N E W   Z E A L A N D

GUIDELINES

FOR UTILISATION OF SEWAGE EFFLUENT ON LAND

PART TWO: ISSUES FOR DESIGN AND MANAGEMENT

NEW ZEALAND LAND TREATMENT COLLECTIVE

L.J. Whitehouse, H. Wang and M.D.Tomer
(Editors)

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Preface

The *Guidelines for Utilisation of Sewage Effluent on Land* comprise a two-part manual prepared to assist persons who design, consent, manage or monitor land treatment systems for municipal or domestic wastewater in New Zealand. Part 1 provides a guide to the overall process involved in designing, gaining resource consents, and setting up management systems. Part 2 provides supporting information, serving as a technical reference on key issues related to designing, operating and monitoring land treatment systems. Further detail can be obtained from sources which are referenced in Part 2.

Note that these guidelines are limited in scope to systems where the final treatment of effluent occurs (or will occur) by irrigating it onto a standing crop that is intended for harvest and economic return. Wetland systems and rapid infiltration basins/trenches are not addressed.

Topics covered in Part 2 are outlined below:

Chapter 1. ***Effluent characteristics.*** Outlines wastewater treatment processes and other factors that determine the quantity and quality of effluent produced by a community.

Chapter 2. ***Soil Processes.*** Describes basic physical, chemical, and biological processes that occur in soils and their importance in determining the effectiveness of waste treatment in soil.

Chapter 3. ***Environmental Effects***. Considers how effluent application can affect the receiving environment, including land, water, and air resources, and summarises how these effects can be minimised.

Chapter 4. ***Site Selection***. Summarises the investigative process that leads to final selection of a land treatment site.

Chapter 5. ***Application Methods***. Describes hardware technologies for safely applying effluent onto land with appropriate control on application rates.

Chapter 6. ***Crop Selection and Management.*** Outlines basic information that must be considered when selecting a crop to grow in a land treatment system.

Chapter 7. ***System Management and Monitoring.*** Outlines the key topics to be included in a managing and monitoring plan, and describes how monitoring can be used to help manage a land treatment system.

Taken as a whole, Parts 1 and 2 of the manual summarise our current technical knowledge of land treatment systems, and suggest a process that, if followed, will help ensure that the chosen system will perform successfully—in terms of providing waste treatment, protecting environmental quality, maintaining crop production, and ensuring public health and safety. The diagram on page v shows the process involved in designing a land treatment system, which is described in Part 1. Chapters in Part 2 provide supporting information that is useful at various stages of design as indicated in the diagram. The two parts of the manual relate to one another and are intended to be used together.

In preparing this manual we have generally assumed the reader already has some basic knowledge and enough experience to exercise professional judgement in applying the information given to a specific situation. The manual should be useful for:

- *System designers.* The documents will be helpful in describing the process of land treatment design, determining what information is needed to evaluate design alternatives, assessing potential environmental effects of different designs, and identifying options for monitoring and mitigating any adverse effects.

- *System owners and operators:* The documents provide system owners and operators with guidance on managing application rates, soils, and crops. They describe how to design and implement a monitoring programme, and how to go about evaluating and improving management of the system.

- *Regulatory authorities:* Although these documents are not intended for restrictive or regulatory purposes, they contain information helpful in evaluating the design of a land treatment system, setting appropriate operational conditions, and interpreting data collected from monitoring. They can be used as a reference for developing regional policies for land treatment.

- *Training and education:* Young professionals and students can benefit from the wide range of information on land treatment that is summarised and referenced in this manual.

Note that we have used the words *sewage effluent* in the title and throughout the text of the manual, thereby clearly stating that the guidelines are concerned with managing wastewater from municipal and domestic sources. Any direct application to other sources of wastewater, of which there are many, is outside their intended use.

The manual does not provide exhaustive coverage in all areas, but includes many references to sources of additional information. Periodic update of the manual is recommended as research progresses and improved technical tools become available.

There are several appendices to these documents, including excerpts from the 1992 Department of Health Guidelines (focussed on protection of public health) which these guidelines do not supplant. A listing of existing land treatment systems, for which a fairly detailed data base on operation and monitoring criteria are available, can be viewed at www.forestresearch.co.nz/nzltc/. Case studies are not detailed herein, however several pertinent case studies are described in past proceedings of the Land Treatment Collective.

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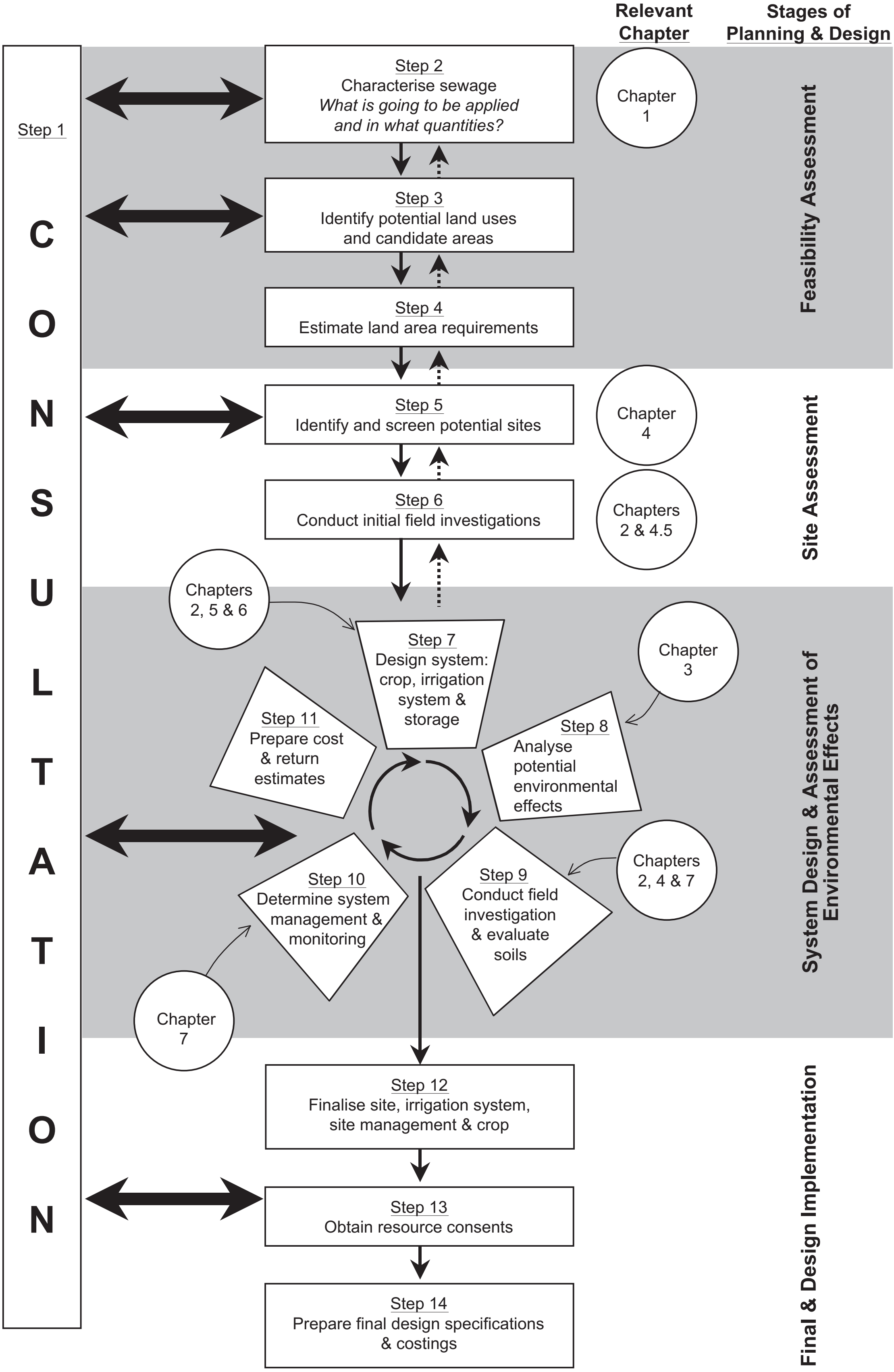

Design process for a land-based effluent treatment scheme

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Mark Tomer
Chairman, Guidelines Steering Committee

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Readers Key to
Guidelines for Utilisation of Sewage Effluent on Land

These topics:	Are important in the following steps in Part 1	Are described in detail in these chapters and sections of Part 2
Wastewater	Step 2	all of Chapter 1
Pathogens	Step 8	Sections 1.2.7, 1.3, 2.4, 3.2.2, 3.3.2, 3.4.2, 3.5.3, 7.10
Soil processes and assessments	Steps 3, 4, 5, 6, 7, 8, 9	all of Chapter 2, Sections 3.3, 4.5.1, 4.6, 7.8.1, Appendix 2
Ground water	Steps 5, 6, 8, 9	Sections 3.4, 4.5.2, 4.7, 7.8.3, Appendix 3
Surface water	Steps 3, 5, 8, 9	Sections 3.3.3, 3.5, 4.5.3, 7.8.3
Air quality and aerosols	Steps 3, 5	Sections 3.2, 5.3, 5.4, 6.3.1, 7.8.2
Application rates	Steps 4, 7	Sections 2.2, 3.3.6, 7.6
Application methods	Steps 7, 8, 11	all of Chapter 5
Crop selection and cropping systems	Steps 3, 4, 7, 8, 10, 11, 12	all of Chapter 6, Section 7.7
Nutrients: removal, uptake, and effects	Steps 4, 7, 8, 10, 12	Section 2.3, 3.3.8, 3.4.3, 7.7, 7.8
Site investigations	Steps 6, 9	all of Chapter 4, Appendices 2 and 3
Monitoring systems	Step 10	Sections 7.7 to 7.10, Appendix 3
Management of land treatment systems	Step 10	all of Chapter 7
Buffer zones	Steps 4, 8, 10	Sections 3.2, 7.9

1. SEWAGE EFFLUENT CHARACTERISTICS

Rob Potts and Brian Ellwood

Glasson Potts Group Limited

1.1. INTRODUCTION

1.1.1 Scope

This chapter describes those constituents contained in wastewater of principally domestic origin. It provides an indicative range of values for each constituent and, for the more common land application methods, indicates levels that present a low, medium or high hazard. The information is intended to assist those implementing a land treatment scheme with decisions on the degree of pretreatment required for wastewater prior to its application onto land. Hence an overview of pretreatment options and their effects on sewage constituents is also included.

1.2. RAW SEWAGE CHARACTERISATION

1.2.1 Flow volumes

Wastewater generation varies between communities, depending on the type of housing, water source, number of industries, age of the sewer system, climate and depth to groundwater. Variation in flow rate occurs both during the day and throughout the year depending on the number of occupants in a given dwelling and their habits.

The average dry weather flow (ADWF) per capita varies from 140 to 180 L/p.d. (litres per person per day) for on-site systems (effluent is disposed of on the site it originates from) to 100 to 570 L/p.d for community systems. Community values are typically 150 L/p.d (summer bach or crib) to 360 L/p.d (luxury home with all modern conveniences), with a normal size house providing 265 L/p.d (Metcalf and Eddy 1991).

The ADWF does not occur over 24 hours of the day. Peak flows occur around mid to late morning (late morning in large reticulated systems) and again in the early evening. Peaking factors (PF) should be determined by analysing flow data for the community. If no flow data are available, then the factor is based either on the connected population or ADWF (Table 1.1). Multiplying PF by the average 24 hour flow provides peak hourly flow. Peaking factors may be slightly lower for systems that include on-site settlement before the effluent enters community reticulation, or where there is a major community use outside of the peak times, such as from a large school.

Table 1.1. *Peaking factors for various size communities*

ADWF (m^3/d)	100	200	300	500	1000	5000	50000
PF	6	4	3.3	2.8	2.4	2.2	1.9

Source: *Christchurch City Drainage and Waste Management Unit Design Manual (9/86)*

Infiltration into pipes from the soil and inflows of storm water also need to be allowed for in design, to estimate both peak wet weather flow (maximum peak design flow for pump stations, pipe sizing and primary screening etc.) and longer term volumetric loading for water mass balances.

Some infiltration needs to be allowed for even in new reticulation systems. Infiltration is usually a steady flow but can vary significantly from summer to winter depending on groundwater levels. Actual infiltration can vary from 0.0094 to 0.94 m^3/d/mm.km (i.e., a factor based on the sum of the pipe diameters times the pipe lengths). A simpler method is to base infiltration on the area of the community; values can range from 0.002 to 0.324 L/s.ha (Metcalf and Eddy 1991). The values used in New Zealand are generally between 0.05 and 0.07 L/s.ha (Christchurch City Council 1986).

Inflows from direct stormwater runoff cause an immediate increase in wastewater flows during rainfall events. Depending on the number of connections (roof downpipes, yard drains, manhole covers, cross connections from stormwater drains) the flow from direct inflow can be huge, i.e., in excess of 5.4 L/s.ha (Metcalf and Eddie 1991). The values used for New Zealand conditions are generally 0.15 to 0.19 L/s.ha (Christchurch City Council 1986), with 30% variation either way to allow for especially wet or dry areas. To provide for peaks in inflow, treatment plants are usually designed to accommodate between four and six times ADWF. In older areas, infiltration can be much greater than this.

1.2.2 Organic matter

Biochemical oxygen demand (BOD)

The BOD test is a measure of the amount of oxygen required for biochemical oxidation of organic matter. However, BOD is not usually critical for land treatment systems, as explained in Section 3.3.7.

The BOD test is the most commonly used parameter for measuring organic pollution. This test measures the dissolved oxygen used by micro-organisms in the biochemical oxidation of organic matter over a five day period. There are several limitations to the BOD test, and care must be taken in interpreting results.

Typical influent BOD concentrations for New Zealand are between 154 g/m^3 and 456 g/m^3 with an average of 244 g/m^3 (NZWWA 1994). The removal efficiency of treatment plants is high, with average removal of 91% and an average effluent concentration of 23 g/m^3.
The BOD load per capita is shown in Table 1.5.

Chemical oxygen demand (COD)

The COD test is also used to assess the amount of organic matter present in a sample. The oxygen equivalent of the organic matter that can be oxidised is measured by using a strong oxidising chemical oxidising agent in an acid medium. This test can be used to measure organic matter when there are compounds toxic to biological organisms. The COD test is quick and easy to perform and its use is therefore increasing. It is possible to correlate COD to BOD and use COD for routine monitoring.

For typical domestic untreated sewage, the BOD/COD ratio is between 0.4 and 0.8, i.e., COD of raw sewage is typically 500 g/m^3. This ratio varies considerably after treatment (Metcalf and Eddy 1991).

Total organic carbon

This is another method for measuring the organic matter content of a sample. The test is performed by injecting a measured amount of sample into a high-temperature furnace or chemically oxidising environment and measuring the amount of CO_2 given off. This method is very good for measuring low carbon concentrations.

For typical domestic untreated sewage the BOD/TOC ratio is between 1.0 and 1.6. This ratio varies considerably after treatment (Metcalf and Eddy 1991).

1.2.3 Suspended material

The solids content must be considered when applying effluent to land because of the danger of clogging spray nozzles or emitters. The suspended solid load per capita is shown Table 1.5. Tables 1.6–1.8 give average suspended solids (SS) loadings for raw and treated effluent. Pretreatment of some form to remove suspended solids prior to application to land is usually required.

1.2.4 Nutrients

Nitrogen

Typically, raw sewage has concentrations of total nitrogen between 7 and 57 g/m^3 with an average of 34 g/m^3 for municipal systems. The nitrogen concentration for small communities or on-site systems can be calculated by assuming a loading of 10 to 12 g N per person per day.

The forms of nitrogen in raw sewage are typically:

- Organic 37.5% of total;
- Ammonia 62.5% of total.

Removal of total nitrogen is achieved partly by volatilisation of ammonia gas, partly by denitrification of nitrates to a variety of nitrogen gases, and partly by withdrawal of organic nitrogen contained within biomass and particulate material.

However, before denitrification can take place, organic and ammoniacal nitrogen must be converted to nitrate by nitrifying organisms. The nitrification process is a two step reaction, *Nitrosomonas* bacteria oxidise NH_4^+ to NO_2^- and *Nitrobacter* bacteria convert NO_2^- to NO_3^-. The process is influenced by factors such as solids retention time (SRT), temperature, pH, dissolved oxygen and carbon to nitrogen (C:N) ratio. Relatively long SRT's or sludge ages are required for nitrification due to the slow growth of nitrifying organisms.

A typical removal range for standard secondary treatment systems is –9% to 84% (average 26%) giving an effluent concentration between 2 and 40 g/m^3 (average 26 g/m^3). Treatment systems can, however, be specifically designed for nutrient removal, as discussed in Section 1.3. The production of nitrate can be a critical process for land treatment as nitrate is highly mobile in the soil (Chapter 2). Therefore, treatment processes that nitrify the wastewater without removing a significant proportion of the total nitrogen can be detrimental to a land treatment system. The nitrogen load per capita is shown in Table 1.5.

Phosphorus

Typically, raw sewage has a total phosphorus concentration between 3.3 and 13.0 g/m^3 with an average of 7.3 g/m^3 for municipal systems. The total phosphorus concentration for small communities or on-site systems can be calculated using a P loading of 3 to 3.5 g/p.d

The forms of phosphorus in raw sewage are typically:

- Organic 37.5% of total;
- Inorganic 62.5% of total.

Phosphorus may be removed biologically or chemically. To remove soluble phosphorus biologically, it must be incorporated into biomass. This can be achieved by subjecting bacteria in the effluent to alternating anaerobic and aerobic conditions. During the anaerobic period phosphorus accumulated within the bacterial biomass as polyphosphate is hydrolised to release energy, and phosphorus is released from cell biomass into solution. During the aerobic periods phosphorus is absorbed in a luxury amount. The extra phosphorus is stored in anticipation of anaerobic conditions, and hence biomass removal is carried out before a subsequent anaerobic step.

Chemical removal of phosphorus involves precipitation with calcium, iron, or aluminium. Phosphorus precipitation is affected by pH. The optimal pH for calcium precipitation is above 10, whereas the optimal pH for aluminium precipitation is much lower, at between 6.0 and 6.5, and the optimal pH for iron precipitation is 5.0.

The typical removal range for treatment systems in New Zealand is 0 to 61%, and the average is low at 29%, giving an effluent concentration of 2 to 7 g/m^3, and average of 6.0 g/ m^3. Treatment systems can, however, be specifically designed for phosphorus removal, as discussed in Section 1.3.

The phosphorus load per capita is shown in Table 1.5.

Potassium

Typically, raw sewage has an average total potassium concentration of 13.2 g/m^3 (based on municipal systems). The total potassium concentration for small communities or on-site systems can be calculated from an average K loading of 4.5 g/p.d (based on the loading received at the Rotorua City treatment plant).

Potassium is removed from wastewater streams in both particulate material, which is settled out or flocculated, and by incorporation into bacterial biomass. Biomass typically contains 0.8–1.5% K. Biological activity is relatively unaffected by potassium but slug concentrations of around 3500 g/m^3 maybe toxic to anaerobic processes (Eckenfelder 1989).

Potassium is not routinely measured in New Zealand treatment systems.

The potassium load per capita is shown in Table 1.5.

Sulphur

Sulphur is naturally present in wastewater and is required for protein synthesis. Protein degradation releases sulphur. Under anaerobic conditions, sulphur is reduced to sulphide which combines with hydrogen to generate hydrogen sulphide (H_2S). H_2S is considered an offensive odour and can form sulphuric acid, which is corrosive to many types of sewer pipes and concrete. Sulphur is usually only a concern because of the formation of odorous compounds. To avoid this problem, effluent should be kept aerobic.

Typical sewage sulphate concentrations range between 20 and 50 g/m^3 and average 30 g/m^3, (Metcalf and Eddy 1991).

1.2.5 Dissolved constituents

Sodium

Raw sewage sodium concentrations of approximately 80–100 g/m^3 are typical for municipal wastewater, as measured at the Tauranga City Treatment Plant effluent[1]. Sodium loadings from effluent can affect soils, as discussed in Section 3.3.4. The sodium absorption ratio (SAR) of the effluent is the key parameter used to assess the risk of adverse soil effects due to sodium loadings. The SAR is a unit-less parameter defined as

$$SAR = \frac{[Na]/23}{\sqrt{[Ca]/40 + [Mg]/24}}$$

in which sodium, calcium, and magnesium concentrations are expressed in g/m^3. Sewage effluents will generally have SAR values between 4 and 7, which is generally acceptable for irrigation (see Section 3.3.4).

Sodium is removed from wastewater streams in both particulate material and incorporated into biomass. Biomass typically contains 0–2.0% Na. Biological activity may be slowed by slug concentrations of around 4600 g/m^3 for anaerobic processes (Eckenfelder 1989).

Chloride

Raw sewage chloride concentrations range between 30 and 100 g/m^3, with 50 g/m^3 being typical for municipal wastewater (Metcalf and Eddy 1991).

Chloride removal in wastewater systems is very limited, so it is expected that biological pretreatment of wastewater before application to land will not significantly reduce the chloride concentration. Chemical precipitation, ion exchange, reverse osmosis and electro-dialysis may all be used for the removal of chlorides, but the cost and technical requirements for installation and running may make these methods impractical.

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[1]Potts,W., 1998. Wastewater Manager, Hamilton City, Personal Communication

Aluminium

The aluminium concentration of wastewater is likely to depend on whether alum is used in the treatment of the community's drinking water. The average aluminium concentration of raw sewage at Rotorua District Council's treatment plant (no alum treatment) is 0.83 g/m^3. It is not known if this is typical for municipal wastewater.

Boron

Boron is a relatively mobile ion and moves through treatment system and soils. At Rotorua District Council's treatment works the average influent boron concentration is 0.26 g/m^3 and effluent concentration[1] is 0.25 g/m^3. Boron in the Tauranga City Treatment Plant's effluent has been measured[2] at 0.22 g/m^3. Boron will be higher in geothermal areas where groundwater is used for drinking-water supplies. Because boron is not usually in high concentrations, routine measurements are not carried out.

Total dissolved solids (TDS)

Total dissolved solids is an indicator of the presence of salts which can affect plant growth. There is a moderate relationship between TDS and electrical conductivity.

$$\text{TDS (g/m}^3\text{)} \cong \text{EC (mmho/cm or dS/m)} \times 640.$$

This conversion is within a ±10% accuracy for agricultural irrigation purposes (Metcalf and Eddy 1991). EC is therefore typically used as an indicator of the concentration of soluble salts. Salt levels typical of sewage effluents in New Zealand are low (see Section 3.3.4).

1.2.6 pH

Raw sewage pH is around 7.5, but varies depending on constituents present. The optimal pH range for biological nitrification is 7.2–9.0 and for denitrification is 7–8. The optimal pH for phosphorus removal is 6.8 ± 0.7.

The pH of effluent leaving typical New Zealand treatment plants is approximately 7.5. In addition, pH has a large influence on the effectiveness of chlorine as a disinfectant, as chlorine is most effective at or below pH 6.

1.2.7 Micro-organisms

Raw sewage micro-organism concentrations are usually indicated by the number of faecal coliforms per 100 mls. Metcalf and Eddy (1991) give typical values for various micro-organisms—these are summarised in Table 1.2.

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[1] Charleson, T. 1998: Laboratory Manager, Rotorua District Council. Personal Communication

[2] Potts, W. 1998: Wastewater Manager, Hamilton City Council. Personal Communication

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Table 1.2. *Typical range of micro-organisms in raw sewage[1] (summarised from Metcalf and Eddy 1991)*

Organism	Total coliforms (No./100 ml)	Faecal coliforms (No./100 ml)	Entero -cocci (No./100 ml)	*Salmonella* (No./100 ml)	*Giardia*[2] cysts (No/100 L)	*Crypto-sporidium* cysts (No./100 L)	Helminth ova (No./100 ml)	Enteric viruses (No./ 10 L)
Range	10^7–10^{10}	10^6–10^7	10^4–10^5	10^2–10^4	10^1–10^4	10^1–10^3	10^0–10^3	10^3–10^4

1. These values may vary markedly depending on the level of infection in the contributing community.
2. Note different units

It is usually the potential for human infection which determines the level of pretreatment for pathogen removal that wastewater receives before it is discharged onto land. Live bacteria and virus concentrations are reduced almost immediately during spray irrigation, both by mortality from the shock of aerosolisation and by dilution during downwind travel. Desiccation and exposure to solar radiation also reduce micro-organism viability (DOH 1992).

Primary treated effluent may still contain large numbers of pathogens. Secondary treated effluent has much lower numbers because bacteria and viruses are strongly adsorbed by biological slimes and flocs.

Helminths found in sewage include nematodes (roundworms and hookworms), cestodes (tapeworms) and trematodes (flukes). The common protozoa of public health concern found in sewage are *Giardia* and *Cryptosporidia*. These organisms survive much longer than bacteria in the soil. Cattle grazing on pasture irrigated with untreated human sewage effluent may become infected with *Cysticercus bovis* and human infection may occur if people eat uncooked beef. There is a low possibility that infection would occur after biological treatment and disinfection. (DOH 1992).

Secondary treated effluent prior to disinfection can contain more than 10^3 faecal coliforms per100 ml. Between 0% and 50% of viruses are removed by primary settling but 90 to 99% are removed after secondary treatment. Viruses are accumulated into the sludge. Secondary treatment (activated sludge) can remove 90% (1 order of magnitude) of protozoa and helminths (see Table 1.7).

1.2.8 Potentially toxic elements

Heavy metals

Heavy metals are often important nutrients in plant and animal systems. It is when concentrations become high that there are potential toxicity effects. The heavy metals (cations) generally associated with sewage are: nickel (Ni); manganese (Mn); lead (Pb); chromium (Cr); cadmium (Cd); zinc (Zn); copper (Cu); iron (Fe) and mercury (Hg). Arsenic (As) is also usually included in the heavy metals category although it can be present as both a salt (anion) and a metal.

Many of the above heavy metals are removed from wastewater by accumulation in the sludge produced. The solubility of many of these metals is very low and is pH dependant. As pH increases, solubility generally decreases (McLaren and Cameron 1996).

Glasson (1996) gives levels of metals in domestic sewage (without tradewaste) based on a literature study. This study showed that industrial premises account for between 30 and 85% of heavy metals in municipal sewage, with domestic sources being food, tap water, detergents, soap, cosmetics, dust, medicine and toilet paper. Table 1.3 gives the per capita heavy metal inputs from a study in Japan, as reported by Glasson (1996). Also shown is the mass per person from Karori (Wellington) that is of domestic origin only (NZ Water and Wastes, May 1998)

Table 1.3. *Metal mass in sewage of domestic origin (mg/person.day) from Glasson (1996) and NZWWA (1998)*

Source	As	Cd	Co	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Karori	0.69	0.08	0.19	1.39	25	389	3.84	22.7	1.88	49
Glasson	-	0.45		1.45	19.1	-	5.52	-	4.96	40.4

- not measured

The effluent from the Tauranga City Treatment Plant has been tested for metals, and the results are given in Table 1.4. The sewage is mainly domestic and is treated using an activated sludge plant. Also shown is the effluent from the Karori plant (after treatment using activated sludge) and the Christchurch plant (where trickling filters and oxidation ponds are used).

Table 1.4. *Metal concentration in tertiary treated sewage effluent (mg/m^3)*

Element	As	Cd	Co	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Zn
Karori	< 1	< 0.05	< 0.02	0.9	8.9	128	1.1	26.1	-	< 1	14
Tauranga	3	< 10	-	< 50	-	-	< 50	-	0.2	-	-
Christchurch	-	0.24	-	52	18	-	5	-		23	54-78

< not detected

- not measured

Trace organic compounds

Trace organic compounds, such as pesticides and herbicides, are toxic to most life forms and can therefore be significant contaminants within the treatment system, soil, groundwater and surface waters. Trace organic compounds may include phenols, chlorinated hydrocarbons (such as DDT, PCB's PCP.) and large organic molecules. These compounds can be extremely resistant to environmental degradation. Removals in activated sludge can occur by bio-oxidation, air stripping, or adsorption to the flocs, providing the levels are such that the micro-organisms within the treatment plant are not killed.

Typical domestic sewage does not contain toxic organic compounds in quantities that limit biological activity, or that would be expected to harm the receiving environment.

Many of the basic hydrocarbons will degrade during secondary treatment as compounds such as benzene, toluene, ethylene and xylene are volatile and can be air stripped.

1.2.9 Characteristics of New Zealand municipal sewage

Table 1.5 gives a summary of data presented by Hauber (NZWWA, 1994). The Hauber report summarised operations for the year ending 30 June 1994 from 12 municipal plants in New Zealand. The plants were Manukau, Christchurch, North Shore, Hamilton, Invercargill, Whangarei, Tauranga, Mt Maunganui, Rotoura, New Plymouth, Hutt Valley and Wainuiomata. Data presented do not include the tradewaste component of the wastewater.

Table 1.5. *Characteristics of average New Zealand raw urban sewage. Summarised from Hauber (NZWWA, 1994).*

Parameter	Units	Minimum	Maximum	Average
Flow[1,3,4]	(L/p.d)[5]	210	475	347
BOD[1]	(g/p.d)[6]	48	130	74
Suspended solids[1]	(g/p.d)	55	138	86
Total nitrogen[1]	(g/p.d)	7	20	11.5
Total phosphorus[1]	(g/p.d)	2.2	4.2	3.0
Total potassium[2]	(g/p.d)	-	-	4.5

1. From NZWWA, 1994
2. Based on data from one council – Rotorua District
3. Includes infiltration and inflows. Typical ADWF per capita is 260 to 270 L/p.d.
4. Based on a reticulated system. On-site system should be based on the lower ADWF values.
5. (L/p.d) = litres per person per day
6. (g/p.d) = grams per person per day

1.3. SEWAGE TREATMENT SYSTEMS

1.3.1 Primary treatment

Primary treatment is limited to physical unit operations. These are usually screening, grit removal, pH correction and primary sedimentation or floatation. Effluent quality resulting from primary treatment systems is shown in Table 1.6.

Solids removal

a) Screening and grit removal

Screening and grit removal is often the first unit process undertaken at a wastewater treatment plant. The primary aim is to remove large solids and any objects which would block or damage pumps and other equipment further downstream in the treatment plant.

b) Sedimentation/clarification

Sedimentation is used to remove: grit, particulate matter in primary settling basins, biological floc in activated sludge systems, and chemical floc in chemical coagulation processes. Primary treatment systems rely on physical processes only and are normally stable, although shock hydraulic loads and rapid changes in pH may cause the rate of solids removal to fluctuate.

Primary clarification of sewage will generally remove between 50% and 70% of the suspended solids and 25 to 40% of BOD. A reduction in the number of micro-organisms of two to three orders of magnitude can be expected, as these are removed with solids from the system.

Physical removal of solids decreases total nitrogen and total phosphorus by approximately 10–20% and 5–10% respectively. If the solids are spread out onto the same land as is being used for effluent land treatment, then the solids nutrient load also needs to be taken into account.

c) Flotation

Flotation is used to separate solids from liquids by introducing fine gas bubbles—a process known as dissolved air flotation (DAF). The bubbles attach to particulate matter, and the buoyant force of the combined particles and gas bubbles is great enough to cause the particles to rise to the surface. The advantage over sedimentation is that very small or light material can be removed. Oils and fats, which have a lower density than water, are also removed.

Performance of dissolved air flotation systems depends on the ratio of air to mass of solids. The ratio required for a given removal rate. should be worked out experimentally, however, typical air to solid ratios used are around 0.005 to 0.060 ml(air)/mg(solids) (Metcalf and Eddy 1991).

Typical performance levels for DAF-type systems are 95% removal of suspended solids, and 40-50% removal of BOD. Increased performance can be achieved if chemical coagulation and/or flocculation is used; SS removals of 98%, and BOD removals of 80% can be achieved (Redox b.v. 1998– DAF supply company).

Primary treated effluent is generally higher in BOD, SS and nutrients than secondary treated effluent and therefore needs to be applied over greater areas of land for the same level of environmental effect.

1.3.2 Secondary treatment

Treatment principles

There are two main types of treatment system: aerobic and anaerobic.

Aerobic treatment occurs by suspended-growth and fixed-growth processes (also called fixed-film processes). The main types of suspended-growth biological treatment processes are: activated sludge, aerated or passive lagoons, sequencing batch reactors and aerobic digestion. The most common forms used in New Zealand are lagoons and activated sludge.

The main types of fixed-growth biological treatment processes are: trickling filters, roughing filters, rotating biological contactors, and fixed-growth nitrification reactors (packed-bed reactors). Trickling filters are the most common fixed-growth process in New Zealand.

Anaerobic processes are used mainly for the treatment of sludges and high strength wastes. There are both suspended-growth and fixed-growth systems. The major application of suspended-growth processes is in the stabilisation of sludges produced from wastewater treatment. The most common treatment system is completely mixed anaerobic digestion.

Table 1.6. *Primary treatment unit operations, showing effluent quality. Percentage reductions from raw sewage are shown in brackets.*

Parameter (g/m^3 unless stated)	Raw effluent	Screening	Sedimentation	Flotation
BOD	250	247 (0–2%)	170 (25–40%)	100 (40–80%)
Suspended solids	240	245 (0–2%)	95 (50–70%)	8 (95–98%)
Total nitrogen	40	40 (0 –1%)	34 (10–20%)	34 (10–20%)
NH_3-N	25	25 (0%)	25 (0–2%)	20 (15–25%)
Total phosphorus	7.3	0	6.8 (5–10%)	6.2 (10–20%)
Faecal coliforms (MPN/100 ml)	10^4–10^7	0–1 order reduction	2–3 order reduction	2–3 order reduction
Viruses reduction	-	-	0–50%	0–50%

MPN – Most probable number of colony forming units

Suspended-growth aerobic systems

a) Activated sludge

Activated sludge is used to remove organic material by an aerobic pathway. It is a flexible process that can be adapted to almost any type of biological waste treatment problem.

Activated sludge makes use of continuous flow systems, in which different treatment units operate simultaneously and effluent flows from one process to another.

Activated sludge is the most common type of suspended-growth process. In this system bacteria are kept mixed in suspension with the substrate to be treated. Examples include: conventional plug flow, completely mixed, extended aeration, contact stabilisation, oxidation ditch and the Bardenpho process. Removal rates for these unit operations are given in Table 1.7.

A typical activated sludge configuration is shown in Figure 1.

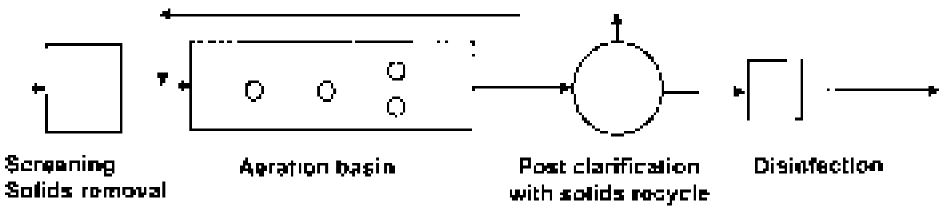

Figure 1.1. *Basic activated sludge plant layout*

b) Sequencing batch reactor

The sequencing batch reactor is a variant of the activated sludge process in which batches of wastewater are treated, using a set sequence, within one tank. To have continuous flow into a treatment system, two or more SBR's are required, or else a large-flow balancing tank. With the appropriate cycle times, removal of both nitrogen and phosphorus can be achieved. An example of an SBR treatment sequence is shown in Figure 1.2. Removal rates for SBR's are given in Table 1.7.

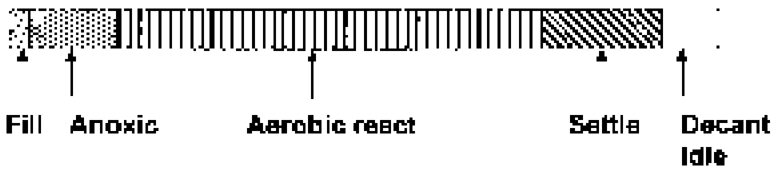

Figure 1.2. *A typical SBR treatment sequence*

c) *Pond systems*

Pond systems are classified based on the availability of oxygen, and include aerobic, maturation, facultative and anaerobic types. Aerobic and facultative (oxidation) ponds have been very popular in small communities due to their low construction and operating costs. Removal rates for BOD and SS are good, but nutrient removal is usually low. Effluent quality can be moderate to poor as the efficiency of the ponds is affected by climatic changes. High algal concentrations in the discharge can also be a problem.

Facultative ponds mimic natural systems. Oxygen is supplied to the upper layers by algae and surface diffusion, but the lower reaches are often anaerobic, allowing denitrification and solids digestion. Mixing occurs by wind action and is greatest during spring and autumn turn over.

In systems where higher effluent loading rates are applied, mechanical aeration and mixing can be added. With these systems it is common to have several ponds in series. The first pond may be fully mixed and aerated, while a second pond may be partially mixed and used for nutrient removal. The removal rates for different pond systems are given in Table 1.7.

Fixed-growth aerobic systems

Fixed-growth systems have bacteria growing on the surface of media, over which waste water flows. Types of fixed-growth systems include trickling filters and rotating biological contactors. The advantage of these systems is the high biomass populations that can be easily generated. Aerobic fixed-growth systems can be used both for removal of BOD and for nitrification.

a) Trickling filters

Trickling filters consist of a bed of media and attached micro-organisms, over which the effluent trickles. Trickling filters are designed to be porous so that effluent drains through and can be collected at the bottom, while air can circulate up through the filter. The early trickling filters used a type of rock media 25 to 100 mm in diameter, however the performance of trickling filters has since been improved by using plastic media which has a larger surface area to volume ratio than rock. This allows more micro-organisms to grow per cubic meter of filter.

b) Rotating biological contactors

Rotating biological contactors (RBCs) consist of a series of closely spaced circular disks of polystyrene or polyvinyl chloride. The rotating disks are partially submerged in wastewater. Disc rotational speed affects the amount of oxygen transferred, and the amount of biomass removed, due to shearing forces created by the rotation. The removal of biomass prevents clogging of the media surfaces and maintains a constant thickness of micro-organisms. The ability of RBCs to withstand hydraulic and organic surges is better than conventional activated sludge processes as most of the biomass is attached to the media (Antoine 1976). RBC systems are prone to mechanical breakage, with shaft failure being the most serious risk. Other problems are media breakage, bearing failure and odour (Metcalf and Eddy 1991).

Removal rates for fixed-growth unit operations are given in Table 1.7.

Anaerobic suspended-growth treatment systems

Anaerobic treatment is used mainly for high-strength wastes and sludges. Anaerobic systems have low cell synthesis rates and so sludge disposal is not as much as a problem as with aerobic systems. The majority of the carbon entering the system leaves as CH_4 and CO_2. One example of a suspended-growth anaerobic treatment is the upflow anaerobic sludge blanket process. In this system the waste is introduced at the bottom of the reactor and passes up through a sludge blanket composed of biologically formed granules or bacterial flocs. Treatment occurs when micro-organisms in the granules come in contact with wastewater.

Effluent generated from anaerobic processes may have an odour that requires removal before the effluent is applied to land. Common odour-causing compounds are sulphur derivatives, sulphides and mercaptans.

Removal rates for anaerobic suspended-growth systems are given in Table 1.7.

Anaerobic fixed-growth treatment systems

The two most common anaerobic fixed-growth treatment processes are anaerobic filters and expanded bed processes. The anaerobic filter is a column of solid media which is flooded continuously with wastewater. Bacteria attached to the media treat the effluent as it passes. In an expanded bed system, wastewater is pumped upward through media and bacteria at such a rate as to keep the bed expanded. Wastewater is often recycled through the filter to maintain a high flow rate.

Removal rates for anaerobic fixed-growth processes are given in Table 1.7.

1.3.3 Tertiary treatment

Tertiary treatment of effluent involves the polishing of effluent from secondary treatment units and/or the disinfection of the effluent.

Wetlands

Constructed wetlands may be used as secondary or tertiary treatment units. There are two main types of wetland, those that operate by surface flow and those using subsurface flow.

a) Surface flow

A surface flow wetland has plants growing in a soil base with the effluent passing above the base through the plant stems. The plants are used both to filter solids and to remove nutrients. A biological film growing on the stems also treats the effluent in a similar manner to a trickling filter.

b) Subsurface flow

Subsurface flow wetlands have aquatic plants growing in a gravel type media. In these systems there is no surface water, as all the effluent passes through the gravel media and plant roots. Less land is required for subsurface flow than for surface flow wetlands.

Wetlands can produce high-quality outflow, with less than 10 g/m^3 BOD, 10 g/m^3 SS, 15 g/m^3 total nitrogen, 5 g/m^3 total phosphorus, and 200 faecal colliforms per 100 ml. Wetlands do not have a great ability to remove ammoniacal nitrogen as there is limited oxygen available for nitrification. Phosphorus removal depends on the phosphorus adsorption properties of the wetland soils. These soils can over time become saturated with phosphorus and hence removal rates will decline. Wetland effluent treatment performance is given in Table 1.8.

Disinfection

a) Chlorination

Chlorine and chlorine-based products are the most commonly used disinfectants in the world. The main concern over their use is that they are toxic to humans and other animals. In addition, chlorine oxidises organic matter to sometimes toxic compounds and is highly corrosive. Chlorine and chlorine-based compounds are used because of their high micro-organism kill rates and their chemical persistence, which gives extended contact times with microbes after application. Chlorine is effective against viruses but is generally not effective against protozoa. Details of treatment performance are given in Table 1.8.

b) Ultraviolet Light (UV)

UV radiation penetrates the micro-organisms and is absorbed by cellular materials, preventing cell replication or causing cell death. A high effluent clarity is required for effective disinfection. UV does not have any residual effect, so micro-organisms not killed initially may still pose a threat. Details of treatment performance are given in Table 1.8. UV is not effective against protozoa at levels of exposure used for sewage effluents. Similarly it is unlikely to be effective against helminths. UV is effective at disabling bacteria but is less effective against viruses.

c) Ozone

Ozone kills micro-organisms by chemical oxidation. Ozone is applied by diffusion of ozone gas at the base of a tall contact tank. A long flow pathway is used to prolong contact and give greater reduction in micro-organism numbers. Ozone is effective against viruses and can be effective against protozoa, given high enough concentrations and contact time. It has the advantage over chlorine of not producing toxic chlorinated organic products, however it does produce other by-products which can be of concern, such as bromates. Details of treatment performance are given in Table 1.8.

