ENVIRONMENT WAIKATO

Memorandum

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TO Don Scarlet

FROM N Selvarajah

SUBJECT **Hardy Martin Estate Sub-Division Proposal at Cooks Beach**

This report assesses the reliability of the predictions of the effects on the ground water environment for the proposed subdivision, and develops environmental limits for waste water quality, compliance monitoring objectives/programmes for waste water disposal, and a ground water quality monitoring programme.

RELIABILITY OF THE PREDICTIONS OF THE EFFECTS ON THE GROUND WATER ENVIRONMENT

1. VOLUME OF WASTE

About 99.9% of the waste water produced in a household is water. From an average household, waste water is produced mainly from the toilet, laundry, bath and kitchen. Households with the same number of occupants can produce a wide range of volumes depending on the nature and extent of water use (e.g. bath vs shower), type of washing equipment in use (e.g. dishwasher vs hand washing), degree of maintenance of water dispensing equipments (e.g. leaking taps and toilet cisterns) and individual washing habits (e.g. two showers per person vs one per person). In this report an average water consumption of 200 litres per person per day is used to estimate total waste water production. The proposal assumes that 5.7 people will reside in each household over the summer. According to this assumption the total volume of waste water produced during summer will be 205 m^3/day for 150 households (this includes an estimated 20% increase in future sewage flow). Another assumption is made that the Average Dry Weather Flow (ADWF) during winter will be 15% of the summer flow.

The proposal has failed to quantify the annual total volume of waste water generated. It is important to estimate the total effluent volume so that the land area required for irrigation may be estimated on the basis of hydraulic loading. The current report attempts to estimate the total quantity of waste water produced per annum assuming high flow occurs during 2 summer months and 15% of the daily summer flow occurs during the balance of the year:

Volume produced during summer = 205 m^3/day x 60 days = 12300 m^3
Volume produced during non-summer period = 15% x 205 m^3/day x 305 days = 9379 m^3

Total volume = 21679 m^3/year

It is emphasised that the number of people that occupy each lot is very critical for the estimation of sewage volume. Underestimation of the population of the proposed subdivision will result in overloading of the sewage treatment systems (ponds and land) and hence environmental problems. According to the previous estimate, there will be one person residing in each lot during the non-summer period. This figure has been obtained by considering a 20% increase in sewage volume for the next 20 years. Thus it can be interpreted from this estimation that many lots will have no permanent residents for the next 20 years. Experience gained from other schemes (e.g. Whangamata) suggests that the permanent and temporary populations in these schemes increase more quickly than predicted prior to subdivision development.

The proposal should also consider waste minimisation. Since 99.9% of the sewage effluent is water, careful consideration should be given to reducing water use during the design and construction of the lots. Following are some examples:

(1) Use of low-flow-shower heads
(2) Installation of leak proof, durable half and full flush systems for toilets
(3) Leak proof and durable taps

2. TREATMENT AND DISPOSAL SYSTEMS

2.1. Sewage influent quality (i.e. untreated sewage)

The report by Tonkin and Taylor (Tonkin and Taylor, 1993) has failed to estimate the quality of the waste water produced from the lots. This estimation is important to ascertain the treatment capacity of the pond systems and the final quality of treated effluent. The main potential contaminants from sewage effluent are identified as nitrogen (N), phosphorus (P), organic-carbon and pathogens (i.e. bacteria and viruses). The presence of organic carbon is also indirectly indicated by a test for Biochemical Oxygen Demand (BOD_5), a method involving a 5 day incubation of an effluent sample for changes in dissolved oxygen levels. The conventional BOD test does not take into account the potential oxygen demand for the oxidation of ammoniacal-N (although ammoniacal-N is present in NH_3-N and NH_4-N forms, the majority of the ammoniacal-N is present as NH_4-N) to nitrate-N (NO_3-N), a process referred to as `nitrification', and the oxygen demand exerted by undissolved organic carbon. The oxygen demand from ammoniacal-N is approximately 4.33 x NH_4-N mg L^{-1}.

Nitrogen (N)

An adult human who has a normal and high protein intake will excrete about 13.2 and 23.3 g of organic-N per day in urine respectively of which about 87% is urea (Harper, 1973). Assuming an elevated protein intake (between normal and high), the amount of organic-N excreted in urine will be 18.3 g per day person (average of 13.2 and 23.3 g). The amount of N in faeces also varies with protein intake, but is generally small (about 1.5 g N per adult per day). Thus the total-N excreted by an adult will be 19.8 g/day. Assuming that there are 5.7 persons residing in each lot during summer the amount of total-N produced from 150 lots will be 16.9 kg N/day. With a projected 20% increase in population, the total-N produced will increase to 20.3 kg N/day. Considering a daily waste volume of 205 m^3/day for summer, the concentration of total-

N will be 99.1 g N/m^3. Thus the total-N produced during summer and non-summer periods will be 1218.9 and 929.4 kg respectively (i.e. 2148.3 kg N/year).

