Environmental Indicators of Effective

Sewage Effluent Re-use

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ABSTRACT

Armidale City Council operates a small scale re-use scheme, irrigating pasture as part of a 24.6 ha cattle grazing operation. Since the 1960s effluent from the treatment lagoons has been used to flood irrigate an area of about 10 ha. Environmental indicators of the effects of the effluent on the soils and pasture have not been monitored and the irrigation scheme has been under-managed with respect of water or nutrient balance.

In a soil survey 42 sampling points were examined for relative changes in plant nutrients and salts from the long term re-use scheme. Plant material was analysed to determine the relative removal rates from varying vegetation densities. Effluent from the detention ponds was also analysed.

For the essential plant macro and micro nutrients a significant increase in the stored nutrients relative to the control was recorded. Nutrient increases ranged from 1200% for sodium, 700% for total Kjeldahl nitrogen (TKN), 1800% for total phosphorus (TP) to 7000% for Bray phosphorus. That salt levels generally increased down the slope indicated that soluble fractions were leached from the system. The plant density positively correlated with the levels of organic carbon, TP and TKN.

An important benefit of monitoring is that nutrients may be spread more evenly over the disposal area to maximise the production of pasture, rather than accumulate unusable quantities close to the discharge outlet. The environmental indicators which most readily provide a perspective on effective management were Bray -P, organic carbon, mineral nitrogen, exchangeable sodium percentage, pH and electrical conductivity for the soil; pH, electrical conductivity, orthophosphate, nitrate and sodium adsorption ratio (SAR) for water. Observations of plant growth, vigour and species composition indicate the outcome of management decision.

The findings indicate that the soil provided a valuable sink for nutrients, salts and heavy metals and provides a valuable nutrient removal process in wastewater treatment. After a long term re-use history the Armidale site maintains a buffer against off-site pollution without degradation of the soil environment.

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Mr Ross Motbey, a previous lessee of the re-use scheme during the 1980, provided valuable oral evidence of his operation.

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviation	Meaning
AEC	Australian Environment Council
ANZECC	Australian & New Zealand Environment & Conservation Council
APHA	American Public Health Association
ASL	average elevation above mean sea level
AWRC	Australian Water Resources Council
BOD_5	Biochemical oxygen demand, 5 day test
BOD_5/TSS	ratio of BOD to TSS usually 20/30 in mg L^{-1}
Bray - P	available phosphorus measured using Bray 1 method
cfu/100 mL	colony forming units per 100 mL
COD	chemical oxygen demand
CSIRO	Commonwealth Scientific & Industrial Research
DSE	dry sheep equivalent (per hectare)
EC	electrical conductivity in deciSiemens per metre
EP	equivalent persons
EPA	Environment Protection Authority
ESP	exchangeable sodium percentage
ET	evapotranspiration
Ksat	saturated hydraulic conductivity
Lpd	litres per person per day
LTA	long term average
MAR	mean annual rainfall
NaCl	sodium chloride (common salt)
NH_4-N	nitrogen measured as ammonium
NHMRC	National Health and Medical Research Council
NO_3-N	nitrogen measured as nitrate
NSW	New South Wales (state of Australia)
NTU	nephelometric turbidity units
OC	organic carbon measured by Walkley & Black method
ortho-P	orthophosphate - soluble phosphorus in water
pH $CaCl_2$	pH measured in 0.01M calcium chloride
pH	logarithm of hydrogen ion activity in water
SAR	sodium adsorption ratio
STW	sewage treatment works
TDS	total dissolved salts in milligrams per litre
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TP	total phosphorus
TS	total solids
TSS	total suspended solids in milligrams per litre

UNITS OF MEASURE

alkalinity of effluent	mg L^{-1} $CaCO_3$ equivalent
bulk density	kg m^{-3}
concentration	mg L^{-1}
concentration	meq L^{-1}, milliequivalents per litre,
exchangeable sodium percentage	percentage
hardness	mg L^{-1} $CaCO_3$ equivalent
pH	dimensionless (see abbreviations)
salinity	mg L^{-1}
salt concentration (chemical)	mg L^{-1}
salt concentration (medical)	mmol L^{-1}, milli-moles per litre
saturated hydraulic conductivity	m s^{-1}; m d^{-1}
sodicity	SAR in water, ESP in soil
sodium adsorption ratio	dimensionless
total dissolved solids	mg L^{-1}
total solids	mg L^{-1}
turbidity	NTUs
water consumption	litres per person per day (lpd)
wastewater production	litres per person per day (lpd)

1 INTRODUCTION

1.1 Generation and Disposal of Wastewater in Armidale

Armidale is situated on the New England Tablelands, in north-eastern New South Wales, at an altitude of approximately 1000 m above sea level (ASL) in undulating hills of basalt, granite and metamorphosed sedimentary country rocks. The landscape is dissected by small to medium sized river systems draining generally to the seaboard 200 km to the eastern seaboard through the major Macleay River system. With an annual rainfall of 793 mm (Bureau of Meteorology, 1988) which has a weak summer dominance, Armidale is fortunate to have a reliable engineered water supply in Malpas Dam, located 25 km to the north east in a basalt landscape. The city of 23 000 persons (EP) draws water from Malpas Dam through a reticulation system and a high quality treatment plant. Wastewater is piped to the sewage treatment works (STW) located on the junction of the Dumaresq Creek (which also drains the urban area) with Commissioners Waters which, at this point, is already draining hundreds of square kilometres of mainly rural lands in all three major geological parent materials.

Like most other inland cities, Armidale disposes of its wastewater back into the hydrologic cycle through the local river system. Figure 1.1 indicates the location of the STW relative to the City of Armidale.

Armidale City generates an average of about 40 megalitres of wastewater each week (see Figure 4.2) which, other than for the loss of evaporation from the expansive treatment lagoons, only a small proportion is applied to land, the remainder is piped from the final treatment lagoon into Commissioners Waters. Downstream users benefit from the added phosphorus and nitrogen load, but environmental requirements for the natural system may be disadvantaged by the increase in chemical load. The small volume of water reused for pasture production benefits the Council through a small but efficient beef cattle project, providing a subsidy to minor works within the sewerage system. The volume of water reused is less than 6% of the annual STW effluent volume.

In New South Wales, the state government has moved to greatly reduce the level of phosphorus entering the river systems while STWs have been recognised as a significant source of phosphorus pollution of the waterways. The NSW Local Government Phosphorus Action Plan attests to a positive approach to removing phosphorus from the wastewater stream. There are many examples of efforts being made to re-use effluent in a variety of ways, including the consumptive use onto pastures, golf courses and playing fields. Blessed with a reliable supply of clean water, re-use within Armidale City is not a major priority, but reducing stream pollution is marked for scrutiny by the EPA and the community generally.

The small re-use scheme has been operating at the Armidale STW since at least the 1960's, although an exact date has not been determined for this report. Effluent from the treatment ponds is pumped to the top of a small gravelly hill, allowed to discharge over the surface and by overland flow replenish soil moisture of the shallow surface soils by gravity flow. A small spray irrigation system was used on the river flats adjacent to the hill but has not been used for more than ten years. With the potential for expanding the re-use project, either from regulatory pressure or for economic benefits, Council had no information on the environmental indicators of the condition of the pasture as a result of the re-use scheme.

As a project, the author approached the Armidale City Council to investigate the on-site effects from the extensive period of irrigation, select environmental indicators and suggest a strategy for expanding re-use options onto adjoining Council owned lands. The project suited the current planning by the Council for expanding their system and maximising returns to ratepayers. Council is aware of the imminent regulatory approach to be taken by NSW EPA and the imposition of load based licences. The outcome of this project will provide a valuable planning tool towards an environmentally sustainable end while providing environmental indicators for a monitoring program.

A current NSW government enquiry “Public Enquiry into the Management of Sewage and Sewage By-Products in the Coastal Zone” indicates the timely investigation into the re-use project. The author provided a written submission to the enquiry and presented material before the commissioner at a sitting of the enquiry in Coffs Harbour. By invitation, the author was part of a focus group, chaired by the Commissioner, which discussed local re-use issues. Preliminary results of the Armidale project were discussed.

1.2 Definitions

Wastewater is referred to as the water which leaves the consumer, having been contaminated by domestic, industrial, commercial operations and storm water inflows with products such as organic matter, chemicals and other particulate matter. The wastewater is conveyed through a sewerage system to the STW where a range of primary, secondary and tertiary treatments can be performed. Effluent is the resulting water flow from the STW after it has undergone either part of or all the available treatment processes. The use of the term "treated effluent" as used by the NSW EPA (EPA, 1995) is redundant and not considered appropriate for use in this report.

The term "re-use" is used in various contexts to refer to effluent (treated wastewater) in a beneficial use, such as irrigation for agriculture as well as replacing clean water with effluent where lower grade water will suffice. In the context of this project, re-use is the consumptive use of water in an operation which would usually be rainfed agriculture or irrigation from a surface water such as a river or reservoir. "Recycle" is taken to mean the return of water from part of a project or operation back into the system to reduce the volume of clean water consumed.

The terms "primary", "secondary" and "tertiary" treatment refer to the level of physical, biological and chemical treatment delivered. In the context of re-use, the point at which water is extracted from the treatment system is commensurate with the use and treatment provided by the re-use scheme. For example, where water is to be used for the propagation of plants, extraction of the effluent before the phosphorus have been precipitated in the treatment processes will provide a valuable resource to the plants and reduce the phosphorus loading in the remainder of the treatment system.

Biosolids, from the anaerobic digester at the Armidale STW, are currently disposed of by surface application onto adjacent lands, although no biosolids have been deposited on the study site. The investigation of biosolids as part of the re-use scheme is beyond the scope of this study.

1.3 Perceived Problem for Armidale

The increasing public perception of the environmental problems of disposal of sewage effluent into the river systems is epitomised by the February, 1997 national scare over contamination of oysters from the Wallis Lakes area north of Sydney. The NSW Minister for the Environment, Ms Pam Allen, on national media (Sydney Morning Herald, **) accused local STW effluent and leaking septic tanks for the pollution. The claim has been refuted by the local Council. Linked with the national controversy over the 1000 km long blue-green algae (cyanobacteria) bloom of the Darling River in western NSW in December 1991 (Crase, 1996), sewage effluent disposal into inland rivers systems is terminal.

For the Armidale City community, river disposal of up to 40 ML of high quality effluent per week has been taken as acceptable. 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 is now required for environmental flows and riparian uses cannot be disputed, but there is an increasing desire by the community to other disposal practices. In Dubbo, Wagga Wagga, Albury and many other centres, woodlots are used to consume effluent and provide removal of chemical components. The climate of Armidale is not suitable to the same intensity of woodlot disposal because of the lower evapotranspiration and low temperature regime of the highland climate, as confirmed in an investigation by Armidale City Council (M.Chapman, Utilities Manager, *pers. comm.*).

Along the coast, artificial wetlands such as those at Ballina, are used to complete the treatment of urban wastewater. Wetlands in the Armidale environment will not provide sufficient evaporation to be economically viable because of low evaporation and cold climate.

The disposal 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. In June, 1994 approval was given for the use of 100 acres (24.6 ha) of land at Armidale Wastewater Treatment Plant to graze and fatten cattle (Council minutes 14/8/95). This approval followed many years of various leasing agreements in which local entrepreneurs grazed cattle on Council owned land irrigated with effluent from the treatment works. Anecdotal evidence suggests that those ventures were highly profitable (R. Motbey, farmer, *pers. comm.*), paying only for the cost of pumping the effluent.

That the Council did not have data on the impact of the operation of their re-use project provided a key to their support for the proposal for an investigative project on the site.

1.4 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. The present site at the Armidale STW has had effluent irrigated onto pasture in a flood irrigation system since the 1960s in a relatively under-managed manner, on lands which were previously a gravel extraction site, and on a landscape with shallow surface soils.

The objectives of the project were to:

(a) determine a nutrient balance of the landscape, over which effluent has been disposed of for many years, by soil sampling, soil, plant and effluent analysis.

(b) determine a suitable model for irrigation based upon nutrient availability and potential for the soil to adsorb and the plants to uptake those nutrients by comparing the irrigation area with an adjacent control site.

(c) determine environmental indicators and outline a monitoring strategy which will adequately record nutrient levels and alert operators to potential environmental or plant nutrient problems.

The project was limited to the current disposal area around the effluent disposal outlet. The current experimental disposal of biosolids onto adjoining lands was not part of the project.

1.5 Thesis Outline

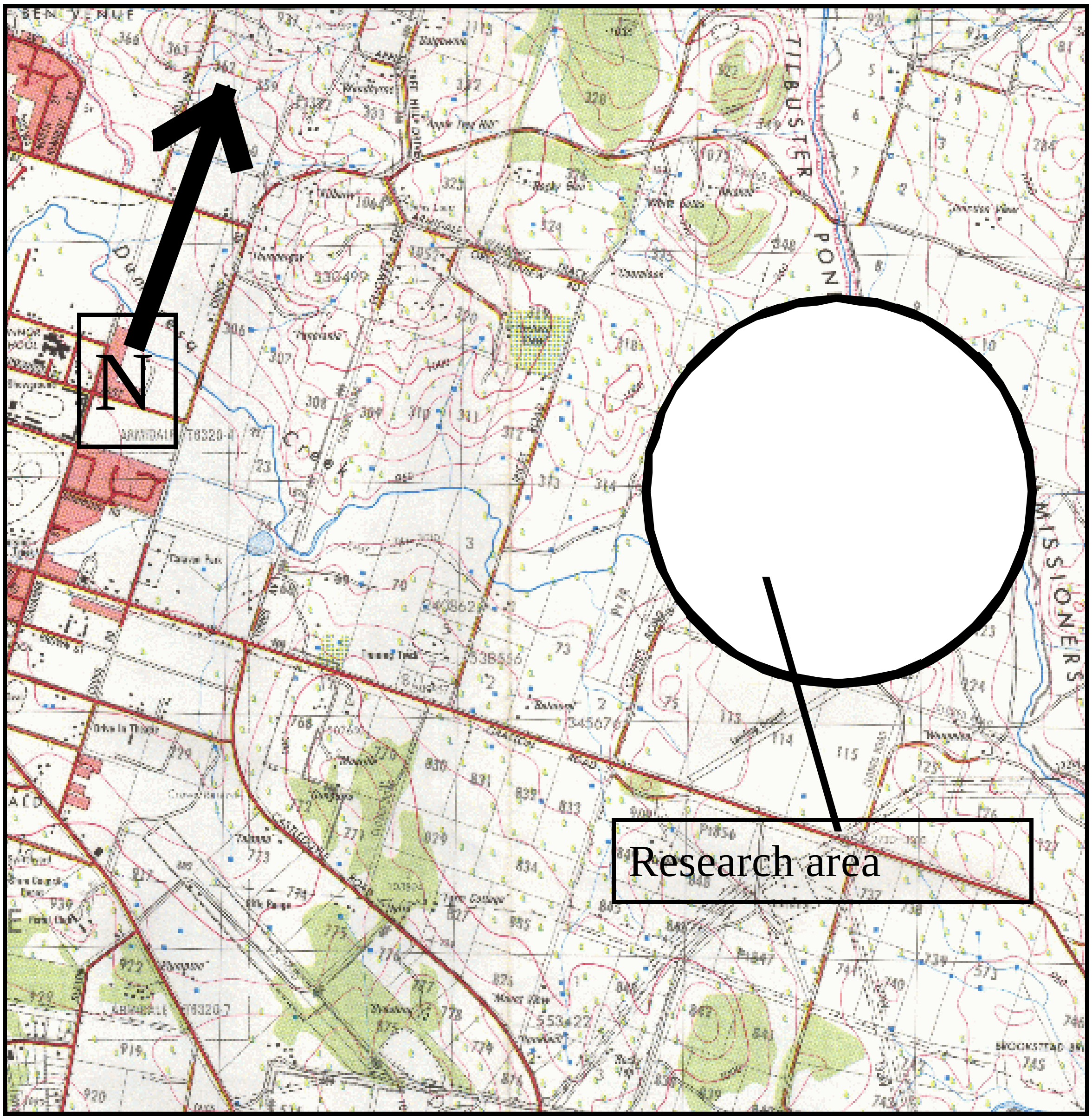
This study is based upon extensive primary research and examines the changes that have occurred to the surface soil over the previous years of under-managed effluent irrigation.

Chapter 2 considers the broad scale of implications that other re-use projects have experienced from the aspects of soil chemical changes and the potential for both on-site and off-site effects, particularly with respect to the operators being alert to monitoring which will indicate that management changes require redirection. Many examples are available where trial-and-error operations have indicated problems for STW effluent disposal.

Chapter 3 encompasses the study methodology, indicating the scale of landscape investigation, soil sampling and laboratory analysis that provided the results documented in Chapter 4. The results of the chemical analysis are complete only with respect to the project's aim. There are many other aspects of soil and effluent investigation which are worthy of inclusion in similar projects, but this project was the first quantification of the disposal area that had occurred since irrigation began in the 1960s.

Chapter 5 examines the implication of the results and outlines the possible causes of the non-uniform distributions of effluent components in the landscape. An examination of the potential to better distribute the nutrients and salts is used to develop a model for further irrigation of effluent.

Chapter 6 provides the conclusions and recommendation for a monitoring program which will more clearly identify areas that are either accumulating or depleting essential plant nutrients, thus allowing management to optimise production. Recommendations for upgrading work on the disposal area are made.



N'Source: CMA. 1984 Armidale 9236-IV-N 1:25000 topographic map. Central Mapping Authority Bathurst. Scale 1 grid square = 1000 x 1000 m

Figure 1.1 Location of the STW in relation the Armidale City

2 LITERATURE REVIEW

2.1 Background

Land application of wastewater may be considered either a disposal technique, a form of wastewater re-use or both (Peavy *et al*., 1985). The most common forms of land application are irrigation and rapid infiltration, wastewater may be used to apply both water and nutrients to plants.

Treated wastewater from sewage treatment plants has been accepted as a valuable irrigation resource for over a century. The most notable re-use scheme in Australia is the Werribee Sewage Treatment Works on the outskirts of Melbourne which treats a large proportion of wastewater from metropolitan areas. Commenced in 1893, Werribee continues to be a world renown example of large scale re-use (Metcalf & Eddy, 1991).

Many other towns have re-used effluent from STWs, abattoirs, flour processing plants and other large volume wastewater generators. Often managed as a means of disposing of large volumes of water which are too large or too polluted to be accepted by local government operated STWs, industry has found re-use as an alternative disposal system and a final treatment mechanism.

AWRC (1991) cites a number of re-use projects across Australia as examples. Richmond (NSW) discharges chlorinated effluent onto a nearby golf course and Hawkesbury Agricultural College where almost 100% usage is achieved during summer. In Alice Springs (NT) - the high evaporation rates caused serious salinity problems on the disposal area. Bolivar (SA) irrigates 30 000 trees, 2500 ML per year on crops (tomatoes, lettuce and fodder crops) and other minor projects with treated wastewater. The most important aspect of the Bolivar process is that commercial vegetables are produced from secondary effluent.

In Victoria, 70 towns were reported using all of their treated effluent while another 38 re-used some effluent (Vic EPA, 1994). Effluent re-use onto land accounts for 8.0% of the total effluent discharge while 75% is discharged to oceans.

One example of the positive economic benefit is the long term wastewater disposal of untreated wastewater by Goodman Fielders Mills Ltd in Tamworth, NSW, where up to 100 kL of backwash water per day is disposed of onto black alluvial soils along the floodplain of the Peel River for over 25 years. Wastewater from the starch mill is treated with lime, a process with increases alkalinity to over pH 10.5 to reduce the growth of bacteria which produce a sickly odour. A successful cropping operation on the disposal area overcame many of the problems of disposing of highly saline waters with very high solids loads when not acceptable to the local sewer. However, the high SAR and high pH decreased infiltration by up to two log units (Patterson, 1994).

