ENVIRONMENTAL INDICATORS FOR EFFECTIVE EFFLUENT RE-USE

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SUMMARY

The Armidale City Council, on the New England Tablelands of New South Wales, has supplied effluent from its sewage treatment works (STW) for pasture production using flood irrigation for more than 30 years. The re-use scheme was run by a lessee and individual neighbouring landowners with less than a firm understanding of environmental issues. Since 1991, the Council has operated the scheme with a view to increasing the area under irrigation. Council's major objective is to minimising licensing costs under a load-based licensing (LBL) scheme by increasing re-use above the present 6% of the total annual effluent.

The authors investigated the environmental indicators of soil fertility and structural stability over the flood irrigated area. For each of 42 sites, including a control, samples of the surface soil were analysed for plant macro- and micro-nutrients as well as indicators of soil structural integrity. The data were arranged graphically using a surface plotting procedure and examined for indications of nutrient movement.

The results indicated that sodium was highly mobile, moving across the disposal area and at 16 sites the exchangeable sodium percentage (ESP) values were recorded above the threshold of 5%. Increases in ESP by up to 800% were registered. Organic carbon (OC) was slowly mobile, presumably through the relocation of carbon as animal manures and water washed decaying plant matter. Phosphorus was the most immobile, showing strong bonding to the area immediately around the discharge. Nitrogen values are sufficiently low in the effluent to warrant additional nitrogen fertiliser to maximise pasture production. Thus, mineral nitrogen may be a more important indicator to monitor than total Kjeldahl nitrogen (TKN).

From the movement pattern of the nutrients monitored and the relationship between particular nutrients, the authors suggest a reduced range of soil chemical constituents be used for monitoring. Likely indicators of on-site contamination and off-site pollution were determined from the current status of the 42 soil samples. The correlations of total phosphorus to orthophosphate (as Bray-P) ($r = 0.97$) and TKN to OC ($r= 0.98$) suggest that the measurement of Bray-P and OC are sufficient to indicate changes within the irrigation area. Nitrate levels are sufficiently low as to require the application of nitrogenous fertiliser to maximise plant growth. Thus nitrate, rather than TKN is the important indicator. As the heavy metals (copper, zinc, cadmium) have not accumulated to levels above nutrient requirements, only an annual examination for their levels is suggested. Sodium and sodium adsorption ratio (SAR) are two critical indicators of both plant health and soil structural stability. Together with EC, potential problems with hydraulic conductivity and salinity effects can be predicted and strategies for amelioration developed.

The strategy of selecting environmental indicators achieves a reduced cost of regular monitoring, while allowing for an increase in monitoring frequency to provide more timely indications of changing soil and plant environments and the prevention of pollution. Thus for the same cost, sufficient data points of the selected environmental indicators will alert management to changes in the irrigation area before an environ-mental malfunction occurs. The positive outcome for the Council is that by developing a monitoring program based upon frequent analysis of sound environmental indicators, the management of the re-use scheme will maximise nutrient removal for beneficial agricultural purposes and minimise LBL fees.

KEYWORDS

Effluent, environmental indicators, hydraulic conductivity, load based licence, monitoring, re-use, sewage treatment works, sodium adsorption ratio,

1 INTRODUCTION

1.1 Generation and Disposal of Wastewater in Armidale

Armidale, a city of 23 000 persons (EP), is situated on the New England Tablelands, in north-eastern New South Wales, approximately 1000 m above sea level (ASL). The landscape is dissected by small to medium sized river systems draining 200 km to the eastern seaboard through the Macleay River system. A small re-use scheme has been operating at the Armidale sewage treatment works (STW) since the 1960s. Effluent from the maturation ponds is pumped through a 100 mm rising main to the top of a small gravelly hill, to discharge over the surface and by overland flow replenish soil moisture of the shallow surface soils. Less than 6% of the annual STW effluent volume is consumed by this 24.6 ha enterprise.

