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# ASSESSMENT OF PHYSICAL AND CHEMICAL PROPERTIES OF SUB-TROPICAL SOIL TO PREDICT LONG TERM EFFLUENT TREATMENT POTENTIAL

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## Abstract

On-site wastewater treatment systems aim to assimilate domestic effluent into the environment. Unfortunately failure of such systems is common and inadequate effluent treatment can have serious environmental implications. A research project was undertaken to determine the role of physical and chemical soil properties in the treatment performance of subsurface effluent disposal areas. Monitoring changes in these properties permit improved prediction of the treatment potential of a soil. The changes within soil properties of the disposal area due to effluent application were found to be directly related to the subsurface drainage characteristics including permeability, clay content and clay type. The major controlling soil physical and chemical attributes were found to be moderate drainage, significant soil cation exchange capacity and dominance of exchangeable Ca or exchangeable Mg over exchangeable Na, low exchangeable Na, clay type and a minimum depth of 0.4m of potential unsaturated soil before encountering a restrictive horizon. The study confirmed that both the physical properties and chemistry of the soil can be valuable predictive tools for evaluating the long term operation of sewage effluent disposal systems.

**Keywords:** on-site sewage treatment, soil chemistry, septic tanks, soil hydrology

## Introduction

Approximately 13% of the Australian population, or more than two million people, are not serviced by reticulated sewerage facilities (Whitehead and Geary 2000) and rely wholly on on-site systems for the treatment and disposal of domestic wastewater. In the United States, this percentage is over 25% (Siegrist 2001). Septic tanks are by far the most common form of on-site wastewater treatment and the associated sub-surface effluent disposal area is a crucial part of the treatment train. The efficiency of this disposal area and the adjoining buffer zones are essential to prevent the contamination of surface and groundwater resources by sewage effluent. This is especially of concern in areas where there is a high density of such systems.

Despite the seemingly low technology of septic systems, failure is common. In many cases, this can lead to adverse public health and environmental impacts (DeWalle and Schaff 1980, Scandura and Sobsey 1997, DeBorde et al 1998, Paul et al 2000, Lipp et al 2001). A primary factor that contributes to failure is the inadequate consideration of site and soil characteristics in the design of the sub-surface effluent disposal area (Martens and Geary 1999, Siegrist et al 2000, Whitehead and Geary 2000).

On-site domestic wastewater treatment systems have traditionally relied on soil properties to remove contaminants as effluent percolates through the soil. Soil can be an excellent treatment medium provided the duration of effluent/soil contact is sufficient. However, the ability of the soil to purify effluent is not completely understood. The capacity of a particular soil to treat wastewater will change over time. The physical properties influence the rate of effluent movement through the soil and its chemical properties dictate the ability to renovate effluent. Numerous researchers (for example Brouwer and Bugeja 1983, Schipper et al 1996, Whitehead and Geary 2000, Siegrist 2001, Van Cuyk et al 2001) have noted the current lack of in-depth knowledge of the processes taking place within the soil matrix. These studies have been carried out on soils from colder climates than the subtropical soils found in Queensland.

Very few studies have been carried out in sub-tropical soils. Carroll et al (2004) in a study on subtropical soils in Gold Coast, Queensland found that Ferrosol and Dermosol soils provided the most evidence of suitability for locating on-site systems due to their high renovation capability. This relates to their high cation exchange capacity values and clay content providing greater cation exchange and therefore contaminant adsorption characteristics. Khalil et al (2004) found that a high cation exchange capacity can enhance the renovation of sewage effluent. These studies presented detailed soil characteristics on control soils. This paper presents the outcomes of research at established subsurface effluent disposal systems undertaken to identify the influential sub-tropical soil properties and their use as predictive tools for evaluating the effective long-term operation of sewage effluent disposal systems.

## Materials and Methods

### Research Project

The research project was based in the urban fringe of the local government area of Brisbane City Council in Queensland State, Australia (Figure 1). This area is currently undergoing significant urbanisation with the development of extensive rural residential allotments which are not serviced by reticulated sewerage facilities. A representative sample of various study sites having septic tanks and sub-surface effluent disposal areas was selected for detailed investigations.

### Site Selection

The site selection was based on the proportionate area of urban development in the region and distributed across different sub-tropical soil types common to southeast Queensland to obtain a comparison of system characteristics and ages. The slopes of the surfaces of the effluent disposal fields varied from relatively flat fields (<5% slope) to significantly sloping fields (>15% slope).

