COMPARING WASTEWATER SYSTEMS FOR A GROWING CITY

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Abstract

A coalition of NSW peak environment non-government organisations (PENGOs) used environmental life cycle assessment (LCA) to inform a critique of Sydney Water Corporation’s strategic planning document *WaterPlan 21* for the 4th PENGO Sydney Water Project. Over 400,000 new dwellings are planned for Sydney within the 2021 timeframe of *WaterPlan 21*. The environment groups have argued for a total water cycle approach using decentralized systems to better meet statutory ecologically sustainable development (ESD) principles which direct the nation’s largest water utility.

This study examines alternative scenarios for the delivery of water and wastewater services in new urban areas and compares them to a base case that would eventuate if Sydney Water extended its current operations. The study compares material and energy inputs required for the base case with decentralized water collection and wastewater treatment scenarios. These scenarios include a low-pressure sewerage system; an on-site septic tank and cluster filter system; and an on-site vermiculture system. Novel source separation processes include urine separation and greywater reuse. A key question to be resolved is whether aggregate environmental impacts of manufacturing and operating decentralized infrastructure at allotment and neighbourhood scales outweigh the benefits from reduced centralized infrastructure requirements.

The study shows quantitatively that, as connecting new fringe suburbs requires material and energy inputs including significant energy for pumping and treatment to augment and extend existing infrastructure, major improvements in the sustainability of water and wastewater systems can be achieved by using localised, water-saving alternatives.

Keywords

wastewater, decentralisation, greenfield, life cycle assessment, vermiculture

1 Introduction

This study contributes to the discussion of more environmentally sustainable services for both future extensive *greenfield* development and for the conversion of existing on-site systems. This study is also timely, given the 2021 projections for an increase of over 400 000 new dwellings for Sydney (including 130 000 new single and multi-unit greenfield dwellings) and the extension of Sydney Water’s *Priority Sewage Program* to consider options for unsewered areas. The NSW government has already announced the development of sixteen greenfield areas in December 2001 (Refshauge 2001; Planning NSW 2003).

This study also highlights alternatives for decision-makers considering the possible extension of centralised water and wastewater treatment services to peri-urban and country areas. This will generate environmental impacts from construction (materials) and operation (utilities, waste). Other operational aspects of sustainability, namely closing material (and nutrient) loops and minimising the contamination of natural flows, should also be considered.

Whilst the PENGOs have proposed an alternative, decentralized approach to servicing Sydney's water cycle needs for over a decade, there is insufficient research and development in this area. For some decades the monopoly service provider, Sydney Water (a state owned corporation) has been a dominant player in the water industry. The PENGOs successfully lobbied for inclusion of statutory ESD objectives in the corporation's enabling legislation (*Sydney Water Act*, 1994) including an effluent recycling target, and rigorous per-capita water efficiency targets in the corporation's operating licence. These have not translated into the necessary degree of change in practice, and the targets not met. Using environmental life cycle assessment (LCA), this study aims to quantify alternative servicing opportunities.

2 Scope of study

This environmental LCA study is novel in comparing existing centralised provision of water and wastewater services with decentralized alternatives. Other Australian studies have looked at on-site alternatives according to an environmental material accounting approach (Hall, *et al*, 2001) and detailed local-cluster-estate iterations for greenfields (Mitchell, *et al*, 2002). Both studies provided data and guided methodological approaches for the current study. This study is a further development, focussing on evaluating alternative on-site configurations and more fully quantifying environmental consequences (with respect to impact potentials, water conservation and resource recovery). Additionally, scenarios are more exploratory with novel technologies and configurations considered.

LCA methods compile a comprehensive inventory of material and energy requirements to manufacture and operate products or systems, and relate this to specific environmental impact categories potentials. In this study LCA methodology has been applied to quantitatively and qualitatively evaluate the environmental impacts of alternative greenfield systems. The results are compatible with a previous LCA study commissioned by Sydney Water and undertaken by the UNSW Centre for Water and Waste Technology (*LCA for WaterPlan 21 Review – Base Case and Scenarios*, Lundie, Beavis & Peters, 2003). The findings of the greenfield sites are compared with the base case of the *Waterplan 21* report.

