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ABSTRACT

While the aim of every wastewater engineer is to perform magic tricks on the cocktail of chemicals and organics that arrive at the sewage treatment works in the watery carrier, many of the components are described by regulators as "contaminants". With an optimistic view, much can be made of the valuable organics and chemicals as fertiliser and soil ameliorants. Phosphorus, sulphur, nitrogen, calcium, magnesium, carbon as well as partly digested organic residues in the wastewater may be sufficient incentive to reduce treatment rather than increase treatment prior to land application. This papers sets out the benefits of municipal sewage treatment as a resource management operation rather than simply water recycling to reduce discharge to a river or ocean for environmental reasons.

The example of Armidale City's wastewater reuse scheme shows production of fodder and cattle as a benefit to reduced discharges to river and the state environmental discharge levies. This paper will present the outcome of four years of monitoring of soil health and compares cropping rates and cattle growth figures over the period. The next stage for effluent reuse has to be one of reduction of inputs of undesirable chemicals from the domestic population to lower their impact of the soils .The example of Armidale City's effluent reuse scheme shows production of fodder and cattle as a benefit to reduced discharges to river and the state environmental discharge levies.

KEYWORDS
Effluent reuse, biosolids, nutrients, pollutants, load-based licence

INTRODUCTION

This case study details the Armidale municipal sewage treatment works (STW) where up to 40% of the city's treated wastewater is used to grow crops and beef cattle on soils that would otherwise be rated as grazing capacity only. Environmental monitoring ensures that chemical additions from the effluent are supplemented with traditional fertilisers and the undesirable salts are managed at acceptable levels. Nutrients benefit the crop and livestock components while water drives the physiological process and sunlight the photosynthesis.

Drought or relatively short periods of low rainfall inspire innovation in water conservation issues. Reusing effluent rather than discharging to natural river systems utilises the water at critical times for plant production. At times other than drought, what impetus will trigger resource conservation of valuable and non-renewable nutrients? Recycling policy (reuse) is primarily concerned with water conservation but should be seen for its contribution to resource management. Nutrients are simply viewed as pollutants.

In terms of food and fibre production, conservation of nitrogen (TN), phosphorus (TP) and potassium (K) demand a higher status than water recycling. Municipal STWs generally convert organic nitrogen (N_{org}) to nitrogen gas (N_2); remove TP by lime or alum dosing;

consume organics through reduction in biochemical oxygen demand (BOD); and stabilise pH (H^+) prior to recycling for crop or pasture production. Water is the driving force for the irrigation system and water use monitored for maximising crop production.

The example of Armidale City's wastewater reuse scheme shows production of fodder and cattle as a benefit to reduced discharges to river and the state environmental discharge levies.

