Evaluation, selection and initial performance of a large scale centralised biosolids facility at Oxley Creek Water Reclamation Plant, Brisbane

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ABSTRACT

Recent upgrades to Brisbane City Council's Water Reclamation Plants (WRP) for improved nutrient removal has led to a significant increase in sludge production, and loss in potential anaerobic degradability. This increase in sludge production brought forth an economic driver for an improved, integrated biosolids handling strategy. The solution adopted by Brisbane Water, was a centralised thermal hydrolysis facility at Oxley Creek WRP to process the waste activated sludges generated at a total of five WRPs in the region. The thermal hydrolysis process uses high temperature and pressure to make non-degradable material more readily digestible by anaerobic bacteria and hence achieve greater efficiency in the overall anaerobic digestion process. Dewaterability is also improved, as the thermal hydrolysis process releases some of the bound water from the waste activated sludge. The viability of this solution is linked primarily to the reduction in mass and volume of biosolids which leads to lower transportation and disposal costs. After four months of operation, the Oxley Creek thermal hydrolysis plant has resulted in a 70% reduction in biosolids quantities (bulk volume) and disposal costs. The process is currently being optimised. Savings to date have reached about AUD 80,000 per month. Technical and operational issues which emerged during commissioning are also described.

Key words | anaerobic digestion, thermal hydrolysis, volatile solids destruction, waste activated sludge

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INTRODUCTION

The aquatic environment of the Brisbane River and Moreton Bay has recently benefited from a major upgrade of the water reclamation plants owned by Brisbane City Council. Brisbane Water, a business unit of the Council, is responsible for the planning, design and operation of nine water reclamation plants that release their effluent directly, or indirectly to the Brisbane River/Moreton Bay receiving water system.

Over the last decade, the six largest WRPs have been upgraded to improve nitrogen removal to produce an effluent less than 5 mgTN/L. These plants make up a total population equivalent of approximately 1.5 million with an average dry weather flow capacity of 322 ML/day. Table 1 contains summary details for the six major plants operated by Brisbane Water.

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Since 1996 Brisbane City Council has spent approximately AUD 270 M (corrected to 2008) for the nitrogen removal and capacity upgrades for these six WRPs. The process design for the Luggage Point and Gibson Island plants were completed in-house by Brisbane Water. Details of the initial upgrade of Luggage Point to achieve less than 8 mgTN/L are given in Solley & Hopkins (2003) and for the latest upgrade to achieve less than 5 mg TN/L are given in Qiao *et al*. (2006). Details of the upgrade and conversion of Gibson Island to achieve less than 5 mgTN/L are given in Solley & Barr (1998).

The remaining four plants were designed and delivered by the Brisbane Water Enviro Alliance (BWEA). The alliance partners were Brisbane Water, John Holland,

Table 1 | Details for the six largest WRPs operated by Brisbane water

WRP	Design Population equivalent	Design ADWF ML/day	2007/08 Influent (median) ML/day	2007/08 Effluent (median) mgTN/L	Year Completed	Ref.
Luggage Point	850,000	170	116	4.6*	2007†	Solley & Hopkins (2003), Qiao *et al.* (2006)
Oxley Creek	270,000	65	46	3.9	2006	Solley (2006)
Gibson Island	180,000	45	34	2.5	1997	Solley & Barr (1998)
Sandgate	120,000	25	15	3.9	2006	Solley (2006), Frougas & Simpson (2007)
Wynnum	37,500	9.0	5.5	2.7	2007	
Wacol	35,000	8.4	3.8	2.4	2006	Solley (2006)
Totals	1,500,000	322	220			

ADWF is average dry weather flow.
*Five months of data since commissioning of upgrade in December 2007.
†Initial upgrade to 8 mgTN/L was completed in 2002.

Aquatec-Maxcon, JWP and MWH. Details of the BWEA upgrades for Oxley, Sandgate and Wacol to achieve less than 5 mgTN/L are given in Solley (2006). Commissioning and optimisation of the Sandgate plant upgrade is described in Frougas & Simpson (2007). All plants achieved their nitrogen effluent objective of less than 5 mgTN/L (see Table 1).

The Alliance method of delivery by BWEA for Oxley Creek, Sandgate and Wacol included financial bonuses for achieving better than the design objective of 5 mgTN/L for effluent nitrogen. These three plants were delivered for AUD 175 M including the bonuses for outstanding nitrogen removal.