Phosphorus (P)

About 2.6 to 4.1 g of inorganic-P is excreted per day in human urine (an average of 3.4 g per adult per day). A small (about 0.5 to 0.7 g adult/day) quantity of P is also present in human faeces in organic form. Most detergents used in New Zealand households contain inorganic-P as polyphosphates. The quantity of detergent-P discharged from each household is not known. However, even strongest detergents (which contain trisodium phosphate (Na_3PO_4) and sodium tripolyphosphate ($Na_5P_3O_{10}$)) such as that used in commercial detergents contain only 4.5% (w/w) of inorganic-P. Considering the small quantities of detergents used in households, the detergent-P contributes only little to the total-P pool in sewage effluent. Thus the total-P in sewage effluent is estimated as 4 g per adult per day (3.4 g inorganic-P per adult per day + 0.6 g organic-P per adult per day). With the projected 20% increase in population the estimated total-P produced in a household will be 27.4 g/day (5.7 persons x 4 g P x 120%) hence for 150 lots the total-P discharged will be 4.1 kg/day. The estimated concentration of total-P in the influent will be 20.1 g/m^3. This will amount to about 247.2 and 188.5 kg total-P for summer and non-summer period respectively (i.e. annual total-P = 435.7 kg).

Five day biochemical oxygen demand (BOD_5)

It has been estimated that the average BOD_5 level in sewage influent will be 280 g/m^3 (Hickey and Quinn, 1990). According to this figure the BOD_5 in the influent will be 3444 and 2626 kg for summer and non-summer period respectively (i.e. annual BOD_5 = 6070 kg).

Pathogens

In general, faecal coliforms are used as indicators for presence of bacterial pathogens in waste waters and found at levels such as 2×10^7/100 mL in sewage influent (Hickey and Quinn, 1990).

2.2. Land disposal of sewage effluent

The key issues with regard to land disposal of sewage effluent are identified as (a) hydraulic loading and (b) nutrient loading.

2.2.1. Soil

The proposal (Tonkin and Taylor, 1993) has failed to identify the soil on the irrigation site. Soil type plays a major role in assimilating waste water. A proper waste water irrigation programme should manipulate hydraulic and nutrient loadings based on soil type. According to the given location for the proposed irrigation site, the soil belongs to a zonal soil type of northern yellow brown earth. The soil type is Puketui clay loam with a parent material of weathered rhyolite (Department of Land and Survey, 1975). Topography is rolling to steep land. The soil has a dark grey clay loam on the surface and pale yellowish brown clay in the subsurface. The soil type is considered as low in nutrient status and likely to pug during wet conditions.

2.2.2. Hydraulic loading

Average daily volume of effluent

The average daily volume of sewage effluent during summer and non-summer periods is estimated as 205 m^3 and 31 m^3 respectively. As indicated before, these volumes are likely to increase further during the lease period (20 years) due mainly to an increase in permanent population.

Infiltration rate

Since the soil at the irrigation site is a clay loam and the topography is rolling to steep, the soil infiltration rate is unlikely to exceed 5 mm/hour. Use of application rates greater than 5 mm/hour on poorly drained soils with steep slopes will lead to effluent runoff and subsequent surface water contamination. An application rate of 5 mm/hour is achievable by most sprinkler irrigation systems and is used in the U.K. for applying waste water onto soils with low infiltration rate (MAFF, Welsh Office Agriculture Department, 1991). The proposal recommends a 20 mm application over a 12 hour period. This rate of application (1.7 mm/hour) should not cause any surface runoff problems.

Net hydraulic loading

Net hydraulic loading is estimated by subtracting the amount of evapotranspiration from rainfall and irrigation. The proposal recommends the use of PI (precipitation index) for managing irrigation after wet weather conditions (where PI = $(0.2 \times R_4) + (0.5 \times R_3) + (1.0 \times R_2) + (1.5 \times R_1)$ and R_1, R_2, R_3 and R_4 is rainfall (mm) on the previous 4 days respectively). Nevertheless, a precipitation index approach to the management of net hydraulic loading itself does not allow for stringent control over surface runoff or rapid leaching losses. This is because PI considers only the preceding rainfall for 4 days and it does not account for post irrigation rainfall and the subsequent nutrient leaching loss. Consequently, any good waste water irrigation practice should adopt conservative hydraulic loading rates. The conventional engineering approach to waste water irrigation is to use land as a `filtering system' hence it encourages greater hydraulic loading on well drained soils. Thus the PI accepted for well drained soils is several folds higher than that for poorly drained soils. Such an approach accounts for surface runoff, but ignores nutrient leaching from top soil. Nutrient leaching is a dynamic and cumulative process with increases in hydraulic loading causing greater nutrient leaching. For a given hydraulic loading the extent of leaching varies according to the soil type, soil moisture conditions and nutrient levels in irrigation water (Scotter, 1993). Waste water irrigation may have a more deleterious effects on the receiving environment than irrigating pure water because dissolved nutrients can move with waste water through the soil profile.

Table 1 estimates the annual and daily net hydraulic loading for the irrigation site. The annual rainfall figure (1769 mm) has been obtained from 1951-1980 rainfall data for Whitianga (NZMS, 1984). The annual net hydraulic loading (1043 mm) suggests that the downward water movement will be at least 2 m assuming a pore volume of 50%. In the absence of any significant hardpan at 0-2 m soil depth, the waste water and rain water are likely to saturate the entire 2 m depth. If a significant hard pan is present between 0-2 m, soil water is likely to move down slope and saturate the foot of the hill.