For the Armidale City community, river disposal of up to 40 ML of high quality effluent per week has beenacceptable. Indeed, downstream irrigators rely upon the additional water in an otherwise low flow river to boost irrigation potential on marginal irrigation lands. That some release of effluent may now be required for environmental flows and riparian uses cannot be disputed, but there is an increasing desire by the community to develop more environmentally sustainable re-use practices.

The irrigation of effluent onto pasture, where application rates could be managed and soil/plant properties monitored, offered the Council a potential enterprise which met their low phosphorus/nitrogen disposal projection required by a load based licensing scheme. In June, 1994, approval was given for the use of 24.6 ha (100 acres) at Armidale STW to graze and fatten cattle (Council minutes 14/8/95).

Because the Council did not have data on the environmental impact of the operation of their re-use scheme, this shortcoming provided a key to their involvement in the project. The view that selecting a range of environmental indicators would enhance management of the agricultural re-use of effluent as well as meet EPA licence requirements provided the impetus for this project.

1.2 Study Objectives

The study aimed at determining the long term environmental conditions which result from land application of secondary treated wastewater (effluent) with particular interest in the potential for off-site effects, such as the movement of nutrients and salts as well as the profitable management of the pastures.

An objective of the overall project was to evaluate the soil analytical data and determine environmental indicators which would adequately record nutrient levels and alert operators to potential environmental or plant nutrient problems. It was desirable that the number of indicators selected provide an economically rational basis to monitoring, a smaller number of data points at more frequent intervals preferable to an extensive monthly or annually program.

2 LITERATURE REVIEW

2.1 Australian Re-use Projects

The Australian Water Resources Council (AWRC, 1991) cites examples of re-use projects across Australia. Richmond (NSW) discharges chlorinated effluent onto both a nearby golf course and Hawkesbury Agricultural College, achieving 100% usage during summer. In Alice Springs (NT), the high evaporation rates caused serious salinity problems on the irrigation area. Bolivar (SA) irrigates 30 000 trees including using 2500 ML per year on crops (tomatoes, lettuce and fodder crops) and other minor projects. In Victoria, 70 towns re-used all their treated effluent while another 38 re-used some effluent (Vic EPA, 1994). Effluent re-use accounts for 8% of the total discharges while 75% is discharged to oceans.

One example of the positive economic benefit is the long term wastewater re-use of untreated wastewater by Goodman Fielders Mills Ltd in Tamworth, NSW, where up to 100 kL of backwash water per day has been disposed of onto black alluvial soils along the floodplain of the Peel River for over 25 years. However, the high SAR and high pH decreased infiltration by up to two log units (Patterson, 1994).

Economic implications of re-use are addressed by the Industry Commission (1992) but the Commission stops short of including the effective re-use of wastewater as a positive economic variable. There are many economic benefits of using wastewater on playing fields, public parks and gardens as well as irrigating land and creating urban forest. These uses should not just be seen as a substitute cost compared to potable water supplies but as a practical means of reducing operating costs and load based licence fees.

2.2 Environmental indicators

Wastewater quality indicators and criteria of particular importance include bacterial counts and the need for a degree of disinfection (AWRC, 1991). This project did not incorporate disinfection as effluent is drawn directly from the maturation ponds and the soil is the disinfection medium.

While monitoring may be a critical part of any re-use scheme, it is not sufficient for the operator to have a lengthy checklist of monitoring variables, which have a high cost of collection, analysis and interpretation. Environmental indicators are simple physical, chemical, biological or socio-economic measures that provide key information about complex ecological systems (CDEST, 1996, p2). The indicators must be used together with suitable interpretive frameworks to direct management to undertake alternative actions or maintain the current direction. They must also be able to predict, with reasonable accuracy, the likely future status of environmental health as well as clarify the current nutrient status.

2.3 Monitoring

When acceptable environmental indicators are chosen for a project, the second stage is to decide upon the frequency of monitoring, the aim of which should be consistent with obtaining early warning of potential problems within the irrigation area. The sampling frequency for a plant similar to Armidale (medium sized) for total suspended solids (TSS), nitrogen, phosphorus and BOD_5 is on a monthly basis while additional measurement for nutrients and metals should be twice yearly (AWRC, 1992). In none of the documents examined for this project was any clear indication given as to what monitoring frequency should be applied to soil and plant monitoring where management of pasture is the prime objective for sustainable re-use.