The process design for low effluent nitrogen concentrations focuses on the use of influent carbon to drive denitrification in the bioreactors. This led to the abandonment of the existing primary settling tanks (PST) and anaerobic digesters (AD) at the Oxley and Sandgate plants and the adoption of direct thickening/dewatering of the waste activated sludge (WAS) stream from the bioreactors. The PSTs were also identified as a significant odour source. Particular attention was also paid to the dissolved oxygen and aeration control to minimise over-aeration over the diurnal cycle, hence offering the best potential for efficient use of the available influent carbon for denitrification.

The elimination of the PSTs and ADs from the process train to achieve low levels of nutrient removal is common practice in Australia. It is accepted that this simplified process train (without sludge stabilisation) does produce more waste sludge for treatment/disposal (Solley 2006). For large plants, total sludge disposal and trucking costs can justify capital intensive, improved biosolids handling (small plants have a high per tonne cost, but low overall cost). For the new Oxley Creek and Sandgate nitrogen removal plants this simple process train was adopted for nitrogen removal. This process train has resulted in a doubling of the waste activated sludge volume generated by these two plants.

THE BIOSOLIDS PROBLEM

Prior to the BWEA upgrade the biosolids produced from the four plants (Oxley Creek, Sandgate, Wacol and Wynnum) was 22,000 wet tonnes/year. Following the completion of the BWEA upgrades in 2007 it is predicted that the biosolids produced will increase to about 48,000 wet tonnes/year. The current method of biosolids disposal is by trucking dewatered cake for use in the rehabilitation of an old mine site at Swanbank (30 kilometres distant in the adjacent city of Ipswich). The increased biosolids quantities produced would have increased the disposal costs from these four plants from approximately AUD 0.85 to 1.9 M per annum.

In addition to this AUD 1 M financial impost, the biosolids generated from the new plants would have resulted in a major increase in truck movements on the road network.

There is also a high risk that the waste activated sludge removed directly from the activated sludge bioreactors may cause significantly more odour management issues at these plants. Hence, the challenge for the BWEA was to determine a biosolids solution to improve the overall economics and better manage the related process and environmental risks for the new plants.

BIOSOLIDS OPTIONS

The options in Table 2 were short-listed for detailed evaluation. The base case is to dewater the WAS for direct disposal for Mine Site Rehabilitation (MSR). This was practised by Brisbane Water for the Gibson Island nitrogen removal plant at the time of the BWEA upgrade.

The dewatered cake stabilised biosolids product from Options 0 to 3 is ultimately disposed by trucking for mine site rehabilitation.

A preliminary process risk analysis led to Option Zero being eliminated from further analysis. The process risks relating to the anaerobic digestion of the 100% thickened

Table 2 | Biosolids options for BWEA nitrogen removal plant upgrades

Base Case–Dewatering WAS from Oxley Creek for mine site rehabilitation
Un-stabilised sludge is trucked to the old mine site
Existing anaerobic digesters at Oxley Creek are abandoned.
Option 0–No Hydrolysis
Thickened WAS from Oxley Creek with stabilisation by the existing anaerobic digesters at Oxley Creek.
Option 1–Ultrasonic Hydrolysis for Oxley Creek sludge
Thickened WAS from Oxley Creek with pre-treatment by an Ultrasonic Hydrolysis Process (UHP) prior to stabilisation by the existing anaerobic digesters at Oxley Creek.
Option 2–Cambi™ Thermal Hydrolysis Process (THP) for Oxley Creek sludge
Dewatered WAS from Oxley Creek with pre-treatment by Cambi™ THP prior to stabilisation by the existing anaerobic digesters at Oxley Creek
Option 3–Cambi™ Plus THP for sludge generated from five plants
Dewatered WAS from Oxley Creek and imported dewatered WAS from the four other nitrogen removal plants with pre-treatment by Cambi™ THP prior to stabilisation by the existing anaerobic digesters at Oxley Creek.

