SEWAGE EFFLUENT MANAGEMENT – WASTE OR ASSET?

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ABSTRACT
"Waste not – want not" is an adage peddled around at various occasions, but the serious aspect with regards to sewage management is that, for most towns, the waste is not wanted. Unfortunately, effluent reuse is a long term goal, rather than a short term consideration.

The removal of essential nutrients from sewage presents several engineering problems, not the least is an understanding of the ultimate benefit or harm these nutrients may have to the environment. Nutrient removal by chemical precipitation and biological processes is easily solved by structural additions to a sewage treatment plant. However, just outside the built environment is the one environment that is capable of assimilating those nutrients with a reward to the operators by way of organic produce.

This paper examines typical sewage quality from rural towns as well as metropolitan areas and converts the data to surrogate fertiliser values. Agriculturalists talk in ratios of N:P:K:S, just the same emphasis we need when talking about sewage treatment. Sustainable sewage management has been grasped by some Councils and water authorities, but many are yet to see the rewards. The data presented here may be the convincing thread that is needed.

Keywords: effluent reuse, nitrogen, nutrients, phosphorus, sewage.

1 INTRODUCTION

Much of our communities' health advantage over the last two centuries, compared with early industrialised cities, is the outcome of modern sewage treatment through engineered works to reduce the bacterial load, lessen the impact of nutrient loading to the receiving environment, and remove most of the suspended load. In terms of water treatment, the standard treatment has endeavoured to reach a 20/30 outcome, that is less than 20 mg/L five-day biochemical oxygen demand (BOD_5) and 30 mg/L total suspended solids (TSS). In all but discharges to marine environments, which can hardly be called treatment, this 20/30 quality target has achieved some success, but only through enforcement rather than beneficial objectives. But is this target valid in these environmentally aware times?

While the engineers may concentrate on structural changes in sewage treatment plant (STP) design to achieve even lower BOD_5/TSS targets through innovations such as intermittently dosed extended aeration (IDEA), rotating biological contactors (RBC) and lately submerged membrane bioreactors (MBR), much of the value of sewage is lost.

Turning organic nitrogen (organic matter, urine) into gaseous nitrogen through microbial processes is easy, but only achieves a loss of a valuable plant nutrient. Removing phosphorus through either precipitation with lime (calcium carbonate) or alum (aluminium sulphate) takes a non-renewable resource (phosphorus) to landfill – hardly innovative! Yet, regulation by state authorities makes the reduction in nitrogen and phosphorus mandatory. In NSW, Load Based Licences (DEC 2005) for 'polluting' industries tied to a 'licence to pollute', permit discharges within various limits but imposes significant charges on excess discharges to air or water. For sewage treatment plants discharging to rivers or creeks, that annual charge may be significant to the community. Once again, marine discharges are exempt – so much for environmental ('green') values!

In single domestic households, the updated aerated wastewater treatment system over-treats and chlorinates wastewater that previously was discharged through a septic tank into a subsurface drainfield. This excess treatment comes at great cost and continual energy consumption (2.4 kW/day) and only in exceptional circumstances leads to an environmental and health improvement.

2 SEWAGE RECEIVALS

2.1 Properties of Sewage

The discharge of domestic and commercial wastes into a reticulated sewerage system uses water as the transporting medium. Toilets are flushed to transport faeces and paper, kitchen sinks mix water and vegetable matter, greases and oils, bathrooms provide a cocktail of 'personal care' products and copious quantities of water, and laundries add to huge chemical loads in excess of any performance requirement. In commercial premises, the chemical load may be under-estimated in terms of potential changes to pH, salinity, total alkalinity. High volumetric discharges may overload the capacity of the STP to adequately treat, such as occurs when stormwater enters damaged and leaking sewers.

Sewage quality changes from day to day and even on an hourly basis because of our wastewater generating capacity. From late at night to almost sun rise, wastewater generation in domestic premises is limited both in terms of water and the wastes discharged. Commercial premises, such as butcher shops, fast food outlets and supermarket delicatessens impose loads in the late afternoon, just as the households are ramping up their discharges. Some trade waste discharges may have lower tariffs for discharging off-peak, while others may have no option other than to discharge at peak.