2.2 Beneficial Re-use

NHMRC (1987) notes the potential benefits to the community from the aspect of water conservation, nutrient recycling, and increased agricultural production. AWRC (1991) indicates that re-use of sewage effluent represents a valuable resource and public attention is focussing increasingly on alternative disposal options, particularly those which return an economic benefit to the community, such as the Armidale re-use scheme. However, the report suggests that direct use of reclaimed water for potable purposes is not warranted in Australia at present. The public perception that sewage effluent is not suitable for potable supplies is fixed, but other uses are acceptable. Potential health effects are of prime importance. Wastewater quality indicators and criteria of particular importance include bacterial counts and the need for a degree of disinfection (AWRC, 1991). Until bacteria and virus impact of effluent have been clarified and have a high degree of correlation with good health, the public is unlikely to accept potable re-use. The disagreement between regulators on disinfection of effluent before land application indicates the scepticism among professionals for non-potable supplies, let alone for domestic re-use.

Economic implications are addressed by the Industry Commission (1992) as part of the wastewater disposal issue but the Commission stops short of including the effective use of wastewater as a positive economic variable in either rural or urban land use. There are many economic benefits of using wastewater on playing fields, public parks and gardens as well as irrigation land and urban forestry and these should not just be seen as a substitute cost compared to potable water supplies.

The re-use of effluent is gaining approval by communities and seen as an essential mechanism for reducing in-stream pollution and blue-green algal blooms. The Queensland Government, in its 1996-97 budget, allocated $65 000 to develop guidelines for re-use or disposal of reclaimed wastewater, $62 500 to develop the effluent re-use strategy and an additional $109 000 to manage research into the use of artificial wetlands. (Crosscurrent, Feb 97, p6). While the combined total is not large as a per capita expenditure, there are encouraging signs that re-use is being taken seriously.

In South Australia, the Hills environmental project (Crosscurrent Feb, 97 p.3) is a SA Water initiative devoting $400 000 to re-using the entire output of treated wastewater from Umeracha WTP on 15 ha commercial pine forest. This is a further example of the involvement of governments in re-use projects, the research of which will further fuel other projects in both the public and private arenas.

2.3 Legislation, Regulation and Guidelines

The traditional practice around the world has been the disposal of effluent to inland waters AWRC (1991), usually from smaller inland communities which have developed along a river system. Armidale and the surrounding towns all subscribe to that practice. Canberra, a large inland city also disposes of its sewage effluent into an inland river system.

In NSW, draft guidelines for the land application of effluent are in place (EPA, 1995). The scope of the guidelines is towards encouraging beneficial use of effluents for land application, whatever the source of the effluent. While these draft guidelines were available for public comment during the first half of 1996, no revision has been published and the draft (uncorrected) document is being used as if it was a standard. As a recent example, the author was made comply with the draft guidelines when making application for a licence to irrigate abattoir effluent, even though the draft guidelines contain scientific inaccuracies.

A licence to irrigate effluent is regulated by the Clean Waters Act 1970 which operates through a system of licences and approvals. Specifically under Section 19(1) *a person shall not install, construct or modify any apparatus equipment or works for the storage, treatment or disposal of matter of a prescribed class*. Any operation of a sewage treatment works will produce matter of "a prescribed class". Therefore, all operators of effluent re-use schemes require licensing, inspection and regulation by the Environment Protection Authority. Similar legislation is in place across Australia.

2.4 Irrigation of Effluent

The complexities of the interactions between sewage effluent, the soil and plant communities result in each proposal requiring unique assessment of the potential impacts. NHMRC (1996) provides a valuable discussion of irrigation schemes and suggests a range of planning issues with a checklist for an assessment program for the proposed irrigation area and monitoring requirements over the life of the operation.

A valuable resource is available in ANZECC (1992) where the interaction of water quality and agricultural uses are discussed. This reference is perhaps the clearest document for interaction of all waters on land and aquatic systems.

2.5 Environmental indicators

While irrigation projects may be considered as agricultural enterprises using a different quality water, the need arises that the environment must be managed to take account not only of the hydrologic impact but also the nutrient load. 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 and analysis. The parameters chosen as the environmental indicators must be indicators which gain their meaning and significance from the interpretive theory built up around them (e.g. standards, acceptable levels, trends, norm etc) (CDEST,1996).

Environmental indicators are simple physical, chemical, biological or socioeconomic 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.

The selection criteria for national environmental indicators has been outlined by CDEST (1996, p21) as those criteria which:

(1) serve as a robust indicator of environmental change;

(2) provide an early warning of potential problems;

(3) are capable of being monitored to provide statistically verifiable and reproducible data that show trends over time;

(4) are easy to understand; and

(5) are cost effective.

Other qualities were also detailed, however the five above are considered appropriate for this project. When items (1) and (5) are considered together, there are many valid reasons why the indicators selected for a particular project are the minimum number of indicators which can be monitored at a more regular interval to better form a picture of the environmental changes occurring, therefore more easily satisfying item (2).

The characteristics of natural treatment systems such as irrigation schemes must examine the wastewater treatment as the water percolates through the soil profile. An understanding by the operator must address the microbial degradation of organic residues which are generally associated with slimes or films that develop on the surfaces of soil particles, vegetation and litter. It becomes essential that soil moisture is maintained so that such degradation occurs at an acceptable rate.

2.6 Current Concerns.

The Wallis Lakes oyster controversy which gained public recognition during January and February, 1997 highlighted the sensitivity of the general public to issues which involve human waste management. Almost without any substantial argument, the Wallis Lake oyster growers were branded as environmental vandals and the NSW Minister for the Environment labelled the Great Lakes Shire Council as worthy of maximum prosecution at law for failing to maintain sewage treatment works. Since the initial scare a task force from various Government agencies has been amassed to identify potential sources of contamination. 405 cases of Hepatitis A has been reported in NSW since the outbreak of the disease in January (Crosscurrent, April, 1997), however, no specific source has been isolated.

Late in 1996, the NSW Government, in response to concerns about sewage outflows into estuaries and marine environments commissioned the NSW Coastal Effluent Enquiry. The aim of the enquiry was to develop long term strategies for sewage management and alternatives in the context of ecologically sustainable development, environmental and social outcomes, institutional and regulatory framework (NSW Government, 1996). Managing effluent in the context of the water cycle was given a major section of the scoping paper. The author forwarded a submission to the Commissioner, addressed the Enquiry during its hearing at Coffs Harbour and was invited to be part of a 12 person focus meeting at Grafton. While the outcome of the enquiry is many months away, the indications are that emphasis will be given to ensuring that re-use projects have minimum impact upon the environment.

2.7 Monitoring

When acceptable environmental indicators are chosen for a project, the second stage of the monitoring program is to decide upon the frequency of monitoring, the aim of which should be consistent with obtaining early warning of potential problems within the disposal 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). While this monitoring program may suffice for water analysis, plant and soil analysis will depend upon the irrigation scheduling, the nutrient application and uptake rate. 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. It is assumed that, by default, an annual program will suffice.

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 highlighting the need for remedial steps after degradation has occurred.

2.8 Typical effluents

Wastewater includes water used for commercial, industrial, institutional and internal domestic purposes (ASTEC, 1995). The range of effluent qualities through sewage treatment works will vary with between seasons and year round (Metcalf & Eddy, 1991) and with peculiar town enterprises. Patterson (1997) showed that around Armidale the STW effluent varied to reflect the use of water and the chemistry of the incoming clean water. For example, the sodium adsorption ratio (SAR) of Armidale was measured at SAR 2.6, Uralla at SAR 5.1 and Guyra at SAR 3.3. Most of the variation was due to geological inputs to the water storage reservoir and not the wastewater stream.

DCNR (1995) records that secondary treated wastewater, similar to the type used in the Armidale re-use scheme, typically varied within the range of 8-10 mg L^{-1} for total phosphorus (TP) and 20-30 mg L^{-1} total nitrogen (TN). In the NSW guidelines, the EPA (1995) cites the expected chemical composition of STW effluent to be considered of low strength; TN <50 mg L^{-1}, total P <10 mg L^{-1}, BOD_5 <40 mg L^{-1} and TDS <500 mg L^{-1}.
Similar qualities have been published by ASTEC (1995) indicating average domestic wastewater, after secondary treatment has values of 20-30 mg L^{-1} BOD_5, TN 20-50 mg L^{-1} and TP of 10 mg L^{-1}; no value is placed upon expected sodicity, even though total salts and sodium in particular impinge upon the soil and plant ecosystem.

2.9 Disinfection

In a review by NSW EPA of a risk study of all 17 STW discharges to Hawkesbury-Nepean River, of 114 chemicals assessed chlorine and chloramines were most likely to threaten the environment (Newsdrop Feb 97, p1). As a result, $120 million will be spent over 5 years upgrading sewage treatment on the river, yet chlorination before land application is still considered preferable for disinfection

The purpose of disinfection is to achieve median level of 1000 faecal coliforms per 100 mL which, by using detention to reduce faecal coliforms, can be achieved with 5-16 days of ponding (NHMRC, 1987). This is in conflict with a later document (NHMRC, 1996) which recommends that the level of disinfection for the non-human food chain should be less than 10 000 faecal coliforms per 100 mL. However, the NSW EPA (1995) requires that for the irrigation of pasture for use by sheep, cattle or horses, any acceptable method of irrigation can only be carried out with water which has a faecal coliforms geometric mean count of less than 3000 colonies per 100 mL. ANZECC (1992) recommends 1000 faecal coliforms per 100 mL for re-use.

The NSW Recycled Water Co-ordination Committee (1993) requires high quality treatment for re-use on municipal landscape watering, irrigation of pastures and crops, construction purposes and groundwater recharge to a quality of less than 1 faecal coliforms per 100 mL and free residual chlorine <0.5 mg L-1 at point of use. The reasons for the non-conformity in levels of disinfection between advisory and regulatory bodies is not known.

Stabilisation and maturation ponds are a very effective and simple means of providing treatment and pathogen reduction (NHMRC, 1996) and to reach a minimum level of disinfection, 10 days ponding is considered sufficient (EPA, 1995).During the spraying operations the public must be excluded and animals must be excluded for 10 days but no level of exclusion or disinfection is given by the EPA for flood irrigation. It is presumed the EPA will consider similar disinfection levels for the effluent irrespective application method.

2.10 Sodium Adsorption Ratio

The ratio of sodium to calcium and magnesium indicates the potential for the effluent to impinge upon soil physical properties and plant biological processes. Patterson (1991) showed that for SAR values as low as 5, the loss of saturated hydraulic conductivity 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.

ANZECC (1992) reported that SAR as low as 5.5 can have effects upon plants, and its effects on soil structure are suggested but states that an ESP of 10-15% is required for that to occur. VICEPA (1982) suggests a maximum SAR to suit particular crops, salinity and sodicity hazards as tabulated in that document.

Battye-Smith (1992) reported a banana irrigation trial in Coffs Harbour which used effluent with the concentrations in mg L^{-1} for sodium 90, calcium 18, potassium 16, magnesium 7 and nitrogen 8. While not calculated for that report, the SAR of the above effluent is 4.6 while the hardness is 74 mg L^{-1}. The irrigation caused accelerated leaching of salts and an increase in salinity in the groundwater. 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.

2.11 Trade Waste Controls

Trade waste guidelines were developed so that trade waste can be managed to minimise the cost to the community of processing that waste, ensure environmental protection and encourage waste minimisation. An increase in the volume of liquid wastes containing toxic materials that may enter the wastewater stream has the potential to limit re-use (ANZECC, 1994). Guidelines which include criteria for general acceptance and restricted substances values should be developed by each local authority responsible for wastewater treatment.

Armidale has developed a Liquid Trade Waste Policy (ACC, 1996) which seeks to protect the environment from the discharge of waste that may cause detrimental effect. The guidelines set maximum general acceptance levels for TKN at 100 mg L^{-1}, TP at 20 mg L^{-1} sulphate at 100 mg L^{-1} , each of copper and zinc at 5 mg L^{-1} .

2.12 Nitrogen

Nitrogen in untreated wastewater is present in the form of ammonia or organic nitrogen as both soluble and insoluble products. Soluble organic N is normally present as urea and amino acids. Untreated wastewater generally contains little or no nitrogen while less than 30% of the TN is removed by secondary treatment (Metcalf & Eddy, 1991)

The potential pool of nitrogen after treatment is reduced because organic materials are removed by sedimentation, ammonia by volatilisation particularly in detention ponds, and ammonia and nitrates take up by vegetation and soil adsorption sites (Metcalf & Eddy, 1991). What becomes important is the control of biological denitrification by microbial activity in anoxic zones in the soil. These zones do not need to be completely anoxic, because micro sites for denitrification can exist around individual soil particles. The prevention of nitrates leaching to groundwater is encouraged by developing micro sites.

2.13 Phosphorus

The phosphorus content of effluent is largely as orthophosphate (ANZECC, 1996b), a product from the domestic use of detergents, foodstuffs and numerous commercial operations. In the treatment system phosphorus can be removed by chemical precipitation and adsorption during primary treatment by 20-50%. In soil systems up to 90% of the phosphorus can be adsorbed by clay minerals and soil organic fractions.

Major sewage treatment works within the Hawkesbury-Nepean catchment (Penrith, St Marys, Riverstone) could be required to meet primary phosphorus targets of 0.04 to 0.10 mg L^{-1} and TN of 3 mg L^{-1} (Clancy, 1997). The aim of the Hawkesbury-Nepean Catchment Management Trust is to reduce the amount of phosphorus flowing into the waterways (HNCMT, 1995). A broad community program is in place to achieve that target.

Typical effluent phosphate levels have been discussed above in section 2.8. New wastewater treatment plants to be built at Warragul and Neerin South for Gippsland Water (Victoria), have been designed to meet 2 mg L^{-1} ammonia, 10 mg L^{-1} nitrogen and 0.5 mg L^{-1} P (Crosscurrent, March 1997, p2)

Treatment plants at Sunbury (Vic), Quakers Hill (NSW) and Lower Molonglo (Canberra) each produce effluent with a TP concentration less than 1 mg L^{-1} (Crase, 1996).

2.14 Efficient Use of Water

In the development of an effluent re-use scheme ANZECC (1996b) recommends an assessment of the land capability, undertaking land forming as required to better prepare the irrigation area for the particular application and reusing drainage water from the irrigation area should be undertaken. Best management Practice (BMP) is critical to achieving ecological and economic sustainability in managing rural land uses.

2.15 Nutrient control strategies

Nutrient enrichment in Australian river systems has been linked to wastewater treatment plants and runoff from agricultural lands (ANZECC, 1996b). To reduce the input of STW derived nutrients into river systems, a goal of maximum values has been set for TP <1 mg L^{-1} and total N <15 mg L^{-1} (ANZEEC, 1996b). The use of land application can assist in achieving this aim because the soil is an ideal treatment system for biologically removing both nitrates and phosphates under well-managed systems. Borough and Johnson (1990) showed that in an effluent irrigated pasture trial in the Snowy Mountains, 148 kg N ha^{-1}, 130 kg and 39 kg P ha^{-1}, 16 kg were removed.

2.16 Summary

That the re-use of sewage effluent is in wide use across Australia and gaining in acceptance by governments and communities, cannot be disputed. There are areas within the regulatory processes that need to consider a uniform approach to acceptable guidelines, such as the requirement for disinfection and monitoring of indicators at particular times or intervals.

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. It should not be taken that all adjustment needs to be taken to avert a catastrophe. Often alternative courses may need to be taken to maximise the removal of nutrient for an economic gain.

The project, the subject of this report, sets out to identify those environmental indicators, as suggested above, which will allow the maximisation of nitrogen and phosphorus removal and the production of cattle from the scheme in an environmentally sustainable manner.

3 RESEARCH METHODS

3.1 Background Examination

The effluent disposal area under investigation had not been monitored by either the Council or lessees at any time from the commencement of irrigation in the 1960s up to the present. Thus the present study had no base data on which to develop a clear vision of the long term environmental effects on the block. Several meetings and a site inspection were held with Council officers before the development of a plan of investigation to meet Council's projections for extending the re-use scheme.

The previous lessee, Mr Ross Motbey, was contacted and a brief oral summary was obtained of previous operations under his management. Mr Motbey grazed cattle on the disposal area from approximately 1981 to about 1991.

3.2 Survey Site - Physical Description

The site was examined with Mr Michael Porter, Process Control Manager, responsible for the current disposal operation. During this inspection the area receiving regular irrigation was clearly defined. The areas where biosolids had been spread were also defined. At a later stage the author traversed the disposal area on foot and the discontinuities in the landscape noted. The site had previously been a gravel quarry, however, it had not been functional for at least the last 14 years, while five years ago some land reshaping was done around the quarry. Two contour banks have been in existence for many years.

The topographic map, Armidale 1:25 000 (CMA, 1984) was the only survey available for the disposal area indicating contours at the 10 m interval, less precise than required for the survey. Figure 1.1 is a photocopy of the 1:25000 CMA map showing the locality of the STW, the City of Armidale and the disposal area. The Council has suitable maps for the treatment facility but not the surrounding rural land. There were no detailed soils maps available for the disposal area.

A theodolite survey was carried out on the disposal area to locate each soil sampling point relative to the discharge outlet in both horizontal and vertical planes. The instrument used was a Wild T1.

Conventional surveying calculations were performed on the field data to derive horizontal and vertical distances. Bearings were taken directly from the theodolite after initial orientation with a magnetic compass. The contours banks as shown on the plan (Figure 4.4) have been marked from field observations, then validated in the field after drafting.

3.3 Soil Survey Selection Sites

From a nearby excavation, it was expected that the soil profile would reflect the attributes of a Red Podzolic (Great Soils Group as per Stace *et al*., 1972), that is a duplex soil having a pale A1 horizon, over a well developed A2 horizon with a bright red medium clay B horizon underneath. When the survey was commenced the area below the discharge point was found to be mainly a Lithosol, a very shallow surface soil over decaying rock. As a result, the soil survey had to be amended from the proposed five downslope profiles because of the difficulty obtaining suitable soil samples and the obvious changes from the expected water movement patterns. Instead a radiating pattern of five arms was selected.

The selection criteria for the radiating transects included identifying:

- (a) the likely path of overland flow of effluent from the discharge point;
- (b) the extremities of the likely flow paths to the north and south of the discharge point, used to define the irrigated area;
- (c) at least one flow path to reflect the depression through which effluent was obviously moving preferentially;
- (d) each radiating traverse extending beyond the obvious limit of disposal as observed from vegetation patterns.

As the project had a working budget for laboratory analysis, a total of five traverses were selected, each with eight sampling points spaced at approximately 15-20 m depending upon local surface conditions. An additional site was selected on transect C, while a control was selected above and 30 m south of the discharge point. The control was in an adjacent paddock and unlikely to have been influenced by manures or other high grazing pressures as would have occurred on the disposal area.

3.4 Soil Sampling Technique

At each of the 42 sampling sites, soil sampling was undertaken using acceptable soil science procedures. Composite samples of the A1 were made from an approximately one metre circle around the site peg. The surface soil was often so shallow that up to five scrapings were necessary to obtain 1 kg sample of soil. Root material and stones were discarded at sampling. The samples were bagged and marked accordingly. Soil samples were returned to the laboratory for processing. No recordings were made of the moisture at time of sampling due to the heavy rains during the previous fortnight and the effluent had not been discharged during that time. Soil moisture could not have been correlated with movement of effluent, however, records were made of the depressions where soil moisture was high or near saturated conditions.

While it was initially planned to undertake soil hydraulic conductivity testing using the CSIRO disc permeameter, that program was aborted after the initial soil survey identified the very shallow soil over a fractured and weather sedimentary mudstone. No purpose could have been gained by attempting the percolation tests.