Filtration

a) Intermittent sand filtration

Intermittent sand filters can be used either for secondary treatment or for final polishing. Treatment is brought about by physical, chemical and biological transformations. Removals of 90–95% for BOD and SS, and around 35–40% for nitrogen are typical for secondary treatment after primary treatment in septic tanks (Metcalf and Eddy 1991).

b) Ultrafiltration

Ultrafiltration systems use pressure to drive effluent through a fine porous membrane and are capable of removing dissolved and colloidal material. These systems are expensive to operate and require relatively clean effluents, as a high solids loading will quickly foul the membrane. Ultrafiltration is effective at removing most pathogens, including protozoa.

Table 1.7. *Secondary treatment—aerobic suspended growth systems, showing typical effluent quality, with percentage reductions from raw sewage shown in brackets*

Parameter (g/m^3 unless stated)	A.S. Completely mixed or plug flow	A.S. Extended aeration	A.S. Oxidation ditch	A.S. Contact stabilisation	A.S. Bardenpho	A.S. SBR	Pond Systems	Trickling filters	RBC
BOD	25 (85– 95%)	22 (75– 95%)	22 (75– 95%)	25 (80– 90%)	22 (75– 95%)	10 (85– 97%)	50 (60– 95%)	50 (6– 90%)	35 (75– 95%)
Suspended Solids	35 (80– 90%)	35 (80– 90%)	35 (80– 90%)	35 (80– 90%)	35 (80– 90%)	20 (>90%)	60 (55– 95%)	65 (60– 85%)	40 (80– 85%)
Total nitrogen	20– 30 (low denitrification)	20– 30 (low denitrification)	10– 20 (50– 75%)	20– 30 (low denitrification)	2 (95%)	5– 10 (75– 90%)	17 (25– 75%)	35 (5– 20%)	35 (5– 20%)
NH4-N	1– 5 (>80%)	1– 5 (>80%)	1– 5 (>80%)	5 (>80%)	1– 2 (>90%)	3 (>90%)	5 (>80%)	12 (40 - 60%)	12 (40– 60%)
Total phosphorus	5 - 6 (5– 25%)	5 - 6 (5– 25%)	5– 6 (5– 25%)	5– 6 (5– 25%)	2 (70– 85)	2 (70– 85)	4– 6 (5– 40%)	6.5 (8– 12%)	6 (10– 25%)
Faecal coliforms (orders of reduction)	3– 4	3– 4	3– 4	3– 4	3– 4	3– 4	2– 3	2– 3	2– 3
Viruses reduction	1– 2 orders of reduction	1– 2 orders of reduction	1– 2 orders of reduction	1– 2 orders of reduction	1– 2 orders of reduction	1– 2 orders of reduction	1– 2 orders of reduction	0.5– 0.75 orders of reduction	0.5– 0.75 orders of reduction
(%)	90– 99	90– 99	90– 99	90– 99	90– 99	90– 99	90– 99	50– 75	50– 75
Protozoa	up to 1 order of reduction	up to 1 order of reduction	up to 1 order of reduction	up to 1 order of reduction	up to 1 order of reduction	up to 1 order of reduction	up to 1 order of reduction	up to 1 order of reduction	up to 1 order of reduction

References: Metcalf and Eddy (1991); Irvine *et al*. (1985); Ketchum *et. al.* (1987); Rusten and Eliassen (1993); Eckenfelder (1989).

Table 1.8. *Advanced treatment options, with typical effluent quality and percentage reduction from raw sewage shown in brackets*

Parameter	Wetlands	Chlorination	UV	Ozone	Intermitant sand filtration	Ultra filtration
BOD	20 (80–95%)	N/A	N/A	N/A	<10 (95%)	?
Suspended solids	20 (80–95%)	N/A	N/A	N/A	<10	<1
Total Nitrogen	25 (25–50%)	N/A	N/A	N/A	24 (20–40%)	?
Faecal coliforms	3 order reduction	6 order reduction	6 order reduction	6 order reduction	5–6 order reduction	6 order reduction
Viruses Reduction (%)	50–95 0.5–1.5 orders of reduction	99 > 2 orders of reduction	99 > 2 orders of reduction	99 > 2 orders of reduction	90– 95 1–1.5 orders of reduction	99 > 2 orders of reduction
Protozoa*	up to 1 order of reduction	2–3 orders of reduction [1]	2–3 orders of reduction [2]	2–3 orders of reduction [3]	2 orders of reduction [4]	3–4 orders of reduction [5]

References: Metcalf and Eddy (1991); Eckenfelder (1989).

Notes
1 Chlorination: The reduction in protozoa numbers is controlled by the chlorine concentration and contact time. There is limited information relating to *Cryptosporidium.*
2 UV: The reduction in protozoa numbers is controlled by the UV intensity and contact time.
3 Ozone: The reduction in protozoa numbers is controlled by the ozone strength and contact time.
4 Intermittent Sand Filtration: Protozoa numbers are controlled by turbidity reduction
5 Ultra Filtration: The efficiency of the membrane filtration will be influenced by the solids loading rates. Filtration efficiency is not affected by the cyst age.

*Protozoa may still be detected after treatment has inactivated the cells. Therefore the test must determine viable organisms and not just the presence of organisms.

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2. SOIL PROCESSES THAT INFLUENCE SEWAGE EFFLUENT RENOVATION

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Landcare Research

2.1. INTRODUCTION

Land application of sewage effluent can adversely affect ground and surface water quality if certain effluent constituents are not removed before reaching the ground water. Soil biogeochemical processes can either remove or retain particular sewage effluent constituents. The amount of effluent renovation depends on the interaction between soil processes and soil water movement. Soil hydraulic properties influence the extent to which effluent constituents interact with the topsoil where many soil renovation processes take place. Understanding both soil biogeochemical processes and soil hydraulic properties is therefore important when assessing a soil's ability to renovate effluent constituents.

In this chapter we describe how sewage effluent moves through soil, and how soil processes affect the fate of effluent constituents. Constituents considered include nitrogen, phosphorus, biological oxygen demand (BOD), cations and pathogens.

2.2. EFFLUENT MOVEMENT THROUGH SOILS

The rate at which sewage effluent moves through the soil determines how much effluent can be applied without causing ponding and surface runoff. Many of the biological processes that renovate effluent occur in the soil rooting zone, therefore retaining sewage effluent in this part of the soil profile will maximise effluent treatment. In the following section we discuss how soil hydraulic properties influence sewage effluent application rates and the renovation of effluent constituents.

2.2.1 Soil hydraulic properties

Wastewater and rain falling on a dry soil surface is initially drawn into the soil by both capillary forces (i.e., suction) and gravitational forces. As irrigation continues, capillary forces contribute less to infiltration, and the gravitational force becomes the main driving force. If the irrigation rate (including rainfall) is less than the soil's *infiltration rate* all the water will generally be absorbed, and large-scale surface ponding and runoff is unlikely to occur. However, localised ponding may still occur due to within-paddock scale variations. Infiltration rates vary with soil type and are generally greatest for coarse textured soils, such as sands, which are highly permeable (i.e., permeability class is "very rapid"; Table 2.1). Infiltration rates will change if there are disturbances to soil structure. For example, compaction of the soil surface, by machinery or livestock, and sodium accumulation in soils can disrupt the soil structure and decrease infiltration rates.

The ease with which water moves through the soil after infiltration is usually characterised by measuring its *hydraulic conductivity (k)*. Soil hydraulic conductivity varies between soil types, and can range from less than1 mm/h in fine-textured, poorly aggregated soils, to more than 360 mm/h in coarse-textured soils. In addition, soil hydraulic conductivity generally increases with soil wetness as larger pores become included in the flow paths. The rate at which water flows through water logged soils is termed *saturated hydraulic conductivity*, whereas *near-saturated hydraulic conductivities* are defined by the moisture tension (degree of dryness) of the soil at

Table 2.1. *Relationship between permeability class and infiltration rate (taken from Griffiths 1985)*

Permeability class	Infiltration rates at 1.2 cm head (mm/h)
1 very slow	<1
2 slow	1-4
3 moderately slow	5-19
4 moderate	20-64
5 moderately rapid	65-129
6 rapid	130-250
7 very rapid	>250

which they are measured. Near-saturated hydraulic conductivities, rather than saturated hydraulic conductivies, are often used to calculate application rates as this provides a safety margin against too high an application rate.

Saturated hydraulic conductivities are greater in soils containing large pores or cracks, and may vary with soil depth (as soil profiles can comprise a number of layers with different textures and structures). If a subsurface layer has a hydraulic conductivity less than the surface layer, water may accumulate at the surface of the second layer causing lateral flow along the interface and/or waterlogging up to the surface soil. Lateral flow may be faster on sloping land than flat land, and consequently soil profiles at the base of slopes may become waterlogged relatively quickly, causing water to resurface. The extent to which this resurfaced water is treated by the soil will depend upon the distance it has travelled before it re-emerges.

Soil hydraulic conductivity will also vary with soil pore geometry. Hydraulic conductivities will be greater if the pores are vertically orientated, and provide a direct route from the surface of the soil to depth, than if the pores are horizontally oriented. Generally, the less direct the route the lower the hydraulic conductivity. Soil hydraulic conductivity may also differ over time. If the soil structure is disturbed, and pores become blocked, the soil hydraulic conductivity may decrease. Alternatively if earthworms and plant roots create relatively large channels in the soil effluent flow may increase.

Soil field capacity is a measure of the amount of water a soil naturally holds. Drainage is inevitable when effluent is applied to soils that are at or above field capacity. To keep soils below saturation, and to make some allowance for rainfall, preliminary data analysis suggests soil should be irrigated to about half of the available pore space that is not already filled with water. In other words, about half the pore volume between saturated water content and field capacity (saturated soils drain to field capacity in approximately 24 h).

2.2.2 The effect of soil water movement on wastewater renovation

Many soil processes that remove wastewater constituents occur at a greater rate in the active rooting zone (i.e., where plant roots influence the biological and chemical activity of the soil). Effluent application rates which retain the effluent in the active rooting zone should increase wastewater renovation (McLeod *et al.* 1998*b*).

Contact between the soil and wastewater constituents will be increased if the wastewater moves through the soil by entering micropores within aggregates (diffuse flow) rather than rapidly around the soil aggregates, and down soil cracks and worm channels (preferential flow). Preferential flow tends to predominate in soils that contain downward draining cracks and channels. As pore pattern cannot be readily changed, application rate may need to be adjusted if it is important that preferential flow does not occur. In general, decreasing the rate of application leads to less preferential flow. For example McLeod *et al.* (1998*b*) found preferential flow was limited at an application rate of 10 mm/h, but not at 15 and 20 mm/h, in two New Zealand soil types.

The goal should be to match irrigation rate with the soil's capacity to accept applied water so as to minimise ponding, runoff, excessive wetness, and excessive flow through macropores (preferential flow). Minimising soil drainage will maximise nutrient renovation in the active rooting zone.

2.3. NITROGEN, PHOSPHORUS, BOD AND CATION RENOVATION

Soil processes are more likely to contribute to effluent renovation when the constituents move diffusely through the soil. Renovation processes will not decrease potential pollution of receiving waters if substantial preferential flow occurs (Section 2.2.2), even in soils with high renovation capacity.

2.3.1 Nitrogen

A number of processes influence the fate of nitrogen in soils. Nitrogen can be removed from the soil by denitrification, plant uptake, volatilisation and leaching. Nitrogen leaching and run-off can cause an increase in the concentration of nitrate (NO_3^-) in ground and surface water supplies. This is considered a factor in eutrophication, as well as a hazard to human health (Carpenter *et al.* 1998). A simplified model of nitrogen cycling in a land treatment system, with no nitrogen fertiliser input, is given in Figure 2.1.

To minimise nitrate leaching it is necessary to maximise denitrification and/or plant uptake of nitrogen. For plant uptake to be a nitrogen sink the crop needs to be periodically removed from the site.

Denitrification

Denitrification is the reduction of nitrogen oxides (*e.g.* NO_3^-, NO_2^-) to nitrogen gases (e.g. NO, N_2O, N_2; Firestone 1982). Denitrification is multi-step process initiated by soil microorganisms and is catalyzed at each step by specific enzymes. Under certain conditions (e.g., specific enzyme absent) complete conversion to N_2 may not be achieved.

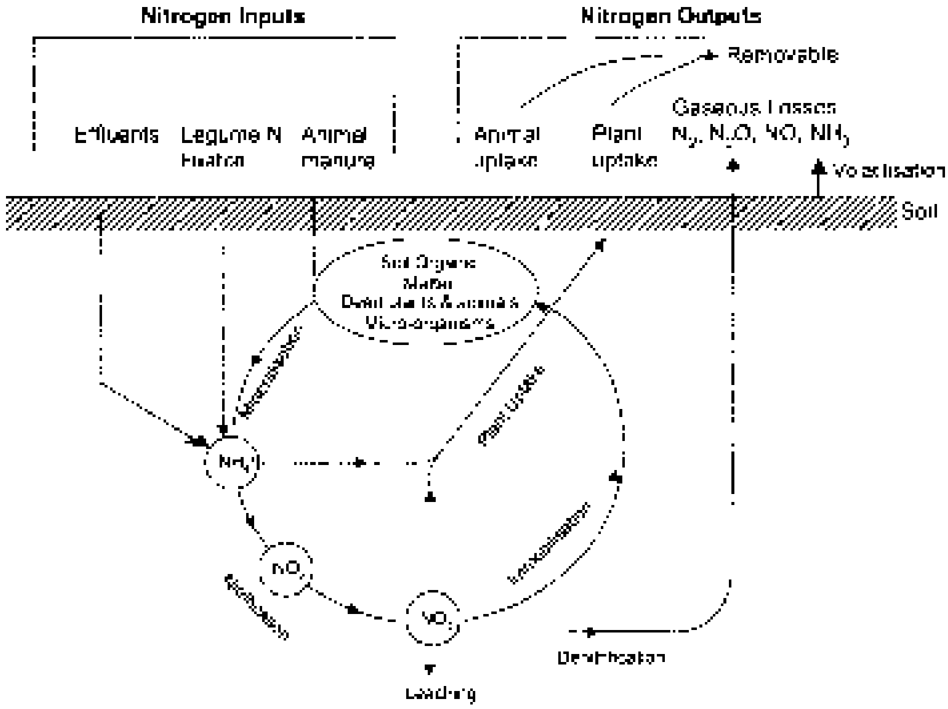

Figure 2.1. *Nitrogen cycling in a land treatment system. Adapted from McLaren and Cameron (1996).*

Denitrification provides a sink for nitrogen by converting soil nitrate to gaseous end-products which are then rapidly released from the soil into the atmosphere. Denitrification occurs in upland (i.e., soils not influenced by groundwater levels) and wetland soils. In upland soils, denitrification mainly occurs in the surface soil (i.e., 0-20 cm). Below this depth, soil organic matter is likely to be insufficient to support denitrification activity.

Denitrification requires the absence of oxygen, the presence of nitrate and carbon, and an adequate soil temperature (greater than 4 °C; Tiedje 1988). In land treatment systems, other physical and biological factors (Figure 2.2) affect these factors. For example, oxygen supply will vary with soil water content and the rate of oxygen consumption by plant roots and soil microbes (respiration). Soil moisture content in turn differs according to the frequency and loading-rate of wastewater, annual rainfall and soil texture. Soil nitrate and carbon contents vary with soil type, cover crop species, effluent composition and application rate, and soil temperature may vary according to the time of the year.

Only nitrate-N contained in the effluent is directly available to denitrifiers. Organic nitrogen and ammonium requires conversion to nitrate before the nitrogen can be denitrified. Conversion of organic nitrogen to inorganic nitrogen is called *mineralisation*, while conversion of ammonium to nitrate is called *nitrification* (Figure 2.1).

The presence of soil oxygen most commonly limits denitrification in upland soils (Tiedje 1988). Consequently, restricting soil aeration by increasing the amount of time the soil has a high soil moisture content generally increases denitrification (Ryden and Lund 1980;

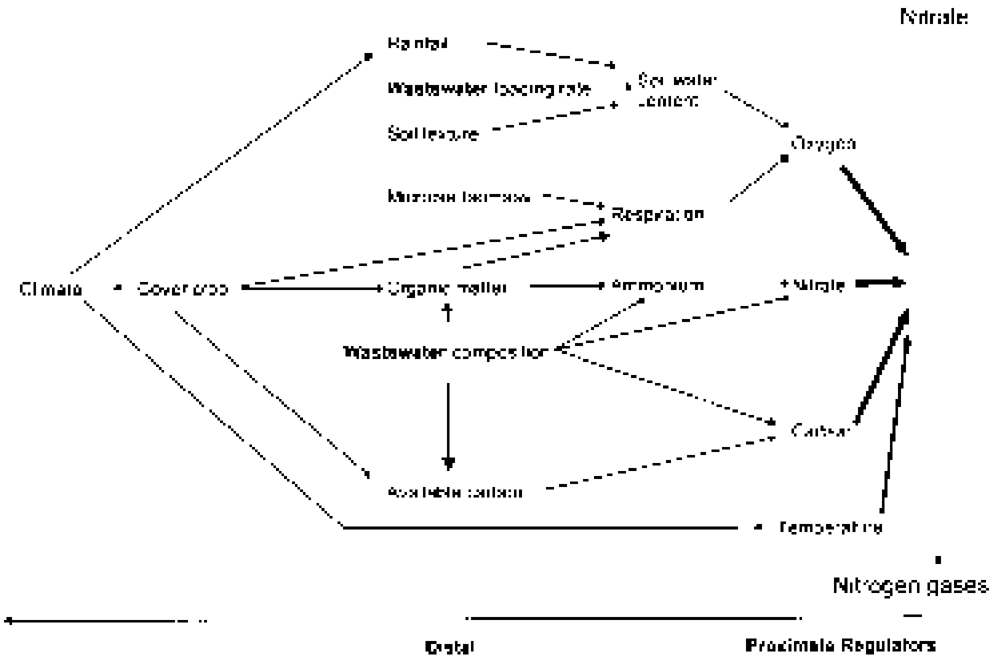

Figure 2.2. *Factors which directly and indirectly regulate denitrification rates in land treatment systems. Adapted from Tiedje (1988).*

Sexstone *et al.* 1985). Soil water-filled porosity (i.e., the proportion of pore space filled with water) above which denitrification rates increase are generally greater for coarser textured than for finer textured soils (Table 2.2). Denitrification is often limited by nitrate availability at soil nitrate concentrations less than 5 mg NO_3-N/kg dry soil (Table 2.3). Soil carbon contents which limit denitrification have not been determined, although denitrification in a forested land treatment system was not limited by carbon availability after five years of effluent-irrigation (Barton 1998).

Denitrification rates vary seasonally, with greatest rates occurring at those times of the year when soils are moist and warm and adequate soil nitrate and carbon are available. For example, denitrification rates were greatest in late summer and autumn in a forested land treatment system in New Zealand (Barton 1998). Irrigating effluent at those times of the year when soil conditions are best suited for denitrification will increase nitrogen removal.

Table 2.2. *Threshold values of water-filled porosity above which in situ denitrification rates increase. Adapted from Barton et al. (1999a).*

Soil Texture	Water-filled porosity[1] (%)
Sand	>82
Sandy loam	>80-83
Loam	>62-80
Clay loam	>50-74
Peat	>71

[1] Water-filled porosity = volumetric water content/total porosity

Table 2.3. *Threshold values of soil nitrate above which in situ denitrification rates increase. Adapted from Barton et al. (1999a).*

Soil texture	Soil nitrate (mg NO_3-N/kg dry soil)
Loam	>5-15
Clay loam	>1-2
Silty clay	>2

Very few annual denitrification rates have been measured in land treatment systems. Annual rates have ranged from 2.4 kg N/ha.yr in a volcanic sandy loam soil in New Zealand (Barton 1999b) to 20 kg N/ha.yr in a mature Appalachian hardwood forest soil (Kim and Burger 1997). The distribution of annual denitrification rates in fertilised grassland soils (not irrigated with effluent) suggests annual denitrification rates will be greater in loam than sandy or clay soils (Figure 2.3). Annual denitrification rates greater than 10 kg N/ha.yr have not been recorded in either sandy or clay textured soils, despite fertiliser applications of up to 750 kg N/ha.yr. By comparison, annual denitrification rates as high as 110 kg N/ha.yr have been reported for fertilised loam soils.

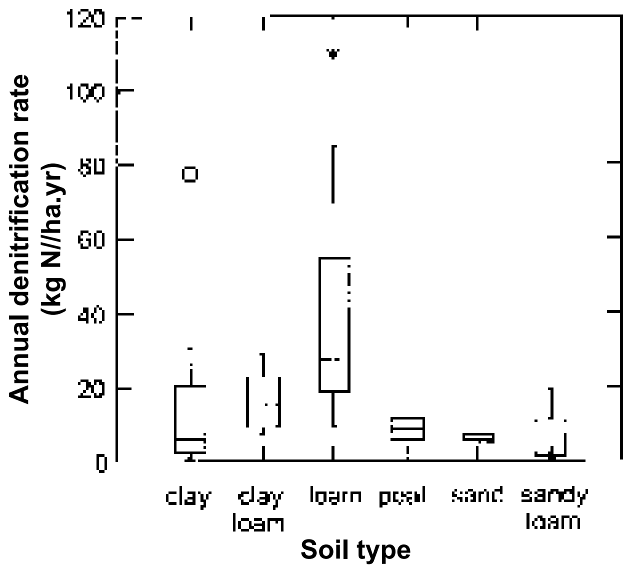

Figure 2.3. *The distribution of denitrification rates according to soil texture in nitrogen-fertilised grassland soils. Taken from Barton et al. (1999a). The central horizontal line in the boxes marks the median, while the central 50% (second and third quartiles) of annual rates are indicated by the length of the box. Vertical lines (whiskers) show the range of values that are, at most, 1.5 times the length of the box from the median. In most cases the whiskers denote the first and fourth quartiles. However, for the loam soil, there is one high value (asterisked) that is within three times the length of the box from the median. For the clay, there is one statistical outlier (circled) that falls outside this range.*

Plant uptake

Plant uptake of inorganic nitrogen (nitrate and ammonium) only provides a sink for nitrogen once the crop is removed from the site (Figure 2.1). If the vegetative cover is not harvested or removed, the nitrogen taken up will be returned to the soil after the plant dies. Furthermore, in deciduous forested land treatment systems a proportion of the nitrogen taken up by the stand can be expected to be returned annually with leaf drop.

The rates of nitrogen uptake vary with plant type, age, and distribution, and are also affected by the amount of irrigation/rainfall, soil type, soil fertility and season. Maximum nitrogen uptake is expected from crops with high nitrogen requirements, and when both nitrogen and water are regularly supplied in relatively small quantities during seasons of vigorous growth. Nitrogen uptake rates of plants commonly grown in land treatment systems are discussed in Chapter 6.

Ammonia volatilisation

Ammonia volatilisation is the loss of ammonia gas (NH_3) from the soil. It occurs at the surface of the soil when NH_3 concentrations and soil pH are high (i.e., greater than pH 7). Although ammonia volatilisation is often expected to be significant following sewage effluent irrigation, few studies have measured ammonia volatilisation rates in land-based effluent treatment systems.

In Australia, ammonia volatilisation removed 5 and 15% of total applied-nitrogen in a land treatment system irrigated with sewage effluent with the following chemical characteristics: pH 8.3; ammoniacal-N, 11.8 g/m^3; NO_3-N, 1.2 g/m^3; Kjeldahl-N, 19 g/m^3 (Smith *et al.* 1996). The greatest losses occurred immediately after irrigation when soil pH and ammoniacal-N were greatest, and evaporation rates high. Ammonia volatilisation increased for the first two days following irrigation, when soil pH was greater than 7, but declined by day three when the soil pH was less than 7.

In New Zealand, ammonia volatilisation rates in municipal land treatment systems have not been reported in the scientific literature. Ammonia volatilisation rates would be expected to be less in New Zealand than in the Australian study, given the lower potential for evaporation in some parts of the country, lower average effluent pH (i.e., pH 7.5, Section 1), and the higher average pH buffering capacity of most New Zealand soils. Further research is needed to determine the relative importance of ammonia volatilisation in sewage effluent irrigated land treatment systems in New Zealand. In the meantime, the study by Smith *et al.* (1996) indicates ammonia volatilisation may not be large sink for nitrogen in land treatment systems.

Mineralisation, nitrification and immobilisation

A large proportion of soil nitrogen, and a varying proportion of effluent nitrogen (see Section 1.2.4), is present in an organic form. Organic nitrogen needs to be converted to inorganic nitrogen (i.e., nitrate and ammonium) before it is available to plants and denitrifiers (Figure 2.1). Organic nitrogen is converted to inorganic nitrogen by soil micro-organisms via a series of reactions (mineralisation). The final stage of mineralisation is the transformation of amino acids to ammonium (*ammonification*). Ammonium can be further transformed into nitrate by soil microbes, through the process of *nitrification*. (Figure 2.1). Ideal soil conditions for nitrifying bacteria include: temperatures between 25 and 30 ^{o}C; a pH between 4.5 and 7.5; and a moisture content close to field capacity. Soil microbes, in turn, can incorporate inorganic nitrogen into their cells. Uptake of nitrogen by microbes is termed *immobilisation* (Figure 2.1), and will vary depending upon soil temperature and soil carbon content.

The impacts of irrigating sewage effluent on rates of mineralisation, nitrification and immobilisation are largely unexplored. In a mature Appalachian hardwood forest, irrigation with secondary-treated effluent was reported to increase mineralisation and nitrification rates (Kim and Burger 1997). Consequently, nitrogen leaching losses also increased because the increased soil nitrate availability was not matched by increased denitrification and plant uptake (Kim and Burger 1997). Schipper *et al*. (1996) also reported increased mineralisation rates at the Rototua Land Treatment System under a high hydraulic loading (> 50 mm/week).

Management practices, which disturb the soil (e.g., forest harvesting, soil cultivation) can also increase nitrogen mineralisation and nitrification rates. However, the effects of these activities on nitrogen leaching losses have yet to be reported for land treatment systems.

Other mechanisms for N storage

Ammonium ions can be fixed within soil clays in some soil types. However the amount of ammonium held this way in topsoil is generally small (McLaren and Cameron 1996), and fixation is not considered to be a sustainable mechanism for nitrogen removal in land treatment systems.

Nitrate ions may be held electrostatically by soil particles that have a positive charge. Although most soils carry a net negative charge, often there are individual sites on colloid surfaces that are positively charged. Soils that contain significant quantities of variably-charged inorganic colloids (e.g., iron and aluminium oxides, non-crystalline aluminosilicates) are most likely to contain positively charge sites (McLaren and Cameron 1996). The amount of exchangeable anions held in this way is much smaller than the amounts of exchangeable cations (Section 2.3.4), and the adsorption of nitrate onto soils is not thought to be a significant sink for wastewater applied nitrogen.

Leaching

Nitrogen not taken up by plants, denitrified, immobilised by soil microbes or volatised is likely to be leached. Nitrate and nitrite are the forms of nitrogen most susceptible to leaching. However, as organic nitrogen can be mineralised and ammonium nitrified, all nitrogen is at risk of being leached. Nitrate leaching generally occurs during wet conditions, when residual nitrate moves below the rooting zone with percolating water. Nitrate is most likely to remain in the top soil, where it is available to plants and denitrifiers, if the amount of applied effluent (plus rainfall) does not cause the effluent to drain rapidly.

Nitrate leaching has been measured in a few land treatment systems, and has ranged from 49 to 127 kg N/ha.yr in the Rotorua Land Treatment System (RLTS) (Gielen *et al.* 2000), 6.8 to

54 kg N/ha.yr in a mature Appalachian hardwood forest (Kim and Burger 1997), to between 5 and 15 kg N/ha.yr in an Australian pine plantation (Polglase *et al.* 1995). Leaching losses tend to increase with increasing loading and irrigation rates (Gielen *et al.* 2000; Kim and Burger 1997) and may vary seasonally. In the RLTS, nitrogen leaching was greatest after the onset of winter rains (Gielen *et al.* 2000).

In addition to causing groundwater contamination, excessive nitrate leaching may also be coupled with cation leaching. The nitrate anion must be accompanied by a cation, in order to maintain charge neutrality. Significant loss of cations from soil may be detrimental to soil structure and plant health depending upon the cation leached (Section 2.3.4). Unfortunately, the extent to which cation leaching occurs as a result of nitrate leaching has not reported for land treatment systems.

Matching nutrient loadings to anticipated rates of harvested plant uptake, volatisation, and denitrification will limit nitrate leaching if application rates are managed to retain effluent near the soil surface.

2.3.2 Phosphorus

Soil storage and plant uptake are major sinks in soil for effluent-applied phosphorus (Ryden and Pratt 1980). A large proportion of sewage effluent phosphorus is in organic form, but is easily converted to inorganic phosphate. In general, phosphate leaching is not considered to be significant in New Zealand soils. Soil storage mechanisms are largely through the adsorption/fixation of phosphate and immobilisation in organic matter; while precipitation of phosphate can occur in some soils. Phosphorus can be lost from the site by soil erosion or by leaching from the root-zone (Ryden and Pratt 1980). Although phosphorus contamination of water is not seen as a health hazard, eutrophication of surface waters has been closely linked to phosphorus contamination, along with nitrogen (Carpenter *et al.* 1998).

Soil adsorption/fixation

Phosphate ions (i.e., $H_2PO_4^-$, HPO_4^{2-}) are adsorbed onto mineral surfaces containing iron or aluminium oxides, such as goethite, ferrihydrite and non-crystalline aluminosilicate minerals (e.g., allophane). Phosphate adsorption predominately involves the exchange of phosphate ions with surface Fe-OH, Al-O, $FeOH_2^+$ and Al-OH_2^+ groups. To a lesser extent, phosphate ions are also held electrostatically onto mineral surfaces (non-specific adsorption). Non-specifically adsorbed phosphorus is not strongly held and is easily desorbed when the concentration of phosphate in soil solution decreases, due to plant uptake or after rainfall. Adsorbed phosphate that is able to move back into the soil solution readily (i.e., desorbed) is often termed *labile phosphate*, while phosphate that is relatively insoluble and not easily desorbed is called *non-labile*. The more strongly held the phosphate, the less likely that it will return to soil solution and be leached.

Phosphate adsorbed by ligand exchange, where the OH^- or OH_2^+ group in the mineral surface is displaced by an O of the phosphate ion, is less likely to be desorbed than non-specifically adsorbed phosphate. Phosphate can only be desorbed by raising the pH or introducing another anion with a greater affinity for the metal oxide. Adsorbed phosphate ions may diffuse into the subsurface of the mineral with time, or be trapped (occluded) on the surface by the development of surfaces of fresh oxide coatings or other precipitates. Once this happens, the phosphorus can not be easily desorbed back into solution and is considered fixed.

Phosphate adsorption/fixation varies with soil mineralogy, pH and availability of adsorption sites. In addition, phosphorus adsorption can change with soil depth. Phosphate retention tests are an empirical measure of the ability of the soil to remove phosphorus from solution, a process which precedes phosphorus fixation. In New Zealand, phosphate retention is generally determined using the method described by Blakemore *et al.* (1987) and devised by Saunders (1965). The method involves shaking air-dried soil with a phosphate solution overnight, and then measuring the concentration of phosphate remaining in the solution. The amount of phosphate retained by the soil is expressed as a percentage of the phosphate originally in the solution.

McLaren and Cameron (1996) have used three broad classes in describing the phosphate retention capacity of different New Zealand soils (Table 2.4). The allophanic soils of the Waikato and Taranaki regions are noted for having very high phosphate retention levels, commonly over 95%.

Phosphate retention tests do not predict the long-term phosphate adsorption capacity of a soil. Instead, results from phosphate isotherms are often extrapolated to calculate how much phosphate a particular soil horizon can adsorb. A technique for calculating phosphate isotherms is described by Fox and Kamprath (1970).

Table 2.4. *P retention by selected topsoils of New Zealand soil orders (adapted from McLaren and Cameron 1996). Classes are: low, 0-30%; medium, 31-85%; and high, 86-100%.*

Soil order	P retention
Semi-arid soils	very low to low
Pallic soils	low
Brown soils	medium to very high
Ultic soils	low
Podzol	low
Pumice soils	medium to high
Allophanic soils	high to very high
Granular soils	high
Oxidic soils	medium to high
Melanic soils	medium to high
Gley soils	various
Organic soils	very low to low
Recent soils	low
Raw soils	low
Anthropic soils	various

Other mechanisms for P removal

Phosphorus precipitation, immobilisation, and plant uptake processes also store phosphorus. Plant uptake of phosphate is only a phosphorus sink if the crop is removed from the site. If the vegetative cover is not harvested or removed, phosphorus taken up by the plant will be returned to the soil after the death of the plant. Crop harvesting generally only removes a small proportion of effluent-applied phosphorus (Section 6), therefore the capacity of the soil to retain phosphorus and prevent leaching below the root-zone may determine the sustainability of a land treatment system.

Phosphate ions can precipitate to form insoluble compounds with calcium (at pH 7.0 and above), magnesium, aluminium and iron. The extent to which precipitation reactions contribute to phosphorus retention in effluent-irrigated soils is not clear.

In land treatment systems, phosphate immobilisation in soil microbial biomass is only likely to be an important sink for phosphorus if the biomass continually increases. Although microbial transformations are known to contribute to phosphorus cycling in soils (Crosgrove 1977), the extent of phosphorus uptake in land-based effluent treatment systems has not been reported.

Leaching

Phosphorus leaching will occur if the phosphorus adsorption capacity of the soil becomes saturated and plant uptake cannot remove the wastewater-applied phosphorus. The amount of phosphorus a soil can receive before it becomes saturated will vary with the adsorption capacity of the soil. For example, phosphorus adsorption capacity would be exceeded at a lower P input in a sand dune soil or organic soil than in an allophanic soil.

Phosphorus leaching is only expected to be significant in soils not containing allophane, sesquioxides, or aluminium and iron oxides. In New Zealand soils, phosphorus leaching is likely to be small, except in very sandy soils, soils in which the adsorption capacity has been saturated, or acid peat soils.

2.3.3 Biological oxygen demand

Biological oxygen demand (BOD) is an indirect measure of the available carbon in the sewage effluent (i.e., organic matter). In soil, carbon is used to provide energy for the soil microbes. In municipal land treatment systems, removal of BOD should generally not be problematic (Section 3.3.7) as BOD loading rates are often low (Section 1.2.2) and the organic carbon is in a form that is easily utilised by soil microbes.

2.3.4 Cations

Calcium, magnesium, potassium and sodium may be stored in the soil, taken up by plants or leached. Immobilisation of cations by micro-oganisms is not considered to be a significant process in soils (Sparling and Berrow 1985). Elevated soil cation concentrations may be a concern soil or plant health are affected. The effects of increased concentrations of sodium and soil nutrient balance issues are discussed in Section 3.3.4.

Cations are positively charged and soil storage occurs largely by adsorption onto negatively charged soil surfaces; potassium can also be fixed in the mineral component of some soils. Cations are held electrostatically on the soil surface and there is a continual process of adsorption/desorption going on with similar cations held in soil solution. Consequently, in soils these cations are referred to as *exchangeable cations* and the soil's total capacity to hold cations in this way is known as the *cation exchange capacity* (CEC). In acid soils, various aluminium cation species and H^+ could also form a significant part of the *exchange complex*.

Clays, sesquioxides and humic materials all contain negatively charged surfaces and the CEC of the soil depends upon the types and amounts of these materials present. For example, organic- and clay-dominated soils have greater CECs than sands. In New Zealand topsoils, organic matter is the main source of CEC. Some components, like humus and non-crystalline minerals such as allophane, have appreciable variable charge, that is the amount of negative charge and CEC increases with increasing pH. Most soils contain organic matter and therefore exhibit some variable charge. However in New Zealand, variable charge only becomes an important management issue in organic and allophanic soils.

The degree to which a particular cation is adsorbed will depend on its concentration relative to the other cations and its relative affinity for the adsorbing surface. In general, monovalent ions (e.g., Na^+ and K^+) are held less strongly than divalent ions (e.g., Ca^{2+}, Mg^{2+}) which are in turn held less strongly than trivalent ions (Al^{3+}). Consequently, Gielen *et al.* (2000) reported greater soil storage of divalent than monovalent cations in a forested land treatment system. Cations with least affinity for the complex are most likely to be leached from land treatment systems.

In addition to soil adsorption, plant uptake may also provide a store for effluent-applied cations. Calcium, magnesium and potassium are essential for all higher plants, while sodium is considered essential for some, but not all.

2.2.5 Heavy metals

Many heavy metals are required for the growth of organisms (e.g., copper, zinc), but can become toxic if present at high concentrations (Section 3.3.5). Applying wastewater effluent to land, however, does not normally increase the heavy metal concentrations in soils. Instead, most sewage treatment plants remove the heavy metal content from the liquid fraction, and accumulate the metals in the biosolids.

2.2.6 Soil pH

Soil pH strongly influences the availability of plant nutrients, the mobility of metals, and the activity of many soil biological and chemical processes expected to contribute to the renovation of sewage effluent. Soil pH refers to the relative concentration of H^+ to hydroxyl (OH^-) ions. Soils which have a pH of 7 are considered neutral, whereas soils with pH less than 7 are termed acidic and soils with pH greater than 7 are termed alkaline. For many plants and microbes, optimal growth and activity occurs between pH 6 and pH 7.

The availability of plant nutrients may increase or decrease with increasing soil pH. Generally speaking, increasing soil pH decreases the availability of iron, manganese, copper and zinc, but increases the availability of molybdenum. Phosphate availability is optimised between pH 6 and 7, while nitrogen availability may decrease at pH values greater than 7.5 if nitrification is the main source of soil nitrate. Although moderate increases in soil pH (i.e., increases of 0.5–1.0) may affect nutrient availability, Stewart *et al.* (1990) suggest that in tree plantations frequent addition of nutrients in the sewage effluent will offset any deficiencies. Furthermore, Falkiner and Smith (1997) propose that “while soil pH remains in the range 5–6.5, and effluent is regularly applied to the soil, it is unlikely that plant growth will be affected by pH-induced nutrient imbalances”.

Soil pH also influences the extent of soil chemical processes, such as phosphorus fixation (Section 2.3.2), CEC (Section 2.3.3.) and heavy metal solubility (Section 2.2.5). In at least two effluent irrigated forest soils, increasing soil pH has induced increases in CEC in the topsoil (Hopkins 1997; Falkiner and Smith 1997). Applying especially high pH effluents (pH>11.5) to soils may also have a detrimental affect on soil physical properties. Leiffering and McLay (1996) reported lower aggregate stability and hydraulic conductivity after applying strong hydroxide solutions to three New Zealand soils. Decreasing soil pH may also increase heavy metal solubility.

2.4. PATHOGEN SURVIVAL AND MOVEMENT IN SOILS

Sewage effluents contain a variety of pathogens, including bacteria (e.g., *Salmonella* spp., *Campylobacter* spp.), viruses (e.g., Rotavirus, Norwalk virus), protozoa (e.g., *Giardia* spp. and *Crytospiridium* spp.), helminths (e.g., round worms and tape worms) and fungi (Straub *et al.* 1993). Hence the application of wastewater effluents onto soil surfaces introduces the risk of groundwater contamination by pathogenic micro-organisms that can cause disease in humans and livestock (Geldreich 1990). A number of soil environmental factors and processes restrict the transport of pathogens through the soil. These processes, however, will not limit pathogen movement if substantial preferential flow occurs (Section 2.2.2), since this causes transport of pathogens through the soil with minimal interaction with the soil matrix. Rather than using specificpathogens for fate studies, researchers often use microbial indicators of faecal contamination, such as the common faecal bacteria *Escherichia coli* or the enterococcus group that includes *Streptococcus faecalis, S. faecium, S. gallinarum and S. avium* or viruses like the F-RNA coliphages (Sinton *et al.* 1997). The following section summarises soil environmental factors and processes currently believed to influence pathogen survival and transport in soil.

2.4.1 Pathogen survival in soil

Many of the same environmental factors are thought to influence the survival of bacteria, viruses and protozoa in soil (Table 2.5), whereas helminths are considered the most resistant of all enteric pathogens. In general, cold moist climates tend to favor survival of pathogens whereas hot and dry climates promote loss of viability. Most research effort has been on the survival of bacteria and viruses in soil probably because they are the most common of the microbial pathogens found in wastewater.

More often than not, early studies on the survival of bacterial pathogens in soil (as in Gerba and Bitton, 1984) were dependent on the ability for these bacteria to be cultured and form colonies on solid media. We now know that some bacteria, both pathogens and indicator organisms, can exist in environmental samples in an injured state, where they are viable but non-culturable (Xu *et al.* 1982). This makes interpretation of the early data difficult. Over the last 10-15 years most effort has been directed to the development of methods which overcome this limitation. Resuscitation techniques for injured bacteria which can be used prior to culturing and enumeration have been developed (American Public Health Association 1992) and molecular methods for the detection of pathogens and indicator species are now available (Bej *et al.* 1991; Mahbubani *et al.* 1998). While molecular methods have been applied to investigations of pathogens and indicators in aquatic samples, including effluents and food, they do not appear to have been used in soils.

Some of the factors proposed to influence the survival of bacteria and viruses in soil are summarised in Table 2.5.

2.4.2 Pathogen movement through soil

Adsorption

Adsorption of microbes on soil surfaces limits their movement, and is considered a major mechanism by which microbes are retained in the soil. The major soil components that affect microbial adsorption are the organic matter and clay fractions, due to their large surface areas and a predominance of negatively charged particles (Gammack *et al.* 1992). Soil type and pH, and the concentration of polyvalent cations, all have an effect on adsorption, as do the surface properties of the microbes. Some bacteria produce extracellular polysaccharide material (exudates) that may help them attach to soil surfaces. The mobility of viruses in soil has been related to the properties of the amphoteric viral protein coat; the net charge of a virus particle is negative at pHs above neutrality. Microbial adsorption to soil can increase in the presence of cations as the repulsive forces of the microbe and soil particles are reduced (Gerba and Bitton 1984).

Soluble organic materials are known to compete with viruses and bacteria for adsorption sites. In organic soils, humic and fulvic acids may interfere with virus adsorption. Consequently organic soils appear to have a lower virus adsorption capacity than mineral soils (Gerba and Bitton 1984).

Leaching and filtration of pathogens

Pathogens not retained or inactivated in the soil are susceptible to leaching, and percolating water, either from irrigation or rainfall will affect their movement. Madsen and Alexander (1982) found that movement of bacteria in soil columns was negligible, in the absence of downward flow, whereas following downward water flow the bacterium could be detected throughout the soil column and in leachate. Straining or filtering processes in the soil reduce micro-organism transport. Consequently, greater microbial movement occurs in coarse soils with larger pore spaces than in finer textured soils (Tan *et al.* 1991; Huysman and Verstraete 1993). Due to their larger size, bacteria and protozoa (1–10 microns) are more easily filtered than viruses (<1 micron).