2.2 Small Village Sewage Inflows

Table 1 shows the monthly inflow data to an STP during a recent licence period. Raw wastewater is sourced mainly from a non-industrial rural town of about 2200 equivalent persons (EP), where clean water inputs are reticulated from a clean water treatment plant (WTP). The raw water and the effluent are sampled once during the last week of each month as required by licence.

Table 1. Monthly raw water inflow quality to STP for town ~2200 EP (Lanfax Labs, unpubl.)

Sample month		Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Average	90th
Sample day		Fri.	Wed.	Thurs.	Thurs.	Tues.	Thurs.	Thurs.	Fri.	Thurs.	Fri.	Mon.	Wed.		percentile
BOD5	mg/L	50	221	158	179	21	39	186	74	22	205	173	63	116	203
TSS	mg/L	40	180	130	380	15	23	250	60	35	560	120	110	159	367
TN	mg/L	62	101	85	38	18	27	47	17	25	113	59	49	53	99
TP	mg/L	11	11	9	10	2	3	15	5	3	18	8	6	8.4	14

It is clear from Table 1 that the variation in the four parameters was high. On which day of the week, and at what time should the sample be taken? Why not take samples on Saturday and Sunday? Why not take composite samples using a refrigerated sample collector? These temporal sampling variations create another set of problems, such as sample age and changes that may occur between time of sampling and time of analysis. The results reported above were not taken on the same day during the last week of each month as can be seen from row 2. We could, however, choose a day and time that gave a desirable result rather than an accurate result – or can we get an accurate result?

2.3 Inflow Data as Load

Some of the variation to inflow quality is the result of water quantity. Dilution may be no solution to pollution, but simply monitoring quality in terms of concentration is erroneous, yet often quoted, as Table 1 shows. For a larger STP (23 000 EP), for which the author has access to flow data (Lanfax Labs, unpubl.), the monthly contribution to nutrient discharges become obvious.

Table 2. Monthly mass contributions in raw water inflows to STP for about 23 000 EP

pollutant	units	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	Total
BOD	tonne/month	27.2	3.2	33.3	51.0	7.1	30.2	33.7	27.4	29.3	28.0	27.3	23.9	**322**
TSS	tonne/month	27.3	2.3	59.5	85.0	5.7	33.8	29.1	54.5	37.8	40.7	27.4	49.4	**453**
TN	tonne/month	8.3	6.2	7.8	16.7	4.2	8.0	9.7	9.0	9.0	8.4	10.7	8.2	**106**
TP	tonne/month	1.3	0.5	1.6	2.8	0.5	1.5	1.9	1.8	1.7	1.2	1.0	1.5	**17**

The outcome from the system referred to in Table 2 is that each year, the raw water contributes 106 tonnes of nitrogen, equivalent to 230 tonnes of urea (46% N), and 173 tonnes of phosphorus, equivalent to about 1977 tonnes of single superphosphate (8% P). The financial value of these two chemicals is in excess of $1,100,000 and not considered an asset! As at 26th August 2011, the Armidale price for single superphosphate was $473/tonne, and for urea $762/tonne (Richardsons Hardware & Agriculture, *pers. comm*.).

2.4 Nutrients in Sewage

Essential macro-nutrients for plants and animals include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S), as well as many micro-nutrients. Sourced from the food we consume and the chemicals we use in our homes, these nutrients are delivered to the STP in the soup that is domestic wastewater. This highly variable concoction of chemicals, diluted with water is difficult to treat because the quality is infinitely variable, temporally, quantitatively and qualitatively. Yet, it is incumbent upon the supervising engineer to ensure that the discharge limits set for the environmental protection licence are achieved and verified through regular monitoring.

While the loads presented in Table 2 could well be used by plants, the treatment processes through which raw sewage is converted into a less obnoxious soup removes some of the nutrients as well as the undesirables. Bar screens and grit traps remove the larger solids and insolubles, oil and grease is floated off, settlement removes a proportion of the suspended solids, and depending upon the treatment process, insolubles are reduced to solubles through microbial degradation. Thus, the discharge is qualitatively different from the raw inflow, depending upon the treatment process.