3.5 Soil Laboratory Analysis

The soils samples were returned to the laboratory and air-dried before analysis for the components as indicated in Appendix A. All the tests were conducted under normal quality protocols using reference methods acceptable for Australian conditions as detailed on the laboratory procedures sheet. The author, with assistance from a technical officer performed the analytical tasks at Lanfax Laboratories. Appendix D lists equipment used. The suite of soil analyses was selected to reflect environmental changes from effluent disposal on soils.

3.6 Plant Collection and Analysis

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, to the best of the operator's knowledge, while there had been no grazing for the previous three months. Three vegetation samples were taken to reflect high density, medium density and poor quality plants. An analysis of this material was undertaken in the laboratory as detailed in Appendix C.

The phosphorus, sulphur and cations determinations on the plant samples were performed by the Department of Agronomy and Soil Science at the University of New England under commercial arrangements between the author and that laboratory. Other analyses were conducted by the author and support staff at Lanfax Laboratories.

3.7 Water Sampling and Analysis

On two occasions, water samples were obtained from sites within the treatment ponds as detailed on Figure 3.1 and from upstream and downstream of the discharge point into Commissioner's Waters. The first event was following a six week period without rain while the second event was after two days of light rain (27 mm) which produced slight runoff.

Effluent pumped to the disposal area is from Detention Pond 5 which has had 18 days of detention. Water samples were not taken from the discharge point (on the disposal area) as there could be no correlation between water quality at the time of sampling and the soil properties because of the extensive period of unmonitored disposal. Water samples were analysed as fresh samples as detailed in Appendix B. All analyses were conducted at Lanfax Laboratories by the author and support staff.

Samples were not analysed for biochemical oxygen demand (BOD_5) or faecal coliforms because these test were considered irrelevant to the re-use scheme under examination.

3.8 Data Processing

A spreadsheet (Quattro Pro V6.01 produced by Novell Inc.) was prepared for the calculation of vertical and horizontal distances from field theodolite readings and for the conversion of polar coordinates to rectangular coordinates. Standard calculation procedures were employed. The preparation of the maps and surface diagrams was made using the three dimensional surface mapping system “Surfer 5.00" produced by Golden Software Inc. from rectangular coordinates prepared in the spreadsheet.

Laboratory analytical data were tabulated, graphed and statistically analysed using Quattro Pro V6.01 in spreadsheets developed by Lanfax Laboratories for routine analysis.

3.9 Rainfall and Evaporation Data

Long term rainfall records were obtained from Bureau of Meteorology (1988) while short term records came from records published in “The Armidale Express” (Jan, 1997) and supplemented by records from Radio Station 2AD, the local meteorological reporting station and other sources.

Evaporation rates for Armidale are taken from material prepared previously by the author (unpublished) from data obtained from the University of New England “Laureldale” research farm for the period 1970-1985 inclusive.

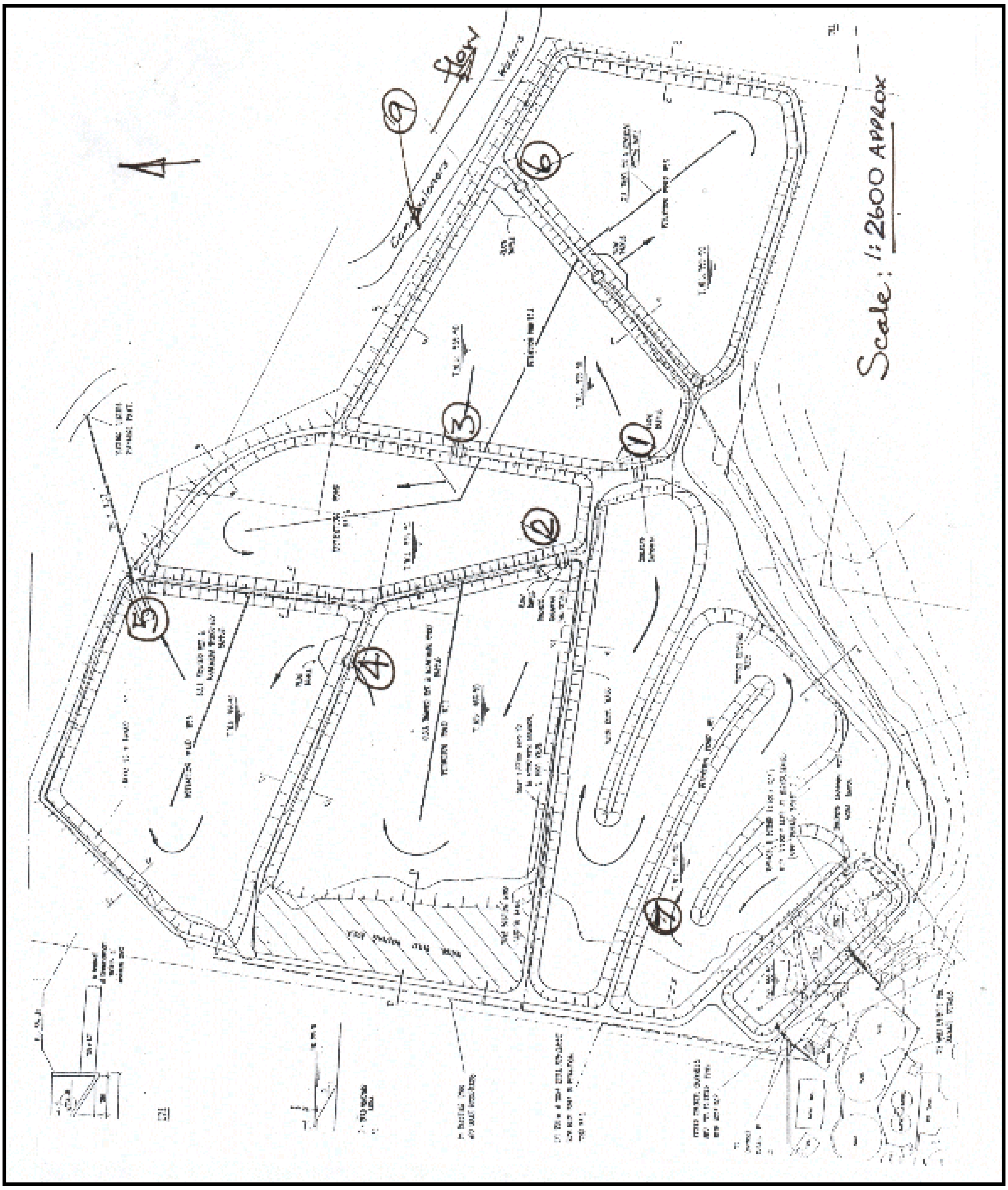


Figure 3.1 Layout of the Armidale STW showing facilities and detention ponds

4 RESULTS

4.1 Description of the Disposal Area

Effluent is pumped from the STW Detention Pond No. 5 through a rising 100 mm main to the top of a hill south of the treatment works complex on land designated as Portion 76 Parish of Armidale, County Sandon, Shire of Dumaresq. The Armidale City Council also owns the land adjoining the property to the east and north, zoned for public utilities.

The disposal area has a generally westerly aspect, with an even slope of about 12%, except for the northern part of a steeper spur which has an old gravel quarry exposed, but fenced off from stock. Runoff from the site is captured by the road embankment and directed through small culverts to the land below which drains towards Dumaresq Creek. Any polluted runoff from the site could be contained at this point, although there is no terminal dam below the site. Figure 4.1 indicates the disposal area relative to the entrance to the facility (looking north) and the main treatment works in the background. The land to the right-hand side (eastern side) in the photograph is the current disposal area (see Figure 1.1).

Figure 4.1 Photograph looking north from entrance to STW, the treatment plant in distance, the disposal area on the hill to the right-hand side (east)

Effluent can be pumped at a maximum rate of 13 L s^{-1} and up to about 10 ML per month, although no records are kept to substantiate the monthly application rate. Pumping is stopped during and after heavy rain. No soil moisture monitoring of the site occurs, although visual inspection and appreciation of the terrain permits a management decision with respect to pumping. Excess irrigation appears as additional drainage water in the table drain and would be obvious to staff as they entered or departed the facility each day. Prior to December 1996, effluent has been pumped continuously for many months. Heavy rains in February 1997 reduced the need to irrigate. Cattle had been moved from the paddock at about the same time, leaving the disposal area unstocked for the first five months of 1997.

The discharge at the top of the hill can be extended, by joining to aluminium irrigation pipes, to pipe effluent further south so that flood irrigation can be directed towards the drainage line. The previous lessee Mr Ross Motbey operated a spray irrigation scheme on the western (lower) side of the entrance road as well as flood irrigated the hill.

Mr Motbey related that effluent killed several trees on the hill and that water would disappear underground and resurface near the road. As the effluent was pumped all the time, it is highly likely that the gravelly soils acted in this way when ponded with excess water. He related that the management strategy behind the use of the effluent was to produce pasture, to sustain stocking rates so that pasture height was maintained at about 50 mm. Water continued to be distributed by both spray and flood irrigation during winter even when evaporation rates were very low and overnight temperatures dropped below zero. Stocking rates of 130-140 cattle on the 100 acres (24.6 ha) were maintained over the summer and about 100 head during winter for most of the lease period. This rate equates to about 60 dry sheep equivalent (DSE) per hectare, an exceptionally high rate for the particular soil type in Armidale. One head of cattle is equivalent to 10 DSE per hectare. No fertiliser was ever applied to supplement the effluent. The lessee was charged for power consumption for the pump but not for the volume of water used.

When Council resumed control of the area in 1992, the quarry below the discharge outlet was reshaped, rubbish and old trees removed and the remaining soil spread over the reshaped landscape. Another disused gravel quarry remains exposed closer to the treatment works but has been fenced off to exclude stock and trees have been replanted.

Today the management of the cattle raising project is returning profits to the Council, however, management of the effluent is being addressed through the commissioning of a spray irrigation area to the north east on the same holding.

4.2 Layout of the Treatment System

Maps prepared by the Armidale City Council have been photo-reduced and reproduced as Figure 3.1 indicating the layout of the treatment facility and the system of detention (maturation) ponds. Effluent has a detention time of about 22.5 days in the system and the lagoons cover 9.5 ha. The water sampling sites are marked on Figure 3.1 as the sample points rather than the sequence of water flow through the system. The effluent from Detention Pond Number 5 is pumped to the disposal area. At this point the effluent has been detained for about 15 days depending upon the rate of inflow. Overflow from the terminal pond enters Commissioner's Waters below the inflow from Dumaresq Creek.

4.3 Quantitative Data on Wastewater Treatment

Council provided the previous 12 monthly summaries of water from both the water treatment plant (clean water) and the sewage treatment works (wastewater). The graphical presentation, Figure 4.2, indicates the comparison of the two quantities. The Council STW officer-in-charge suggested that the differences between the clean water produced and the wastewater received is correlated with the weather conditions. When the weather is hot and dry clean water consumption exceeds wastewater production with the difference being used for gardens and other outside uses. Leakages from the system into the surrounding environment may also occur. When the weather is cold and dry the two values are approximately the same and when the weather is very wet the wastewater production is elevated because of leakages into the sewerage system.

From data provided by the Council, the clean water use and wastewater production has been calculated for the four seasons as shown in Table 4.1. Correlations have not be done for the effects of rainfall and temperature. The difference between the winter and the summer clean water use may be related to outside use of water. However, the similarities between summer and winter wastewater production have not be addressed.

TABLE 4.1

Comparison of seasonal flows of clean water and wastewater for Armidale
(all values calculated as litres per person per day)

	Clean water production	Wastewater generation
Spring (Sep-Nov)	340	195
Summer(Dec-Feb)	393	262
Autumn (Mar-May)	390	190
Winter (Jun - Aug)	320	262

(Data supplied by Armidale City Council, May 1997)

The wastewater disposed of into Commissioner's water is the difference between losses from the lagoons due to subsurface movement of water into the groundwater system, evaporation from the 9.5 ha surface of the ponds and up to 10 ML per month taken as irrigation water. Evaporation in a normal year could account for up to 58 ML per annum loss from the pond system. The losses to groundwater have not been examined.

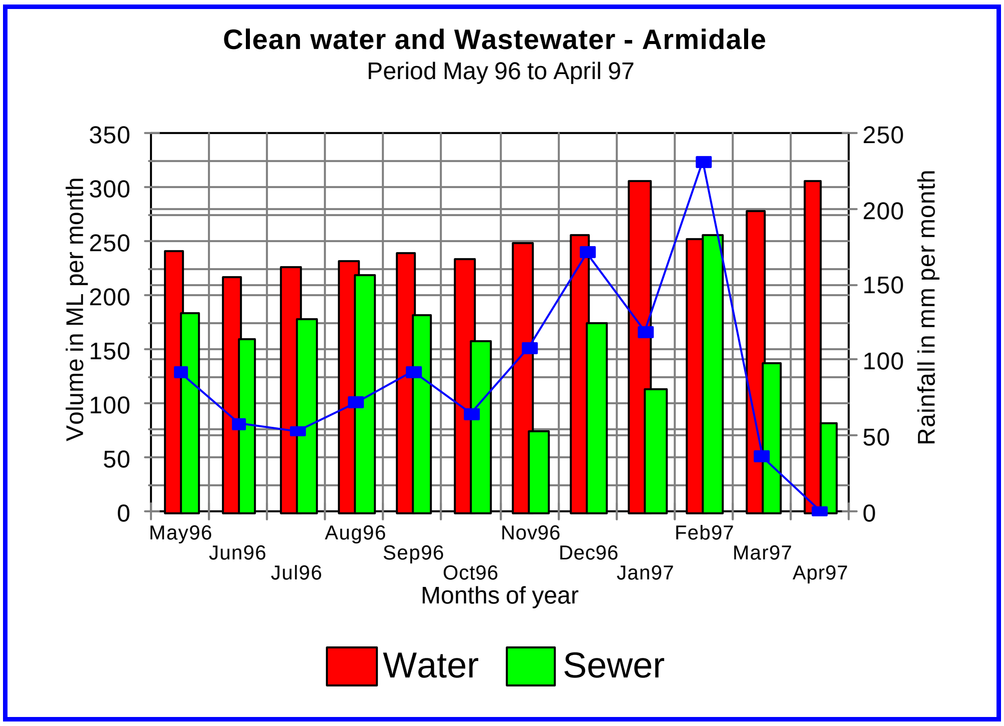


Figure 4.2 Clean and water production, wastewater generation and rainfall for Armidale for the year May 1996 to April 1997

4.4 Rainfall and Evaporation Data

Evaporation is recorded at the University's Laureldale farm, on the northern outskirts of Armidale. Data obtained by the author for previous projects is shown in Table 4.2. While the mean or median values are usually published for use in hydrologic planning, the 20th and 80th percentiles were also derived as those values indicate the more extreme statistics and would be used for any sensitivity analysis for planning purposes, but not for this project.

TABLE 4.2
Monthly evaporation data - Laureldale University Farm, Armidale NSW
Years 1970 - 1985 (16 years)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	177	146	140	99	62	51	56	68	105	140	162	195
Median	180	146	133	93	56	45	50	68	93	140	153	198
20th	121	120	109	78	43	36	47	56	84	118	138	155
80th	245	174	161	123	84	57	62	87	126	161	192	239

Source: Data Analysis by R.A. Patterson, data obtained from Laureldale (unpublished)

Rainfall data obtained from the "Armidale Express" newspaper and other sources have been used to show the rainfall over the previous 10 years compared with the mean annual rainfall (MAR) or long term averages LTA) as published by the Bureau of Meteorology (1988). While drought conditions such as the previous 8-10 years may not be repeated, such conditions will favour the disposal of effluent by land application.

TABLE 4.3
Rainfall for Armidale, comparing last 15 years data with long term data
(all values in millimetres)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean-15yr	120	85	45	56	46	35	57	42	45	62	66	96
Median-15yr	100	81	36	30	37	30	52	41	41	60	65	94
mean LTA	103	87	67	46	44	59	49	49	52	69	80	88
median LTA	90	73	54	40	34	49	44	42	49	62	75	76
No. wet days LTA	10	10	10	8	8	10	9	9	8	9	9	10

From the data above, the residual curve for the mean rainfall and evaporation are presented in Figure 4.3 indicating the periods when irrigation is suitable as a means of disposing of the water. The graph does not account for either a soil moisture or a groundwater recharge component. The summer differences do not address the opportunity to optimise production by accounting for soil moisture storage and loss by deep percolation.

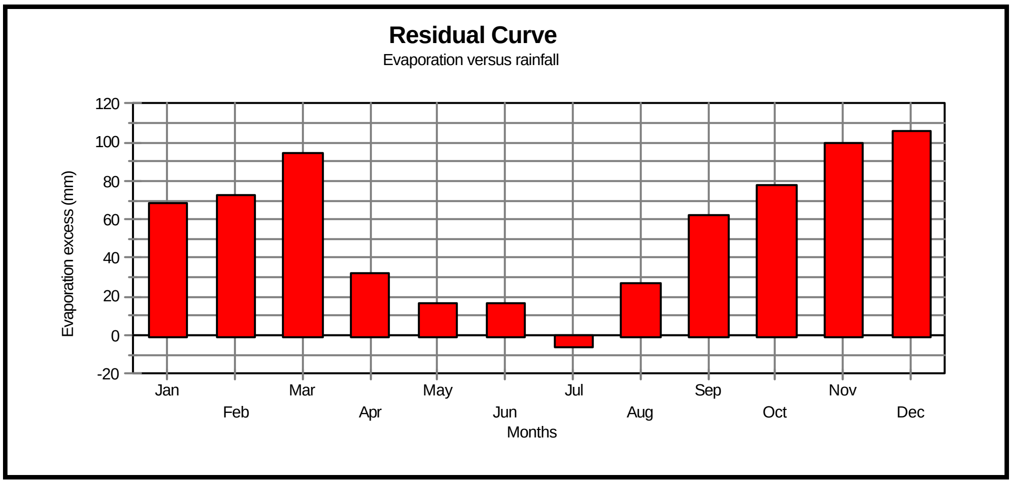


Figure 4.3 Residual curve of monthly rainfall and evaporation for Armidale

The MAR from 123 years of data is 793 mm while the annual evaporation rate from the Laureldale data is 1400 mm, resulting in excess evaporation of 607 mm per year. In irrigation terms, that equates to 6 ML ha^{-1}, which is consistent with the anecdotal value suggested by the local farmers as the requirement for irrigation. At the disposal rate of 10 ML per month, the current system could account for about 20 ha of irrigation per year.

4.5 Mapping

A theodolite survey was undertaken of the disposal area, using as reference points the 41 soil survey sites and the access road below the hill. The results of that survey are shown in Figure 4.4. The five transects radiate from the discharge main at the top of the hill, the elevations are given in metres below the outlet while the site label refers to the soil sample reference. The complete data set produced from the field survey, together with the spreadsheet calculations are reproduced as Appendix E.

The three contours have been drawn from field observations. Transects A and E were considered the extremities of surface flow from the discharge outlet. In particular sites A1 and D2 were above the contour bank and not subjected to the same conditions for overland flow as the other sites.

