Phased upgrading for nitrogen removal – a low cost approach

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Abstract A phased approach has been adopted for upgrading the Luggage Point WWTP for nitrogen removal. Luggage Point WWTP (900,000 EP) is the largest plant operated by Brisbane Water. Management actions recommended by the South East Queensland Wastewater Management Strategy require the effluent total nitrogen levels to be reduced to less than 5 mg/L (50th percentile) by 2005. Luggage Point WWTP originally featured primary settling and a completely nitrifying activated sludge process. Effluent total nitrogen levels from the plant averaged 27 mg/L. Characteristics of the wastewater are highly variable, with primary settled wastewater having a COD/BOD_5 ratio averaging 2.5, a TKN/COD ratio averaging 0.12 and effluent non-ammonia TKN averaging 1.8 mg/L (but up to 5 mg/L). The upgrade presented a substantial challenge, due to the limited available substrate for denitrification, a significant level of unbiodegradeable nitrogen and the low existing bioreactor HRT. The phased upgrading strategy was adopted to overcome these challenges most effectively and at low cost. The first stage of the upgrade included modifications to the existing plant infrastructure, without constructing new tankage. The existing bioreactors have been retro-fitted using a five stage Bardenpho nutrient removal process, incorporating significant flexibility. The first phase upgrade has been commissioned and preliminary results indicate that the effluent total nitrogen has been reduced below the required first phase target of 8 mg/L. This represents a reduction of 3 tonnes of nitrogen per day entering Moreton Bay. The process is also operating with good stability and with excellent sludge settleability. The first phase of the upgrade will be completed for $AUS25M, which represents a low cost of $28 per equivalent person. Further upgrade works are likely to include separate treatment of the digested sludge dewatering centrate and advanced control of the biological process. The upgrade of Luggage Pt WWTP has shown that low effluent nitrogen can be achieved at low cost, through optimum utilisation of existing assets and a phased approach to modifications.
Keywords Activated sludge; biological nutrient removal; large WWTPs; nitrogen; upgrading

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Introduction

Luggage Point WWTP (900,000 EP) is the largest plant operated by Brisbane Water, a business unit of the Brisbane City Council. The plant is located at the mouth of the Brisbane River, which discharges into Moreton Bay. As a result of management actions recommended by the South East Queensland Wastewater Management Strategy, aimed at protecting the Moreton Bay ecosystem, the effluent total nitrogen levels from Luggage Point WWTP are to be reduced to less than 5 mg/L (50th percentile) by 2005 (BRMBWMS, 1998).

The project described in this paper outlines the phased approach to upgrading the plant that has been adopted to achieve the required nitrogen reduction. Upgrading the plant for nitrogen removal to the low levels required has presented a substantial challenge, due to the limited available substrate for denitrification, a significant level of unbiodegradeable nitrogen and the low existing bioreactor HRT.

Background

Original plant

Luggage Point WWTP was originally commissioned in 1981 and featured primary settling followed by a conventional activated sludge process, designed for complete nitrification only (Greenhalgh and Don, 1978). A second stage of the plant, using essentially the same process configuration, was commissioned in 1993. Stage 1 of the plant has a nominal capacity of 600,000 EP (126 ML/d ADWF) and Stage 2 a capacity of 300,000 EP (63 ML/d ADWF). The plant's design and current license effluent requirements are for 20 mgBOD_5/L, 30 mgTSS/L and 30 mgNH_4/L.

The main treatment process consisted of screening, grit removal, six primary sedimentation tanks, six bioreactors and twelve final settling tanks, arranged into three equivalent process trains. The bioreactors were fully aerated and of plug flow configuration. The average hydraulic retention time (HRT) of the biological process was 8 hours at design loading. Effluent total nitrogen levels from the plant averaged 27 mg/L.

Sludge treatment includes rotary screen thickening of primary sludge, DAF thickening of waste activated sludge, mesophillic anaerobic sludge digestion and centrifuge dewatering of the digested sludge. Biogas produced from the anaerobic digestion process is used by on-site generators, and provided approximately 80% of the plant's energy requirements prior to the nitrogen removal upgrade.

