Assessing Nutrient Value For Promotion Of Municipal Wastewater Reuse for Agricultural Purposes in Non Arid Regions – A New Zealand Case Study

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Abstract: Historically there has been a reluctance to dispose treated effluent to land because of high costs and a lack of awareness of the potential benefits of reclaimed wastewater as an irrigation and nutrient source for agricultural purposes. With pressure to cease discharging treated effluent to surface waters, the adoption of enhanced treatment standards and the increasing cost of fertiliser, there is a growing acceptance of the benefits of discharging treated effluent to productive land. This paper presents the outcomes of a case study in New Zealand which examines the hydraulic, nutrient and economic benefits of discharging the effluent from the Dannevirke WWTP to land.

Keywords: agriculture, effluent, fertiliser, municipal, reuse, wastewater

INTRODUCTION

Through the 1960's and 1970's it was widely accepted in New Zealand (NZ) that the practice of discharging untreated municipal sewage to surface water was no longer acceptable for both environmental and public health reasons. For most of NZ outside of the main centres, this meant the installation of a two pond facultative pond system.

With changing environmental standards through the 1990's and into the 2000's, the pressure for further improvement upon the existing pond treatment systems has grown. For many communities the primary driver for treatment improvements is the impact of the discharge on surface waters.

In New Zealand there are a number of wastewater land disposal schemes operating. To date the focus of these systems is disposal rather than beneficial reuse and the schemes are managed to maximise the volume disposed while minimising the adverse effects on crops (Bristow and Prieto-Curiel, 2002). This type of land disposal system is utilised as a cost-effective means of minimising the effects on surface water receiving environments and negates the need for significant upgrades to the pond systems. This type of land disposal system is only suitable if the soil type is free draining, there is a capacity within the soil structure to fix nutrients, particularly phosphorus, and if there is land available. In most instances the irrigation is to tree plantations as they represent the least intensive land use and allow semi-permanent irrigation systems to be utilised.

It is a common perception that acceptance of municipal wastewater, irrespective of the treatment standard is not of sufficient benefit to the land owner to justify on-farm expenses. Consequently land disposal of effluent (municipal and agricultural) is not managed for maximum benefit but rather for ease of operation and practicality to fit within daily farm operations (Monaghan et al, 2007). It is therefore left to the district council to provide suitable mitigation measures and cover all the operational and management costs of the land disposal system, or alternatively to purchase land specifically for the purpose of wastewater irrigation. There are many parts of the country however, where intensive, high production land use around rural towns and sewage treatment plants means that land purchase price, or alternative long distance pumping costs are beyond the means of the council for the purpose of wastewater disposal.

In recent times there have been a number of key shifts both in regulations and in influencing factors such as global fertiliser prices and community expectations in terms of the environmental effects of treated wastewater discharges. These factors are paving the way for a paradigm shift in the New Zealand psyche on land application of domestic wastewater from being a means of disposal, towards the notion of utilisation of a resource. The next step in this progression is to generate a demand for that resource so that there can be some cost sharing and more active pursuit of land application systems. This paper presents a case study on how this knowledge can be shared.

BACKGROUND

In the New Zealand agriculture sector fertiliser application represents one of the main farm expenses, being the second (sheep and beef) or third (dairy) major expenditure item behind debt servicing and labour costs (MAF 2007). Fertilisers are applied on a significant scale with 9,050 tonnes of urea and 40,966 tonnes of super phosphate being used in the Tararua District in the year to June 2007 (Statistics NZ, 2007). In recent years global fertiliser prices have increased dramatically. In the past four years there has been a three fold increase in the New Zealand price of urea including a doubling within the last twelve months from $560 /tonne in mid 2007 to a current price of $1,100 (Balance Price List, price ex works and excluding GST). Prices of phosphate fertilisers have risen even more dramatically. New Zealand Superphosphate (9.3% P by weight) has risen to around $560 in September 2008 representing a nearly 3-fold increase in only one year.