The measurement of 20 variables once per year will not provide the same window of environmental change that can be gained from measuring five environmental indicators at quarterly intervals. The shorter monitoring period allows prediction to be made rather than correcting for already degraded conditions.

2.4 Essential Indicators

Patterson (1991) showed that for sodium adsorption ratio (SAR) values as low as 5, the loss of saturated hydraulic conductivity (Ksat) was decreased by over 2 log units. In a later study, Patterson (1995) showed that sewage effluent reduced Ksat values in as short a period as two hours under field trials when measured using a CSIRO disc permeameter. This outcome confirms the concerns expressed by AWRC (1992) that land discharge of effluent without proper controls for salinity has the potential to create serious environmental problems. It is, however, interesting to note how few reports on re-use address the implication of SAR and exchangeable sodium percentages (ESP) on the environment.

Thus, important indicators are known and need to be measured regularly. Of concern is the lack of uniformity in identifying environmental indicators which, through more regular monitoring of a few specific parameters, can be used to predict the environment's response to a particular management operation, with sufficient lead time to permit adjustment of the system. Current monitoring requirements under licence conditions do not address the benefits of this simple and cost effective approach.

2.5 Research Methods

Five traverses were selected across the effluent irrigation area, radiating from the distribution point, each with eight sampling points spaced at approximately 15-20 m depending upon local surface conditions. A control was selected above and 30 m south of the discharge. At each of the 42 sampling sites, composite samples of the A1 soil horizons were taken and returned to the laboratory for processing.

Field notes were made on the depth of the sampled horizon, the density of roots within that horizon rated on a scale 1-10, and a brief description of the surface vegetation made with respect to composition, height and density. A botanical description of the vegetation was beyond the scope of this project as there had been no pasture improvement conducted over the last 14 years.

On two occasions, water samples were obtained from sites within the treatment ponds and from upstream and downstream of the discharge into Commissioner's Waters. These data were supported by other data on effluent quality from the Armidale STW.

3 RESULTS

3.1 Soil organic matter

Soil organic matter was quantified by Walkley & Black Method of OC determination. The results indicate that, relative to the control, increases of up to 300 to 500% were associated with the areas closer to the discharge, with a few exceptions, while increases only slightly above the control were associated with greater distance from the discharge. OC content above 3% is considered desirable for soil structural stability and increase cation exchange capacity. Levels about this threshold were found in the majority of sites close to the discharge (4-6% OC), but were generally less than 2% OC at more than 70 m.

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3.2 Soil Nitrogen

The TKN values indicate that nitrogen has moved away from the discharge and is spreading down slope, with a weak trend (r=0.56) in relation to distance from the discharge. Level of 400-700% higher than the control occur around the discharge, however, the area remains at very low levels of TKN. There is a strong correlation (r = 0.98) between OC and TKN. The mineral nitrogen correlates weakly with distance from the source (r = 0.55) as it is relatively mobile through the soil, however only close to the discharge are levels approaching plant requirements. At more than 50 metres, the mineral N levels are at deficiency status, often falling below the control (10.8 mg kg^{-1}).

3.3 Soil Available Phosphorus

The Bray phosphorus test is a measure of the plant available (soluble) phosphate in the soil, held lightly to the soil particles. Bray-P levels of 20 mg kg^{-1} are considered adequate for agriculture and levels above 30 mg kg^{-1} are unlikely to show a response to additional phosphatic fertilisers. Around the discharge, levels of 328, 167, 172 mg kg^{-1} indicate extremely high levels of phosphate. Figure 1 illustrates the levels of phosphorus relative to increasing distance from the single discharge. The control was at deficiency status, as were 14 of the 42 sites sampled.