In 2000, a 14 ML/d dual membrane (micro-filtration/reverse osmosis) water reclamation plant was commissioned, treating a fraction of the plant effluent for industrial reuse.

Wastewater characteristics

All stages of the plant receive a common influent, which includes a significant industrial wastewater component (approximately 30%). The catchment for the plant is large, with the longest sewer path more than 30 km and almost all wastewater transported to the plant via a 10 km rising main.

Table 1 Average wastewater characteristic for Luggage Pt WWTP (1/7/00 to 31/12/01)

	Plant influent (mg/L)	Primary effluent (mg/L)
COD	635	400
BOD_5	250	165
TKN	48	47
NH_4	33	38
TSS	320	120

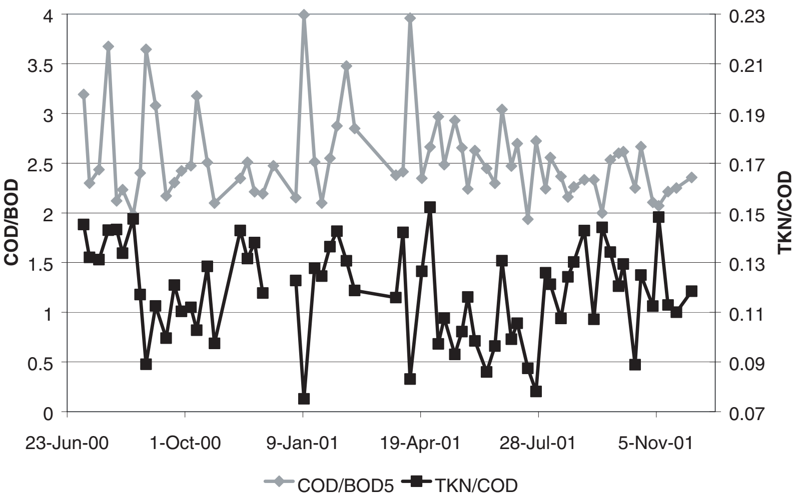

Figure 1 Primary settled effluent COD/BOD_5 and TKN/COD ratios for Luggage Pt WWTP

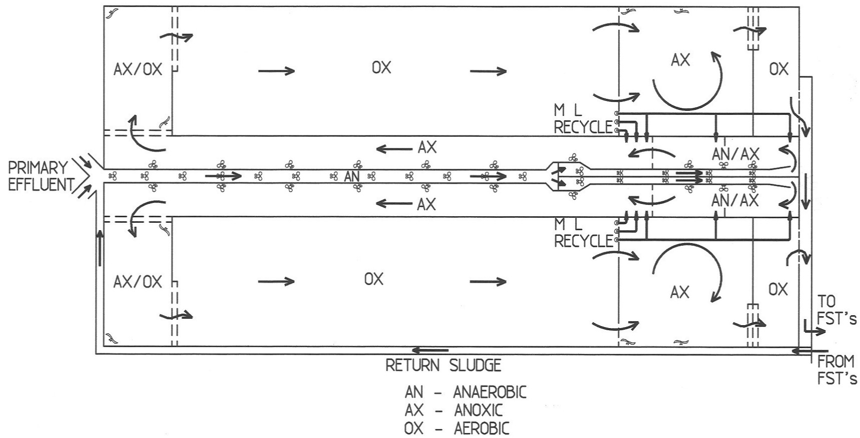

Figure 2 Five stage Bardenpho bioreactor layout for Luggage Pt WWTP N removal upgrade

Characteristics of the wastewater are shown in Table 1 and Figures 1 and 3. The characteristics are highly variable, with primary settled effluent having a COD/BOD_5 ratio averaging 2.5, a TKN/COD ratio averaging 0.12 and effluent non-ammonia TKN averaging 1.8 mg/L (but up to 5 mg/L). The high degree of variability of the ratios is shown in Figure 1 and effluent non-ammonia TKN in Figure 3. Possible causes of this high degree of variability and low fraction of readily degradable substrate, include:

- significant industrial component (including some large industries that pre-treat anaerobically prior to discharging to sewer);
- oxygen injection into the 10 km rising main (aimed at controlling odours and corrosion);
- biosolids dewatering centrate returned to the main process.