Table 1. Estimation of net hydraulic loading

	Annual	Daily
Average rainfall	1769 mm	4.9 mm/day
Average ET	1050 mm	2.9 mm/day
Application rate	324 mm	0.9 mm/day
Net hydraulic loading	1043 mm	2.9 mm/day

The net hydraulic loading estimates in Table 1 provide a rough guide for water movement and the subsequent solute (i.e. nutrient) movement in soil. In reality several factors can influence nutrient leaching and water movement in soil. For example, when waste water containing nutrients is irrigated onto dry soil the nutrients are absorbed into small soil pores and the potential nutrient leaching is reduced even if there is a high rainfall following irrigation. However, when waste water is applied onto wet soil the nutrients are absorbed mainly in large pores resulting in a high leaching potential (Tillman et al., 1991). Thus a high rainfall event following irrigation can leach most of the nutrients that are located in the macropores. It is emphasised here that proper use of PI will only prevent surface runoff, but it does not guarantee minimal leaching loss. Irrigation should be planned according to the season and the ability for soils to assimilate the applied nutrients.

Generally, for the Waikato region there are about 10 days with > 1 mm rainfall occurring in every month. Irrigation should not be performed on these days. This leaves approximately 205 days for non-summer irrigation and 40 days during summer. With adequate storage facilities, irrigation can be performed with greater flexibility. It is emphasised that the main limitations for high rate of irrigation are land slope and a heavy soil type. However, unlike pastoral land, nutrients can be allowed to leach to a greater depth due to deeper penetration of forest tree roots. Considering these factors a PI index of 10 mm can be adopted to avoid surface or subsurface runoff of waste water. The land area required to meet a 20 mm irrigation/week at 180 m^3/day is estimated in the proposal as 6.3 ha (page 12, Tonkin and Taylor, 1993). A land area of 7.4 ha is required to irrigate 205 m^3/day which is predicted after an increase in population. Since about 8.4 ha area have been identified as suitable for spray irrigation it is recommended to use the entire sprayable area for spray irrigation from the beginning of the operation. *With no irrigation on days receiving > 1 mm rainfall, a PI index of 10 and an application rate of 20 mm/week the irrigation operation is achievable without causing any hydraulic problems. However, spray irrigators are susceptible for malfunction, breakages and leakages and hence surface runoff of the effluent can be expected occasionally. Installation of runoff water collection devices will provide information about the occurrence of such failures should they occur.*

Any waste water irrigation administered onto forest land should attempt to confine the applied waste water nutrients and the existing soil nutrients within the top 1.5 m of soil where most tree roots are located. Plant uptake of nutrients is used as the major nutrient removal mechanism, and hence the nutrient leaching below root zone has greater potential to contaminate ground water. Decaying tree roots can also provide a good source of electron donor (as organic carbon) for denitrification of leached nitrate-N in the subsoil. Consequently, the longer the residence time for nitrate in the rhizosphere, the greater potential for nitrate-N removal through plant uptake and denitrification.

It is also recommended that a soil survey be performed and a soil map produced for the proposed irrigation land. The infiltration rate of the soil type and any presence of a hard pan between 0-2 m soil depth are unknown. For a successful and sustainable waste water irrigation practice, knowledge of the soil types, soil profiles and their land area are vital.

2.2.3. Nutrient loading

Sewage effluent is a good source of essential plant nutrients. It contains a considerable amount of macronutrients such as N, P, K, Ca, Mg, and S. Thus land disposal of this waste water is considered very useful for silviculture. The waste water also contains a substantial amount of organic carbon and under optimum irrigation practice this can improve the soil structure.

2.2.3.1. Nitrogen

Nitrate-N

According to Table 6 given in the proposal (Tonkin and Taylor, 1993), the total-N concentration of the sewage effluent will be 20 g/m^3, of which about 5 g/m^3 will be nitrate-N. Most of the total-N will be in the form of ammoniacal-N with the balance being organic-N. Upon land application, ammoniacal-N will nitrify to form nitrate-N which is a rapid process in volcanic soils (Sarathchandra, 1978). Organic-N will mineralise slowly into ammoniacal-N and will be subsequently nitrified. Whilst ammoniacal-N is positively charged (NH_4^+) and easily adsorbed to negatively charged clay minerals and organic matter, negatively charged nitrate-N (NO_3^-) is not held efficiently by soil and hence has greater potential for leaching. Leached nitrate-N builds up in the soil profile and is transported into ground water aquifers during a high rate of irrigation or rainfall. Thus the presence of nitrate-N in ground water provides an indication of ground water contamination.