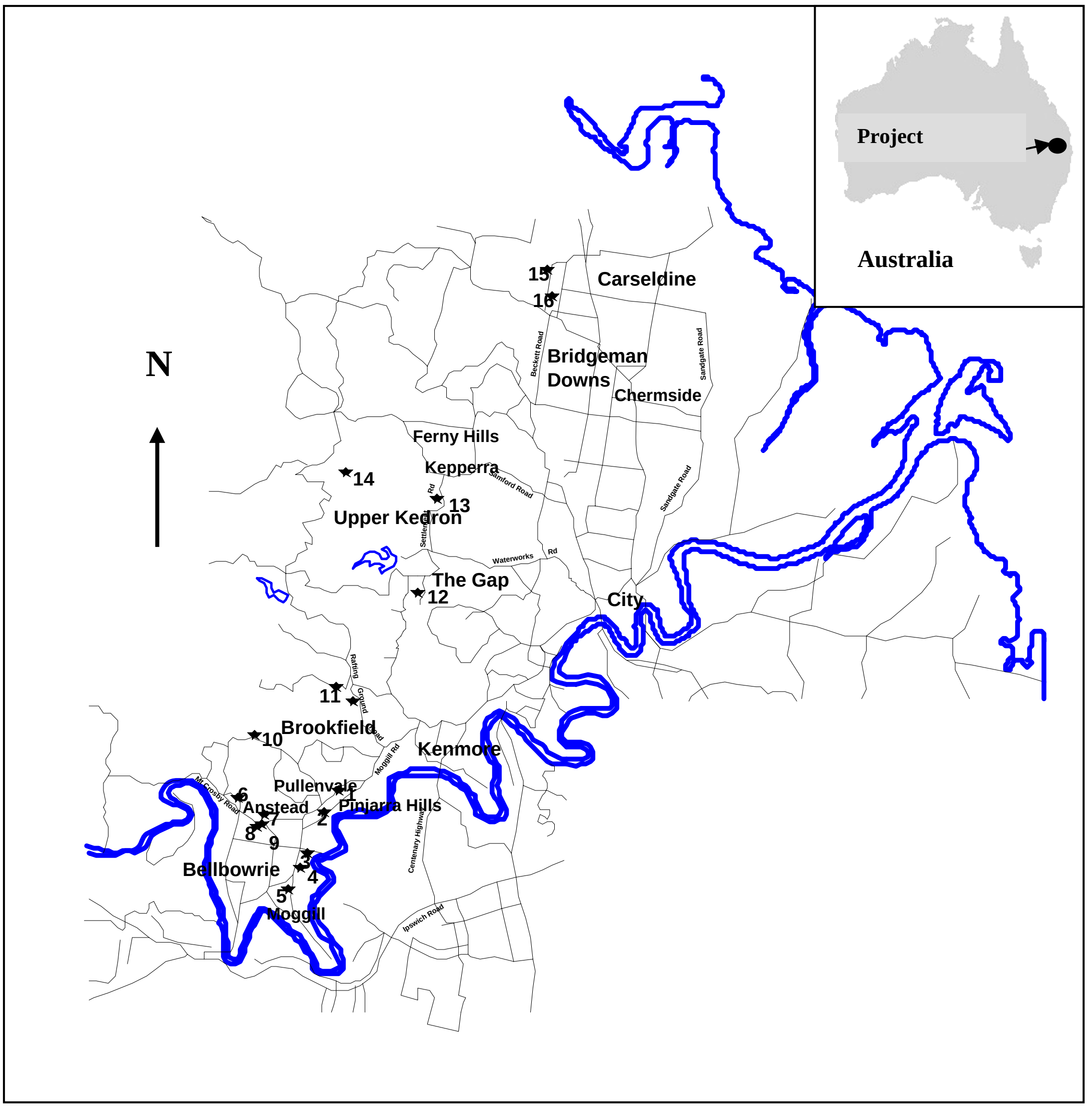



**Figure 1** Project area location

## Soil Sampling

Initially, a total of 16 study sites were selected. Representative duplicate soil samples of 500grams were collected at 100mm depth increments from each site. These samples were characteristic of soils that had been subjected to sewage effluent disposal and control soils that had not received effluent. Five sites were subsequently rejected due to insufficient soil water samples in the piezometers installed and/or lack of reliable historical information. Site and soil classifications derived are given in Table 1.

**Table 1** Sewage effluent disposal area soil classification

| Site No. | System age (yr) | Australian Soil Classification[a] | Soil Texture[b]<br>A – A horizon<br>B – B horizon | Soil Drainage[c] | Slope (deg.) |
|---|---|---|---|---|---|
| 1 | 4 | Red Chromosol | A – Sandy loam<br>B – Clay loam | Moderately well drained | >15 |
| 2[d] | 8 | Red Chromosol | Sandy clay loam | Moderately well drained | >10 |
| 3 | 5 | Brown Chromosol | A - Sandy loam<br>B – Light Clay | Imperfectly drained | <10 |
| 4 | 3 | Brown Chromosol | A - Sandy loam<br>B- Clay loam | Imperfectly drained | <5 |
| 5[d] | 1 | Brown Chromosol | Sandy clay loam | Imperfectly drained | <5 |
| 6[d] | 11 | Red Dermosol | Sandy clay | Poorly drained | <5 |
| 7 | 2.5 | Red Chromosol | A - Sandy loam<br>B – Sandy clay loam | Moderately well drained | >10 |
| 8 | 4 | Red Sodosol | A - Clay loam<br>B – Heavy clay | Poorly drained | <5 |
| 9 | 17 | Grey Sodosol | A – Clay loam<br>B – Heavy clay | Poorly drained | <5 |
| 10[d] | 14 | Red Kandosol | Sandy loam | Moderately well drained | >10 |
| 11 | 4.5 | Red Kandosol | A - Sandy loam<br>B – Sandy clay loam | Well drained | >15 |
| 12 | 19 | Brown Kurosol | A -Loamy sand<br>B – Sandy clay loam | Moderately well drained | >10 |
| 13[d] | 16 | Brown Kurosol | Loamy sand | Imperfectly drained | <10 |
| 14 | 14 | Brown Chromosol | A - Loam<br>B – Medium clay | Moderately well drained | >15 |
| 15 | 3 | Red Ferrosol | A - Sandy loam<br>B- Light clay | Moderately well drained | >5 |
| 16 | 4 | Red Ferrosol | A - Clay loam<br>B- Medium clay | Poorly drained | <5 |

a Australian Soil Classification after Isbell (1996)
b soil texture based on McDonald et al. (1998)
c the classification used complies with AS/NZS 1547:2000 (Standards Australia, 2000), McDonald et al. (1998).
d sites abandoned due to insufficient soil water sample and unreliable historical site information

Initial soil samples collected by hand auger were classified, noting features such as parent material and profile description. Undisturbed soil core samples were also collected from each site to characterise the permeability of each soil using laboratory methods. Soil profile descriptions including colour, texture, structure and biological activity were recorded in depth increments of 100mm as described by McDonald et al (1998). The dominant soils were Red and Brown Chromosols, which generally exhibit a strong texture and contrast between the A and B horizons (Isbell 1996).

Site conditions such as topography, slope and drainage characteristics were described in detail at the soil sampling points. In-situ drainage information that was collected included the presence of preferential flow paths and redoximorphic features. Laboratory testing included hydraulic conductivity using methods described in AS/NZS 1547:2000. Additionally, in-situ information on water table depth, presence of effluent flows, depth of soil horizons and depth to the impermeable soil layer were recorded. This information was utilised in establishing boundary failures based on USEPA On-site Wastewater Treatment Manual (2002), Section 5.8. The position of each site within a landscape pattern or catena was identified as described by White (1997).

## Analytical Program Soil

The soil samples were air dried within 24 hours of collection. Each sample was then ground to pass a 2mm sieve and sub-sampled for the following tests: (i) Electrical Conductivity (EC) and pH in a 1:5 soil:water suspension; (ii) Exchangeable cations were measured using displacement with $NH_4Cl$ and analysed by Inductively Coupled Plasma (ICP-ES); Methods described in Australian Laboratory Handbook of Soil and Water Chemical Methods, Rayment and Higginson (1992) and (iii) Soil particle fractions. The sand size particle sizes were determined by sieve analysis and the silt and clay contents were measured by hydrometer analysis.

Parameters such as exchangeable sodium percentage (ESP), Ca:Mg ratio, cation exchange capacity (CEC) or effective cation exchange capacity (ECEC) and Sodium Adsorption Ratio (SAR) were derived from the data obtained. In the case of acidic soils which cover a significant area of South East Queensland, it is ECEC that is relevant where the summation also includes exchangeable acidity (Peverill et al 1999). Particle size analysis was measured by hydrometer analysis including sample pre-treatment for removal of organic matter where necessary. The type of clay was interpreted using published values of CEC and clay activity ratio (CCR = CEC/clay %) (Shaw et al 1997) and random samples were validated using X-Ray Diffraction.

## Soil Water Sampling

Before selecting the final location of piezometers, a thorough site investigation using a dynamic cone penetrometer was undertaken. This helped to locate where the effluent was flowing in the soil subsurface and generally allowed the use of only two piezometers downslope of the trenches as well as maximising sample collection. Depths of trenches were measured with a dynamic cone penetrometer, with all trenches being between 300 and 400mm deep. Soil water samples were collected from the piezometers installed 1 and 3m downslope from the edge of the subsurface effluent disposal area (i.e. the adsorption trenches) to establish the effluent treatment capacity of the different soil types. The chemical results were compared with the chemistry of the distribution box water samples. A typical piezometer installation is shown in Figure 2. The piezometers were installed to a maximum depth of 1.5m or to a clay layer of low permeability. Piezometers were purged using a converted hand bailer before sampling commenced. Three to four separate sampling episodes took place from July through to October, 1999. Comparison with meteorological records confirmed that the 150mm clay plug at the top of each piezometer allowed only minor seepage from rainfall through the soil profile.