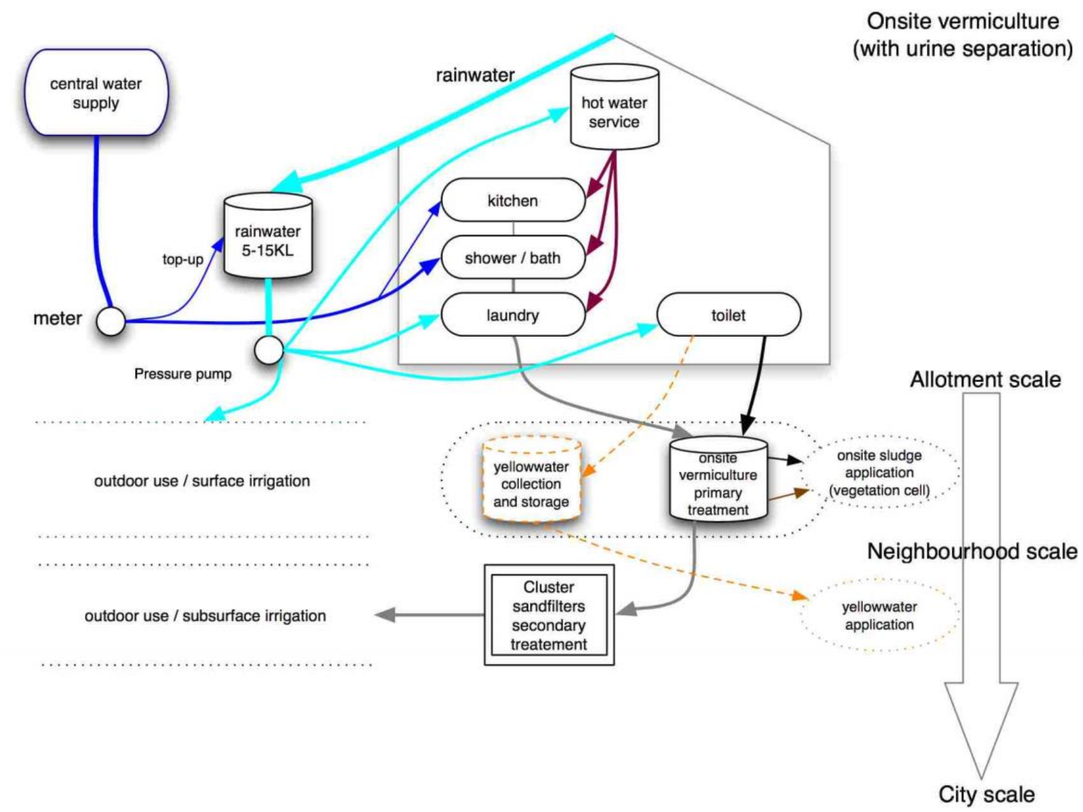
For this study a *functional unit* (FU) was chosen based on the proposed Edmondson Park site in South-Western Sydney to maintain comparability with the *LCA for WaterPlan 21 Review*, and to benefit from options investigation in the feasibility study (Mitchell, et al 2002) undertaken for Sydney Water. The study results are applicable to all greenfield areas in Sydney but allowance must be made for varying proximity to existing infrastructure.

The functional unit is defined as water and wastewater services for a specified population, i.e. 12,000 households (three persons/household) and with a specification of 91.1 tonnes/annum nitrogen and 15.8 tonnes/annum phosphorus produced in the combined wastewater, with a breakdown according to greywater, yellowwater and blackwater.

System boundaries and components for this LCA report are depicted in Figure 1 (one of the five scenarios and iterations is illustrated). Water sources are considered (rainwater harvesting and centralised potable treatment) as well as liquid waste stream treatments including septic systems; on-site vermiculture; cluster filtration; and centralised tertiary treatment with aerobic digestion. Water, nutrients (nitrogen and phosphorus) and key contaminant balances were completed across scenarios to ensure comparability. Resource recovery initiatives are evaluated within system options via greywater recycling; yellowwater separation; water reuse by industry; biosolids application to land and effluent application to land. The stormwater system is not included in the model.

The systems included in the scenarios are comprehensive (covering all household wastewater streams), technically feasible, and considered to provide sufficient sanitation in their broad context. While comprehensive greenfield servicing scenarios are specifically explored and results presented on this basis, it is valuable to consider the component parts of each system.