The greatest removal of bacteria, and possibly also protozoa, occurs in the topsoil. Mawdsley *et al (1996)* found that when oocysts of *Crytosporidium parvum* were applied to soil columns and subjected to 21 days of simulated rainfall the majority of the oocysts were retained in the top 2 cm of the soil. A number of recent studies with animal wastes have demonstrated the movement of microbial indicator species into the subsoil by preferential flow (Joergensen *et al*. 1998; McLeod *et al.* 1998a). Microbes were able to move into lower layers via earthworm or plant root holes, plant or cracks in the soil structure. To minimise preferential flow in two Waikato soils, McLeod *et al.* (1998b) concluded that an application rate of less than 10mm/h was required.

In summary, maximising the interaction between soil particles and pathogens minimises pathogen leaching.

Table 2.5. *Soil environmental factors influencing the survival of bacteria and viruses. Adapted from Gerba and Bitton (1984), Straub et al. (1993) and Blanc and Nasser (1996).*

Factor	Influence on bacteria	Influence on viruses
Water content	Survival decreases with decreasing water content.	Survival decreases with decreasing water content.
Temperature	Longer survival at low temperatures. Pathogens can survive for months at < 4°C.	Longer survival at low temperatures. Pathogenic viruses survive ambient temperatures.
Sunlight	Survival decreases with exposure to sunlight at the soil surface.	Survival is thought to decrease with exposure to sunlight at the soil surface.
Soil pH	Shorter survival time in acid than alkaline soils. Indirectly influences survival by controlling adsorption on soil particles	Indirectly influences survival by controlling adsorption on soil particles.
Biological factors	Increased survival in sterile soil. Introduced microbes are susceptible to predation, starvation and possibly antibiotic producing or lytic micro-organisms.	No clear trend.

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3. ENVIRONMENTAL EFFECTS

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3.1. INTRODUCTION

Treated sewage that is applied to land can impact upon the environment in many ways. This Chapter describes what those effects may be and how they can be assessed.

As the Resource Management Act (RMA) is concerned with end effects of an activity on the environment, this section has been structured using headings that relate to the environment, in preference to a focus on contaminants. Therefore effects of land treatment on air, land, water and communities are discussed, rather than effects of particular contaminants, such as excess nutrients or pathogens.

This approach will assist users of this document to structure their Assessment of Environmental Effects (AEE) based on the different parts of the receiving environment, as required by the RMA.

3.2. EFFECTS ON AIR

3.2.1 Introduction

The discharge of droplets and aerosols of treated effluent into air can result in the transfer of pathogens to people and may severely affect amenity values. Standards defining an acceptable level of illness from such transfer are not well developed, hence precedents from other localities where similar land uses surround a treatment site become significant when determining acceptable effects. While acceptable risk of illness has been considered for activities such as contact recreation, such approaches are unlikely to be useful in land treatment systems where the potentially affected people have no choice about being exposed.

Odour can be released into the air either directly from the sewage as it is being applied or through secondary processes occurring when effluent ponds on the surface. As for aerosols, acceptable standards are not well defined, despite many attempts to do so. Given that the significance of an odour is so heavily dependent on the disposition of the receptor, unlike, for example, the probability of infection from exposure to pathogens, it is likely to be some time before an acceptable level of odour will be quantified.

3.2.2 Aerosols

A consequence of spray-irrigating treated sewage onto the land will be the formation of small particles of water called aerosols. These small particles, which will not be visible to the human eye, may contain micro-organisms. In addition to particles of water, there will be small particles of organic or inorganic matter, which also may contain micro-organisms. There is the potential that these micro-organisms are pathogenic, therefore the risks to neighbouring land users must be assessed.

The concentration of aerosol particles will depend upon the method of application, with higher pressure, higher trajectory applications systems posing greater risk than low pressure, low trajectory systems. Table 3.1 provides an approximate guide to the degree of risk associated with different land application systems. It should be remembered that other factors such as wind, buffer distances, disinfection provided and population density around the site also influence the risk profile of a land treatment system.

Table 3.1. *Approximate guide to risk associated with irrigation equipment*

Level of risk from airborne pathogens	Higher risk	Medium risk	Lower risk
Type of irrigation system	· Big guns · Linear booms · Rotary booms · High pressure solid-set	· Medium pressure solid-set · Long laterals · Centre pivots	· Border dyke irrigation · Rapid infiltration · Drip irrigation · Sub-surface irrigation

In assessing the effects of aerosols, the emission rate of the pathogenic organisms, their subsequent survival, dispersion and deposition are all important. When assessing effects of pathogens, a full range of pathogenic organisms should be considered, not just bacterial indicator organisms.

The emission rate depends upon the concentration of the organism in the treated effluent, combined with the proportion of the wastewater which will enter the aerosol phase. The aerosolisation efficiency of spray irrigation systems has been assessed by Sorber *et al.* (1976) and Camman (1980). This study noted little difference (within an order of magnitude) between differing irrigation systems, and estimated the aerosolisation efficiency to be 0.3%. Based on this figure, an emission rate for the organisms can be estimated, from a combination of the initial concentration in the treated effluent, the flow rate through the irrigator, and the proportion of water aerosolised (0.3%).

After release from the irrigator, an organism’s survival is affected by processes such as the shock of aerosolisation, exposure to UV light, and desiccation. These factors are not well understood in the context of treated sewage application to land, therefore conservative assumptions are required, such as no die-off occurs post irrigation.

Factors which affect the concentration of organisms downwind of a treatment and disposal site include atmospheric dispersion, deposition and adsorption. Conservative assumptions that ignore deposition and adsorption should be used in the absence of better data.

The atmospheric dispersion models that are available, AUSPLUME (Victorian EPA 1986) and ISCT (USEPA 1978), provide a method of predicting concentrations of airborne contaminants downwind of a source. Thus from the source characteristics, the emission rate of the organisms, and appropriate consideration of the meteorological conditions and topography, the relative exposure to airborne pathogens can be estimated.

Infective dose rates for various organisms (which will widely differ for different organisms) can be compared with the concentration of the organisms in the air downwind, and inhalation rates of humans potentially exposed to the organisms.

Sewage contains pathogenic organisms that pose a public health risk. The types of pathogens which may be found in sewage include bacteria (e.g., *Salmonella* species, *Yersinia* species, *Campylobacter* species, *Listeria* species,), protozoa (e.g., *Cryptosporidium* and *Giardia*), helminths (as eggs), and viruses (refer Chapter 1). The paths for infection from these organisms vary and accordingly so do the risks. The highest public health risks arise from ingestion, either through drinking or eating contaminated water or food, or breathing the airborne organisms. Other routes of infection arise from skin contact, and include recreational use of contaminated water, handling contaminated soils, plants or stock, and direct exposure to spray drift.

The number of disease-causing organisms in the effluent is variable and generally quite low but may on occasions exceed 1000 cfu/100 ml wastewater. By comparison, faecal coliform indicator bacteria and other (harmless) bacteria are present in much higher numbers (approximately 4,000,000 cfu/100 ml wastewater). A droplet of untreated wastewater will contain 100 to 1000 bacteria and consequently most droplets will contain no pathogens. The concentration level will depend, however, on the level of pathogenic infections in the community at that time.

The infectious dose of microbial pathogens which may be present is somewhat variable between species and between strains. For example the probability of infection after exposure to one campylobacter organism is 7×10^{-3}, one salmonella is 3.8×10^{-5} and one *Giardia* cyst is 2×10^{-2} (Rose and Gerba 1991). This means that exposure to approximately 1000 campylobacter cells would be very likely to produce infection, with the risk lessening as the number of cells to which you are exposed lessens. With exposure to only one cell your risk of infection is 1 in approximately 7000. With respect to viruses, however, where only one virus particle may be an infective dose, the risk will be much greater. The risk in all cases is greater for the very young, the elderly and the immunely compromised individual.There have been many studies investigating the health of people exposed to aerosols generated by wastewater treatment plants, and none have been able to show conclusively that aerosols have been the cause of ill health among communities. Indeed, surveys of sewage treatment plant workers, exposed for many hours on end to aerosols emitted by the treatment facilities, have failed to show an increased risk of infection among the workers, when compared to control groups of workers outside of the wastewater treatment industry (Clark *et al.* 1979). It is, however, recognised that land treatment and sewage exposures are not directly comparable, as acclimatisation to pathogens is more likely to exist for the sewage treatment plant workers.

As aerosols disperse from a sewage or land treatment site, they are increasingly diluted in the surrounding air. Studies of communities living close to an activated sludge plant (Johnson *et al*. 1979) could not distinguish levels of micro-organisms in the air from background levels that already existed in the area.

Fattel *et al.* (1986) could not provide definite proof that the added health risk in effluent-irrigating kibbutzim was associated with the dispersion of pathogenic micro-organisms by aerosols, because a number of pathways of infection other than aerosols existed, such as direct contact via clothing or bodies of sewage irrigation workers or exposure to the crops.

Pahren and Jakubowski (1981) list several explanations advanced for the fact that people working and living near wastewater treatment facilities have not become infected:

- The densities of specific pathogens in the aerosols were low, and were reduced rapidly with time and distance from the source.
- With a respiration rate of approximately 1 m^3/hr, a person would ordinarily inhale very few organisms unless constantly exposed for many hours.
- The exposure levels were below the minimum infective dose.
- Micro-organisms in wastewater are primarily enteric organisms whereas the route of exposure was respiratory. The proper surface receptor sites for the organisms may not have been available.
- Non-specific immunity, which responds quickly to foreign substances, was capable of handling the few micro-organisms inhaled.

There have been several attempts to measure and model pathogen concentrations in the air downwind of sewage treatment plants and spray irrigation disposal systems. Some of this work has been reported by Jones and Stevenson (1984). This paper summarised a number of studies and concluded that there was little difference in the potential risk from aerosols from a sewage treatment plant and spray irrigation of treated sewage. The authors summarised the range of geometric mean values for aerosol bacteria in the air within 100 m of spray irrigation as being between 220 and 725 per cubic metre. These figures represent the total viable particles and not just potentially pathogenic bacteria. Of the total viable particles, one to two orders of magnitude less would be coliform-containing particles, and probably another order of magnitude less would be organisms such as salmonellae and streptococci.

It is therefore very difficult to link specific effects to specific activities or to different management techniques. Land treatment and disposal of sewage will always require some degree of conservatism, application of best practice, and following the basic principle of maintaining separation between the treated sewage and humans, unless in-depth studies are undertaken to assess the risks. The establishment of buffer zones between incompatible land uses will be a principal method of mitigation.

There are many ways to improve the efficiency of land buffers, so reducing the need to allow big distances. Hedges, landscaping, shelter belts and control over spraying based on wind direction are all useful. There is little scientific information relating to buffer distances, and most recommendations for buffers are based on rules of practice passed down over time. Past experience should not however be ignored.

3.2.3 Odour effects

The impact of odour is to annoy people and if severe enough it will create a nuisance. It therefore has the potential to adversely affect quality of life. Normally odour is not associated with any direct health effect, but more with personal stress and annoyance, which in turn may manifest as a health effect.

A nuisance odour is very difficult to define. People respond differently to odours depending on their age, sex, background, momentary disposition, and many other factors. There has been much research done on how to define and quantify what might constitute an odour nuisance.

There are four factors which all have a part to play in whether something will cause a nuisance, given a particular location. These are the FIDO factors.

- F Frequency
- I Intensity
- D Duration
- O Offensiveness

Frequency relates to how often a person might be exposed to a particular odour. If it is often they might reasonably become more annoyed. For this reason, prevailing wind directions become an important factor.

Intensity is a measure of the concentration of an odour. A very pleasant odour can become nauseating if the concentration becomes high enough; for example, the strong scent from a spilt bottle of perfume in a car.

Duration is how long a person is subjected to that odour. An exposure of short duration does not annoy to the same extent as a long sustained exposure. This is like driving past a silage pit as opposed to living next to it.

The offensiveness of an odour refers to the odour’s intrinsic ability to cause annoyance. Obviously, there is a difference between the smell of baking bread and that coming from a piggery.

When considering ways in which to control odours, all of these factors need to be kept in mind. Frequency and duration are normally determined by climatic conditions. Therefore from a study of the prevailing climatic conditions, the relative frequency and duration for which surrounding receptors might be exposed to odours can be assessed.

The intensity of an odour can be controlled by minimising the rate at which the odours are produced or released, by reducing the concentration, by treating the odorous air at source, or by keeping sources far away from everyone else. The offensiveness of odours can relate to the processes by which they are created. Odours that result from anaerobic activity are often the source of complaints. For this reason it is essential to maintain the wastes in an appropriate state for disposal. This is usually an aerobic state.

When assessing the effects from odour, there are two approaches that can be adopted. These are the quantitative and the qualitative approaches.

3.2.4 Quantitative odour assessment

Quantitative odour assessment requires odour emission data, site meteorological data, site topographical data and the relative locations of potential receptors. Atmospheric dispersion modelling can then be used to calculate the exposure to odour around the site. Comparison with "odour standards" is used to assess acceptability.

The first piece of data required is an estimate of the rate at which odour is released from the land treatment and disposal area. This may have two components, the odour from the application system, and the odour from the land surface that has recently received the treated sewage. From these an odour emission rate (expressed as odour units per second ou/s) can be determined. This estimate is not easy to make, as there is little information on odour emission, and measurements can be expensive.

Meteorological data ideally should be representative, hourly, data covering a full year. If data are not available from an existing meteorological station, a small on-site station can be established.

The dispersion models commonly used are AUSPLUME (Victorian EPA 1986) and ISCT (USEPA 1978). These models provide reasonable predictions provided the site topography is not extreme and can be defined within the model. Each of these models can produce a percentile odour concentration data set, which can be used to plot a percentile odour contour plan. This plan is a plot of the odour concentration that will not be exceeded for a given percentage of the time, such as 99.5%.

The "odour standard", if expressed as a percentile compliance limit ,can be compared with this plot. Such a limit would specify the odour concentration (5, 10, or 20 ou/m^3) that must not be exceeded for 99.5% of the time, i.e., it can only be exceeded for 0.5% of the time, or 44 hours per year.

At present in New Zealand there is no nationally accepted "odour standard" and the use of such an approach would also require justification of the "odour standard" adopted which is outside the scope of this document. Odour guidelines may be set at a local level by Regional Councils.

3.2.5 Qualitative odour assessment.

A qualitative assessment of odour involves making a subjective assessment of the potential to cause a nuisance, assuming that best practice techniques are used to minimise the production and release of odour, and taking into consideration the proximity of local receptors and the local topography and climate.

Examples of best practice techniques include:

- Avoiding anaerobic conditions in the effluent, either during the treatment process or within the conveyance pipelines.
- Maintaining adequate separation distances between the land treatment site and neighbours.
- Incorporating a greater degree of treatment in situations where neighbours or other land users may be close to the site.

- Utilising appropriate application techniques such as low pressure and low trajectory spray systems, or flood or drip irrigation or sub-surface drip irrigation, if in a particularly sensitive area.
- Providing adequate shelter and screening around the site, to increase wind turbulence and odour dilution across the boundary and to minimise the visual aspects.
- Not irrigating directly upwind of a sensitive neighbour. This may be achieved by designing an irrigation layout and control system that allows wind direction to be taken into account when selecting the irrigation block.
- Providing storage so that irrigation need only occur during times when there will be no nuisance, i.e., late at night or when wind conditions are satisfactory.

After considering practices such as these, it then becomes a matter of professional judgement as to their effect on acceptability of the scheme, and consultation with potentially affected parties will be important to help assess this. It will then be possible for decision-makers to determine which, if any, of the above techniques should be put into practice.

3.3. EFFECTS ON LAND

3.3.1 Introduction

The application to land of treated effluent containing contaminants such as pathogens, heavy metals and unknown chemicals may restrict its use for growing food or for recreation. Even after wastewater application has ceased, some contaminants will remain forever. Where soil from the site can blow onto surrounding areas the adverse effects are potentially greater. Standards relating soil concentrations of various contaminants to the use of the land are now well advanced and may be used to define an acceptable level of adverse effect (Woodward-Clyde 1998).

Also needing consideration are factors which affect permeability of the soil, including organic matter, salts and hydraulic loadings, land management practices, prolonged saturation, and erosion. Neighbouring land can be affected by surface run-off and spray drift. Land stability may be an issue if hydraulic loadings are high, prolonged saturation occurs, and certain geological conditions exist.

3.3.2 Pathogens

The direct application of treated sewage to land will result in pathogens accumulating on plant material and the soil surface. These potentially pose a risk for workers on the site and others who may visit the site, stock that may graze on the site, and those exposed to crops or animal products derived from the site. There is also a risk of contamination of neighbouring land and water bodies as a consequence of surface runoff and overland flow.

Crop plants grown using water containing viable *Giardia intestinalis* cysts can cause giardiasis (Pell 1997; Bemrick 1984). Owen (1984) reported that *G. intestinalis* cysts remain viable for at least three months under favourable environmental conditions. Waterborne transmission can also occur through direct exposure of individuals to *G. intestinalis* cysts present in contaminated recreational aquatic environments. The introduction of inadequately sanitised wastewater into recreational aquatic environments has been reported to result in human giardiasis (Ortega and Adam 1997).

The current New Zealand guidelines for the irrigation of sewage effluent state that effluent must contain less than 10,000 faecal coliforms per 100 ml for irrigation to fodder crops and pasture. Typical treatment requirements are "conventional biological oxidation or equivalent". The pastures must also be free from ponding before crop growing is allowed, and no harvesting or grazing is allowed within 48 hours of irrigation or while the site is wet with irrigated water. The World Health Organisation guidelines place more emphasis on the intestinal nematode levels, reflecting the prevalence of these species in some developing countries. The WHO guidelines recommend that nematode levels should not exceed 1 egg per litre (as indicated by *Ascaria* and *Trichuris* species and hookworms) in treated sewage to be used for irrigation of sports fields, public parks, crops likely to be eaten uncooked, cereal crops, fodder crops, pasture and trees. The faecal coliform levels and sewage treatment practices advocated in the New Zealand guidelines are deemed adequate to meet the intentions of the WHO guidelines.

In New Zealand, helminths, including *Taenia saginata* (beef tapeworm), are considered of importance both from a public health perspective and for the agricultural industry. Helminths are in general very persistent in the environment, and can survive from several weeks to several years. Eggs of *Taenia saginata* have been known to survive up to 6 months on grass and soil. Hence the New Zealand guidelines state that unless it can be demonstrated that the treatment process is sufficient to remove helminths (for example, physical settling in an oxidation pond with a retention of 30 days), cattle and pigs shall be withheld from effluent-irrigated land for at least 6 months. Following suitable treatment, however, the pastures are deemed suitable for grazing after 48 hours.

With respect to the reuse of sewage effluent for the production of silage, the issue arises of transfer of pathogenic organisms to the silage, and subsequently to cattle which will be fed the material. Whilst microbiological guidelines exist for sewage effluent disposal to pasture, the process of silage production is not directly comparable to the exposure of cattle to irrigated pasture. Once baled, the pasture is no longer exposed to the same adverse environmental factors (particularly ultra-violet light and desiccation). Also, as the bales may, at the time of baling, still contain micro-organisms originating from the sewage, the possibility exists for re-growth in the bale. However, low pH and anaerobic conditions in the silage may limit the ability of organisms to survive.

Information concerning the survival of pathogens indicates that the essential environmental factors in limiting pathogen persistence are time and temperature. Success of a treatment process in reducing the pathogenicity depends on retention time and the creation of an environment that is hostile to the organisms. Pathogen mortality is essentially assured at temperatures over 55°C (Feacham *et al*., 1983). Whilst temperatures increase during the process of silage fermentation, it is preferable that temperatures do not increase above 30°C. The potential for survival of pathogens therefore exists.

The Taupo District Council (TDC) has trialled the irrigation of Yatsun rye grass pastures with secondary treated sewage effluent (application concentration of around 10^5 CFU/100 ml, "*Monitoring Report 14 Sept 1995 – 31 March 1996*" Taupo Pollution Control Plant, Appendix 6), and the subsequent use of the pasture for the production of silage. Silage was made by the plastic wrapping method, and is referred to by the TDC as haylage. Grab samples were taken from 46 bales of haylage over a 2 to 3 month period, and monitored for faecal coliforms. The results show considerable variation, however, it is apparent that re-growth of faecal coliforms can and does occur. Concentrations at the time of cutting and baling (limited testing only) ranged from 10^2 to 10^3 MPN (most probable number) per gramme dry matter, but after around 1 to 2 months concentrations in haylage were sometimes as high as 5 x 10^6 MPN per gramme dry matter. Generally, after 3 months, concentrations had only dropped to around 10^5 MPN per gramme dry matter, but after 4 months concentrations fell to low levels (<30 MPN per gramme dry matter).

Initial bales were tested for *Clostridium perfringens* and *Salmonella*, with no detection of the latter.

As high faecal coliform regrowth results may be misleading, the TDC has undertaken individual testing for specific pathogens, including *Salmonella* species, *Yersinia* species, *Campylobacter* species, *E.coli*, and *Listeria monocytogenes,* and also fungal levels. In 62 samples, *Listeria* was detected just once, and five samples had high fungal isolates (i.e., greater than 10^6 organisms/100 ml). High *Listeria* counts in silage produced overseas have been associated with silage from the bottom of pit-produced silage.

To date, the TDC has sold all of the haylage with the exception of those bales spoiled with mould and therefore not palatable to cattle, and the Listeria containing bale. The TDC currently has no set microbial criteria to meet before the silage can be sold, other than that posed by the Resource Consent for the operation.

3.3.3 Spray drift and run-off

Spray drift and run-off are two mechanisms by which treated sewage applied to the land may impact on neighbouring land. These should be controlled by management practices, however the potential for adverse effects is present. In particular these relate to pathogens, which can be transferred to the surface of land that is not under the control of the consent holder.

Airborne pathogens, if they settle on crops that may be eaten raw, pose a health risk. For spray irrigation systems, it is not currently possible to calculate the potential extent of spray drift that may cross the boundaries of the property and settle on a neighbour's crop. To be able to do this, the water droplet particle size distribution from the irrigators would be required. This information does not exist; therefore it is not possible to calculate the proportion of wastewater that is potentially available to be carried as spray drift.

Notwithstanding the above, the particle size distribution that potentially carries as spray drift is in the size range 20–200 microns. Particles above 200 microns settle very rapidly even in strong wind conditions, while particles below 20 microns behave as aerosols, travel greater distances, and disperse more rapidly. For a particle of 200 microns, the travel distance, for it to settle from a height of 4 m would range from less than 20 m at 3 m/s wind speed, to 65 m at 10 m/s. A particle of 100 microns would travel 60 m at 3 m/s and 200 m at 10 m/s. These distances assume there is little or no effect from evaporation.

If evaporation is taken into account, particles will reduce in size to approximately 20 microns, at which stage it can be assumed that they will not settle. A particle of 100 microns in climatic conditions such that the wet bulb depression is 10 ^{o}C (this is the difference between dry bulb and wet bulb temperatures and reflects the relative humidity at the time) will only last 10 seconds, so will not settle in higher wind speeds. This factor further complicates the estimation of spray drift volumes and settleability.

The risks associated with crop quality or consumption, primarily exist when the crop is harvested or eaten and the greatest care must be taken to avoid contamination at, and before, this time. Bacterial and protozoal pathogens contaminating plant surfaces are inactivated by desiccation and/or sunlight and a suitable irrigation withholding period (i.e., diversion of irrigators to other parts of the property) should be in place to ensure that sensitive crops near to harvest are not compromised. However, effluent irrigation onto crops intended for direct human consumption is generally not recommended.

Faecal coliform estimates and heterotrophic bacterial plate counts are routinely used to ensure quality of foods. Elevated levels may mean that crops are down graded or completed rejected. Various guideline levels for faecal contamination of foods are given by the Ministry of Health – for example the guideline for fruit or vegetable salads requires a faecal coliform level less than 1000 cfu/g in every sample and less than 100 cfu/g in 60% of samples (Till 1994).

3.3.4 Salt and sodium (salinity and sodicity)

One issue that can be of concern when land is irrigated is the application of salt. In particular the concerns relate to the effects of total soluble salts on plant health, and effects of sodium on soil structure. Salt accumulation in soil will reduce crop production, while sodium accumulation can disrupt the soil structure and thereby reduce permeability.

The total salt concentration (indicated by the electrical conductivity or EC), the Sodium Adsorption Ratio (SAR), and the pH are key effluent characteristics needed to assess the risks of salt and sodium accumulation in a land application scheme. However, for land irrigated with sewage effluents in New Zealand, risks are low, because the EC and SAR levels of municipal and domestic wastewaters are generally low. Also New Zealand's humid climate promotes leaching of soils to a degree that prevents accumulation of soluble salts. Furthermore soils dominated by 'swelling-type' clays, which are most sensitive to sodium loadings, are not common in New Zealand. The following discussion considers issues of salt and sodium accumulation in soils separately.

Salt accumulation: In cases where soils may be susceptible to salt accumulation, methods to calculate a hydraulic loading that will avoid such accumulation are available (Snow *et al.* 1998). A "leaching fraction" can be calculated that expresses the amount of water that must be added in order to leach salts from the soil profile. The calculation is based on the effluent

EC, amount of effluent applied annually, average annual rainfall, and the threshhold soil EC at which plant growth declines; this threshold is crop specific, with examples shown in Table 3.2. If the water balance of the site includes a drainage volume greater than the leaching fraction, then salinity problems will not occur. (Note, however that a high water table can effectively prevent leaching of salt.)

Table 3.2. *Salt tolerance of crops (from Rhoades 1990)*

Tolerance level	Low	Medium	High
Example species	Lucerne	Ryegrass	Barley
Critical EC threshold (dS/m)	2	5.6	8

Sodium accumulation

The potential for sodium accumulation in soils can be assessed using the effluent SAR (see Section 1.2.5) and soil Exchangeable Sodium Percentage (ESP), which is the percentage of the cation exchange capacity (CEC, see Section 2.3.4) occupied by sodium. The accepted limit for SAR for wastewater application to land may be anything between 4 and 18 depending on the soil type (Rowe and Abdel-Magid 1995). Sewage effluents are at the lower end of this range and only pose a sodicity threat if irrigated onto the most sensitive (swelling-type clay) soils.

As the proportion of sodium attached to the cation exchange sites increases, the risks of deflocculation also increase. Therefore for a particular soil, the risk of soil degradation can be measured by the ESP.

The actual relationship between ESP and sodicity hazard is complex and depends on a range of factors including soil type, effluent salinity, and soil management. As a rule of thumb, US Salinity Staff (1954) suggested an ESP of 15% as the critical level above which soil structure and therefore permeability could be deleteriously affected. (assuming irrigation water has an EC of between 0.3 and 1.0 dS/m). This value has been widely accepted, but has been considered too high by some authors.

A correct interpretation of ESP depends markedly on the soil type as well as irrigation water quality, as illustrated by contrasting examples. Hopkins (1997) found that ESP values ranging from 7 to 30% in a sandy volcanic soil at the Rotorua Land Treatment System had no apparent effect on soil permeability. By contrast, for a fine-textured Australian soil, McIntyre (1979) suggested an ESP of 5% was critical for a soil being irrigated with very low salinity water (EC of 0.07 dS/m). Overall, coarse sandy soils are not sensitive to sodium, but fine-textured soils can be, particularly if the irrigation water has very low salinity.

Should it become necessary to reduce soil ESP this can be done by adding calcium in soluble form. This is most effectively achieved by the addition of gypsum, which is thoroughly watered into the soil. The soluble calcium replaces some of the sodium on the cation exchange sites, thereby reducing ESP and the sodicity hazard. This is a recognised management technique for sodic soils and has been used in New Zealand to reclaim soils irrigated with highly sodic industrial effluents.

Generally, the risk of salt or sodium problems for New Zealand soils irrigated with sewage effluent is low. Nevertheless, periodic monitoring of the soil exchange balance is recommended, given potential effects on crop nutrient balance (see Sections 7.8.1 and 7.10).

3.3.5 Heavy metals

Heavy metals accumulate within the soil, and over a long period they can accumulate to an extent that the usefulness of the soil becomes limited. This is not normally a limitation in the application of treated sewage, as most sewage treatment processes reduce the heavy metal concentrations in the liquid fraction, and accumulate them in the biosolids.

Heavy metal loadings and limits are therefore more useful in assessing the effects of biosolids application to land. *New Zealand Guidelines for the Beneficial Use of Biosolids* (Woodward-Clyde 1998) are in preparation at present, and public submissions have been sought. The limits for heavy metals in soils which have had biosolids applied can be found in that document.

3.3.6 Hydraulic loadings

With respect to hydraulic loading, what is important is how much water will infiltrate the surface and how much will move laterally and potentially flow off the site.

For a land treatment scheme, the aim is to ensure the effluent enters the soil so that the natural processes within the plant/soil system may assimilate the contaminants. This requires the effluent to enter the soil from the surface, and then to drain through the bottom of the soil profile. The efficiency of this process depends primarily upon the application rate rather than the total quantity or depth of effluent applied.

If the instantaneous application rate exceeds the infiltration capacity at the soil surface, the water will move laterally. However, because the water moves sideways, this does not in itself mean that the effluent will run off and lead to ponding and the associated problems. This lateral re-distribution of flow is relied upon in many irrigation systems, with border dyked systems being the ultimate example. Water applied over the wetted footprint of the irrigator will re-distribute until it finds areas where it can enter the soil surface, and these may be adjacent to the area which is being irrigated at that time.

The mechanism involved in this is a "pond and drain" sequence, as described by Clothier and Heiler (1983). If the application rate of water is less than the surface infiltration capacity, the water will directly drain into the soil. If the application rate approaches the infiltration capacity, incipient ponding conditions arise where small surface depressions (referred to as micro-storage) start to fill, but drain before more water is applied. Preferential or macropore flow, which is the preferential flow of water down large holes such as wormholes or plant root channels, is not significantly active during this phase. If the application rate exceeds the surface infiltration capacity, then the over topping of the micro-storage will lead to lateral re-distribution and a continuous supply of water which activates macropore flow. A significant increase in the quantity of liquid draining directly through the soil profile will occur at this stage, with an increased potential to flush contaminants into the groundwater.

It is therefore important to understand how much water can be applied without contaminants being flushed through the soil rather than being retained within the soil. Classical theory suggests a plug or piston flow of moisture. The water on the top pushes the water beneath through the soil profile. Therefore, if one pore volume (equivalent to the water holding capacity) were applied to the soil, then contaminants contained within the soil moisture would be displaced out through the base of the soil.

In practice, breakthrough of contaminants occurs *before* this point, due to preferential flow paths through the soil. It was reported by Fraser *et al.* (1994) that nitrate leaching from a silt loam on sandy loam soil peaked well before 1 pore volume of water had drained through the soil profile, although significant nitrate leaching did not occur until the cumulative drainage had exceeded half a pore volume. The hydraulic loading simulated during this study was the seventy-fifth percentile rainfall plus flood irrigation over the summer period.

A method that can be employed to control the extent to which preferential flow is activated, is to limit the application depth to half the difference between the saturated capacity of the soil and the field capacity of the soil. This will ensure that if the soil is at field capacity, then the application of wastewater will not directly lead to saturation, and that some allowance is made for subsequent rainfall. Table 3.3 provides indicative application depths for three New Zealand soils based on a rooting depth of 300 mm.

To ensure soil and plant health, it is essential to allow the soil profile to drain and re-aerate. If, as a consequence of wastewater application and rainfall, the soil becomes saturated, then drainage for 5–7 days minimum will be required. The degree to which this is acceptable will determine an appropriate application depth and return period for the irrigation design.

Table 3.3. *Allowable application depths for three New Zealand soils*

Soil	Average total porosity to 300 mm	Saturation at 93% porosity (mm)	Field capacity at 10 kPa (mm)	Allowable application depth (mm)
Te Kowhai	0.55	153	126	13.7
Horotiu	0.70	195	141	27.2
Templeton	0.46	128	105	11.7

3.3.7 Organic matter

Provided that the effluent is applied to the land in a uniform manner and at loading rates to match the nitrogen uptake, its effects on the soil will be beneficial. The added moisture, organic matter and nutrients will enhance plant growth, which will aid in keeping the soil friable and free draining.

Organic matter present in the effluent assists the soil in retaining moisture and nutrients. Tipler *et al.* (1996) identified that in soils used for irrigation of meatworks wastewater, significant improvements in soil quality can occur (when compared to soils under usual cropping systems). Organic matter content increased by up to 40% and nutrient holding capacity up to 15%, along with an increase in water holding capacity and a decrease in the soil's bulk density, reflecting a better soil structure and worm population.

The BOD and/or COD loading to the land can be used as a measure of the organic loading to the plant-soil system. Although empirical studies have not established a maximum load of oxygen-demanding organics, sludge and manure are usually applied at annual loadings of about 10 to 20 tons/acre (25 to 50 tons/ha). Loehr (1979) suggests that very large loadings in excess of 8,000 lb. COD/acre.day (9,000 kg/ha.day) have been renovated without excess loss of organics to groundwater. Eckenfelder (1989) states that loadings in the range of 600 kg/ha.day are generally acceptable for irrigation and rapid infiltration systems. Adequate aeration, associated with well-drained soils and adequate resting periods, is required. With treated sewage, it is unlikely that BOD/COD loadings will be limiting.

3.3.8 Phosphorus

Phosphorus is a relatively immobile element in most New Zealand soils. Experience at the Taupo land treatment site indicates little change over time (O'Conner *et al.* 1998). The phosphorus applied to the land will accumulate within the soil as described in Chapter 2. In soils with low phosphorus retention indices, the soil may become "saturated" with phosphorus and leaching may commence.

If a biological treatment process has been selected to remove nitrogen from the sewage, then phosphorus may not be removed, and consequentially on sites with higher nitrogen loadings, the phosphorus loadings may be well in excess of plant requirements.

Losses from agricultural systems largely occur through soil erosion. Phosphorus can slowly mobilise in groundwater, at rates that depend on the form in which it exists within the soil. But, apart from the fraction removed from solution by plants, insoluble compounds of phosphorus can be created, in effect acting as a long-term sink. Application of phosphorus in effluent will seldom have any significant effect on groundwater quality and, provided that soil erosion is prevented, there will be minimal effects on surface water quality (see Section 2.3.2).

3.3.9 Land management practices

In land treatment systems that provide for the harvesting of nutrients in crops for removal off-site, there is the potential to damage the soils with the mechanical harvesting machinery. In particular, crops that are harvested for silage and removed from the paddocks in a green state may require use of vehicles with high wheel loads. Compaction of the soil from these vehicles is a problem, especially in the headland areas where vehicles turn and park. Factors such as wheel loading, time of year, soil moisture, soil type, and remediation, all have to be considered in assessing the risks from this.

Land management and monitoring is further covered in Chapter 7.

3.4. EFFECTS ON GROUNDWATER

3.4.1 Introduction

The major concern with contamination of groundwater is the impact on the use of that resource for potable water supply. Sewage products such as nitrate-nitrogen and pathogens migrating through soils and aquifers may adversely affect the potability of groundwater supplies. Criteria that must be met by water used as a supply of drinking water are provided in the New Zealand drinking water standards (MoH 1995). The Standards require that the nitrate concentration is less than 50 g/m^3, nitrite concentration is less that 3 g/m^3 (and their fractional parts are less than 1), and the faecal coliform concentration is less than 1 FC/100ml.

3.4.2 Pathogens

Pathogens that are applied to the land can migrate into groundwater. The path that these organisms take may be complex and is influenced by soil structure and hydraulic loadings (Section 2.4). Application systems that involve saturated soils or high instantaneous application rates may activate preferential flow, which will allow all contaminant to flush quickly through the topsoil.

Nevertheless, some of the pathogens will be adsorbed onto soil particles, filtered out as they are carried through fine soil pores, or retained within the soil moisture for sufficient time that they die. Once they get below the topsoil, they will pass through an unsaturated zone (assuming groundwater levels are not high) before entering the groundwater. Within the groundwater system, the pathogens are likely to move with the groundwater, being subjected to dilution and dispersion, and in many instances may die-off. An assessment of these processes will generally be required to estimate the extent of any contamination of the groundwater by pathogens.

A convenient indicator for assessing pathogen contamination is concentration of faecal coliforms. Considerable data exist on the survival rate of this group of organisms within soil systems and groundwater. Other indicator organisms, such as the enterococcus group or coliphages, may also be useful. It should be noted that faecal coliforms are not good indicators of helminths and protozoa, and that the New Zealand drinking water standards require these not to be detectable in a 100-ml sample.

The starting point for a water quality assessment is the expected concentration of faecal coliform organisms in the effluent (see Chapter 1), which will depend upon the treatment processes and the incorporation of disinfection.

The next step is to consider conditions under which the treated effluent will be applied. When primary oxidation pond effluent was applied at a rate of 32 mm every four days during a period of high rainfall, onto a silt loam soil, Noonan (1995) showed reductions in faecal coliforms of 2–3 orders of magnitude in the topsoil alone, compared with the original effluent.

As effluent passes through the unsaturated zone between the topsoil and groundwater, pathogen reduction will continue. Little information has been collected on faecal coliform die-off through deep vertical unsaturated zones as the fieldwork required for such investigations is extensive—and the data would anyway be largely site specific. However Cagle (1994) has reported that a sand filter of 600-mm depth, loaded with septic tank effluent at 50 mm/day, achieved a pathogen reduction of three orders of magnitude.

The die-off through the topsoil and unsaturated zone must therefore be estimated, either by reference to work similar to that above, or from field leaching trials. This estimate will provide a concentration of organisms in the drainage water that will enter the groundwater.

When the organisms enter the groundwater, they will initially be diluted, and then transported down gradient. It is usual to account for dilution and die-off within the groundwater, but to ignore the dispersion effects. This is a slightly conservative approach that also makes the calculation much simpler.

The distance down gradient to the point where the concentration of faecal coliforms in the groundwater will become less than 1/100 ml. (i.e., meet the drinking water standard) can be calculated from the die-off and the groundwater velocity.

The decay rate for faecal coliforms in groundwater is a half life of 60 hours. This is based on three values obtained for the half-life of coliform organisms in groundwater which range from 2.5–2.9 days (McFeters 1974; Sinton 1980; Noonan 1995). Thus, in approximately 2.5 days, the concentration of faecal coliforms in the groundwater will halve through die-off alone.

The initial concentration is determined from the initial dilution as the organisms in the drainage water mix into the groundwater aquifer. This dilution depends upon aquifer thickness and groundwater velocity. Thickness can be determined from local bore logs, and needs to account for the fact that the organisms may not mix over the full depth of the aquifer, and therefore conservative assumptions are required.

As the groundwater velocity increases, the initial dilution will increase, but so too does the distance that the organisms will travel down gradient before die-off reduces the concentration to less than 1 FC/100 ml. If the groundwater velocity is very high, then initial dilution may be sufficient to reach this target at the boundary. If the groundwater velocity is very low, then the travel times to move beyond the boundary may be so long that this target is reached at the boundary. There will be an optimum velocity that balances initial dilution and dieoff, such that a maximum distance can be calculated.

This is an iterative process and should be used to define the maximum distance from the site, within which the groundwater faecal coliform concentrations may exceed the standards. Groundwater models such as AT123D and DISPSOLV can be used to assess the travel distances of pathogens in groundwater systems. These models allow the decay of various pathogens to be included, and also provide a method of determining the worst case groundwater velocity, which results in pathogens travelling the greatest distance. A conservative approach assuming the worst case groundwater velocity can then be used to define the zone of potential impacts.

3.4.3 Nitrate

Nitrate is a contaminant of concern in groundwater systems because of its ability to convert to nitrite within a human's body and affect the blood supply's ability to carry oxygen. In particular, babies of less than three month's age and the elderly are susceptible to this condition, known as methaemoglobinemia (blue baby syndrome). The limit in the New Zealand Drinking Water Standards requires that the nitrate-N concentration is less than 11.3 g/m^3 (equivalent to 50 g/m^3 nitrate).

A number of processes affect the movement of nitrate in the soil. These processes differ in the unsaturated and saturated zones. Within the unsaturated zone above the water table, as seepage leaves the root zone and percolates towards the groundwater the following processes are anticipated to occur:

Filtration	A physical process that removes fine particles from fluid as it moves through a porous material. Only dissolved constituents, including dissolved nitrate-N, will enter the groundwater system unaffected.
Decay and Respiration	A process that occurs when proteins, e.g., dead bacteria, are broken down by living bacteria, releasing nitrate.
Denitrification	Under conditions of saturation, reduction of nitrate to nitrogen gas can take place (Section 2.3.1). The nitrogen is removed by upward migration of gas or can be dissolved back into the water, again forming nitrate.
Dispersion	Variations in the permeability of the strata forming the unsaturated zone result in dispersion, which spreads the seepage over a wider area and reduces the point concentration of the solutes in the fluid.

Within the saturated zone beneath the water table dilution and dispersion dominate the processes affecting the movement of nitrate-N.

Dilution	The percolating seepage from irrigation mixes with, and is diluted by, the groundwater flowing beneath the site.

Dispersion — Dispersion is both a physical process (hydrodynamic dispersion) and a chemical process (chemical dispersion). Hydrodynamic dispersion results from the different velocities of the fluid moving through the various pore connections in the media. Some pore interconnections allow more rapid fluid flow than others. Chemical dispersion results from movement along a chemical gradient. Solutes in solution move away from areas of higher concentration towards areas of lower concentration.

In general, both processes spread the solutes over a larger volume, thereby reducing the point concentration of the solute, that is diluting the constituent.

In estimating the impacts of nitrate on groundwater, the first stage is to prepare a nitrogen balance for the site, that estimates the quantities of nitrogen applied, volatilised, immobilised, taken up by plants and harvested or recycled, removed by stock, denitrified, and leached as nitrate. This last component is required as the input to the assessment of effects on groundwater.

In general, if the concentration of nitrate in the drainage water is less than the drinking water standard, then the drainage water cannot cause the groundwater concentration of nitrate to exceed the standard. In practice, there will be times throughout the year when levels in drainage waters will be higher. Such periods are more likely during the colder months from late autumn to early spring, when plant uptake is low, mineralisation of nitrogen may still occur and excess nitrate may have accumulated in the soil water after a preceding dry period.

A nitrogen balance for the Taupo land treatment site is given in Table 3.4. Nitrogen loadings have been calculated as 539 kg/ha.yr of N, (O'Conner *et al.* 1998; NZWWA 1996). Leaching was measured at 71 kg/ha.yr or 13% of that applied. Harvesting of pasture at Taupo is removing 76% of the applied nitrogen in the pasture.