WAS stream and the likely poor dewatering performance and odours generated were deemed too great to accept. In addition, there would also be insufficient biogas produced to maintain the viability of the existing Combined Heat and Power (CHP) generation unit at Oxley Creek. Hence only Hydrolysis Options 1, 2 and 3 were evaluated in further detail. Early analysis also indicated that Option 3–Cambi™ Plus, where sludge from five plants is stabilised would be superior (due to economies of scale) to the Option 2–Cambi™, where only the sludge from Oxley Creek is stabilised. The remainder of this paper will focus on the comparisons between the Base Case and Options 1 and 3.

EVALUATION AND SELECTION OF BIOSOLIDS SOLUTION

The objective of this biosolids project was to determine the required biosolids management facilities at Oxley Creek WRP that are able to process the WAS produced using a method that has the lowest whole of life costs, is sustainable, does not adversely impact upon the community and is able to be integrated to future biosolids reuse opportunities. A detailed business case was developed which compared the hydrolysis options using various process operational performance, financial, environmental, community and risk management considerations– Oxley Creek WWTP Hydrolysis Options (2004).

Assessment of the process operational performance of the options 1 and 3

Option 1–Ultrasonic hydrolysis process for Oxley Creek sludge followed by AD at Oxley Creek

There are several suppliers of ultrasound disintegration–hydrolysis technology. Ultrasound pre-treatment of sludges causes the cavitation of the bound water bubbles within the sludge and hence changes the structure of the sludge to enable efficiencies to be gained in the rate of anaerobic digestion and dewaterability.

The evaluation of Ultrasonic Hydrolysis involved bench scale trials at Oxley Creek with equipment provided by two suppliers of sludge sonication systems together with small batch operated anaerobic digesters. This study was carried out by the BWEA Alliance. From these trials it was determined that the percentage volatile destruction from the bench scale UHP/AD system was 13%.

At the time of this evaluation the project team was unable to find elsewhere in the world any examples of sonication that matched the Oxley Creek project requirements (i.e. anaerobic digestion of a 100% WAS feed from a long SRT nitrogen removal plant).

Option 3–Cambi^{TM} Plus for sludge generated from five plants (THP/AD at Oxley Creek)

Thermal hydrolysis denatures and dissolves organic material contained in sludges (Kopp & Ewert 2006). This process makes the sludge more readily available for anaerobic digestion and hence enables an improvement in the rate of the anaerobic digestion process. THP also releases large amounts of bound water from within the organic material. This also enables an improvement in the dewaterability of the sludge produced.

The Cambi^{TM} THP is a proprietary technology developed in Norway by Cambi AS. The Cambi^{TM} process is a batch process carried out with saturated steam at a temperature of 165°C at 6 bar for 30 minutes. The first plant was commissioned in Hamar, Norway in 1995. The technology has found application as a sludge pre-treatment system prior to anaerobic digestion in the municipal and industrial markets. By 2007, a total of eleven Cambi^{TM} THP plants have been built, with a further five under contract in eleven different countries (mainly in Europe). A summary of the evolution of the Cambi^{TM} THP is given by Norli (2006). The particular benefits of the process are reported as:

- Significant mass and volume reduction of sludge by efficient anaerobic digestion.
- Allows greater than 50% destruction of volatile matter by anaerobic digestion even for the traditionally difficult to digest waste activated sludges.
- The biosolids product produced is free of pathogens with low odour potential.
- Capacity of anaerobic digesters can be doubled in most cases. Loading rates of volatile solids of greater than 5 kgVS/m^3/day are achievable at detention times of less than 15 days.
- Foaming of digesters due to activated sludge scums (Nocardia, Microthrix) does not occur.
- Improved dewatering of digested sludge up to 35%DS can be achieved giving the related benefits of reduced transportation and disposal costs for biosolids.
- The additional biogas produced from the anaerobic digestion process usually allows co-generation and its related energy recovery and environmental benefits. The THP/AD process is a net producer of energy.

The Cambi^{TM} THP/AD system was not pilot tested by BWEA, as this was not practically possible. Additionally, one of the reference plants, Naestved is processing a 100% WAS stream. The assumed volatile destruction from the Cambi^{TM} THP/AD system was 50% which is well supported in published reports, see Kopp & Ewert (2006) and Norli (2006).