According to the New Zealand drinking water standards the maximum acceptable level for nitrate-N is 10 g/m^3 (Board of Health, 1989). Bottle fed infants less than 6 months old consuming water containing nitrate-N are reported to have developed a disease called methaemoglobinaemia (`blue baby' syndrome). Overseas studies report many such cases with several cases resulting in death (Winton *et al.*, 1974). To date, no cases have been reported in New Zealand, although methaemoglobinaemia is not classified as a notifiable disease by the New Zealand Health Department. However, the symptoms for the Sudden Infant Death Syndrome (`cot death') are similar to that of `blue baby' syndrome, implying that there may have been methaeomoglobinaemia cases in New Zealand which have never been noticed. In adults consumption of drinking water with high nitrate-N levels have been linked to gastric cancer and hypertension cases (quoted by Burden, 1982).

Apart from being a potential health hazard, the subsurface flow of nitrate-N in ground water into streams or rivers can pollute waterways causing algal blooms and may subsequently affect aquatic life such as fish. Many waterways in the region are used for recreation and unwanted algal growths can affect the revenue gained by tourism. High nitrate-N flow into the sea combined with P availability has also been considered as one of the main factors for toxic algal blooms reported frequently around the globe and recently in New Zealand.

Nitrogen loading rate

The estimated annual N loading rate in the proposal is 210 kg/ha (page 45, Tonkin and Taylor, 1993). This loading has been estimated using an application rate of 20 mm/week throughout the year. The proposal also estimates the summer Average Dry Weather Flow (ADWF) as 205 m^3/day (page 8, Tonkin and Taylor, 1993) and 15% of it for non-summer period (305 d) (i.e. 31 m^3/day). Consequently, the total volume of waste generated should be 21755 m^3/year. Using this volume, it is estimated that approximately 435 kg total-N will be produced annually in the sewage effluent. Thus the annual N loading stated in the proposal is likely to be over estimated unless similar volumes of waste are produced throughout the year. Considering an area of 8.4 ha available for irrigation, the annual N loading is estimated as 52 kg/ha (i.e. 435 kg N/8.4 ha).

Nitrogen management is very important under a forest plantation. The conventional N loading rate determination is based mainly on the amount of crop uptake. The proposal estimates that 100 kg N/ha/year will be removed by a mixture of eucalypts and radiata pine. The rate of nutrient removal varies with the age of trees. Considerable amounts of nutrients are returned to surface soil through decaying leaves in well established forest systems. Consequently, for such a system the annual N loading rate from a waste water irrigation point of view should be kept at low levels to avoid any adverse effects on the receiving environment. If required, with careful N budgeting, plant requirement for N can be met with a moderate use of N fertilisers. This is because the volume of waste water application involved is likely to cause more potential leaching problems than the actual extent of nutrient loading in the surface and subsurface soil. It is emphasised that any waste water irrigation system should **primarily** consider the possible effects caused by such practice rather than obtaining economical return from it. However, one of the positive aspects of the proposed irrigation system is the higher nutrient and hydraulic loading during summer when the crop uptake of N and evapotranspiration are greatest. A nitrogen application rate of 100 kg N/ha/year is sustainable from a silvicultural and environmental point of view.

It must be emphasised that regardless of efficient N management practices, some nitrate-N is still likely to leach beyond the root zone and subsequently reach ground water aquifers. This is because high rainfall is received during winter when the plant uptake of N is at its lowest level. For example the June, July and August average rainfall figures at Whitianga are 212, 195 and 186 mm respectively (NZMS, 1984). Since soil-N transformation processes in a young forest system are complex, it is difficult to predict the extent of nitrate-N leaching during the high rainfall period. With careful soil water and ground water nitrate-N monitoring the extent of nitrate-N leaching can be detected, and if required, the N loading can be manipulated. *However, considering the amount of N applied (a maximum annual loading of 100 kg N/ha) and the average annual plant requirement (approximately 100 kg N/ha) the potential for leaching should be very small.*

2.2.3.2. Phosphorus

The proposal anticipates that the level of total-P in the effluent is 10 g/m^3. Thus the annual output of P in the effluent will be 218 kg total-P and hence the annual loading will be 26 kg

P/ha. Most of this P will be as inorganic-P and hence reactive upon application onto soil. Organic-P will slowly mineralise into inorganic-P form in soil. Inorganic-P readily reacts with aluminoferrous oxides and calcium present in soil and forms a stable chemical complex. The soil type at the disposal site belongs to the yellow brown earth soil group, which has a high P retention capacity. Phosphorous is retained effectively in subsurface soil due to the high presence of P retaining minerals. Thus the plant available P will be limited and hence the potential for P build-up and leaching is limited. *Considering the high P retention capacity, plant uptake and the relatively small amount of P applied through sewage effluent irrigation, applied-P is likely cause little or no environmental problems. The only time when soil P can contribute to adverse environmental effects will be when harvest of trees leads to soil disturbance and the subsequent transportation of P with sediments in runoff water entering streams and rivers.*

2.2.4. Pathogens

Sewage effluent contains numerous microorganisms even after treatment in pond systems. The proposal estimates a faecal coliform concentration of 10^4/100 mL in the sewage effluent. Upon land application of sewage effluent, microbes are generally filtered effectively by soil. Many microbes such as bacteria and virus are adsorbed by clay minerals. Microbes can migrate to greater depth when there are preferential flow pathways in the soil profile. Under such conditions microbes can move into shallow ground water aquifers. When effluent is released subsurface, under saturated conditions in a granular aquifer microbes can travel with ground water for distances up to 30 m (Romero, 1970). However, since many of these microbes (e.g. faecal coliforms) require a substrate for energy requirement, their survival depends mainly on the availability of these substrates. These substrates are carbon based (organic) which are not present in many ground water aquifers unless a large quantity of dissolved organic-C leaches into the aquifers. Consequently, the microbes of sewage origin that migrate into ground water environment die-off before they travel long distances.