Regulations governing the application of wastewater to land, particularly dairy land have recently been modified to reflect increased global understanding and acceptance of the re-use benefits derived from land application of effluent. In 2005, Fonterra (NZ's main dairy product supplier) revised its policy from one which effectively banned the application of domestic wastewater to land, and adopted the rules of Title 22, California Code of Regulations which are incorporated in the California Health Laws Related to Recycled Water. While the requirements for wastewater under this policy are still very stringent, where sufficient treatment is achieved it is now possible for District Councils to actively promote the wastewater product as a fertiliser and irrigation water source. Pond treatment systems alone are unlikely to achieve the required effluent quality to consistently meet the requirements of the Fonterra policy. However with upgrades such as the one undertaken at Dannevirke wastewater treatment plant (WWTP) in the Tararua District in 2004, application to productive farm land, including dairying is now a viable option.

There remain a number of factors limiting the uptake of application to productive land in New Zealand. These include a relatively good supply of fresh irrigation water and rainfall, difficult terrain (Bristow and Prieto-Curiel, 2002) and public perceptions regarding irrigation of treated domestic wastewater to production land. It is therefore necessary to promote the beneficial aspects of the wastewater product so that the negative aspects of the activity can be kept in perspective and potentially outweighed. An analysis of the wastewater produced from the Dannevirke WWTP has been undertaken to demonstrate the potential benefits of such reuse. Discussion on the practical aspects of wastewater application in the farm operation is also included as this represents a key element in the viability of such a scheme. The primary focus for demonstrating the potential beneficial elements of treated wastewater is the nutrient components.

CASE STUDY METHODOLOGY

The methodology has included undertaking a nutrient analysis of the effluent wastewater stream, analysing potential nutrient availability, examining typical farm fertiliser application practice and examining the economic value of the wastewater nutrients for the Dannevirke WWTP.

Dannevirke is a rural town, population 5,517 (Statistics NZ, 2006) in the Tararua region of New Zealand. In 2004 the Tararua District Council (TDC) completed installation and commissioning of a micro-filtration membrane system for further treatment of the secondary treated pond wastewater.

The drivers for the significant upgrade were two-fold, being that from an iwi (local indigenous Maori population) perspective the current practice of discharging treated effluent to water was unacceptable and secondly, from a technical perspective the existing three-pond facultative system was unable to meet required standards for the receiving environment in terms of TSS, bacteria and dissolved reactive phosphorus (DRP) (GEM, 2001). A key reason for the choice of this upgrade, which represented a significant cost to the Council, was the potential flexibility for future land disposal options to be adopted.

The treatment process consists of two waste stabilisation ponds followed by a flow balancing pond. Tertiary treatment of the pond effluent comprises a Zeeweed® membrane micro-filtration plant commissioned in 2004. At the time of design there was little information available on the likely performance of a membrane plant for tertiary treatment of pond effluent. Data on the final discharge has been collected since commissioning with more frequent data collected since November 2007. Samples are collected weekly from the treatment plant with analysis for a suite of nutrients during summer (1 November – 30 May). Outside of this period analysis of nutrients is monthly while the operational suite is tested weekly year-round.

The level of treatment achieved by the membrane plant at Dannevirke means there is a unique opportunity in the New Zealand context to utilise the wastewater as a safe and reliable source of irrigation water and nutrients for agricultural applications. Key additional benefits of a land irrigation system include improved water quality in the Mangatera Stream (receiving water for existing discharge), and reduced pressure on alternative sources of irrigation water.

The membrane system at Dannevirke is a ZeeWeed® MTT module with nominal and absolute pore sizes of 0.035 and 0.1 microns respectively. The membranes are operated as a filtration unit only and there is no biological treatment undertaken in the membrane tanks. Backwash brine from the membrane tanks is recycled back to the primary facultative pond.

Figure 1: Layout of Dannevirke WWTP
(1 = Primary Inlet Screen; 2 = Surface Aeration of Primary Pond; 3 = Chemical Phosphorus Removal; 4 = Flow Balancing Pond; 5 = Micro-filtration Plant; 6 = Emergency Storage Pond)

Oron et al investigated the suitability of combined ultrafiltration membranes and reverse osmosis to treat secondary effluent from a pond system for agricultural reuse. The reported conductivity measurements for these systems was 1,880 uS/cm (ultrafiltration) and 350 uS/cm (reverse osmosis) (Oron et al, 2008). In comparison the residual dissolved solids in the Dannevirke WWTP permeate have an average electrical conductivity of 550 uS/cm. This suggests that while only one step of filtration is provided at Dannevirke the system is operating well and the permeate is of reasonable quality for agricultural reuse.