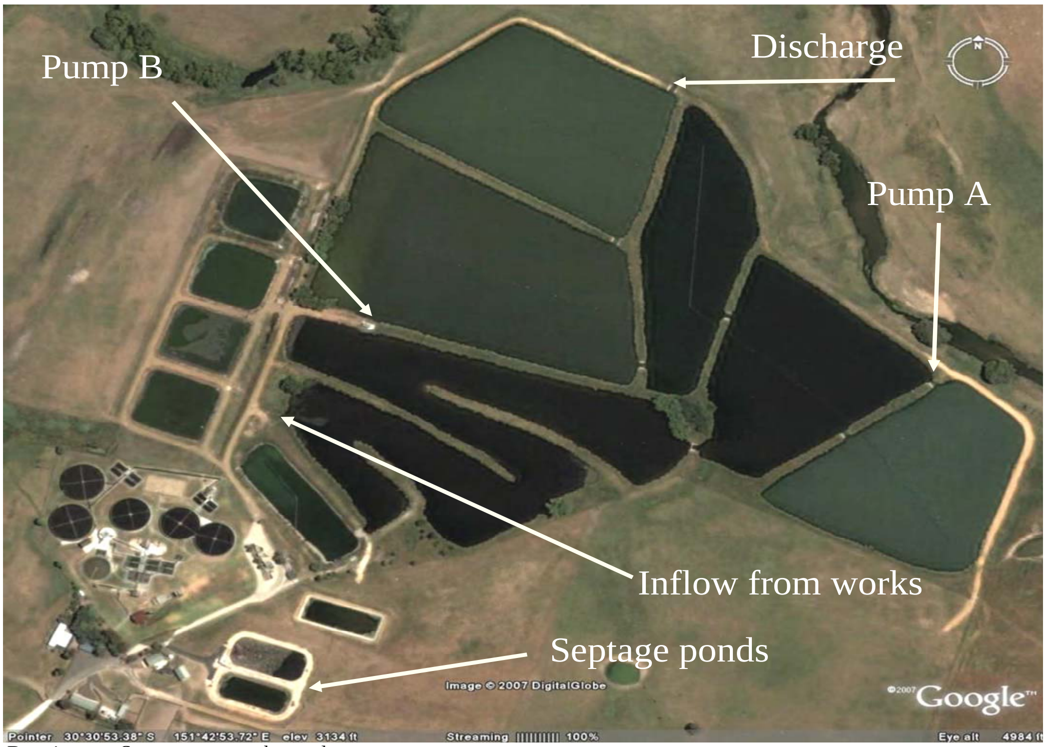
Armidale's Sewage Treatment

Armidale is a city with a population of 23 000, located at 1000 m altitude, 200 km inland and west of the Pacific Ocean coast. Rainfall patterns, as shown in Table 1, are summer dominant with a small peak in mid-winter. Evaporation rates, while reasonable in summer are very low in winter and winter temperatures reduce plant growth to simple subsistence levels. In winter, opportunity exists for replenishing soil moisture by irrigation in excess of evaporation without contributing to excessive runoff from saturated pastures.

Table 1. Monthly average climate data for Armidale, NSW. Source: Bureau of Meteorology

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Rain	103	88	65	45	44	57	59	58	52	68	90	89	790
Evap.	161	132	121	78	50	36	43	65	96	127	141	167	1217
Min^{o}C	13	13	11	8	4	2	0	1	4	7	10	12	
Max^{o}C	27	26	24	21	166	13	12	14	18	21	24	26	

Rainfall and evaporation in millimetres, average minimum and maximum temperatures in degrees Celcius.



Base image: Source www.earth.google.com

Figure 1. Armidale sewage treatment plant with maturation ponds and discharges

Daily sewage inflows to the treatment works for 2007/08 were 5.26 ML with an annual total of 1925 ML. These inflows are sourced mainly from domestic residences as Armidale has no manufacturing industry discharging to sewer. Average daily flows from laundries connected to the university, hospital, boarding schools, motels and a commercial service are possibly similar to laundry water on a per-capita basis, with some economies of scale gained. The livestock saleyards discharge settled wastewater to sewer on an irregular basis, although the quantity of waste is minimised as the cattle section is covered from rain. Grease trap and septic waste (see Figure 1) are discharged to a separate lagoon system from where only settled overflow enters the head of works. Where butcher shops, fast food outlet and commercial kitchen (clubs, hotels, hostels) do not have separate well-maintained grease traps, significant loading of organics and greases will enter the sewer, as well as grease from every home.

The treatment system is 'old school' with screening, grit removal, grease and oil flotation, trickling filter aerobic treatment followed by up to 20 days passage through shallow aerobic maturation ponds. Figure 1 shows an aerial view of the treatment plant with the final discharge into the adjacent Commissioners Waters. While modern intermittently dosed-extended aeration (IDEA) plants discharge a higher quality effluent, the alum dosing and high sludge formation create separate problems. Armidale STW operates without chemical additions at any stage so the effluent could be termed "organically processed".

While 'chemical-free' treatment may have advocates with certain interest groups, chemical inputs to the water-at-source (in the homes and businesses) are unregulated. A walk-though a modern supermarket will convince that all those products and the digested products of the foods with their wastes will at some time arrive at the STW. The difference between the Armidale plant and modern treatment plants is that many of the valuable plant nutrients are removed in the latter as volatilised (converted to gases), precipitated (alum or ferric chloride dosing) and highly flocculated particulates (sludge removal). The modern plant is designed for nutrient minimisation because legislation requires such treatment prior to discharge to enclosed waters. The sludges become landfill wastes. Discharges to ocean outfall require only primary screening and all benefits are lost to the ocean's depths.

Three locations are marked as Pumps A and B and Discharge to Commissioners Waters (Figure 1). A modern flume accurately records discharge volumes on a continual basis and when compared with raw sewage inflows, the proportion of irrigation water can be calculated. Sites A and B are draw-off points to the irrigation system, each with individual flow meters. The location of these three sites has significant influence upon the potential use of the waste-water for recycling the entrained resources as the effluent quality improves with passage through the maturation ponds and valuable nutrients are lost (volatilised or suspended).

Nutrient variations and effect upon fees

After primary and secondary treatment in the structural components of the STW, effluent flows to 10 ha maturation ponds and further treatment will occur through aeration, sedimentation and bacterial die-off. Table 2 shows the nutrient status of the three locations A, B and C.

Table 2. Nutrient status of three locations in maturation ponds – averages 2007/2008.