It must be emphasised that many studies on underground pathogen migration have been performed on sewage effluent disposed beneath the soil surface (e.g. on-site sewage disposal). In such cases microbes are not exposed to adverse micrometeorological conditions. However, when effluent is sprayed onto the surface ground a considerable amount of microbes can be retained at the surface, adhering to litter and surface soil. These microbes are exposed to drying and some ultraviolet radiation from sunlight and have greater probability for die-off. It is not clear at this stage whether preferential pathways are present in the soil profiles at the disposal site. If these pathways occur, there will be ground water contamination due to pathogens and nutrients such as nitrate-N. However, generally these pathways are not continuous and hence there is a potential for filtration or treatment in the soil profile. Large fractures or cracks in the soil profile can be significant pathway for migration of waste water. Before the commencement of irrigation the land should be thoroughly surveyed for any such fractures which are generally recognisable at the soil surface. *In the absence of these soil fractures, pathogen migration to the ground water aquifer is unlikely in the proposed disposal area.*

2.3. Alternative treatment and disposal systems

The proposal did not consider reviewing disposal systems such as on-site sewage treatment (by infiltration or evaporation) because the consent issued by the TCDC for the subdivision stipulated that the sewage collection must be reticulated. However, since on-site sewage disposal systems are widely used in semi-rural and rural areas, it is possible to assess the appropriateness of these systems for the proposed subdivision. It is outside the scope of this report to assess the merits and demerits of on-site systems. However, an attempt has been made to briefly address the impacts of such systems on water bodies.

2.3.1. On-site sewage disposal

Conventional system

The conventional on-site disposal system requires a storage/treatment system (septic tank) and a soakage area. *This system is not based on any removal mechanism for nitrate released from effluent.* The only possible removal mechanism is through denitrification where nitrate-N is reduced to gaseous N forms by denitrifiers (bacteria). It is emphasised that the system design criteria cater mainly for the filtration of pathogens and waste water disposal and this system is not designed for nutrient polishing. Denitrification of nitrate requires anaerobic conditions, a source of electron (either dissolved carbon or chemicals such as reduced iron (Fe^{2+})) and denitrifying organisms. *When one of the above components is absent there will be no denitrification.* In sandy soils the potential for such removal is low due to the prevailing aerobic conditions. Nitrate-N is highly mobile and hence can move rapidly into ground water aquifers underlying sandy soils. As indicated before, dissolved carbon is generally absent from ground water and hence the leached nitrate can build up in the aquifer due to little or no denitrification. Thus such systems attempt to utilise the **dilution** effects provided by ground water recharge to reduce nitrate-N levels in ground water (Selvarajah *et al*., 1994 (in press)). If dilution is the main process of nitrate-N reduction in ground water aquifers, such systems require a large effective disposal area. Computer modelling of nitrate-N contamination of ground water showed that a minimum effective disposal area of 800 m^2 is required for effluent disposal through conventional soakage system (Cochrane and Selvarajah, 1993). The model identifies that following such dilution, ground water nitrate levels are likely to remain below 10 g/m^3, although in some cases nitrate levels can rise to 15 g/m^3. Consequently, in sandy areas, the safe effective disposal area should be 2500 m^2. Conventional soakage systems are susceptible to malfunction due to clogging of infiltration surfaces by slimes (Gunn, 1993). Consequently, the effluent is disposed into a very small treatment area where the potential for any treatment is low.

It must be emphasised that use of such systems in areas where the lots are very closely spaced can cause severe ground water contamination due to overlapping contaminant plumes. The problem is accentuated when water supplies are obtained from the same aquifer. On the other hand, where water supply is reticulated, effluent water can contribute substantially to ground water recharge in the area which may increase adjacent stream flow (Gibbs, 1991). Such rapid flow minimises the nutrient polishing of contaminated ground water by reducing the residence time.

Other systems

Gunn (1993) identifies the KISS principles (keep-infiltration-system-shallow) as a better alternative for conventional on-site disposal systems. It has been reported that by using the low pressure flow pipe system, effluent can be `irrigated' into the surface soil and treated. This system uses vegetation for N removal. Gunn (1993) also identifies design requirements for 20 sublots with individual or combined disposal areas.

Rock *et al*. (1991) propose an on-site system which is capable of removing nitrate-N released from effluent using a constructed denitrification sand-filled tank. The construction appears to be very simple and applicable under New Zealand conditions. The authors claim that this system can remove 90% of N in effluent but the treated water still contains nitrate levels up to 10 g/m^3.

There are various other modern on-site systems that are available which are capable of reducing nitrate leaching (Gunn, 1989). Most of these systems require proper maintenance, without which, efficiency in reducing nitrate loading to the ground water can suffer substantially.