This desk top study uses the data collected over the past year to assess the fertiliser value of the wastewater. Fertiliser prices for the two main suppliers have been used to obtain prices for nitrogen and phosphorus (based on urea and superphosphate prices as the cheapest sources of these two key nutrients). The value of trace nutrients potassium, calcium and sulphur has not been assessed at this stage not withstanding that such nutrients will also represent further added value.

It is assumed for the purposes of this study that the quantity of nutrients in the wastewater as measured at the treatment plant will not be different to that which is actually applied to the land. In particular this assumes total nitrogen concentrations are not significantly affected by volatilisation, evaporation or drift between the point of dispersal from the irrigator and the ground (Chastain and Montes, 2004). Volatilisation of effluent ammonia can be elevated where evaporation rates are high (Smith et al, 2006). For the purpose of this paper it is assumed that volatilisation of ammonia from applied urea, under the same field conditions is similar and therefore the pre-application N mass of urea and wastewater is equivalent. Fertiliser use and application patterns on farm have been considered through common practice systems to ensure any application of treated effluent can be utilised within existing farm practices. N application on pasture farm land is typically 2 – 4 applications per year to an ideal total of up to 150 – 200 kg N/ha/year (Cameron et al, 2005). An average application of 30kg P/Ha per year is assumed for the purposes of this analysis.

The assessment of the nutrient value of the wastewater assumes irrigation primarily to a Takapua silt loam. This soil is described as a somewhat excessively well drained shallow soil, typically with 8 – 18 % by volume of stones in the top soil (Shepherd & Parfitt, 1998).

Due to discharge permit requirements the removal of phosphorus at the Dannevirke WWTP is partially achieved by addition of alum when flows in the Mangatera Stream (receiving environment) are at or below half median flow. As such the concentrations of P in the final discharge are affected by this chemical removal. This has been taken account of in the analysis reported in this paper by using the full years data.

RESULTS AND DISCUSSION

The potential irrigation period in Tararua is generally restricted to between mid November through to mid March. The monthly water deficit is illustrated in Figure 2 below (NIWA, 2008). The flows from Dannevirke WWTP over the modelled irrigation season 14 November 2007 – 13 March 2008 (120 days) averaged 3,026 m^3/day.

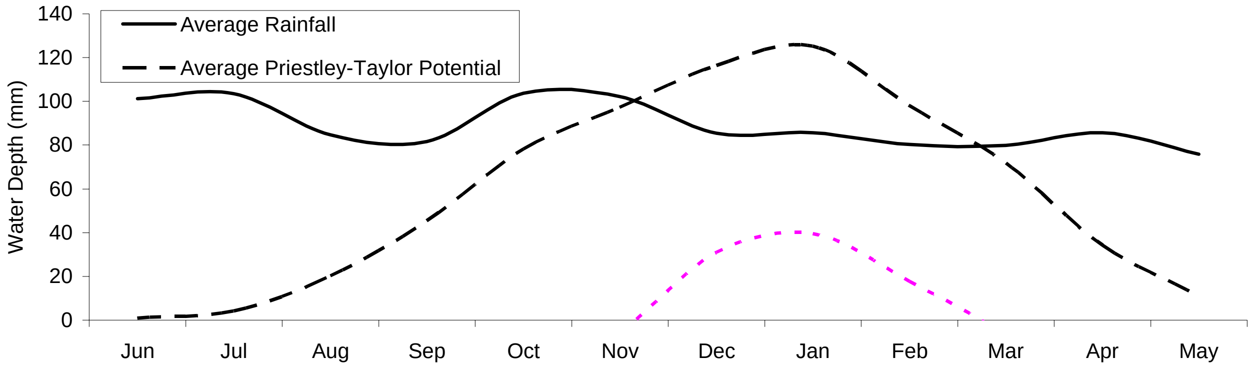

Figure 2: Water Deficit for Dannevirke, New Zealand

The physical properties of the permeate are consistent. Key parameters are shown in Table 1.

Table 1: Dannevirke WWTP Permeate Quality

Parameter	Units	Mean	90th Percentile
Total $cBOD_5$	mg/L	2.3	< 3
TSS	mg/L	2.4	< 3
TDS	mg/L	290	332
pH	-	7.97	-
EC	µS/cm	550	663
E Coli	cfu / 100 mL	< 1	< 1

Nutrient Availability

Nitrogen. Results indicate that the nitrogen (N) fractions of the wastewater vary considerably with climatic influence, due to the algal activity in the treatment ponds. Data for ammonia, nitrate, nitrite and total N (TN) in the discharge show that the soluble inorganic N (Nitrate-N, Nitrite-N and Ammonia-N) (SIN) fractions comprise >95% of TN. The variation in SIN concentration through the irrigation period is illustrated in Figure 3 below.