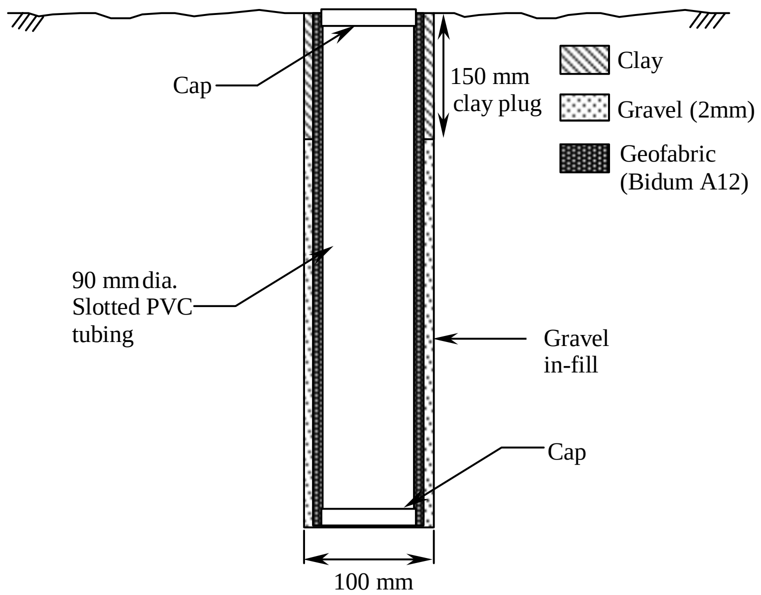



**Figure 2** A typical piezometer installation

## Analytical Program Soil Water

Standard wastewater analysis for pH, Electrical Conductivity (EC), Total Nitrogen (APHA-4500), Total Organic Carbon (Combustion-Infrared Method 5310D. Rosemount Dohrmann TOC Analyser DC190) and Faecal Coliforms (Membrane Filtration Method 9222D) were performed according to the methods described in APHA (1995). Water soluble cations calcium (Ca), magnesium (Mg) and sodium (Na) ion concentrations were measured using inductively coupled plasma (ICP) spectroscopy. pH and EC are useful surrogates for evaluating the chemical quality of effluent. The calcium, magnesium and sodium ion concentrations were needed for estimating the Sodium Absorption Ratio (SAR) of the effluent. Results for all sites are shown in Table 2.

**Table 2** Water chemistry changes after passing from distribution box through adsorption trenches

| **Site No.** | **Age** | **Total N** mg/L | **TOC** mg/L | **EC** mS/cm | **pH** | **Faecal** cfu/100ml | **SAR** |
|---|---|---|---|---|---|---|---|
| 1DB | | 131 | 80 | 3290 | 7.9 | 10000 | 3 |
| 1P1 | 4 | 2.5 | 34 | 1303 | 6.8 | 420 | |
| 1P2 | | 4.0 | 21 | 1170 | 6.9 | 26 | |
| 3DB | | 40.5 | 77 | 1550 | 7.9 | 6000 | 6 |
| 3P1 | 5 | 27.7 | 39 | 2355 | 7.2 | <10 | |
| 3P2 | | 4.2 | 40 | 2505 | 7.3 | <1 | |
| 4DB | | 93 | 75 | 2870 | 7.4 | 150 | 4 |
| 4P1 | 3 | 57 | 14 | 1950 | 5.1 | <10 | |
| 4P2 | | 5.6 | 12 | 1450 | 6.2 | <1 | |
| 7DB | | 290 | 121 | 3457 | 7.5 | 60000 | 3 |
| 7P1 | 2.5 | 24 | 36 | 1395 | 6.1 | 3800 | |
| 7P2 | | 7.4 | 61 | 893 | 6.2 | 6000 | |
| 8DB | | 225 | 145 | 3180 | 8.1 | 6000 | 4 |
| 8P1 | 4 | 55 | 28 | 8215 | 6.2 | 1370 | |
| 8P2 | | 37 | 21 | 6450 | 6.5 | 1227 | |
| 9DB | | 75 | 80 | 1520 | 6.9 | 20000 | 5 |
| 9P1 | 17 | 3.9 | 27 | 2825 | 6.6 | 3550 | |
| 9P2 | | 2.3 | 27 | 2220 | 6.5 | 20217 | |
| 11DB | | 17.2 | 52 | 1310 | 7.8 | 25 | 2 |
| 11P1 | 4.5 | 3.2 | 24 | 800 | 5.9 | 141 | |
| 11P2 | | 4.7 | 35 | 330 | 6.9 | 4100 | |
| 12DB | | 123 | 72 | 1875 | 7.4 | 250 | 4 |
| 12P1 | 19 | 14 | 23 | 780 | 6.6 | 37 | |
| 12P2 | | 6.1 | 47 | 575 | 6.1 | 155 | |
| 14DB | | 245 | 133 | 2540 | 7.7 | 34000 | 2 |
| 14P1 | 14 | 3.9 | 31 | 802 | 7.2 | 24000 | |
| 14P2 | | 3.2 | 26 | 645 | 7 | 4133 | |
| 15DB | | 57 | 87 | 1560 | 7.3 | 34000 | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 15P1 | 3 | 31 | 7 | 900 | 5.5 | 15 | |
| 15P2 | | 26 | 6 | 1029 | 5.7 | 14 | |
| 16DB | | 190 | 113 | 3443 | 7.1 | 34000 | 8 |
| 16P1 | 4 | 26 | 20 | 1837 | 5.9 | 1879 | |
| 16P2 | | 4.4 | 6.7 | 1468 | 5.3 | 570 | |

Composite sampling average of 3 separate sampling episodes
DB – Distribution Box prior to flowing through trenches
P1,P2 – Piezometers in direction of effluent flow, 1m and 3m from edge of trenches

### Research Rationale

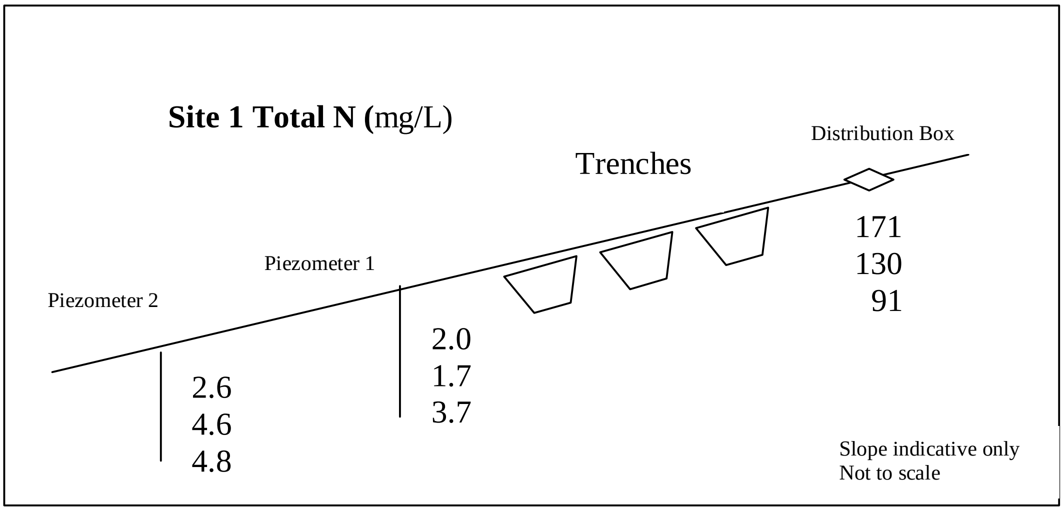
The approach adopted in this research involved obtaining field information including site conditions of existing operating on-site sewage treatment systems. This was to determine to what extent contact with effluent has altered the properties of the soil along with the travel distance of pollutants from the subsurface disposal trenches. Soil sampling and monitoring data at established subsurface effluent disposal systems were used as a convenient method for evaluating renovation efficiency and to obtain an insight into renovation mechanisms. The advantage of using soil parameters as indicators is that they are not weather dependent and samples can be taken at any time. In conjunction with soil sampling, a comparison of quality parameters for soil water and effluent samples collected at the soil interface indicated the degree of change in quality experienced by the effluent moving through the soil.