Considering the high number of lots (150) in the proposal it is anticipated that there is a greater probability for system malfunction during the use of an on-site disposal system and hence degradation of ground water environment. Even when these systems are claimed to have high efficiency under controlled conditions (e.g. Rock *et al*., 1991), they are still capable of releasing . On-site disposal systems have been identified as a significant source of nitrate-N and faecal coliform in ground water in many parts of New Zealand. Sinton (1982) investigated an unsewered semi-rural area in Canterbury (Yaldhurst) and found that 33% of the 120 wells sampled contained coliform bacteria, faecal coliform or faecal streptococci. Gibbs (1991) concluded that reticulation of sewage from Taupo had a beneficial effect on the inshore waters of Lake Taupo along most of the foreshore. Reticulated sewage systems have many other advantages over on-site disposal systems. Reticulated systems combined with land based disposal of effluent allow **waste recycling** with minimal impact on the receiving environment when managed properly. Similar systems with waste discharged into water bodies require high treatment of waste before disposal. Despite such treatment of sewage, the mass loading of nutrients from these systems often remains high (Selvarajah *et al*., 1993 (in press)). In the case of on-site sewage systems where water supply is not reticulated it can be claimed that water is recycled. However, the environmental and health hazards associated with underground sewage disposal systems far outweigh the benefits of `water recyling'.

2.4. Pond operation

2.4.1. Pond holding capacity

It is proposed that there will be a facultative pond and a storage pond constructed at the land disposal site. The capacity of these ponds should be sufficient to hold effluent during peak periods with consideration given to population growth for next 20 years. Since there will be a stringent hydraulic loading requirement imposed by Environment Waikato, the storage pond should be constructed to hold effluent during non-sprayable periods.

2.4.2. Leakage

Pond systems constructed without proper liners have the potential to leak (e.g. Whiritoa system). Once the system is established it is difficult to stop and reconstruct a pond system when leakage is detected. Many pond systems depend on soil compaction to retain most of the effluent: Even liner with low permeability (10^{-10} m/s) will not prevent several cubic metres of effluent leaking underground annually. Even the concrete liners are considered permeable. Moreover, in locations where the water table is high, ponds can leak directly into shallow aquifers. In this instance there is limited information available on the proposed pond design hence further information is required. In particular, design on the design permeabilities is required.

2.4.3. Odour and insect problems

Facultative pond

Odour from sewage effluent is caused by certain volatile chemicals released into the atmosphere. These chemicals are mainly hydrogen sulphide (H_2S), ammonia (NH_3) and mercaptans (e.g. CH_3SH and C_2H_5SH). Anaerobic conditions caused by breakdown of carbonaceous materials in effluent are conducive to the release of these chemicals. The problem can be overcome mainly by using an efficient aerating system. Generally odourless ponds do not attract insects and any insect problems can also be controlled. When aerated these chemicals are oxidised *in situ* resulting in chemicals that are odourless. Aeration is essential to oxidise ammoniacal-N to nitrate-N form and due to the high presence of dissolved carbon, nitrate-N can be denitrified.

Storage pond

When effluent is stored for a long period anaerobic conditions develop and odour can be a problem. Moreover, a non-agitated pond system can also provide a suitable environment for surface algal growth which can be a nuisance. *It is recommended to install an aerator (e.g. similar to that at the Whiritoa site) in the storage pond.* Installing an aerator in storage pond has additional advantages. Intermittent use of aeration in such a pond system helps to nitrify ammoniacal-N into nitrate-N, which in turn is reduced to gaseous form during the non-aerating period. This operation enhances additional nutrient polishing which reduces the potential for soil N loading.

2.4.4. Effluent treatment standard

Table 2 shows the estimated influent quality, the anticipated effluent quality (Table 6, Tonkin and Taylor (1993)) and treatment efficiency.

Table 2. Expected treatment efficiency

	Influent	Effluent	Treatment Efficiency (%)
Total-N (g/m)	100	20	80
Total-P (g/m)	20	10	50
BOD_5 (g/m)	280	50	82
Faecal coliform (per 100 mL)	2×10^7	1×10^4	100

In the case of total-N treatment, removal of up to 50% of the influent-N does not require any sophisticated treatment methods since ammonia (NH_3) volatilisation is the main N loss pathway at the initial stage of N breakdown. Ammonia loss occurs from urine in the effluent. The balance of the N and BOD_5 breakdown a relatively long residence time and aeration. Although it appears that the treatment efficiency of faecal coliforms is 100%, the count obtained in the effluent is still considered as high under New Zealand conditions. Hickey and Quinn (1990) sampled 18 pond systems in New Zealand and found a median concentration of 4300 faecal coliforms per 100 mL from a 2 stage system. It can be argued that most New Zealand pond systems discharge their waste into water ways and hence the low count requirement. Most of these river discharges require an ultraviolet treatment to kill all the pathogens present. Sewage waste disposed onto land does not require such sophisticated treatment, because of the very low probability and low health risk associated with human contact with soil in the disposal area and the greater assimilative capacity of soil.