Armidale Sewage Treatment Works - Effluent disposal area

Survey of soil sampling points

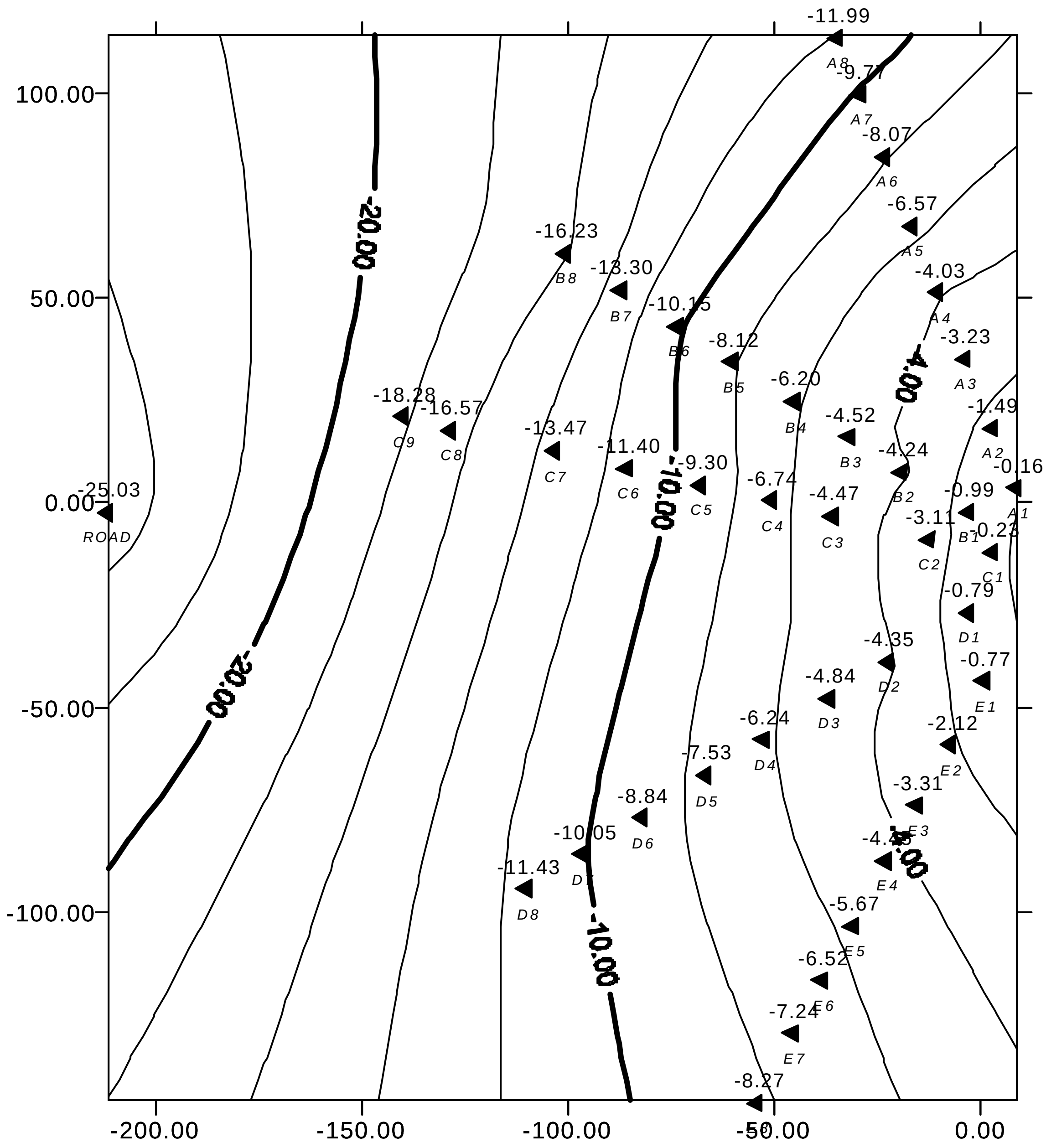


Figure 4.4 Contour map of the disposal area produced from theodolite survey

Traverse C was through a depression with C5 - C8 saturated at the time of sampling, although it was not possible to determine whether the excess moisture was a result of high rainfall of the previous fortnight or drainage from previous irrigation.

All the sample points have been considered in the calculations for changes to the soil chemical conditions. An alternative strategy would be to exclude those sites below the discharge outlet, however, the effect of capillary flow and the translocation of minerals by grazing animals must also be considered, although have not been quantified in this study.

4.6 Results of Soil Analysis

4.6.1 Data presentation

The 42 soil samples (41 in disposal area and one control) were analysed as detailed in Appendix A. The complete results are tabulated in Appendix F and soil data are ranked according to distance from the discharge as a percentage change relative to the control.

4.6.2 Soil depth

The surface soil above the -8 m contour (see Figure 4.4) was uniformly of a very shallow A horizon, generally less than 75 mm deep except that on the ends of the ridges, about A8, B8 and C9 the soils returned to very shallow A horizons. It is suggested that the shallow soils are remnant A2 horizons as they were hard setting, low in organic material and supporting scant vegetation. Below this contour, an A2 horizon began to appear above a red to yellow B horizon. In the drainage line about sites C4 to C8, the soil had an A1 of about 200 mm overlying a red (5YR 4/4) heavy clay B horizon. This region was wet with reeds (*Juncus spp*) being the dominant species.

4.6.3 Soil organic matter

Soil organic matter is quantified by Walkley & Black Method of organic carbon (OC) determination. The results, as displayed in Figure 4.5, indicate that the higher levels of OC are associated with the areas closer to the discharge, with a few exceptions as described above. A weak trend (r = 0.54) of distance to concentration is suggested. 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 outlet. At only two sites was OC lower than the control. There is a significant correlation between OC and TKN (r = 0.98).

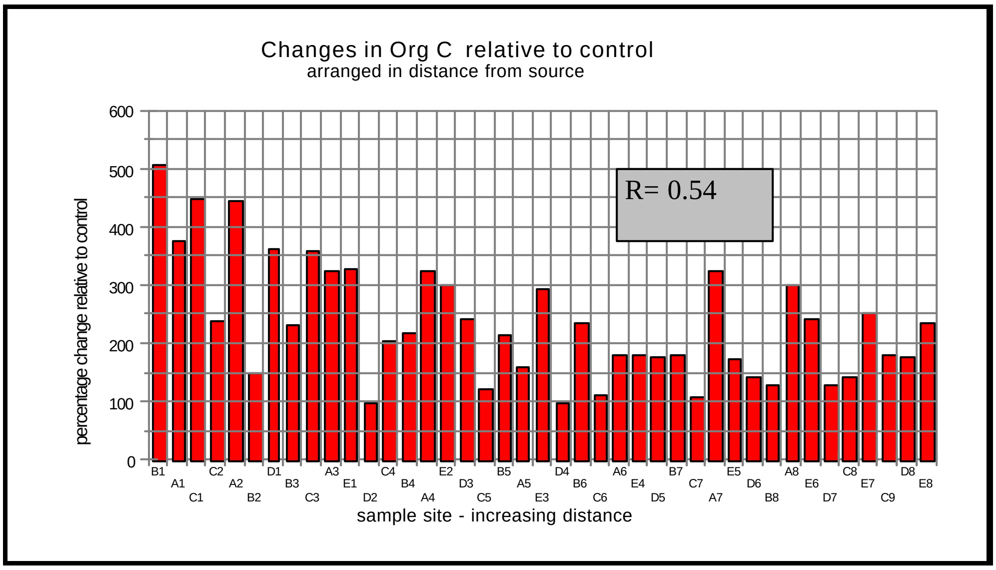


Figure 4.5 Soil OC levels ranked relative to distance from discharge at origin

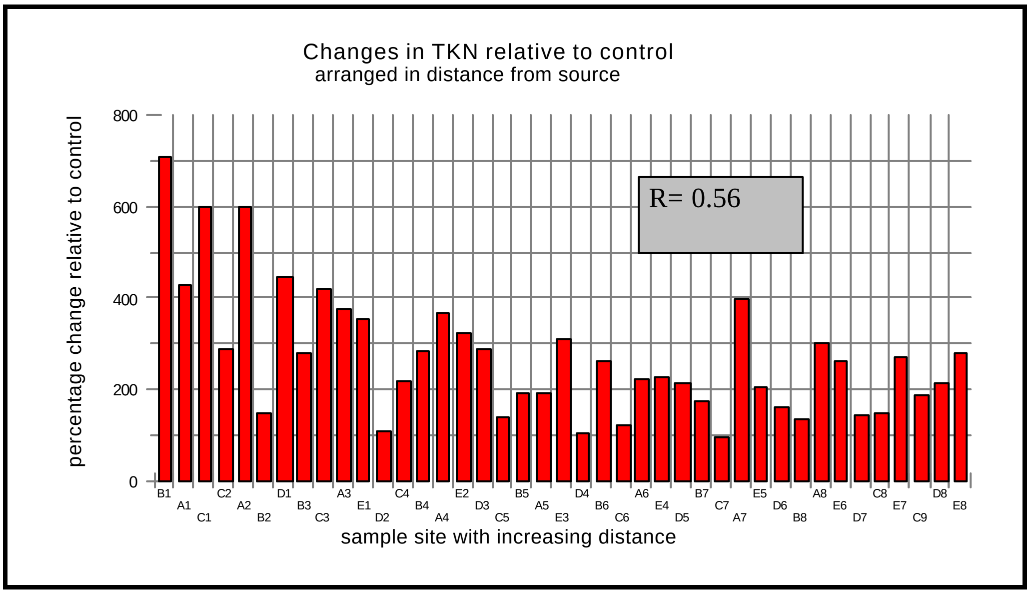
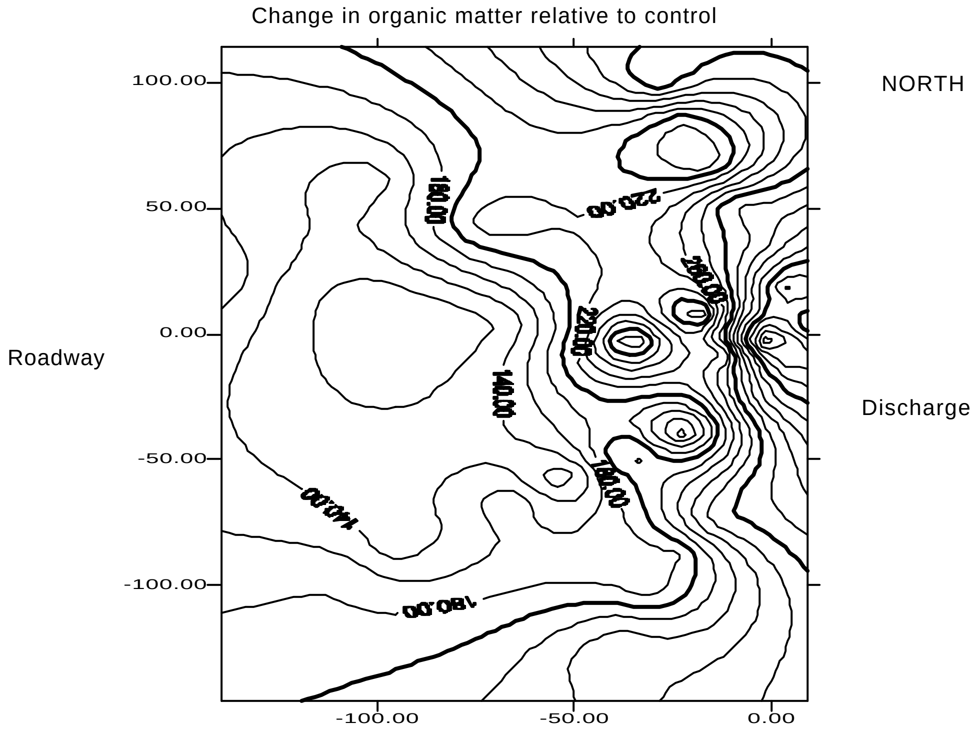


Figure 4.6 TKN distribution ranked in order of distance from discharge at origin

In a graphical presentation as contour maps and surface projections (Figure 4.7), the concentration of OC around the discharge outlet is more obvious, with the spreading occurring downslope and concentrating in the depression around traverse C.



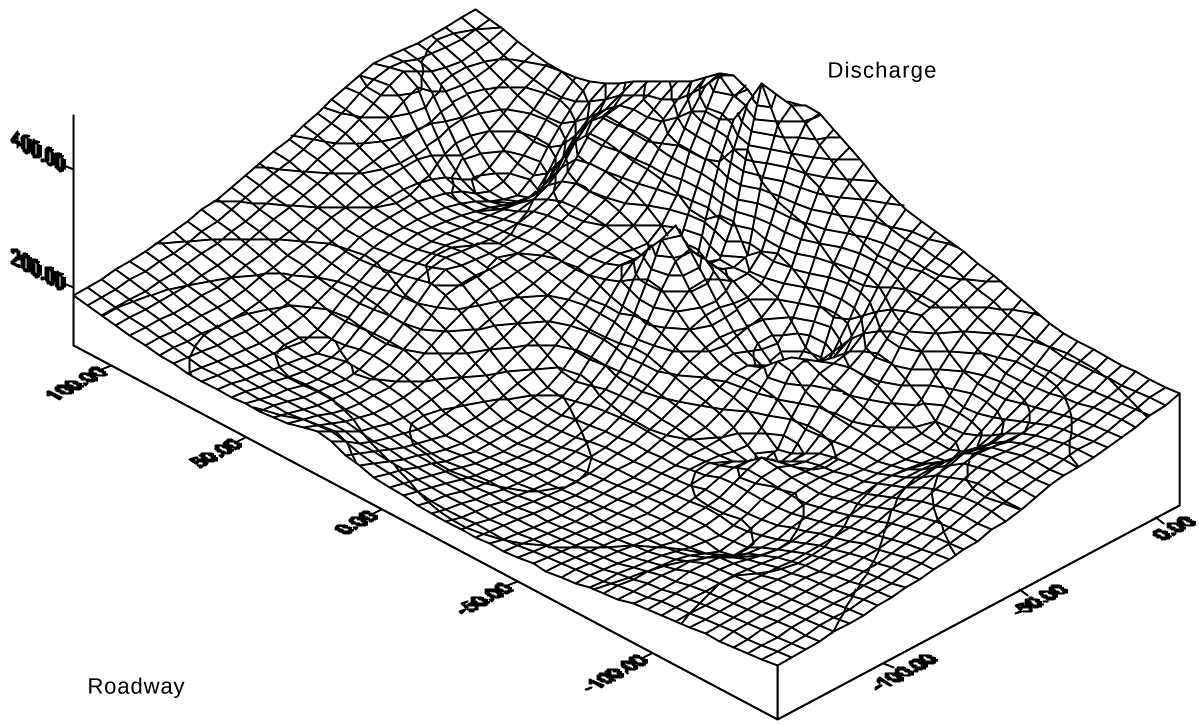


Figure 4.7 Surface plot and contour map of OC relative to discharge outlet

4.6.4 Soil total Kjeldahl nitrogen

The TKN values as indicated in Figure 4.6 show that nitrogen has moved away from the discharge outlet and is spreading down slope, with a weak trend (r=0.56). Level of 400-700% higher than the control occur around the discharge. Again the lower levels of C1, B2 and D2 deflect the runoff away from those sites. The mineral nitrogen correlates weakly with distance from the source (r = 0.55) as it is relatively mobile through the soil. There is a strong correlation (r = 0.98) between OC and TKN.

4.7 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 outlet levels of 328, 167, 172 mg kg^{-1} indicate extremely high levels of phosphate. While the graph in Figure 4.8 indicates the levels of phosphorus relative to increasing distance from the source, Figure 4.9 indicates the concentration of phosphorus around the single discharge outlet.

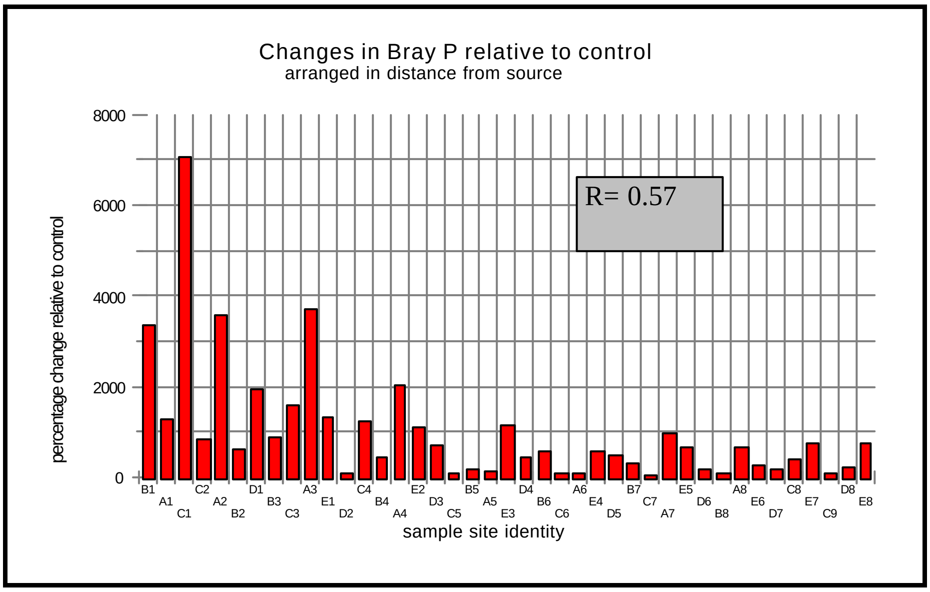
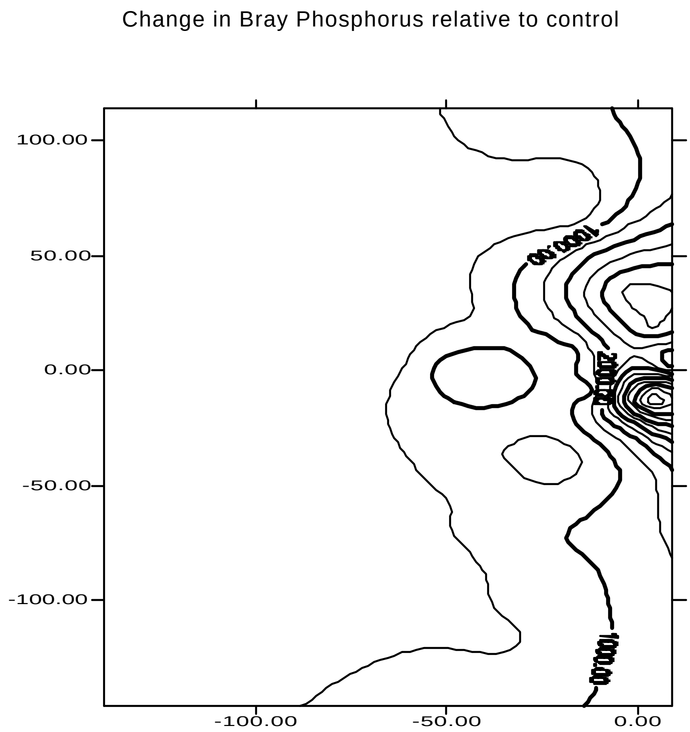


Figure 4.8 Concentration of Bray-P clustered around the discharge, levels ranked with increasing distance from discharge at origin.