These wastewater characteristics generally indicate that achieving the target effluent of 5 mgTN/L will be significant challenge.

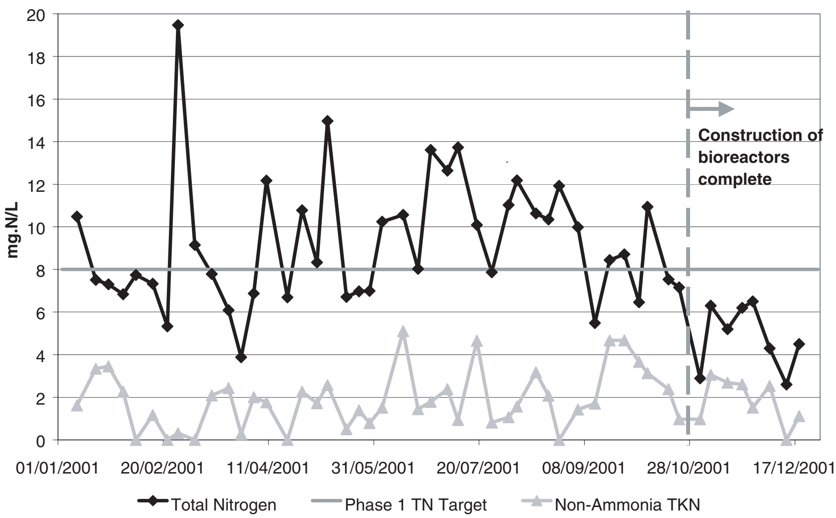

Figure 3 Effluent nitrogen for Luggage Pt WWTP during construction and commissioning

Upgrade strategy

Phased upgrade

To overcome the challenges of limited existing bioreactor tankage, and uncertainty and variability in the wastewater characteristics most effectively and economically, a phased upgrading strategy was adopted. The aim was to systematically stage the upgrade works and measure the effectiveness of each phase at its completion, to progressively overcome uncertainty and determine any further works required.

The first phase of the upgrade included works that modified the existing plant infrastructure, without constructing any major new tankage. The first phase upgrade target was set at achieving a 50th percentile effluent total nitrogen of 8 mg/L by 2003. Future phases required to achieve the 5 mg/L target by 2005 are to be determined following optimisation of the phase one works.

The three identical stages of the upgraded plant are ideal for process proving and testing, including:

- stress testing the process to determine the effect of load and determine the reliable plant capacity etc.;
- trialing the effects of process modifications; and
- trialing the benefits of additional processes (such as separate treatment of the digested sludge dewatering centrate).

Further upgrade works may include separate treatment of the digested sludge dewatering centrate, which is high in ammonia and represents approximately 15% of the influent nitrogen load. Pilot trials are currently under way to investigate novel high strength ammonium removal processes, including SHARON, ANAMMOX and the KAD ion exchange process. Advanced control of the biological process (aeration system, recycle rates, etc.) also shows promise for lower nitrogen levels.

Treatment process

The existing bioreactors have been retro-fitted for nitrogen removal using a five stage Bardenpho nutrient removal process. The process was selected to give the best nitrogen removal performance utilising the existing plant tankage. Brisbane Water's Gibson Island WWTP achieves very low effluent total nitrogen averaging 2.4 mg/L, however using over twice the bioreactor volume and without the benefits of primary treatment and biogas generation (von Münch and Komarowski, 2000). Plants that achieve very low total nitrogen values, typically have bioreactor HRT's greater than 20 hours (Solley, 2000).