The various process configurations with actual and predicted biosolids quantities produced for the options considered are presented in Tables 3a–3d. Of note, from Tables 3a–3d is the reduction in wet tonnes of biosolids

Table 3a | Actual biosolids quantities prior to BWEA plant upgrades

	Existing processes and MSR (Prior to BWEA upgrades)			
Actual plant data 2004 & 2005	**Processes**	**Wet t/y**	**% DS**	**Dry t/y**
Oxley Creek	PST, 3BP & AD	14,000	22.4	3136
Sandgate	PST & TF	3,500	16.6	581
Wacol	MLE	2,200	12.2	268
Wynnum	PST & TF	1,900	13.3	253
Totals	Wet t/y	21600	Dry t/y	4238
	Wet t/d	59	Dry t/d	11.6

Table 3b | Predicted biosolids quantities in 2008 for base case

	Base case (Dewatered WAS to MSR and abandoned anaerobic digestion)			
Predicted plant data for 2008	**Processes**	**Wet t/y**	**% DS**	**Dry t/y**
Oxley Creek	OD	**31,000**	13.5	4185
Sandgate	OD	10,000	13	1300
Wacol	5BP	2,600	12.2	317
Wynnum	OD	4,200	13	546
Totals	Wet t/y	47800	Dry t/y	6348
	Wet t/d	131	Dry t/d	17.4

Table 3c | Predicted biosolids quantities in 2008. Option 1—UHP for Oxley Creek Sludge

Predicted plant data for 2008	Option 1—Ultrasonic hydrolysis for 13% VS Dest. By AD (With ultrasonic hydrolysis & anaerobic digestion for Oxley WAS, PDW & MSR)			
	Processes	Wet t/y	% DS	Dry t/y
Oxley Creek	OD, UHP & AD	**18,885**	20	3777
Sandgate	OD	10,000	13	1300
Wacol	5BP	2,600	12.2	317
Wynnum	OD	4,200	13	546
Gibson Island	OD	33,000	11.4	3762
Totals	Wet t/y	68,685	Dry t/y	9702
	Wet t/d	189	Dry t/d	26.7

Table 3d | Predicted biosolids quantities in 2008. Option 3—THP for Sludge from all five plants

Predicted plant data for 2008	Option 3—Cambi plus for 50% VS Dest. By AD (With thermal hydrolysis & anaerobic digestion of all WAS at Oxley, PDW & MSR)			
	Processes	Wet t/y	% DS	Dry t/y
Oxley Creek	OD, THP & AD	**8,719**	30	2616
Sandgate	THP/AD at OX	2,708	30	813
Wacol	THP/AD at OX	661	30	198
Wynnum	THP/AD at OX	1,138	30	341
Gibson Island	THP/AD at OX	7,837	30	2351
Totals	Wet t/y	21,062	Dry t/y	6319
	Wet t/d	58	Dry t/d	17.4

PE: Population Equivalent, BWEA: Brisbane Water Enviro Alliance, TF: Trickling Filter, PST: Primary Settling Tank, MLE: Modified Ludzack-Ettinger, 3BP: 3 Stage Bardenpho, 5BP-5 Stage Bardenpho, OD: Oxidation Ditch, WAS: Waste Activated Sludge, DWAS: Dewatered Waste Activated Sludge, UHP: Ultrasonic Hydrolysis Process, THP: Thermal Hydrolysis Process, AD: Anaerobic Digester, PDW: Post dewatering, MSR: Mine Site Rehabilitation.

produced at Oxley Creek from 31,000 t/year for the Base Case (Table 3b) to 18,900 t/year for Option1–Ultrasonic Hydrolysis (Table 3c). This mass of sludge is reduced to 8,700 t/year (24 t/day) for the Option3–Cambi™ Plus (Table 3d).

Economic analysis

The present value of options is presented in Table 4. A present value analysis is a financial feasibility tool that indicates whole of life cost for a reference year and currency. This PV analysis was completed in 2006 in Australian dollars (AUD) as part of the overall business case for biosolids options.

Bracketed values in Table 4 are expenses. When the capital subsidy is included, Option 3–THP Cambi™ Plus is significantly superior with a Present Value (capital and operational cost including cost savings from co-generation) of AUD 32.9 M. This represents a present value whole of life cost saving of approximately AUD 5 M over Option 1–UHP at AUD 37.7M.