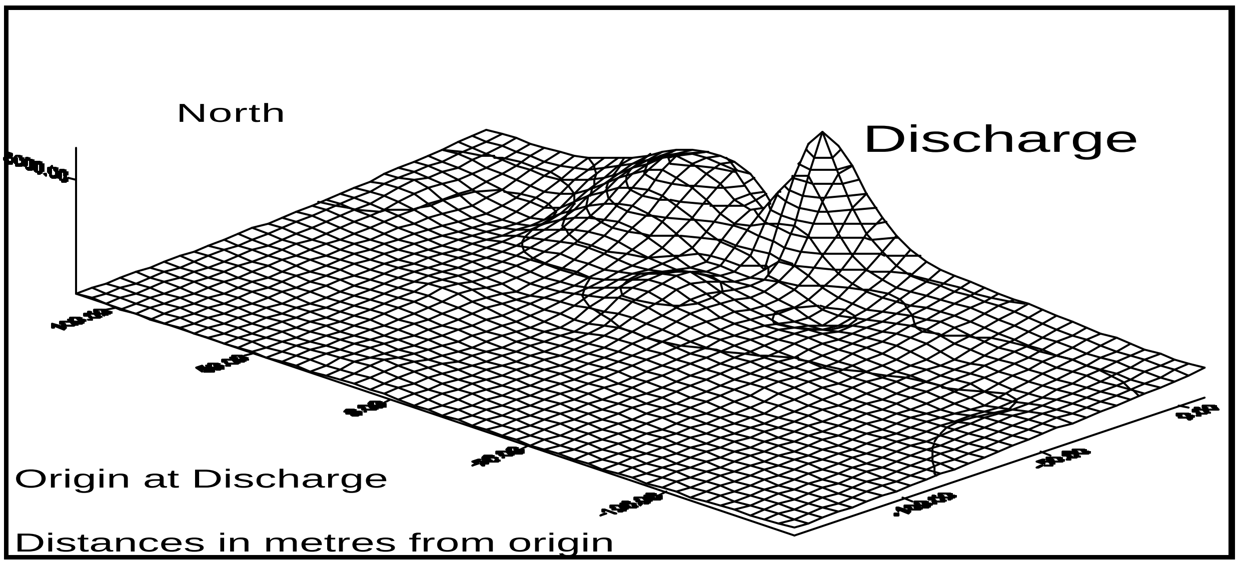

Figure 1 Concentration of Bray-P (as percentage relative to control) over the irrigation area.

3.4 Exchangeable Sodium Percentage

The ratio of sodium to the four base cations is used to indicate the potential for sodicity to adversely affect either the structural stability of the soil aggregates or the osmotic potential of the soil moisture on biological activities. ESP levels above 5% are likely to cause soil problems. The control soil had an ESP 1.6%, however where effluent had been disposed of over the surface ESP levels greater than 6% were found. ESP levels increase away from the discharge with almost a positive trend. Levels more than 300% higher than the control were common, five sites were elevated by more than 500%. While calcium and magnesium levels also increased, those increases were not sufficient to offset the increases in sodium.

Figure 2 indicates the sodium changes with increasing distance from the discharge as soluble salts move away with drainage water and in runoff water following rainfall. While the soils are not saline, all EC levels were below 0.106 dS m^{-1}, the increases in ESP over the threshold of 5% are considered significant.