The soil sampling strategy was specifically formulated to focus on the ‘zone of influence’ of a sub-surface effluent disposal field. Detailed soil evaluation was undertaken directly downslope of the disposal field. Soil descriptions were used to qualitatively assess the hydrology of the soil profile. Valuable information for characterising soil capability for sewage effluent renovation can be derived from terrain evaluation and geomorphologic features that are significant in relation to subsurface drainage. The more important parameters in regard to subsurface effluent disposal include the position of perched and true water tables and duration of saturation (Cresswell et al 1999).

## Results and Discussion

### Soil Water

Table 2 presents water chemistry changes after passing from the distribution box through adsorption trenches and clearly shows an improvement in effluent quality with distance. Figure 3 depicts the results of three sampling episodes for total nitrogen for Site 1. Generally, the improvement in effluent quality appears to take place only within the initial 1m of travel from the edge of the adsorption trench. An appreciable further improvement in quality is not apparent between the 1 - 3m distances. A few exceptions appear to be Sites 3, 8, 12 and 16 in respect to nitrogen. This conclusion is similar to that derived by other studies (for example, Brouwer and Bugeja 1983). However, contrary to other studies an additional improvement in Total Nitrogen removal is also noted at most sites. Based on initial assessment, it would appear that with regard to faecal coliforms too, most systems are functioning satisfactorily, but overall the investigation of faecal coliforms proved inconclusive.




Piezometer 1 - 1m downslope of trenches; Piezometer 2 – 3m downslope of trenches
Numbers represent three separate sampling episodes

**Figure 3** Water chemistry changes for Total Nitrogen at Site 1

The natural soil system offers a medium for not only absorbing pollutants, but for treating and utilising waste constituents. The porous nature of soil can provide an ideal media for absorbing and transmitting effluent. A sinuous flow path through soil pores that is neither too rapid nor too slow allows for a variety of natural treatment processes to take place. Purification occurs through physical filtration, chemical treatment through ion exchange, adsorption and transformation, biological decomposition by micro-organisms as well as enrichment of the nutrient pool for uptake by plants (Dawes and Goonetilleke 2003).

The results obtained imply that in a significant majority of the sites investigated, the quality that is achieved within the initial 1m of travel is the final quality. This hypothesis could be interpreted to mean, that while the concentration of pollutants may be expected to decrease with distance due to dispersion and dilution, the total quantity percolating into a water course or aquifer may be determined by the processes occurring within the initial few meters of soil downslope of the adsorption trenches. It is important to note that the results discussed above relates only to the effluent percolating through the subsurface. In the case of four systems out of sixteen, some type of failure of the effluent disposal system was noted with surface break-out of effluent. Therefore even though the subsurface may be treating the effluent to a satisfactory quality, failure of the system could result in poor quality effluent flowing over the surface.

Under these circumstances it is open to question whether the common practice of stipulating setback distances from sensitive water bodies is of any tangible value. However this argument should be tempered with the fact that only a small number of effluent samples were analysed, thus results obtained preclude drawing statistically significant conclusions.

## Physical Characteristics

The physical properties of a soil profile, particularly texture, structure and moisture regime can be used to determine the effect of movement of water into and through the soil (Baker and Eldershaw 1993). The sub-surface characteristics of the disposal area are among the most important factors governing the performance of effluent treatment processes (Jenssen and Siegrist 1990, Bond 1998). Purification of effluent will occur within a minimum depth of unsaturated soil beneath the disposal trenches. In this context, effective depths ranging from 0.6m to 2m have been quoted in research studies (Johnson and Atwater 1988, Mote et al 1995, Siegrist and Van Cuyk 2001).

The drainage characteristics result from a complexity of factors such as layering or stratification of the soil, permeability of soil horizons, presence of restrictive layers, position in the landscape catena and weather conditions (White 1997). Table 3 presents the drainage observations noted in relation to the sub-surface disposal areas at the study sites. These results illustrate that lateral seepage of effluent from the disposal field can occur independent of sites being well drained or poorly drained.

The data in Table 3 along with laboratory permeability test data in Table 4 confirm the wide variation in infiltration rates for similar soil types. Additionally, the surface soils can be 1000 times more permeable than the clay enriched 'B' horizon. The permeability contrast between the 'A' and 'B' horizons is primarily associated with soil texture and the illuviation of clay particles by water movement through the soil profile. The clay enrichment deeper in the profile reduces permeability, thereby impeding drainage and can cause waterlogging.

**Table 3** Subsurface drainage characteristics

| Site No. | Soil profile observations at piezometer sites | Drainage Class[a] | Observed Drainage[b] | Depth from surface to restrictive layer[c] |
|---|---|---|---|---|
| 1 | Significant lateral seepage at 0.5m. Saturated zone at top of B horizon | Moderately well drained | mainly downward<br>minor ponding observed | 0.6 |
| 3 | Significant lateral seepage at 0.5m. Saturated A horizon | Imperfectly drained | lateral<br>minor ponding observed | 0.5 |
| 4 | Minor lateral seepage at 0.4m. Saturated profile throughout | Imperfectly drained | mainly downward | 0.6 |
| 7 | No lateral seepage observed. Saturated A horizon | Moderately well drained | downward | 0.7 |
| 8 | Significant lateral seepage at 0.3m. Saturated A horizon. High water table | Poorly drained | lateral<br>ponding observed | 0.3 |
| 9 | Significant lateral seepage at 0.4m. Saturated profile throughout | Poorly drained | lateral<br>ponding observed | 0.3 |
| 11 | No lateral seepage observed. Uniformly saturated profile | Well drained | downward | 0.7 |
| 12 | Minor lateral seepage at 0.4m. Saturated zone at top of B horizon | Moderately well drained | downward | 0.7 |
| 14 | Significant lateral seepage at 0.3m. Saturated zone at top of B horizon | Moderately well drained | mainly downward<br>ponding observed | 0.4 |
| 15 | No lateral seepage observed. Well drained A horizon | Moderately well drained | mainly downward | 0.7 |
| 16 | No lateral seepage observed. Saturated at top of B horizon | Poorly drained | lateral<br>ponding observed | 0.4 |