Table 3.4. *Nitrogen balances for New Zealand Taupo Land Treatment Scheme*

	Taupo nitrogen balance
Applied nitrogen (kg N/ha)	539
Measured leaching loss (kg N/ha) [1]	71 (13%)
Harvested as crops (kg N/ha)[1]	410 (76%)
Grazing (kg N/ha)	0
Gaseous and immobilised N (kg N/ha)[2]	58 (11%)

Notes:
1. Determined by actual field measurements
2. Remaining portion of nitrogen applied which has not been measured.

There are a number of methods to assess the impact of increased nitrate entering the groundwater. The most simple is the mass balance calculation, which allows for initial dilution only. Numerical and analytical models (such as PLUME, PLUME3D, WMPLUME, ASM, and Domenico and Robbins) are available to estimate concentrations of contaminants in groundwater systems. Each has its advantages and disadvantages, and there are varying abilities to cope with vertical dispersion, different source geometry and differing mass loadings. These are useful predictive tools and where possible should be used with supporting site data.

3.4.4 Groundwater mounding

When additional water is applied to a land treatment site, the drainage volume will increase causing an increase in groundwater level beneath the site which provides the hydraulic gradient to remove the additional volume of water. The rise in groundwater level will be greater than the depth of water applied, due to the small amount of air-filled porosity just above the water table. If the porosity is 0.1, then a deep percolation of 10 mm will result in a 100-mm rise in groundwater level. (This concept would be regarded by groundwater hydrologists as the specific yield of an unconfined aquifer.)

The potential exists on sites with poor sub-surface geological conditions, for the drainage water to cause mounding that will reach the surface, either on the site or close to it. This has the potential to adversely affect land use. Sites with free-draining topsoils may still be unsuitable for a land treatment and disposal site, if the hydrogeological conditions are such that the water can not leave the site. Sites with hydraulically restrictive sub-soil layers, shallow depths to groundwater, low hydraulic gradients beneath the site, or ones which have soils where saturated conditions temporarily exist should be treated with caution (see Section 4.6). Numerical models are available to assess groundwater mounding, such as the Aquifer Simulation Model ASM (Kinzelbach and Rausch 1995).

3.5. EFFECTS ON SURFACE WATERS

3.5.1 Introduction

Sewage entering surface water directly can adversely affect a number of uses and values associated with that water. Organic matter will remove oxygen from the water as it decomposes, compromising life-sustaining capacity; nutrients may promote growth of undesirable plants and fungi; pathogens may be transferred to swimmers and other recreationists; and amenity value will be affected simply by the knowledge that sewage is in the water. Such effects may outlast the actual period of discharge, and loss of amenity value may occur even if there is only a potential for direct discharge to occur. The actual volume of water discharged may also cause adverse effects, by for example adding additional flow at times of peak flow in the waterway.

The preceding sections on groundwater discuss the issues that primarily affect drinking water resources (pathogens and nitrate), and effects on land due to groundwater rise. In addition to these there may be situations where groundwater discharges into surface waters, as experienced at Rotorua (Peacock *et al.*1998; Tomer *et al.* 1997; and Tomer *et al*. 1996).

In the situation where land treatment is proposed, direct discharge to surface waterways should be avoided, as the ability to provide an alternative is one of the major benefits of such a system. However there may be situations where overland flow, or intermittent or seasonal discharges into surface waters, may occur and their effects should be assessed.

3.5.2 Water quality

This document is primarily concerned with the application of treated sewage effluent onto land; therefore discharge into surface waters is a secondary effect. Groundwater discharge into surface waterways may also affect surface water quality. The impacts from these two sources will require assessment.

Water quality guidelines for surface waters are contained in the ANZECC guidelines for fresh and marine waters ANZECC (1992), and the MfE water quality guidelines for the control of undesirable biological growths and bacteria in water (MfE 1992 and 1998).

3.5.3 Pathogens

Water quality in general should not be degraded. In particular it should be recognised that the existence of human pathogens in surface waters provides the opportunity for direct contact. Contact recreation guidelines for fresh and marine water are to be found in "*Bacteriological Water Quality Guidelines for Marine and Fresh Water*" published by the Ministry for the Environment and the Ministry of Health (MfE 1998). Shellfish gathering standards are set at a median (taken over a season) of 14 MPN faecal coliform/100 ml, with a 90 percentile limit of 43 MPN/100 ml (MfE 1998).

Standards for waters not used for contact recreation have a higher limit. Waters used for agricultural purposes should have a faecal coliform concentration of less than 1000/100 ml.

3.6. OTHER EFFECTS

3.6.1 Economic

It is a common perception that properties become devalued if adjacent to a sewage treatment and disposal site. Market value is a summation of a number of factors that the market thinks add to or detract from the value of a property, including location, soils, climate and any detriment such as the presence of a noxious land use.

Market value is defined as the estimated amount for which an asset should exchange between a willing seller and a willing buyer, after proper marketing and where each party has acted knowledgeably, prudently and without compulsion.

With respect to sites close to sewage land-treatment sites, market value is a complex issue, and only a summary of the factors that may affect it is provided here.

The impact of risk of contamination varies with the land use in a particular area. For example, industrial activities within an industrial zone allow effects greater than would be acceptable in a residential zone. In general, the more intensive the residential development, the greater the potential adverse effect on land values.

Contamination of the air, principally by odour, is the most commonly perceived detriment with sewage treatment and disposal. Effluent quality, methods of application, and land management must be such that odour effects are negligible.

Contamination of groundwater to an extent that a neighbouring land user cannot use that water for domestic consumption may detract from property values. Mitigation measures such as guaranteed water quality or alternate potable supplies may be available.

The general stigma on an area in the vicinity of a land treatment site relates to an adverse public perception that is intangible or not directly quantifiable. This can impact on value even when there is no contamination present. The value impact of stigma will decrease over time, and is usually greatest at the start where reaction is driven by uncertainty, but moves to more realistically reflect the situation over time.

If there should be documented or suspected contamination effects on surrounding land, then there may be an adverse effect on values. Cross-boundary contamination should be managed so that there are no effects sufficient to impact on land values.

Guarantees and indemnities may be used by the owners and operators of sewage treatment and disposal schemes where appropriate.

3.6.2 Amenity values

The amenity values of an area must be considered as part of an assessment of effects. Amenity relates to the enjoyment one derives from the environment, which in turn relates to the ability to relax, recreate and to generally undertake activities that provide enjoyment in life. Adverse effects from sewage treatment and disposal sites, such as odour, visual effects, and even the existence of a site, may reduce a person’s wellbeing. Consultation with the community will be the prime mechanism to understand the issues related to a particular site, and appropriate mitigation measures can be sought.

Disturbance of land of cultural or historical significance should also be avoided.

3.6.3 Visual and aesthetic

The appearance of the site could detract from values, if it is purely functional. Landscaping could have the effect of enhancing the surrounding land, as well as providing screening from the “sewage” related activities.

Landscaping will also have benefits in terms of providing buffer plantings to mitigate effects of odour and spray drift. There will be a need to ensure that plantings are in keeping with the surrounding environment.

3.6.4 Cultural

The responsibility of consent authorities towards Tangata Whenua extends beyond consideration of any of the above adverse effects on them. Consent authorities must take into account the principles of the Treaty of Waitangi (Te Tiriti o Waitangi) when considering applications for consent. Consent authorities are also directed to recognise and provide for the relationship of Maori and their culture and traditions with their ancestral lands, water, sites, waahi tapu and other taonga, which are deemed to be matters of national importance.

As a general observation, the land discharge of sewage is favoured by Maori, compared with direct discharge into surface water, however one of the Treaty principles to be taken into account is the responsibility of acting in good faith. A fundamental principle following from this is that only Maori having mana whenua (customary authority) over the rohe (area) within which the system is located should be consulted, unless they direct otherwise. Consultation means supplying full details of a proposal not yet decided, listening to the feedback and then making decisions. It is important that you consult with the appropriate representatives for Maori early on in your investigations and fully inform the consent authority of the consultation that has taken place, along with the outcome.

3.6.5 Perception

In addition to the effects describe above, issues of perception are important. The perception of a land treatment scheme will have a large influence on its success or otherwise. Concepts around reuse and utilisation will be seen as positive, while concepts around sewage and disposal will be seen as negative.

Cropping and land use may be affected by market and political influences. Trade and/or market barriers to land receiving treated sewage effluent, do not exist at present, but may be a future factor to consider.

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4. SITE SELECTION

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4.1. INTRODUCTION

The location of a land treatment site can have a considerable influence on the magnitude and significance of environmental effects, and on the capital and operational costs of sewage treatment. This Chapter identifies the important criteria for land evaluation, details the types and sources of available information, and outlines a procedure for site selection.

Site selection is intricately linked to other parts of the design process and cannot be considered in isolation. Essentially, designers of land treatment systems match the characteristics of the waste with the characteristics of a site and the sensitivity of the receiving environment. The final selection of a site will be iterative with other design decisions relating to pretreatment, application method and site operating rules.

This chapter lists a large amount of information that could be collected for each potential site. However, in selecting a land treatment site there are usually a few key limiting or critical considerations and these will differ from situation to situation. In circumstances where there are only a few available parcels of land, all in the same vicinity, site selection may be predominantly determined by economic/land-price considerations. Site selection will then be only a small part of the design process, and design will focus on how the effluent can be best applied to the site. Alternatively, if there is a wide choice of sites, all on different soil types, then technical or environmental considerations may be the critical parameters for differentiating between them. The purpose of the site selection process is to identify the key parameters, assess relative suitability of sites, and quantify the tradeoffs among potential sites.

The procedure for site evaluation and selection is shown in Figure 4.1. There are basically four stages, which relate to Steps 3 to 6 in the overall design process described in Part 1.

A. <u>Identify candidate areas</u> (the most suitable areas) within a reasonable distance of the effluent source, based on a broad-scale assessment of potential technical and environmental constraints.

B. <u>Select potential sites</u> from within the candidate areas, based on an initial estimate of the land area required.

C. <u>Assess potential sites</u> using readily available sources of information, including knowledge that exists within territorial authorities and local communities. The information is combined into a site screening framework that scores sites according to key parameters and is used to select the most suitable site(s) before field investigations are conducted.

D. <u>Conduct field investigations at the preferred site(s)</u> to verify existing information and identify site constraints that will need to be taken into account at the design stage and when developing a monitoring programme.

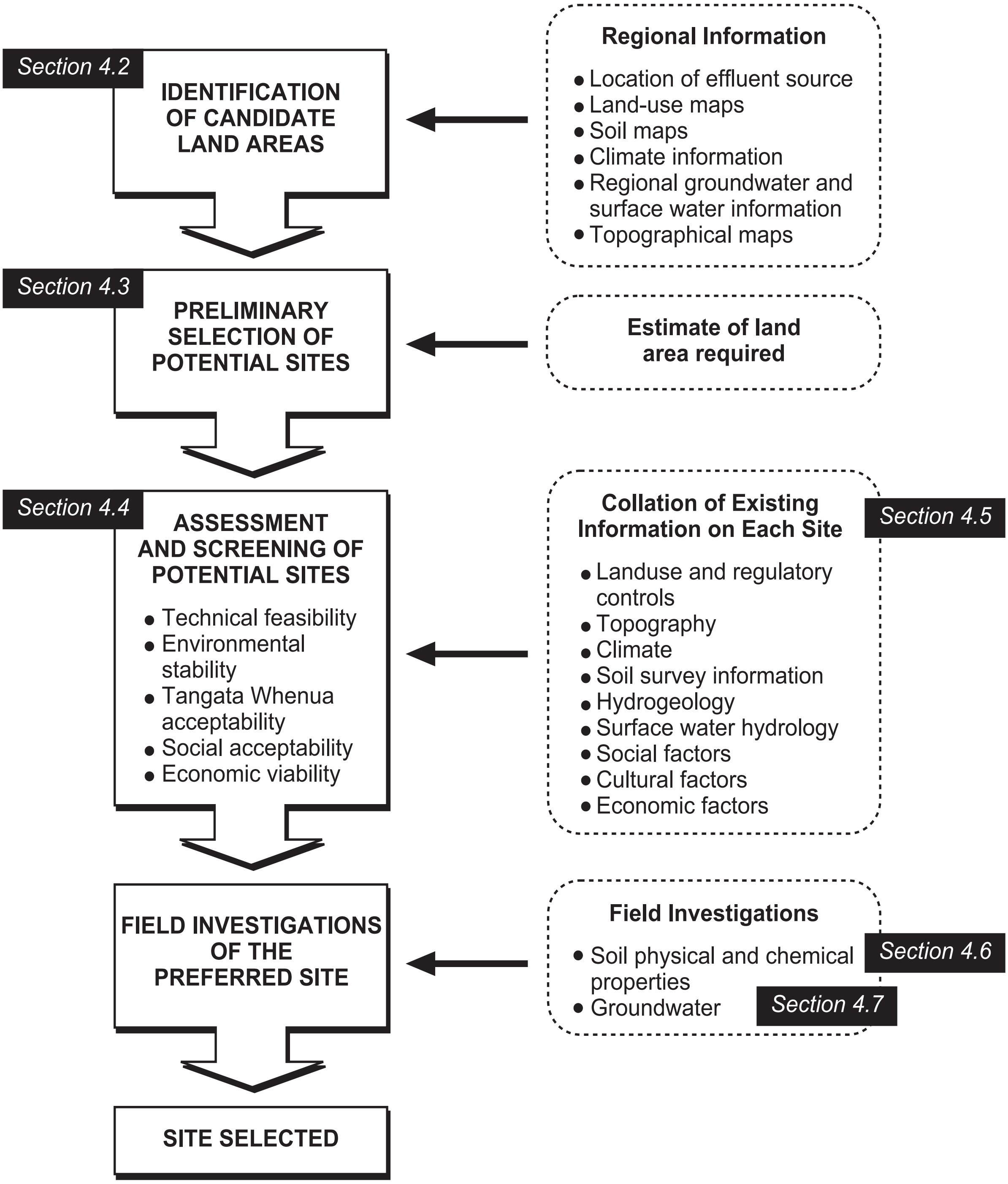

Figure 4.1. *Site selection process*

4.2. IDENTIFICATION OF CANDIDATE LAND AREAS

The first step in designing a land treatment system is to identify suitable areas based on a broad-scale assessment. Identification of candidate land areas forms part of the feasibility assessment for land treatment and is a desktop exercise carried out during early planning (see Step 3 in Part 1). General information on land-use, climate, soils, topography, surface and groundwater bodies, social, cultural and economic issues is used to eliminate unsuitable land areas and assess on a regional basis which areas are most suited to a land treatment system. The assessment should identify those factors likely to be critical or limiting in a given area. The list of possible environmental effects outlined in Chapter 3 can be used as a checklist of potential environmental issues.

The criteria used to determine candidate land areas will differ from region to region but should include the following key factors:

- Distance and change in elevation from effluent source(s) or treatment plant. The longer the distance the greater the pipeline construction cost. The need for pumps, and the energy costs of operating them, will be determined by the elevation difference and the piping distance.

- Land zoning. Zoning provides an indication of land-use and is used to assess the compatibility of a location (surrounding land-use) with a land treatment site. Broad-scale land zoning is shown on district or city plans and can be used to eliminate any areas with obviously incompatible land uses, for example residential zones.

- Soil types. The most suitable soils are naturally well drained and contain reasonable amounts of organic matter. The drainage characteristics and texture of different classes of soils are given in New Zealand Soil Bureau *Soil Maps of New Zealand* (available from Landcare Research). Poorly drained soils (water remains at or near the surface much of the year) are not well suited for land treatment. Excessively drained soils (very rapid removal of water with little or no retention) are less suitable than moderately or well-drained soils. Medium-textured soils, ranging from sandy loams to silty clay loams, are generally best suited for effluent irrigation.

- Topography. The degree to which slope affects waste application varies with the type of application system, soil characteristics, and the cultivation system. As a guideline, irrigation on slopes of greater than 10 degrees or a 1 in 6 gradient will be difficult due to the increased potential for surface runoff. Ground surface slope and elevation information is available from the New Zealand Topomap series at a scale of 1:50,000 (20 metre contours).

- Location of surface water bodies. Areas close to surface water bodies or subject to surface flooding should be avoided.

- Regional groundwater flows and seasonal depths to groundwater. General information on the extent and number of aquifers, whether they are confined or unconfined, and indicative flow directions is often available from regional councils. This information can be used to eliminate land areas that are upstream of domestic water supply wells, have high water tables, are in recharge zones of confined aquifers or have groundwater flows that feed directly into a significant wetland or river.

- Regional climate variation. Local variations in climate such as predominant wind directions or areas in rain shadows can make some sites more suitable than others.

- Social, economic or cultural issues. High land prices, proximity to dwellings, schools, important recreational areas, waahi tapu or other aspects important to Tangata Whenua could make some sites less suitable. One of the biggest hurdles in getting a land treatment system established is overcoming negative public perception and opposition from potential neighbours.

4.3. PRELIMINARY SELECTION OF POTENTIAL SITES

Once candidate areas have been selected, an assessment of the critical or important environmental effects can be made and these effects used to provide an initial “ball-park” estimate of the land area required. In most New Zealand land treatment systems nitrogen loading or hydraulic considerations are the limiting factors that control minimum land area. However, neither of these should be assumed to be the limiting factor without looking at other possibilities such as phosphorus, heavy metals or pathogens. Calculations for estimating land area needed for given nitrogen and hydraulic loadings are outlined in Step 4 of Part 1.

The net area calculated must be increased to allow for buffer zones along boundaries, separation distances to any surface watercourses, and irregularly shaped areas that are difficult to irrigate. As a starting point, it is recommended that the area of land required is assumed to be 25% larger than the net area calculated.

Once the land area required has been estimated, the candidate land areas can be examined for suitably sized properties and a list of potential sites prepared. Existing land boundaries and the area of each legal parcel are available from territorial local authorities. Property boundaries are shown on district or city planning maps.

Identification of a number of potential sites will allow designers to highlight the relative suitability and tradeoffs between sites. At the end of the site screening procedure (Section 4.4), it is advisable to have at least two viable sites. This will provide the “adequate consideration of alternative” sites as required by the Resource Management Act (RMA, 1991) and provide some bargaining leverage for land purchase or leasing. This preliminary stage should therefore identify more than two sites (a usual number is four to eight) as it is likely that some potential sites will be disregarded once more detailed information on technical, social, economic or cultural factors is obtained.

4.4. ASSESSMENT AND SCREENING OF POTENTIAL SITES

For site screening, all the existing information on the potential sites is combined into an assessment framework to determine a preferred site or sites. Site selection cannot be carried out in isolation from other decisions related to land treatment. The approach outlined here requires information on environmental effects, effluent characteristics, potential crops, application methods, and operation of the site.

We recommend developing a matrix that scores each site according to key factors. The key factors selected in each case will differ but must cover the following aspects of a land treatment site:

- Technical feasibility
- Environmental sustainability
- Tangata Whenua acceptability
- Social acceptability
- Economic viability

Information which could be used to score each factor is listed below. Section 4.5 provides more details and lists information sources.

Technical feasibility
- Soil type and characteristics
- Depth to groundwater
- Topography—slope and local relief
- Potential uses of land treatment site
- Climate

Environmental sustainability (refer to Chapter 3 – Environmental Effects)
- Proximity to surface water
- Type of aquifer (confined or unconfined)
- Existing groundwater quality
- Flow paths and final destination of groundwater (based on aquifer properties)
- Capture zone for drinking water wells
- New Zealand Drinking Water Standard classification of aquifer (Ministry of Health, 1995)
- Prevailing wind direction—or other climatic factors that differ from site to site
- Soil type and characteristics
- Flood-prone land
- Regulatory controls

Tangata Whenua acceptability
- Location of traditional or sacred sites or features
- Importance of interconnected surface water bodies

Social acceptability
- Compatibility of adjoining land uses both current and potential

- Proximity of neighbouring dwellings, schools, recreation sites
- Values and uses of interconnected surface water bodies
- Land ownership and existing land use
- Provision of buffer zones
- Potential uses of the land treatment site
- Regulatory controls on land-use

Economic viability

- Existing land use
- Property costs
- Capital or development costs—related to topography, existing land use
- Position relative to treatment plant—required pumping lifts and distance, costs of piping
- Potential uses of and revenues from the land treatment site

While this may seem a large list of factors, many of them will not vary from site to site. The matrix will concentrate on those factors that differ most between sites and therefore highlight the major tradeoffs to be made among sites. The key factors will be those characteristics that distinguish one site from another and which ones are chosen will differ from situation to situation. For example, rainfall only needs to be included for site screening purposes if it differs from site to site. Similarly, if all sites are above the same aquifer, groundwater considerations could be limited to the depth to groundwater and/or proximity of down-gradient wells.

A simple scoring system, which uses three or five gradations, provides an easy to use but effective method of presenting a comparison between factors and sites. Such a matrix allows decision makers to choose a preferred site or to rank sites.

An example matrix is shown below.

Table 4.1. *Property evaluation matrix*

Property	Soils	Depth to groundwater	Tangata Whenua acceptability	Compatibility of adjoining land uses	Proximity of neighbouring dwellings	Distance & elevation relative to plant	Property cost
A	●	◆	●	☒	☒	●	●
B	●	◆	●	●	◆	◆	☒
C	◆	◆	●	●	☒	◆	◆
D	◆	◆	☒	●	☒	◆	◆
E	◆	☒	●	●	◆	◆	●

<u>Keys:</u> ● Very favourable ◆ Favourable ☒ Unfavourable

4.5. COLLATION OF EXISTING INFORMATION

This section further outlines information that needs to be obtained for each of the potential sites. The information will be used to fill in a matrix similar to Table 4.1. All the information required should already exist, either as written material or as knowledge that can be obtained from discussions with territorial authorities, regional councils and local communities.

4.5.1 Topography, climate and soils

Topography

The topography of the groundsurface at a potential site determines how well the site will handle water, and can limit the options for effluent application and for cultivation. Steep grades increase the potential for surface run-off and erosion, and the pressure differential required to operate piped irrigation systems. Details of any local variations in topography (e.g., depressions or high spots) can help determine surface run-off patterns or likely ponding areas. As a guideline, surface irrigation of crops on slopes of greater than 10 degrees or a 1 in 6 gradient will be difficult due to the high potential for surface run-off.

Ground surface slope and elevation information is available from the New Zealand Topomap Series at a scale of 1:50,000 (20 metre contours – 10 metre contours in some areas). Regional or district councils may have more detailed information on topography from aerial photogrammetry or surveys.

Climate

Climate will have a major effect on the feasibility of land treatment and the design of treatment systems. However, in most instances, rainfall and potential evapotranspiration are unlikely to vary significantly among potential sites and are generally not deciding factors for site selection. Given that potential sites are usually close together, the only climatic factor that will often vary from site to site is the predominant wind direction. Standard climate data includes mean annual wind directions and frequencies.

Because climate data will also be required at the detailed design stage, it is sensible to request all the climate information at one time. The data set should include wind information and a time series of monthly values for rainfall, potential evapotranspiration and temperature. A time series of monthly values is needed to provide adequate detail on the distribution and variation in rainfall throughout the year and from year to year. NIWA coordinate a database of climate stations throughout the country—some stations only measure rainfall whereas other collect sufficient climatic information to calculate potential evapotranspiration. Data are available from NIWA and, for some local sites, from regional councils.

Soil survey information

Understanding soil properties at a site is a critical part of site assessment (see Chapter 2 – Soil Processes).

Soils information is contained in NZ Soil Bureau Bulletins (DSIR publications, now available, with updates, through Landcare Research). Soil Bureau Bulletins 6 and 27 cover the soils of the North and South Islands respectively at a scale of 1:250,000. Other Soil Bureau bulletins cover specific areas in more detail. District councils may also have records of recent soil surveys within the area of interest.

The Soil Bureau Bulletins give information on soil texture and drainage class. Information on other soil parameters including representative soil profiles, depths, permeability and available water capacity (or plant-available water) is available from the Soil Bureau Bulletins for some soil types. This information is specific to the representative profile but can be used to generally compare soil types. Ideal soils are deep and medium- textured, with moderate permeability and high plant-available water.

Soil features such as mottles or oxidised root channels, when they occur within the upper metre of the soil profile, indicate that seasonal saturation occurs at the site. Addition of irrigation water at times of seasonal wetness in these soils is likely to cause soil inundation, surface runoff, and crop mortality. If such features only occur in the lower part of the upper metre, then seasonal irrigation (summer only) may be an acceptable land treatment option. The presence of organic soil (peat) at the soil surface is an indicator of perennial wetness and such sites should be avoided if possible. If it is impossible to avoid use of soils with perennial or seasonal wetness, then alternative treatment and storage options will need to be considered in combination with land treatment. On such soils, constructed wetlands should be considered as a treatment option, given that structures to control water levels and drainage from the site will be required. Crop selection and management will have to be handled very carefully at such sites.

Given the importance of soil in the design of a land treatment system, it is worth consulting a qualified soil scientist at this stage. This is because the actual variability in soils at the site may not be represented at the scale of a soil map. A soil scientist will be able to comment on the suitability of the available soil types for land treatment, and indicate the extent of variation that may exist for a given soil type and whether there are likely to be impermeable layers. It may be necessary for the scientist to carry out a soil survey using an auger to establish soil variability and any major soil features.

4.5.2 Hydrogeology—groundwater and location of wells

Knowledge of the hydrogeological conditions under a site is critical for determining if the site is suitable for land treatment. It is important to understand the wider aquifer system that underlies the site, including the direction and speed of water movement, the depth to groundwater and how much water levels vary over a year and from year to year. In addition, the location and uses of wells around the study area must be known.

For an initial desktop assessment, four characteristics of the local aquifers will be needed to determine how the irrigation of effluent might affect groundwater levels and groundwater-fed water or wells beyond the site. These are:

- Type of aquifer (confined, unconfined, semi-confined, perched)
- Aquifer materials and hydraulic properties

- Depth to groundwater and aquifer flow paths
- Groundwater quality.

Unconfined aquifers are recharged directly by percolation through overlying soil, and will receive any nutrients/contaminants that leach below the rootzone in a land treatment site. Confined aquifers receive their recharge water from areas where the aquifer comes to the surface (outcrops). It is important not to site land treatment facilities in the recharge area of confined aquifers, because any contamination that enters the confined aquifer may stay there for a long time and travel large distances. Any down-gradient users of the confined aquifer may be affected by the contamination caused in the recharge area. If an aquifer is confined or semi-confined, it is important to determine if the confining layer is imperfect because if it is, contaminants may have a pathway to the aquifer. Confinining layers often leak around fractures and faults. In other cases slow leakage (either up or down) through silts or muddy sand layers may indicate that the confining layer is permeable.

There is a small possibility, given enough monitoring sites, that existing monitoring may show variations in water quality among sites. In this instance there may be arguments for ranking a site based on existing water quality. Examples might be, selecting a site where background levels of nitrate are already elevated above natural levels, or choosing a site where background levels are low enough to receive effluent leachate without exceeding standard contaminant levels. Such preferences would depend on specific conditions, local priorities and anticipated effects of greater leaching. Although existing groundwater quality is unlikely to be a determinant in site selection, water quality in aquifers under a proposed land treatment facility should be measured *before* operation of the facility to provide background baseline chemical data.

Information sources

Regional councils can provide information on well locations and use (i.e., whether for drinking water or irrigation) and indicate those wells for which information on water levels, well bore logs and/or water quality is available.

Regional councils may also hold broad-scale information on underlying aquifers, whether they are are confined or unconfined, and indicative flow directions. Generally, regional council staff can provide sufficient information from water depth recordings and their own local knowledge. More detailed information on a site can be obtained from well log information, well tests, water level recorders and water quality measurements.

Aquifer properties may be obtained from reports or investigations into an aquifer system held by regional councils or may be estimated based on typical values for the materials recorded on a bore log. Local values will need to be confirmed at the preferred site by field testing.

Well logs contain information on the geological materials encountered while drilling a groundwater bore/well. Information such as the rock type, grain size, hardness, porosity and permeability may all be recorded in a driller's log or well log. Well logs may be obtained from a variety of sources, but the quality of these logs may be variable. The original sources for most well logs are the well drillers themselves. Drillers may have a vast amount of experience in a particular area, but they are not geologists. Therefore, well log information supplied by drillers must be viewed with some caution. Another source of high-quality well log data is the Institute of Geological and Nuclear Science's (GNS) geological database. This is an extensive database with a national scope. The database may not have information for wells in your particular area, but it may have information on wells that are close by.

Water quality data may be available from regional and district council databases, CRI's, the Ministry of Health, and private companies or landowners. Water quality information contained in regional council databases is generally specific to problems that were to be solved at the time the analyses were taken. For this reason, the parameters measured may be unusual or incomplete. Samples that have been taken over several years are especially useful, as they may show natural trends that are important to recognise before a land treatment site is commissioned.

The Ministry of Health have a database of water quality "Water Information NZ – WINZ". It covers aquifers that are currently used for drinking-water supply. Aquifers that have been demonstrated to be secure from the "direct influence of surface water" are classified as "secure groundwater" and are monitored once a month. Monitoring frequencies in other aquifers varies. The WINZ database is managed for the Ministry of Health by ESR, Christchurch. The requirements for "secure groundwater" are given in the NZ Drinking Water Standards (Ministry of Health, 1995).

GNS also maintains a water quality database called the National Groundwater Monitoring Programme (NGMP) which contains extensive water quality information obtained from approximately 100 bores through the country (Rosen, 1997a,b). Although the number of wells in the programme is limited, the amount of information collected for each bore is extensive, and has been collected quarterly since (in some cases) 1992. This means that historical trends should be apparent in NGMP wells.

Another source of water quality information may be large businesses that use groundwater for irrigation or drinking water supplies. If the company does not see a competitive disadvantage to supplying the data, it may be possible to obtain information collected from their bores. Individual landowners may also have water quality information on their water supplies.

4.5.3 Surface water hydrology

Effluent can reach surface water bodies in two ways, either through direct surface runoff or through groundwater recharge. In addition, increased groundwater levels resulting from effluent application can change the patterns of groundwater flow and may affect the interaction between groundwater and surface water. The potential for all these effects decreases with distance of the land treatment site from surface water.

The location of surface water resources can be readily determined from many sources including district and regional planning maps, aerial photographs, and the NZ Topomap Series. Small watercourses on the potential sites (e.g., stock water races) should be identified along with more major features.

The risks of surface runoff depend on the particular effluent and soils, design and operation of the system, and the local topography. A comparison of likely overland flow paths and the location of surface water can give a preliminary assessment of surface runoff risks.

If a surface water body could potentially be affected by the application of effluent, further information on water resource and management policy will be required. This type of information can be obtained from the regional council and could include water quality objectives, details of existing uses of the water and any regulations covering discharges. In the resource consent application both health effects on existing users and ecosystem effects should be discussed. Land treatment proposals for sites that are close to and hydraulically connected to a popular swimming or fishing river, or a river containing native or rare species will be difficult to gain consent for.

For potential sites close to the coast any shellfish growing areas, aquaculture sites and fishing areas along the coast should be identified. This information can be considered along with ground-water flow paths or location of surface water to assess the risk of contaminating seafood areas.

Another consideration is the potential for flooding of the land treatment site. Areas where building restrictions are in place for flooding will be identified on district/city plans and in any plans relating to the management of a river. The frequency and severity of flooding as well as the extent of the area at risk should be examined.

4.5.4 Land use and regulatory controls

Regional policy statements, bylaws and regional plans

Under the RMA, regional authorities can prepare regional plans for the management of resources including surface water, groundwater, water quality, the coastal marine area and natural hazards. While the preparation of regional plans is not compulsory, all regional councils are required to have a regional policy statement that sets out their policies for the management of water, air, soil and other resources. Regional bylaws relating to water abstraction and discharges to water are considered as regional rules and remain in force until an appropriate regional plan becomes operative. The specifics of regional policies, plans and rules will vary among regions but in most cases there will be restrictions related to the quality and quantity of discharges to groundwater and surface water.

District or city plans

Under the RMA, all territorial local authorities must prepare district or city plans. These plans are predominantly concerned with land use and must be consistent with the regional policy statements and any regional plans and policies that are in force in their district. District or city plan maps delineate land-use zones, each with a set of rules and/or zone standards relating to potential uses of the land. In some cases, specific activities can be prohibited within a zone. City or district plans therefore provide vital information for site selection because they indicate potential and current land use and how compatible it is with a land treatment site. Provisions related to pipes and infrastructure should also be examined to assess likely pipeline routes to the site and the ease of procuring access for pipelines.

As yet, not all councils have an operative city or district plan. It is important to find out the current status of the plan and, if the plan is not yet operative, to look at both the proposed district plan and the transitional plan. Until proposed plans become operative, both plans can be considered by the consent authority in deciding whether to approve the resource consent application.

City or district plans often contain restrictions based on regional issues. For example, a regional authority may have identified a groundwater recharge zone and the district plan will restrict land uses in this zone. Similar land use restrictions occur in zones delineated as floodable. Other planning constraints such as may apply to areas with "elite" soil types , or sites of ecological, historical or cultural significance will be identified on district planning maps.

Existing land use and ownership

Existing land-use and positions of dwellings on a potential site and on neighbouring properties may be key determinants affecting suitability of the site for land treatment. Zones in city and district plans do not usually provide sufficiently detailed information on existing land use. The best way to obtain this information is to conduct a visual survey of the potential properties. Other sources include aerial photographs, local knowledge, the New Zealand Land Resource Inventory (held by most regional councils or Landcare Research), or the Quotable Value NZ (formerly Valuation NZ) database that provides a land-use classification for all legal land parcels.

To help assess the likely scale and extent of environmental effects, it is useful to mark the position of existing infrastructure on each of the potential sites and neighbouring properties, e.g., dwellings, other buildings, fences, power supply, shelter trees and surface water courses.

Details of land ownership and property valuations for potential sites are available from the local council. It is also useful to know the type of ownership of neighbouring properties – whether the land is in private or public ownership.

Potential land use of treatment site

Potential uses of land treatment sites include: production of agricultural or forest products, reclamation of land (by using sewage effluent to help establish vegetation cover), development of recreational areas (e.g., golf courses) and formation of buffer areas around public facilities such as airports. The effectiveness of the site will be increased if the crop or groundcover can be harvested and transported off site, either for use or appropriate disposal.

Public Health Guidelines for the safe use of sewage effluent and sewage sludge on land (Department of Health, 1992) provide advice on suitable land uses (Appendix 4). They define five categories of secondary or tertiary treated effluent, differentiated by faecal coliform level. The categories, faecal coliform ranges and irrigation restrictions given in Appendix 4 should be considered as broadly based guidelines designed to safeguard human health The guidelines are intended to encompass most situations and can be used at this site selection stage to assess possible uses of the land treatment site. As design proceeds, a more accurate assessment of potential effects of micro-organisms can be made.and issues such as the type of crop, withholding periods for irrigation and buffer width determined on a site specific basis.

The Department of Health guidelines give suggested buffer zones for spray systems in frequent use (for normal wind exposure) of 150 metres to the nearest residential property and 15 metres to areas of public access for multi-storey canopy forest cover. These widths are guidelines only and relate to public health requirements—other environmental considerations may require greater buffer distances. At this site selection stage the guideline values can be used but the final choice of a buffer width will be site specific and dependent on the likelihood of members of the public coming into contact with the sewage. Appropriate buffer widths depend on factors such as wind exposure, canopy height and adjoining land use.

4.5.5 Social, cultural and economic factors

The land use and regulatory control information detailed in Section 4.5.4 can also be used to assess social, cultural and economic factors required for site selection. For example, neighbouring land use and location of dwellings are relevant to the social feasibility of a potential site. However, in addition to the land use information, there are attitudinal factors that need to be considered. This type of information may be difficult to obtain from written sources and talking to council staff familiar with the requirements or directly to Tangata Whenua, other cultural groups or community groups is a better option. Discussions on site selection will be part of a wider process of the ongoing communication with these groups which should be an integral part of planning for and implementing a land treatment system.

Social factors

The location of any housing, schools, commercial premises, sites of cultural/historic /ecological significance, popular recreation areas or public land can be taken from district planning maps. Public health guidelines suggest buffer zone widths, but these are guidelines only and design buffer zones should be determined on an individual basis (see Section 7.9). The further a site is from dwellings and residential areas the less likely it is to attract strong public opposition.

Recreation or parks staff from local or regional councils should be able to provide guidance on sites that have a high level of public use. Recreational and community groups are another source of information. Health Department guidelines allow irrigation of sewage effluent onto land used for public amenities but there are restrictions placed on the level of public access and the faecal coliform levels. For example, if the effluent has less than 1000 faecal coliforms per 100 ml then it can be sprayed onto recreation grounds but the public must be excluded until the ground has thoroughly dried out (48 hours or more).

Tangata Whenua issues

The RMA requires recognition of the relationship of Maori with their culture and traditions regarding land, water, sites, waahi tapu and other treasures. Maori are often attributed as being one of the driving forces behind the trend away from direct discharge of sewage effluent into surface water (MfE, 1997). While Maori usually support the land application of waste in principal, there will be sites or areas where it is not considered appropriate to site a land treatment facility.

City, district and regional plans may not always identify all sites and features that are important to local Maori. The best way to obtain this information is by direct contact with the Maori group who have Tangata Whenua status for the study area. District and regional council staff may be aware of likely Maori concerns and can provide contact details for the appropriate iwi, hapu or runanga. As mentioned above, discussions on site selection should form part of an ongoing consultation process related to a land treatment project.

Economic factors

The cost of a land treatment facility can be broken down into planning and design costs, capital costs and operational costs. Information on the current land use and the topography of a site will help assess the capital costs of converting the site to a land treatment system. Planning and to some extent operational costs will be increased if there are contentious social or cultural issues associated with a site. Many of the other costs will only vary among sites if there are significant differences in the possible types of application system and operation. The only other information needed relates to property values for the potential sites and potential markets for and revenues from crops.

Consideration should be given to options for acquiring the site for land treatment operations. Does the whole property need to be purchased? Can the parts not used for land treatment be subdivided and sold? Does the site need to be purchased? Could it be leased or continue in its current ownership and land use?

It is important that the holder of the land use and discharge consents for a land treatment system has control over how the site is managed. Experience has shown that this is best achieved when the holder of the resource consents for the land treatment system also owns the land treatment site.

4.6. FIELD INVESTIGATIONS—SOIL

Once a preferred site(s) has been selected field investigations are undertaken to verify existing information, provide local details, and identify site constraints that will need to be taken into account at the design stage and when developing a monitoring programme. Initially, field investigations are aimed at ensuring the proposed site is suitable for land treatment. However, this evaluation also needs to lay the groundwork for later more detailed field testing examining the soil's ability to renovate effluent constituents (see Chapter 2 and Appendix 2). The level of detail required increases as the design process moves from confirming a preferred site through to detailed design of the land treatment site and monitoring systems.

Soil investigations can be carried out on an iterative or prioritised basis. For example, detailed soil maps could be prepared for a few of the top ranked sites followed by physical and chemical analyses of soils at the site with the most suitable soils. A more detailed discussion of field investigations of soil properties can be found in Balks (1995; see Appendix 2).

4.6.1 Mapping soil type, texture, depth and water holding capacity

A soil scientist should prepare a detailed map of the extent, distribution and key properties of the soils at the preferred site(s). The scale and level of detail required will vary. A map scale of 1:25,000 could be used for designing a land treatment system but 1:5000 or 1:1000 will often be more appropriate, particularly at sites where there is a lot of soil variability (Balks, 1995; Appendix 2).

The site information should include the following:

- Depth of each layer in the soil profile and boundary transitions

  Soil depths are required to calculate available water. The presence of any low permeability layers is very important, as these may be the limiting factor in determining hydraulic loading rates.

- The depth to unconsolidated material, gravels or the water table

  This depth determines the depth of soil that is available for contaminant treatment and plant growth.

- Soil colour, texture and structure (including presence of macropores) in the top 1 to 1.5 metres of soil

  Soil colour provides an indication of soil organic matter, gleying and reducing conditions. Soil texture and structure indicate soil properties including water storage capacity, permeability, drainage and ion exchange properties. The presence of macropores relates to the potential for bypass flows or preferential flow. Effluent application rates should be adjusted to prevent preferential flow (see Section 2.2.2).

- Slope and microtopography

  Local topography provides an indication of potential runoff and accumulation/ ponding areas. It can show old drainage pathways, which may become important under irrigation. Surface topography often gives clues to soil drainage patterns.

- Vegetation

  Vegetation species can indicate soil drainage properties and the suitability of soils for specific crops.

These maps can be prepared by a soil expert. The time required to prepare such maps will depend on the soil types present and their spatial distribution.

4.6.2 Soil physical properties

Soil physical properties influence the rate of effluent movement into and through the soil. This information is also required as a baseline for ongoing monitoring of soil properties once the land treatment site is operating.

For each soil type detail:

- Available water content (plant-available water) for each layer

  Available water content is a measure of the ability of the soil to retain effluent in the rooting zone and supply water to the plants. It is therefore critical to system design.

- Surface infiltration rate

  In combination with the hydraulic conductivity, the surface infiltration rate determines the ability of a soil to receive and convey water and hence the wastewater application rate. Surface infiltration rate is very sensitive to management practices, and consideration must be given to possible soil compaction. Appropriate site management, such as reduced effluent application prior to harvest or other traffic pressure, can minimise but not entirely avoid compaction (Land Treatment Collective, 1990). Because surface infiltration rate is sensitive to compaction, measurement of the near-saturated hydraulic conductivity of the surface is often preferred. Measuring near-saturated conductivity eliminates flow carried in wormholes, soil cracks and other such transient macropores that are often affected by management.

- For each soil layer, vertical hydraulic conductivity (k) both near-saturated and saturated

  The conductivity describes the infiltration rate and drainage characteristics of a soil. The limiting or critical parameter for hydraulic loading considerations will be the hydraulic conductivity for the least permeable layer. Rather than measure the conductivity of every layer, at this stage measurements of the topsoil and slowest subsoil layer may be all that is required. The slowest conducting subsoil layer can be identified based on morphology (Griffiths, 1985). If the soil morphology indicates water perching on the slowest subsoil layer, then the hydraulic conductivity of the layer above may need to be determined to establish rates of water movement to the slowest layer. On sloping ground, or in soils with stratigraphic or pedologic layering, both vertical and horizontal k are measured. During system design, the unsaturated hydraulic conductivity of the soil will be compared to the effluent application rate (plus rainfall). If the application rate is less than the lowest k for the soil profile, subsurface ponding and saturation should not occur.

The sampling system used is important because soil physical properties vary both temporally and spatially. A number of replicates need to be taken at each sampling point (Balks, 1995; Appendix 2).