Table 3 shows a comparison of wastewater treatment as it flows through a small IDEA plant servicing about 2200 EP. The plant is designed to: remove phosphorus using alum as a precipitant; denitrify during the quiescent period prior to decant; remove total suspended solids (TSS); and reduce biochemical oxygen demand (BOD). From the results, the plant is effective in those four areas. The increase in sulphur is from the alum (aluminium sulphate), while the increase in sodium has not been investigated, but is not significant. Effluent is ultra-violet disinfected before discharge into the local watercourse as the treatment system does not have maturation ponds. No re-use occurs, therefore this level of treatment is consistent with the proposed use – discharge into enclosed waters.

Table 3. Nutrient status of small IDEA plant from inflow to discharge – averages 2010/11

Location	**TN (mg/L)**	**TP (mg/L)**	**K (mg/L)**	**S (mg/L)**	**(TSS) (mg/L)**	**BOD_5 (mg/L)**	**Sodium (mg/L)**
RAW	53	8.4	13.8	16.8	159	116	76.3
Discharge	3.2	0.13	13.5	52.8	8	3.5	98

(Source: Lanfax Labs, unpublished)

At an older traditional trickling filter and pond STP, where water passes through a contorted array of maturation ponds (shallow aerobic ponds with long flow path), losses in nutrients occur through nitrification/denitrification, precipitation of chemical complexes, solar radiation, aeration and degradation by microbial activity. Table 4 shows the losses over a 2000 m flow part as water moves through a series of ponds, through A to B and then to discharge into the local watercourse without prior disinfection. At A and B effluent is extracted for irrigation onto pastures and crops.

Table 4. Losses of nutrient as water flows through maturation ponds without chemical treatment

Location	**TN (mg/L)**	**TP (mg/L)**	**K (mg/L)**	**S (mg/L)**	**(TSS) (mg/L)**	**BOD_5 (mg/L)**	**Sodium (mg/L)**
RAW	45.5	10.8	15.6	20	206	158	73
A	10.0	7.9	16.5	15	11	7	67
B	6.8	7.2	16.0	15	6	4	65
Discharge	4.6	5.9	14.9	15	10	3	64

Values are averages over 12 month licence period. (Source: Patterson, 2009)

Some of the TSS will be mineral matter (sand, soil, non-volatile product) while the BOD_5 can be regarded as the organic component. Certainly the treatment process has significantly reduced the BOD_5 to levels that are less stressful on the receiving environment, but the removal is almost no benefit where the effluent is used for irrigation. During the 2010/11 licence period, this 22 000 EP effluent has a faecal coliform range of 4-82 colony forming units per 100 mL (cfu/100 mL), well within primary contact range.

This treatment was consistent with end use when the plant was designed decades ago – discharging to waters, but in recent years, effluent re-use has become a significant activity at this STP to reduce load based licence fees. The discharge quality is now less ideal for irrigation purposes, although only a proportion of the total discharge can be re-used for irrigation (because of shortage of available land) and the rest is discharged at a fee.

The important issue with treatment of sewage prior to reuse for irrigation is that the higher the treatment process, the less nutrients available for re-use and the more the effluent simply resembles saline water, its value only in the value of the water. Since plant nutrient requirements are in the ratio of N:P:K:S of 10:1:1:1, the effluents presented in Tables 3 and 4 are well out of ratio, unless additions of nutrients are made from other sources. Effluent irrigation schemes must address this imbalance, putting back into the system elements that it vigorously removed. Is there some story in that?

3 Sewage Treatment

3.1 Treat for Purpose

The treatment of municipal sewage should be consistent with the ultimate discharge of the effluent. Where effluent is discharged to the environment, treatment must address the potential for degrading the receiving waters through introducing a biological and/or chemical load to the river. Public health addresses the bacteriological indicators to assess the effectiveness of the treatment process in disinfecting the effluent either through long term holding, ultraviolet treatment or chlorination. Chemical concentrations in effluent may encourage growth of aquatic species that lead to future eutrophication events, such as phosphorus encouraging cyano-bacteria and aquatic flora, and ammonia affecting fish populations. Removal of pollutant chemicals in the treatment process is aimed at minor and insignificant changes in the receiving environment – a desirable target in the treatment process.

However, where the effluent is to be used for irrigation of crops and/or pastures, the treatment process may best be modified to preserve nutrients that would otherwise be lost through atmospheric discharges (denitrification) or removed by precipitation. Typical off-the-shelf treatment systems may, in fact, simply waste these resources that could otherwise be used to produce food and fibre.