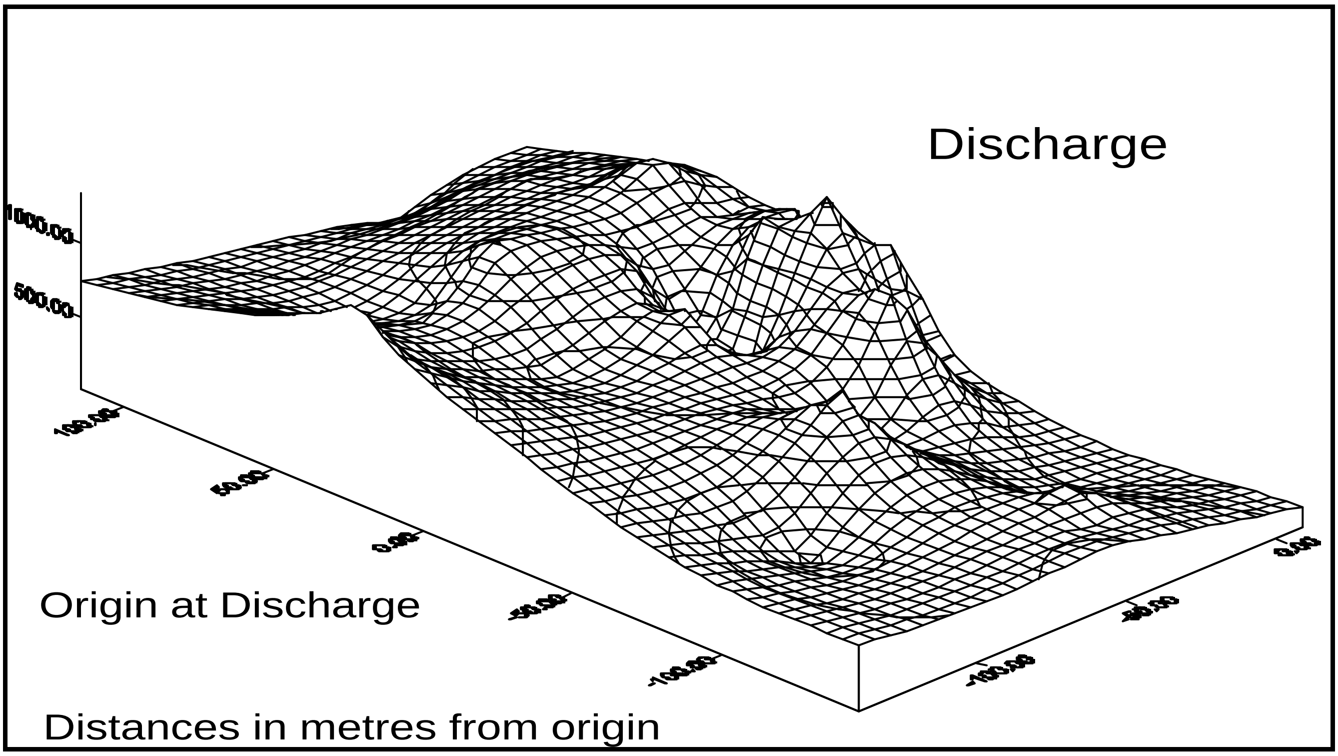

Figure 2. Sodium concentrations (as percentage relative to control) over the irrigation area.

3.5 Phosphate Levels in Effluent

At the outlet to pond 4, which is just beyond the uptake for irrigation effluent the quantity of phosphorus is equivalent to 6.7 kg P or 61 kg single superphosphate per ML. An irrigation rate of 6 ML of effluent per hectare equates to 7.3 bags of single superphosphate to the hectare, more than three times the traditional fertiliser application rate. For the total effluent production, the release of phosphorus into the river system is equivalent to 120 tonnes of single superphosphate per annum. Single superphosphate has a current commercial value of $280 per tonne. Additionally, significant savings under a load based licensing scheme may be gained by removing phosphorus in a land based re-use operation.

3.6 Sodium Loading from Effluent

There was little change in the levels of sodium (68 mg L^{-1}), calcium (32 mg L^{-1}) and magnesium (16 mg L^{-1}) throughout the treatment process, thus no change in the SAR. At an irrigation rate of 10 ML per month onto the irrigation area, a total of 1750 kg of sodium chloride (NaCl) equivalent or common salt is discharged each month or approximately 21 tonnes per annum. Annual discharge from the STW into the river system amounts to 323 tonnes NaCl equivalent. Current indications are that salt will not be part of the load based licensing costs imposed on STW discharges, although the environmental cost remains high.