Effluent with high suspended solids content (>500 g/m^3) can reduce the infiltration rate of a soil. Therefore, infiltration rates should be measured using the effluent rather than water. Soil moisture conditions also influence infiltration and measurements should be made when soils are wet. If, as design proceeds, there is concern about the effects on groundwater or surface water, it may be appropriate to conduct lysimeter trials or small scale pilot irrigation trials to accurately characterise how fast and how well the soil is able to receive and treat effluent.

Methods for obtaining soil physical properties are discussed, and further references provided in the Land Treatment Collective Technical Review No. 2 (LTC, 1990).

4.6.3 Soil chemical properties

Soil chemical properties dictate a soil's ability to renovate and absorb nutrients, dissolved constituents, and micro-organisms from the effluent, and reflect the suitability of the soil for a given crop. Initial measurements of soil chemical properties will also provide baseline information for ongoing monitoring once the land treatment site is operating.

For each soil type:

- pH (*influences ability of micro-organisms, pathogens and viruses to survive in the soil*)
- Cation exchange capacity (*describes a soil's buffering capacity and nutrient reserves)*
- Phosphorus retention (*relates to the ability of a soil to adsorb phosphate*)
- Total carbon (*relates to the reserves of organic matter, soil structure and water holding capacity*)

As for soil physical properties, the sampling protocol used is very important. Samples collected must be as representative as possible of the defined soils units (see Appendix 2). Soil chemical properties can differ by more than 100% between comparable horizons in the same soil type (Landon, 1991).

4.7. FIELD INVESTIGATIONS – GROUNDWATER

Like the soil investigation, groundwater investigations are aimed at verifying existing information to ensure the proposed site is suitable for land treatment. Knowledge of the hydrogeological conditions under a potential land treatment site is critical for determining if the site is suitable. It is important to understand the wider aquifer system that underlies the site including the direction and speed water moves at, the depth of groundwater and how much water levels vary, over a year and from year to year. Parameters such as the thickness of the unsaturated zone (the zone from below the ground surface to just above the water table), the permeability of the aquifer below the site, and the degree to which the aquifer is confined or unconfined are also essential to determine how effective the site will be. For example, water added from irrigation can more than double the annual recharge volume at a land treatment site. Knowledge of the response of the aquifer to this additional loading is needed to be able to determine loading rates and assess if low-lying areas of the site will become flooded. This understanding is particularly important when wetlands form part of the treatment system.

We recommend that as much information as possible is derived from existing wells. If these do not provide a clear picture of the aquifer under the site then they should be supplemented by additional wells. As installation of bores is costly, new ones will likely be restricted to the preferred site and will usually only proceed once all other site characteristics have been found suitable for land treatment.

Groundwater field investigations are generally thought to be expensive because of the cost of drilling monitoring bores and the expense of sampling the bores. However, if placed appropriately, the field investigation bores can be subsequently used as part of a monitoring and environmental management system. Compared with the overall capital expense of designing and operating a land treatment facility, the cost of setting up a useful groundwater monitoring network is small, and the benefits, in terms of providing early warning signs of potential contamination, are large.

4.7.1 Pump tests to confirm aquifer structure and hydraulic properties

The aquifer hydraulic properties and the nature of a confining layer can be tested using drawdown tests and other types of pump tests on groundwater bores. The main use of pump tests is to determine aquifer parameters such as transmissivity (T), storativity (S and S_y) and hydraulic conductivity (k). S (confined aquifer) and S_y (unconfined) can be defined as the volume of water that an aquifer releases from storage per unitsurface area of aquifer per unit decline in the component of hydraulic head normal to that surface (Freeze and Cherry 1979). Both T and S are important parameters to measure because they give information about the quantity of water available in an aquifer (S), how quickly water flows through an aquifer (k and T) and the ability of the aquifer to handle additional water from irrigation.

Many pump tests are designed to be specific to either confined or unconfined conditions. In general, it is best to know the nature of aquifer before testing begins, but plots of the pump test data can be used to evaluate whether the best fit is for a confined, leaky or unconfined system. The characteristic pattern of the drawdown when a bore or well is pumped indicates the degree of confinement of the aquifer. It is important to determine if the confining layer is imperfect because if it is contaminants may have a pathway to the aquifer. The type of pump test that is used in a particular case will depend on the number of monitoring wells available and the nature of the aquifer (i.e., if it is confined or unconfined). An excellent guide to the evaluation of pump test data can be found in Kruseman and de Ridder (1991).

The details of all of these pump tests are beyond the scope of this manual, but the interested reader can find more material in Bear (1979), Freeze and Cherry (1979), Rushton and Redshaw (1979), Kruseman and de Ridder (1991), Kasenow (1995) and Walton (1987, 1996).

4.7.2 Depths to groundwater, groundwater pressures and flow paths

In unconfined aquifers, the depth to the water table is important because it influences groundwater flow directions. In a fully confined aquifer, hydrostatic pressure is a more critical parameter than the depth to groundwater because pressure gradients determine the direction of groundwater flow. Seasonal variations in rainfall may effect groundwater flow paths as pulses of recharge water move through the aquifer system. Therefore it is essential to examine groundwater levels and pressures on a seasonal basis to accurately assess all potential flow paths. Depth to groundwater is also important for determining if irrigation water will saturate the soil depth or if mounding of the water table can occur.

<u>For unconfined aquifers,</u> typical depths below ground are less than 10 metres, but some may be less than 1 metre below the ground surface. In some areas, water depths may be as great as 30 or 40 metres. Water depths can vary significantly from year to year and seasonally. Depth variations of 5 metres are not uncommon.

<u>For confined aquifers,</u> hydrostatic pressure varies depending on the thickness of the confining layer and the degree of confinement. As for unconfined aquifers, the range of heads should be recorded. Recorded water levels in the semi-confined aquifers on the Canterbury Plains vary by as much as 25 metres.

A general flow direction can be determined from measurements at just three points as long as they are not located in a line. Existing water supply bores or irrigation bores can provide the sampling points necessary for determining the slope of the water table. However, it is necessary to know that all the points used to construct the flow diagram come from the same aquifer (this highlights the importance of well logs). The elevation of the bores must be accurately determined, either with the use of surveying techniques or by using Global Positioning Satellite (GPS) units, and tied to a consistent datum (for example mean sea level or some other fixed datum). In this way the relative height of the water in each bore can be determined reference to topography. Flow directions can be estimated by contouring the map with bore elevation data in a similar manner to topographic contours. Lines of equal groundwater height (equipotential lines) are constructed, and groundwater will flow perpendicular to these contours (Figure 4.2).

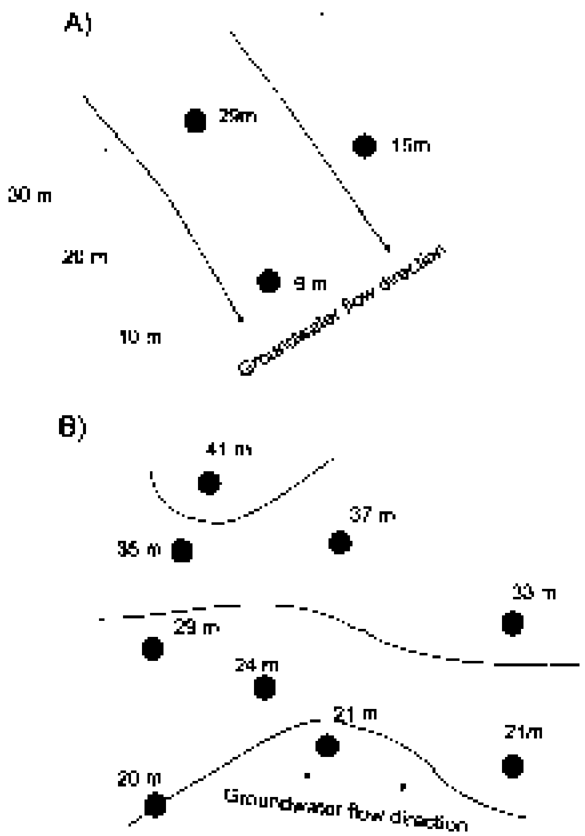

Figure 4.2. *(A) Equipotential lines showing groundwater flow directions using minimum data (three points). Values are groundwater levels above mean sea level. (B) Equipotential lines showing groundwater flow directions using a network of wells.*

Streams may also give some indication of groundwater levels because during low flow conditions, many stream levels represent the top of the water table in that area. However, caution should be exercised because many rivers in New Zealand act as recharge sources rather than discharge areas. This means that the groundwater flow direction could be away from the river rather than towards it. A good way to test this is to find (or construct) a bore about 20 to 50 metres away from a river. If the water level in the bore is below the water level in the river, the groundwater is flowing away from the river. If the water level in the bore is above the water level in the river the groundwater is flowing towards the river. If the groundwater level and the river level are equal, it may be that on some occasions groundwater is flowing towards the river (i.e., after heavy rainfall), but on other occasions it may be flowing away from the river (i.e., during drought conditions).

4.7.3 Use of monitoring wells to supplement data

Once a general groundwater flow direction has been determined, monitoring wells can be added to the network to accurately define the groundwater flow and to capture any flow of contaminants that enter the groundwater. At least one up-gradient bore should be installed so that the chemistry of the down-gradient bores can be compared to something that has not been influenced by the land treatment activities (see Chapter 7).

Depending on the location of available bores, monitoring bores should be placed so that they increase the ability of the network to define flow paths, but more importantly are placed to intercept potential migration pathways of contaminants. This can be difficult to determine if only limited data is available on flow directions. Regional groundwater flow may be different from local groundwater flow, and in the case of a land treatment site, it is the local flow that may be more important.

4.7.4 Current groundwater quality characteristics

The level of detail required at this site selection stage will depend on how closely the existing groundwater quality matches the water quality requirements for any current and potential uses of the groundwater.

Unconfined aquifers are generally well oxygenated because their upper surface is open to exchange with the atmosphere. (This may not be true near wetlands and in areas that have high organic content in the aquifer sediments.) If the aquifer is well-oxygenated, high concentrations of reduced metals such as iron or manganese are unlikely to be present. The most abundant form of nitrogen is likely to be nitrate. Groundwater quality will vary with seasonal temperature fluctuations

Water quality in confined aquifers is less likely to vary seasonally than the water quality of unconfined aquifers. Because it takes longer for water to penetrate to a confined aquifer, the seasonal variation is diminished. In addition, dissolved oxygen concentrations may be reduced in confined aquifers due to their isolation from the atmosphere. This isolation and lack of oxygen may favour the growth of anaerobic micro-organisms. Organisms such as denitrifying bacteria may become important and nitrate concentrations may be reduced in confined aquifers.

Water quality in semi-confined aquifers may be somewhere in the middle (i.e., the water may be partially oxygenated or be slightly reducing etc). But semi-confined aquifers may have water quality characteristics that are similar to either unconfined or confined aquifers, depending on the degree to which the aquifer is open or closed.

To accurately characterise the effects of any leachate on groundwater quality it will be very important to have good information on existing water quality. The current water quality of the unconfined aquifer under a proposed land treatment facility should be measured *before* operation of the facility to provide background baseline chemical data. This will provide information so that any changes in water quality noticed after the facility is operating can be properly evaluated. In general, too few analyses are performed before operation begins. Monthly data from at least one up-gradient and two or three down-gradient sites should be monitored for at least one year before starting irrigation to allow the collection of baseline data over an entire annual cycle. This amount of data may seem excessive; however, compared with the overall cost of a facility the expense is relatively small. By delineating the potential variation in critical water quality parameters, such as nitrogen and phosphorus, before operation begins it is possible to better define the natural variation (or variations caused by previous land use), which may allow better management of the facility. If this amount of time is not available, at least 6 months' data should be collected over the winter period when recharge is likely to be greatest. Ideally two years of monthly data would give the best results for creating a baseline water quality data set, because this would incorporate some yearly variation in rainfall and other factors.

4.8. SUMMARY

At the end of the site selection process, a preferred site will have been selected and sufficient field investigations carried out to confirm that the site is compatible with an affordable, environmentally sustainable, and practical land treatment system. The reason for choosing this site over other potential sites will be clearly recorded.

The selection of a final site is likely to be made once design of the application system and detailed field investigations have started. Exactly how much of the system design and detailed field investigations need to be carried out before confirming a site will vary considerably from situation to situation. Field investigations will be ongoing throughout the detailed design of the system and will form the basis of an ongoing monitoring system. Site selection, system design, field investigations and design of the ongoing monitoring and management of a land treatment site are closely intertwined and usually carried out on an iterative basis.

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5. APPLICATION METHODS

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5.1. INTRODUCTION

There are a wide range of application methods that can be used to apply sewage effluent to land. This section provides an overview of application methods, outlines the features of the various systems and provides an assessment of these systems.

Each application system is described together with an explanation of how it functions and its mode of operation. The key advantages and disadvantages of each system are discussed. Finally the application systems are assessed according to a number of factors that need to be considered when selecting a system.

Irrigation design information is outside the scope of this Chapter. Design information would need to be obtained from irrigation handbooks and standards, such as. ASAE (1983) and NZS 5103 (1973).

5.2. DESCRIPTION OF APPLICATION SYSTEMS

A range of application systems can be used to apply sewage effluent to the land. These are:

- Spray irrigation systems – travelling irrigators, centre-pivot systems, solid-set systems and moveable sprinkler systems
- Border-strip irrigation systems
- Drip irrigation systems
- Direct injection.

5.2.1 Travelling spray irrigation systems

Travelling spray irrigation systems involve pumping effluent to a travelling irrigator using an underground mainline system, hydrants and a flexible hose. Travelling irrigators are self-propelled machines that move continuously across the paddock while irrigating, and require shifting once or twice per day.

There are four types of travelling irrigators: hose-pull travelling guns, hard-hose travelling guns, linear booms and rotary booms. The mode of operation of each of these types of travelling irrigators is shown in Figure 5.1.

Hose-pull systems and hard-hose systems normally operate at high pressure. In hose-pull systems, the water gun is mounted on a wheeled carriage, water is supplied through a flexible drag hose and the machine is winched along the travel lane. A water turbine or a piston mechanism is used to drive the winch. In hard-hose systems, the gun is mounted on a small carriage. Water is supplied through a polyethylene hose, which is wound slowly onto a large stationary reel. A water turbine or a piston mechanism is used to drive the stationary reel.

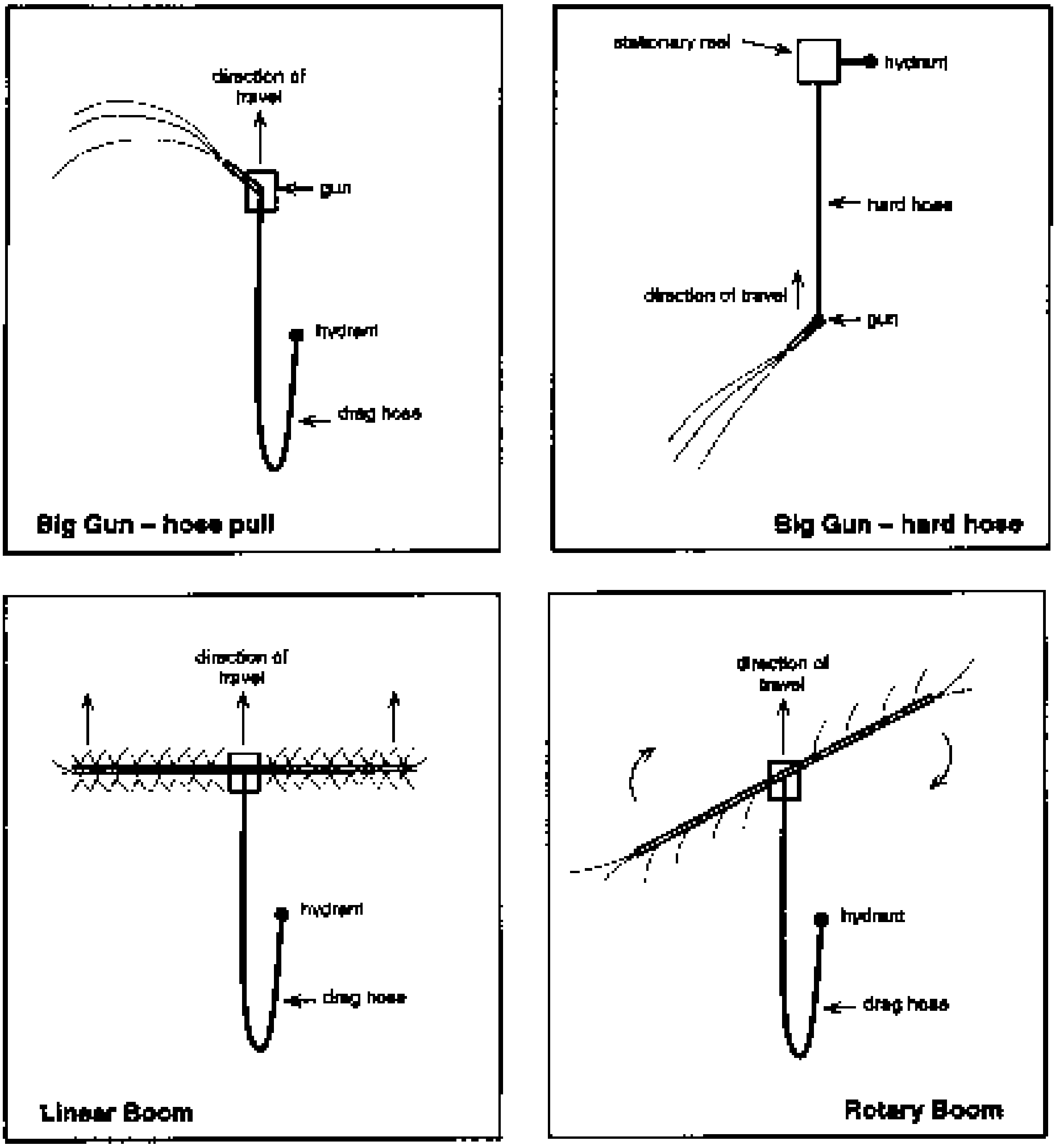

Figure 5.1. *Mode of operation of travelling irrigators*

Linear booms operate in a similar way to hose-pull gun systems, except that a wide boom is fitted to the machine instead of a gun. Booms can be fitted with small guns, impact sprinklers, low pressure mini-sprinklers or spray jets. The operating pressure depends on the type of sprinklers fitted to the boom. Rotary boom machines are similar to linear booms except that the boom rotates continuously and the winch is driven by the reaction of the rotating boom. They are generally fitted with a small number of large nozzles.

The performance of various types travelling irrigators has been compared by John *et al.* (1985). The performance characteristics investigated were uniformity of application depth and the extent to which surface redistribution of applied water occurred due to application rates exceeding soil infiltration rate.

5.2.2 Centre-pivot systems

Centre-pivot irrigation systems consist of a single galvanised steel lateral that rotates in a circle about a fixed point in the centre of a paddock. The lateral is supported above the crop on wheeled towers approximately 50 m apart. Effluent is pumped to the centre of the pivot through an underground mainline. A wide range of sprinkler devices can be fitted, ranging from low-pressure spray jets to medium-pressure impact sprinklers. Centre-pivots may be fixed permanently in one position or towed to various positions. They can be easily automated and controlled from a central point.

5.2.3 Solid-set spray irrigation systems

Solid-set or permanent sprinkler systems consist of laterals and sprinklers placed in a paddock to cover the irrigated area, so that no equipment needs to be moved. Generally, all pipes are buried below ground, and sprinklers are placed on permanent risers. Sprinklers can be high-pressure guns or medium-pressure impact sprinklers, although pop-up sprinklers have also been used. Semi-permanent systems are similar in layout to permanent systems except that both the sprinklers and laterals are above ground and can be moved from the paddock if necessary.

5.2.4 Moveable sprinkler systems

Long-lateral systems (also known as bike-shift or long-line systems) consist of permanently buried mainlines and movable sprinklers on sleds connected to the mainline with polyethylene hose. The sprinklers are moved manually around a number of positions to cover the area.

K-line systems consist of moveable sprinkler lines that are connected to permanently buried mainlines. These sprinkler lines consist of a polyethylene pipe with sprinklers spaced at approximately 15 m intervals. A skid under each sprinkler allows the sprinkler lines to be relocated by towing with a four wheeled ATV or other vehicle. Typically each K-line would operate for up to 24 hours in each set up before being moved to the next sprinkler line position.

5.2.5 Border-strip irrigation systems

Border-strip irrigation is a surface irrigation method that utilises the force of gravity. In traditional border-strip irrigation systems, effluent is released from headraces at the top of groups of formed border strips at flow rates high enough to ensure effluent reaches the bottom of the border. Borders are typically 12 m wide, and 150–300 m long, with four to six borders being irrigated at once.

Controlled border-strip systems are systems in which borders can be be individually irrigated. Effluent is commonly piped to the borders from supply rather than travelling through open headraces. Flow to each border is usually controlled by valves. These valves can be automated from a central control point.

A typical border-strip irrigation system requires a flow of 300–400 litres/sec for a traditional system and 50–100 litres/sec for a controlled single border system.

5.2.6 Drip irrigation systems

There are two types of drip irrigation, namely surface drip and subsurface drip. In drip irrigation systems the effluent is applied to the land in the form of droplets from a series of discrete point sources. Both surface and subsurface drip systems have buried mainline pipes. Laterals for surface drip irrigation are placed on top of the ground, while laterals for subsurface drip are buried at anything from 100 mm to 900 mm below the surface, and typically 150 mm under pasture.

5.2.7 Direct injection systems

Direct injection of the effluent involves the use of a specialised tine implement that is towed by a tractor unit. As the tines are pulled through the soil a cavity is created into which the effluent is injected. Effluent is supplied to the tines either from a tank attached to the tractor unit or from an umbilical cord (flexible pipe) connected to a stationary tanker.

5.3. KEY ADVANTAGES AND DISADVANTAGES OF APPLICATION SYSTEMS

The key advantages and disadvantages of the different application systems are outlined below.

5.3.1 Spray irrigation systems

Solid-set irrigation systems are generally more expensive than travelling irrigator systems. However, permanent solid-set systems require little labour input compared with travelling irrigator and moveable sprinkler systems, which need to be moved daily. Apart from labour cost, the operating costs of spray irrigation systems are directly related to the sprinkler operating pressures.

Advantages of travelling irrigator systems

- The depth of application can be controlled.
- Medium to low operating costs for low pressure boom irrigators and rotary boom irrigators.
- Able to irrigate irregularly shaped paddocks.
- Filtration of the effluent is less critical.

Advantages of solid-set and centre-pivot systems

- The application depth can be controlled.
- Systems can be easily automated and controlled from a central point.
- Medium to low operating costs except for systems fitted with high-pressure guns.
- Low labour input required.

Disadvantages of travelling irrigator, solid-set, centre-pivot and moveable sprinkler systems

- Potential for creation of spray drift and aerosols especially for high-pressure systems.
- For travelling irrigator and moveable sprinkler systems, a regular labour input is required for shifting the irrigator.
- High operating costs for high-pressure systems.

5.3.2 Border-strip irrigation systems

Border strip irrigation systems are gravity systems that require large flow rates to operate. In a traditional border-strip system a storage facility is used to provide the volumes required. A treatment pond, for example, could provide this storage. Controlled border strip systems have the advantage that they may be able to be designed with only a small amount of storage. However, these systems are generally more expensive.

Advantages of border-strip irrigation systems

- Negligible potential for the creation of aerosols.
- Medium to low labour input.
- Low operating costs.

Disadvantages of border-strip irrigation systems

- Less control over the depth of application.
- Greater potential for leaching of effluent to the groundwater.
- With traditional border-strip systems the ponding of effluent in headraces after use has the potential to generate odour.
- Land forming required.

5.3.3 Drip irrigation systems

Drip irrigation systems have a number of advantages, such as being fully controllable and not subject to odour, aerosol or wind problems. In addition, drip irrigation avoids crop leaf wetting which can promote disease and pest problems. Drip irrigation systems are expensive to install and require high quality filtration of effluent. In addition, allowances have to be made for their periodic flushing. However, they have low operational costs. Surface drip systems are feasible for row crops, horticulture or plantation trees – but they are not feasible for pasture.

Advantages of drip irrigation systems

- The depth of application can be controlled.
- Negligible potential for the creation of odours and aerosols.
- Can be easily automated and controlled from a central point.
- Low labour input.
- Low operating cost.
- Effluent can be applied directly to the root zone.

Disadvantages of drip irrigation systems

- High level of filtration of the effluent is required to ensure that drip outlets do not become blocked.
- Filtration failures are difficult to fix in subsurface drip systems.
- High capital cost for surface drip systems and very high capital cost for subsurface drip systems.
- External root intrusion can occur in subsurface drip systems and needs to be managed.

5.3.4 Direct injection systems

Direct injection systems are most suited to situations where there is high-strength effluent which needs to be applied at low annual application depths. Direct injection is more appropriate for deeper soils and it is not suitable for shallow stony soils (Kerr and Noonan 1993).

Advantages of direct injection systems

- The depth of application can be controlled.
- Negligible potential for the creation of odours and aerosols.

Disadvantages of direct injection systems

- High energy and operating cost.
- The number of repeat applications to an area of land is limited by the need to avoid disturbance to the growing crop.

5.4. SELECTION CRITERIA AND ASSESSMENT

There are a number of factors that need to be considered when deciding which method of effluent application to use. In Tables 5.1 to 5.6 performance of the different irrigation system types is compared for a range of important criteria. The relative importance of these will vary according to circumstances.

Note that average application rates are given as a range in Tables 5.1, 5.2 and 5.3. The average application rate for a particular system depends on the design (for example the nozzle size and spacing for solid-set systems) and the size of the irrigator (for example the length of the boom for centre-pivot systems). For border-strip irrigation systems (Table 5.4) average application rates are extremely variable and depend on specific site characteristics.

The instantaneous application rate is critical to the irrigation system's operation. For example, a travelling big gun or centre-pivot irrigator may have the same average application rate as a solid-set system in terms of millimetres per hour, but their instantaneous application rates can be considerably higher than for the solid-set system. This can often be an important factor because most effluent irrigation systems will operate on moist to wet soils, in contrast to freshwater supplemented irrigation. Irrigation of moist to wet soils at high instantaneous application rates can lead to ponding and overland flow.

It is not possible to provide meaningful figures for capital cost of the application systems because cost varies significantly with the size of particular land treatment systems and with site specific factors. A relative ranking of capital cost is given in Tables 5.1 to 5.6.

The distribution efficiency of an application system depends on the design and management of the system. In addition, distribution efficiency is affected by site specific factors such as topography and soil characteristics. Therefore, it is possible that in different situations each of the application systems could be designed and managed to have a high distribution efficiency.

As land application systems normally operate continuously throughout the year, there will be times when effluent irrigation is required but the soil is at or near saturation, either from rainfall or from previous irrigation. The design must account for the worst case condition of soil saturation and possible sealing of the soil surface. The instantaneous sewage effluent application rate should not exceed the infiltration rate of the saturated soil. Designing to this criteria means that the system will often be under-loaded, particularly during dry summer periods, but it will avoid occurrences of significant overland flow and surface runoff during extreme wet periods (McIndoe and Borrie 1996).

Once an application system has been designed to meet soil limtations on application rate, the depth and frequency of applications—that is the management of the system —is largely dependent on the sewage effluent content, and the ability of the soil/plant system to assimilate the sewage effluent waste components.

Table 5.1. *Assessment of irrigation options for selection of travelling spray irigators*

Criteria	Big Gun- Hard Hose	Big Gun- Hose Pull	Linear Boom	Rotary Boom
Average application rate	10-25 mm/h	10-25 mm/h	20-75 mm/h	10-25 mm/h
Variable application depths	Possible	Possible	Possible	Possible
Nozzle operating pressure	450-700 kPa	450-700 kPa	200-400 kPa	300 kPa
Labour input	<1 hour per irrigation set up	1 hour per irrigation set up	1 hour per irrigation set up	1 hour per irrigation set up
Capital cost	Medium	Medium	Medium	Medium
Operating cost	Function of operating pressure, sewage effluent volume and labour input required			
Land use options	A range of land uses are possible with these irrigators			
Risk of crop damage	Low	Medium	Medium	Medium
Ease of use	Good	Average-good	Average	Average
Potential for wind drift	High	High	Medium	Medium
Potential for odour	High	High	Medium-high	Medium-high
Potential for aerosols	High	High	Medium-high	Medium-high
Filtration of effluent required	Medium	Medium	Medium	Low
Level of management required	Average	Average	Average	Average
Automation	Difficult	Difficult	Difficult	Difficult

Table 5.2. *Assesment of irrigation options for selection of solid-set and centre-pivot spray irrigation systems*

Criteria	Solid-Set High Pressure Guns	Solid-Set Medium Pressure Impact Sprinklers	Long Laterals	Fixed Centre-Pivot
Average application rate	10-25 mm/h	<15 mm/h	10-25 mm/h	10-25 mm/h
Variable application depths	Easy	Easy	Possible	Easy
Nozzle operating pressure	400-600 kPa	300-400 kPa	300-400 kPa	200-400 kPa
Labour input	Regularly check on system's operation	Regularly check on system's operation	Up to 4 hours depending on number of sprinklers	Regularly check on system's operation
Capital cost	High	High	Medium	Medium
Operating cost	Function of operating pressure, sewage effluent volume and labour input required			
Land use options	A range of land uses possible	A range of land uses possible	Pasture	A range of land uses possible
Risk of crop damage	Low	Low	Low	Low
Ease of use	Excellent if automated	Excellent if automated	Average	Good-excellent
Potential for wind drift	High	Medium	Medium	Medium
Potential for odour	High	Medium	Medium	Medium
Potential for aerosols	High	Medium	Medium	Medium
Filtration of effluent required	Low	Medium	Medium	Medium
Level of management required	Low	Low	Average-high	Low
Automation	Easy	Easy	Difficult	Easy

Table 5.3. *Assessment of irrigation options for selection of moveable sprinkler systems*

Criteria	Long Laterals	K Line
Average application rate	10-25 mm/hr	2.5-5 mm/hr
Variable application depths	Possible	Possible
Nozzle operating pressure	300-400 kPa	200-300 kPa
Labour input	Up to 4 hours, depending on number of sprinklers	1-3 hours, depending on number of sprinkler lines
Capital cost	Medium	Low
Operating cost	Function of operating pressure, sewage effluent volume and labour input required	
Land use options	Pasture	Pasture
Risk of crop damage	Low	Low
Ease of use	Average	Average
Potential for wind drift	Medium	Medium-low
Potential for odour	Medium	Medium-low
Potential for aerosols	Medium	Medium-low
Filtration of effluent required	Medium	Medium-high
Level of management required	Average-high	Average-high
Automation	Difficult	Difficult

Table 5.4. *Assessment of irrigation options for selection of border strip irrigation systems*

Criteria	Traditional	Controlled
Average application rate	>50 mm/h	>50 mm/h
Variable application depths	Difficult	Difficult
Operating pressure	Atmospheric pressure	100 kPa
Labour input	Up to 1 hour per irrigation set up	Regularly check on system's operation
Capital cost	Medium	High
Operating cost	Function of sewage effluent volume and labour input required	Function of operating pressure, sewage effluent volume and labour input required
Land use options	Pasture	Pasture
Risk of crop damage	Low	Low
Ease of use	Good	Good
Potential for wind drift	None	None
Potential for odour	Medium, if use headraces	Low
Potential for aerosols	None	None
Filtration of effluent required	None	None
Level of management required	Average	Average
Automation	Partial automation is easy	Easy

Table 5.5. *Assessment of irrigation options for selection of drip irrigation systems*

Criteria	Surface Drip	Subsurface Drip
Average application rate	<10 mm/h	<10 mm/h
Variable application depths	Easy	Easy
Dripline operating pressure	100-150 kPa	100-150 kPa
Labour input	Regularly check on system's operation	
Capital cost	High	Very high
Operating cost	Function of operating pressure, sewage effluent volume and labour input required	
Land use options	Row crops	Best suited to pasture
Risk of crop damage	Low	None
Ease of use	Excellent	Excellent
Potential for wind drift	None	None
Potential for odour	Low	None
Potential for aerosols	None	None
Filtration of effluent required	High	High
Level of management required	High	High
Automation	Easy	Easy

Table 5.6. *Assessment of direct injection systems*

Criteria	Direct Injection
Average application rate	Not applicable
Variable application depths	Possible
Operating pressure	Not applicable
Labour input	Labour required continuously during operation
Capital cost	High
Operating cost	Function of size of tractor unit required, sewage effluent volume and labour input required
Land use options	Pasture
Risk of crop damage	Medium-high
Ease of use	Fair
Potential for wind drift	None
Potential for odour	None
Potential for aerosols	None
Filtration of effluent required	None
Level of management required	High
Automation	No

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6. CROP SELECTION AND MANAGEMENT

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6.1. INTRODUCTION

This chapter outlines crop systems suitable for sewage irrigation. Following a general introductory section on nutrient renovation (Section 6.1), it discusses the different major crop types used and their management. Section 6.2 focuses on pasture and arable crops, and on management techniques that will enhance nutrient removal, while minimising nutrient loss to ground water. This section describes the “cut and carry” system needed to remove nutrients from the site. It lists site and crop requirements, compares crops for their suitability for land treatment, provides guidance on effluent application rates, and gives recommendations for the establishment and maintenance of the best cropping options. The remainder of the Chapter (Section 6.3), in a similar manner, focuses on forest crops and their role in land treatment systems.

6.1.1 Overview

A major aim of land treatment systems is to remove plant nutrients, particularly N and P, from applied sewage effluent so that concentrations in nearby ground and surface water are either not increased, or are held at acceptable levels. The irrigation of crops with nutrient-rich effluent will allow them to achieve optimum yields and to take up more nutrients than are required for maximum growth. If crops are harvested at a stage where no more nutrient can be taken up from the soil and the system is managed sustainably large amounts of nutrient will be utilised, at the same time as producing a useful end product, which can be sold.

The effectiveness of land-based sewage effluent treatment depends on three major factors:

1. Suitability of the site on which the crop is established, maintained and harvested.
2. Suitability of the crop to take up the maximum amount of nutrient per year over as many years as possible.
3. A suitable application rate of effluent. The appropriate rate will maximise crop growth and nutrient uptake while minimising nutrient loss to ground and surface water.

6.1.2 Effluent renovation by nutrient stripping

The effectiveness of different crops in taking up nutrients from soils depends on the following factors:

1. Total dry matter yield (DMY): other things being equal, the higher the yield, the higher the nutrient uptake. In some parts of New Zealand, yield may be limited by water stress.
2. Plant ability to accumulate nutrients: for a given DMY, the higher the plant nutrient concentration, the higher the nutrient uptake. As plants mature, average foliar nutrient concentrations generally decline, but nutrients can accumulate in seeds or other parts of the plant. Different plant parts (e.g., leaves and stems) may also routinely contain different concentrations of nutrients.
3. Seasonality of production: where effluent needs to be applied to soil all year round, perennial grass or tree species that grow continuously throughout the year have a distinct advantage as crops, especially if they are capable of active growth during winter. Some

annual crops make little or no growth during winter and in addition there is no growth in the period between crop ripening and harvest through to re-establishment.

The largest nutrient removals are generally achieved with harvested perennial grasses.

Nitrogen

Application of wastewater at rates that provide greater amounts of nutrient than the crop can take up increases the risk of nutrient leaching. Nitrogen, which is present in sewage effluent in highly soluble forms, such as ammonium and nitrate, is typically the critical nutrient that is susceptible to leaching in a land application system. Nitrate leaching may be minimised by maximising N accumulation in vegetation. This may be achieved through appropriate system design, selection of crops, irrigation management and vegetation management.

Phosphorus

The amounts of phosphorus applied with wastewater are much higher than are required by most crops, and quantities of phosphorus taken up by crops will generally be small compared with the amounts of phosphorus that are removed from solution by adsorption to soils. Consequently, the assimilative capacity for phosphorus in land treatment systems is controlled by soil properties rather than by plant uptake (see Section 2.3.2).

Potassium

Potassium is used in large amounts by many crops and wastewater generally does not provide enough of this element to maximise growth. The concern in land treatment is therefore, not how to remove potassium, but rather with the potential for a crop deficiency. If a deficiency does occur it will reduce uptake of N and P by the crop. Each crop has a specific ratio of nutrient requirements to optimise growth or, from a treatment point of view, to optimise removal of N or P. If the proper balance is not maintained, removal of N or P will be less than expected. In general, there is an excess of nitrogen in municipal wastewaters with respect to potassium for most crops (Reed and Crites 1984). Often potassium fertiliser will be needed to provide for optimal plant growth, at rates that depend on the particular soils and crop.

Other nutrients

Although other macronutrients (e.g., Mg, Ca and S) are usually present in more than adequate quantities in the effluent, there may be imbalances. For instance, deficiency levels of calcium and magnesium may occur in the crop if high sodium loadings are applied. This will mean having to supplement the crop (or animals eating the crop) with calcium and magnesium. Nutrient imbalances have been observed in effluent-irrigated radiata pine at Whakarewarewa, Rotorua (Thorn *et al*. 2000). Effluents high in sodium may also affect soil physical properties (Section 3.3.4).

The micronutrients, such as B, Mo, Cl, Cu, Fe, Mn, and Zn, are required in “trace” amounts for normal plant growth, and either absence or oversupply can severely affect plant function. Wastes usually contain an ample supply of micronutrients. Sometimes high levels of micronutrients can retard growth, e.g., excessive boron. In other cases micronutrient deficiencies affecting animals but not plants, e.g., cobalt and selenium may need to be supplemented.

6.1.3 Effects of heavy metals

Heavy metals that can adversely affect stock or human health are not normally found at high concentrations in sewage effluent as they are primarily retained in the sludge. However the on-going monitoring programme should include analyses of soil and foliage for trace elements such as As, Cd, Cr, Cu, Hg, Ni, Pb and Zn. These tests should be carried out annually for pasture and arable crops and less frequently for plantation trees. Concentrations of heavy metals in effluent used on crops should not exceed the public health guidelines for the safe use of sewage effluent (Department of Health 1992). Crop monitoring programmes to evaluate crop health and yield are discussed in Sections 7.7 and 7.8.

6.2. PASTURE AND ARABLE CROPS

6.2.1 What is a 'cut and carry' system?

A 'cut and carry' system is an agricultural operation that involves growing a crop or pasture, generally to near maturity, harvesting it, and removing the harvested material in bulk from the growing area. Inherent in such an operation is the absence of grazing animals. The aim is to remove large amounts of nutrients from the irrigation site and disperse them over a larger area. On-site grazing by stock can result in high losses of nitrate N (up to 200 kg/ha) to groundwater through leaching from urine patches.

The nutrients applied to the crop/pasture are taken up by the growing plant and removed in the harvested material. As nitrogen is of most environmental concern and is usually also present in the highest concentration, the loading rate is dictated by the quantity of N that can be removed by the crop, together with soil hydraulic properties such as infiltration rate. This contrasts with a grazed system in which increased pasture production from N inputs is cycled through the grazing animal, leading to a higher N concentration in the urine, with resultant increased nitrate leaching to groundwater.

Although grazing systems have been used in some circumstances for land treatment of sewage effluent, effluent loadings have had to be reduced because of nutrient recycling through excreta. Grazing systems are only appropriate if large land areas are available (so that low loading rates of N are possible), or if an analysis of environmental effects for the site shows that losses of N are of little concern. This is not commonly the case and so grazed systems will not be discussed further here.

6.2.2 Site requirements

Apart from the need for the land treatment site to be close to the source of the effluent, and yet isolated so that communities are minimally affected, the main requirement is a suitable soil type. A flat to gently inclining site is necessary for the successful operation of a spray irrigation system. The soil needs to be naturally well-drained and to contain reasonable amounts of organic matter, so that:

1. The large volumes of effluent applied infiltrate quickly into the soil and there is no ponding on the surface causing death of plants.
2. Soil conditions are dry enough to allow harvesting machinery to operate at most times of the year without compacting the soil and causing lower crop yields.

The most suitable soil types include recent alluvial soils, sands, volcanic ash and pumice soils. A history of management under pasture grazing will usually indicate higher soil organic matter levels. An inspection of the soil characteristics of the site by a soils specialist is strongly advised.

6.2.3 Crop requirements

There is a wide range of pasture and crop cultivars that can be used in a land-based effluent system. The choice of crop is important and the following factors should be taken into consideration:

1. Select a crop that will achieve a high yield when grown on the chosen site because nutrient removal by plants increases with plant yield.
2. Ensure that there is a market for the harvested crop. Grain from cereal crops will always find a market, but greenfeed crops and pasture silage will require a buyer within a reasonable distance of the site
3. A fast-establishing crop is desirable as it allows effluent to be applied early in the life of the crop. A crop that grows throughout the year will allow better utilisation of effluent than one that can only take up nutrient for a limited period.
4. A crop that requires a low level of cultivation for renewal is preferable. Cultivation accelerates mineralisation of organic nitrogen, increasing the risk of nitrate leaching, especially during fallow periods. Crops that can be direct drilled will minimise this effect.

In many situations the best option may be a combination of different crops in different areas of the land treatment site.

6.2.4 Crop options

Crops suitable for irrigation with sewage effluent include perennial grasses, annual grasses, legumes, cereal crops, and vegetables. This section will discuss how well these different crop types fit the criteria given above.

Perennial grasses

Perennial grasses (e.g., ryegrass, tall fescue, phalaris) have the following advantages as a crop:

1. Once established, they persist for a number of years if managed correctly, so that there is not a constant need for cultivation.
2. They are high yielding, being able to produce 15-20 t DM/ha/year under irrigation with effluent. In consequence they can remove large amounts of nutrient annually (500–600 kg/ha of N, 130–160 kg/ha of P, 140–160 kg/ha of K).

3. Grasses can be made into either silage or hay, both of which, if handled and stored correctly, make highly digestible feed for stock.
4. Ryegrass is fast establishing, will grow in soils of low fertility, and will tolerate less than ideal management. Other species, such as phalaris and tall fescue, tend to be slower establishing but once established can provide advantages, such as different seasonal growth patterns and greater capacity to withstand crushing by machinery.

Disadvantages of perennial grasses are:

1. The crop must be harvested three to five times per year to avoid too much bulk at each cut (less than 4 t DM/ha is advised). If this is not done the grass plants will thin out from shading and yield will be reduced.
2. Pasture growth is low in winter.
3. Some perennial grasses require a high level of management to remain productive. For example, the plant density of prairie grass will quickly decrease if it is not cut at the optimum time. If cut when there is too much bulk, tall fescue and phalaris will have low digestibility and produce lower quality feed.