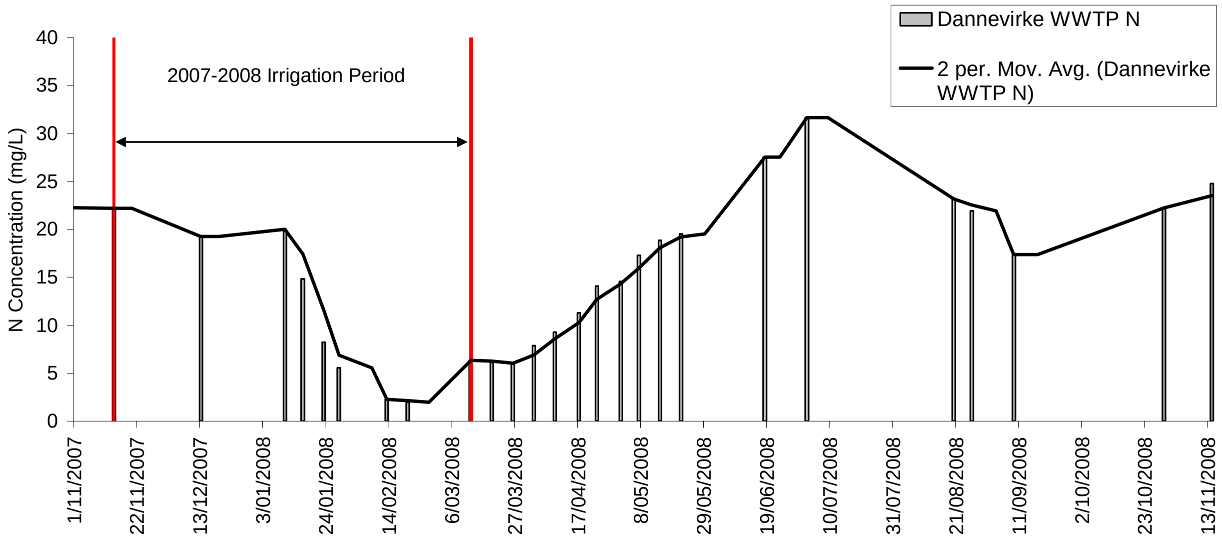

Figure 3: Wastewater nitrogen concentrations

The estimated price for nitrogen is $NZ 2.40 /kg N (Urea price, Balance Agri-Nutrients, September 2008). The average daily SIN mass in the Dannevirke WWTP discharge between 14 November 2007 and 14 November 2008 was 57 kg giving an annual total of 20,960 kg N, compared to an irrigation season (14 Nov 07 – 13 March 08) average of 47 kg N/day. At 120 days of irrigation over summer the available N is 5,650 kg giving a fertilisable area of 38 Ha (150 kg N/Ha). This represents a value of $NZ 13,600 per year.

Phosphorus. The average P concentration for the entire year (full annual data used to allow for partial chemical removal over summer) was 3.9 mg/L. At the average Plant flow of 3,026 m^3/day the daily mass flux is 11.8 kg/day or 1,400 kg P over the 120 day irrigation period. The P concentrations through the irrigation period are illustrated in Figure 4 below.

The cheapest available price for fertiliser P is $NZ 4.06 /kg P and is primarily a monocalcium phosphate (Ballance Agri-Nutrients, 2008), which, being soluble in water is comparable to the dissolved phosphates in the Dannevirke WWTP discharge. While superphosphate is more commonly used source of P it represents a more expensive source and conservative values are sought here. Applying the average concentration of P over the 120 days of irrigation yields an area of 47 Ha that could receive the full P application (30 kg P/Ha/yr). This P application represents a current market value of $NZ 5,680.00 per year.