Figure 1: Illustration of system components: source, on-site and downstream (OVS)



3 Greenfield Scenarios in this LCA

The decentralised scenarios were conceived for the PENGO project as a progressive development from traditional on-site systems:

- addressing problems with conventional on-site absorption trench systems by introducing neighbourhood-scale clusters of secondary treatment sand filters with recycling (cascading use) of treated effluent for irrigation of allotment and municipal landscaping (substituting for potable water use for these applications);
- addressing problems with on-site primary septic tank treatment by substituting on-site aerobic biolytic effluent filters (vermiculture chamber) for primary treatment;
- reducing water consumption by collecting rainwater and recycling greywater and/or treated wastewater; and
- achieving higher resource recovery with urine separation/collection and application substituting for chemical fertiliser.

A starting point for the PENGOs alternative scenario was the Mobbs sustainable house in Sydney (Mobbs 1999), which employed local rainwater/stormwater collection, water efficient appliances, on-site wastewater treatment via a DOWMUS biolytic filter (vermiculture chamber), miniature wetland, and recycling of water to outdoor (garden) and indoor (toilet and laundry) uses. Benefits include augmentation of water supply, reduction of stormwater infrastructure and reduced impacts on the downstream environment.

The PENGOs wished to compare these technologies with conventional servicing options to discover whether the material and energy requirements of alternative systems outweighed the water cycle benefits claimed by Mobbs and others (Lens, Zeeman & Lettinga, 2001; Brennan, 2001; Rodney District Council, 2002). The PENGOs also wished to determine the extent to which reductions in material and energy requirements would follow from application of these technologies on a neighbourhood scale instead of an individual allotment scale. The following scenarios were considered in comparison with the base case

Table 1: Scenarios

System	Components	Products	Environmental Interventions
Low Pressure Sewerage System (LPSS)	Full central potable water source. On-site grinder pumps, tertiary effluent via Glenfield STP to Malabar STP and ocean. 30% reuse by industry from Georges River scheme	Biosolids from aerobic digestion; reuse water from sewer mining	Tertiary effluent to ocean; biosolids to land
LPSS 1*	As above with rainwater harvesting for 55% of potable water demand; effluent discharged to inland rivers	Biosolids from aerobic digestion	Tertiary effluent to inland water; biosolids to land
Septic	Rainwater harvesting; on-site septic treatment; greywater reuse for toilet; common effluent drainage to recirculating sand filters, irrigation to land; solids to central vermiculture site	Nutrients in effluent; vermicast from vermiculture treatment	Fugitive methane/ ammonia emissions to air; 1% run-off from land application of effluent; effluent to land; some effluent to inland river
On-site vermi-culture System (OVS)	Rainwater harvesting; on-site vermiculture/biolytic filter based on AquaClarus package units; yellowwater separation; common effluent drainage to recirculating sand filter and to irrigate land; solids pumped to on-site vegetation cells	Nutrients in effluent; diluted vermicast	Fugitive emissions of ammonia to air; effluent to land; on-site application of vermicast
OVS 1*	As above; rainwater tanks reduced for multi-unit dwellings; reduced pumping on-site with AquaClarus units configured for operation with cluster sand filters; reduced pumping to sand filters based on subdivision layout.	Nutrients in effluent; diluted vermicast	Effluent to land; on-site application of vermicast

* Indicates an iteration of the scenario, i.e. LPSS and OVS

For the LPSS scenario, Sydney Water's Georges River Project (duplication of trunk drainage from Sydney's south-west to Malabar ocean outfall) is assumed to be successful, with 30% industrial reuse by 2021. For the OVS scenario, a vermiculture/secondary treatment package plant manufactured by AquaClarus was specified, as designed for individual allotment scale use. For OVS 1 a modified configuration better suited to a greenfield site (with a proportion of multi-unit dwellings) was specified.

These scenarios represent a combination of spatial treatment levels, i.e. on-site (allotment scale), cluster (neighbourhood scale) and centralised (city scale). These allow exploration of more complex distributed and decentralised systems, and optimum treatment scales, while maintaining sanitation and environmental health criteria.

4 Results of Life Cycle Assessment

The following environmental indicators and environmental impact categories are calculated: total energy, potable water use and water use for manufacturing product inputs, global warming potential, eutrophication potential, photochemical oxidant (smog) formation potential, human toxicity potential, terrestrial, freshwater and marine eco-toxicity potential.

4.1 Aggregate results

Table 2 summarises results for all indicator categories. The interpretation of these results should be undertaken with several caveats. Firstly, to maintain comparability with *LCA for WaterPlan 21 Review*, Sydney Water's original assumptions for potable water use for different scenarios were retained. Specific modelling of water conservation and demand management scenarios gives more conservative results from modelling for rainwater collection in several areas of Sydney, including Macarthur where the Edmondson Park scenario was specified, due to drier climate and likely demographics (Coombes, 2002).