The layout of the upgrade process for each pair of bioreactors (per plant stage) is shown in Figure 2. The three separate stages of the plant have been preserved in the upgrade. The fractions for each bioreactor zone are given in Table 2. Significant flexibility has been

Table 2 Bioreactor zone fractions for Luggage Pt WWTP

Bioreactor zone	Fraction (% of total)
Anaerobic	3.5
Anaerobic/anoxic swing	4
Primary anoxic	15
Anoxic/aerobic swing	7.5
Primary aerobic	50
Secondary anoxic	15
Secondary aerobic	5
Total anaerobic fraction	3.5–7.5
Total anoxic fraction	30–41.5
Total aerobic fraction	55–62.5

incorporated into the design through the inclusion of variable volume anaerobic, anoxic and aerobic zones. These have been made possible by fitting one of the aeration zones with membrane diffusers that can be turned off and mechanically mixed, so that it can be operated in either an aerated or non-aerated mode. The ability to direct the mixed liquor recycle to one of three non-aerated zones, has allowed these zones to operate in either anoxic or anaerobic modes. Large operating ranges have also been provided for the mechanical equipment to increase flexibility. The phase one works included the installation of new baffle walls, mixed liquor recycles and mechanical mixers for the non-aerated zones.

Mixed liquor wasting has replaced the existing RAS waste system, including the provision of an additional DAF thickener. Scum is removed with the waste activated sludge from the end of the bioreactors, using a novel skimmer device proposed by Earth Tech P/L.

The primary settling tanks have been retained for their environmental and economic benefits, as even with the additional load of the nitrogen removal and dual membrane water reclamation plant upgrades, 60% of the site's energy requirements are currently met by the biogas generated from anaerobic sludge digestion. One bonus from keeping the primary treatment is enhanced VFA extraction from the fermented primary sludge, which will be made possible through modifications to the primary sludge thickening equipment.

Where possible, pre-aeration of the wastewater has been eliminated prior to entering the bioreactors. Ogee weirs installed on the primary settling tanks and on-line control of the downstream level have proven very effective in reducing dissolved oxygen levels from about 2 mg/L down to less than 0.2 mg/L.

A high level of control and on-line instrumentation has been included in the first phase of the upgrade, including on-line nutrient analysers (for ammonia and nitrate at various locations through the bioreactors), ORP meters, multiple aeration zones with individual DO control, sludge blanket measurement and flow measurement.

Construction considerations

Although the upgrade involved significant modifications to the existing plant, construction of the plant was achieved without breaching the existing plant effluent licence. The plant was loaded to 75% of design capacity during construction, which required one third of the plant to be taken off-line for periods. The use of precast concrete walls for the new internal baffling was of great assistance to the speed of construction.

Contract arrangements

Concept and process design for the upgrade were completed in-house by Brisbane Water personnel. A contract for the detailed design and construction of the upgrade was awarded to a John Holland/Purac consortium, under an AS4300 contract. This contract has not been completed to date, with control system and primary sludge filtrate dosing works remaining. Responsibility for the performance of the process remains with Brisbane Water. Operation and maintenance of the plant is also the responsibility of Brisbane Water.

Results

Plant performance

Bioreactors for the first phase upgrade have been progressively commissioned and preliminary results indicate that the average effluent total nitrogen has been reduced below the required first phase target of 8 mg/L. This effectively represents a reduction of 3 tonnes of nitrogen per day entering Moreton Bay. The nitrogen removal performance of the plant during the last year (during construction and the start of commissioning) is shown in Figure 3. It is also interesting to note the level of non-ammonia TKN in the effluent, indicating that a significant fraction of the effluent nitrogen is essentially unbiodegradeable and thus not able to be removed by the biological process. The plant has been operating with a sludge retention time of approximately 13 days since commissioning, giving a mixed liquor suspended solids concentration of between 3,000 and 3,500 mg/L.

The process is also operating with good stability and with excellent sludge settleability, as indicated by a SSVI generally less than 120 mL/g since commissioning (refer Figure 4). This is likely due to the long plug flow anaerobic selector provided in the upgrade bioreactor layout, specifically installed to improve the sludge settling characteristics.