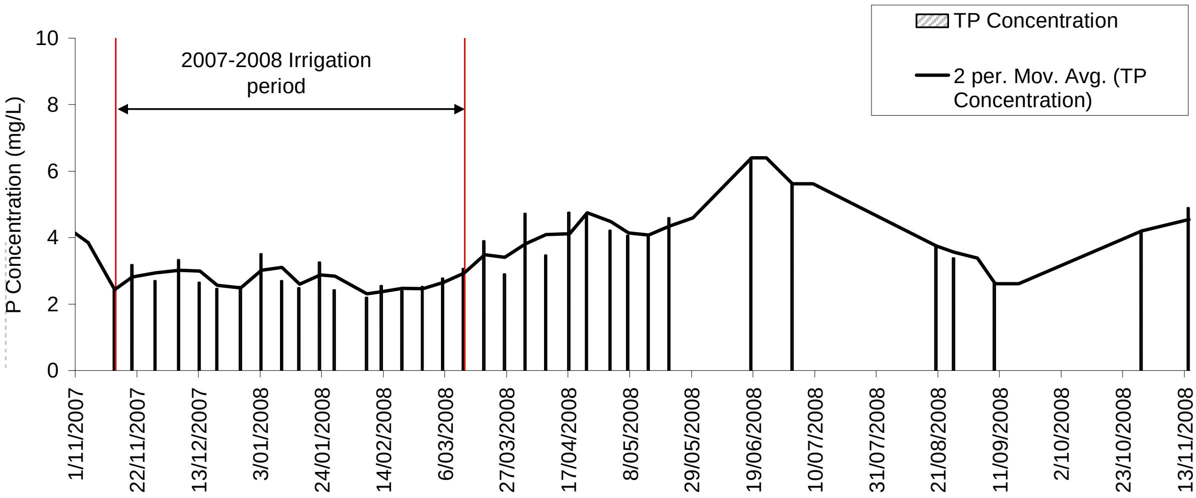

Figure 4: Wastewater phosphorus concentrations

Due to the relative concentration of the nutrients identified above it will be phosphorus that is the limiting nutrient determining the area required for irrigation. This is important in terms of environmental sustainability and to ensure the land application will meet the environmental regulations that will be applied by the Regional Council as the regulatory authority.

Nutrient Application

Nitrogen. In order to compare the effluent nutrient application rate with the equivalent fertiliser application the land area determined by the P delivery above of 47 Ha is used. To achieve a typical N application of 30 kg/Ha a total N requirement would be 1,400 kg N. For dairy farm pasture growth it is desirable to have this application over a short time frame to promote spring grass growth. The cumulative number of days irrigation represents how many days of WW irrigation would be required to achieve an application of 30kgN in the “single” application.

One of the issues with promoting the nutrient value of the wastewater, is the variability of the nutrient concentrations, particularly the nitrogen over summer. In 2006 and 2007 significant drops were measured in the total n concentrations at the onset of summer. During the 07/08 summer there was a 90% drop from 20 mg/L on 10 Jan 2008 to 2 mg/L on 20 Feb 2008. During the 06/07 summer the drop occurred between 7 Nov 2006 (24 mg/l) and 19 Dec 2006(7 mg/l). These changes represent a drop in nitrogen concentration of 70% in 06/07 and a 90% drop in 07/08. This drop is most likely caused by the increase in algal growth in the ponds as temperatures increase. While the drop is not unexpected it does mean that the value portion of the wastewater product is subject to significant fluctuation and reliance on the nutrient value for farm fertiliser management is made more complicated, and hence the product is less desirable.

If typical fertiliser N application is carried out at 30 kg/Ha in March, approximately 8 weeks of the daily WW application is required to achieve the same application rate. This accumulation period is illustrated in Figure 5 below. The desired boost in grass growth during the Autumn feed shortage (to maintain dairy production) is therefore not likely to be achieved to the required extent. This short fall could be offset by additional feed growth during the summer period leading to excess feed supply and storage, but utilisation of this change would require a change in management practices on the dairy farm.