Annual ryegrasses

Compared with perennial grasses, annual ryegrasses (e.g., Moata, Concord), are higher yielding in the first year, grow better over winter, and have higher digestibility. Their big drawback is that they produce only 1–2 years of growth before yields decline drastically and the crop dies out, after which it must be re-established.

Lucerne

Of the legumes, only lucerne will persist and yield adequately when grown alone. It also has the advantage of responding well to irrigation and being highly digestible, but suffers from lack of growth during winter, and having to be cut at a specific growth stage to maximise yield. Nevertheless lucerne yields of up to 25 t DM/ha are possible and can remove up to 700 kg/ha of N per year. Lucerne yields are higher than grass yields because lucerne does not go through the annual reproductive cycle of the grass plant. Plant diseases can reduce the life of the lucerne crop and so cultivar selection is likely to be an important factor.

Cereal crops

Cereal crops take up large amounts of N, which is removed when the grain is harvested (Scott 1994). High yielding wheat and feed barley crops (producing up to 8 t grain/ha.year) will remove 150 kg/ha of N and 25 kg/ha of P. Harvesting the whole crop will remove another 50 kg/ha of N and 5 kg/ha of P. Maize is the most suitable crop in favourable warmer environments as it requires large quantities of N, but N content is low (1.5%). An attainable yield of 12 t grain/ha requires 250 kg/ha of N with a further 270 kg/ha removed in leaf and stem, if harvested as silage.

The economics of using the harvested crop as a feed depend on yield, the nutritive value of the leaves and stems, and the cost of transport from the site to the user. Crops have the advantage over pasture in that they are removed in one operation, they have a higher nutritive value per kilogramme of dry matter, and, because of their higher dry matter content, lower transport costs. However, with all arable crops, effluent will not be able to be applied during fallow periods. The need to replant each year means frequent cultivation is required. Also the crop cannot be spray irrigated once it reaches a certain height. These limitations need to be addressed in scheme designs as a greater area of land may be required to allow fallowing, cultivation, and constraints on application to be included, as there is normally no opportunity to store sewage effluent for long periods.

Vegetable and fruit crops

Vegetable crops have high N and P requirements but the short growing season and low plant density limit uptake. Estimates of annual N removal are 60 kg/ha of N for squash and pumpkins, 100 kg/ha of N for early potatoes and onions, and 150/ha of N for main crop potatoes. Kiwifruit and persimmons remove about 30 kg/ha of N per year. However, due to health concerns, crops intended for direct human consumption are not normally recommended for land treatment using spray irrigation systems. Sub-surface irrigation may be feasible, but probably not for root crops (onions, potatoes).

6.2.5 Crop yields and N concentrations

Estimates of crop yields and typical N concentrations in the harvested crop are given in Table 6.1. These yields and N concentrations can vary with different soils and climates. Crops can also take up more N and have a higher concentration as the rate of application of effluent increases. However higher rates of effluent application increase the risk of nitrate N leaching to groundwater. Greater leaching will occur on coarser textured soils (e.g., sands) and as rainfall increases.

Table 6.1. *Annual yields and typical N concentrations for different crops*

Crop type	Yield (t DM/ha)	% N
Perennial grasses	16	3.5
Annual rye grass	20	4.0
Lucerne	20	3.0
Wheat grain	8	4.0
Maize silage	25	1.5

6.2.6 Establishment of crop

Since yield is such a critical factor in nutrient uptake, it is essential that the crop is established to give optimum plant populations so that yield is maximised.

(DM yield/ha = DM yield/plant $\times$ number of plants/ha)

Grasses

- An ideal seedbed should be weed-free, moist, firm and sufficiently fine-textured to enable accurate seed placement and good seed-to-soil contact. After soil testing, lime and fertiliser should be applied 3 months before sowing to give a soil pH of 6.0 and an Olsen P of 20–30 mg/kg of P in the top 75 mm of soil. On average, 1 tonne/ha of lime is required to increase soil pH by 0.1 units and 5–10 kg/ha of P is needed to increase soil Olsen P by one unit.
- Sowing rates are 15–20 kg/ha for ryegrass, 25–30 kg/ha for tall fescue and phalaris, and 35–40 kg/ha for prairie grass, all as pure species. Grasses are ideally sown in late summer before the end of February. After emergence, N fertiliser applied at 30–50 kg/ha will help seedling growth.
- The main insect pests are grass grub and porina. Seed pre-treated with an insecticide should be used in areas where grass grub is present. Porina should be monitored and treated with autumn-applied insecticide if present at high grub densities. In seasons with low rainfall, irrigation may be required for successful establishment.

Lucerne

- An ideal seedbed is even more important for lucerne than for grasses because of its smaller seed size. Soil pH should be in the range 6.0–6.3 before sowing and boron (10 kg/ha borate fertiliser), molybdenum (100 g/ha sodium molybdate), and copper (5 kg/ha copper sulphate) may also be required.
- Seed should be sown at 12 kg/ha, using pelleted innoculated seed. Sowing should be carried out in early spring in areas with warm dry summers but can continue through to March in colder wetter areas. There are a number of cultivars with resistance to various pests and diseases (see AgFACT no. 201 available from AgResearch) and the choice should be made according to local conditions.
- Pests and diseases include aphids, stem nematodes, bacterial wilt, phytophora root-rot, verticillium wilt, and leaf diseases. No starter N is required for lucerne since it is a legume. Weed control, carried out with winter applications of herbicides, may be needed in later years (see AgFACT no. 205 available from AgResearch).

Cereal crops

- An ideal seedbed is not critical for cereals, as seed size is larger. Initial soil pH and nutrient requirements are similar to those for perennial grasses.
- Wheat is sown in either autumn or spring at 90–120 kg/ha of seed. Barley and oats are sown in spring at similar rates to wheat. The choice of cultivar will depend on sowing time and end-use of the grain. Greenfeed maize for silage is sown in spring at 75 kg/ha.
- Cereal crops are prone to a range of diseases including rusts, smuts, mildews, leaf spots and viruses. All can be treated with fungicides. There are also a wide range of insect pests that can affect cereals, and particularly maize. These include argentine stem weevil, greasy cutworm, black beetle, soldier fly, and wireworm. Chemical insecticides can be applied in accordance with label specifications to control these.

6.2.7 Crop maintenance

- In a cut and carry system, maintenance K fertiliser may need to be applied. O'Connor, and others found that the amount of K added in effluent at recommended rates was only about half that needed to achieve the 2% herbage K in ryegrass required for maximum production (O'Connor *et al*. 1998c).
- Lucerne should be spelled for 35–42 days between harvests to allow full recovery. Soil pH will decline over time and this should be monitored and corrected with lime application.
- Harvesting of grass and lucerne crops should only be carried out when soil conditions are dry to avoid soil compaction. Effluent should be sprayed onto grasses and lucerne soon after cutting and onto cereal crops at monthly intervals early in the life of the crop. Good roading access, a system design that makes it easy to maintain equipment, and a well-thought-out sprinkler operating programme are all essential for successful operation of land treatment schemes (O'Connor *et al*. 1998b).
- Avoid fallowing. The soil should not be left bare for extended periods (greater than 2 weeks) with no vegetation to take up nutrients.

6.2.8 Crop monitoring

To maintain high crop yield and quality, and minimise disease organisms the crop should be regularly monitored for plant nutrient concentration, feed energy and protein, and *Listeria* and faecal coliform content (O'Connor *et al*. 1998a). Soil testing should also be carried out on an annual basis to check that soil nutrient levels are being maintained in the adequate range for plant growth. If any of these values are not optimal, changes in crop management should be made to correct them. Monitoring is covered more fully in Section 7.7.2.

6.2.9 Product end use

It is important that the end-product use is carefully considered. Where the end-product is a feedstuff for animals care needs to be taken that there is no disease risk involved. This may mean further processing of the product, e.g., heat treatment and pelleting to make it safe for animals. Alternatively it may mean growing a crop or grass which has a use other than as an animal feed.

6.2.10 Conclusions

Taking all factors into consideration, perennial ryegrass is probably the best option for arable crops in most environments. Lucerne is suitable in lower rainfall areas where weed invasion is less likely. If the site is too isolated to have a ready market nearby for silage and hay, then cereal crops for grain could be considered.

6.3. FOREST CROPS

6.3.1 Overview of forest crops

Tree plantations have several advantages for land treatment systems. Trees can accumulate more standing biomass than any other crop, without a need for annual harvesting and intensive management. Trees can also be grown on sites that may not be suitable for arable crops. The use of trees reduces risks to human health because they are not a food-chain crop, and there is less risk of people being directly exposed to spray drift. In New Zealand, radiata pine has been the main species used in forest land treatment systems (Carnus *et al.* 1994), but various other hardwood and softwood species have been used overseas (Brockway *et al.* 1986). In many cases, radiata pine plantations have been selected in New Zealand because they were already established at the land treatment site, and deemed suitable for irrigation at the site.

When a new tree plantation must be established at a land treatment site, short-rotation forest crops offer certain advantages over saw-log regimes. These include greater nutrient removal capacities, greater moisture tolerance for certain species, and a shorter wait before harvest and generation of a cash flow (3 to 8 years). A range of species can be considered for short rotations, including eucalypts, willows, and poplars. Yields from short-rotation tree crops can vary greatly under New Zealand conditions, but under municipal wastewater irrigation, eucalypt trees have been reported to yield over 25 oven-dry tonnes of total biomass per year (Nicholas *et al*. 2000). The harvested crop can be used for energy, pulp, or other specialty purposes, as discussed below.

6.3.2 Species selection

The final choice of a plantation species for a land application system will strongly depend on what market exists for potential products. Several species may be suitable for a particular scheme. Factors that should be considered in selecting candidate species include ease of establishment and expected growth of the crop, the species' capacity to survive and stay healthy under irrigation, its ability to take up nutrients, requirements for management and harvesting, and the end use, quality, and marketability of the harvested material.

A number of forest regimes can be considered for land treatment systems in New Zealand. A manager can choose between saw-log and veneer log regimes (usually on more than 25-year rotation), long-rotation pulpwood and/or energywood regimes (10 to 20 year rotations), and short-rotation forestry (SRF) regimes for pulpwood and/or energywood, utilising species with the ability of coppicing, such as eucalypts, willows and poplars. The SRF options being studied and demonstrated in New Zealand involve harvesting at tree age three to eight years. Other possible regimes involve growing specialty species for timber, including eucalypts, acacia, and *Cupressus*, as well as a few other deciduous species. It should be noted that, in comparison with the database for radiata pine, there is much less information about growth rates, likely markets, and economic returns for these species and little is known about the costs of silvicultural operations.

In New Zealand's climate, a combination of agricultural crops and forest plantations may be highly efficient, because of high nutrient uptake potential of the agricultural crop, and the possible use of the forest component during periods when arable crop areas are dormant or fallow.

6.3.3 Nitrogen uptake

Forests take up and store nutrients, but they also return a portion of those nutrients back to the soil through litterfall and decomposition. Tree crops are generally less efficient than agricultural crops for nutrient removal. The harvesting method will affect the net nutrient removal from the site, and whole-tree harvesting, where possible, will maximise nutrient removal.

Nitrogen uptake and biomass production of forest crops are generally low during the initial growth stage (1 to 2 years), rise to a maximum at canopy closure, and then decrease significantly as litter fall and decomposition supply an increasing portion of the trees' continuing needs. Ideally, the tree crop should be harvested shortly after growth and net nutrient uptake rates begin to decrease, and this is a key advantage of the short-rotation system. Understorey vegetation may also play a role in nutrient uptake and retention during the first years of a rotation, but there are few data available to indicate how important this factor is in forested schemes in New Zealand.

Nitrogen uptake rates for sewage-irrigated poplar, mature Douglas-fir, loblolly pine and mixed hardwoods with loblolly pine have been reported at 300, 175, 250, and 200 kg/ha.year, respectively (Brockway *et al.* 1986). Forest cropping using close-spaced *Eucalyptus* harvested on a 3 to 4 year cycle will remove up to 200 kg/ha.year of N (Barton *et al.* 1991). Radiata pine in New Zealand can take up more than 140 kg/ha.year of N, but data for land treatment systems are sparse. Foliar uptake of nitrogen was 35 kg/ha.year of N in a five-year-old stand of radiata pine irrigated for four years (Thorn *et al.* 2000), although this figure was affected by windthrow mortality. Willow (*Salix kinuyanagi*) may also have large capacity to use nitrogen (Roygard *et al*. 1998).

6.3.4 Water uptake

There is a common belief that trees utilise more water than arable crops. This is supported by observations of decreased water yield from forested catchments and by occasional observations of high water use by irrigated trees in arid areas (Myers and Talsma, 1992). However, in forested catchments, these observations can be mostly explained by increased interception of rainfall. Interception is related to leaf area. Feller (1981) stated that *Eucalyptus* forests could intercept between 10 and 25% of the incident rainfall.

Plant water use is, in fact, driven by the energy available to evaporate water. In arid areas, there is an 'oasis effect', in which heat energy is transported by wind from adjacent dry areas, and then drives increased evaporation in the irrigated area. Water use by irrigated *Eucalyptus* species in Australia has been measured at up to 8 mm/day (Myers *et al*. 1996). In New Zealand, however, the more humid climate reduces any oasis effect. This effect would only be important in irrigated areas of New Zealand on windy, warm summer days. Generally, evaporative water use for trees should not be considered greater than that of arable crops, particularly in winter. Pan evaporation data provide a reasonable estimate of maximum transpiration rates for any crop. Pan data should be multiplied by a crop factor to estimate actual water use. Except under strong oasis conditions, this value will not exceed one. Myers *et al*. 1996 found crop factors of between 0.95 and 0.85 for a range of tree crops.

6.3.5 Plantation establishment

Seedlings of suitable tree species should be obtained from a reputable nursery. Tree stocking rate should be based on the recommended rate for the intended end product. In general, higher stocking rates are desirable when stem size is not important and the aim is to maximise fibre production, but for saw-logs lower final stocking rates are necessary to produce large stem size. For radiata pine and Douglas-fir in New Zealand, saw-log regimes are typically planted at a stocking of 1000–1200 stems per hectare (sph), are then thinned to 300 to 400 sph by age 12, and harvested at 25 to 30 years for radiata pine, or 40 to 50 years for Douglas-fir. Long-rotation pulpwood and/or energywood regimes should have an initial stocking of 1200 sph, which may be thinned to about 800 sph at four years, and clearfelled at 12 to 20 years. Short-rotation forestry regimes for pulpwood and/or energywood may have initial tree stocking rates of between 2500 and 5000 sph (and some systems in cold areas of Europe utilise much higher stocking rates). It is important that sufficient space should be left between the tree rows to allow access for irrigation equipment and for the effluent to be distributed evenly.

Weed control is one of the most important factors for successful plantation establishment. Site preparation should include herbicide spraying around planting spots, and possibly cultivation for new forest sites, to allow the tree seedlings to grow without undue competition for water, nutrients and light. Specialist advice is required because tree species react differently to herbicides and tree seedlings may be sensitive to common formulations.

6.3.6 Plantation management

Irrigation of the tree plantation should not start until the trees are established. The period required for establishment varies with species. A few months may be sufficient for *Eucalyptus* species, but at least two years should be allowed for radiata pine. This requirement for holding off irrigation is an important consideration for establishment of new stands after harvest. The down period may be quite brief in SRF systems in which the new stand will coppice from the cut stumps of the harvested one. In saw log systems, however, a three-year period for harvesting and establishment of the new stand may be necessary. Therefore, the system design will need to include disposal options for such periods, and often reserve areas will be necessary so that irrigation can be rotated between different areas.

After establishment, management practices may differ, in accordance with the specific practices recommended for each species and regime. Pruning and thinning may be needed for saw-log plantations that have closed canopy. Pruning may also help to provide a more uniform distribution of effluent under the tree canopy. Self-pruning species may be preferred to provide greater visibility and easy access for maintenance of irrigation lines and sprinklers.

Successful plantation management includes weed, insect and disease control, and protection from wind, animals, and vandalism. As described in Chapter 7, one must recognise that effluent irrigation carries increased risks to crop productivity and health, and tree crops are no exception. For example, irrigated trees may be more susceptible to windthrow, if loadings increase soil wetness to the point that development of the root system is hindered. Management and monitoring of tree crops should be carried out to allow the manager to recognise problems early on.

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7. SYSTEM MANAGEMENT AND MONITORING

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7.1. PURPOSE OF MONITORING AND MANAGEMENT PROGRAMMES

A major aim in the design of a land treatment system (LTS) is to find an optimal effluent application rate that provides sufficient treatment, whilst minimising the land area and thus the cost of the system. Once the design is arrived at and the system is constructed, the success of the system can be measured in different ways, but the degree of success will depend on appropriate management. Integral to management is ongoing monitoring of different components of the LTS to determine its performance. A good monitoring programme provides feedback that allows managers to respond to problems soon after they develop, when they are most easily dealt with. Also, the LTS must be considered an asset of the system's owners, i.e., the ratepayers. Management and monitoring is critical to ensure that the value and function of this asset is sustained, and that the ratepayers realise the full benefit of their investment in it.

Successful operation and management of a land treatment system provides:

- Treatment and re-use of wastewater and its constituents.
- Sustained environmental quality.
- Crop growth that provides nutrient removal and economic return.
- Assurance of the public's health, safety, and acceptance of system.

Monitoring and management activities must be aimed at ensuring adequate performance in all four areas. However the levels of performance that are defined as adequate (i.e., performance criteria) will be unique for each system, and will depend jointly on expectations of the public, the nature and sensitivity of surrounding and receiving environments, and resource consent requirements. The operator must recognise that simply fulfilling resource consent requirements does not necessarily ensure successful operation of the system in the long term. Therefore monitoring requirements of the resource consent will not generally capture all the information needed to properly manage an LTS.

The purpose of this Chapter is to aid managers with setting up management and monitoring programmes that will ensure that an LTS performs successfully, and fulfils resource consent requirements. The Chapter describes the types of measurement and sampling activities that should be considered in a monitoring programme, providing technical references as appropriate. But first, the management of construction and commissioning phases of an LTS is briefly discussed.

7.2. CONSTRUCTION AND COMMISSIONING

Construction and start up of an LTS are critical links between system design and system operation. What takes place between final approval of an LTS's design and its becoming fully operational will largely determine whether operation goes as anticipated. Problems resulting from construction can be minimised by making specifications flexible, and tailoring the final design to fit specific attributes of the site. System installers should be instructed to exercise judgement in avoiding small areas of steep slopes, drainage-ways, or poorly drained soils not explicitly identified in design plans. Similarly they should avoid compaction of wet soils. Disturbance to soil and vegetation needs to be be minimised; meaning that trafficked areas should be restricted to narrow lanes where pipes are being laid. Even with due care, construction unavoidably results in some soil disturbance in areas to be irrigated, and the need for recountouring, topsoiling, cultivation, and reseeding of these areas should be anticipated.

The commissioning of land treatment systems is also a critical period. Often the commissioning of a new system marks the transition from direct discharge to surface water, to total irrigation to land. Stakeholders will be watching closely and may expect rapid and significant environmental improvements. It is important for designers and operators to work closely with each other to provide a smooth transition from start-up to full operation.

A phased start-up of the new system should be planned, with perhaps several months of reduced hydraulic loadings. Standing crops and soil biota may benefit from a period of adjustment to conditions of increased soil wetness. The crops and soil conditions may not be suited to immediately accept the “design” application rates. The opportunity to gradually increase loading to the “design” application rate can result in better crop establishment and prevent soil erosion problems. Unforeseen problems may also arise with the new system, and so the old system should be kept available as a back-up if possible.

Some of the more common issues to be considered during system commissioning are:

- Teething problems – Liaison between the designers and operator is required to minimise and quickly correct any early problems with the system’s hardware. This includes plans to quickly access spare parts and service.

- Training – Staff who will operate the new LTS are probably trained in conventional waste treatment processes. Training in the principles and operation of a land treatment system should be provided, focusing on written plans for management of the new system.

- Documentation of construction – The layout of the actual system will differ from the design plans, and even if those changes are minor, they should be documented. If important changes are made, then ‘as built’ plans should be supplied.

These points cannot be over-emphasized, and therefore the contracts between the system owner, designer, and builder should fully elaborate procedures to ensure they are addressed.

7.3. PREPARATION OF MANAGEMENT AND MONITORING PROGRAMMES

Management and monitoring programmes need to be detailed in written plans that are accessible and understood by anyone who carries out activities described in them. Even the smallest maintenance duty, if neglected, could lead to a serious problem, and therefore all personnel carrying out the programme must understand the importance of what they do. They must clearly understand how their duties fit into the management and monitoring programmes, and how those programmes function so that the success of the LTS is ensured.

Written plans are also needed to ensure consistency in management and monitoring of an LTS. If the effort put into developing these plans is minimal, then plans and procedures can become a haphazard collection of excerpts from other documents, and this will not provide sufficient guidance for the system operator. Authors of management plans should not simply focus on engineering detail, to the neglect of soil, water and crop systems. Obviously engineering detail is needed, but documented plans for consistent and timely monitoring for each part of the system and its environment are also required.

Development of management and monitoring programmes at the outset requires close liaison between the designer and the owner (operator) of an LTS. This ensures that the owner clearly understands the basis of the LTS design, and that particular management requirements assumed in the design are clearly communicated to the owner. The plan should spell out how the LTS was tailored to be compatible with the soils, topography, and water resources of the site, and what features of the surrounding environment are most important for monitoring. The system operator will then be fully informed of site and design limitations. Before the designers commence their work, the system owner should specify how the designers must contribute to writing of management and monitoring plans. Their contribution could range from providing summary information to preparing part or all of the document itself.

Management plans should be treated as changing updateable documents, which are expected to alter as experience is gained and with the passage of time. The initial plan, as written by the designers and/or owners of the LTS, will certainly need revision from time to time, perhaps due to construction changes, but always as operation of the system is fine-tuned. The system operators may uncover design problems that can be solved by adjusting management practices. Some areas may respond to irrigation during wet periods differently than most other areas, leading to modifications in irrigation management. Monitoring data may indicate that some parameters are being monitored too often, or not often enough. An appropriate monitoring programme needs to be devised at the outset, but results may lead to a re-assessment of monitoring requirements. The operators need the flexibility to revise written plans as experience with the system is gained, although consultation with the designers, and perhaps the Regional Council, about such revisions is generally advised.

7.3.1 Role of monitoring in management

Management of an LTS must be aimed at ensuring its successful operation, with acceptable environmental effects on soil, water, air, crops, and other important ecosystem resources. To achieve this, ongoing monitoring is required, and results must be reviewed regularly to determine if the LTS is functioning properly, and if its management and operation can be improved. The monitoring system should allow the LTS manager to: (1) track effluent and nutrient loadings; (2) record operational and environmental performance; (3) ensure consent conditions are met; (4) establish and maintain an efficient database to help keep abreast of operational and environmental data, and (5) identify events and conditions that signal a review of the management or monitoring system is needed. In the best-run land treatment systems, monitoring data will be reviewed regularly with an eye to finding areas where the system could be improved. Improvements may be possible even if the system is meeting all its objectives and no operational or environmental problems are apparent.

To successfully operate a land treatment system, a manager will need to combine routine technical monitoring with first-hand observation. Visual observation is a critical aspect of monitoring and it's role should be formally recognised. This includes maintenance checks on pipelines and sprinkler heads, and reconnaissance of areas most prone to runoff or ponding. Reconnaissance duties encourage system operators to become familiar with visible indicators of system performance and eventually anticipate problems under certain conditions of season or climate. Crop monitoring is also largely based on observation. Therefore maintenance of irrigation hardware, irrigation scheduling, and soil and crop management all benefit from monitoring through visual observation.

7.3.2 Design of a monitoring system

This section covers general issues of designing a monitoring system. Specific recommendations for monitoring soil, climate, water, and crops are given in later sections. Some monitoring activities will be routine, and carried out on a frequent, regular basis by operations staff, while others may require consultants with expertise in environmental or crop monitoring and management. In designing a monitoring system the manager/designer should consider the following factors:

- Parameters to be monitored. For each component to be monitored (i.e., soils, crops, ground and surface waters, etc.), what specific parameters will be measured and why? How will the data help in managing the system or determining environmental effects?
- Frequency of measurements. How often are monitoring activities and analyses required in order to provide representative information at reasonable costs?
- Methods of sampling and analysis. What sampling procedures are required, and what analytical methods will be used? Factors to consider are the cost and frequency of monitoring, the degree of automation possible, and availability and cost of analytical services.
- Information feedback. How will the monitoring results be reported and stored? How will the computer database storing the data be designed? How often will results be reported to the manager and reviewed? What specific events or concentration levels will signal the need to review the management system?

The monitoring programme should not simply be based on what is done at other LTS sites, but needs to be tailored to the requirements of the particular system. Only those monitoring activities required to manage the LTS and meet its objectives need be included.

A period of regular environmental monitoring before irrigation commences is strongly recommended. For most soil parameters single measurements of pre-irrigation conditions are all that are generally needed. But for ground waters and surface waters, some indication of seasonal variability in flows, levels, and chemistry of waters before irrigation begins may be essential. These parameters often show a large degree of natural seasonal variation, and understanding the seasonal dynamics of a site will help with interpretation of monitoring data. Natural "background" concentrations of key nutrients and contaminants may be critical data for evaluating system performance and environmental effects, and it's best to understand what these background levels may be at different times of the year.

The monitoring programme must also address any statutory requirements, particularly requirements set out in resource consents or plans under the RMA (1991). If the consultation process for granting the consent was well-conceived and helpful, then the conditions placed on a resource consent should provide data that are also useful to manage the system and assess its performance. However, in most cases, the system manager will actually need more monitoring information than specified by resource consent conditions.

As mentioned above, changes to the monitoring programme will probably be considered on occasion. If the monitoring data stabilise and show little or no effect of irrigation on a given parameter, then alterations to the monitoring programme may be warranted. After a system is newly commissioned, frequent monitoring is suggested to determine if the system is performing as designed. As the database and management experience accumulates, the frequency of monitoring may be able to be reduced. Such changes should not be made too quickly, though, as it may take several years for the environmental effects of waste application to be observed, as experienced at Rotorua's LTS (Tomer *et al*. 2000).

Nyer (1998) outlines how monitoring intensity can be decreased over time. However some monitoring will be specified in the resource consent and it can be difficult to change consent conditions. Such problems can be avoided by having the consent conditions made "flexible" at the outset. For example, frequent monitoring of nitrate concentrations in groundwater may be stipulated in the resource consent to determine if concentrations exceed the New Zealand guideline of 50 g/m^3 nitrate. After a period of monitoring the nitrate levels may increase, but then level off at a small fraction of this concentration. It may be then appropriate to reduce the monitoring frequency. Such situations may be foreseen and covered in the resource consent by stating that monitoring frequency can be reduced if the data show that nitrate concentrations stabilise at concentrations less than the critical level.

7.4. SUGGESTED OUTLINE OF MANAGMENT AND MONITORING PLAN

The management and monitoring plan should be comprehensive, yet easy to read and organised for quick access. The following is a list of sections which should be considered for inclusion in a management and monitoring plan for an LTS. Although operational plans for the treatment plant itself may be part of these plans, for brevity mention of them has been kept to a minimum.

- *Introduction*. Briefly summarises the system objectives, the general outcome of the resource consent process, and overviews organisation of the document.

- *System Description*. Describes site characteristics, including mapped information on soils, topography, and key water resources, and how these characteristics were considered in the system design. Includes maps of system layouts that show the location of plant, effluent storage areas and their capacity, irrigation areas, buffers, etc. Some detail on how irrigation layout was matched to distribution of soil types, topography, and water resources should be included.

- *Process Operation*. Includes plans of the treatment plant and irrigation system, but avoids unnecessary detail. Concisely outlines the infrastructure of the system and the basic principals of operation and treatment as applied to this particular system. Refers to appendix or separate document with detailed engineering plans of the system.

- *Maintenance Procedures*. Reviews routine maintenance procedures on pipes, pumps, and sprinklers, their frequency, and who is responsible to carry them out. Describes automated internal monitoring systems and their routine use for detection of faults. Describes schedule of activities to keep sprinkler lines accessible for maintenance and sprinklers free of interference from vegetation. Refers to appendix with sample maintenance records.

- *Effluent Management and Monitoring*. Specifies procedures for monitoring effluent volumes and quality (see Chapter 1 and Section 7.6.1). Reviews the design irrigation schedule, including any seasonal variation in that schedule, and outlines how and when the schedule should be modified, such as: (1) during crop harvest; (2) after excessive rainfall or when the soil is saturated, and (3) to reduce storage volumes. Describes how storage volumes are to be managed. Refers to appendix with forms to document daily applications, and describes how irrigation applications are to be tracked.

- *Vegetation Management and Monitoring*. Details management of the preferred crop (or crops) in the system, with attention to maintenance of crop health and vigour. Includes information and schedules for crop monitoring, harvesting operations, and marketing. (see Chapter 6 and Section 7.7). Common or probable pest, disease, and fertility problems, and their symptoms, should be described. Refers to appendix showing forms for recording results of crop monitoring and harvesting, plus costs and returns on sale.

- *Environmental Monitoring*. Separate programmes need to be detailed for monitoring soils, climate, ground water, and surface water. Includes frequency of measurements and sampling, analytical methods and references, procedures for recording and reviewing data, and the use of data in determining performance of system, and as warning flags to indicate a review of management is needed (see Section 7.8). Relates programme to Resource Consent Requirements, and refers to appendix with sample data recording forms.

- *Buffer Zones*. Describes layout of buffers and the logic of their design. Special considerations to manage and monitor buffers should be described (see Section 7.9).

- *Consent and Compliance Management*. Provides a concise overview of the current consent. Lists key consent conditions and monitoring requirements. Outlines schedule and requirements for compliance reporting, consent reviews, and renewals. Identifies staff position responsible for liaison with Regional Council.

- *Public Use/Public Relations*. Describes what public uses of the LTS are possible/acceptable, and how access to and use of the site are controlled. Recommends ways to inform and educate public about the system, including signs, public release of performance reports, etc. Also details procedures for recording and responding to public complaints.

- *Contingency*. Describes procedures to be followed in case of spills or other accidents.

- *Appendices:*
  - Resource Consent (full text)
  - Detailed system plans
  - Sample forms for:
    - maintenance records
    - irrigation records
    - monitoring data:
      - effluent (pumping volumes and chemical data)
      - rainfall and climate
      - crop monitoring
      - crop harvest and yield results
      - soil monitoring
      - air monitoring
      - surface water monitoring
      - ground water monitoring

The management and monitoring plan should be viewed as a guiding document that describes the system for successfully operating the LTS. Its utility should be reviewed on occasion and revisions made as needed. A review of the management plan should be considered a review of the management system. A management system review should be carried out if: (i) recurrent maintenance problems arise; (ii) design loadings are consistently exceeded; (iii) monitoring data indicate unsatisfactory environmental performance of the LTS; (iv) consent conditions are not being met, or (v) schedules and systems described in the plan are not consistently followed.

The following sections describe management and monitoring activities as they would appear in the plan. Systems to take measurements, record observations, and evaluate trends must be put in place, and these systems should be described. Descriptions given above for the Introduction, System Descriptions, Process Operation, Consent Compliance and Management, Public Use / Public Relations, and Contingency sections are considered sufficient, and these sections are therefore omitted below.

7.5. MAINTENANCE PROCEDURES

This section of the Management and Monitoring Plan would detail hardware maintenance, including checks on pumps and pipe joints at appropriate intervals. Sprinklers also need to be checked on a regular basis and access to sprinkler lines must be maintained. The sprinklers themselves must be kept clear of interference from vegetation, particularly vines. Also, harvesting equipment can damage sprinkler lines, and systems to minimise, monitor, and repair this damage must be written and followed. Maintenance routines in each of these areas should be specified in this section of the plan.

7.6. EFFLUENT MANAGEMENT AND MONITORING

The management and monitoring plan, perhaps above all other considerations, must describe procedures for managing irrigation, and monitoring effluent flows and quality. This information is required by operators to verify that design application rates are not being exceeded. Records of loading data are also needed to determine the mass balance of wastewater constituents, which will be an important measure of performance of most systems. A key monitoring task is to track, for each separate irrigated area, effluent flows, and application rates of water and key wastewater constituents (e.g., N and P). Visual observation, particularly when irrigating onto wet soils, is also an important aspect of this monitoring.

7.6.1 Irrigation management

The operator must be able to compare actual irrigation loadings with what the designers intended. Therefore the design irrigation schedule, including design loadings of water and nutrients, provides benchmark information that must be included in this section. The design schedule can vary seasonally, due to some areas having seasonally high water tables, or crops or soils being unable to consistently handle the same loading of wastewater throughout the year.

Some need to modify the irrigation schedule from time to time should be anticipated. The management plan should accommodate:

- Set-aside periods for crop harvest and rotation.
- Times of increased soil wetness that leave soils near saturation and unable to accept further irrigation loadings in the short term.
- Times when reserve storage is filled to near capacity, which may require a short-term increases in loadings that are greater than design.

This section of the plan should specify when and how the design irrigation schedule can be modified in each of these circumstances. These are all critical issues, and their importance cannot be overstated. Ignoring them will almost inevitably lead to problems in performance and resource consent compliance. The management and monitoring plan must address how the excess flows during these times are to be handled, whether through storage, application of effluent to reserve areas, or through increased applications to the operational irrigation zones. When applications to the operational zones are increased, there should be rules describing when and how such increases are allowed. During these times, frequent monitoring (as described below) should be carried out to guard against runoff and excessive soil saturation.

7.6.2 Monitoring effluent volumes

Effluent volumes will normally be monitored on a daily basis. Generally, the most appropriate flow monitoring techniques will involve some form of automatic measurement and recording. Daily effluent volumes are used to calculate application depths of effluent to the land. The application depths can be expressed on an hourly, daily or weekly basis. Both hourly and longer-term applications are important and should be tracked. The hourly application may be a key design factor of the system, which ensures effluent infiltrates the soil without runoff and ponding. The daily or weekly rate is matched to the capacity of the site to consistently treat the wastewater once it has infiltrated the soil.

Along with monitoring of application rates, visual monitoring of the response of soils to irrigation is important. This is a key factor in interpreting results of effluent and soil monitoring and will give an early indication of any problems. Given variations in soil type, and perhaps soil disturbance during construction, areas of ponding and runoff may occur, particularly when soils are wet from recent rains. Regular reconnaissance observations during these critical times, along with matching these observations with irrigation loadings and recent rainfall data, will provide information that allows the operator to avoid excessive soil wetness and consequent runoff problems. In small areas such problems can be solved by adjusting the application rate (changing to smaller sprinkler nozzles), or infiltration may be improved by cultivation.

On occasions when much of the site is wet due to recent rain, surplus storage capacity or reserve irrigation areas may need to be available to avoid runoff. Procedures should be in place to handle these conditions. But if surface runoff or ponding is widespread in the absence of recent, heavy rains, then this problem needs immediate attention. If application rates have exceeded the design then they need to be reduced. Either the instantaneous application rate needs to be reduced by using smaller sprinkler nozzles or pulsed applications, or, if daily applications are too high, then the irrigation area may need to be expanded. If design application rates are being met, then soil infiltration/drainage conditions may have changed due to the irrigation or soil conditions were perhaps not assessed properly at the outset. In these circumstances specialist advice and/or a management review is probably required.

7.6.3 Monitoring effluent quality

Data on the quality of effluent are needed early in system design to determine loadings of nutrients and other constituents. Mass loadings of these constituents are usually key to the design of any LTS, and environmental monitoring is focused on determining the effects and concentrations of these constituents in the receiving environment. Parameters most often monitored are discussed in Chapter 1, and further detail is available in Metcalf and Eddy (1991) and other similar texts.

It is likely that monitoring will be required for the following groups of constituents:

- *Organic load and suspended matter*. In wastewater treatment, BOD_5 and suspended solids are standard parameters that characterise effluent quality. But for land treatment these are not usually critical as soils can generally accept high organic loads. Suspended solids can, in extreme cases, cause blockage of sprinklers, but concentrations that are typical for municipal effluent should not cause problems for land treatment.

- *Major nutrients*. The concern here is with nitrogen and phosphorus. Obviously, some monitoring of N and P in effluent will be required for land treatment systems, because they often determine design application rates. Loading of these nutrients must be known to assess the performance of the system. For nitrogen, it is important to determine both the total amount and the form of N being applied (nitrate, ammonium, and organic forms).

- *Common ions.* Other cations may also be monitored, including calcium, magnesium, potassium, and sodium, as well as anions, particularly chloride and sulphate. This information will help in managing soil quality and productivity of the crop being irrigated. Chloride, although not a plant nutrient of concern, is useful as a tracer ion and to help interpret data from receiving waters (that is if Cl^- is monitored in them as well). Effluent pH and electrical conductivity are simple measurements that would provide a complete set of effluent quality data.

- *Micro-organisms (pathogens)*. Counts of micro-organisms are often routinely done to assess performance of the treatment plant. Coliform counts are commonly carried out, and measurement of specific organisms also appears to be gaining favour; this may include counts of *E. coli*, *Campylobacter*, *Salmonella*, and protozoans. These data are most important if there is public access to the site, and in such cases disinfection will often be required prior to irrigation. Movement of pathogens in the soil environment is an active research issue (see Chapter 2).

- *Heavy metals and trace organics*. These constituents may have long-term effects on soil and crops, and are most important where known sources (industrial inputs) are reticulated to the sewer system. In non-industrial areas, this monitoring may generally be reduced in frequency and need only target key contaminants, such as copper, zinc, mercury, and cadmium.

The exact chemical characteristics of the effluent that will need to be monitored will vary with the specific circumstances. In many systems, regular sampling for key nutrients will be required to monitor the treatment plant's performance, and this will nicely suit irrigation monitoring requirements. Effluent monitoring should provide data for constituents that were considered in the design of the system, and that could affect the soils and crops of the LTS, and the general receiving environment. The sampling system should be carefully designed to provide representative data. Because effluent quality varies with time, flow-weighted sampling or bulking of grab samples taken on a regular basis is generally recommended. Sampling frequency can be determined by the likely variation in effluent quality. For example, aerobic pond systems have long residence times and thus effluent quality changes slowly, whereas activated sludge systems have short residence times with rapid changes in effluent quality. Sampling of effluent from an activated sludge system should therefore be done more frequently, perhaps several times in a 24-hour period, than for a pond system, where a sample every day or two may suffice. Note these samples can be bulked over longer time periods (i.e., weekly to monthly, to keep analytical costs under control). It may also be a good idea, at least on occasion, to check if there are changes in effluent chemistry between the treatment plant, the storage facility, and the sprinkler nozzle, particularly if some change is suspected (for example, ammonium volatilization).

7.7. VEGETATION MANAGEMENT AND MONITORING

Plants play an important role in land treatment systems. They take up water and nutrients from the waste, provide cover and prevent erosion, and maintain soil physical properties and biological activity through rooting. Management of crops in the land treatment setting should be aimed at harvesting a marketable crop, maximising nutrient removal, and ensuring that site productivity is maintained. A healthy crop is vital to meet these objectives. Waste application can, however, be detrimental to plants, and it is important to recognise this in crop selection and management. Many of these aspects are covered in Chapter 6.

7.7.1 Crop harvesting and monitoring of harvested material

Part of the management and monitoring plan for vegetation must address harvesting strategies and schedules. Harvesting equipment may cause compaction if soils are too wet, and so adequate time needs to be allowed between irrigation and harvest for soil drainage. During harvest and crop re-establishment, irrigation has to be diverted to other areas. Harvest schedules can be devised to rotate between different irrigation areas so that the area out of the irrigation schedule at any one time is minimised.

Monitoring of the harvested crop can be important for two reasons. First, a measure of the mass of nutrients removed in crop material is an important performance indicator for the system. Second, crop quality measurements will generally be needed to inform buyers as to the value of the crop. For animal feed (in a cut and carry system), these measurements should include regular pathogen counts to protect animal health (see Sections 3.3.2 and 3.3.3). Procedures for measurement will vary with the crop, and need to be documented in the plan. A measure of the biomass removed should generally be involved, along with data on nutrient concentrations, and key crop-quality parameters.

7.7.2 Crop monitoring

Activities to monitor/control insect and disease problems, promote crop rooting, and maintain adequate nutrient balance within the plants should be a standard part of the management of any crop. It becomes doubly important to carry out these activities in the land treatment setting where continual waste applications can cause crop stress. Crop monitoring will help determine whether the crop is fulfilling its intended role in the LTS. Also, it provides early detection of problems with disease, insects, nutrient balance, and general growth and survival.

General risks of waste application for plants

In wastewater irrigation systems, plants may be at increased risk of developing problems with disease, rooting, and nutrient balance. This is because of the wet conditions, and the fact that the nutritional requirements of crops are not likely to be balanced by the composition of effluent being applied.

Plant pathogens that spread through soil or are disseminated in the air will generally be spread more easily under the moist conditions that prevail in an LTS. Many pathogens are crop-specific, although some root rots may attack a range of crop species. Insect and disease resistance should be considered when the crop is selected (Chapter 6).

Rooting problems may occur if soils become too wet. Inundation can result from over-application, from a combined event of irrigation closely followed by heavy, unanticipated rainfall, or from an unusually wet season. Persistent problems would be most likely in systems where the design application rate is closely matched to the soil's drainage capacity. Crop monitoring can provide an indication of soil inundation if the crop is not adapted to water-logged soils.

Probable crop fertility problems resulting from waste application can be predicted based on the waste constituents, knowledge of the particular soil, and the crop's nutritional requirements. Waste loading must also be considered. In some systems nitrogen loading will be matched to the anticipated crop uptake of nitrogen (USEPA 1995). But in others, nitrogen may be applied in excess of plant requirements. Nitrate leaching may result, a process that also removes cation nutrients from the soil (Cole 1997). Under high loadings, nutrient balance issues can become important as the effluent's composition will eventually overwhelm the soil's balance of available nutrients. Even if waste is applied based on anticipated crop uptake of nitrogen, other nutrients may become limiting, particularly if they are present in small concentrations in the waste. Contingency plans to anticipate and correct such problems with supplemental fertilisers are recommended.

Potential nutrient balance problems associated with waste application

Phosphorus is generally required in amounts that are second only to nitrogen. It is also important to monitor P cycling in any land treatment system, particularly where protection of surface water quality is a concern. Phosphorus deficiency in crops would be unusual in land treatment systems using municipal effluents. Nevertheless, it is still important to compare the availability of P in the waste with the amount of P required to attain the yield goal for the crop being grown. For leguminous crops, which have a high requirement for P, additional P fertiliser may be required to realise the potential yield and nitrogen uptake anticipated for the crop (USEPA 1995).