Further optimisation and stress testing of the plant is required for the completion of the first phase project. One interesting feature of the effluent results is the weekly variation in nitrate levels, which shows a distinct peak following each weekend (refer Figure 5). This is likely due to a weekly imbalance in the TKN/COD ratio, where during the weekend, there may be insufficient substrate available for denitrification. This may be a similar phenomenon to the "Monday effect" described for phosphorus removal in the literature (Sedlack, 1991). It is anticipated that this will be overcome through better control of the process and

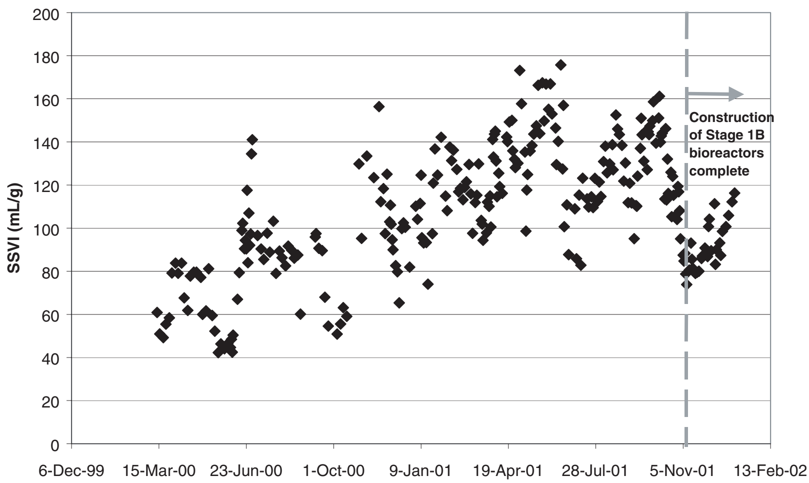

Figure 4 SSVI for Stage 1B of Luggage Pt WWTP during construction and commissioning

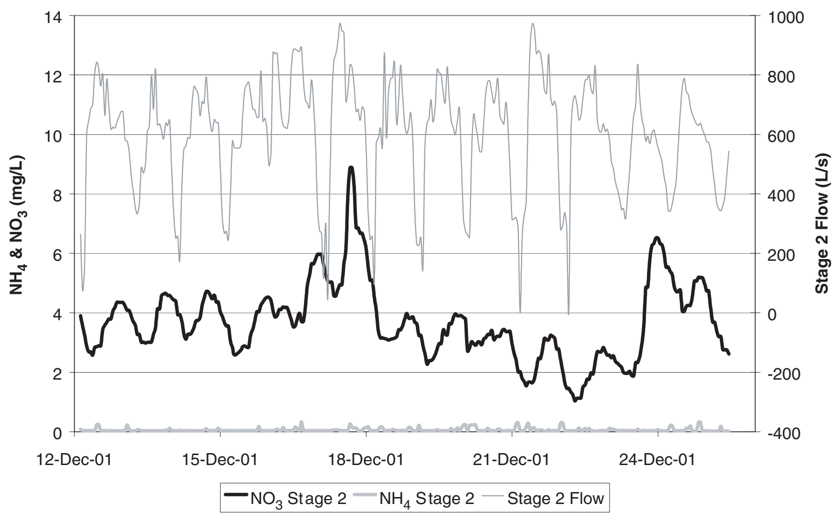

Figure 5 Stage 2 on-line nutrient analyser trends showing weekly nitrate variation

utilisation of the available substrate, including endogenous substrates. Addition of an external carbon source such as methanol, is also an option that has not been trialed to date.

Costs

The first phase of the upgrade will be completed for approximately $AUS25M, which represents a low cost of $28 per equivalent person. This compares well with recent upgrade costs presented by Hartley (1998), where the costs for nutrient removal upgrades ranged from $90 to $560/EP and averaged $250/EP (referenced to 1997 Australian dollars). There is likely to be an economy of scale effect between the smaller plant upgrades presented and the Luggage Point WWTP plant upgrade. Also, there is presently no requirement for phosphorus removal at Luggage Point.

As a result of the low results achieved with the first phase upgrade, it is expected that further work to reach the 5 mgTN/L target can also be completed at low cost.

Conclusion

The upgrade of Luggage Pt WWTP has shown that low effluent nitrogen can be achieved at low cost, through a phased approach to modifications of the existing treatment process and optimum utilisation of existing assets. Despite low available bioreactor HRT, uncertainty in the wastewater characteristics and limited available substrate, these low nitrogen levels have been achieved. By systematically staging the works, it is possible to progressively determine what works are required to overcome any uncertainty that exists. This has led to both an effective and economical solution. The project has also been successful in retaining the anaerobic sludge digesters and biogas power generation.

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