Secondly, scenarios were combined to cover a range of novel and decentralised technologies. However, the optimum system would be configured on the basis of further investigation at the project scale. It was not possible to model a number of promising technologies or all possible combinations to ensure the most beneficial options were explored.

Thirdly, assumptions used for the LCA model (with the except of rainwater collection) were generally conservative for decentralised systems (in the sense that we tended to specify worst case due to uncertainties) but less conservative for centralised systems (because these are better known and information was obtained from Sydney Water's model). Some sensitivity analysis was undertaken on result changes due to variability of assuming fugitive emissions. Key sensitivities to the results are fugitive emissions and material use. The sensitivity analysis focused on emissions. If volatile organic carbons (e.g. methane) are included in centralised atmospheric emissions, an additional 936 tonnes of global warming potential is added to the LPSS options. Additionally, LPSS impacts to smog potential would increase by 0.31 tonnes.

Table 2: Summary of LCA results for novel and decentralised technologies

IMPACT CATEGORY	Unit/equivalent*	LPSS	LPSS I	SEPTIC	OVS	OVS I
Total energy	10^6 MJ	62.6	59.3	52.1	70.1	51.4
Centrally Sourced Potable water use	ML	2,210	984	900	984	984
Water use (for manufacturing)	ML	25	13	13	13	8
Global warming	CO_2 equiv.	4,990 (5,926)	5,030 (5966)	11,900	5,420	4,150
Eutrophication	O_2 depletion equiv.	98	96.1	336.2	149 (93)	137 (81)
Smog	Ethylene equiv.	0.47 (0.78)	0.42	2.77	0.94	0.91
Human toxicity	DCB equiv.	128.00	49.80	36.80	35.30	31.20
Terrestrial ecotoxicity	DCB equiv.	234	226	319	286	278
Freshwater ecotoxicity	DCB equiv.	16.6	1240	65.8	43.7	43.3
Marine ecotoxicity	DCB equiv.	1,310,000	197,000	103,000	130,000	108,000

Note: *Tonnes unless specified. Sensitivity test data in brackets (see text). DCB = Di-Chloro-Biphenol

OVS system contributions to eutrophication potential are variable, with emissions based on a 5% volatilisation of the ammonia created in yellowwater storage tanks (and the assumption that it precipitates and makes its way to freshwater ecosystems). If the assumption was 1%, the ammonia contribution reduces by 56.4 tonnes. A similar reduction occurs if urine (yellowwater) separation was excluded, but recovery of nitrogen would drop significantly.

4.2 Comparison to business-as-usual

Results for the novel and decentralized scenarios are compared with the business-as-usual scenario from the *LCA for WaterPlan 21 Review* in Table 3, expressed as % of the base case. The "business-as-usual" base case is often the worst (in five out of ten categories) and never the best option, while the best decentralised scenario using on-site biolytic filters and urine separation is usually the best option (in eight out of ten categories) and never the worst option.

Table 3: Comparison of LCA results for novel and decentralised technologies with "business-as-usual" base case scenario (per capita per year)

	BASE CASE		LPSS	LPSS I	SEPTIC	OVS	OVS I
Total Energy	1.66 GJ	*100%*	*105%*	*99%*	*114%*	*118%*	**86%**
Potable Water Use	0.13 ML	*100%*	45%	**20%**	**19%**	**20%**	**20%**
Water Use (manufacturing)	0.57 kL	100%	*120%*	84%	61%	92%	**39%**
Global Warming	146.9 kg CO_2	100%	94%	95%	*225%*	103%	**81%**
Eutrophication	47.1 kg O_2	*100%*	**6%**	**6%**	20%	**9%**	**8%**
Smog	0.03 kg ethylene	100%	**40%**	**42%**	*236%*	81%	76%
Human Toxicity	12.9 kg DCB	*100%*	27%	**11%**	**8%**	**8%**	**7%**
Terrestrial Ecotoxicity	8.7 kg DCB	100%	**75%**	**72%**	*102%*	91%	89%
Freshwater Ecotoxicity	15.4 kg DCB	100%	**3%**	*220%*	**12%**	**8%**	**8%**
Marine Ecotoxicity	103.3 t DCB	*100%*	35%	**5%**	**3%**	**3%**	**3%**

Note: Best results are bold, worst results are italic. Results within 10% are considered equivalent

4.3 Resource recovery

Nutrient recovery is quantified in absolute figures and quantities of fertiliser substituted. Separation of urine allows the recovery of a large proportion of nitrogen from wastewater.