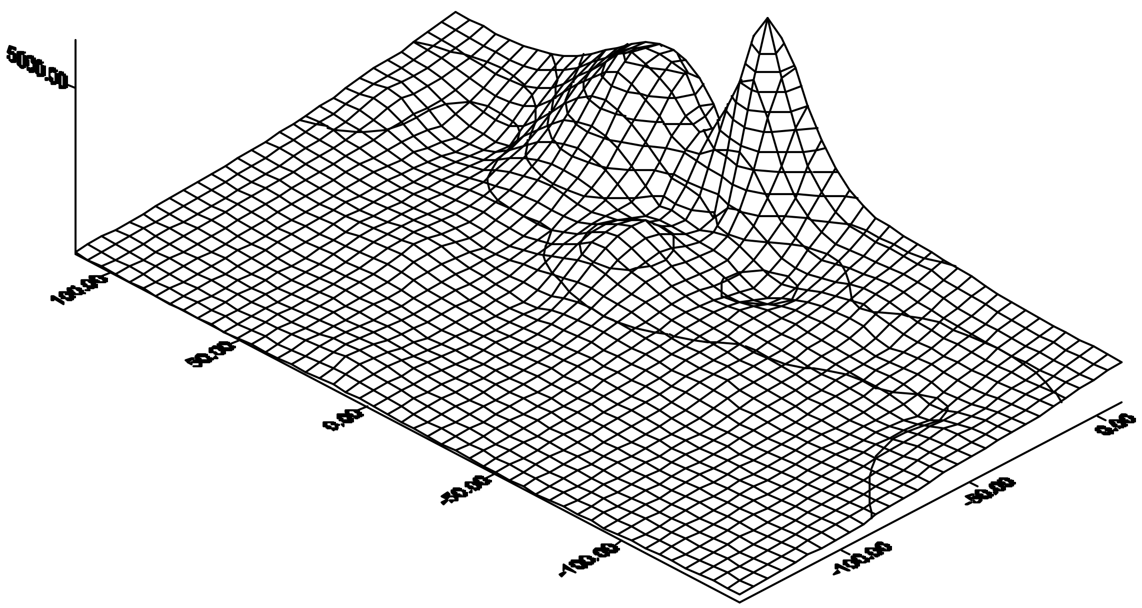


Figure 4.9 Contours and a surface plot of Bray-P indicating the concentration of phosphorus around the discharge.

4.8 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. As related in Chapter 2, 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 outlet with almost a negative 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 ESP.

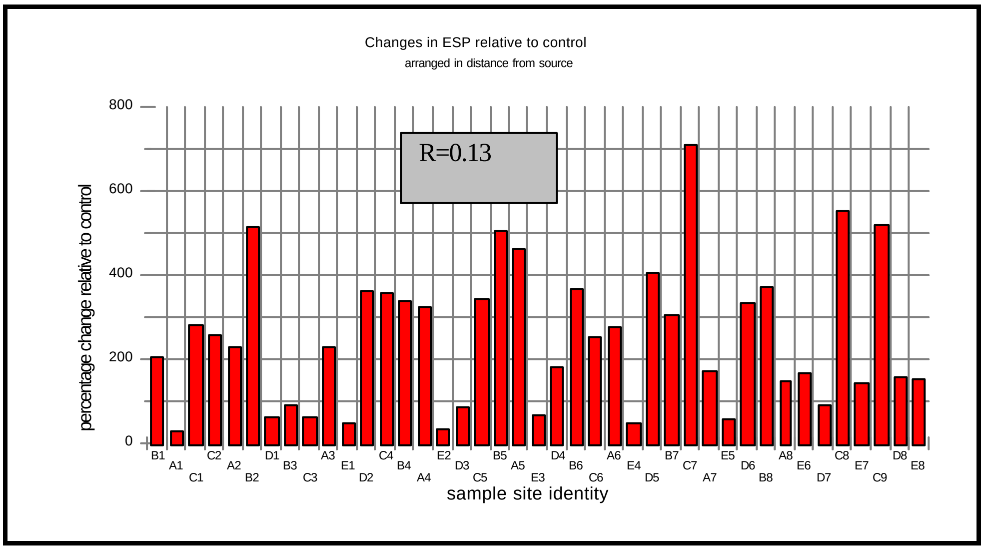
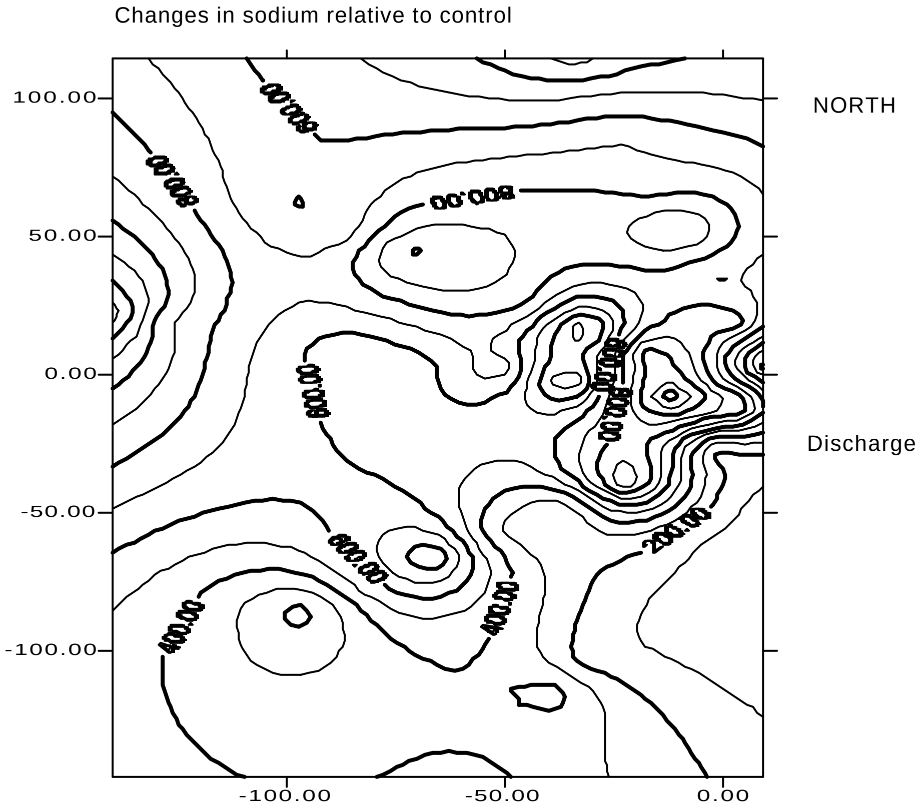


Figure 4.10 ESP at sample sites ranked in increasing distance from the discharge at origin.

Figure 4.10 indicates the changing levels with increasing distance from the discharge as soluble salts move away with drainage water and in runoff water following natural rainfall events. Figure 4.11 indicates the contour map and surface plot for sodium salts in the disposal area, clearly indicating the movement of salts away from the discharge outlet. Sodium is the more mobile of the four cations and the one giving rise to the greatest soil and plant problems. While the soils are not saline, all EC measurements were below 0.106 dS m^{-1}, the increases in ESP over the threshold of 5% are considered significant. It is obvious, that unlike the immobile Bray phosphorus (Figure 4.8), the sodium salts indicate their mobility as a bulge forms downhill from the discharge outlet.



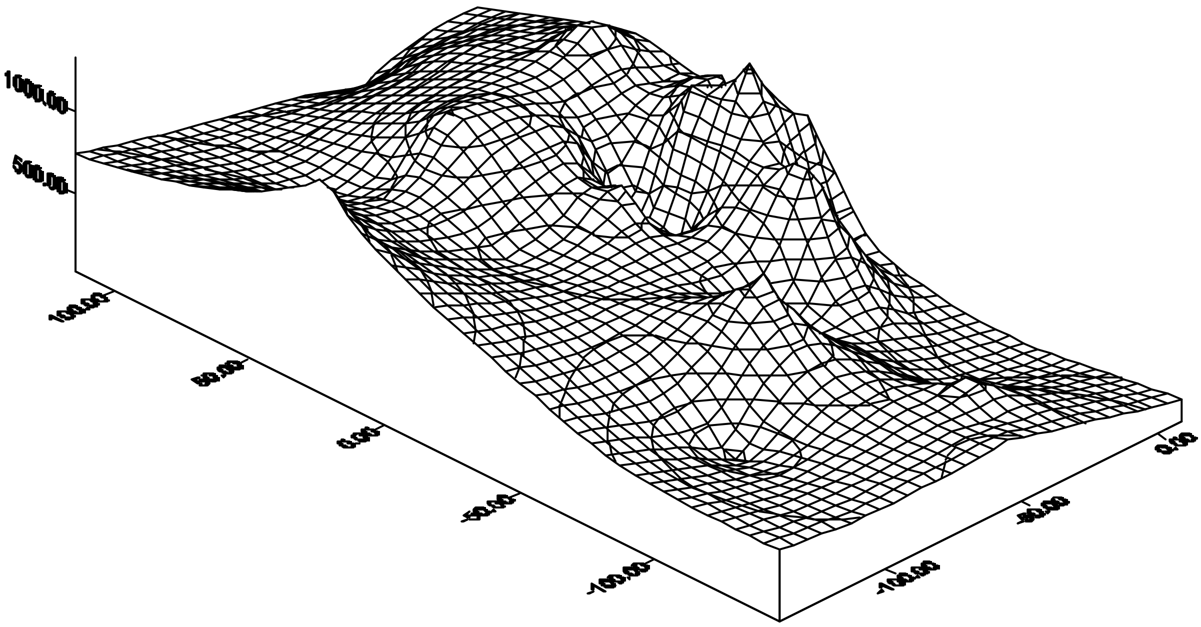


Figure 4.11. Contour and surface plots showing the movement of basic salts, measured as ESP, from the point of discharge into more distant areas.

4.9 Heavy metals in soil samples

Two heavy metals which are prominent in wastewater are copper and zinc, both from water reticulation services and other proprietary products used in the house. The relative increases in copper and zinc are shown in Figures 4.12 and 4.13 respectively.

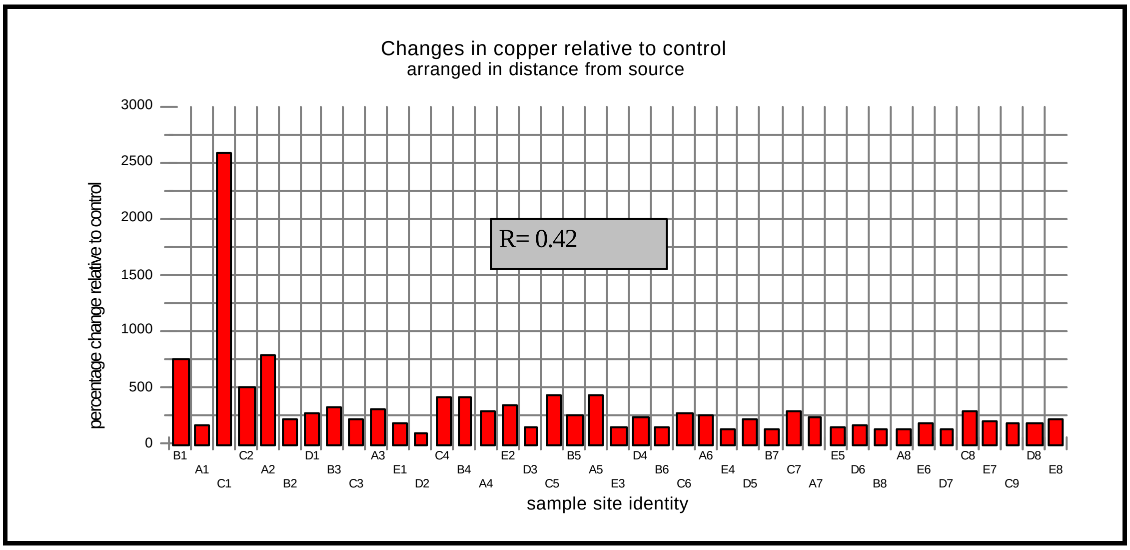


Figure 4.12 Percentage increases in copper relative to the control, ranked in increasing distance from the discharge taken as the origin.

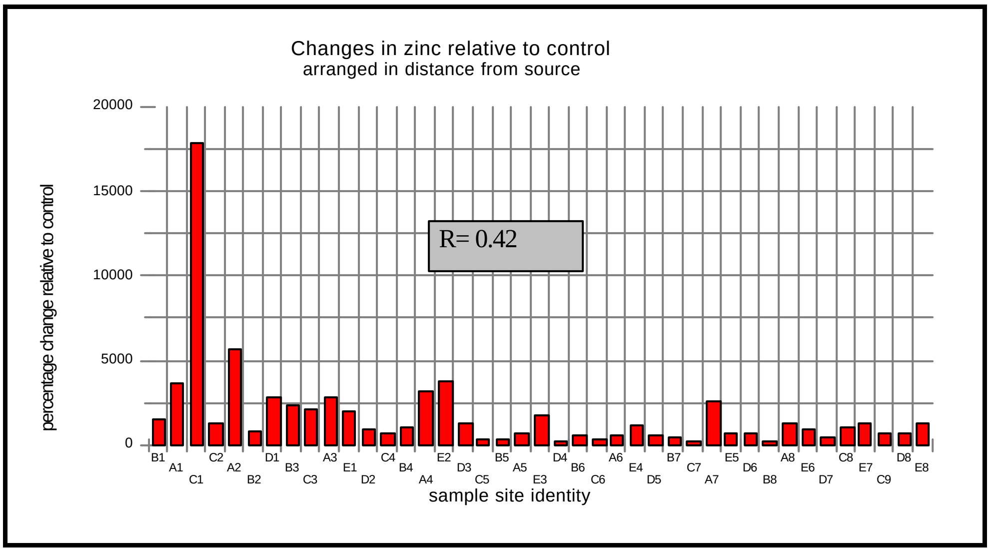


Figure 4.13 Percentage increases in zinc relative to the control, ranked in increasing distance from the discharge taken as the origin.

Increases of up to 17000% for zinc and almost 2600% for copper at site C1, in closest proximity to the discharge are extremely high. Only one sample (C1) returned a positive cadmium reading, less than 1 mg kg^{-1}.

4.10 Plant analysis

Three samples of plant material were taken from sites which represented high, medium and low quality and quantity cattle feed. The highest density vegetation with the highest proportion of important grasses and clovers were closest to the discharge outlet and where effluent ran over the surface without ponding. Ponding tended to increase the density of herbs, reeds and sedges, the less palatable material for stock. Table 4.4 indicates the more important chemical properties of the plants with respect to the ability to remove nutrients from the soil as well as indicating the relative proportions of those nutrients required for non-limiting growth.

The full listing of the plant analyses is given in Appendix G. Boron levels in the medium and high density crops are adequate while that in the low density is below threshold levels. The boron could be derived from the wastewater but was not tested in this project.

TABLE 4.4
Plant nutrient status with respect to removal ability and non-limiting growth
(percentages based upon dry weight)

	N %	P %	S %	K %	Na %	Ca %	Mg %
High density at C1	2.9	0.394	0.275	2.040	0.465	0.342	0.224
Medium density at B2	2.6	0.381	0.321	2.362	0.045	0.332	0.259
Low density below C9	1.1	0.112	0.106	1.343	0.370	0.194	0.145

The weight of high density plant material growing close to the discharge outlet was approximately 8200 kg ha^{-1} compared to the very low rate of 760 kg ha^{-1} . The desirable pasture growth is the high density vegetation which has the ability to remove approximately 32 kg P ha^{-1}, 237 kg N ha^{-1}

and 38 kg Na ha^{-1}. Under the low density removal rate, only 0.9 kg P ha^{-1}, 9 kg N ha^{-1} and 3 kg Na ha^{-1} could be removed. As most of the low density vegetation is poorly palatable, removal is unlikely.

These values calculated above can be used to determine the ideal disposal rate of effluent of a given quality to ensure that the soil is not overloaded with nutrients from the effluent.

4.11 Water Quality Analysis

4.11.1 Sampling and Reporting

A total of 18 water samples was taken, representing the sampling points as shown on Figure 4.1. The complete data for the samples are given in Appendix H. The important constituents for the disposal area are tabulated in Table 4.5 and show that the levels of phosphorus, nitrogen as the total of ammonium and nitrate components, and SAR. It is these constituents on which disposal area design is developed. The levels of total solids (TS) and total dissolved solids (TDS) are relatively small compared with the residues produced by the plants and animals on the disposal area. The TDS values have been calculated and do not accurately reflect the low salinity of the water, however, they are presented here because the regulators use the calculated value.

TABLE 4.5

Average water quality measurements for Armidale STW and Commissioner's Waters

(all quantities in mg L^{-1} unless stated)

Sample location	pH	TDS mg L^{-1}	TS mg L^{-1}	P mg L^{-1}	N mg L^{-1}	SAR
Pond 1	7.52	393	610	6.3	1.14	2.4
Outlet 4	7.93	383	440	6.7	0.82	2.5
Outlet at river	7.92	376	504	7.0	0.45	2.5
Upstream	7.95	216	438	nd	nd	0.9
Downstream	7.88	277	584	2.3	0.07	1.5

4.11.2 Phosphate levels in Effluent

The phosphate levels from Pond 1 to the outlet at the river show that phosphate level increases by 0.7 mg L^{-1} and when diluted by the non-detectable levels (<0.02 mg L^{-1}) of Commissioners Waters the river phosphate level decreased to 2.3 mg L^{-1}. At the outlet to pond 4, which is beyond the uptake for irrigation effluent the quantity of phosphorus is equivalent to 6.7 kg ML^{-1}, which equates to 61 kg single superphosphate per ML. At this rate, just over one bag of super, spreading 6 ML of effluent per hectare is similar to 7.3 bags of single superphosphate to the hectare.

The annual rate of 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.

4.11.3 Nitrogen levels

The nitrogen in the water is composed of ammonium, nitrite and nitrate components in the soluble form. Other forms are present as organic compounds but these have generally precipitated as or with particulate matter and for convenience have not been measured here. The nitrite rapidly oxidises to nitrate and has not been measured for this project. The ammonium level decreases with treatment as the ion oxidises to nitrate. The level of nitrogen decreases as treatment continues through denitrification processes. The combined nitrogen decreases throughout the process and at the outlet is less than the 10 mg L^{-1} recommended as the maximum in drinking water as discussed in Chapter 2.

4.11.4 Sodium adsorption ratio

There is 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 (refer to complete data set at Appendix H), thus no change in the SAR throughout. There is dilution of the sodium content of the water from upstream sources while the calcium and magnesium levels are similar in the natural system, which results in a decrease in SAR. At the downstream value of 1.5, the effects of the water on the dispersibility of the river banks is low.

At an irrigation rate of 10 ML per month from the discharge outlet on the disposal area, a total of 1750 kg of sodium chloride (NaCl) equivalent or common salt is discharged each month, giving a total of approximately 21 tonnes per annum. The disposal field cannot sustain high sodium values which are reflected in the movement of sodium in the surface soil (Figure 4.11).

Discharges from the treatment works into the river system, at a volume calculated from the values used in Figure 4.2 (1914 ML) less an irrigation use of 120 ML, amount to 323 tonnes NaCl equivalent releases into the environment from the Armidale wastewater system.

4.12 Summary

The determination of the chemical variability across the disposal area indicates that nutrients such as phosphorus and organic carbon does not move more than 50 metres from the discharge while nitrogen and salts are mobile and spread across the whole area. The area has acted as a sink for heavy metals such as copper and zinc although neither at significant levels. None of the levels of nutrient measured presents a toxic environment to either the plants or animals. Other than the leakage of salts towards the lower slopes there is no evidence that phosphorus, nitrogen (as nitrates) or heavy metals will be transported by surface flows out of the disposal area.

5 DISCUSSION

5.1 Project Outline

The objectives set for the project were met after considerable alteration of the sampling procedures. Because there were no historical data on the use of the site as an effluent re-use area, other than anecdotal evidence, it was unclear as to how to limit the investigation, other than by financial consideration. The shift from the proposed sampling at five pits down the landscape to sampling only surface soil at 42 locations provided a valuable reference to the movement of those nutrients known to be significant environmental indicators, namely phosphate, nitrate and sodium. From the findings discussed below, it is clear as to how nutrients move across the landscape in response to irrigation, runoff and natural processes and how several components are the key indicators of nutrient movement.

5.2 Management of Disposal Area

From anecdotal evidence of the previous lessee-operator of an irrigation system on the disposal area and with the information obtained from Council staff, the underlying strategy for the utilisation of the effluent has been from the hydrologic benefit. That water quantity was not monitored or controlled in any manner suggests that the water was seen as almost a “free good”. At stocking rates of 60 DSE on shallow fragile soils, without pasture improvement other than self seeding or seeds carried in with effluent or stock, a degradation of the landscape should have ensued. Such degradation has not been observed, rather the reverse is a more accurate description of an otherwise stony hillside.