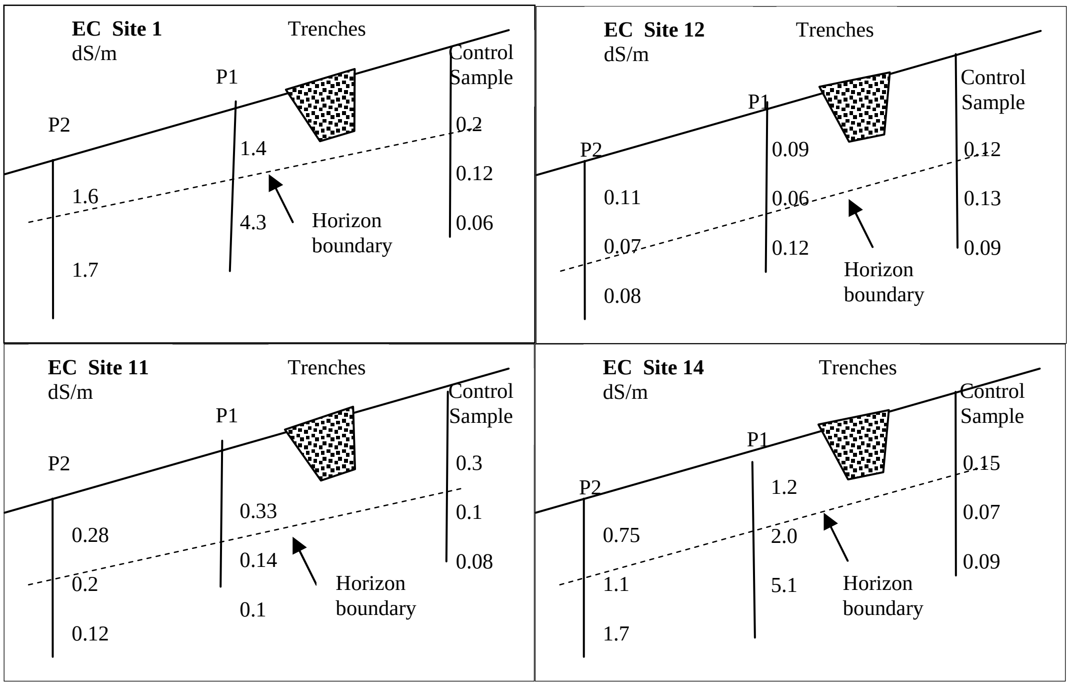
a the classification used complies with AS/NZS 1547:2000 (Standards Australia, 2000), McDonald et al. (1990).
b derived from soil moisture profiles and soil chloride profiles to determine drainage flow
c based on soil profile description and field measurements

Several of the study sites had slowly permeable soil at the 'B' horizon indicating that lateral flow is prevalent. A medium to heavy clay 'B' horizon effectively acts as an impermeable barrier to vertical flow through the soil. Therefore as the 'A' horizon becomes saturated, lateral flow of effluent is preferred rather than downward movement. These conditions were further confirmed by the fact that the 'B' horizon showed signs of redoximorphic features such as free water, presence of mottling and iron accumulation. Such variations indicate a seasonal groundwater table during wet periods (Gross et al 1998). Under these circumstances, flow of effluent into surface water bodies can potentially occur. The lateral flow rate is dependant on the slope and hydraulic conductivity of the soil. The soil electrical conductivity profiles shown in Figure 4a and 4b also support the lateral movement of effluent through the more permeable surface layers. Where effluent ponding was observed, salt accumulation in the soil significantly increased independent of drainage class (Sites 8, 9 and 14 in Figure 4a, b). This could indicate that structural breakdown of the soil has led to restricted water entry and changed the moisture regime of the soil.

**Table 4** Laboratory permeability results for undisturbed soil samples

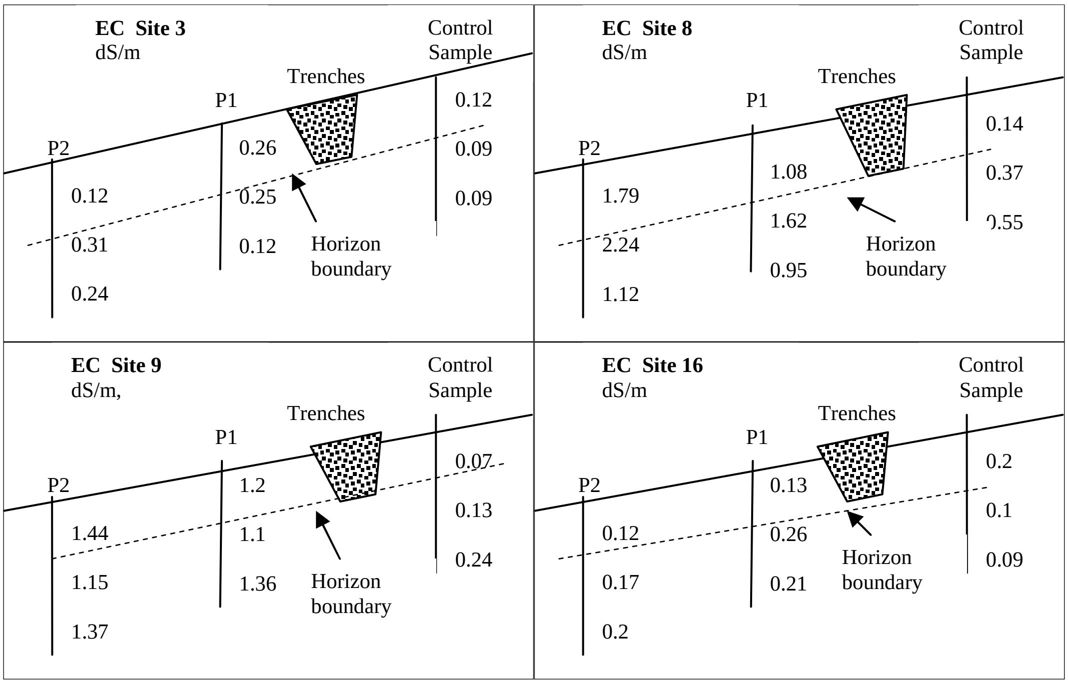
| Location | Sample Depth (m) | Horizon | Permeability (mm/day) | Observations |
|---|---|---|---|---|
| Site 1C | 0.2 - 0.35 | A | 378 | Sandy loam |
| | 0.6 – 0.74 | B | 45 | Swelling clay |
| | 1.2 – 1.32 | C | 1730 | Jointed Shale with clay infill |
| Site 1ED | 0.55 - 0.68 | B | 28 | |
| Site 3C | 0.25 – 0.40 | A | 1258 | Sandy loam |
| | 0.55 – 0.67 | B | 17 | Mottling of light clay |
| | 1.1 – 1.2 | C | 33 | Mottling of sandy clay |
| Site 3ED | 0.50 – 0.65 | B | 2 | |
| Site 4C | 0.6 – 0.78 | B1 | 11 | Minor mottling of sandy clay |
| | 0.95 – 1.1 | B2 | 22 | |
| Site 8C | 0.1 – 0.22 | A | 1245 | Brown sandy loam |
| | 0.3 – 0.44 | B1 | 8 | Mottling of loamy clay |
| | 0.60 – 0.72 | B2 | 13 | Mottled heavy clay |
| Site 9C | 0.3 – 0.51 | B1 | 12 | Red and yellow mottling |
| | 0.90 –1.10 | B2 | 37 | |
| Site 11C | 0.7 – 0.85 | B1 | 172 | |
| | 1.1 – 1.24 | B2 | 439 | Silty loam with some gravel |
| Site 12C | 0.2 – 0.37 | A | 2540 | Brown sand |
| | 0.7 - 0.87 | B1 | 565 | Well drained loamy sand |
| | 1.1 - 1.25 | B2 | 280 | |
| Site 15C | 0.25 – 0.41 | A | 881 | Sandy loam |
| | 0.7 – 0.85 | B1 | 65 | Kaolinite clay |
| | 1.1 -1.25 | B2 | 18 | Red and white sandy clay |
| Site 16C | 0.6 – 0.7 | B1 | 5 | Red and grey mottling |
| | 1.2 – 1.3 | B2 | 10 | Mottled grey red heavy clay |
| Slowly permeable less than 10mm/day<br>Moderately permeable 10mm to 1000mm/day<br>Highly permeable more than 1000mm/day<br>(Adapted from Baker and Eldershaw 1993) | | | | |

Sites 7 and 14 were not sampled due to difficulty in obtaining a representative undisturbed soil sample
ED – permeability of soil within disposal field
C – permeability of control soil (outside the influence of effluent disposal)



