Ecological Sustainability and On-Site Effluent Treatment Systems

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In non-sewered urban and rural residential developments, domestic wastewaters are treated and disposed of on-site. Surveys indicate that the performance of domestic systems needs to be significantly improved to overcome potential public health and nuisance problems caused by failing systems. Many current effluent disposal practices are clearly not sustainable according to the accepted definitions of ecological sustainability. It is essential that the on-site disposal of domestic effluent is considered as an integral part of the land development process. Individual soil and site assessment needs to be undertaken in the design and sizing of effluent disposal systems. An important implication from the consideration of land capability criteria for on-site effluent disposal is that individual lot sizes will need to be larger in future developments of this nature.

Introduction

Over the last decade or so there has been a fundamental shift in attitudes to the environment. The National Strategy for Ecologically Sustainable Development identified a number of key areas where the concept of "ecologically sustainable development (ESD)" could be applied. One of these areas, agriculture, seems to have adopted this sustainability concept, paying particular attention to surface and groundwater contamination by nutrients and pesticides, soil erosion, soil acidification and secondary salinisation. Many of the sustainability issues which apply to agriculture also apply to urban areas, and these issues are often ignored in planning new urban developments. The interest of urban planners on natural resources tends to be on soft focus issues such as vegetation and habitat protection. Whilst it is not appropriate to challenge the importance of these areas, it is suggested that land and water sustainability issues have been grossly underrated, particularly in the area of effluent disposal. Moreover in non-sewered areas, the concept of out of sight, out of mind, often reigns supreme.

This article describes the various methods that an urban society uses to dispose of its domestic (sewage) wastes, establishes some concepts of nutrient and water sustainability as it applies to effluents and makes some recommendations that will hopefully push urban development and effluent management towards the sustainability end of the ecological spectrum.

Methods of treating domestic effluent

There are four major generic methods of treating domestic effluent which are described below:

- Sewage treatment plants and reticulated sewerage systems
- Septic tanks plus soil absorption trenches
- Aerated wastewater treatment (AWT) systems
- Composting toilets with greywater treatment.

Sewage treatment plants

Sewage treatment plants (STPs) and the associated reticulated sewerage pipeworks are the most familiar of all the wastewater treatment systems. STPs service about 89 per cent of Australia's population, which is high by international standards reflecting the strongly urban nature of Australian demography.[1] In comparison only 75 per cent of the population in the United States is serviced by sewage treatment plants, reflecting the much more dispersed population across rural America. The remaining United States population (approximately 70 million people) largely uses septic absorption systems with a multitude of variations on this theme.[2]

The major objective of an STP is to reduce the 5-day Biochemical Oxygen Demand (BOD_5) and Suspended Solids (SS), using aerobic oxidation and sedimentation processes, to levels which make it acceptable for discharge to water bodies. In many cases, the effluent is disinfected by chlorination or ultraviolet light before discharge, but efficacy may be highly variable.

Nutrients such as nitrogen (N) and phosphorus (P) are rarely removed in the secondary treatment process and a typical composition of treated effluent is less than: 20 mg/L BOD_5, 30 mg/L SS, 25 mg/L Total Nitrogen, 10 mg/L Total Phosphorus and 200 *Escherichia coli* (E Coli) faecal coliforms per 100 mL. Because of concerns about eutrophication and associated algal blooms in river and estuary systems, the standards on allowable concentrations of nitrogen and phosphorus in STP discharges are becoming stricter, for example, $\leq$ 5 mg/L N and $<$ 0.5 mg/L P. These levels can only be reached by tertiary treatment (such as Biological Nutrient Removal followed by effluent polishing) which requires extra capital investment by local authorities and water authorities.