A current proposal by the Council looks to enlarging the irrigation area to another part of the property with the installation of a spray irrigation system having commenced. That the hydrologic component of the irrigation is the easy planning aspect of effluent use cannot be denied. What has been missing from the current and past approach is combining the value of the nutrients in the water to maximise pasture production.

5.3 Water Monitoring

The Council does not keep records of the actual amount of water delivered to the disposal site, rather the pump, with a maximum capacity of 13 L s^{-1}, is operated when the weather appears to be favourable. The treatment plant manager stated that he believes the pump does not meet its capacity over its full operation cycle. The current operators manage the water by understanding the disposal area and observing the “wet areas”, restricting disposal when the weather is inclement. The operation is not designed for more than this basic operation and no site monitoring.

Measurements for soil hydraulic conductivity on this disposal area were aborted after the detailed nature of the soil profile was observed. The extremely shallow soils and the gravelly subsurface would have presented alternative flow paths to the percolating water rather than because of the properties of the soil. The contour banks provide an opportunity for water to be ponded temporarily, to increase infiltration into the soils of the lower slopes rather than runoff as overland flow. The concentration of phosphorus and organic matter have been maintained around the discharge point as a result of these contours.

The soil textural analysis of the thin A1 indicates that the sandy loam, well endowed with a dense root mass would have a high infiltration rate. The A2 horizon above a red-yellow clay indicates that lateral flow of water and periodic ponding in the A2 is likely.

5.4 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 point and while deficiency levels exist less than 50 metres from downslope from the excessive levels. That soluble nutrients are moving across the landscape is not uncommon, as is reflected by the movement of sodium.

5.4.1 Soil phosphorus

Plant available phosphorus as measured by Bray-P, indicates that there is almost no movement of phosphorus away from the disposal area. Figure 4.8 is unambiguous in showing that very high levels of phosphorus occur close to the discharge point and are further restricted in movement by the first contour bank. It is suggested that because the paddock is heavily vegetated, and because of the effluent the landscape is always vegetated, the loss of soil mineral particles by erosion would be an extremely slow process. The three contour banks would prevent movement of soil down the landscape, thus minimising the loss of phosphorus sorbed onto soil particles. There is evidence to show that soil phosphorus has accumulated in the contours as Site B1 (on the first contour) has 155 mg P kg^{-1} compared to B2 (30 mg P kg^{-1}) which is not affected directly by ponded effluent.

The high levels of organic material, plant residues, growing vegetation, dried senescent plants still standing and dense root mats are sinks for phosphorus as indicated by the TP measurements. The TP values mimic the soluble Bray-P values ($r = 0.97$) in that they cling to the area around the discharge point although weaker correlation exists between the TP values and organic carbon (OC) ($r = 0.77$). The cattle grazing the pastures, preferentially where the lush grasses are produced close to the outlet, will provide some movement of phosphorus from that area to other parts of the paddock. That the remainder of the disposal area is at deficiency levels in available phosphorus indicates that movement by either water or animals is not an effective process for relocating phosphorus.

It was not possible to determine the mass of soil phosphorus available as a reserve for future years, however, because soils with 30 mg P kg^{-1} as Bray-P are considered unlikely to show a plant response to added phosphorus, levels of 100 to 150 mg P kg^{-1} are likely to provide reserves for many years. The strategy for future use of this site should be to move the discharge away from its current location, develop contour banks to spill water further down the landscape and improve the soil's nutrient status by spreading the phosphorus to the deficient areas. Some allowance would have to be made to maintain water around the present discharge site to maximise the use of the stored phosphorus.

5.4.2 Soil nitrogen

The movement of nitrogen from the disposal area is expected as nitrate does not bond readily to soil particles, in most forms is highly soluble and will move with soil water. Measured as total Kjeldahl nitrogen (organic nitrogen and ammonia), and graphed in Figure 4.6, the levels of TKN relative to the control show a weak trend with distance from the source ($r = 0.56$). The high levels of organic material provide a valuable sink for nitrogen products as well as a buffer against their removal from the environment.

There has been considerable movement of nitrate, which could not be expected on a similar site without irrigation with effluent, from the higher to the lower elevations. Some organic nitrogen will be relocated as animal manures and urine, thus increasing the distribution of nitrogen products across the disposal area. Levels of soil nitrate are mostly above 15 mg N-NO_3 kg^{-1} and are unlikely to be limiting to plant growth. There is a weak correlation ($r = 0.55$) between nitrate and distance from discharge, thus indicating the likely translocation of mineral nitrate as water (effluent and rain) moves through and over the surface.

As no soil below the A1 was analysed because of the gravelly nature of the hillside, it is not possible to determine the movement plane for the nitrogen products. It is expected that nitrates, as highly soluble products, have the potential to move with the moving soil water, either gravitational water following rainfall or irrigation, or as capillary water. It could be expected that in this disposal area, as in other disposal areas, a nitrate bulge would occur in the lower horizons. In this case the lower horizons are degraded sedimentary rocks and the fate of the nitrate has not been determined. Some protection against the nitrates moving off site and into the creek system should be encouraged.

High ammonium levels adjacent to the discharge point indicate that complete oxidation of this nitrogen product has not occurred. Ammonium ions are highly assimilable by plants and as a cation can be bonded to soil colloids and organic fractions to reduce the removal rate from the soil. The oxidation product of ammonium ions is nitrite and nitrate, both free to move with soil moisture as discussed above. As animals had not grazed the pasture for over four months, it is unlikely that high ammonium or nitrate levels are related to urine or dung.

5.4.3 Organic carbon

The two major sources of OC on the disposal area are from total solids and soluble organic products from the effluent and the breakdown of plant and microbial products in the dynamic soil environment. It is expected that due to the high nutrient status of the soil and the continuing favourable soil moisture conditions that microbial activity is high, although no testing was undertaken. The dark colour of the A1 horizon signifies the rich organic content of this mineral horizon.

The OC content across the disposal area has been detailed in Figure 4.5. It is clear that OC is mobile from the discharge point and at all sampling sites there has been an increase in OC relative to the control as displayed in Figure 4.4. A valid reason for the weak 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. Other soil fauna also provide a key to maintaining high OC levels in both translocating and burying plant residues, while active growth of plant material fixes atmospheric carbon dioxide into organic 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 is to be expected. However it makes the future monitoring of movement of nutrients more simple, since the Walkley and Black organic carbon method is more simple than the TKN procedure. There is a weak trend between mineral N-NO_3 and OC ($r = 0.61$) therefore, the monitoring of either nitrate or OC will not accurately predict the other.

The increase in cation exchange capacity (CEC) as detailed in Appendix F shows that around the discharge point there is a tendency for the CEC to increase. This occurs because the organic fraction acts to increase the CEC potential. Increases of 300-400% above the control are common across the disposal area. The increase in CEC is a benefit to the landscape in restricting the movement of cations and providing a sink of available nutrients.

5.4.4 Other nutrients

Essential plant nutrients are available from the effluent other than those discussed above. Carbonate (as bicarbonate) provides a buffer to the water and the soil water, limiting environmental changes brought about by acidic or alkaline waters. The high pH of the effluent (7.5 - 7.9) has limited the alteration of soil pH to less than one pH unit while the soil is around a favourable 5.5 to 6.2 measured in 0.01M $CaCl_2$ (refer appendix F). Within this pH range there is unlikely to be major problems with nutrients forming insoluble complexes or the toxic effects of aluminium.

The chloride level in the soil does not equate with the sodium, although there is a relationship in the water. The levels of chloride are unlikely to cause vegetation 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. There is unlikely to be a salinity problem with the soils, however, EC does not address sodicity which is detailed in section 5.4.6.

Other nutrients required by the plant and known to occur in domestic effluent include boron, aluminium and sulphur, which, because of various reasons have not been measured in this study. While boron can be toxic to plants its determination was outside the budget for the project. Aluminium is only a problem in acid soil, below pH 4.5 which did not occur at this site. The sulphate determination has presented a number of problems to the laboratory over the last two months and was not able to be completed for this project. It would be expected that the sulphate levels in the soil would not be limiting, taking account of the plant growth. Sulphate, like nitrate, is easy to detect in observations of growing plants. Neither sulphate nor nitrate deficiency was seen in high or medium density plants and the low density plants lacked vigour for many reasons.

5.4.5 Heavy metals

The metals cadmium, copper and zinc can cause severe environmental consequences at high levels, while copper and zinc impinge upon plant health at very low levels. The only registration of cadmium was adjacent to the discharge with a value of less than 1 mg kg^{-1}.

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 point has a level exceeding the threshold (55 mg kg^{-1}), all other sites were above deficiency levels but below toxic levels. Copper is derived from the dissolution of copper pipes used in plumbing as well as from dietary sources. Minute amounts in the effluent have accumulated over the years, however, movement of copper away from the source is not of concern in this re-use project.

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 point and the other closely associated with the discharge. There was an increase over the whole site of both copper and zinc concentrations relative to the control. In the case of zinc, there may be a benefit in that all the sites were above deficiency levels. Zinc, as an important chemical in the elongation of internodal tissue, its addition to deficient soils is essential while its uptake in plants ensures a better animal health. Zinc in the water is derived from galvanised fittings and pipes, household products and commercial wastewater streams.

5.4.6 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 sites 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}) causes the ESP to increase as the sodium is easily removed from the effluent by the soil colloids. With excess rainfall, sodium salts are removed from the cation exchange sites and move with the drainage water. Thus, as shown in Figure 4.10, sodium has moved away from the discharge point and accumulated as a number nodes of high concentration. Sodium is moving through the line of least resistance that is directly from the discharge point towards the roadway - due west, forming a bulge towards the end of the C1-C9 traverse. The highest ESP occurs at C7 which was saturated at the time of the survey and reeds indicated the prolonged nature of a saturated (or high water content) regime.

The high sodium concentrations occurred close to the discharge points, A2-A4, B1-B2, C1-C2 and D2 however, these sites also received added calcium and magnesium from the wastewater as detailed in Appendix F with the resulting lowering of ESP. The potential for the effects of sodium to impinge negatively on the soil can be offset with the addition of calcium salts onto the landscape. In this case, gypsum would be distributed as it provides calcium without altering the pH.

5.5 Water Quality

5.5.1 Value of nutrients

There is little difference in the quality of the water across the treatment ponds other than for the loss of nitrate with increasing detention. As nitrate is a plant macro-nutrient and a product which can be equated to a fertiliser having a commercial value, the use of water from Detention Pond No. 1 would create a greater nutrient increase on the disposal area. A benefit may also occur because of the increased solids load, which at this point would be organic products, adding to the cation exchange capacity in the soil. However, the nitrate value of the effluent fails to replace the uptake by plants.

For each megalitre of water extracted only 1.14 kg N ML^{-1} is removed. The high density plants removed 2.9% N which equates to about 237 kg N ha^{-1}. At an application rate of 6 ML ha^{-1}, replacement of only 7 kg N occurs. This induces a deficiency status because neither water nor phosphorus is limiting at the same time. Thus, from the value of nitrate, it is irrelevant as to which pond provides the effluent.

The phosphate content (measured as orthophosphate) of the effluent through the pond system increases slightly towards the terminal pond. The increase in ortho-P levels is insignificant and no economic benefit would be gained by moving the current intake. Nor would there be a benefit in choosing a water quality suitable for flushing the irrigation area as quality is uniform across the system.

5.5.2 Hazardous substances

No investigation was undertaken of the potentially hazardous substances which may come through a public wastewater system. The levels of copper, zinc and other metals in the effluent were not determined because of the extremely low levels expected in the wastewater.

5.5.3 Differences between upstream and downstream water chemistry

The effluent released to Commissioners Waters has a higher nutrient loading than the receiving waters as shown in Table 4.5. That there may be downstream consequences of the increase in phosphate and nitrogen levels was not explored. It is known that about six major irrigators downstream have come to depend upon the flows in the river elevated by Armidale's wastewater production.

5.6 Plant Nutrient Status

Although samples of plants from three distinct densities were analysed, there was no definitive measurement of the quantity of pasture produced over a given time period. The quantities calculated for Section 4.10 were obtained from a single cut, representing the period between when the cattle were moved out of the paddock and the time of sampling, approximately 4 months. The pasture varied considerably from site to site in both density and composition. As there had been no pasture improvement over the last 10 years the dominant species are likely the result of either less palatable plants or more resistant species. The reeds (*Juncus spp*) are the product of a saturated soil environment while the low density plants are likely those denied adequate moisture and nutrients. The low density plants occur outside the sphere of influence of the irrigation, along the high points which drain rapidly following rain and in areas where the A1 horizon is less than 50 mm.

5.7 Effluent Disposal Strategy

That the disposal area has a higher pasture production rate than the non-irrigated around surrounding it cannot be denied, even from visual examination. However, the re-use scheme has suffered from under-utilisation of the quality of the water and poor distribution of the surface flow through inadequate contouring.

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.

An opportunity exists for Council to continue use of this disposal area and to profit from the examination of the soil and water interactions on any future irrigation area to understand the need to distribute the effluent more uniformly across the disposal area.

5.8 Environmental Indicators

The nutrients available in the effluent and the capacity of the soil to adsorb them and the plants to assimilate them takes place when climate and soil water conditions are favourable. While effluent may provide a hydrologic advantage in dry periods, the nutrient status should be considered in the development of a re-use management plan. The indicators of valuable and detrimental components of wastewater need to be monitored. In the same way, the pool of nutrients in the soil needs to be addressed, particularly with respect to those nutrient which may be either toxic to plants or at levels sufficiently low to cause deficiencies. The potential for nutrients to move off -site must be considered and action taken to avoid loss of valuable nutrients.

While a check list of soil, water and plant analyses can be drafted which will indicate all these requirements for monitoring the re-use area, the matter of economical monitoring arises. Thus, an outcome of the measurements made in this project suggest that several nutrients are keys to how they and other nutrients react in a similar soil and topography in Armidale. In view of the above discussion of correlation between measurements of TP and Bray-P, for example, it is suggested that measuring only one of those components at regular intervals will also 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. Through careful determination of the key environmental indicators a more regular monitoring system will permit fine tuning the re-use scheme to firstly maximise pasture production and secondly reduce the potential for off-site pollution.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Project Outcome

The soil survey and analytical work for the disposal area suggest that in the current re-use operation there is an under-utilisation of the nutrient benefits of the effluent. The re-use scheme has been operated as a means of providing water to pasture to maximise production and carried out on lands which have been used for that purpose since the 1960s. Only minor alteration to the landscape has been undertaken to maximise the spreading of the effluent or capture runoff. Both effluent and rain can be captured in the three contour banks to infiltrate and percolate downslope through the soil.

It is unclear as to what proportion of effluent enters the fractured gravels underneath and percolates to groundwater or finds a preferential flow path to a downslope exit point. Along transect C1-C9 there was a progressive increase in soil water to the point of saturation. At the time of sampling it was not possible to determine whether the excess soil water resulted from effluent disposal or rain. Due to the very wet February (, it is probable that rainfall caused the saturation, however, the reeds indicate that it is more usual for the soils to have excess moisture. The elevated levels of sodium in these lower slopes indicates that salts are moving through the system with the drainage water.

6.2 Recommendations

6.2.1 Irrigation area monitoring

While no monitoring has occurred on the disposal area over the previous years, there is a need to maximise the nutrients available for plant growth and limit the potential for environmental hazards. The accumulation of phosphorus around the discharge outlet needs to be addressed with a view to spreading the effluent further afield and improve plant nutrition away from the outlet. It is important, therefore, to monitor soil phosphorus. As it was shown that the Bray-P and the TP values are well correlated, the more simple Bray-P test is recommended as a means of understanding the extent of the soil phosphorus pool.

As the nitrate nitrogen and TKN levels are very low in both the effluent and the soil, it is recommended that only the measurement of nitrates occur in the soil and tail water. It is unlikely that the nitrogen levels in the effluent will suffer significant increases over time. However, a greater understanding of the vertical and horizontal movement of water on this, or any other irrigation site, is a prerequisite to thorough planning.

ESP has the potential for a significant impact upon the landscape because of its potential to impinge upon soil structural and plant nutrient qualities. That rain will move the soluble bases (sodium, calcium, potassium and magnesium) with drainage water is not disputed, however as the sodium salts are translocated with drainage water while calcium and magnesium ions remain absorbed by plants, monitoring of the ESP is essential.

The monitoring model is one which provides a view of changes in the soil nutrient status. It is recommended that a grid of at least 10 sites be set up on the disposal area and monitored every six months at the minimum. There is no evidence to show that an environmental hazard is brewing on the site after more than 30 years of operation. Therefore a six monthly survey will permit the fine tuning of nutrient maximisation to be developed. At the same time, the effluent quality should be monitored.

6.3 Environmental Indicators

The environmental indicators, as shown in Table 6.1, are suggested as the model for annual soil and water modelling. 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 monitoring schedule to commence. Animal health will also indicate potential problems with either deficiencies or toxic properties of plants.

The program would be ideally carried out in winter after the effects of maximum growth and highest rainfall have occurred. At this time the plants will have removed the maximum amount possible and soluble salts will have had the greatest opportunity to move under wet conditions. For reasons presented in Chapter 3, qualities such as BOD_5, faecal coliforms and total solids are not considered relevant to sewage effluent disposal onto soils.

TABLE 6.1
Environmental indicators for Armidale re-use scheme

Indicator	Effluent	Soil
pH	pH	pH in 0.01M $CaCl_2$
buffer capacity	alkalinity	no
salinity	electrical conductivity	electrical conductivity
sodicity	sodium adsorption ratio	exchangeable sodium percentage
phosphorus	orthophosphate	Bray-P
nitrogen	nitrate nitrogen	mineral nitrogen
organic matter	no	organic carbon

6.3.1 Landscape engineering

The distribution of effluent is not uniform across the landscape, due in part to the previous use of the hillside as a gravel quarry. Drainage is typically into the natural drainage lines at the detriment of the ridges and spurs. A series of small contours, less than 150 mm in depth can be utilised to re-distribute the effluent away from the natural drainage lines. These small contours could be developed using a ripper, running at less than one degree off the contour away from the drainage lines, a design similar to Yeoman's Keyline.

A terminal pond below the disposal area is essential to capture and re-apply runoff from the site. Account will have to be made of the salt content of any re-application.

6.3.2 Nutrient imbalance

The significant quantity of phosphorus relative to the small amount of nitrogen creates an imbalance in the plant nutrient availability. While correcting such an imbalance is important to pasture production, the Council may not consider the additional use of fertiliser an economic proposition, particularly considering the poor soil and the disjointed nature of the paddock.

However, the use of gypsum to ameliorate the potential hazardous effects of the annual application of 21.6 tonnes of sodium must be considered essential.

6.3.3 Management considerations

The strategy that the re-use area has been used as a means of grazing cattle on pasture irrigated with a relative “free-good” must be enlarged to consider the maximisation of that operation by spreading the nutrients more evenly across the landscape. In any extension of the operation, planning and management must consider that the effluent is a valuable resource of “free phosphorus” and other plant nutrients. Whereas the present operation has locked phosphorus into a very small area, future operations need to address the benefits of integrating hydrological and chemical considerations.

6.4 Further Investigation

The study did not examine the potential for nutrients to move vertically through the shallow profile, into and through the gravels underneath. An opportunity exists to expand upon the current study by making excavations into the landscape and analysing the weathered mineral for patterns of either binding or rejecting nutrients. Of particular interest should be the movement and adsorption of phosphorus, nitrate and sodium.