Table 4: Nutrient recovery via novel technologies (tonnes/yr)

System	Area	Nutrient		Fertiliser equivalent	
		Nitrogen	*Phosphorus*	*Nitrogen*	*Phosphorus*
LPSS	Solids from central treatment	13.09	15.70	7.34	28.23
	Total	**13.09**	**15.70**	**7.34**	**28.23**
Septic (greywater reuse)	Effluent from cluster filter	16.78	12.61	21.92	36.42
	Vermicast from central treatment	14.75	3.15	12.44	11.79
	Total	**31.53**	**15.80**	**34.36**	**48.22**
OVS (yellow-water reuse)	Yellowwater	61.22	6.31	117.15	26.28
	Effluent from cluster filter	6.39	6.62	8.35	19.12
	Vermicast from local treatment	5.47	2.84	3.66	8.58
	Total	**73.08**	**15.80**	**129.16**	**53.98**

4.4 Retrofitting novel technologies

Results may also apply to retrofit situations, including Sydney's Priority Sewerage Program areas where reticulated sewerage infrastructure is not installed. If decentralised cluster systems are retrofitted to existing stand-alone systems, including re-using existing septic tanks, there are significant improvements across all indicators (see Table 5). Calculation of these benefits includes saved materials but does not include benefits of further product offsets.

Table 5: Additional percentage improvements in septic scenario with cluster retrofitting

Total Energy	Water use (manufacturing)	Global Warming	Eutrophication Potential	Terrestrial Ecotoxicity	Human Toxicity	Smog
9.5%	3.5%	4%	5.9%	1.3%	0.5%	0.4%

% benefits in addition to the benefits indicated for the septic scenario

5 Conclusions

The results indicate that urban development which utilises the opportunities of individual and cluster configurations at the allotment and neighbourhood scale outperforms centralised treatment in terms of minimising most of the environmental impacts.

Furthermore, the opportunities for nutrient resource recovery are significant in decentralised systems. There are opportunities for source separation and preservation of nutrient resources. These are achieved whilst covering all the liquid waste streams from the household in a sanitary manner. The study questions the logic of the material and energetic effort to treat combined wastewater and recycle water and nutrients via highly centralised infrastructure.

The system boundary incorporates water and wastewater provision. The LCA identifies relative environmental impacts of providing centralised recycled effluent for industry with water conservation alternatives (rainwater collection, greywater reuse). Centralised recycling has total embodied energy requirement of 39.5 MJ/kL (and only avoiding 21.7 MJ/kL from potable water production) a significant net energy requirement. The decentralised alternative through water conservation potentially saves 19.9 MJ/kL compared to the base case and the LPSS recycled alternative. Recycling water cannot via highly centralised infrastructure be considered sustainable according to this energy indicator. Effluent reuse for irrigation (used judiciously, with source control of metals and organics) acts as a substitute for fertilizers and is superior compared to discharge to waterways.

Biolytic filtration for primary treatment from the OVS scenario gives better results than either grinder-pump and centralised STP or anaerobic septic treatment across indicator categories with the specific configurations modelled. All scenarios would benefit from rainwater harvesting. Greywater reuse is beneficial and provides additional water savings, especially in lower rainfall areas. The separation of yellowwater enables a large proportion of nitrogen and some additional phosphorus to be recovered. Storage to reduce ammonia volatilization and local application (short haulage) is critical here in order to minimize environmental impacts.

Alternative servicing carries perceptions of higher cost and risk resulting from unfamiliarity, even if borne out in practice. Correct specification and analysis of scenarios is important. Generally, when decentralized system options are included for comparison in the planning and environmental impact assessment process, they are poorly specified. For example, see the *Hawkesbury-Nepean Wastewater Strategy* (SWC, 1997); *EIS for Brooklyn & Dangar Island Priority Sewerage Program* (SWC 2000a); *Upper Georges River Wastewater Strategy – Economic & Financial Evaluation* (ACIL 2000); *Penrith STP EIS Summary* (SWC, 2000b). The preferred option is usually a conventionally specified and centralised treatment scenario, never a sustainable decentralised one. Incorrect options ranking leads to poor decision-making when allocating resources to wastewater treatment and slow progress towards sustainability.