P1 – Piezometer 1 at 1m; P2 – Piezometer 2 at 3m
Numbers represent different sampling depths

**Figure 4a** Soil electrical conductivity profiles for well drained sites



P1 – Piezometer 1 at 1m; P2 – Piezometer 2 at 3m
Numbers represent different sampling depths

**Figure 4b** Soil electrical conductivity profiles (imperfectly/poorly drained sites)

As part of the analysis undertaken each of the study sites was located on a hypothetical hydrological sequence, based on the drainage characteristics, landscape position and profile description. Physical soil properties that influence soil structure and stability including soil permeability, clay content and clay type were compared at each site with observed treatment performance. Shaw et al (1994) found that soils with mixed mineralogies are the most sensitive to sodium variations and will form the least permeable matrix if the clay content is around 40 to 50%. Sites 3, 8 and 9 (Figure 5 and Table 5) exhibit these characteristics. Subsurface effluent disposal involves a series of wetting and drying cycles which would align the clay and restructure the soil. In soils with minimal shrink swell characteristics (kaolinite and illite clay), a dense soil matrix will form, whereas in soils with appreciable shrink swell properties (smectite clay), some regeneration of soil properties and porosity would result. Thus soils with a predominance of smectite clays have the ability to efficiently renovate effluent even with moderately high exchangeable sodium.

A strong correlation ($r^2$ = 0.83) between the depth to the restrictive horizon measured at a site, and observed treatment performance was noted from the study results. Observed performance was defined by field observations, soil water sampling results**,** detailed site history obtained from the householder and surface and sub-surface site conditions noted during the study. In cases where the restrictive horizon shown in Table 3 was less than 0.4m from the surface, inadequate purification of effluent was the general outcome. Figures 5 and 6 which show a standard depiction of soil drainage (White 1997) for sites in imperfectly to poorly drained landscapes illustrate these conclusions. All moderately to well drained sites have restrictive horizons greater than 0.5m from the surface and are not shown in these figures.

**Table 5** Soil Properties from Top of B Horizon

| Site No.[a] | Observed Performance[b] | Particle size | | | Clay type | pH | EC dS/m | Ex Na meq/100g | ESP % | CEC meq/100g | Ca:Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | | | | | | | |
| 1C | Satisfactory | 41 | 28 | 31 | S | 6.7 | 0.12 | 1.55 | 3 | 43 | 0.95 |
| 1ED | | 26 | 43 | 34 | | 6.9 | 1.54 | 2.40 | 5 | 48 | 0.54 |
| 3C | Fail (Hydraulic) | 44 | 21 | 35 | K/I | 5.1 | 0.09 | 1.95 | 18 | 10 | 1.29 |
| 3ED | | 35 | 24 | 41 | | 5.7 | 0.25 | 2.01 | 20 | 12 | 0.06 |
| 4C | Satisfactory | 51 | 19 | 30 | I | 4.2 | 0.08 | 0.68 | 4 | 9 | 0.94 |
| 4ED | | 48 | 18 | 34 | | 4.5 | 0.14 | 0.84 | 10 | 14 | 0.50 |
| 7C | Satisfactory | 66 | 14 | 20 | S | 7.3 | 0.17 | 0.41 | 2 | 34 | 4.00 |
| 7ED | | 62 | 15 | 23 | | 7.2 | 0.24 | 0.49 | 2 | 36 | 1.72 |
| 8C | Fail (Contamination) | 13 | 30 | 57 | K/I | 5.7 | 0.46 | 4.84 | 26 | 7 | 0.59 |
| 8ED | | 11 | 25 | 64 | | 6.3 | 1.93 | 5.20 | 28 | 11 | 0.13 |
| 9C | Fail (Hydraulic) | 8 | 34 | 58 | K/I | 5.5 | 0.37 | 0.47 | 6 | 8 | 0.79 |
| 9ED | | 12 | 21 | 67 | | 6.4 | 1.25 | 1.41 | 16 | 11 | 0.19 |
| 11C | Satisfactory | 45 | 35 | 20 | S | 5.4 | 0.11 | 1.80 | 4 | 42 | 1.05 |
| 11ED | | 40 | 42 | 18 | | 6.9 | 0.17 | 2.10 | 8 | 45 | 0.84 |
| 12C | Satisfactory | 49 | 30 | 21 | K/I | 4.7 | 0.07 | 0.12 | 13 | 10 | 1.38 |
| 12ED | | 41 | 33 | 26 | | 5.2 | 0.07 | 0.28 | 15 | 12 | 0.61 |
| 14C | Satisfactory | 38 | 30 | 32 | I | 4.8 | 0.07 | 0.33 | 5 | 10 | 0.47 |
| 14ED | | 32 | 32 | 36 | | 6.4 | 1.10 | 0.42 | 6 | 11 | 0.38 |
| 15C | Satisfactory | 33 | 30 | 37 | K | 4.8 | 0.11 | 0.09 | 1 | 7 | 1.42 |
| 15ED | | 30 | 30 | 40 | | 5.2 | 0.16 | 0.15 | 1 | 5 | 2.60 |
| 16C | Fail (Hydraulic) | 16 | 25 | 59 | K | 4.3 | 0.10 | 0.40 | 6 | 6 | 0.38 |
| 16ED | | 20 | 21 | 59 | | 5.4 | 0.19 | 0.52 | 7 | 7 | 0.09 |

a missing numbers are sites abandoned due to insufficient soil water sample and unreliable historical site information
b based on field observations, soil water sampling, detailed site history and surface and sub-surface site conditions noted during the study. Failure criteria based on USEPA On-site Wastewater Treatment Manual 2002, Section 5.8
**Hydraulic** – untreated or partially treated sewage ponding on surface or sewage breakouts on slopes
**Contamination** – high nitrate levels, microbial contamination
ED - Effluent disposal soil, C - Control soil
S – Smectite, K – Kaolinite, I – Illite, K/I - Mixed mineralogy

## Chemical Properties

The soil chemistry parameter selection was based on the suite of tests generally carried out in land resource evaluation (Rayment and Higginson 1992). These tests have been developed through extensive agricultural research and are designed to distinguish between deficient, adequate and toxic supply of elements in soil as well as between degraded and non-degraded soil conditions. These criteria are being increasingly used in environmental monitoring (Peverill et al 1999).

Chemical data such as exchangeable cations, Ca:Mg ratio and exchangeable sodium percentage (ESP) were employed as possible indicators to investigate the likely deterioration of the soil structure due to sewage effluent disposal. Influential soil parameters were identified and correlations and linkages between these parameters and drainage factors were investigated. These parameters included cation exchange capacity (CEC) or Effective Cation Exchange Capacity (ECEC), dominance of exchangeable Ca or exchangeable Mg over exchangeable Na concentration, Ca:Mg ratio and dispersiveness (ESP or Emerson test).