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Water Analysis :

Parameter	Method	
total solids (TS)	2540 B	gravimetric
volatile solids	2450 E	gravimetric
suspended solids (TSS)	2540 D	gravimetric
pH	4500 - H^+ B	potentiometric
EC	2510 - B	potentiometric
salinity (TDS)	2320 A	calculation
alkalinity	2320 - B	titration
anions		
carbonate	2320 - B	titration to 8.3
bicarbonate	2320 - B	titration to 4.5
sulphate	J1(a)	modified $BaCl_2$/Tween
chloride	4500 - Cl^- D	Ion specific electrode
Nitrogen-NH_4^+	G1a	distillation/titration
Nitrogen-NO_3	G1a	distillation/titration
Nitrogen TKN	G1a	digest/steam distillation
phosphorus- total	H1a	digestion/colorimetric
phosphorus-ortho-	H2a	colorimetric
cations		
Na, Ca,Mg,K	3500	flame AAS
Fe,Zn,Mn,Cu	3500	flame AAS
hardness	2340 B	calculation
SAR	M1a	calculation

Four digit prefix: APHA (1995) *Standard Methods For the Examination of Water and Wastewater. 19th Edition*. American Public Health Association.

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(Methods as at 20 Dec 96)

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Soil Analysis :

	Method	
moisture content	2A1	gravimetric (air-dry)
Dry Matter	2A1	calculation
pH 1:5 water	4A1	potentiometric
pH 1:5 $CaCl_2$	4B1	potentiometric
EC 1:5 water	3A1	
anions		
chloride(1:5 water)		ISE
carbonate	19A1	titrometric
sulphate	10B3#	MCP/ turbidimetric
organic carbon	6A1	Walkley & Black
Nitrogen-NH_4^+	7C1	distillation/titration
Nitrogen-NO_3	7c1	distillation/titration
Nitrogen TKN	7A1	digest/steam distillation
phosphorus- total	H1a#	digestion/colorimetric
phosphorus-ortho		
Bray	9E1	fluoride extr./colorimetric
cation		
Na, Ca,Mg,K	15D3	Amm.acetate/flame AAS
Fe,Zn,Mn,Cu	12A1	DTPA extraction/flame AAS
CEC		calculation
ESP	15N1	calculation

modification to test method

Reference methods:

Four digit prefix: APHA (1995) *Standard Methods For the Examination of Water and Wastewater. 19th Edition*. American Public Health Association.

Alphanumeric: Rayment, G.E. and Higginson, F.R. (1992) *Australian Laboratory Handbook of Soil and Water Chemical Methods.* Inkata Press. Melbourne.

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Feed, vegetative matter

Physical parameters	Method	
Moisture content	2A1	gravimetric
Dry Matter	2A1	gravimetric
Ash		ignition/gravimetric
Volatile solids		ignition/gravimetric
Chemical Parameters		
Nitrogen-TKN		acid/peroxide, colorimetric
Chloride		digestion / ISE
Phosphorus - total		digestion / ICP
Sulphur - total		digestion / ICP
Cations		
Na, Ca, Mg, K	3500	digestion / ICP
Fe,Zn,Mn,Cu		digestion / ICP

Reference methods:

Four digit methods: APHA (1995) *Standard Methods For the Examination of Water and Wastewater. 19th Edition*. American Public Health Association.

Alphanumeric: Rayment, G.E. and Higginson, F.R. (1992) *Australian Laboratory Handbook of Soil and Water Chemical Methods.* Inkata Press. Melbourne.

A reference for plant analysis is currently being prepared by the Australian Soil and Plant Analysis Council and will be used as the reference when published.

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Council Soil and Water Resource Consultants

Equipment used in Analysis

IL 951 Atomic Absorption Spectrophotometer

Philips UV-VIS spectrophotometer

Hach 2100A Turbidimeter

Labec 300 L refrigerated incubator

BTL Bench centrifuge

Sunvic - 6 position heating mantle, 1500 W

Orbital tumbler

Qualtex 50-200 degree oven, 150 L

Gallenkamp muffle furnace

Duralab sieve shaker

“Novaglass” steam distillation equipment

Hanna pH meter, ATC probe

Activon conductivity meter, ATC probe

Assorted glass ware

1	2	3	4	5	6	7	8	9	10	11	12	13	14.00	15.00	
Instr. Stn	**Staff**	**Horizontal**	**Vertical**	**tadia Reading**		S = Col5-Col6	**Stadia**	**Horizontal**	**Vertical**	**+/- V minus**	**Ht of Inst**	**R.L. at**	**CALCULATED**	**CALCULATED**	
and	**Station**	**Angle**	**Angle**	**upper**	**lower**	**D = 100 S**	**Mid**	**distance**	**distance**	**Midreading**	**(R.L.)**	**staff**	**X COORDINATE**	**Y COORDINATE**	
Height of		**(degrees)**	**0.0000**				**reading**	**100S.[Cos0]^2**	**100S.Sin20/2**				**X=D.SIN(h.o.)**	**Y=D.Cos(h.o.)**	
Instr. axis						**(m)**		**(m)**	**(m)**	**(m)**			**col 9*@SIN(col 3**	**col 9 *@cos(col**	
1.47	A1	65.6300	86.5167	1.520	1.420	10.000	1.470	9.963	0.606	-0.864	0.7	-0.16	9.08	4.11	A1
	A2	9.6306	92.1783	1.565	1.375	19.000	1.470	18.973	-0.722	-2.192		-1.49	3.17	18.71	A2
	A3	354.6000	93.9222	1.655	1.295	36.000	1.470	35.832	-2.457	-3.927		-3.23	-3.37	35.67	A3
	A4	349.1417	93.5300	1.730	1.200	53.000	1.470	52.799	-3.257	-4.727		-4.03	-9.95	51.85	A4
	A5	346.5711	94.7350	1.820	1.115	70.500	1.470	70.020	-5.800	-7.270		-6.57	-16.26	68.11	A5
	A6	344.9983	94.4033	2.440	1.555	88.500	2.000	87.978	-6.775	-8.775		-8.07	-22.77	84.98	A6
	A7	343.9933	94.6422	2.540	1.490	105.000	2.000	104.312	-8.470	-10.470		-9.77	-28.76	100.27	A7
	A8	343.2083	94.7458	3.400	2.200	120.000	2.800	119.179	-9.894	-12.694		-11.99	-34.43	114.10	A8
	B1	236.0833	94.0850	1.486	1.455	3.100	1.470	3.084	-0.220	-1.690		-0.99	-2.56	-1.72	B1
	B2	293.3225	99.6467	1.570	1.360	21.000	1.470	20.410	-3.469	-4.939		-4.24	-18.74	8.08	B2
	B3	297.7800	96.0183	1.650	1.290	36.000	1.470	35.604	-3.754	-5.224		-4.52	-31.50	16.59	B3
	B4	299.3717	96.0325	1.730	1.210	52.000	1.470	51.426	-5.435	-6.905		-6.20	-44.82	25.22	B4
	B5	300.2658	96.0650	1.820	1.120	70.000	1.470	69.219	-7.355	-8.825		-8.12	-59.78	34.89	B5
	B6	300.8517	95.9383	2.430	1.570	86.000	2.000	85.080	-8.850	-10.850		-10.15	-73.04	43.63	B6
	B7	301.1017	95.9683	3.915	2.890	102.500	3.400	101.392	-10.600	-14.000		-13.30	-86.82	52.37	B7
	B8	301.4292	96.1292	4.900	3.710	119.000	4.300	117.643	-12.633	-16.933		-16.23	-100.38	61.34	B8
	C1	163.7556	87.4000	1.530	1.410	12.000	1.470	11.975	0.544	-0.926		-0.23	3.35	-11.50	C1
	C2	235.0000	96.9683	2.080	1.930	15.000	2.000	14.779	-1.806	-3.806		-3.11	-12.11	-8.48	C2
	C3	265.4083	95.9350	1.650	1.290	36.000	1.470	35.615	-3.702	-5.172		-4.47	-35.50	-2.85	C3
	C4	271.2842	96.7683	1.740	1.230	51.000	1.470	50.292	-5.969	-7.439		-6.74	-50.28	1.13	C4
	C5	274.0783	96.5778	2.540	1.855	68.500	2.200	67.601	-7.795	-9.995		-9.30	-67.43	4.81	C5
	C6	275.9533	96.5792	2.640	1.770	87.000	2.200	85.858	-9.903	-12.103		-11.40	-85.39	8.90	C6
	C7	277.3069	96.4778	2.930	1.880	105.000	2.400	103.664	-11.770	-14.170		-13.47	-102.82	13.18	C7
	C8	278.0806	96.1567	3.940	2.630	131.000	3.300	129.493	-13.968	-17.268		-16.57	-128.21	18.20	C8
	C9	278.7667	96.1308	4.515	3.085	143.000	3.800	141.369	-15.185	-18.985		-18.28	-139.72	21.55	C9
	D1	185.4150	90.0467	1.600	1.335	26.500	1.470	26.500	-0.022	-1.492		-0.79	-2.50	-26.38	D1
	D2	209.8367	93.6850	2.420	1.975	44.500	2.200	44.316	-2.854	-5.054		-4.35	-22.05	-38.44	D2
	D3	217.5292	93.9014	1.770	1.170	60.000	1.470	59.722	-4.073	-5.543		-4.84	-36.38	-47.36	D3
	D4	222.3383	94.0342	1.860	1.080	78.000	1.470	77.614	-5.474	-6.944		-6.24	-52.27	-57.37	D4
	D5	225.0433	94.1333	1.940	1.000	94.000	1.470	93.512	-6.758	-8.228		-7.53	-66.17	-66.07	D5
	D6	226.9550	94.1233	2.040	0.915	112.500	1.470	111.918	-8.068	-9.538		-8.84	-81.79	-76.39	D6
	D7	228.3817	93.8967	2.640	1.350	129.000	2.000	128.404	-8.746	-10.746		-10.05	-95.99	-85.28	D7
	D8	229.4533	93.8550	3.120	1.670	145.000	2.400	144.345	-9.727	-12.127		-11.43	-109.68	-93.83	D8
	E1	178.3458	90.0050	1.685	1.255	43.000	1.470	43.000	-0.004	-1.474		-0.77	1.24	-42.98	E1
	E2	186.6611	91.3075	1.770	1.180	59.000	1.470	58.969	-1.346	-2.816		-2.12	-6.84	-58.57	E2
	E3	191.6972	91.5333	2.380	1.630	75.000	2.000	74.946	-2.006	-4.006		-3.31	-15.19	-73.39	E3
	E4	194.6422	92.0100	2.450	1.550	90.000	2.000	89.889	-3.155	-5.155		-4.45	-22.72	-86.97	E4
	E5	196.5472	92.3333	2.535	1.460	107.500	2.000	107.322	-4.373	-6.373		-5.67	-30.57	-102.88	E5
	E6	198.1817	92.4433	2.615	1.390	122.500	2.000	122.277	-5.218	-7.218		-6.52	-38.15	-116.17	E6
	E7	199.2894	92.4891	2.680	1.310	137.000	2.000	136.742	-5.944	-7.944		-7.24	-45.17	-129.07	E7
	E8	200.2056	92.5617	2.780	1.220	156.000	2.000	155.688	-6.965	-8.965		-8.27	-53.77	-146.11	E8
	ROADWA	269.4883	96.5517	2.530	0.390	214.000	1.470	211.214	-24.258	-25.728		-25.03	-211.21	-1.89	ROADWAY

APPENDIX E

Summary of results of soil samples from Sewage Treatment Works

				as received- air dry									air dry		
	Unique				moisture	dry matter		loss on		pH	pH	EC	chloride	air-dry	oven dry
Lab No.	Sample No				% O.D. wt.	% O.D. wt.		ignition %		1:5 water	1:5 CaCl2	1:5 water	1:5 water	carbonate	carbonate
								from O.D.				uS/cm	mg/kg	mg/kg	mg/kg
1	A1				3.77	96.23				6.15	5.20	77	46	0	0.0
2	A2				4.96	95.04				6.78	6.01	119	35	12.5	13.1
3	A3				4.29	95.71				6.80	6.00	102	27	25	26.1
4	A4				4.17	95.83				6.85	5.94	95	35	25	26.0
5	A5				2.86	97.14				6.52	5.50	73	46	12.5	12.9
6	A6				2.79	97.21				6.99	6.07	69	50	12.5	12.8
7	A7				3.75	96.25				6.46	5.43	79	36	12.5	13.0
8	A8				3.23	96.77				6.06	5.02	51	33	25	25.8
9	B1				5.01	94.99				6.92	6.17	103	35	37.5	39.4
10	B2				2.59	97.41				6.80	5.76	70	46	0	0.0
11	B3				3.62	96.38				6.12	5.01	70	26	12.5	13.0
12	B4				3.29	96.71				6.75	5.82	85	41	25	25.8
13	B5				2.74	97.26				6.74	5.63	63	55	25	25.7
14	B6				4.06	95.94				6.99	6.08	87	50	37.5	39.0
15	B7				2.34	97.66				7.02	6.02	58	43	25	25.6
16	B8				1.88	98.12				6.73	5.60	44	46	12.5	12.7
17	C1				5.09	94.91				6.83	6.08	115	36	37.5	39.4
18	C2				4.63	95.37				6.92	6.15	122	79	37.5	39.2
19	C3				3.99	96.01				5.88	4.96	98	35	37.5	39.0
20	C4				3.18	96.82				6.43	5.55	90	50	25	25.8
21	C5				3.00	97.00				6.30	5.23	51	50	12.5	12.9
22	C6				2.16	97.84				6.81	5.76	51	57	25	25.5
23	C7				1.63	98.37				6.30	5.02	46	59	25	25.4
24	C8				1.90	98.10				6.70	5.58	61	55	12.5	12.7
25	C9				2.74	97.26				6.87	5.67	70	67	25	25.7
26	D1				4.21	95.79				5.90	5.08	128	39	25	26.1
27	D2				4.72	95.28				7.49	6.45	94	67	12.5	13.1
28	D3				3.38	96.62				6.13	5.13	69	38	25	25.8
29	D4				1.79	98.21				6.77	5.73	44	48	12.5	12.7
30	D5				2.62	97.38				6.36	5.36	76	57	25	25.7
31	D6				2.39	97.61				6.09	4.91	47	32	0	0.0
32	D7				1.97	98.03				5.97	5.00	36	32	25	25.5
33	D8				1.98	98.02				6.19	5.06	89	73	25	25.5
34	E1				3.27	96.73				6.06	5.20	63	39	37.5	38.7
35	E2				2.88	97.12				5.58	4.87	133	26	37.5	38.6
36	E3				2.87	97.13				6.27	5.33	68	50	25	25.7
37	E4				2.27	97.73				6.15	5.31	43	39	37.5	38.4
38	E5				2.22	97.78				6.40	5.52	51	28	25	25.6
39	E6				2.69	97.31				6.42	5.50	58	48	25	25.7
40	E7				2.80	97.20				6.45	5.71	64	43	37.5	38.5
41	E8				2.79	97.21				6.39	5.42	67	46	25	25.7
42	CONTROL				1.15	98.85				6.27	5.15	25	28	0	0.0

Summary of results of soil samples from Sewage Treatment Wo														air-dry
	Unique			air-dry	ovendry	air dry	oven dry	air dry	oven dry	air-dry	Oven dry	air-dry	oven dry	Bray
Lab No.	Sample No			OC (%)	OC(%)	NH4-N	NH4-N	NO3-N	NO3-N	TKN	TKN	soil TP	soil TP	soil P
						mgN/kg	mgN/kg	mgN/kg	mgN/kg	%	%	%	%	mg/kg
1	A1			5.03	5.22	18.68	19.38	13.34	13.85	0.487	0.506	0.274	0.284	59.2
2	A2			5.91	6.20	5.34	5.60	29.35	30.81	0.669	0.702	0.612	0.643	167.4
3	A3			4.34	4.53	13.34	13.91	21.35	22.26	0.423	0.441	0.506	0.527	172.2
4	A4			4.31	4.49	8.01	8.34	24.02	25.02	0.414	0.432	0.441	0.459	93.7
5	A5			2.14	2.20	0.00	0.00	24.02	24.71	0.220	0.226	0.158	0.163	6.2
6	A6			2.45	2.52	5.34	5.49	16.01	16.46	0.253	0.260	0.141	0.144	3.7
7	A7			4.35	4.51	13.34	13.84	13.34	13.84	0.451	0.468	0.249	0.258	44.4
8	A8			4.03	4.16	10.67	11.02	10.67	11.02	0.344	0.356	0.248	0.256	30.7
9	B1			6.71	7.04	10.67	11.21	21.35	22.42	0.792	0.832	0.580	0.609	155.5
10	B2			2.02	2.07	5.34	5.48	10.67	10.95	0.167	0.171	0.148	0.152	29.8
11	B3			3.11	3.22	8.01	8.30	13.34	13.83	0.316	0.328	0.219	0.227	40.4
12	B4			2.94	3.04	0.00	0.00	24.02	24.81	0.321	0.331	0.202	0.208	20.1
13	B5			2.90	2.98	8.01	8.23	10.67	10.97	0.218	0.224	0.134	0.137	7.5
14	B6			3.14	3.26	2.67	2.78	21.35	22.22	0.295	0.307	0.206	0.215	26.0
15	B7			2.43	2.48	0.00	0.00	13.34	13.66	0.202	0.206	0.123	0.126	13.9
16	B8			1.76	1.79	2.67	2.72	10.67	10.87	0.154	0.157	0.077	0.079	3.7
17	C1			5.96	6.27	8.01	8.41	26.69	28.04	0.671	0.705	1.085	1.140	328.1
18	C2			3.17	3.32	8.01	8.38	16.01	16.75	0.323	0.338	0.294	0.307	38.7
19	C3			4.79	4.98	8.01	8.32	24.02	24.97	0.475	0.494	0.215	0.223	75.0
20	C4			2.74	2.82	5.34	5.51	18.68	19.27	0.249	0.257	0.275	0.284	58.2
21	C5			1.65	1.70	2.67	2.75	10.67	10.99	0.157	0.161	0.105	0.108	3.7
22	C6			1.50	1.53	0.00	0.00	13.34	13.63	0.141	0.144	0.114	0.117	4.7
23	C7			1.45	1.47	5.34	5.42	0.00	0.00	0.108	0.110	0.088	0.090	2.8
24	C8			1.96	1.99	0.00	0.00	13.34	13.60	0.171	0.174	0.103	0.105	18.4
25	C9			2.44	2.50	0.00	0.00	13.34	13.71	0.213	0.219	0.102	0.105	3.5
26	D1			4.82	5.02	16.01	16.68	13.34	13.90	0.500	0.521	0.299	0.311	90.3
27	D2			1.28	1.34	2.67	2.79	2.67	2.79	0.120	0.126	0.144	0.151	4.7
28	D3			3.27	3.38	8.01	8.28	8.01	8.28	0.325	0.336	0.207	0.214	33.5
29	D4			1.34	1.36	5.34	5.43	8.01	8.15	0.120	0.123	0.102	0.104	21.2
30	D5			2.41	2.47	8.01	8.22	13.34	13.69	0.244	0.250	0.156	0.160	22.6
31	D6			1.93	1.98	2.67	2.73	13.34	13.66	0.183	0.188	0.110	0.112	7.6
32	D7			1.77	1.81	0.00	0.00	10.67	10.88	0.165	0.168	0.094	0.096	8.6
33	D8			2.41	2.46	8.01	8.16	8.01	8.16	0.246	0.251	0.110	0.112	10.0
34	E1			4.42	4.56	5.34	5.51	18.68	19.29	0.400	0.413	0.196	0.202	60.9
35	E2			4.06	4.17	18.68	19.22	18.68	19.22	0.371	0.382	0.214	0.220	51.1
36	E3			3.97	4.08	5.34	5.49	8.01	8.24	0.354	0.364	0.185	0.190	53.6
37	E4			2.45	2.51	5.34	5.46	8.01	8.19	0.258	0.263	0.155	0.158	27.5
38	E5			2.36	2.41	5.34	5.46	5.34	5.46	0.234	0.239	0.158	0.161	31.9
39	E6			3.27	3.36	5.34	5.48	5.34	5.48	0.298	0.306	0.148	0.152	11.7
40	E7			3.41	3.51	34.69	35.66	8.01	8.23	0.311	0.319	0.204	0.210	35.2
41	E8			3.18	3.27	2.67	2.74	13.34	13.72	0.321	0.330	0.185	0.190	34.8
42	CONTROL			1.38	1.40	0.00	0.00	10.67	10.80	0.116	0.118	0.061	0.061	4.7