4 DISCUSSION

4.1 Soil Nutrient Imbalance

The soil sampling and chemical analysis revealed a significant imbalance in the nutrient reserves in the soil. The immediate concern is the accumulation of phosphorus close to the discharge while deficiency levels exist less than 50 metres downslope from the discharge. That soluble nutrients are moving across the landscape is not uncommon, as is reflected by the movement of sodium. Soil nitrate levels are very low.

4.2 Soil Phosphorus

Plant available phosphorus as measured by Bray-P, indicates that there is almost no movement of phosphorus away from the irrigation area. Figure 1 is unambiguous in showing that very high levels of phosphorus occur close to the discharge, while the remainder of the irrigation area is at deficiency status.

The TP values mimic the soluble Bray-P values ($r = 0.97$) in that they congregate around the discharge although weaker correlation exists between the TP values and OC ($r = 0.77$). The cattle, preferentially grazing the lush pasture close to the outlet, provide some movement of phosphorus from that area to other parts of the paddock. That the remainder of the irrigation area is at deficiency levels in available phosphorus indicates that movement of phosphorus by either surface flow of water or in animal droppings is ineffective.

4.3 Soil nitrogen

The movement of nitrogen from the irrigation area is expected as nitrate does not bind readily to soil particles, in most forms is highly soluble and will move with soil water. The levels of TKN (organic nitrogen and ammonia), measured relative to the control show a weak negative trend with distance from the source ($r = 0.56$). The higher levels of organic matter close to the discharge provide a valuable sink for nitrogenas well as a buffer against their removal from the environment, however, TKN levels are mostly low.

Some organic nitrogen will be relocated with animal manures and urine, thus increasing the distribution of nitrogen products across the irrigation area. Soil nitrate levels are mostly below 15 mg $N\text{-}NO_3$ kg^{-1} (26 of 42 sites) and nitrogen is likely to be limiting to plant growth. There is a weak negative correlation ($r = 0.55$) between nitrate and distance from discharge, thus indicating some translocation of mineral nitrate as water (effluent and rain) moves through and over the surface, but insufficient to favour productive pastures.

4.4 Organic carbon

The major sources of OC on the irrigation area are from total solids and soluble organic products in the effluent and from the breakdown of plant and microbial products in the dynamic soil environment. At all sampling sites there has been an increase in OC relative to the control. A valid reason for the weak negative trend ($r = 0.54$) with distance from the source is that the cattle assist the movement of OC as dung and urine, while overland flow moves low density dead plant tissues with runoff water. Increased plant production due to nutrients and irrigation water cause an increase in OC derived from atmospheric carbon.

There is a stronger trend of association between TP and OC (0.77) but a significant correlation between TKN and OC ($r = 0.98$). Since TKN is a measure of organic nitrogen, the link with other plant nutrients is expected. However it makes the future monitoring of movement of nutrients more simple, since OC is more simple and repeatable to measure than TKN. The weak trend between mineral $N\text{-}NO_3$ and OC ($r = 0.61$) suggests that the monitoring of either nitrate or OC will not accurately predict the other.

4.5 Other nutrients

Other essential plant nutrients are available from the effluent. Carbonate (as bicarbonate) provides a buffer to the effluent and the soil water, limiting environmental changes brought about by acidic or alkaline conditions. There has been only a slight increase in pH (5.5 to 6.2 measured in 0.01M $CaCl_2$) in the irrigation area relative to the control. The chloride level in the soil does not equate with the sodium concentration, although there is a relationship between the two in the effluent. The levels of chloride are unlikely to cause plant problems.

The electrical conductivity (EC) is a measure of the total dissolved salts (TDS) in the soil solution. Where EC levels are below 1 dS m^{-1}, it is unlikely that serious salinity problems will arise. In this case, salinity problem with the soils need to considered in view of the total salt load. EC does not address sodicity.