While nitrogen in its gaseous form is unavailable to plants and animals, nitrogenous products formed by bacteria are essential to life. It seems a wasted effort that the nitrogenous products in sewage are denitrified back into gaseous products, while crops are fertilised with nitrogen products that are generated from nitrogen gas and large amounts of energy. A simplified step would be to use the nitrogenous products in sewage where possible. Under current energy policy there is no driver for this action to occur. Thus, we are over-treating our effluent at the expense of the environment and the lost opportunity benefit to plant production.

Phosphorus is a non-renewable resource, and while transport engineers consider 'peak oil', food industries consider 'peak phosphorus'. While we may have substitutes for oil (biofuels), we will not be able to grow the biofuel inputs without phosphorus, or the food we need to survive.

While the removal of BOD may benefit a receiving aquatic environment, for land application the removal of BOD is irrelevant. Manures are regularly used for home gardens as well as broad-scale agriculture and even by accepted environmental practices, additions of BOD in excess of 1000 mg/kg soil are not unusual. Why then is land applied effluent with greater than 20 mg/L (20 kg/ML) regarded as polluting? It simply does not make either environmental or agronomic sense.

3.2 Waste not, Want Not

We see in Tables 3 and 4 that the current treatment systems remove nitrogen and phosphorus, plant macro-nutrients, during the treatment processes. Where this effluent is used for irrigation of crops and pastures, the farm manager has to add chemical fertiliser to meet the needs of the plants. The additional water will only drive production as far as the nutrients are available in the soil and where land is farmed year after year, depletion will result in a need for additional fertiliser, over and above the nutrients contained in the effluent. So why remove the N and P in the first place?

At present, Sydney discharges about 1300 ML sewage per day, 498 ML of high-rate primary to the ocean outfall at Malabar, 308 ML of high-rate primary at North Head (Sydney Water, 2011). Assuming that the wastewater has a nitrogen (50 mg N/L) and phosphorus (8 mg P/L) concentration similar to the two examples used above, then the population of Sydney is wasting 65 tonnes of nitrogen (141 tonnes urea) and 10.4 tonnes phosphorus (118 tonnes of single superphosphate) each and every day. The annual cost in lost nutrients exceeds $39 million for urea and $20 million for single superphosphate, without counting the value of potassium, copper, zinc and other metals.

On a per-capita basis from Table 2, the annual generation rates are about 4.8 kg N, and 0.77 kg P. If those values were applied to the population of NSW of 7.27 million (ABS, 2011), collectively we waste 4900 tonnes of N (10 650 tonnes urea), and 5 600 tonnes of P (63 600 tonnes superphosphate).

So why do we have fertiliser plants turning atmospheric nitrogen into ammonium nitrate, and rock phosphate mining and chemical plants turning phosphorus into plant available forms? Could we not reduce the amount of rock phosphate imported and reuse all of what is in the wastewater?

4 Biosolids

The treatment of sewage separates a range of constituents from the water component and accelerates the degradation of these organic and biodegradable products under anaerobic conditions, aerobic conditions or a mixture of both. The solids are either separated for treatment in anaerobic digesters, or diverted into sludge lagoons. The type of sludge removal depends upon the treatment train but a thick black ooze results, of about 4-6% solids.

The IDEA plant referred to in Table 3 removes sludge from the IDEA tank and stores it in a reservoir for a period to allow further dewatering through settling and degradation through both anaerobic (below about 2 m depth) and aerobic (surface) processes. After a period, the biosolids are removed and disposed of either as landfill or pasture renovation. The former method simply wastes a valuable resource, while the latter adds nutrients and organic matter to the soil, recycling the nutrients through the soil ecosystem. There are many examples where the land application of biosolids has shown a significant improvement in pasture and crop production. A withholding period is required before cattle grazing to prevent the infection by parasites.

Where alum dosing is used for precipitation of phosphorus from the raw sewage, the sludge retains the aluminium and may present problems for soil renovation. Aluminium in high concentrations is toxic to plants and will lower the pH, often creating other nutrient availability problems. Although all clays are alumino-silicates, the aluminium is in bound forms and except at low pH (< 5.5) is not bioavailable, unlike the aluminium entrained in the biosolids.