Generally, decentralised systems were competitive with conventional centralised systems and should convincingly outperform conventional centralised solutions across all environmental impact categories considered in this study. Feasibility studies undertaken for Sydney Water for the greenfield site at Edmondson Park (Mitchell, *et al*, 2002) indicated that these solutions are likely to be cost competitive and score well under sustainability assessment criteria.

Using decentralised technologies for new development will lead to significant improvements in environmental impact and should form a key part in achieving a sustainable Sydney.

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More information, including the report prepared by the Centre for Water & Waste Technology for the PENGOs, is available at www.totalwater.info

References

ACIL Consulting (2000) *Upper Georges River Wastewater Strategy – Economic and Financial Evaluation Report – A Report to Sydney Water*, August 2000.

Ankers, S (2003) Personal Communication with Shaun Ankers of Vermitech Pty Ltd through March 2003

Aqua Claris (2003) *Simply Natural Wastewater Treatment System: Models SN1IP, SN1EP*

Brennan M (2001) An Economic, Social and Environmental Review of Effluent Disposal using TBL Principles ***In***: *Proceedings of On-site '01 Conference: Advancing On-site Wastewater Systems*. University of New England 25th –27th September 2001 pp.63-70

Coombes PJ (2002) *An Evaluation of the Costs and Benefits of Demand Management Solutions in the Greater Sydney Region*. A report prepared for the PENGOs as part of 4th Sydney Water Project, December 2002.

E/One Sewers (2003) GP 2000: *Low Pressure Sewer Systems Using Environment One Grinder Pumps*

Hall M, Lovell H, White S, Mitchell C. (2001) To Centralise or Not? Broadening the Decision Making Process. ***In:*** *Proceedings of On-site '01 Conference: Advancing On-site Wastewater Systems*. University of New England 25th –27th September, pp.163-169

Hellstroem D, Johansson, E, Greenberg, K (1998) *Storage of Human Urine: Acidification as a method to inhibit decomposition of urea* ***In***: Nutrient Management in Sewerage Systems: Investigation of Components and Energy Analysis. Doctoral Thesis Lulea University Sweden.

Hutton N (2001) Illuka Wastewater Management – A Case Study ***In***: *Proceedings of On-site '01 Conference: Advancing On-site Wastewater Systems*. University of New England 25th –27th September 2001 pp.201-204

Lens P, Zeeman G & Lettinga G (2001) *Decentralised Sanitation & Reuse: Concepts, System & Implementation*

Lundie S, Beavis PC, Peters G (2002) *LCA for Waterplan 21 Review: Basecase and Scenarios* Centre for Water and Waste Technology, University of New South Wales July 2002

Metcalf and Eddy (1994) *Wastewater Engineering: Treatment, Disposal, Reuse* 3rd Edition. McGraw Hill

Mitchell C, Mitchell G, Shipton R, Speers A, Turner A, White S (2002) *Edmondson Park Feasibility Report*

Mobbs, M (1999) *Sustainable House: Living for Our Future*, Otago Press

NSW Health (2000) *Greywater Reuse in Sewered Single Domestic Premises* April 2000.

Orenco Pty Ltd (1999) Case Study Elkton, Oregon

Patterson R (1999) *Modifying Wastewater Inputs for On-site Systems Principles* In: Proceedings of On-site '99 Conference: Advancing On-site Wastewater Systems, University of New England 13th-15th July 1999.

Peters G (2003) Personal communication with Dr. Gregory Peters of Sydney Water Corporation March 2003

Planning NSW (2003) Managing Sydney's Urban Growth April 2003 Update

Refshauge A (2001) *New Land to House Sydney's' Families* Ministerial Statement 5th December 2001

Rodney District Council (2002) *Kumeu, Huapai, Waimauku, and Riverhead Wastewater Services Options – Preliminary Investigations* prepared by Bruce Fulford

SWC (1997*) Hawkesbury-Nepean Wastewater Strategy,* Sydney Water Corporation, Sydney.

SWC (2000a) *EIS for Brooklyn and Dangar Island Priority Sewerage Program*, Sydney Water Corporation

SWC (2000b) Penrith Sewerage Treatment Plant Amplification & Glenbrook Waste Water Transfer EIS Summary, Sydney Water Corporation, Sydney.