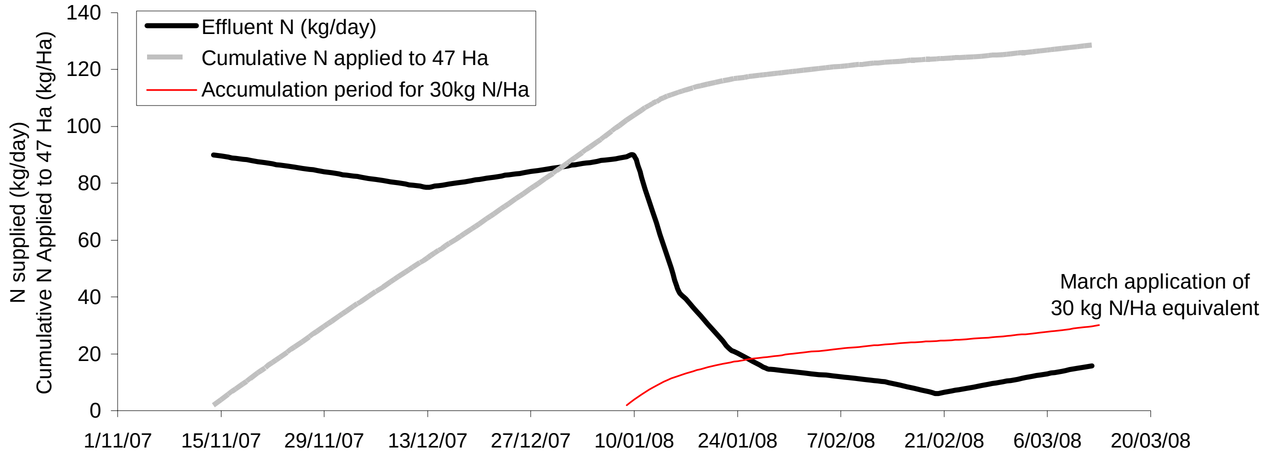

Figure 5: Summer N application (30kg/Ha) from 2007/2008 nutrient data

The long period of time required to achieve the desired application means the specific purpose of the 30 kg N/Ha application may not be achieved with a more even grass growth response occurring over the 8 week period compared to the single application. This is particularly the case for a dairy farm where the application of nitrogen is used to promote grass growth during the feed shortages either side of the peak summer growing season. If this grass growth promotion is not achieved during the feed shortage, there may be considerable consequences on the farm profitability, where the WW is relied upon as the main source of fertiliser.

Phosphorus. The concentration of P was less affected by significant changes in early summer as a result of increased algal growth in the ponds. Therefore P is delivered more consistently throughout the irrigation season.

Hydraulic Loading. Over the irrigation period of 120 days the average water application on the 47 Ha is 6.4 mm/day. Being a well drained soil it is expected that this application rate of 6.4 mm would be easily accommodated. The low daily application of nutrients at this irrigation rate means leaching effects are likely to be low. However, if broadcast application of N is undertaken as a supplementary measure during the irrigation season increased leaching is likely to occur following continuous irrigation (Monaghan et al, 2007).

Ideally the hydraulic loading would be lower than 6.4 mm/day and should reflect the typical daily evapotranspiration rate of 5mm/day (Dravid et al, 1995, Lincoln Environmental, 2000). At 5mm/day the irrigable area is 60 Ha giving nutrient applications of 23.3 kg P/Ha/yr and 100 kg N/Ha/yr. This rate of application would best be achieved by a centre pivot irrigation system operating over the whole 60 Ha each day.

Balance of Fertiliser Needs

In order to meet the full farm fertiliser application needs there will be supplementary fertiliser application. Based on the applications on 60 Ha above of 100 kg N/Ha/yr and 23.3 kg P/Ha/yr the additional inputs would mainly be in the form of N for a dairy situation. For a sheep and beef farm in the Tararua both the N and P concentrations of the WW could substitute the total farm fertiliser requirements.

Future Work

The significant variability in the N concentration of the wastewater leading to uncertain nutrient delivery presents the possibility for manipulation of the pond treatment system to maximise the nutrient value of the wastewater for irrigation purposes and align more closely with farm practice. This manipulation may also lead to cost savings in the treatment process of the WWTP.

CONCLUSIONS

Analysis of the water quality data from Dannevirke WWTP shows there is considerable value in the N and P content. Up to $20,000 worth of fertiliser could be substituted by the WW nutrients.

The delivery of the nutrients is a slow, sustained application which may not suit the typical management practices of dairy farms in the Tararua region. This is due to the inability to generate short-term increased pasture growth through nutrient applications during pasture shortages in early spring and autumn. However, this may fit well with a sheep and beef operation.

The irrigation benefit of the wastewater is also significant and could either off-set the existing take for an irrigated property, or significantly increase the productivity of a dry-land property without creating pressure on any available water resources which might otherwise be used for supply.

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