Value-for-money analysis

Brisbane City Council uses a "Value-for-Money" project analysis technique as part of the selection process for major projects. Some of the environmental and community criteria included in the analysis were odour minimisation, ability to produce a biosolids product suitable for reuse, energy efficiency (biogas production for co-generation) and minimisation of biosolids truck movements via local and major transport routes. Due to the large number of biosolids truck movements involved a transportation index was developed to compare this aspect between options. The unit used was biosolids tonnes per kilometre travelled per annum (t.km/year).

The outcomes of the Value-for-Money analysis are presented in Table 5. On the basis of a Value-for-Money Life Cycle Cost assessment the Cambi™ Plus option provides the greatest value (18.1 from Table 5) for Brisbane City Council. The Cambi™ Plus thermal hydrolysis option was selected. Capital cost for this option was AUD 23 M. The capital cost estimate for BWEA Alliance upgrades of AUD 175 M had included a sum of AUD 4 M for sludge stabilisation. Hence a variation of AUD 19 M was approved for the BWEA Alliance to deliver the Cambi™ Plus extension for a total cost of AUD 194 M for the Oxley, Sandgate and Wacol plants.

THE THERMAL HYDROLYSIS PROCESS SOLUTION

The Oxley Creek nitrogen removal plant upgrade was commissioned in late March 2006. For the eight month

Table 4 | Present value and costs for options 1 and 3

Options	Costs PV $ '000	Year 0 Capex $ '000	Year 1 Opex $ '000
	without capital subsidy		
Option 1 UHP	(39,240)	(4,000)	(2,990)
Option 3 THP – Cambi™ Plus	(41,570)	(23,291)	(1,583)
	with capital subsidy		
Option 1 UHP	(**37,745**)	(2,505)	(2,990)
Option 3 THP – Cambi™ Plus	(**32,862**)	(14,584)	(1,583)

Table 5 | Value-for-money summary matrix for Oxley Creek biosolids project

Criteria	Weighting	Option 1 Ultrasonic Ave. Score	Option 1 Ultrasonic Wtd. Score	Option3 Cambi™ Plus Ave. Score	Option3 Cambi™ Plus Wtd. Score
Environmental benefits/risks	24.5	3.67	89.6	9.0	220.6
Community benefits/risks	14.3	5.33	76.3	4.33	62.0
Commercial benefits/risks	23.6	3.4	80.2	7.4	174.6
Operational issues	37.6	4.92	184.9	3.67	137.9
Total weighted scores			431		595
Discounted Capex* $M			2.505		14.584
V for M index for Capex*			172		41
Life cycle cost $M			39.24		41.57
V for M life cycle index			11.0		14.3
Life cycle cost $M*			**37.745**		**32.862**
V for M life cycle index*			11.4		**18.1**

*with subsidy in year 1

period of operation from April to November 2006 all WAS from the new plant was dewatered to about 13.5%DS and trucked direct to the disposal site. This period of operation represents the Base Case Option from Table 2. The existing digesters were refurbished and re-commissioned together with the THP plant in December 2006. The start-up of the THP and AD processes is described by in Batstone *et al.* (2007). Only two of the four existing digesters were required. This demonstrates the effective doubling in anaerobic digestion capacity that can be achieved by the Cambi™ THP/AD process, and provides for future capacity.

The improvements in process performance and cost reductions achieved after four months of operation from Dec 2006 to March 2007 can be observed in Figure 1.

The average biosolids generated for the base case period (April to Nov 2006) was 2600 wet tonnes/mth. Following the commissioning of the THP/AD process (Dec 2006) the biosolids transported to the disposal site reduced by over 70% to 700 wet tonnes/mth. Average cost savings for this four month period was AUD 78,000/mth (105,000 to 27,000). Also of note is the average 40% reduction in wet tonnes/mth and cost/mth from Pre-BWEA upgrades values (Jan 2004 to March 2006 in Figure 1) of 1150 wet tonnes/mth and AUD 45,000.

The average cake dryness of the dewatered WAS (by belt filter press) from April to Nov 2006 was 13.5%DS. The stabilised dewatered (by centrifuge) cake after the THP/AD process has averaged 27%DS. Centrifuge performance is still to be optimised in terms of type of polymer, polymer dosing location, polymer premixing system and the use of supplementary flocculants eg aluminium or iron salts.