4.6 Heavy metals

Under the contaminated soils protocols (ANZECC, 1992) levels of copper in excess of 60 mg kg^{-1} and 200 mg kg^{-1} for zinc require an environmental investigation, none of the samples reached those levels. However, plant toxicities can occur when levels of copper exceed 20 mg kg^{-1}. Only the area adjacent to the discharge has a level exceeding the threshold (55 mg kg^{-1}), all other sites were above deficiency levels but below toxic levels. Zinc may be toxic to plants at levels greater than 20 mg kg^{-1} . There were seven sites which approached or exceeded that value, the greatest (119.6 mg kg^{-1}) located at the discharge.

4.7 Exchangeable sodium percentage

Exchangeable sodium percentage (ESP) values above 5% are consistent with soil structural problems and sodicity effects upon plant osmotic mechanisms. Of the 41 sample sites, 13 had ESP >6, while the highest was 11.25%. Those elevated levels are adjacent to the sites most likely to be the first to receive effluent. The high sodium level in the effluent (70 mg L^{-1}) will, over time, causes the soil ESP to increase.

4.8 Nutrient Value

The value of the re-use scheme is in both the hydrology and chemistry of the effluent. Water disposed of at the rate of 10 ML per month has a value of 609 kg single superphosphate, 11 kg N and 1.8 tonnes NaCl as well as other nutrients. While the benefits of the N and P can be readily applied to pasture production, the impact of the 1.8 tonnes of NaCl are more difficult to determine. Therefore the irrigation strategy should be to use excess water to flush the salts from the system. Nitrate levels are significantly depressed.

5 ENVIRONMENTAL INDICATORS

The nutrients available in the effluent, the capacity of the soil to adsorb them and the plants to assimilate them interact when climate and soil water conditions are favourable. While effluent may provide an advantage in dry periods, the nutrient status should be considered in each re-use management plan. From the long term re-use scheme in operation in Armidale, the important indicators of potential pasture management and environmental pollution concerns are tabulated below.

Table 1. Environmental indicators for regular monitoring for Armidale re-use scheme

INDICATOR	EFFLUENT	SOIL
pH	pH	pH in 0.01 M $CaCl_2$
buffer capacity	alkalinity	none
salinity	electrical conductivity	electrical conductivity
sodicity	sodium adsorption ratio	exchangeable sodium percentage
phosphorus	orthophosphate	Bray-P
nitrogen	nitrate nitrogen	mineral nitrogen
organic matter	none	organic carbon

While a check list of soil, water and plant analyses can be drafted to indicate a range of requirements for monitoring, the matter of economics arises. Thus, from observations made in this project, it is suggested that several nutrients are keys to how they and other nutrients react in a similar situation. In view of thediscussion of correlation between TP and Bray-P, for example, it is suggested that measuring only one of those components at regular intervals can be used to reflect the expected behaviour of the other. Thus one test can replace two, which in this case the less expensive and rapid Bray-P would be used instead of the TP test. Similarly the mineral nitrogen test is preferable to the TKN test, the latter being a measure of the organic nitrogen. Even after 30 years the levels of heavy metals are of little consequence and have been shown to be relatively immobile, thus monitoring can be reduced to annual assessments.

6 CONCLUSIONS

The data collected from the current re-use scheme suggest that pollutants have not moved off-site and that the irrigation area will benefit from continued application of effluent and additional nitrate fertilisers. The environmental indicators, as shown in Table 1, are suggested as the model for soil and water monitoring. It is expected that sound agricultural management of the pastures will alert farm managers to plant nutritional problems as they occur rather than waiting for a licence monitoring schedule to commence. Monitoring should occur at intervals sufficient to determine plant nutrient status and soil conditions before an adverse environmental condition occurs, rather than to simply meet licensing requirements. For the Armidale operation, quarterly programs will capture essential soil and plant relationships.

As the effluent has a high economic value in an agricultural re-use project, such as that operated by Armidale City Council, it is imperative that the environmental monitoring addresses both the management aspects and licensing conditions. When the agricultural enterprise is functioning successfully, the environmental conditions will tend to be in harmony with the utilisation of the effluent. Through careful determination of key environmental indicators, a more regular monitoring system will permit fine tuning the re-use scheme to maximise pasture production while reducing the potential for off-site pollution and the costs incurred under a load based licensing scheme.

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