Alternatives such as irrigation of agricultural land and recreational grasslands using existing nutrient levels of the secondary treated effluent are clearly attractive, but there are some difficulties in an above ground disposal system. These include locating sufficient land within a reasonable distance of STPs in high population areas, storing effluent in wet weather when irrigation is not required, consideration of public health aspects of pathogen levels in effluent used for parks, gardens, playing fields and golf courses, and equitable sharing of (treated) effluent reticulation costs between the supplier (the local authority) and the consumer (for example, farmers, golf courses).

Sludge

Sludge is an inevitable by-product of sewage treatment plants and in it accumulates most of the heavy metals, pesticides, pathogen cysts and eggs, and of course nitrogen and phosphorus. Because of the many

1 R Patterson, "Effluent Disposal—The Sodium Factor" (1993) *Environmental Health Review—Australia* 42–44 (Nov 93/Jan 94).

2 *Small Flows, Winter 1996*, US-EPA, 10, 1, 4.

excellent attributes of sludge as an organic fertiliser, it is better called biosolids and an extensive reuse scheme on farms, forests, mine sites and landscaping is underway in a number of States.

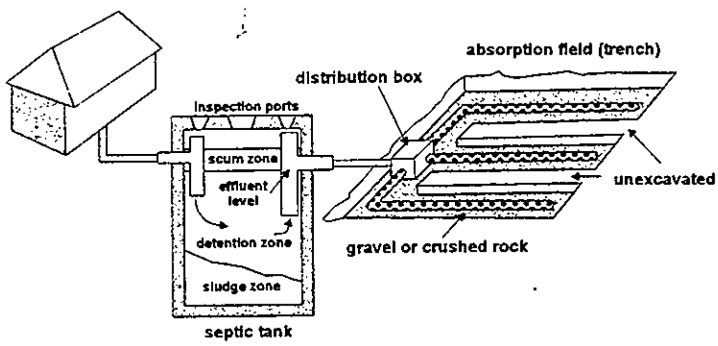
A well developed set of reuse regulations has been devised by the NSW Environment Protection Authority,[3] with the public health risk of the end use (for example, home gardens versus mine site rehabilitation) assessed on heavy metal and pesticide concentrations, pathogen levels and degree of stabilisation (that is, ability to produce malodours on rewetting).

Septic systems

Within Australia approximately 2 million people rely on septic tanks to treat domestic wastewater. In New South Wales alone, there are 250,000 on-site systems, and of these, approximately 130,000 dwellings which utilise septic systems are served by reticulated mains water supply.[4]

FIGURE 1

Conventional Septic Tank/Disposal System



The conventional domestic on-site system has two components: a septic tank, used to provide partial treatment of the raw waste, and the disposal field, where final treatment and disposal of the liquid discharged from the septic tank takes place. Both are generally installed below ground surface (Figure 1). The passive anaerobic pre-treatment of wastewaters in the septic tank results in the removal of approximately 50 per cent BOD_5, 75 per cent SS, 10 per cent Total N, 15 per cent Total P and a reduction in numbers of biological contaminants.[5] The effluent from the tank percolates through the soil where renovation occurs, prior to it reaching surface or groundwaters. The inefficient use of the renovative capacity of the soil

3 R Fraser, "The NSW Interim Biosolids Code" (1995) in *Proceedings of 16th Federal Convention of Australian Water & Wastewater Association*, Sydney, 2, pp 293–300.

4 Patterson, op cit n 1.

5 K Wiswall, L Dabagian and P Wegmann, *Innovative and Alternative Technology Guide for On-Site Wastewater Disposal Systems in Sussex County* (Sussex County, Newton, New Jersey, 1982).

can result in the transport of biological and chemical contaminants over substantial distances.

Forms of nutrients in effluent

The forms of nitrogen and phosphorus in treated effluent are particularly important because of the effect on nutrient mobility and hence potential to cause contamination in surface and groundwaters. The septic tank is an anaerobic digester which allows solids to settle to the bottom of the tank as sludge, accumulates oil and grease as a semi-aerobic scum layer, and hydrolyses the complex organic compounds into simpler compounds producing ammonium, methane and carbon dioxide in the process.