The most likely nutrient balance problem would be an imbalance of the major cations (Ca, Mg, K, Na), most commonly an excess of monovalent cations relative to divalent cations. High potassium is known to inhibit magnesium uptake in a range of crops. Large concentrations of sodium may also interfere with nutrient uptake.

Planning a crop monitoring programme

Increased risks of disease, poor rooting due to inundation, and nutrient balance problems in an LTS highlight the importance of crop monitoring. Without monitoring, problems may not be discovered until they are obvious, by which time corrective measures may be too late.

A crop monitoring programme is largely based on visual inspection, but it should be devised with assistance from experts in diagnosis of health and nutrition of the crop being grown. Frequency of monitoring may vary from once every year or two for trees, to perhaps monthly for intensively managed forage crops. There may be specific timing requirements and procedures for tissue sampling, plus types of analyses required, that will depend on the crop and its growth stage (Walsh and Beaton 1973). A list of prevalent disease and insect problems for the crop being grown, with photographic examples, could be developed for operations personnel who carry our monitoring. For radiata pine, pictorial field guides to diseases and insects can be obtained from Forest Research (Will 1985; Chapman 1998). Specific advice from experts with experience with the crop being grown should be obtained to help finalise a monitoring plan.

In a crop monitoring programme, it is beneficial to include non-irrigated control areas. This provides the best basis to determine how waste application is affecting the crop. Monitoring areas where ponding or runoff are most likely to occur is also a good idea because these areas could be the first to show problems with rooting, disease, or general mortality.

It is also recommended to collect biomass samples along with foliar nutrition samples. Then changes in nutrient concentration can be interpreted correctly, as either due to dilution of a steady nutrient uptake into a larger biomass, or as an antagonistic response caused by waste application. Will (1985) describes a pertinent methodology to make this analysis, which is applicable to any crop.

Remediation measures

Once identified, problems with the crop should be immediately addressed before they significantly depress yields and affect the performance of the LTS. Remediation measures may include disease or pest control, which would be specific to the crop and the disease or insect of concern. If inundation problems occur, reducing irrigation amounts, retiring areas susceptible to inundation, or cultivation could be simple measures to carry out. Drainage improvements may be appropriate in some cases, but might require a separate consent or consent modifications. For nutrient problems, crop rotation and specialised fertiliser applications are the most effective remedies.

Over the longer term, land treatment systems that are intensively cropped may develop nutrient balance problems that are outside the range of normal agronomic experiences. Specialised fertilisers and application practices may be required to address such problems.

Summary of crop monitoring process

The steps required to anticipate and ameliorate nutrient balance problems in a crop under land treatment are to:

- Determine the potential yield for the crop being grown, and amounts of N, P, K, Mg, Ca, and other nutrients required to achieve that yield.

- Identify which nutrients are likely to become a concern, given any mismatches between waste loading and crop requirements, and considering native soil fertility.

- Choose areas for crop monitoring, including some irrigated and some non-irrigated areas.

- Initiate a monitoring programme tailored to the crop to determine growth and health and enable timely management. This should include both regular sampling for biomass, and nutrient uptake in selected areas, and visual survey of areas of specific management concern (e.g., prone to inundation).

- Take corrective action, such as pest control, changes in irrigation or soil management, or addition of supplementary fertiliser, as necessary. USEPA (1995) provides further detail on corrective management which should be put in place with advice from appropriate experts.

This is a loop process, as the effectiveness of remedial measures must in turn be evaluated through monitoring. This may lead to changing both the crop and management practices. Crop monitoring results must also be considered in relation to results of other monitoring, and especially soil conditions, so that they are viewed in the context of the overall performance of the scheme.

7.8. ENVIRONMENTAL MONITORING

7.8.1 Soil Monitoring

Soil water monitoring

Effluent treatment processes occur at a faster rate near the soil surface (as outlined in Section 2.2.2). Thus effluent renovation is improved by using application rates that retain the effluent in the topsoil (McLeod *et al.* 1998). This will help maintain aerobic conditions in the soil that are needed to maintain plant roots, and soil biological activity, which in turn promotes effluent treatment. Overall, maintaining effluent treatment processes in the soil requires knowledge of the water status of the soil.

The soil water balance can be calculated as a budget, with effluent and rainfall as inputs to soil water storage, and plant water use and drainage as outputs. Keeping plant water use as the largest possible fraction of the total outputs will maximise treatment (providing salt does not accumulate in the soil). A spreadsheet is available[1] to calculate the water balance of a site, and expected crop water use for each of five regions in New Zealand. Daily rainfall and effluent applications are entered and the plant water use is calculated automatically. A record of predicted soil water storage, leaching potential, and available capacity for effluent

[1] A copy of the spreadsheet can be downloaded from the Land Treatment Cooperative's web page: www.forestresearch.co.nz/nzltc/

application is generated. The available capacity indicates the amount of effluent that can be applied without occurrence of leaching. Such a calculation allows the operator to generally track leaching volumes.

Observations of any ponding or runoff should be recorded and cross referenced against the soil water status. This will help define conditions of excessive soil water, so that decisions to reduce or defer effluent applications can be made consistently. If ponding or runoff increase in frequency, then the area should be closely inspected for changes in water table levels or soil hydraulic conductivity, and appropriate action taken.

There are two types of devices that can be used to measure soil water conditions in the field. A time domain reflectometry (TDR) system can provide accurate information on soil water content and its changes in response to irrigation and rainfall, and has the advantage that it can be set up to work automatically. TDR data can be compared to predictions from the water balance calculation to fine tune irrigation management. The second type of device is a tensiometer, which measures the soil water suction, thus indicating soil aeration and giving an indirect measure of soil wetness. Tensiometers require regular maintenance, but they provide the best information on the soil water conditions as they affect plants. If low values of soil water tension (e.g., less than 100 cm water tension) are sustained after irrigation, this may indicate anaerobic problems. Tensiometer readings can also be cross-referenced to calculations of the soil water balance. Specialist advice is required to design, install, and operate a TDR and/or tensiometer systems for improving LTS management.

Soil quality and its indicators

There has been concern expressed about the effects of land treatment systems on soil quality. There are several definitions of soil quality, the shortest being *fitness for use*. The Soil Science Society of America (1995) further defines soil quality as “The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.” This broad definition recognises that the soil ecosystem has multiple roles in the environment, such as maintaining productivity, providing habitat, and preventing off- or on-site pollution. This definition also includes the notion of sustainability, i.e., to be able to continue to use the soil in the future as at present.

For land treatment systems the major soil quality issue is sustainability: will the soil physical and biochemical properties involved in effluent renovation deteriorate or improve with time? Early warning of declines in soil quality would allow corrective management procedures to be implemented. In New Zealand, a suite of soil indicators (Table 7.1) have been proposed for assessing soil quality across a range of soil types and land uses (Sparling and Schipper 1998). To assess soil quality in a land treatment system we would particularly suggest including additional parameters described in the bullet list below Table 7.1.

Table 7.1. *Soil indicators, adapted from Sparling and Schipper (1998). Some of the soil quality information is not derived from a single soil property but from a combination of measured properties.*

Property	Soil quality information
	Chemical
Total carbon	Organic matter reserves, soil structure, ability to retain water
Total nitrogen	Organic nitrogen reserves
Cation exchange capacity	Buffering capacity and nutrient reserves
Olsen phosphorus	Plant-available phosphate
Phosphorus retention	Ability of the soil to retain phosphorus
pH	Acidity and alkalinity of soil
	Biological
CO_2 production	Availability of organic matter reserve, microbial activity
Microbial biomass	Size of microbiological population, rapidly cycling organic matter and nutrients
Anaerobically mineralisable N	Availability of nitrogen reserve
Denitrification enzyme activity	Size of the denitrifying population
	Physical
Bulk density	Soil compaction, physical environment of roots and soil organisms
Moisture release	Availability of water and air, retention of water, drainage properties
Hydraulic conductivity	Infiltration rate, drainage properties
Particle size distribution	Physical environment for roots and soil organisms, potential nutrient holding capacity

A soil monitoring programme

Before irrigation begins at a new site, base-line, pre-irrigation data for the soils will be needed. Soil samples can be frozen and stored to archive the initial soil properties. Thus if a nutrient becomes of interest after some period of time and the initial values were not recorded in the design stage, the stored samples can be utilised to gain the base-line value (Balks 1995).

Regular soil sampling and analyses will provide monitoring data to help track changes over time. Sampling at one to three year intervals is recommended. Details on collection and analysis of such samples have been outlined (Appendix 2; Balks 1995; Sparling and Schipper 1998). The following types of soil analyses should be considered most important for monitoring:

- *Major nutrients:* Total phosphorus and phosphorus retention capacity will be the most important parameters to measure. Changes in the concentrations and forms of nitrogen in soil can be difficult to assess, but the information is useful for managing crop productivity. Soil analyses provide a poor indicator of leaching of N in soil, and, typically, ground water sampling should be used to detect problems with nitrogen leaching.

- *Exchangeable cations:* Calcium, magnesium, potassium, and sodium are most important. Wastewater irrigation is likely to change the balance of nutrients in the soil, and such changes must be considered in evaluating soil quality and plant health. These data are also used to determine any changes in soil sodicity (See Section 3.3.4).

- *Metals:* Build up of metal concentrations in the soil may limit future uses of the land treatment site and should be avoided. Frequency of monitoring for metal accumulation in soils will depend on their concentrations in the effluent, but should generally be at 2–5 year intervals. Zinc, copper, mercury, and cadmium would be most important, with other metals included depending on effluent and soil characteristics.

- *pH and electrical conductivity (EC):* The pH of the soil affects the availability of plant nutrients, and rates of soil processes contributing to wastewater renovation, as discussed in Section 2.2.4. The EC indicates soil salinity.

- *Denitrification enzyme activity (DEA).* Soil DEA provides information on the size of the denitrifying population in the soil.

Note that, while sodium and salt may increase in the soils of an LTS, the effects should not be critical in New Zealand (see Section 3.3.4). However, monitoring for salinity and sodicity represents little, if any, added cost to the monitoring programme.

Including the other parameters listed in Table 7.1 will provide the most complete picture of soil quality for the site. Physical properties will usually be determined as part of the site characterisation (Chapter 4). Other properties may be needed to help manage the crop, or to provide baseline data on soil quality and the potential for different land uses.

Chemical analysis of samples is best done by a reliable laboratory; different methods are available for many soil parameters, and the choice of method can affect data values and interpretation. Consistency in the methods used for analysis is therefore essential. Specialist advice may be needed to confidently interpret results of monitoring, however reference texts, such as Sparling and Schipper (1998), can also be helpful.

Dynamic assessment (Larson and Pierce 1994) is probably the best approach for using soils data to track changes in soil quality in an LTS. Repeated, regular sampling of fixed sites can be used to determine whether a soil property has reached equilibrium or is in a state of change. It is the *rate of change* rather than the *absolute value* of the indicator that is used as the monitoring index. Data collected from irrigated sites over a number of years or decades would be used to detect the direction and speed of change. The approach has the advantage that it is the trend that is monitored, and that absolute limits for indicators need not be defined.

Beare *et al.* (1997) and Cameron *et al*. (1998) also advocate the same dynamic method for longer-term soil quality monitoring. An example of long term-monitoring trends is shown in Fig. 7.1. This approach also considers the concept of intergenerational equity, where soil quality is expected to remain within, or be restored to, a target range within one human generation. As part of such a monitoring approach, ‘snap shots’ of soil quality can be obtained. These snap shots will indicate if there is an immediate problem; for example, soil pH increases above 7.5 or large declines in microbial biomass would indicate some inherent problem with the effluent being applied.

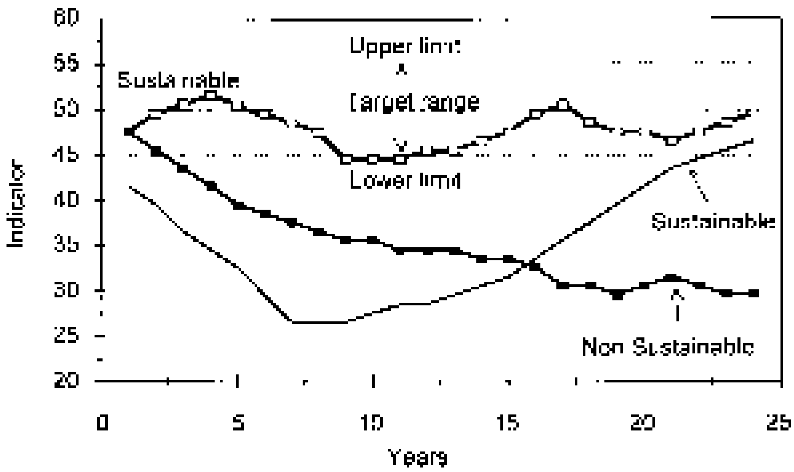

Figure 7.1. *Sustainability defined in terms of a quality standard achieved with an intergenerational time span of 25 years (Reproduced from Sparling and Schipper 1998, with permission).*

Pathogens

There is considerable interest in monitoring survival and movement of pathogenic organisms in soil. However there is insufficient information at this time to suggest that routine monitoring of pathogens in soil should be recommended. Methods for collecting soil water from field soils for pathogen analyses are not well developed, although zero-tension lysimeters can be used for this purpose. Ground and surface waters should normally be preferred media for monitoring for movement of pathogens from the LTS (see Section 7.8.3).

7.8.2 Climate and Air Monitoring

Climate Monitoring

To calculate a water balance of an LTS accurate rainfall data is necessary. Therefore rainfall is the most critical parameter to include in climate monitoring. Rainfall is highly variable in space and even data from existing weather stations that are nearby may not be representative. If a full-time climate station is located within several kilometres, some comparative rainfall data may be gathered at the site to determine if the two sites receive similar rainfall.

The interception of rainfall by the crop may reduce the total amount of rainfall reaching the soil surface. Rainfall interception is likely to vary with the development of the crop, and the intensity and the duration of the rainfall event. Interception is most important in tree crops. Australian pine forests have been shown to have 33% of total annual precipitation unavailable to the trees due to canopy and leaf litter interception (Myers 1992). Canopy interception of hardwood forests has been reported to be from 10–25 % of total annual precipitation (Feller 1981; Zinke 1967).

Spray drift is a common concern in wastewater irrigation systems and there will often be a need to measure the wind speed and direction at the site. In some systems, wind speed and direction may be used to restrict conditions under which effluent may be irrigated. The spray drift itself may also need to be monitored for pathogens, particularly if the irrigated area is near a residential or public use area.

Although on-site monitoring of rain and wind is generally preferable, climate monitoring is carried out at many places throughout New Zealand, and weather data are available (at a cost) through NIWA. Evapotranspiration (ET) is important to the soil water balance of an LTS, and can be calculated from temperature, humidity, radiation and wind data. A simple on-site alternative would be to establish a pan evaporation station within the LTS[1]. For most smaller systems, however, the default values of ET (Coulter 1973) provided for five regions of New Zealand in the water balance spreadsheet (see footnote, p. 136) will suffice. Because effluent-irrigated crops are unlikely to be water stressed, use of typical ET values is considered appropriate. These values, calculated by a robust formula related to the day of year, are a reliable enough alternative to calculations from climate data, given the expense of such data. On a given day the actual ET may differ from the provided values, but the variation will be minor over weekly or monthly periods.

Air quality/odour

Buffer zones are essential to minimising the odour impact on the surrounding areas. Routine monitoring of odours, or of pathogens in spray drift is not necessarily needed unless the LTS is situated close to an urban area. Specialist advice to design an odour or spray drift monitoring programme is recommended.

7.8.3 Ground and surface water monitoring

Programmes for sampling and analysis of ground and surface water in the vicinity of the LTS are a critical component of the overall monitoring programme. Careful attention must be given to using consistent, appropriate sampling protocols, as well as to selection of analytical methods. This section cannot cover all the pertinent issues in detail, and the reader is referred to other more technical references for further information. Here we discuss basic issues such as the number of samples to take, where to take them from, parameters to measure, and frequency of sampling. Appendix 3 describes construction of groundwater monitoring bores, and protocols for sampling groundwater.

Water flow measurements for surface water

Water flow measurements from potentially affected streams and rivers are important in supplying baseline information on the environmental conditions surrounding a land treatment facility. In some cases, surface water measurements can alert the facility manager to increases from irrigation water entering the system. Monitoring of small streams, and, if they are present, interceptor drains, will provide the best information. However, surface water measurements of large river flows are unlikely to show the input of even large amounts of irrigation water due to the volume of water naturally present in the river.

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[1]These alternatives may be appropriate at large LTSs.

Surface water flow can be calculated from the cross-sectional area of the stream/river and a measurement of the velocity of the water. For small to medium-size streams/rivers, a weir can be constructed that will give accurate measurements of flow. For very small streams a bucket and a stopwatch are an inexpensive alternative, as long as you are capturing all of the flow, and make repeated measurements. Sophisticated automatic water flow measurement devices are available that can be used in all rivers and streams for accurate, relatively continuous, flow measurements.

Groundwater monitoring: number of wells

The number of down-gradient monitoring bores required will depend on the size of the land treatment area, resource consent conditions, and the nature of the underlying aquifer (i.e., its hydraulic conductivity, how homogeneous it is, etc.). For example, the Taupo District Council municipal sewage land treatment area irrigates onto approximately 150 ha. There are ten monitoring bores at this site, eight down-gradient bores, one up-gradient bore, and one within the site. The Turangi land treatment site is much smaller (approximately 12.4 ha irrigation area), but because the water also flows through a wetland, six down-gradient monitoring sites were required (Rosen and Chagué-Goff 1997). Four of the Turangi bores sample groundwater from two depths. Given the position of these land treatment facilities and a lack of down-gradient groundwater users, the monitoring coverage is quite good. However, if down-gradient groundwater users are numerous, more complete coverage of the groundwater may be necessary. Examples of possible monitoring bore configurations are presented in Figure 7.2.

Groundwater level measurements

Groundwater level measurements in individual down-gradient bores may be extremely important in helping to manage a land treatment system. The irrigation of crops or trees at an LTS may more than double the annual recharge to shallow aquifers. Therefore it is important to know if the aquifer under the land treatment facility can cope with the excess water. Increasing water tables may result in erosion of riverbanks, flooding of low-lying areas or saturating ground where heavy machinery is required. In some circumstances the addition of irrigation water could cause mounding of the groundwater table under the site. Mounding could actually change the groundwater flow directions under the site; this is generally undesirable and will significantly complicate the ground water monitoring programme.

Groundwater level measurements are usually made when samples are taken for chemical analyses but *before* water is withdrawn from the well for sampling. However, water level measurements are relatively quick and easy to do, and should be monitored at least once a month (which is often more frequent than water chemistry monitoring). Automatic, short interval (hourly or daily) water level measuring devices can also be deployed in some monitoring sites and these can be useful for measuring the direct effect of rainfall and irrigation on aquifer water levels. Natural seasonal changes in water levels can be expected for shallow unconfined aquifers, particularly if rainfall is uneven throughout the year. Natural changes will have to be considered when evaluating effects of irrigation. For these reasons it is useful to have data on water level variations before the treatment facility is operational.

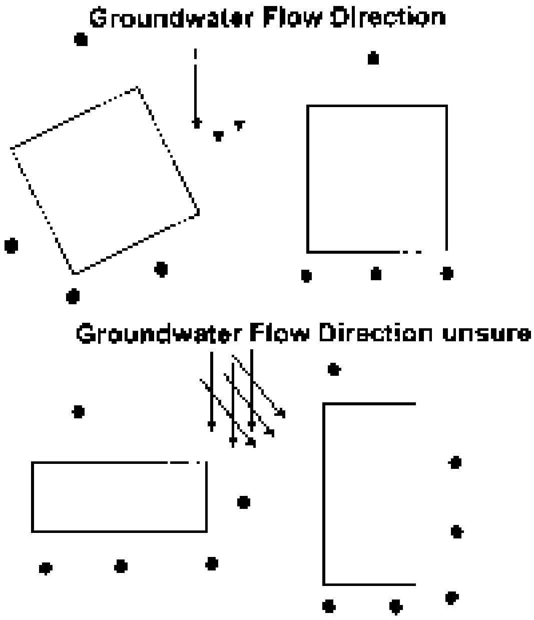

Figure 7.2. *Typical patterns of monitoring bore emplacements using the minimum number of monitoring sites possible. Monitoring sites are represented by black dots, the land treatment facility is represented by the box. At least one up-gradient monitoring site is included.*

Water level measurements should be taken from the same height on the stand pipe each time the measurement is taken, and the sampling point should be marked on the pipe so that anyone taking the measurement will know where to place the measuring tape. The measurements need to be converted to some datum point (usually height above mean sea level) so that all monitoring sites can be compared against each other.

Water chemistry parameters

Routine chemical monitoring of surface water and groundwater at land treatment facilities applying municipal sewage usually includes the following general parameters: temperature, pH, conductivity, and chloride (Cl), plus nutrient analyses for nitrate (NO_3), nitrite (NO_2), ammonium (NH_4), total nitrogen (TN), and dissolved reactive or total phosphorus. Some monitoring of heavy metals, such as lead (Pb), zinc (Zn) or cadmium (Cd), may be required, but usually the concentration of nutrients will be of most concern.

Nitrogen compounds can be measured in different ways by different laboratories. It is important to be consistent in the analyses chosen. Nitrite is not stable in groundwater solutions and is relatively short-lived. Therefore, concentrations of nitrite are not expected to be high in groundwater. This is why some laboratories analyse for total oxidisable nitrogen (TOXN), which is a combination of nitrate + nitrite.

Monitoring of pH and temperature is important because these parameters can indicate changes to the groundwater system caused by the introduction of water of different character. For example, water from a land treatment area may be warmer than the ambient groundwater temperature due to evaporation and storage in holding ponds. This may be seen as a rise in temperature in monitoring bores that are not characteristic for the time of year of sampling. Conductivity and chloride measurements are also useful general parameters because they indicate the introduction of water that is more concentrated than the ambient groundwater. However, care should be taken in coastal areas, because groundwater concentrations in low-lying coastal zones may be influenced by sea water and have naturally high conductivity and chloride concentrations.

The measurement of different types of nitrogen compounds is important because they can show changes in the aquifer conditions. For example, nitrate will be the dominant nitrogen species in oxidising environments and ammonium will be dominant under reducing conditions. However, the introduction of water derived from the land treatment operation, may significantly change the aerobic nature of the aquifer. Therefore, it is important that both nitrate and ammonium be analysed. Organic N is determined by difference between all forms of mineral N and total N. High concentrations of organic N or P in the groundwater may mean that there is a direct route of contamination from the surface to the aquifer. A similar interpretation can be applied if dissolved reactive (mineral) and total P are both determined.

Monitoring of heavy metals may be important in some areas, particularly if there are down-gradient users of the aquifer. Long term ingestion of water with high heavy metal concentrations may cause health problems in humans and animals. Groundwater will generally contain low concentrations of heavy metals and so any increases in metal concentrations in the groundwater will be cause for concern.

Monitoring pathogens in water

Typically indicator pathogens are monitored in groundwater and surface water. Generally, faecal coliforms, are monitored as an indicator of sewage reaching the groundwater. Other bacterial and protozoan pathogens may also be measured at the same times. Although expensive, viral pathogens can also be measured, and this may be advised in rare instances. Careful handling and strict protocols are needed to collect useful groundwater samples for bacterial analysis because cross-contamination of samples is a major concern.

7.9. BUFFER ZONES

Buffer zones are included in the design of an LTS to protect adjacent lands from direct and indirect impacts of waste application. Properly designed buffers will minimise risks of human and livestock exposure to pathogens carried by aerosols, minimise odour problems, protect surface waters from wastewater runoff, and maintain aesthetic and economic values of adjacent lands. Also, in some cases, buffers may be required to protect groundwater if water supply wells are located down gradient from the land treatment site. In designing the buffers for an LTS, both buffer distances and vegetation must be decided upon; these two aspects, while inter-related, are discussed separately below. The design of buffer zones is critical for any LTS, and indeed, the success and public acceptance of the system may depend on adequate design and management of buffers.

The buffer zone section of the management and monitoring plan should specify the location, composition, and widths of buffer zones, and explain the rationale used in designing the buffers. Management practices to maintain the function of the buffers should be outlined, such as maintenance or harvest of vegetation (including weed control, pruning, etc.). Some monitoring of plant health in the buffers is also recommended. There may be several types of buffers for a given LTS, such as internal buffers for access routes within the LTS, and different buffer distances for each adjoining land use along the LTS boundary.

7.9.1 Buffer zone distances

The approach taken in deciding the distances (widths) of buffer zones largely depends on the existing or, in some instances, anticipated uses of lands surrounding the LTS. These may be recreational, agricultural, industrial, or residential, and each strongly affects the degree of conservatism required in designing the buffer zones. If the LTS is in or near an urban area, the possibility of odour problems will probably be the major concern to address. Note the storage pond facility may require the largest buffer distance for odour control.

When setting buffer zone distances, one should also consider the prevailing wind direction, local topography, the method of effluent application, and buffer vegetation. The width of buffers cannot be prescribed, and in fact may vary by two orders of magnitude, or more, within and around any particular LTS. For example, a buffer of 5 m may suffice for internal access roads within a site that has restricted public access, whereas a buffer of 500 m or more may be required if there are drinking supply wells in the direction of groundwater flow. Intermediate buffer distances would generally be required for property lines, surface waters, public roads, businesses, or homes. Section 3.3.3 provides information which could be useful in deciding buffer distances. The largest buffers would be required where a community water supply well is down-gradient of the LTS, and then special investigations to establish a well head protection area would generally be advised.

7.9.2 Buffer zone vegetation

Often buffer zone vegetation will not be the same as in the application area, but rather be specifically chosen to minimise off-site spray drift, and provide a visual screen. A mixture of trees and shrubs is often best. An effective buffer of tall vegetation may allow the width of buffers to be reduced, thus reducing the overall land area requirement for the LTS.

Although there is published information on odour and spray drift (see Sections 3.2 and 3.3.3), there is little, if any, published information on effectiveness of vegetation barriers in reducing odour and spray drift. However, a barrier's permeability to spray drift would probably be related to it's permeability to wind. This is a common subject of shelterbelt research, and literature is available in this area. A combination of species that provide an effective visual screen will also provide good shelter. Kenney (1987) found that a shelterbelt's optical porosity (a measure of how readily one can see through the screen) is related to the reduction in wind velocity on its lee side.

The most common tree species used in New Zealand shelterbelts are *Pinus radiata*, cedars (*Thuja*, *Cedrus*, and *Cryptomeria* spp.), cypresses (*Cupressus* and *Chamaecyparis* spp.), *Eucalyptus* spp., poplars (*Populus* spp.), and willows (*Salix* spp.) (Hovarth *et al*. 1997). Publications on a number of these species are available from Forest Research. Other common species (e.g., shrubs) include barberry (*Berberis* spp.), hawthorn (*Cretaegus* spp.), pampas grass (*Cortaderia* spp.) and New Zealand flax (*Phormium* spp.). It is also recommended that local conservation authorities be consulted on the design of buffer zone vegetation on a particular site.

7.10. SUMMARY: A RECOMMENDED SUITE OF MAINTENANCE AND MONITORING ACTIVITIES

Table 7.2 lists a range of monitoring activities that should be considered for inclusion in an LTS management and monitoring plan.(The actual parameters used can be matched to the particular situation.) A range of suggested frequencies of monitoring is suggested for each parameter, along with a methods reference for further details on analytical techniques. Note that the frequency of monitoring can in many instances be reduced as managers gain confidence in understanding the performance of the system and its responsiveness to management changes.

If these activities are considered carefully in the design of a management and monitoring

Table 7.2. *Recommended suite of monitoring activities. Methods references are provided for analytical procedures only.*

Media monitored	Parameter or feature	Recommended frequency (range)	Methods reference (suggested)	Reason for including/Notes
Irrigation system	Pipelines	At least monthly	(n.a.)	Automated systems recommended
	Sprinklers	At least monthly	(n.a.)	Visual inspection during irrigation is best
Effluent	Flow volumes	Each day of irrigation	(n.a.)	Needed to determine irrigation loadings; automated systems generally required.
	Biological oxygen demand and suspended solids	Fortnightly to quarterly	APHA, 1995	Needed to evaluate treatment plant performance.
	Nitrogen concentrations (NO_3, NH_4, total N), Phosphorus concentration	Fortnightly to quarterly	APHA, 1995	Needed to calculate loading rates of N and P. Analysis for three dominant forms of N strongly recommended.
	Chloride	Fortnightly to quarterly	APHA, 1995	Useful to trace effluent through hydrologic system.
	Other nutrients (K, Mg, Na, Ca, S)	Monthly to semi-annually	APHA, 1995	Useful for soil and crop management.

Media monitored	Parameter or feature	Recommended frequency (range)	Methods reference (suggested)	Reason for including/Notes
Effluent	Pathogens (faecal coliforms, protozoa, *Salmonella*, *Campylobacter*)	Fortnightly to quarterly	APHA, 1995	Helps evaluate treatment plant performance. Usefulness to evaluate LTS performance may improve in future.
	Metals (Cu, Zn, Hg, Cd)	monthly to semi-annually	APHA, 1995	Frequent monitoring only needed if LTS serves industries.
Vegetation	Yield	At harvest	(n.a.)	Tracks crop performance.
	Crop quality	At harvest	(n.a.)	Crop specific; but should include key pathogens (e.g., *Listeria* for silage) as appropriate for food chain crops.
	Nutrient uptake (N and P)	At harvest and at times of foliage sampling	Cornforth and Sinclair 1984	Frequency varies for different crops (see text); needed to evaluate role of crop in nutrient removal.
	Other nutrients (e.g., K, Mg)	At times of foliage sampling	Corforth and Sinclair 1984	Crop-specific planning required.
	Crop health (insects, diseases)	Monthly to annually	USEPA, 1995 (general ref.)	Crop-specific planning required.
Climate	Rainfall	Daily to weekly	Brooks *et al.* 1991	Used to track soil water status; adjust irrigation schedule after heavy rain.
	Wind	Continuous if possible	Rosenberg *et al.* 1983	Needed to predict aerosol movement.
	Evapotranspiration	Daily to weekly	Coulter, 1973	Use of default values in water balance spreadsheet recommended for most systems.
Soil	Soil water status, deep percolation	Daily	Klute, 1986	Estimate using water status calculator – may be used to adjust irrigation schedule.
	Soil water tension (tensiometer)	Hourly (if automated) to weekly	Klute, 1986	Measure of soil aeration.
	Fertility (available N, P, K, perhaps other nutrients)	1–3 years	Page *et al.* 1986	To assess need for supplemental crop fertilisers; crop specific planning required.
	Major exchangeable cations (K, Mg, Ca, Na), pH, EC	1–3 years	Page *et al.* 1982	Determine changes in cation balance, sodicity, salinity, nutrient availability.

Media monitored	Parameter or feature	Recommended frequency (range)	Methods reference (suggested)	Reason for including/Notes
Soil	Heavy metals	2–5 years	Page *et al.* 1982	To monitor for soil contamination
Surface water	Height of stream and flow volume	Hourly to daily	Herschy, 1978	LTS performance evaluation. Consent conditions.
Groundwater	Depth of groundwater below surface or datum.	Hourly (if automated) to monthly	Rosen *et al.*, in press	LTS performance evaluation Consent conditions
Surface and ground waters	NO_3, NH_4, phosphorus, Cl, pH temperature, faecal coliforms, protozoa, *Salmonella Campylobacter*	Monthly to quarterly	Wilson, 1995 Keith, Rosen *et al.* (in press)	LTS performance evaluation and consent conditions

system, and due attention is paid to consistently following a well-planned written programme for management and monitoring, then any well-designed LTS should function properly to meet its particular objectives in areas of waste treatment, environmental quality, crop performance, and community acceptance.

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APPENDICES

APPENDIX 1. GLOSSARY OF TERMS

(Compiled by Andy Bruere, Environment BOP)

Activated sludge	An active mass of micro-organism capable of treating a waste aerobically.
Aerobic	Refers to micro-organisms and processes which rely on the presence of oxygen to function.
Aerosolisation	The formation of small droplet-like particles of liquid that remain suspended in the air and readily disperse. The release of these aerosol droplets is usually from irrigation nozzles or other high-pressure application methods.
Allophane	A clay mineral (aluminosilicate). Occurs especially in soils formed from volcanic ash, and has a high capacity to retain phosphate.
Anaerobic	1. The absence of molecular oxygen. 2. Growing in the absence of molecular oxygen (e.g., anaerobic bacteria). 3. Occurring in the absence of molecular oxygen (e.g., an anaerobic biochemical process).
Application depth	The average depth of water applied at each irrigation event (units – mm).
Application rate	The average rate at which irrigation water is spread across the land surface. Units of expression are depth of water applied per time unit, usually mm/hour)
Aquitard	A layer of material of low permeability that does not allow significant quantities of water to pass through it.
Available water content (soil)	The difference between the ambient water content of a soil and the permanent wilting point (PWP) (may be expressed as mm of water per mm of soil or may be multiplied by 100 to give a percentage). The maximum available water content is the difference between field capacity and PWP and is also referred to as the soil water holding capacity.
Average dry weather flow	The average wastewater flow received during extended periods of dry weather when there is little or no infiltration or storm water entering the sewerage system.
Bardenpho	A biological nutrient-stripping process using alternating zones of aerobic and anaerobic conditions to treat wastewater.
Biochemical oxygen demand (BOD)	The amount of oxygen used in the metabolism of biodegradable organic compounds (contained in waste or wastewater), usually within a 5-day period.

Buffer zones or areas	Boundary areas around and within a land treatment site that are not irrigated with effluent. They are often planted with different vegetation than the application area itself, to provide a visual- or wind-screen against movement of aerosols, in the interest of public health protection. They may also improve the aesthetic appeal of a land treatment site.
Cation exchange capacity (CEC)	Sum of exchangeable cations that a soil can adsorb, either at a specific (buffered) or the ambient (unbuffered) soil pH. Cations are usually held weakly and may be subject to displacement and removal if the ionic composition of the soil solution changes significantly. Expressed as centimoles of positive charge per kilogram of soil ($cmol_c/kg$).
Chemical oxygen demand (COD)	A measure of the amount of oxygen required completely oxidise the organic constituents of a waste. Technically described as the oxygen equivalent of the organic matter that can be oxidised by using a strong chemical oxidising agent in an acidic medium.
Chlorination	The application of chlorine to water, or wastewater typically for disinfection.
Confined aquifer	An aquifer overlain and underlain by impermeable layers. Water depth in a confined aquifer is spatially variable and depends on the thickness of the confining layer and the degree of confinement. Though this aquifer may be at considerable depth, the hydrostatic pressure in a well penetrating a confined aquifer may be high. This may lead to the water level in the well being near the surface (artesian) or even above the surface (flowing artesian). In New Zealand, artesian wells are most common in the Canterbury Plains and Hawkes' Bay areas.
Contact stabilisation	An activated sludge wastewater treatment system which uses two separate tanks or compartments for the treatment of wastewater and stabilisation of the activated sludge.
Conventional plug flow	In a plug flow process, all fluid particles pass through a chamber or medium travelling at the same speed and in the same direction. Therefore all particles spend the same amount of time in chamber or medium, with little or no dispersion or mixing.
Denitrification	The biochemical reduction of nitrite (NO_2^-) or nitrate (NO_3) to nitrogen gases (i.e., nitrogen (N_2), or nitrous oxides (NO, or N_2O)).
Efficiency of the irrigation application system	[Volume of water delivered to the crop root zone] ÷ [Volume of water supplied to the application system]

Electrical Conductivity (EC)	The ease with which an electrical current passes through water or a soil extract. Commonly used to estimate soluble salts content.
ESP (Exchangeable Sodium Percentage)	The percentage of the Cation Exchange Capacity that is occupied by sodium ions. This is often approximated by summing the exchangeable Ca, Mg, K, and Na to estimate the CEC.
Electrodialysis	A process where ionic compounds of a solution are separated through the use of semi-permeable, ion-selective membranes.
Eutrophic	Having high concentrations of nutrients optimal, or nearly so, for plant, animal, or microbial growth. Can be applied to nutrient or soil solutions and bodies of water. The process whereby waters become eutrophic is known as eutrophication.
Extended aeration	A treatment process where wastewater is aerobically treated and has a relatively long retention time (days rather than hours) in the system. The mass of biological solids produced is generally small.
Facultative	Often refers to bacteria that can function in the presence or absence of oxygen. Also refers to pond treatment systems which incorporate both aerobic and anaerobic conditions
Field capacity (soil)	The percentage of water remaining in a soil two or three days after having been fully wetted, and after free drainage has practically ceased (the percentage may be expressed on the basis of weight or volume).
Field saturation	The water content (cm^3/cm^3) under saturated conditions in the field. Due to non-contiguous pore space and very small voids within the soil structure, it is generally not possible under field conditions to displace all of the air from the soil profile even under artificial ponding conditions. If data are not available on the field saturated water content then 0.93 times porosity can be used as an estimate.
Groundwater table	The surface of an unconfined aquifer. Technically, it is the elevation in an unconfined aquifer at which the water pressure is equivalent to atmospheric pressure. It is usually measured in a well, as the depth of the water surface from the ground surface, or as a relative elevation.
Helminths	Parasitic worms. Helminths found in sewage include nematodes (roundworms and hookworms), cestodes (tapeworms) and trematodes (flukes).
Hydraulic conductivity (k) (also referred to as vertical hydraulic conductivity)	A measure of the capacity of the soil to transmit water under a unit pressure gradient (i.e., gravity). The value of k varies drastically with soil water content, but is at a maximum for any

	given soil under saturated conditions. Saturated hydraulic conductivity (k_s) is therefore a key soil property that is required to determine the maximum application rate that a soil will accept. Near saturated values (k_{-40} ; see near-saturated hydraulic conductivity) are often used in design as a conservative precaution. K can be expressed as mm/hr or m/s.
Hydraulic conductivity of an aquifer (k)	The ability of aquifer material to allow water to pass through it. The volume of water that will move through a porous media in unit time under a unit (gravitational) pressure gradient through a unit area. (Units – m/s.)
Hydrostatic pressure	The level to which water will rise in a well penetrating a confined aquifer.
Infiltration rate	A soil characteristic describing the maximum rate at which water can enter the soil surface. Infiltration rates can be strongly influenced by tillage practices and crop cover.
Intermittent sand filtration	A treatment process where effluent is applied intermittently to shallow beds of sand to remove solids. Usually a secondary or tertiary treatment process.
Ion exchange	A process by which ions of a given species are displaced from an insoluble exchange material (soil) by ions of a different species in solution.
Mineralisation	The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.
Near-saturated hydraulic conductivity of soil	The hydraulic conductivity at a near-saturated water content, e.g., at a metric potential of –0.4kPa, at which the largest soil pores are filled by air rather than water.
Nitrification	The biochemical oxidation of ammonium to nitrite and nitrate.
Non-crystalline clay minerals	Clay minerals in which the arrangement of Si-O-Al bonds is irregular and non-repetitive, as opposed to crystalline clays in which the arrangement of bonds is repeated, predictable, and well described for a number of clay-mineral types. Allophane is one of the most recognised non-crystalline clay minerals that exist in soils; it occurs most commonly in volcanic-ash soils.
Nozzle operating pressure	The pressure at which a spray nozzle is designed to operate.
Organic nitrogen	Nitrogen contained in organic material. This excludes ammonia, nitrate, nitrite and nitrogen gas species.
Ozone disinfection	A method for disinfection of water and wastewater using ozone gas.

Pathogen	A disease-causing organism.
Perched aquifer	A perched aquifer is a special case of an unconfined aquifer held above the normal water table but its properties will be similar to that of an unconfined aquifer.
Permanent wilting point (soil)	The water content in a soil at which plants will permanently wilt (expressed as a percentage, or mm of water per mm of soil), even if moisture content is subsequently raised.
Permeability	The property or capacity of a rock, sediment or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow between two points under a pressure gradient. May also refer to classes of hydraulic conductivity, e.g., a soil of low permeability would have a small hydraulic conductivity.
pH (soil)	The negative logarithm of the hydrogen-ion activity of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quinhydrone, or other suitable electrode or indicator at a specified moisture content or soil-water ratio, and expressed in terms of the pH scale. Soil pH affects plant nutrient availability and soil biological activity.
Phosphorus fixation	The immobilisation of phosphorus, either by strong adsorption or by precipitation.
Porosity	The percentage of the bulk volume of rock or soil that is occupied by voids (i.e, pores or interstices), whether isolated or connected.
Pretreatment	Screen and solids removal before activated sludge treatment of wastewater.
Recharge	The replenishment of groundwater by infiltration or seepage from percolation.
Reverse osmosis	Filtration to remove dissolved salts from solution using pressures greater than the osmotic pressure of the ions.
Rotating biological contactors (RBC)	A type of fixed-film biological treatment system where plates containing the biological organisms responsible for treatment are rotated between the wastewater and the air above the treatment vessel.
SAR (sodium absorption ratio)	A water quality parameter that is calculated by a relation between soluble sodium and soluble calcium plus magnesium (as given in Section 1.2.5). SAR is used to determine if a given irrigation water poses a risk of inducing a sodic condition in a soil. Water with an SAR below five is acceptable, while values between five and 18 can pose some risk, particularly if the soil to be irrigated is sensitive to sodium loadings.