Location	TN (mg/L)	TP (mg/L)	K (mg/L)	(SAR)	(TSS) (mg/L)	BOD_5 (mg/L)	Sodium (mg/L)
RAW	45.5	10.8	15.6	2.6	206	158	73
A	10.0	7.9	16.5	2.4	11	7	67
B	6.8	7.2	16.0	2.3	6	4	65
Discharge	4.6	5.9	14.9	2.3	10	3	64

Source: ADC Annual Return 2008

The obvious changes as water passes through A to B and Discharge, are that nutrients TN and TP decrease with travel distance, sodium adsorption ratios (SAR) are essentially unchanged while 5-day BOD (BOD_5) stabilises below 10 mg/L. As effluent quality improves between Pump A and Discharge, resources are lost, some permanently as TN reverts to the nitrogen gases and escapes into the atmosphere, and temporarily as TP in sediment. Fortunately, the reuse scheme utilises sludges for land application, where TN and TP are partly recovered as fertiliser. Sodium is unchanged at levels that are potential problems for plants and soil.

In NSW, the state government levies licence fees on the load (volume by concentration) of pollutants discharged to the natural river (DECC 2005). For reasons of licensed discharge conditions, site C (Discharge) is the most appropriate because nutrient discharges are lowest at this point and with improved treatment could be further reduced. Such improvements could reduce TN, TP and TSS in the effluent or reduce discharge by increasing irrigation rates. When resource management is the determinant of ideal draw-off locations, site A is preferred because the nutrients can be better used for plant production, although do not provide all plant needs in the appropriate ratios. Reduction at-source is an option yet to be attempted.

Based upon the 2008 load-based licence fees for Armidale's discharges, Table 3 shows the potential cost of discharging all the effluent to Commissioners Water (zero reuse) and the cost for the 2007/08 year based upon reuse of 30% for crops and pastures, while 50% further reduces Council's expense. Clearly the benefit relates to reducing the load of pollutants while additional benefit is gained from the reuse of those pollutants (nutrients) on the land, both of which can be translated to dollar values. Table 3 assumes that 'no reuse' means all the inflow is equal to the discharge, without internal losses through evaporation.

Table 3. Load-based fees for 2007/08 licence period inflow for various rates of reuse (AU$)

Pollutant	TN	TP	TSS	BOD_5	Sodium
no reuse	747	55 128	5 520	21	no fee
30% reuse	522	38 590	3 864	15	no fee
50% reuse	374	27 565	2 760	11	no fee

Obvious from Table 3 is that the load-based fee is weighted heavily for TP as a significant polluter and that reductions in TP in the discharge carry the greatest benefit compared with savings in other pollutants. Other than increasing irrigation or chemical precipitation of TP (and problems with high aluminium in sludges), TP reduction at source, in household chemicals, is a valid option. Currently the reuse component is operating at about 30%.

Sodium, an element detrimental to many aquatic species, terrestrial plants and soils, is unregulated as if it did not exist in municipal wastewater. While for some industries, salinity is an issue, but includes beneficial elements like calcium, magnesium, potassium and various anions as well as sodium. At-source reduction of sodium is essential to long term reuse.

Beneficial use of effluent

Actual pasture nutrient removals are shown in Table 4 together with the availability of nutrients for the actual data for the 2007-2008 licence year (May 2007 to April 2008) for Sites A, B and C (discharge) at the rate of 4 ML/ha. Irrigation in Armidale at 4 ML/ha is close to an achievable level, given the cold winters and wet summers, while 6 ML/ha is achievable when rainfall is distributed in more even monthly shares rather than alternately wet and dry months as has been the experience over the last three years.

Clearly, the nutrients applied with effluent are neither at the rate required by the plants nor in the ideal ratio of N:P:K (10:1:1). The deficiency has to be met by additions of other sources of organics or chemical fertilisers. Sodium presents a special problem where accumulations in the soil lead to plant losses and/or soil structural instability.

Table 4. Comparison of plant requirements for nutrients and annual rates through irrigation

	Total Nitrogen (kg/ha)	Total Phosphorus (kg/ha)	Exch. Potassium kg/ha)	Sodium (kg/ha)
Pasture uptake	250	30	150	10
Nutrient input A	40	32	66	268
Nutrient input B	27	29	64	260
Nutrient input C	18	24	60	256

(Source: Lanfax Labs 2008)

The more beneficial plan would be to select a draw-off point before Site A, or earlier if possible, to maximise the utilisation of TN and TP for plant production. However, the upper limits of these nutrients are related to the raw resource and the losses through the essential primary and secondary treatment. Raw wastewater is unsuitable for direct disposal because of solids, odour and health considerations. BOD is irrelevant when considering irrigation of effluent. Soils can receive large quantities of BOD as agricultural wastes (dairy shed washwater, piggery wastewater, manures, milk or grape processing wastes) without detriment, and by comparison wastewater with BOD_5 of <20 mg/L is irrelevant.