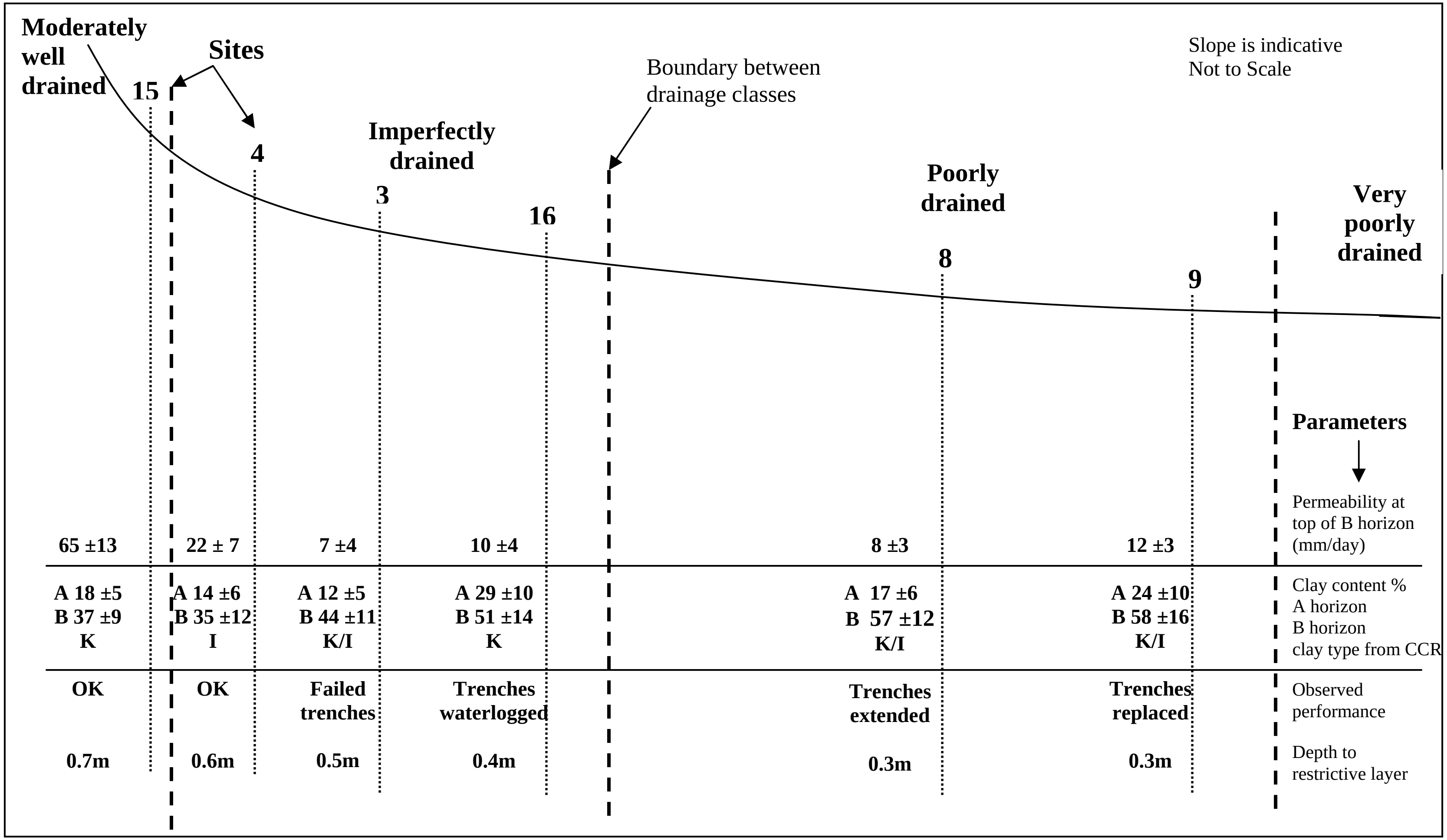



**Figure 5** Profile and physical characteristics of drainage classes

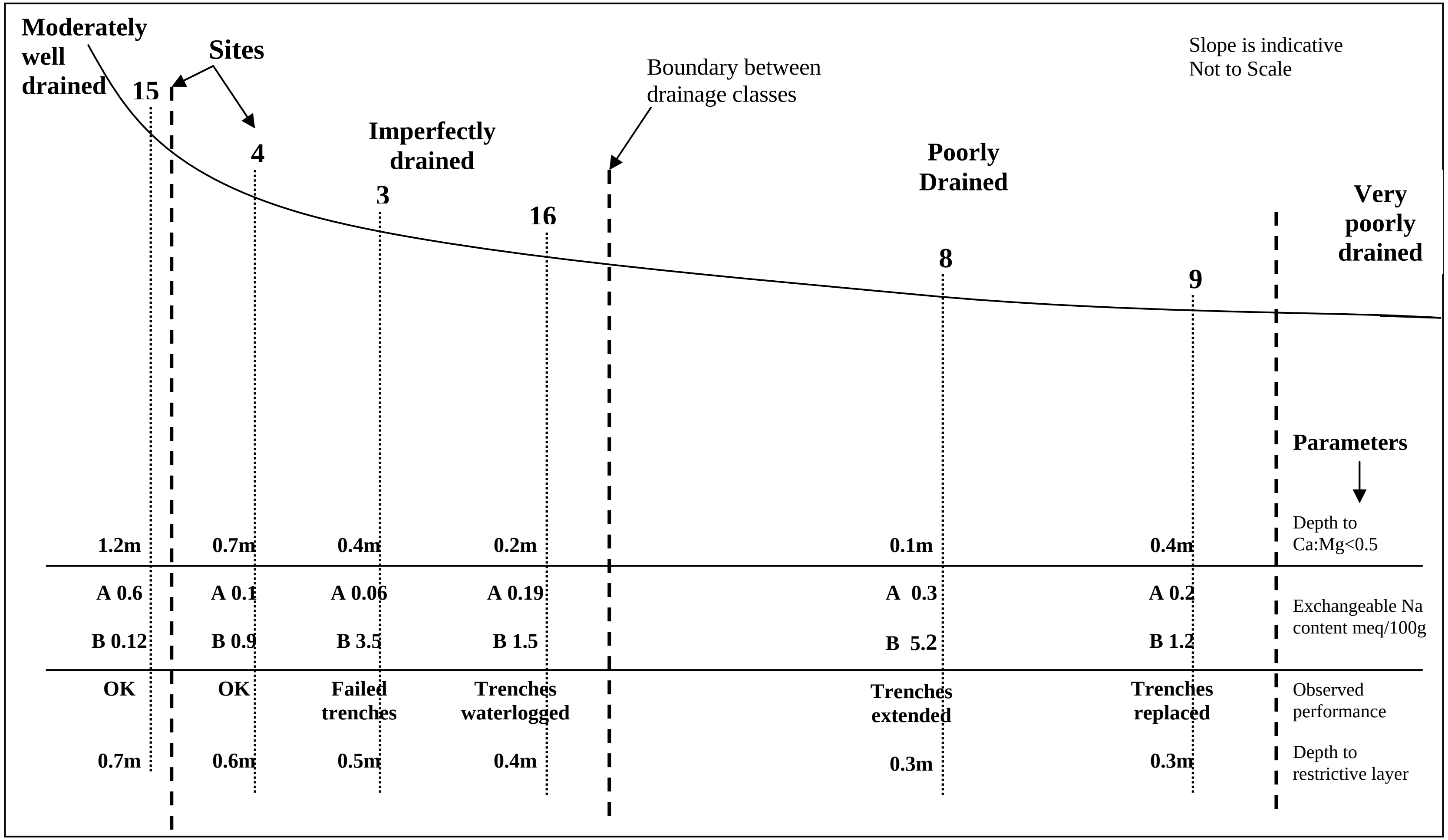



**Figure 6** Combined chemical and physical characteristics of drainage classes

The results from the sampling and testing program found appreciable changes in exchangeable cations such as Ca, Mg and Na as well as in parameters such as pH, EC and CEC (or ECEC) compared to control sites due to the sub-surface application of sewage effluent (Table 5). Suarez et al (1984) found that altering soil pH can strongly influence the dispersibility of kaolinite. These chemical parameter changes were comparable with other findings relating to New Zealand and Southern Australian soils (Stewart et al 1990, Falkiner and Smith 1997, Speir et al 1999, Menneer et al 2001,).