Desludging is also necessary for good performance of any facultative pond system. Consequently, proper sludge management is considered to be important. The proposal indicates that there is no need to desludge during the anticipated operation time which is 20 years. It is recommended that sludge management should not be overlooked and should be monitored by a registered pond treatment person every 5 years during the operation period. If required ponds should be desludged. During desludging sediments can be agitated and care should be taken to avoid irrigation waste water loaded with increased levels of chemical components. The sludge should not be applied on the land disposal site.

3. ADVERSE EFFECTS DUE MAINLY TO MISMANAGEMENT OF WASTE TREATMENT AND APPLICATION

As identified in the previous discussion, the proposed operation will cause some environmental effects on soil, air, ground water and surface water *under the following circumstances:*

1) Although the irrigation of sewage effluent will enhance soil conditions at the land disposal site, soil disturbance, compaction and some erosion and nutrient and sediment transportation may occur during the harvest of trees.

2) Even under the recommended waste management operation, there will be leaching of nutrients; mainly nitrate-N during the winter period due to high rainfall in the area. However, since the applied-N and the amount of N removed by trees are similar such leaching is likely to be minimal. The small amount of nitrate-N that may be leached is unlikely to reach the stream due to the subsurface flow of nitrate-N through prevailing wet margins around the water ways on the site and the subsequent biochemical reduction of nitrate-N.

3) Severe leaching of nitrate-N and other N forms (organic-N and ammoniacal-N) can occur when irrigation is applied at levels far exceeding the recommended levels. Although part of the nitrate-N can be biochemically reduced in the wet margin of the waterbodies, a substantial amount can escape the aquifer depending on rates of ground water throughflow and nitrate-N levels in the ground water.

4) Excessive irrigation can cause anaerobic soil conditions which will result in death of trees. This will reduce the potential plant-N uptake which in turn can increase the nitrate-N build-up and subsequent leaching.

5) Poorly treated effluent will contain high nutrients, BOD_5 and bacteria loadings (levels in effluent in excess of those recommended) which will result in nutrient and bacteria leaching and soil anaerobic conditions due to high BOD_5 levels.

6) Excessive irrigation during a rainfall event will cause surface water contamination through overland flow.

7) In the case of breakage or excessive leakage from the irrigation system effluent can runoff into adjacent waterbodies. Effluent runoff can cause elevated N, P, BOD_5 and faecal coliform levels in the adjacent stream and pond.

8) Excessive underground leakage from the pond system will cause significant ground water contamination.

9) Poor management of pond systems (e.g. poor aeration) can result in odour problems.

4. RECOMMENDATIONS AND MONITORING

Sampling sites for environmental impact monitoring are illustrated in Figure 1. Note that the location of the ground water sampling sites are subject to change depending on the topography, geolgy and aquifer charateristics of the sampling site prior to the installation of wells. Wells should be constructed to yield water throughout the entire year.

Hydraulic loading

(a) Waste minimisation should be considered during the installation of taps, shower heads and toilets.

(b) Accurate estimation of waste water volume (influent) (m^3/day) is required.

(c) A PI of 10 should be used throughout the irrigation period.

(d) The **net** hydraulic loading should not exceed 30 mm (i.e. PI (10 mm) + hydraulic loading (20 mm)) for a 7 day irrigation cycle.

(e) The rate of irrigation should not exceed 2.0 mm/hour.

(f) No surface ponding or surface runoff should be apparent during the entire irrigation operation.

(g) A daily record of effluent irrigation such as area sprayed, plot number and spray volume (m^3) should be maintained.

(h) A daily record of weather conditions such as rainfall (mm), temperature and general comments on weather conditions should be maintained.

(f) A 20 m non-sprayable zone should be maintained adjacent to all waterways.

Nutrient management

(a) Land nitrogen loading should not exceed 100 kg N/ha/year.

(b) Fertiliser-N use or other N based waste water should not be applied in areas which receive 100 kg N/ha/year via the waste water irrigation.

(c) The irrigation water should be characterised for the following properties every month:
pH, conductivity, BOD_5, organic carbon, total kjeldahl nitrogen, faecal coliforms, nitrate-N, ammoniacal-N and total-P.

Pond systems management

(a) All pond systems should be inspected at commencement and every five years during pond operation by a registered waste treatment specialist for (i) loading capacity (ii) retention time (iii) treatment efficiency and (iv) desludging requirements.

(b) Permeability of the pond liner should be less than 10^{-10} m/s and this could be achieved by compaction or clay lining.

(c) Both facultative and storage ponds should be aerated as required.

(d) A suitably qualified person should be in charge of pond management, maintaining the following records:

- (i) daily influent volume for the facultative pond
- (ii) sludge management (both ponds)
- (iii) daily pH, conductivity and dissolved oxygen measurement (both ponds)
- (iv) pond level (cm)
- (v) duration of aeration (hours)
- (vi) comments on presence of algae

Ground water quality monitoring

(a) Ground water samples (wells 1, 2, 3, 4 and 5) should be monitored for nitrate-N, faecal coliforms and total kjeldahl nitrogen on a monthly basis and total-P on an annual basis. Ground water samples should be analysed separately without obtaining composite samples from all wells.

