sewage flow, the input from the fermenter was equivalent to an increase of 5 mg/L of VFA. This indicates that the fermenter converted approximately 1% of the influent COD into VFA. These performance indicators are at the lower end of the reported performance of full scale fermenters (von Munch & Koch, 1999). Changes such as a decrease of the HRT would be probably one way of increasing the efficiency of the prefermenter (Barnard, 1992). The production of non-VFA organic compounds in the prefermenter could be illustrated by the increase of the soluble COD between sewage (150 mg/L in average) and the prefermenter effluent (500 mg/L in average). The impact of these molecules on the process is unknown although they might contribute to the residual COD in the final effluent.

Nitrogen and phosphorus removal

The results presented in Figure 1 show that despite the high variability of the influent nitrogen the total nitrogen 50%ile requirement of 5 mg/L is achieved almost continuously. Phosphorus removal performance is less constant showing the sensitivity of this part of the BNR process (Figure 2). Since lots of effort has been spent on nitrogen removal optimization (see next paragraph) some draw backs such as secondary P release due to unwanted anaerobic conditions in the cells and /or the clarifier are thought to be responsible for the erratic P-removal performance. After 400 days of operation the primary treatment works

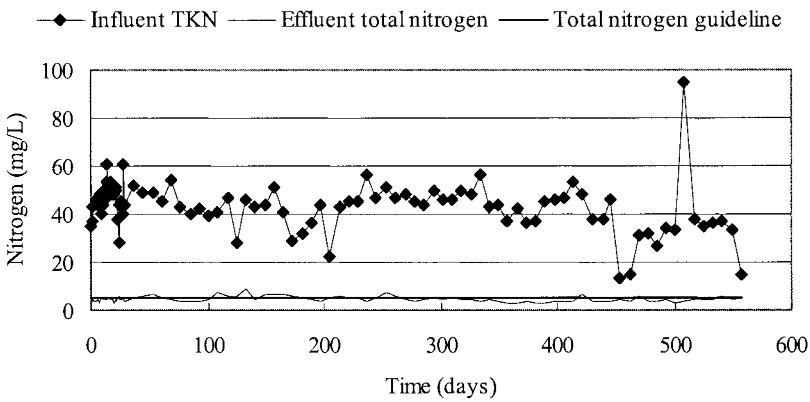

Figure 1 Nitrogen removal (results from the 8 day test controls)

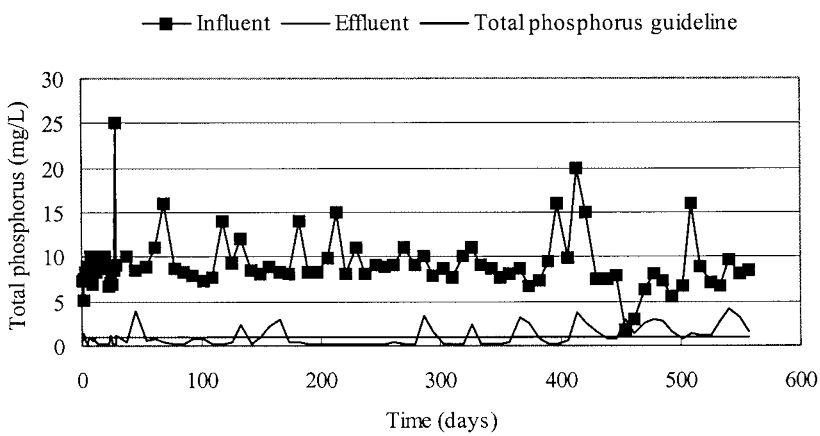

Figure 2 Phosphorus removal (results from the 8 day test controls)

was turned off due to claims related to odor problems. This resulted in a greater instability of phosphorus removal that was attributed to the absence of buffering capacity to the “tanker waste” added every day at the inlet works, and less fermentation of the sewage and sludge as well.

Benefit of the endogenous anoxic zone

The endogenous anoxic zone (cell 9 of the 10 cells in series) was added after several weeks of operation in order to reduce the total nitrogen concentration and therefore keep the 24 h average effluent concentration below the 5 mg/L value. The role of this endogenous anoxic zone was studied along a period of 2 months where 17 grab samples were analyzed at the outlet of cells 8 (aerobic), 9 (anoxic) and 10 (aerobic) at peak flow (11:00 or 16:30 am). The results summarized in Table 4 show that an average net removal of 1.5 mg NO_3-N/L could be achieved including the slight nitrification that takes place in cell 10.