So and Aylmore (1993) suggested using exchangeable sodium content (ESC), measured on a dry soil basis, as a means of eliminating the texture factor in evaluating an index for sodicity. This was supported by Cook and Muller (1997) who concluded that ESC explained soil behaviour better than ESP and hence was a better index of sodicity. It is important that Exchangeable Sodium Percentage (ESP) and ESC (meq/100g) values are corrected for soluble salts, to ensure that these parameters are not overestimated. As shown in Figure 7, comparisons of performance observed at satisfactory and failed sites support this contention. Exchangeable sodium content is highly correlated with ESP in sites where soil degradation and subsequent hydraulic failure occurs. Whereas in sites defined as satisfactory no correlation is observed. Thus exchangeable sodium content (ESC) is a better indicator for prediction of how soils behave under long term effluent disposal with exchangeable sodium percentages (ESP) over 10%.

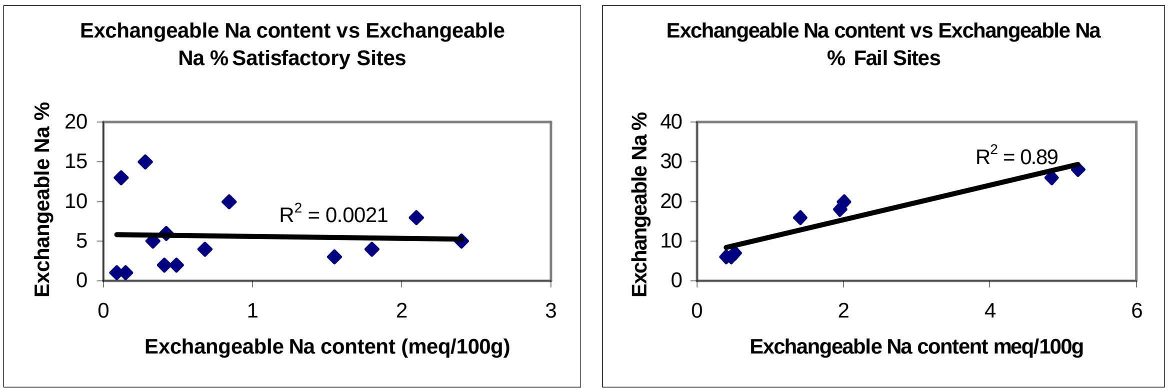



**Figure 7** Regression analysis of exchangeable sodium indices

The Ca:Mg ratio in the soil was employed to indicate cation distribution, particularly in the case when the subsoil is dominated by $Mg^{2+}$. An excess of one cation may inhibit the uptake of another. Emerson (1977) found that ratios less than 0.5 are associated with soil dispersion. This is supported by Shaw et al. (1997) who postulated that low Ca:Mg ratios in conjunction with high ESP indicate enhanced dispersion. Figure 6 shows these chemical characteristics included in the hydrological sequence compared for each site with observed treatment performance and depth to restrictive layer.

Soils with moderate to high CEC (or ECEC), Ca:Mg >0.5, dominance of exchangeable Ca or exchangeable Mg over exchangeable Na concentration and thus low ESP have the ability to treat effluent over time without major soil structure deterioration (Dawes and Goonetilleke 2001). In some cases such as Sites 1 and 11, moderate to high exchangeable Na concentration was offset by the presence of swelling clays and the co-dominance of exchangeable Ca and exchangeable Mg. These characteristics have the ability to aid the adsorption of cations at depth and confirm that soils with swelling clays can be stable even at high exchangeable sodium levels. These conclusions are supported by Curtin et al (1994) in a study on prairie soils in Saskatchewan, Canada and by Shaw et al (1994) in a review of sodic soil behaviour in Queensland.

## Hydrological Sequence

Generally, in undulating landscapes on permeable material, the soils near the top of the slope tend to be free draining with a deep watertable, whilst the soils at the valley bottom are poorly drained with the watertable at or near the surface (McDonald et al 1998, McIntosh et al 2000). The succession of soils forming under different drainage conditions on relatively uniform parent material comprises a hydrological sequence. This was employed to classify sites into drainage classes as given in Table 1 and shown in Figures 5 and 6. The results of the study undertaken confirmed that by determining the site location, its position in the landscape, slope and other relevant topographic features, it is possible to determine whether more detailed soil chemical investigations are justified.

During the study, sites were initially categorised by their landscape position along with subsurface drainage characteristics. Where the soil profile evaluation confirmed favourable drainage characteristics, no further detailed chemical analysis was found to be warranted. In the case of poor drainage, knowledge of detailed soil chemistry was found to be a valuable tool in predicting site suitability for effective long term effluent disposal. Very poorly drained sites can be deemed unsuitable for on-site wastewater treatment especially in small lot developments even without further investigations.

An example was a 'duplex' soil at Site 3, which was thought to be imperfectly to moderately drained based on its position on the landscape. However, the detailed soil profile evaluation at the control site revealed the presence of a clay-enriched zone at the top of the 'B' horizon at a depth of 0.5m. Subsequent soil chemistry revealed low Ca:Mg ratio and high exchangeable Na and thus a high ESP, low ECEC) and the exchange capacity being dominated by exchangeable Mg. These results indicated that poor soil conditions exist for effective effluent treatment. Conclusions of this nature could only have been derived from soil chemical analysis. It was subsequently confirmed that the householder had replaced a failed septic system due to constant overflowing and waterlogging of the disposal trenches. This highlights the importance of detailed subsurface soil evaluation and confirms the strong site specific nature of effluent treatment.

## Conclusions

The physical and chemical properties of a soil which can be used to predict suitability for long term effluent disposal include:

1. Moderate to slow drainage (permeability) to assist the movement of effluent (percolation) through the soil profile and allow adequate time for treatment to occur. With longer percolation times, the opportunity for exchange and transport processes increases.
2. Significant soil cation exchange capacity and dominance of exchangeable Ca or exchangeable Mg over exchangeable Na. Although a soil dominated by Mg is found to promote dispersion of soil particles to some extent, its impact is far less than that of Na. A stable soil would have a Ca: Mg ratio > 0.5.

3. Low exchangeable Na content to maintain soil stability.
4. Minimum depth of 0.4m of potentially unsaturated soil before encountering a restrictive horizon to permit adequate purification to take place.
5. Clay type having appreciable shrink swell properties causing some regeneration of soil properties and thus increased porosity.

Suitability of sites for effluent disposal depends on whether the soil exhibits the above characteristics. Suitability also depends on the position of the site within the hydrological sequence. By determining the site location, its position in the landscape, slope and other relevant topographic features, it is possible to determine whether more detailed investigations should be undertaken. As an example, if a soil lies in the upper section of the landscape and is well drained, soil chemistry as a predictive tool adds less value than where the soils lie in lower positions in the landscape where drainage is poor. Soils in the lower landscape position need soil chemical investigations to assist in characterisation and prediction.

An in-depth knowledge of the local soil characteristics and associated soil hydrology is essential for a better prediction of long-term treatment potential of subsurface effluent disposal systems. It is important to be aware of the need to integrate the factors described above in understanding soil structure stability and predicting long-term sustainability of effluent disposal areas.

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