	This sensitivity is generally determined by the amount of clay in the soil and its mineralogy. Water with an SAR greater than 18 may not be suitable for irrigation on most soils. Sewage effluents generally have SAR values less than eight, and pose little risk of sodification to most New Zealand soils. Note that SAR, as a ratio, has no units.
Saturated hydraulic conductivity	The rate at which water flows through water-logged soils.
Semi-confined or leaky aquifer	An aquifer confined by a layer of moderate permeability that allows some vertical leakage of water into or out of the aquifer. A semi-confined aquifer has properties of both unconfined and confined aquifers. Water depth in a semi-confined aquifer is variable and depends on the thickness of the confining layer and the degree of confinement.
Sequencing batch reactors (SBR)	An activated sludge treatment process where effluent is treated in a single tank on a batch basis until all treatment steps are complete.
Soil aggregate	A structural unit of soil consisting of an arrangement of individual soil particles held in a relatively stable cluster, which may be shaped as a crumb, plate, block or prism. Most physical properties of the aggregate will differ from those of an equal mass of dis-aggregated soil. (See also soil structure.)
Soil horizon	A layer of soil or soil material approximately parallel to the land surface and differing from adjacent layers in physical, chemical, and biological properties, or characteristics such as colour, structure, texture, consistency, kinds and numbers of organisms present, degree of acidity or alkalinity, etc.
Soil structure	The combination or arrangement of individual soil particles into compound units, called aggregates. Aggregates are characterised and classified on the basis of size, shape and degree of distinctness into classes, types and grades, respectively. Soil structure affects ease of water and gas flow into and through the soil, and therefore has important physical and biological effects. Management practices that avoid soil compaction and dis-aggregation will help promote or maintain soil structure and its benefits.
Soil texture	The coarseness or finess of soil particles. Depends on the relative proportions of sand, silt, and clay in the mineral fraction of the soil.
Specific storage (confined aquifers)	The volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head – applies to confined aquifers

Specific yield (unconfined aquifer)	The volume of water that is released from storage per unit surface area of aquifer for a unit decline in the water table (also referred to as unconfined storativity).
Storativity (confined aquifer)	The volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head. It is the specific storage times the thickness of the aquifer (dimensionless).
Total organic carbon (TOC)	The total amount of carbon material in wastewater sample. It is measured by converting the carbon present to CO_2 and measuring the CO_2 present.
Transmissivity	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Note transmissivity is equal to the hydraulic conductivity times the thickness of the aquifer (confined aquifers) or the hydraulic conductivity times the depth of water (unconfined aquifers).
Trickling filters	A fixed-film biological treatment system where wastewater is sprayed over a reactor filled with media with a high surface area to accommodate the bacteria necessary for degradation.
Ultrafiltration	A pressure filtration system using porous membranes for the removal of dissolved and colloidal material.
Unconfined aquifer	An aquifer in which the water table forms the upper boundary. Water in unconfined aquifers is not under pressure; water in a well is at the same level as the water table outside the well. Unconfined aquifers occur near the ground surface in most areas of New Zealand.
Unsaturated zone	A soil or rock zone above the water table, extending to the land surface in which the pore spaces are only partially filled with water.
Water holding capacity (soil)	The amount of plant-available water held in a soil profile that is wetted to field capacity. It is the difference between the field capacity and permanent wilting point, multiplied by the depth interval of interest (often the depth of the rooting zone). (Units of measurement – mm.)

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APPENDIX 2. FIELD INVESTIGATIONS OF SOIL PROPERTIES

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INTRODUCTION

In order to implement a successful land waste treatment scheme it is necessary to undertake a careful assessment of the soils and site upon which it is planned to dispose of the effluent. In most projects, soil and related studies should form an indispensable part of the basic planning process, and without adequate soils information very costly mistakes have been made (USEPA 1981, Landon 1991). Overcash and Pal (1979) estimated that 90% of the failures in land effluent application systems are directly attributable to the neglect of site data (including soil, climate, vegetation and hydrology) in the scheme design. Therefore it is important to ascertain the extent, distribution and key properties of the soils at a proposed effluent irrigation site.

The level of detail required for designing and implementing an effluent irrigation scheme is such that site investigations should be undertaken by a qualified soil scientist. While previously published soil surveys will provide a useful guide it is necessary to check that the site conforms to the soil units mapped and it is likely that a more detailed map, (for example, at a scale of 1:5000) will be more appropriate for effluent irrigation scheme planning. The variability of the site will influence the level of detail of investigations that will be required.

Soil site investigation provides an opportunity to obtain base-line data for soil properties so that changes that occur as a result of effluent application can be monitored over time. Monitoring will ensure that adverse effects are identified early so that ameliorative action can be taken if necessary.

The following sections describe methods for undertaking field soil investigations to identify the occurrence and extent of the soils at a site. Considerations involved in soil mapping, soil profile description, and sampling for determination of soil chemical and physical properties are discussed.

SOIL MAPPING

Acquisition of background information

Prior to undertaking any field work as much information as possible should be obtained that relates to the proposed effluent irrigation site and surrounding area. Information should include appropriate topographic maps, aerial photographs, geological maps, and soil maps.

The 260 series 1:50 000 scale topographic maps are available from map shops and some book stores. For further information about topographical maps you can e-mail topo-info@linz.govt.nz. Aerial photographs are available from the Photogrammetric Branch of LINZ in Wellington (Private Bag 5501, Wellington, phone 04 460 0110) with most of New Zealand covered at a scale of about 1:25 000. More detailed aerial photographs may also be available. Other firms that hold aerial photographs include New Zealand Aerial Mapping in Hastings, Aerial Survey in Nelson, and Air Maps in Tauranga. Geological maps are available from the Institute of Geological and Nuclear Sciences, (P.O. Box 30 368, Lower Hutt, phone 04 570 4866).

Soil maps are available from Maanaki Whenua Press at Landcare Research Ltd in Lincoln (e-mail mwpress@landcare.cri.nz). A number of publications that contain potentially useful geological and soil information are now out of print and a trip to a library may prove worthwhile. Related information on vegetation and land use may also be useful.

Reconnaissance Survey

A reconnaissance survey should be undertaken to determine the range of landforms and topography on the site. A dutch auger can be used to quickly and easily sample the soil to a depth of at least 1 m to observe soil variability, and major soil features. Soil record cards should be used to ensure uniformity of data recording. It is important to accurately record the location for any site observed, along with key site and soil properties including slope, aspect, vegetation, landform position, soil horizon thickness and depth, colour, texture, presence of gleying, water-table depth, and other potentially useful information. Exposed road cuttings, drain sides etc. should also be inspected to obtain information about the soils and range of soil variability that occurs at the site.

Free survey, rather than grid sampling, will usually be the most appropriate method for use in reconnaissance surveys. When undertaking "free" survey the surveyor selects representative sampling sites, based on professional judgement and interpretation of landforms, microtopography and other factors such as the presence of fences or tracks. During the reconnaissance survey the surveyor should develop a conceptual model of the relationships between the soil and other observable elements of the environment such as landform, vegetation or other surface expression (Dent and Young 1981). An effective predictive soil-landscape model can save a lot of work during detailed soil mapping.

The reconnaissance survey should identify potential problem areas (for example, areas that are prone to flooding, poor drainage, or rock outcrops) and the level of soil variability over the site. It will also assist in determining requirements for later, more detailed, work.

Detailed soil survey

Once the reconnaissance survey has been completed and it is decided that the site is generally suitable for an effluent disposal scheme, a more detailed survey should be undertaken to provide data for use at the project development stage. A detailed survey is particularly important on sites where there is a lot of soil variability. For example, it may be necessary to determine the extent of well-drained and poorly drained areas, as poorly drained areas may not be suitable for irrigation during winter periods or may require installation of a drainage system. For scheme design purposes, soil map units may be be mapped at at the soil series level, but in many instances, where a particular soil property is important with respect to effluent irrigation, a detailed classification level and map scale may be more appropriate. Soil map units should be based on criteria that are distinguishable in the field. Free auger survey should then be used to map the soils, with boundaries being delimited on an appropriate map (preferably an aerial photo.) It may be necessary to undertake grid survey if marked soil variability is found within landform units that cannot be related to visible changes in surface features (Landon 1991).

It may prove useful to develop "single factor" maps that detail relevant information for effluent irrigation scheme design, such as soil depth, subsoil permeability or interpreted units such as restrictions on irrigation methods. Land Use Capability (LUC), maps may also be required, particularly for consent application purposes. The NZ LUC system is defined by the Soil Conservation and Rivers Control Council (1971) and also described by Ministry of Works and Development (1979).

When interpreting soil maps it is important to remember that soils form a continuum across the landscape and no soil map unit will be "pure". Soil boundaries may be inferred from interpretation of aerial photographs, interpretation of ground observations or merely drawn between observed sites. The significance of boundaries can, therefore, be highly variable. Even on a single map, some boundaries will represent narrow zones of rapid soil change between uniform areas whilst others merely approximate the mid-point of gradual changes (Landon 1991). The scale of mapping and the intensity of sampling will have a marked impact on the usefulness and reliability of a soil map. For effluent irrigation design purposes, a map scale of 1:25,000 could be used, however at some sites, especially where soils are variable, a scale of 1:5000 or 1:1000 will be more appropriate. It is **not** acceptable to simply enlarge a 1:25,000 scale map in order to obtain, say, a 1:5000 scale map. The scale of the map should reflect the level of sampling and checking that was undertaken in the field. As a general rule, there should be one soil observation per cm^2 of finished map. This may be varied depending on the soil variability and the predictability of the soil pattern.

Map legends should be designed with careful attention to the needs of the client. Descriptive information should avoid jargon and should emphasise the soil properties that enable a non-specialist to recognise the soil in the field (especially colour and texture), and the soil properties of significance for effluent irrigation.

SOIL PROFILE DESCRIPTION

Once the extent of the main soil map units have been determined, typical sites should be selected for each important map unit and detailed soil profile descriptions and sampling undertaken. Soil profile description should include, as a minimum, the features listed in Table A2. 1.

To ensure uniformity of description, and unambiguous communication of results, soil properties should be determined using the methods described in Milne *et al.* (1991). The soil horizon nomenclature that is used should be that of Clayden and Hewitt (1989). Making up standard field data sheets for recording soil profile descriptions helps ensure that all relevant information is recorded.

Table A2.1. *Data recorded in field observations*

Information recorded	Relevance to effluent treatment/disposal
REFERENCE DATA	
Profile identifier, surveyor, date, soil name	Accurate record keeping
SITE DATA	
Description of location, grid reference, photo number/position	Accurate record keeping, map preparation
Elevation, landscape position	Indication of topographic restraints for effluent application
Erosion or mass movement	May indicate land instability that could be exacerbated either during earthworks associated with installation of the irrigation system or by increased hydraulic loading on the site
Deposition of soil material	May indicate flood-prone site or mass movement
Vegetation, land use and management	May indicate drainage state, potential areas requiring protection
Hydrology of site, drainage, depth to water table, geology, soil parent material	Indication of likely fate and rate of movement of applied effluent
SOIL DATA	
Horizon name, depth and thickness, boundary transitions	Accurate record keeping, depths required for calculation of available water capacity
Soil colour	Indication of organic matter, gleying, reducing conditions, degree of weathering of parent material
Soil texture	Indication of soil properties, including water-storage capacity, drainage, and ion exchange properties
Soil structure	Defines soil pores which determine soil permeability, drainage, water-holding capacity, aeration
Soil consistence, including stickiness, plasticity, penetration resistance	Indicates potential impediments for cultivation and trafficability
Plant root distribution	Indicates limiting layers, useful for determining plant-available water-holding capacity

The methods of Griffiths (1985) for assessing soil permeability classes may be used to provide initial estimates of soil permeability and to identify layers that may limit effluent percolation. Griffiths's permeability class estimation methods can be readily applied to every horizon in a soil profile, during profile description, and give a relatively cheap guide to likely problem areas prior to undertaking measurements.

It may be useful to carry out a field test for reactive aluminium (often referred to as an allophane test) as described in Milne *et al*. (1991). Allophane is a non-crystalline clay mineral which provides a soil with very high P retention and soil physical properties that are generally advantageous for effluent disposal.

Earthworms, due to their burrowing habits, can have a marked influence on soil physical properties, particularly infiltration rates. They help to ensure a rapid recovery in infiltration rates when pores become blocked by suspended solids material in an effluent or by the microbial material that develops in response to effluent application. High pH effluents and prolonged periods of saturation can be detrimental to earthworm populations. The presence and variety of earthworms should be recorded while undertaking soil profile description. This will provide some base data for future monitoring, should there be either an increase, or a decrease in earthworm population as a result of effluent application or other management practices.

For the purposes of a land waste treatment investigation it is not necessary to use accepted soil series names or classifications (Soil Unit 1, 2 etc would suffice). However, it is preferable to later correlate the soils to known soil series and to classify them using accepted classification systems. This will enable comparison with published soil information. If published data are available, such as clay mineralogy and soil physical or chemical properties, they may be utilised effectively to save you time and money. Correlation with known soil series will also facilitate communication with other consultants who may be familiar with soils in the area. The classification system of Hewitt (1992) should be used. Older New Zealand soil classification systems such as the New Zealand Genetic System (Taylor and Pohlen 1979) may also be necessary for comparison with older published literature.

SAMPLING FOR DETERMINATION OF SOIL CHEMICAL AND PHYSICAL PROPERTIES

Sampling for soil chemical analysis

Soil chemical properties will provide information about a soil's ability to retain soluable materials from the effluent. It is also important to monitor properties that provide an indication of soil fertility so that if any adverse affects occur due to effluent application, then ameliorative action can be taken.

With the present accuracy and reproducability of chemical analysis the weakest link in the whole soil analytical chain is often the sampling procedure. While most laboratories would regard duplicate variation of greater than 10% as unacceptable in most of their chemical analysis, it would not be unusual to encounter differences in specific chemical analysis of more than 100% between comparable horizons in the same soil type in the same field

(Landon 1991). Therefore the soil surveyor must take care to ensure that the samples collected are as representative as possible of the defined soil units. Interpretation of the results should take into account the constraints imposed by the sampling procedure.

Sampling sites should be selected to represent those soils occupying the greatest areas, regardless of their nature. Typical sites should be selected and the temptation to sample the site that is the “best” example of a particular soil or soil property should be avoided. Composite samples should generally be used, particularly for the topsoil where 5 or 10 equal-weight samples should be collected then mixed and sub-sampled for analysis. Care should be taken to avoid collecting sub-samples from locations with a different history of land-use or fertiliser application. Land use and fertiliser application histories should be recorded for the sites that are sampled.

Usually about 1 kg of sample will be adequate for soil chemical analysis, but it should be borne in mind that it is very much more expensive to repeat a sampling than it is to take a little extra the first time around. Samples should be clearly labelled, preferably with a label inside the bag and another tied to the outside. Labels should be short and simple to help prevent mistakes in transcribing them. A portion of each soil sample should be air-dried then stored. Samples taken before effluent irrigation is started can prove useful if unforseen problems should occur later, as it is then possible to get stored samples analysed to determine the initial values of soil chemical properties, not examined earlier.

Soil chemical properties that should be monitored are described in the Land Waste Treatment Collective Technical Review No. 3 and also discussed in USEPA , 1981.

Sampling for determination of soil physical properties

Soil physical properties will have an impact on such factors as the rate that effluent moves into and through soil and on the total amount of effluent that can be applied in one application. Physical properties that should be determined when planning an effluent irrigation scheme include infiltration rates, hydraulic conductivity, water-holding capacity and bulk density. Soil physical properties, such as infiltration rate, vary greatly, both temporally and spatially. Some soil physical properties can also be altered by management of a site, for instance mob stocking has been observed to reduce an infiltration rate from about 200 mm/hr to about 2 mm/hr (Balks, unpublished data), while activities such as ploughing or ripping can greatly increase infiltration rates. Because the variability between individual measurements of parameters such as hydraulic conductivity or infiltration rate may exceed 100% (Landon 1991) adequate numbers of replicates are essential. In some situations as many as 20 replications may be preferable.

Effluents with high suspended solids contents (>500 g/m^3) can cause blockage of soil pores and a decline in infiltration rates during one effluent application (Balks 1995). Therefore, for planning purposes it is strongly recommended that effluent infiltration rates be measured using the effluent that is to be disposed of, rather than water. It is preferable to make measurements in winter, when soils are wettest and infiltration rates are often markedly slower than in summer.

Methods for measurement of soil physical properties are not given here as they were included in the Land Waste Treatment Technical Review No. 2. Useful accounts can also be found in USEPA (1981), Burke *et al.* (1986), and Landon (1991).

COST-BENEFITS

Very often the soils information obtained at a site is superficial as people cut costs and spend no more than 1 or 2 days in the field and a similar period of time preparing a report. However you get what you pay for and use of accurate soils information can prevent much more expensive problems developing at a later stage. Young and Dent (1981) suggest that about 22 days should be allowed for field work in order to prepare a 1:10,000 scale soil map of an area of 800 ha, with a similar amount of time in the office to prepare maps and an accompanying report. The absolute cost of a soil survey may seem high, but it is low in relation to the total costs of establishing an effluent irrigation scheme. Where a project does not go ahead, or is substantially modified, as a result of a soil survey, the savings can be many hundreds of times the cost of the survey.

To achieve the maximum benefit from the soil-related investigations it is important that there is good communication between the soil scientist and other members of the design team. This will ensure that important characteristics of the soil are not overlooked or misunderstood.

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APPENDIX 3. A PRIMER FOR CONSTRUCTION OF MONITORING WELLS AND SAMPLING GROUND WATER

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A. WELL CONSTRUCTION REQUIREMENTS

Construction of monitoring wells is a topic worthy of detailed discussion; here only a simple summary is provided. The proper construction of groundwater monitoring bores is still debated in New Zealand and there is no national guideline for bore construction. The outline given below will not apply to every situation and is intended as a guideline for installing monitoring bores in unconfined aquifers composed of sedimentary units (the usual case in New Zealand).

The casing of a monitoring bore can be made of several different materials. From least expensive to most expensive these are: PVC, teflon, and stainless steel. Different grades of stainless steel are possible and different types of plastics are also available. Stainless steel casing is used when organic materials and solvents are expected as water contaminants. For most land treatment facilities handling municipal sewage, stainless steel will not be required. Teflon is used when there is concern that the contaminants may adsorb onto the casing. Some heavy metals and soluble organic materials such as hydrocarbons may adsorb to PVC casing. Once again, for monitoring potential contaminants from most municipal sewage treatment facilities, teflon will not be necessary.

PVC is a good all-purpose material that can be used for most groundwater monitoring. It is best to use PVC casing that has threaded ends so that PVC glue does not need to be used when constructing the bores. Threaded PVC is more expensive than unthreaded PVC, but the quality of the monitoring bore using the threaded PVC is much greater than bores that use the unthreaded type.

Once the intended depth of the bore has been reached it is best to place about one metre of solid casing at the bottom of the hole with an endcap at the bottom. This is known as a sump (Figure A.3.1). Any sediment or other material that may get into the bore will sink to the bottom of the hole and will be out of the way of the screen. This will help maintain good flow into the bore.

Above the sump is the screen. This consists of a length of PVC (or what ever the bore casing is made of) that is slotted at regular intervals to allow water to enter the bore over the desired depth range. The screen may vary in length from approximately 1 metre to ten's of metres. In general, a good screen length is between 3 and 5 m for non-specific monitoring wells. Solid casing is then fixed to the top of the screen up to the top of the hole. Clean, well-sorted sand or gravel that has a grain size larger than the diameter of the slots in the pipe is placed around the sump and screen to help maintain good flow into the bore. The sand or gravel should be filled up to approximately 1 metre above the top of the screen. Above the sand, a 1-metre thick layer of bentonite (an expanding clay material) is emplaced to seal the top of the hole above the screened section of the bore. This prevents water from the surface travelling down the pipe and contaminating the aquifer. Above the bentonite layer, material that was taken out of the hole when it was drilled can be placed back in the hole to fill it up (alternatively clean fill of silt or mud from off-site can be used). Within 1 metre of the surface, a concrete grout should be used to fill up the surface and cement the standpipe in place. At this time a lockable metal casing can be placed around the standpipe and cemented into the structure. Another endcap should be placed at the surface to prevent surface water entering the hole. A diagram of the construction of a “standard” monitoring bore for an unconfined aquifer is shown in Figure A.3.1.

It is important when installing a monitoring bore into a confined or semi-confined aquifer to make sure that contaminants that may originate above the confined layer are not transmitted through to the confined aquifer. It is important to maintain the seal between the confined unit and the surface. This will mean that the depth of the confining unit must be accurately known and bentonite placed at the appropriate level and thickness to maintain the seal.

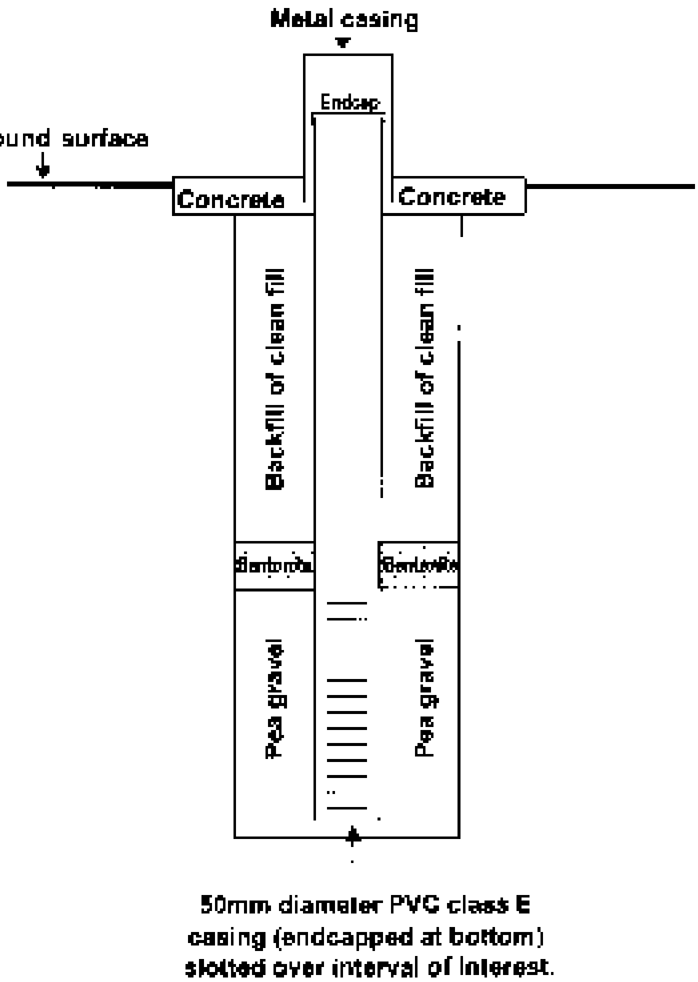

Figure A.3.1. *Typical construction of a monitoring bore for measuring groundwater quality and groundwater levels.*

B. DEPTH OF WELLS

The minimum requirement for the depth of monitoring wells is that they must be below the lowest groundwater level in any given year. Generally, 3-5 metres below the water table is sufficient to meet this requirement. However, the vertical distribution of contaminants may also be important, because of multiple aquifers, a need to track three-dimensional flow, or because a particular contaminant is heavier than water. In these cases bores at the same location drilled to different depths may be necessary. Installing bores that are sampling the entire thickness of the aquifer may not be a good plan, because having such a broad sampling point may make it difficult to detect the source of contamination.

C. WATER QUALITY SAMPLING TECHNIQUES

Groundwater sampling techniques vary depending on the types of contaminants and water that is to be sampled. There is a large body of literature that specifically addresses groundwater sampling issues. What is presented below is a short introduction. More detail can be found in the following references: Driscoll (1986); Collins and Johnson (1988); Garret (1988); Keith (1988), and Byrnes (1994).

Groundwater samples are collected using either dedicated pumps or portable pumps and bailers, as described below. The rule of thumb for collecting groundwater samples is that at least three times the volume of standing water in the well should be removed before a sample is collected. This is called purging the well. The amount of standing water in a well can be calculated by knowing:

- the depth of the well,
- the water level in the well, and
- the interior diameter of the well.

For example the volume of water in a well that is 30 m deep, has a standing water level of 20 m below the ground surface, and is 100 mm in diameter can be calculated using the following equation:

$$V = \pi R^2 h$$

Where:

V	=	volume of the water in the well
R	=	the radius of the well
h	=	the height of water in the well
π	=	3.1416 (a constant)

For the above example then:
The radius of the well is 50 mm (half the diameter). However the units must all be the same so millimetres must be converted to meters (0.05 m). The height of the water is equal to the depth of the well minus the depth to the standing water (30 – 20 = 10 m).

$$V = 3.1416 \times (0.05\ \text{m})^2 \times 10\ \text{m}$$

$$V = 0.079\ \text{m}^3$$

One cubic meter (m^3) is equal to 1000 litres of water. So 0.079 m^3 of water means that you would have to pump out 79 litres of water to clear the well of ONE volume of standing water, and 237 litres to clear THREE volumes of standing water in the well. If you are pumping at a rate of perhaps 10 litres per minute, it would take 24 minutes to pump out 3 volumes of the standing water in the well.

The easiest way to determine the pumping rate is to time how long it takes to fill a 20-litre bucket (i.e., if it takes 2 minutes then you are pumping at 10 litres per minute). Do this three times and take the average to determine the pumping rate.

D. FIELD MEASUREMENTS OF WATER QUALITY

Although most chemical and biologic water quality parameters will be measured in the laboratory, some parameters, particularly pH, conductivity, dissolved oxygen and temperature, should be determined on site. These parameters should be measured from a steady stream of water pumped from the bore into a clean container (placed in the shade) containing the probes necessary for the measurements. Dissolved oxygen measurements should be made from a stream of water that is closed to the atmosphere. The measurements should be recorded only after temperature and conductivity have stabilised (see below).

These field measurements provide a way to ensure that the sample is representative of the groundwater, but this first requires measuring the temperature and conductivity of the water being pumped from the well during purging. If after purging three times the volume of standing water in the well, the temperature and conductivity are still changing, then the water is not representative of what is in the ground. Pumping should continue until these measurements have stabilised. The temperature and conductivity of the water can be sampled continuously by placing the temperature and conductivity probe in a beaker that has a constant stream of well water entering it. In this manner, any changes in temperature or conductivity can be monitored with time. However, if the temperature and conductivity stabilise **before** three standing water volumes have been purged, pumping should continue until three standing water volumes have been pumped.

E. SAMPLING EQUIPMENT

Bailers

Hand held bailing devices can be purchased or made using PVC, Teflon, or stainless steel construction materials. If a mixture of materials is used, the device can only be used in conditions suitable for the most limiting material. In other words, if the bailer construction is to include PVC, there is no need to incorporate more expensive materials such as Teflon into the design because the water will be in contact with PVC and the PVC will limit the use of the bailer.

Bailers are useful because they require no electric power source. However, they are slow and do not necessarily produce the most representative results.

Pumps

There are many different types of pumps that can be used to extract water from monitoring wells. These include air-lift pumps, centrifugal pumps, bladder pumps and others. Centrifugal pumps give the most representative sample, but they are generally more expensive than the other types of pumps. In addition, a generator is required to run the pump.

One aspect that must be kept in mind when sampling groundwater bores is that the water that is purged from the well must have somewhere to go. If the monitoring bore is in a paddock or rural setting, the water can be spread onto the field. However, it is best not to allow the water to pond or create a disturbance to other sampling sites or neighbours.

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Excerpt from "Public Health Guidelines for the Safe Use of Sewage Effluent and Sewage Sludge on Land" (Chapters 4, 8 and selected tables) (Department of Health 1992). Reprinted with permission.

APPENDIX 4. PUBLIC HEALTH GUIDELINES FOR THE SAFE USE OF SEWAGE EFFLUENT AND SEWAGE SLUDGE ON LAND

PATHOGENS OF PUBLIC HEALTH SIGNIFICANCE IN SEWAGE EFFLUENT AND SEWAGE SLUDGE

Pathogens associated with sewage effluent and sewage sludge

Sewage effluent and sewage sludge can contain a wide variety of pathogens including bacteria, fungi and eggs of parasites. These originate largely from the human population serviced by the sewage system, and levels of the pathogens roughly reflect the current state of the health of that population.

The sewage treatment of primary sedimentation does not remove bacterial pathogens to any great extent, and the resulting treated sewage effluent is likely to be still relatively high in bacterial numbers. The heavier helminth eggs will settle and be present in the resulting sludge. During biological treatment, however, bacteria and viruses are strongly absorbed to biological filter slimes or the flocs of activated sludge. Biologically treated sewage is therefore likely to have fewer pathogens in its effluent than effluent from sewage treated by a physical process. Sewage sludge, however, has higher concentrations of pathogens than the incoming, untreated sewage (Pike 1986).

Pathogen indicators for sewage

Faecal coliforms can be used as reasonably reliable indicators for the presence of bacterial pathogens, because their environmental survival characteristics and rates of removal or die-off in treatment processes are broadly similar. Faecal coliforms are less effective as indicators of excreted viruses, and of very limited use for protozoa and helminths for which no reliable indicators exist. Epidemiological studies in the United States, however, have shown that for fresh waters, but not marine waters, *Escherichia coli* has a better correlation with illness in populations than faecal coliforms (Donnison and Cooper 1990).

Bacteria

Bacteria found in sewage include Faecal coliforms, *Salmonella spp., Vibrio cholerae, Campylobacter fetus, Escherichia coli, Legionella, Listeria, Shigella, Yersina enterocoliticia*.

The majority of enteric pathogens die off very quickly outside of the human gut but *Escherichia coli*, which is used an indicator bacteria, persists for longer periods (Gerba 1975).

Salmonella species may survive 11 to 280 days in soil, compared to 7 to 53 days in crops (Kowal 1982). A study of *Salmonella* survival in digested sludge applied to arable land demonstrated die-off rates for *Salmonella* in organic soils and sandy soil were T_{90}=22 days and T_{90}=14–16 days respectively (Watson 1980). (T_{90} is the time taken for 90% of the organisms to die).

Viruses

Viruses found in sewage include Enteroviruses, (67 types including poliovirus, echovirus, and coxsackievirus, which cause meningitis), rotavirus, parvovirus-like agents, hepatitis A virus, adenoviruses (31 types), HIV.

Generally viruses do not survive well in the environment and their numbers decrease rapidly. In particular, spray irrigation will shock viruses into about half a log loss of virus particle, and subsequent die off is about one log every 40 seconds (Scorber 1976). Viruses on crops have similar survival times to those of bacteria but bacteria indicators are not adequate indicators of viral pollution.

Protozoa

Protozoa found in sewage include *Entamoeba histolytica* cysts, *Cryptosporidium, Balantidium coli, Giardia intestinalis*.

Protozoa are able to persist only for a matter of hours in crops. For example fruit and vegetable surfaces, but can survive for days in the soil (Lui 1982).

Giardia cysts are known to survive in water for more than two months at 8°C, one month at 21°C and four days at 37°C (Ampofo 1991). They would not, therefore, survive a municipal sludge treatment process but are present in sewage wastewater. (Typically, when sludge is treated in heated digesters, temperatures are between 25°C and 37°C for more than 16 days.)

Helminths

Helminths found in sewage include nematodes (roundworm, hookworm), cestodes (tapeworm, including *Taenia saginata*), trematodes (flukes).

In contrast to bacteria and viruses, helminth eggs and larvae are stable in the soil environment and may remain viable for a long time. Roundworm eggs are reasonably dense and most settle on primary sludge. Hookworm eggs, however, are not as dense and are therefore not as likely to be removed by physical treatment facilities.

Parasite infection in the New Zealand human population is low, especially in comparison to underdeveloped countries. However, with the high mobility of New Zealand's population, parasite infection from other countries is increasing and helminths will be present in sewage.

Cattle grazing on pasture with untreated human sewage may become infected with *Cysticercus bovis* (the larval stage of the beef tapeworm *Taenia saginata*). The transmission route for human infection with beef tapeworm is established if people then eat raw or under-cooked beef contaminated with viable cysticerci. Previous Department of Health guidelines required a six month "no grazing" period for cattle and pigs because of the concern about *Cysticercus bovis*. An Israeli study found little evidence to imply that beef tapeworms were transmitted to humans eating meat from cattle grazed in fields irrigated with treated sewage or fed crops from such fields (Shuval 1987). This could be due to sewage treatment process, the pasture management, or an absence of cysticercosis in the human community. Pasture irrigation with untreated sewage effluent is practised at Werribee Farm in Melbourne, Australia, as part of the sewage treatment system. Cattle are grazed on the irrigated land after a five day drying period. Their irrigating regime appears effective at preventing tapeworm transmission because the rate of carcasses condemned for contamination with *Cysticercus bovis* is similar to other local farms (Duncan and Cairncross 1989).

The Christchurch City Council apply sewage sludge to their farmland, and graze cattle there after a withholding period of six months. They have not yet had any instances of *Cysticercus bovis* in their cattle, but this may be because there is still very low infection in the community. Studies on the survival of *Taenia saginata* eggs in Danish soils showed that they remained infective for about six months, but not after nine months. Therefore, continued pasture irrigation management practices that ensure that the transmission cycle for *Cysticercus bovis* is not established are essential.

GUIDELINES FOR IRRIGATION WITH TREATED SEWAGE EFFLUENT

Explanation of guideline levels

The guidelines set out in Table A.4.1 relate to the degree of risk associated with irrigation with treated sewage and follow standards which have been proven elsewhere.

The faecal coliform guideline and other controls for Category I (salad crops) land reflect the level of associated risk. They correspond in general to Australian guidelines. Studies of irrigated crops with treated sewage were carried out near Melbourne in the early 1980s.

The faecal coliform guidelines and other controls for Category II (recreational) land correspond in general with World Health Organisation and Australian guidelines. The level of 200 faecal coliforms per 100 ml was suggested by the World Health Organisation Scientific Group. The Department of Health guideline for freshwater full-contact recreation (that the median of samples taken shall not exceed one or the other of 33 enterococci per 100 ml, or 126 *E. coli* per 100 ml), can be used as an alternative quality standard to the faecal coliform level of 200 per 100 ml.

World Health Organisation guidelines generally require faecal coliform levels to be less than 1000 per 100 ml for irrigation of sports fields, public parks and crops likely to be eaten uncooked. These guidelines have adopted a more conservative approach, restricting effluent of this quality to crops likely to be eaten cooked rather than uncooked.

Experience at the Werribee sewage treatment facility, near Melbourne, has shown there to be little or no additional risk of infection of cattle with *Taenia saginata* (beef tapeworm) where the cattle are grazed in land irrigated with sewage treated by stabilisation ponds or by flow across grasslands. Faecal coliform guidelines and other controls suggested for Category III (fodder crops and pasture) land correspond to Australian guidelines.

World Health Organisation guidelines place more emphasis on intestinal nematode levels. Their approach reflects the prevalence of nematode infections in some developing countries. The World Health Organisation recommends that nematode levels should not exceed one egg per litre (as indicated by *Ascaris* and *Trichuris* species and hookworms) in treated sewage to be used for irrigation of sports fields, public parks, crops likely to be eaten uncooked, cereal crops, fodder crops, pasture and trees. The faecal coliform levels and sewage treatment practices set out in Table A.4.1 are deemed adequate to meet the intentions of the World Health Organisation guidelines (*see over*).

Table A.4.1. *Recommended microbiological guidelines and other control measures for the irrigation of sewage effluent*

Land application option	Typical quality	Typical treatment requirements, comments
Category I: Irrigation of salad crops, fruit and other crops for human consumption, which may be eaten unpeeled or uncooked.	< 10 faecal coliforms per 100 ml	Treatment by "conventional" biological oxidation or equivalent, with tertiary disinfection. No harvesting of crops when wet with irrigated water.
Category II: Irrigation of public amenities, for example, sports fields, public parks, golf courses, playgrounds. Irrigation of crops for human consumption which will be peeled or cooked before being eaten, orchards where dropped fruit is not harvested, industrial and non-edible crops.	< 200 faecal coliforms per 100 ml	No public access while land is being irrigated. Treatment by "conventional" biological oxidation or equivalent with tertiary disinfection.
	< 1000 faecal coliforms per 100 ml	Grass surface or sprayed area must be allowed to dry out thoroughly after irrigation (48 hours or longer as necessary) before public allowed. Treatment by "conventional" biological oxidation or equivalent with tertiary disinfection.
	No quality restrictions (public amenities only)	Subsurface irrigation system which prevents sewage effluent reaching the ground surface. Treatment by "conventional" biological oxidation or equivalent.
Category III: Irrigation of fodder crops and pasture.	< 10,000 faecal coliforms per 100 ml	Treatment by "conventional" biological oxidation or equivalent. Pastures to be free from ponding before crop growing permitted. No harvesting or grazing for 48 hours or while wet with irrigated water. Warning signs around irrigated area.
Category IV: Irrigation of forest and treelots, public gardens, bush and scrubland.	No quality restrictions	Treatment by "conventional" biological oxidation or equivalent. No public access for 48 hours after irrigation. Warning signs around irrigated area.

These guidelines are to be read with Notes to Table A.4.1

NOTES TO TABLE A.4.1

Sewage treatment processes

"Conventional" biological oxidation or equivalent includes the following treatment processes:

- Activated sludge systems and variants
- Biological filter systems and variants
- Rotating biological contractor systems and variants
- Oxidation pond systems with a minimum detention of 30 days
- Two (or more) stage aerated lagoon systems, or aerated lagoon/ oxidation pond systems, with a minimum total of detention of 10 days
- Physico-chemical systems which remove or inactivate high proportions of micro-organisms (e.g., lime-based treatment systems)

Tertiary disinfection means a disinfection stage which follows the biological oxidation (or equivalent) stage. The disinfection system must be appropriate to the nature and quality of the treated sewage and to the microbiological quality to be achieved. Disinfection processes may include, as appropriate:

- Tertiary treatment ponds or holding ponds
- Chlorination
- Ultra-violet light

Evidence must be available to demonstrate that a disinfection system is suitable for its proposed application. Aspects such as chlorinated organics and regeneration of pathogens must be adequately addressed.

Withholding periods for stock

Interruption of the life-cycle of helminths such as *Taenia saginata* is important both for public health protection and for the New Zealand agricultural industry. Cattle and pigs should be withheld from grazing effluent-irrigated land for at least six months unless it can be demonstrated that the treatment process is sufficient to remove helminths. For example, pasture irrigated with effluent that has undergone a physical settling process in an oxidation pond with a retention of 30 days may be grazed by cattle or pigs after 48 hours; pasture irrigated with effluent from biological filter systems and variants may not.

Buffer zones and methods of application

Buffer zones are necessary primarily to ensure that nuisance conditions, including problems from odour, are not created.

For application of treated sewage to land by means of border dyke irrigation, ridge and furrow irrigation, subsurface irrigation, or localised (trickle, drip or bubbler) irrigation, concern over odour and nuisance predominate and buffer zones can be determined on a site by site basis. A conservative approach is necessary where a hydraulic pathway to shellfish beds and other aquaculture exists.

A high proportion of aerosols generated from spray irrigation are in the potentially respirable size range of one to five microns. The risk of inhalation of aerosol borne viruses by people exposed to spray irrigation with treated sewage necessitates a minimum exposure distance (buffer zone) between spray sources and people. The safety margin can be increased by using low-pressure spray nozzles with large orifices. These generate large water droplets and reduce the production of fine mist.

For application of treated sewage to land by spray irrigation the recommended size of the buffer zones is similar to those used for sewage treatment plants, except where high wind exposure gives rise to special circumstances or where forested areas or shelter belts provide a multi-storey forest canopy. Stable atmospheric conditions, which inhibit micro-organism die-off, usually occur at night or during calm mornings when temperature inversions exist. When added to the effects of lack of sunlight and generally higher night-time humidities, it is advisable to avoid spraying at night. Suggested criteria for buffer zones for spray disposal systems in frequent use are:

- Sites with high wind exposure: design computations should be prepared to demonstrate the likely wind drift of spray from the irrigation area. Buffer zones should be based on these computations.
- Normal situation with open ground: buffer zone of 150 metres to the nearest residential property.
- Forest or shelter belts with multi-storey forest canopy: buffer zone of 15 metres to areas of public access.

The final choice of the buffer zone size, however, is site specific and dependent on the likelihood of members of the public coming into contact with the sewage.

General features

Where faecal coliform levels are stated, appropriate sampling and monitoring should be carried out to demonstrate that the guidelines levels are not exceeded.

Systems should be designed in accordance with good practice, with reference to appropriate design manual and codes of practice. The United States Environment Protection Agency's *Process Design Manual Land Treatment of Municipal Wastewater* (EPA 625/1-81-013) is particularly relevant.

Systems which use potable water as well as treated sewage for irrigation must be fitted with backflow preventers as stipulated in the Water Supplies Protection Regulation 1961.

Systems should be designed to minimise impact on the quality of groundwater and surface waters. Any discharge to surface water should comply with the Department of Health's *Provisional Microbiological Water Quality Guidelines for Recreational and Shellfish-Gathering Waters in New Zealand*, *January 1992*. During system design, investigations and predictive calculations of the dispersive pathways in the subsoil should be made to demonstrate that water supples will not be contaminated by micro-organisms, organics, inorganic compounds, heavy metals and the like.

Systems should be designed and operated to be free from odour.

Runoff should not be permitted, unless the system is specifically designed as an "overland flow" system or is otherwise provided with collection drains.

Signposts should be erected outside the fenced buffer zone whenever treated sewage is used for the Category IV (forest and treelots) application option. These should state where and when treated sewage has been applied in the area.

Table A.4.2. *WHO recommended microbiological quality guidelines for wastewater use in agriculture*[a] *(the Engelburg Guidelines)*

Category	Re-use conditions	Exposed group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, and public parks	Workers, consumers, public	≤ 1	≤ 1000[d]	A series of stabilisation ponds designed to achieve the microbiological quality indicated or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Workers	≤ 1	No standard recommended	Retention in stabilisation ponds for 8-10 days, or equivalent helminth and faecal coliform removal
C	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] *Ascaris* and *Trichuris* species and hookworms.

[c] During the irrigation period.

[d] A more stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into contact.

[e] In the case of fruit trees, irrigation should not be picked off the ground. Sprinkler irrigation should not be used.

The 'Engelberg' guidelines for non-residential irrigation, that is, irrigation of trees, fodder and industrial crops, fruit trees and pasture, require minimum reductions of bacteria and helminth eggs of 4-log and 3-log units, respectively (Duncan and Cairncross 1989). Even the removal of helminth eggs alone is considered sufficient to protect the health of field workers.

Table A.4.3. *Examples of guidelines for maximum concentrations of heavy metals in soils (mg/kg)*

Element	NZ 1992 guidelines (mg/kg)	NZ 1984 guidelines (mg/kg)	UK 1989 code of practice (mg/kg)	EC 1986 Council Directive (mg/kg)	French 1988 regulations (mg/kg)
Arsenic	10	10			
Cadmium	3	3.5	3	1 to 3	5
Chromium	600	600	400	-	150
Copper	140	140	135	50 to140	100
Lead	300	550	300	50 to 300	100
Mercury	1	1	1	1 to 1.5	1
Nickel	35	35	75	30 to 75	50
Zinc	300	280	300	150 to 300	300

Table A.4.4. *Some pathogenic bacteria found in sewage*

Agent	Disease/ symptom
Campylobacter fetus ssp. Jejuni	Diarrhoea, vomiting
Escherichia coli	Gastroenteritis (diarrhoea)
Legionella	Pneumonia
Listeria	Listeriosis, can cause human bacterial meningitis and miscarriages
Salmonella typhi	Typhoid fever
paratyphi	Paratyphoid fever
other *salmonellae*	Food poisoning
Shigella species	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
other *vibrios*	Diarrhoea
Yersinia enterocolitica	Diarrhoea
Y. pseudotuberculosis	Miscellaneous conditions

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* Note: References are as footnoted in DOH Guidelines (1992).