Efficiency of the disinfection stage

The efficiency of the UV disinfection system is monitored *via* the fecal coliforms analysis. The results show that the fecal coliforms count is within the requirements (10/100 ml) most of the time (Figure 3). The first increase was linked to a failure of some of the UV lamps but stayed below the maximum limit of 600/100 ml. The two other increases were linked to an increase of the flow over the hydraulic capacity of the UV system due to strong rainfalls.

Table 4 Inorganic nitrogen concentration in the last 3 cells of the bioreactors in Noosa (average data from 17 grab samples analyzed on different days over a 2 month period)

		Cell 8	Cell 9	Cell 10
Average NO_3-N concentration at the outlet of each cell (mg/L)	Bioreactor 1	5.5 ± 0.6	3.6 ± 0.6	4.0 ± 0.8
	Bioreactor 2	6.0 ± 0.9	4.2 ± 0.9	4.6 ± 1.1
Removal of nitrates by endogenous denitrification in cell 9	Bioreactor 1		1.9 ± 0.7 mg/L	
	Bioreactor 2		1.8 ± 0.3 mg/L	
Net removal: “cell 8-cell 10”	Bioreactor 1		1.5 ± 0.8 mg/L	
	Bioreactor 2		1.4 ± 0.8 mg/L	

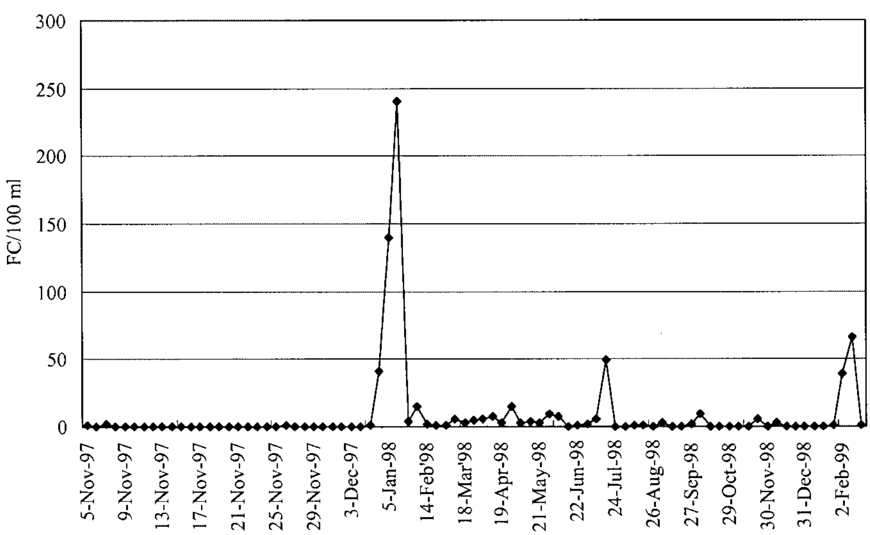

Figure 3 Fecal coliforms analysis in the final treated effluent grab samples

Conclusions

The BNR plant of Noosa has been operated successfully since its commissioning at the end of 1997. Since then optimization programs have been undertaken mainly to control the level of nitrate by means of endogenous denitrification and the level of phosphorus by means of acetic acid addition. It could be observed that optimized nitrogen and phosphorus removal is sometimes difficult to handle simultaneously especially because of the risk of secondary P release when anoxic zones turn into anaerobic conditions. Current research efforts are being done to try optimizing the addition of the external carbon source in order to minimize this risk and to reduce the dosage for cost savings. In addition to nutrient removal the UV disinfection system has proved to be efficient after a set of technical adjustments that were provided by the supplier. Low and stable fecal coliform counts can be achieved in treated effluent.

References

Barnard, J. (1992). Design of prefermentation processes. In: *Design and retrofit of wastewater treatment plants for biological nutrient removal*, C.W. Randall, J. Barnard and H.D. Stensel (eds), Technomic Publishing Company, 85–95.

Von Munch, E. and Koch, F.A. (1999). A survey of prefermenter design, operation and performance in Australia and Canada. *Wat. Sci. Tech*., **39**(6), 105–112.