The soils on the farm associated with the Armidale STW irrigation are mostly of sedimentary origin, extensively weathered to a duplex soil profile (sand over clay). The 92 ha irrigated pastures are used to graze cattle under a cell-grazing strategy and weight gains recorded for the period the animals stayed on the property. For any period, the total weight of cattle grazed on a given area can be calculated and a monetary value placed on that benefit compared with local figures for non-irrigated land. In 2007/2008, those 92 ha irrigated pastures generated 76 000 kg of beef, removing 1140 kg N, 760 kg P and 608 kg K (estimates only). Over four years, a total of 230 665 kg cattle have been grown on the irrigated pastures. Herbage from one paddock for 2007/08 was estimated at 12 – 16 tonnes Dry Matter (DM)/ha and stocking rates of up to 45.6 Dry Sheep Equivalent (DSE)/ha/yr (Dr Lewis Kahn, *pers.comm.*). Last year one paddock produced 18.5 tonnes DM/ha and 50.7 DSE/ha.

Crops are grown to maximise the returns from the water and nutrients on two areas of the farm. Lucerne (*Medicago sativa*) is grown on a 31 ha block irrigated using a five-tower pivot irrigator. The soils in this lucerne paddock are a mixture of sedimentary origins around the edges and basalt derivatives through the centre. Table 5 shows that DM production of lucerne for the four year period 2005/05 to 2006/07 utilises all the TN and K from the effluent and requires additions from other sources, as well as natural soil reserves. TP is usually in excess but adsorption potential reduces loss due to leaching. Another block of 32 ha is irrigated using a similar pivot to grow two crops annually, sorghum (*Sorghum vulgare*) in summer and oats (*Avena sativa*) in winter. These crops are sold locally as fodder.

Chemical fertilisers are required as urea, superphosphate, potash and gypsum to supplement the effluent. During 2007/08 biosolids returned 1823 kg N, 1018 kg P and 161 kg P to three paddocks. Insufficient biosolids are produced to top-dress all the paddocks in any one year.

While the value of reuse allows production of pasture and crops at times when rain is limiting, together with some beneficial nutrients, sodium in domestic wastewater cannot be managed except at-source. Armidale's 2007-08 raw sewage had in excess of 137 tonnes of sodium (equivalent to 340 tonnes of sodium chloride). Other than by reverse osmosis (desalination), the sodium simply travels with the water, some to reuse areas, the rest to discharge.

Table 5. Example of utilisation of nutrients from applied effluent from Pump A.

	TN (kg)	TP(kg)	Exch. K(kg)	DM (tonnes)
Lucerne production	37 026	5 215	42 015	1427
Effluent applied nutrients	9 022	6 485	15 514	
Difference	-28 004	1 270	-26 501	

Similar budgets can be derived for other areas of the Armidale STW where exports of nutrients as cattle and fodder, and inputs as effluent, biosolids and chemical fertilisers are computed. In each case, an additional requirement exists for nitrogen and potassium, while sodium remains excess in all cases and soils will require monitoring for sodic effects.

CONCLUSION

Armidale Dumaresq Council reuses effluent from the municipal STW to grow crops, pasture and cattle. The load-based fees for pollutants (nutrients) discharged in effluent are a major consideration as to the financial viability of the reuse scheme. Discharge all, or redirect a proportion is the financial consideration. Table 3 shows the potential saving in charges for TP by irrigating more rather than less. Redirecting effluent for irrigation of fodder crops and grazing cattle on lush pastures reduced the burden of load-based licence fees on the Council.

When management considers nutrients as essential resources, value is derived from a resource that would otherwise run to waste and perhaps pollute the river environment. Redirecting the discharge to irrigation is not the answer. For Armidale the lower quality effluent (with respect to TN and TP) as shown in Table 2 comes closer to the treatment system than the discharge.

The land application of biosolids can supplement some TN and TP shortfall in nutrients, while the added benefit of organic matter to the soil enhances other soil functions. However, chemical fertilisers are essential to balance the nutrient requirements in the crops and pastures, otherwise nutrient mining will become counter-productive. The next phase of beneficial reuse is to reduce the phosphorus and sodium at source. This goal will require the cooperation of the community, for the benefit of the environment.

ACKNOWLEDGEMENT

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