Summary of results of soil samples from Sewage Treatment Works

Cations and Metal Ions

		Results reported on air-dry basis						Results reported on air-dry basis			
	Unique	result	result	result	result	ESP	CEC	Cu	Zn	Mn	Fe
Lab No.	Sample No	Na	Ca	K	Mg	4 bases	4 bases	mg/kg	mg/kg	mg/kg	mg/kg
		mg/kg	mg/kg	mg/kg	mg/kg	%	me/100g	air-dry	air-dry	air-dry	air-dry
1	A1	26.2	2908.4	1273.4	824.6	0.46	24.7	3.3	24.5	65.5	280.5
2	A2	205.2	2031.1	621.4	1466.2	3.62	24.7	16.7	38.2	29.1	162.9
3	A3	164.2	1543.7	680.3	1140.5	3.65	19.5	6.6	19.2	27.2	170.9
4	A4	248.2	1507.0	588.2	1307.5	5.17	20.9	6.1	21.4	36.0	222.7
5	A5	177.8	661.7	401.9	665.6	7.31	10.6	9.0	4.9	84.3	246.4
6	A6	166.6	1310.9	430.8	979.4	4.41	16.4	5.1	3.7	43.0	91.4
7	A7	125.5	1753.7	1147.5	925.8	2.75	19.8	4.9	17.1	105.2	118.9
8	A8	62.6	1018.1	810.9	531.1	2.31	11.8	2.6	8.8	75.0	131.0
9	B1	185.8	2114.6	550.4	1467.5	3.25	24.8	16.0	10.2	22.4	154.5
10	B2	249.1	909.8	512.0	762.2	8.21	13.2	4.4	5.2	24.0	213.4
11	B3	42.2	1047.8	1221.4	562.3	1.40	13.2	6.9	15.4	90.9	286.8
12	B4	197.5	1417.9	486.2	836.0	5.35	16.1	8.6	7.0	48.1	211.1
13	B5	226.3	917.3	334.8	714.6	8.00	12.3	5.4	2.6	35.0	190.1
14	B6	247.4	1548.0	344.5	1057.3	5.86	18.4	2.9	3.5	21.5	125.2
15	B7	152.4	1076.4	433.8	794.2	4.85	13.7	2.7	3.1	26.5	53.8
16	B8	142.6	890.2	327.8	556.2	5.92	10.5	2.6	1.6	37.1	85.3
17	C1	228.0	1727.0	423.4	1422.1	4.43	22.4	55.0	119.6	59.6	194.8
18	C2	304.6	1740.2	499.0	2581.5	4.07	32.5	10.4	8.7	24.3	167.2
19	C3	36.5	1356.5	1364.9	702.7	0.98	16.2	4.5	14.5	77.3	268.2
20	C4	187.0	1359.6	422.0	692.6	5.66	14.4	8.9	4.8	50.6	180.2
21	C5	138.0	1179.1	315.4	461.5	5.41	11.1	9.1	2.5	77.6	208.9
22	C6	125.0	1318.8	272.2	687.8	4.03	13.5	5.5	1.9	34.6	141.0
23	C7	161.5	590.6	173.3	261.8	11.25	6.2	6.0	1.6	56.8	171.5
24	C8	221.3	1181.5	196.6	439.2	8.77	11.0	6.0	6.6	24.2	206.0
25	C9	329.3	1712.9	437.8	768.7	8.22	17.4	3.7	4.2	38.7	136.6
26	D1	38.6	1415.8	1448.5	846.1	0.94	17.9	5.5	18.7	102.7	197.6
27	D2	252.2	1269.1	1885.0	843.5	5.72	19.2	1.9	6.3	1.8	17.0
28	D3	54.7	1836.0	1002.2	664.8	1.37	17.4	3.0	8.4	90.9	162.9
29	D4	71.5	1163.8	450.0	443.0	2.85	10.9	4.7	1.6	44.1	45.8
30	D5	218.9	1646.6	313.9	586.1	6.44	14.8	4.4	4.1	40.2	305.0
31	D6	133.4	1152.7	463.2	422.6	5.28	11.0	3.3	4.7	83.9	161.1
32	D7	35.0	1184.4	402.2	452.9	1.41	10.8	2.7	2.8	69.7	85.2
33	D8	70.6	1309.7	529.9	479.3	2.53	12.1	3.8	4.3	70.4	248.6
34	E1	36.0	2105.0	1528.8	820.1	0.73	21.3	3.9	13.4	62.2	162.7
35	E2	30.2	1942.6	1817.2	1231.6	0.53	24.6	7.3	25.0	71.2	217.0
36	E3	28.3	1198.1	579.8	463.4	1.08	11.4	3.0	12.0	44.6	164.2
37	E4	27.8	1824.5	345.4	681.1	0.77	15.7	2.7	7.9	39.8	175.8
38	E5	33.1	1791.8	511.9	611.8	0.93	15.4	2.8	4.3	29.7	217.2
39	E6	108.5	1987.4	320.4	796.3	2.66	17.8	3.9	6.3	44.9	222.5
40	E7	78.7	1274.9	366.5	891.4	2.29	15.0	4.3	8.7	28.2	180.1
41	E8	102.7	2100.7	512.9	784.6	2.39	18.7	4.4	8.5	35.2	219.0
42	CONTROL	24.0	751.9	368.6	214.1	1.59	6.6	2.1	0.7	46.5	37.8

comparison of the changes in soil analysis relative to the control

Armidale Sewage Treatment Plant soil samples from disposal area

Lab No.	unique site	distance from outle	change pH CaCl2	change EC dS/m	%change OD OC (%)	%change OD TKN (%)	%change OD TP (%)	%change Bray P mg/kg	%change Na mg/kg	%change CEC 4 bases me/100g	%change Copper mg/kg	%change Zinc mg/kg	%change Mn mg/kg	%change Iron mg/kg	%change ESP %
1	A1	9.96	0.05	52	374	430	462	1271	109	29	153	3646	141	741	29
2	A2	18.97	0.86	94	444	598	1045	3593	855	227	786	5680	63	430	227
3	A3	35.83	0.85	77	324	375	858	3696	684	230	308	2852	59	452	230
4	A4	52.80	0.79	70	322	367	746	2011	1034	325	286	3183	77	589	325
5	A5	70.02	0.35	48	158	192	265	134	741	460	421	727	181	651	460
6	A6	87.98	0.92	44	181	222	235	80	694	277	241	552	93	241	277
7	A7	104.31	0.28	54	323	398	420	953	523	173	231	2539	226	314	173
8	A8	119.18	-0.13	26	298	302	417	659	261	145	124	1313	161	346	145
9	B1	3.08	1.02	78	504	708	991	3338	774	204	750	1511	48	408	204
10	B2	20.41	0.61	45	148	145	247	641	1038	516	209	771	52	564	516
11	B3	35.60	-0.14	45	231	279	369	868	176	88	326	2292	196	758	88
12	B4	51.43	0.67	60	217	282	339	432	823	336	402	1036	103	558	336
13	B5	69.22	0.48	38	213	191	223	162	943	503	256	382	75	502	503
14	B6	85.08	0.93	62	234	262	349	559	1031	368	134	525	46	331	368
15	B7	101.39	0.87	33	178	176	204	299	635	305	126	468	57	142	305
16	B8	117.64	0.45	19	129	133	128	79	594	372	124	233	80	225	372
17	C1	11.98	0.93	90	449	600	1854	7043	950	278	2585	17804	128	515	278
18	C2	14.78	1.00	97	238	288	499	832	1269	256	489	1289	52	442	256
19	C3	35.62	-0.19	73	357	420	363	1610	152	62	212	2164	166	709	62
20	C4	50.29	0.40	65	202	219	462	1249	779	356	417	715	109	476	356
21	C5	67.60	0.08	26	121	137	176	79	575	340	428	377	167	552	340
22	C6	85.86	0.61	26	109	123	190	102	521	254	259	276	74	373	254
23	C7	103.66	-0.13	21	106	93	146	60	673	707	281	239	122	453	707
24	C8	129.49	0.43	36	143	148	171	396	922	551	280	988	52	544	551
25	C9	141.37	0.52	45	179	186	170	75	1372	517	176	632	83	361	517
26	D1	26.50	-0.07	103	360	443	506	1939	161	59	257	2785	221	522	59
27	D2	44.32	1.30	69	96	107	245	101	1051	359	88	936	4	45	359
28	D3	59.72	-0.02	44	242	286	348	720	228	86	142	1245	196	430	86
29	D4	77.61	0.58	19	97	104	170	454	298	179	221	232	95	121	179
30	D5	93.51	0.21	51	177	213	260	486	912	404	205	608	86	806	404
31	D6	111.92	-0.24	22	142	160	183	164	556	332	155	704	181	426	332
32	D7	128.40	-0.15	11	129	143	156	184	146	89	126	413	150	225	89
33	D8	144.34	-0.09	64	176	214	182	214	294	159	179	643	151	657	159
34	E1	43.00	0.05	38	327	352	328	1307	150	46	181	1990	134	430	46
35	E2	58.97	-0.28	108	299	325	358	1096	126	34	343	3718	153	573	34
36	E3	74.95	0.18	43	292	310	309	1150	118	68	140	1788	96	434	68
37	E4	89.89	0.16	18	180	224	258	590	116	48	128	1174	86	465	48
38	E5	107.32	0.37	26	172	203	262	684	138	59	134	645	64	574	59
39	E6	122.28	0.35	33	240	261	247	252	452	167	182	938	97	588	167
40	E7	136.74	0.56	39	251	272	341	756	328	144	202	1292	61	476	144
41	E8	155.69	0.27	42	234	280	310	747	428	150	205	1258	76	579	150
42	CONTROL		0.00	0	100	100	100	100	100	100	100	100	100	100	100

Data ranked by distance from discharge outlet - all site taken

Armidale Sewage Treatment Plant soil samples from disposal area

Lab No.	unique site	distance from outle		change pH CaCl2	change EC dS/m	%change OD OC (%)	%change OD TKN (%)	%change OD TP (%)	%change Bray P mg/kg	%change Na mg/kg	%change CEC 4 bases me/100g	%change Copper mg/kg	%change Zinc mg/kg	%change Mn mg/kg	%change Iron mg/kg	%change ESP %
9	B1	3.08		1.02	78	504	708	991	3338	774	204	750	1511	48	408	204
1	A1	9.96		0.05	52	374	430	462	1271	109	29	153	3646	141	741	29
17	C1	11.98		0.93	90	449	600	1854	7043	950	278	2585	17804	128	515	278
18	C2	14.78		1.00	97	238	288	499	832	1269	256	489	1289	52	442	256
2	A2	18.97		0.86	94	444	598	1045	3593	855	227	786	5680	63	430	227
10	B2	20.41		0.61	45	148	145	247	641	1038	516	209	771	52	564	516
26	D1	26.50		-0.07	103	360	443	506	1939	161	59	257	2785	221	522	59
11	B3	35.60		-0.14	45	231	279	369	868	176	88	326	2292	196	758	88
19	C3	35.62		-0.19	73	357	420	363	1610	152	62	212	2164	166	709	62
3	A3	35.83		0.85	77	324	375	858	3696	684	230	308	2852	59	452	230
34	E1	43.00		0.05	38	327	352	328	1307	150	46	181	1990	134	430	46
27	D2	44.32		1.30	69	96	107	245	101	1051	359	88	936	4	45	359
20	C4	50.29		0.40	65	202	219	462	1249	779	356	417	715	109	476	356
12	B4	51.43		0.67	60	217	282	339	432	823	336	402	1036	103	558	336
4	A4	52.80		0.79	70	322	367	746	2011	1034	325	286	3183	77	589	325
35	E2	58.97		-0.28	108	299	325	358	1096	126	34	343	3718	153	573	34
28	D3	59.72		-0.02	44	242	286	348	720	228	86	142	1245	196	430	86
21	C5	67.60		0.08	26	121	137	176	79	575	340	428	377	167	552	340
13	B5	69.22		0.48	38	213	191	223	162	943	503	256	382	75	502	503
5	A5	70.02		0.35	48	158	192	265	134	741	460	421	727	181	651	460
36	E3	74.95		0.18	43	292	310	309	1150	118	68	140	1788	96	434	68
29	D4	77.61		0.58	19	97	104	170	454	298	179	221	232	95	121	179
14	B6	85.08		0.93	62	234	262	349	559	1031	368	134	525	46	331	368
22	C6	85.86		0.61	26	109	123	190	102	521	254	259	276	74	373	254
6	A6	87.98		0.92	44	181	222	235	80	694	277	241	552	93	241	277
37	E4	89.89		0.16	18	180	224	258	590	116	48	128	1174	86	465	48
30	D5	93.51		0.21	51	177	213	260	486	912	404	205	608	86	806	404
15	B7	101.39		0.87	33	178	176	204	299	635	305	126	468	57	142	305
23	C7	103.66		-0.13	21	106	93	146	60	673	707	281	239	122	453	707
7	A7	104.31		0.28	54	323	398	420	953	523	173	231	2539	226	314	173
38	E5	107.32		0.37	26	172	203	262	684	138	59	134	645	64	574	59
31	D6	111.92		-0.24	22	142	160	183	164	556	332	155	704	181	426	332
16	B8	117.64		0.45	19	129	133	128	79	594	372	124	233	80	225	372
8	A8	119.18		-0.13	26	298	302	417	659	261	145	124	1313	161	346	145
39	E6	122.28		0.35	33	240	261	247	252	452	167	182	938	97	588	167
32	D7	128.40		-0.15	11	129	143	156	184	146	89	126	413	150	225	89
24	C8	129.49		0.43	36	143	148	171	396	922	551	280	988	52	544	551
40	E7	136.74		0.56	39	251	272	341	756	328	144	202	1292	61	476	144
25	C9	141.37		0.52	45	179	186	170	75	1372	517	176	632	83	361	517
33	D8	144.34		-0.09	64	176	214	182	214	294	159	179	643	151	657	159
41	E8	155.69		0.27	42	234	280	310	747	428	150	205	1258	76	579	150
42	CONTROL			0.00	0	100	100	100	100		100	100	100	100	100	

STW PLANT ANALYSIS

Nutrient	Units	high density	medium density	low density
dry matter	%	99.3	92.5	94.0
fibre	%	99.4	99.4	99.6
nitrogen	%	2.92	2.62	1.05
protein	%	18.3	16.4	6.59
Cl	%	0.34	0.34	0.320
P	%	0.394	0.381	0.112
S	%	0.275	0.321	0.106
K	%	2.04	2.36	1.34
Ca	%	0.342	0.332	0.194
Mg	%	0.224	0.259	0.145
Na	%	0.465	0.045	0.067
Mn	mg/kg	29.1	87.2	90.4
Fe	mg/kg	65.2	66.1	69.7
Zn	mg/kg	41.8	37.2	37.0
Cu	mg/kg	12.2	12.3	8.33
Al	%	0.006	0.007	0.007
B	mg/kg	5.08	5.91	1.04

Sample	Na	Ca	K	Mg	SAR	hard	sample ID		pH	EC	TDS	TS	EC	Cl-	PO4	NH4	NO3	NH4+N	turbidity
No.	mg/L	mg/L	mg/L	mg/L		mg/L	sample ID			us/cm	mg/L	mg/L	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	NTU
7	66	33	28	16	2.4	147	pond 1	11	7.51	667	400	736	667	56	6.3	0.61	0.54	1.15	6.3
16	64	31	18	15	2.3	140	pond 1	12	7.52	642	385	484	642	46	6.2	0.54	0.58	1.12	6.5
	65	32	23	16	2.4	144	**average pond 1**		7.52	655	393	610	655	51	6.3	0.58	0.56	1.14	6
1	69	31	15	16	2.5	145	outlet 1	21	7.68	683	410	448	683	58	7.1	0.63	0.30	0.93	6
10	64	30	15	16	2.4	139	outlet 1	22	7.98	614	368	412	614	58	6.5	0.26	0.37	0.63	6
	66	31	15	16	2.4	142	**average outlet 1**	22	7.83	649	389	430	649	58	6.8	0.45	0.34	0.78	6
3	77	35	17	16	2.7	155	outlet 4	31	7.73	656	394	492	656	56	6.6	0.49	0.33	0.82	5
12	65	30	16	16	2.4	141	outlet 4	32	8.13	620	372	388	620	48	6.8	0.47	0.35	0.82	6
	71	33	16	16	2.5	148	**average outlet 4**	32	7.93	638	383	440	638	52	6.7	0.48	0.34	0.82	6
6	73	37	18	17	2.5	163	outlet 5	41	7.93	588	353	772	588	56	5.5	0.70	0.40	1.10	4
15	65	32	15	17	2.3	150	outlet 5	42	7.90	562	337	492	562	46	5.3	0.07	0.19	0.26	5
	69	35	16	17	2.4	156	**average outlet 5**	42	7.92	575	345	632	575	51	5.4	0.39	0.30	0.68	5
2	71	32	17	17	2.5	147	outlet 6	51	7.73	662	397	500	662	58	6.8	0.35	0.33	0.68	5
11	67	31	16	16	2.4	143	outlet 6	52	7.77	624	374	464	624	52	6.4	0.49	0.19	0.68	5
	69	31	16	16	2.5	145	**average outlet 6**	52	7.75	643	386	482	643	55	6.6	0.42	0.26	0.68	5
4	71	32	17	17	2.5	148	outlet 7	61	7.89	646	388	540	646	56	6.3	0.33	0.19	0.52	6.5
13	66	31	15	16	2.4	141	outlet 7	62	7.79	609	365	396	609	48	6.3	0.42	0.14	0.56	6
	68	31	16	16	2.5	145	**average outlet 7**	62	7.84	628	377	468	628	52	6.3	0.38	0.17	0.54	6
5	73	35	16	17	2.5	157	outlet river	71	7.98	640	384	656	640	58	7.0	0.28	0.14	0.42	6
14	66	31	16	16	2.4	145	outlet river	72	7.85	612	367	352	612	48	6.9	0.33	0.14	0.47	6
	70	33	16	16	2.5	151	**average outlet r**	72	7.92	626	376	504	626	53	7.0	0.31	0.14	0.45	6
8	27	31	3	18	1.0	152	upstream	81	7.91	364	218	472	364	38	nd	nd	nd	nd	4.5
17	26	31	3	19	0.9	157	upstream	82	7.98	355	213	404	355	36	nd	nd	nd	nd	6
	26	31	3	19	0.9	154	**average upstrea**	82	7.95	360	216	438	360	37	0.0	0.00	0.00	0.00	5
9	44	33	9	18	1.5	154	downstream	91	7.86	465	279	604	465	46	2.4	nd	0.05	0.05	5.5
18	43	31	8	17	1.5	150	downstream	92	7.89	457	274	564	457	41	2.2	0.09	nd	0.09	6
14	43	32	8	17	1.5	152	**average downstr**	92	7.88	461	277	584	461	44	2.3	0.05	0.03	0.07	6
Sample	Na	Ca	K	Mg	SAR	hard	sample ID					Raw							
									pH	EC	TDS	TS	EC	Cl-	PO4	NH4	NO3	NH4+N	turbidity
No.	mg/L	mg/L	mg/L	mg/L		mg/L	sample ID			us/cm	mg/L	mg/L	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	NTU

RESULTS OF WATER ANALYSIS
APPENDIX H