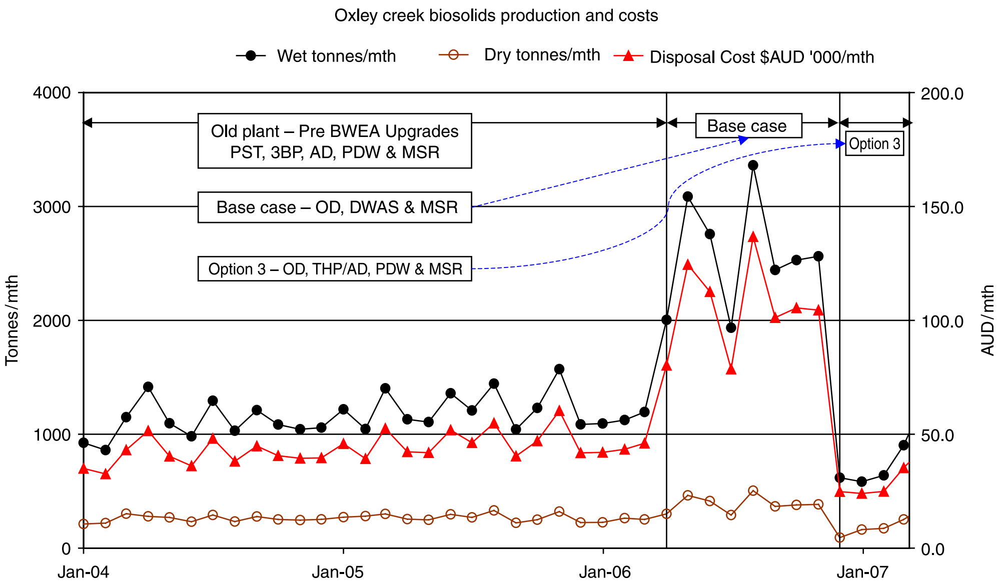

Figure 1 | Oxley Creek Biosolids Production and Costs—Jan 2004 to Mar 2007. Left axis is Wet or Dry tonnes/month. Right axis is Biosolids Disposal Cost $'000/month.

ISSUES AND LEARNINGS

Difficulties understanding the rheology of sludge produced by thermal hydrolysis led to an undersizing of the post THP sludge heat exchangers to cool the hydrolysed sludge prior to anaerobic digestion. This is currently being rectified by BWEA. During commissioning, various problems with the control system, steam boiler, feed pumps to THP and digester mixing systems were identified and addressed. A particularly troublesome event was the entry of foreign objects into the dewatered sludge storage bin. These objects fouled the isolation valves from the storage bin, screw conveyors and the THP feed pumps. This caused a major hold up in sludge processing as the 360 tonne dewatered sludge storage bin had to be emptied and pipework dismantled to remove the offending objects. This highlighted the critical importance of ancillary equipment for the THP/AD system.

Problems longer than 24 hours with ancillary equipment or the THP/ADs can rapidly become a bottleneck in the sludge processing train. This limits the feed to the THP/AD system and leads to the immediate occurrence of higher transportation costs. The back-up system is dewatered cake to landfill, hence a cost of about AUD 80,000/month will occur for the treatment of sludges from Oxley Creek plant alone when the THP/AD system is off-line. No feed to the THP/AD system also limits operation of the co-generation facility. It is essential that the removal and treatment of WAS is reliably achieved to ensure sludge age in the nitrogen removal plant is optimised.

The stabilised dewatered cake at 27%DS is less than desired cake of 30%DS. This is believed to be related to a low VS destruction in the digesters of 45%. Optimisation activities are proceeding to elevate the VS destruction to the desired 50%. Post THP digested sludge is particularly difficult to capture in a centrifuge, due to the large number of fines generated. These fine particles have a very large surface area to weight ratio and tend to soak up a large amount of polymer and have low capture rates. This may be causing a recycle of digested material back into the process (essentially ash) and lowering apparent VS destruction. The optimisation of the solids capture from the dewatering centrifuge is a high priority project. Cambi AS have found that dewatering of the post THP/AD sludge by belt filter press generally provides better solids capture than centrifugal dewatering.

CONCLUSIONS

The operation of THP/AD process for the new nitrogen removal plant at Oxley Creek has resulted in a reduction in biosolids transported to landfill (and related costs) by over

70% in the first four months of operation. Importation of sludges from four other plants will commence shortly and therefore derive greater economic benefits.

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