Table 5 compares two sewage treatment works biosolids, one employing an IDEA plant with phosphorus removal using alum, and a traditional trickling filter system with anaerobic digester without any chemical phosphorus removal. The results are based upon oven-dry weights.

Table 4. Biosolids nutrient from two different treatment processes from small IDEA plant

Location	TN (%)	TP (%)	K (%)	S (%)	Al (%)	Ca (%)	Sodium (mg/L)
Alum system	3.2	4.2	0.05	0.68	5.0	1.9	0.06
Biological system	5.4	1.8	0.16	0.89	0.8	3.7	0.2

Percentages based upon oven dry weight of biosolids. 1% = 10 000 parts per million or milligrams per kilogram (Source: Lanfax Labs, unpubl.)

The alum dosing system presents a biosolids that is higher in total phosphorus (TP) and aluminium because the dosing process uses the aluminium ions to remove the phosphorus. That STP needs to meet a 0.3 mg P/L licence discharge quality. The biological system is the typical trickling filter, anaerobic digester system referred to in Table 4. This STP avoids the use of additional chemicals in the treatment process, thus has a lower TP (less TP removed) and a significantly lower aluminium because of the avoidance of additives. The latter system has a load based licence penalty based upon the annual phosphorus load (in kg) discharged to the waterway, but the phosphorus in the effluent is a benefit when re-used on pastures and crops.

In relation to the ideal ratio of plant nutrients, the biological system has a better balance of N:P (3:1), even though not ideal, than that of the alum system where TP exceeds TN (N:P is 0.8:1). Potassium is low in both cases, a reality in residential wastewater systems. The sodium is not an issue because it does not accumulate in the sludge, but is moved with the effluent, where it may be of concern.

5 Plant Nutrient Requirements

5.1 Macronutrients

The essential nutrients required in relatively large proportions are termed ‘macro-nutrients’ and include N, P, K, S, Ca, Mg as well as carbon (C), oxygen (O) and hydrogen (H). Without these elements, plant and animal life as we know it would not exist. Nitrogen is used to grow proteins (amino acids), phosphorus is a component of DNA and acts as an energy transfer mechanism as well as a major component of bones and teeth, potassium is an essential cell electrolyte and calcium is a major component of cell walls in plants and bones and muscle in animals. Wasting these macro-nutrients through sewage treatment simply removes these elements from recycling through the food chain. The macro-nutrients present in sewage are the result of consumption of plant and animal material and the wasting of the unwanted or converted portions through faeces, urine and kitchen scraps.

An inspection of Tables 3 and 4 shows that our modern sewage treatment systems are very effective in removing these macro-nutrients for a fate that is simply to dispose of them as waste. These macronutrients should be recycled back into the food chain from whence they came, supporting the replenishment of the soils from which they originated. Unfortunately, excuses conceal the lack of practice of sustainable cities, the dumping of essential products and the continued rape of the soil resources outside the cities. Sewage treatment is just another victim of progress, and failure to pay for environmental costs by end users (consumers).

5.2 Micro-nutrients

Elements required by plants and animals in very small quantities include boron (B), copper (Cu), iron (Fe), chloride(Cl), manganese (Mn), molybdenum (Mo) and zinc (Zn). These micro-nutrients are also essential to life, often as catalysts to more significant life processes. When viewed in light of the ‘Environmental Guidelines: Use and Disposal of Biosolids Products (NSW EPA, 1997), the micro-nutrients are lumped in with known unwelcomed trace elements such as arsenic, chromium and mercury. To disallow biosolids with copper (>100 mg/kg) and zinc (> 200 mg/kg) even though our soils show significant deficiencies for these elements, is ignoring plant nutrition. Thus, biosolids that may not contain known trace element contaminants are downgraded because of high copper and zinc.

Copper leaches from the copper pipes in our homes, and the cleaner the water the faster the leaching – we therefore ingest copper from our drinking water but do not ban copper pipes. Similarly, zinc from our pipes, tanks and roofs leach into our water supplies – but we do not ban the use of zinc. How does the dumping of biosolids constitute sustainable cities?

5.3 Nutrient Ratios

Plant and animal requirements for macro-nutrients and micro-nutrients are in relative proportions to their importance in metabolism of the organism. As indicated in Section 2.2, ratios of N:P:K:S for plants are 10:1:1:1 for ideal conditions, provided water is not limiting. Under irrigation with effluent, the ratios must be boosted by the addition of chemical fertilisers, even when biosolids are spread.