(b) Ground water levels should be monitored prior to each ground water sampling.

(c) Ground water quality monitoring could be carried out on a quarterly basis until half of the proposed sublots are in full operation.

Surface water quality and quantity monitoring

(a) Stream water quality should be measured for nitrate-N, ammoniacal-N, pH, total-P, temperature and faecal coliform on a monthly basis (all 6 sites shown in Figure 1) during the full operation of the programme.

(b) Stream water quality for the above parameters should also be measured twice a month in January and June following a rainfall event greater than 20 mm/day rainfall.

(c) Stream flow rates should be measured at all sampling sites at the time of each sampling.

(d) Normal monthly stream water quality and quantity monitoring can be performed on a quarterly basis until half of the proposed sublots are in full operation.

Soil quality monitoring

(a) Annual soil test for pH, total kjeldahl nitrogen, organic carbon, ammoniacal-N, nitrate-N and total-P at 0-10, 20-30 and 90-100 cm depths. Soil samples can be collected using simple augers and the sample holes should be filled with soil material. Soil samples may be collected from the sites shown in Figure 1.

Information required prior to the operation

(a) Soil mapping and sample profile descriptions for the irrigated area.
(b) Soil test for total kjeldahl nitrogen, nitrate-N, organic carbon and total-P at 0-10, 20-30 and 90-100 cm depths.
(c) Stream water quality and stream flow rates from all stream water sampling sites.
(d) Ground water quality and water level data for all ground water sampling sites.

REFERENCES

Board of Health. 1989. Drinking water standards for New Zealand. A report prepared for Board of Health by the Department of Health. Department of Health., Wellington. pp 1-49.

Burden, R.J. 1982. Nitrate contamination of New Zealand aquifers: a review. *New Zealand Journal of Science* **42**, 205-220.

Cochrane, P.R. and Selvarajah, N. 1993. Ground water and soil quality issues associated with the on-site disposal of domestic sewage effluent. **In** Proposed Changes to Environment Waikato's Transitional Regional Plan. 2 On-site Sewage. Environment Waikato, Hamilton.

Department of Lands and Survey. 1975. Land Inventory Survey - Coromandel-Thames Counties, Department of Lands and Survey, New Zealand. pp 1-88.

Gibbs, M.M. 1991. Nutrient concentration changes in the ground water beneath Taupo township following sewage reticulation. *New Zealand Journal of Marine and Freshwater Research* **25**, 153-161.

Gunn, I. 1989. On-site wastewater disposal from households and institutions. **In** The NZ manual of alternative wastewater treatment and disposal systems. Volume II, Part A. Auckland Regional Water Board. Technical Publication No.58.

Gunn, I. 1993. On-site wastewater disposal - A sustainable alternative. A paper presented at the NZ Water and Wastes Association Annual Conference, Hastings. pp 1-6.

Harper, H.A. 1973. The kidney and the urine. **In** Review of Physiological Chemistry. 14th edition. Lange Medical publications, Los Altos, California. pp 386-403.

Hickey, C.W. and Quinn, J.M. 1990. Evaluation of the performance of domestic sewage oxidation ponds in New Zealand. **In** Proceedings of the IPENZ Annual Conference 1990. pp 523-533.

MAFF, Welsh Office Agriculture Department. 1991. Code of good agricultural practice for the protection of water. MAFF Environment Matters, Ministry of Agriculture, Fisheries and Food, MAFF Publications, London SE99 7 TP. pp 1-80.

New Zealand Meteorological Service. 1983. Summary of Climatological Observations to 1980. NZ Meteorological Service Miscellaneous Publication. 177. ISSN 0110-6937.

New Zealand Meteorological Service. 1984. Rainfall Normals for New Zealand 1951-1980. NZ Meteorological Service Miscellaneous Publication. 185. ISSN 0110-6937.

Romero, J.C. 1970. The movement of bacteria and viruses through porous media. *Ground Water* **8**, 37-48.

Sarathchandra, S.U. 1978. Nitrification activities of some New Zealand soils and the effect of some clay types on nitrification. *New Zealand Journal of Agricultural Research* **21**, 615-621.

Scotter, D. 1993. An alternative view of solute movement in soil and the dilemma of the three hats. *New Zealand Soil News* **41**, 7-14.

Selvarajah, N., Maggs, G.R., Crush, J.R. and Ledgard,S.F. In press. Nitrate in ground water in the Waikato region. Proceedings 7th Annual Workshop (Feb, 1994). Fertilizer and Lime Research Centre, Massey University, Palmerston North.

Sinton, L.W. 1982. A groundwater quality survey of an unsewered, semi-rural area. *New Zealand Journal of Marine and Freshwater Research* **16**, 317-326.

Tillman, R.W., Scotter, D.R., Clothier, B.E. and White, R.E. 1991. Solute movement during intermittent water flow in a field soil and some implications for irrigation and fertilizer application. *Agricultural Water Management* **20**, 119-133.

Winton, E.F., Tardiff, R.G. and McCabe, L.J. 1971. Nitrate in drinking water. *Journal of American Water Works Association* **63**, 95-98.