It is known that lucerne not only produces protein from atmospheric nitrogen because it is a legume, but also requires nitrogen from the soil. Decaying organic reserves provide that nitrogen source, released by the activity of micro-organisms in a moist environment. Harvested lucerne has 10-25% protein (dry matter), 9-13% mineral content, and 30-50% carbohydrate (Robinson, 1999). These components have been synthesised by the plant but come from the soil and atmosphere. Where we can replenish these nutrients from sewage, there are good scientific reasons why we should not simply waste those resources but recycle our sewage through this food production process.

For each irrigation plan, a schedule of nutrient application through effluent, biosolids and chemical fertilisers needs to meet the demands of the plant growing under irrigation, that is when water is not limiting. The plan should be developed to either maximise the use of effluent to lower a load based licence fee, or maximise production as a return on investment. These two objectives are not mutually exclusive but require a different emphasis on meeting the nutrient demands of the plant system.

5.4 Sodium

While often overlooked in the treatment of sewage, simply because the use of sodium by plants is relatively minor, the over-abundance of sodium in effluent, measured as sodium adsorption ratio, may be detrimental to plant health and soil structural stability. Unfortunately, much of the sodium in domestic wastewater is derived from our insatiable appetite for salty foods and the use of the high solubility of sodium salts in our pursuit of cleanliness.

Other than reverse osmosis, the removal of sodium from the effluent is not possible, therefore management of the effluent with respect to the soil has to be raised in importance.

6 Conclusions

A sustainable town or city will have its own wastewater treatment system and some means of neutralizing its impact upon the receiving environment, whether ocean discharge, river discharge or landfill. The ideal example of sustainable towns and cities will likely include the re-use of nutrients for the maintenance of plant communities that may provide food and fibre for the community through vegetable gardens and to livestock through improved grazing. That re-use of nutrients is likely to be outside the city boundaries. Plants demand these nutrients for their metabolism and regeneration. Thus, benefits derived from a holistic approach to sewage management will always exceed those of simple engineering excellence in wastewater treatment. The soil, plants and micro-organisms will always do better with less energy and almost no waste.

Councils that work towards effluent re-use should be congratulated for their recycling of essential nutrients, such as nitrogen and phosphorus. While governments may penalise discharges to enclosed water ways through load based licences, by far the greatest impediment to effluent re-use is that metropolitan areas mostly discharge to oceans and blatantly waste significant resources. Not only should there be a discount for effluent re-use, there should be other incentives from the state government that reward forward thinking councils.

It is a poor indictment of our community when we can discount the value of the nutrients in our wastewater, yet accuse increased chemical fertiliser use as energy and resource hungry. When turned into economic value, the nitrogen and phosphorus in our sewage are worth tens of millions of dollars, yet engineering excellence disregards their value and looks to high quality treatment and inconsequential discharge.

While ever the mindset of wastewater engineers is focused on only public health and discharges to inland waters or major coastal river systems, we can expect more of the same – turn nitrogen into gaseous emissions and remove phosphorus to landfill. It will take some change but we need to treat for purpose, not just treat to a premium.

7 REFERENCES

ABS (2011) Australian Demographic Statistics, December 2010. Report 3101.0 accessed from http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0, August 2011

Department of Environment and Conservation (NSW) (2005*) Load Calculation Protocols for use by holders of NSW environment protection licences when calculating assessable pollutant loads*. Department of Environment and Conservation. Sydney.

Environment Protection Authority (1997) Environmental Guidelines: Use and Disposal of Biosolids Products. Environment Protection Authority, Sydney.

Patterson, R.A. (2009) Reuse of municipal effluent for crops and stock – impact on urban water use. *Proceedings of 20th Anniversary New Zealand Land Treatment Collective Conference,* Taupo New Zealand, 25-27 March 2009, pp135-141.

Robinson, P.H. (1999) Neutral Detergent Fiber and its Role in Alfalfa Analysis sourced from http://animalscience.ucdavis.edu/faculty/robinson/Articles/FullText/Pdf/Web200001.PDF

Sydney Water (2011) Wastewater Treatment Plants. Accessed 26th August 2011, http://www.sydneywater.com.au/oursystemsandoperations/WastewaterTreatmentPlants/