TABLE 1
Comparison of Raw Effluent Quality With Effluent from Septic Tank, Aerated Wastewater Treatment System and a Sound Mound[6, 7, 8, 9]

Parameter (mg/L)	Raw Effluent	Septic Tank Effluent	AWT Effluent	Sand Mound Effluent
BOD_5*	300–340	120–150	5–80	1–10
SS*	260–300	40–190	5–100	5–20
TN* NO3-N (% of TN)	50–60 (0%)	40–50 (0%)	25–50 (80%)	30–50 (85%)
TP* PO_4 - P (% of TP)	10–15 (45%)	10–15 (90%)	7–12 (85%)	5–10 (90%)
Faecal Coliforms org/100mL	10^5–10^7	10^5–10^7	10–10^3	10–10^3

* BOD_5—Biochemical Oxygen Demand; * SS—Suspended Solids; * NO_3—N—Nitrate Nitrogen
* TN—Total Nitrogen; * TP—Total Phosphorus; * PO_4—P—Orthophosphate Phosphorus

Table 1 shows typical concentrations and forms of BOD_5, SS, and forms of nutrients from the raw influent entering, and the semi-treated effluent exiting a domestic septic tank.[10,11] While the BOD_5 is halved, it is too high for surface disposal (sewage treatment plants produce a BOD_5 of about 20 mg/L). Suspended Solids is significantly reduced showing the effects of settling and decomposition processes. The nitrogen and phosphorus amounts and forms are particularly interesting. While there is normally a slight reduction in Total Phosphorus, orthophosphate P now dominates the phosphorus forms. The dominance of this form is due to the breakdown of complex phosphates, while the overall reductions represent losses due to sludge settlement. There is little difference in the Total Nitrogen entering and leaving the septic tank, although the breakdown of organic nitrogen in the tank results in a significant increase in the ammonium (NH_4) form.

The environmental consequences of these now dominant forms of nutrients is that ammonium can be readily nitrified to highly mobile nitrate (NO_3) in the unsaturated aerobic zone which often underlies the absorption trench organic mat (biomat), and hence can be leached to the groundwater. For orthophosphate (PO_4), the mobility reduces because the phosphorus is in a form which can be immobilised by adsorption and precipitation

6 Wiswall et al, op cit n 5.

7 W Zieball, D Nero, J Deininger and E McCoy, "Use of Bacteria in Assessing Waste Treatment and Soil Disposal Systems" (1975) in *National Home Sewage Disposal Symposium Proceedings*, American Society of Agricultural Engineers, Publication proc-175, Chicago, Il, pp 58–63.

8 P Beavers and E Gardner, "Prediction of Virus Transport Through Soils" (1993) in *Proceedings of 15th Federal Convention of Australian Water & Wastewater Association*, 2, pp 530–535.

9 R Otis, W Boyle and D Sauer, "The Performance of Household Wastewater Treatment Units Under Field Conditions" (1975) in *National Home Sewage Disposal Symposium Proceedings*, American Society of Agricultural Engineers, Publication Proc-175, Chicago, Il, pp 191–201.

10 Wiswall et al, op cit n 5.

11 Zieball et al, op cit n 7.

reactions. A number of variations to the conventional system have been developed over the years. These variations to the way in which the septic tank effluent is distributed or dosed often results in improved system performance. One important variation in Australia is the evapotranspiration system which uses both soil percolation and transpiration by trees and pasture to remove the effluent from the application site. This system is typically constructed closer to the soil surface than absorption trenches, and effluent is distributed in a bed rather than trenches. As with all effluent disposal systems, the uniform distribution of effluent is critical to the performance of the system.[12]

Aerated wastewater treatment systems

Aerated wastewater treatment (AWT) systems are small self-contained proprietary biological treatment systems which rely on mechanical devices to provide mixing, aeration and pumping of effluent. AWT systems are based on either two tanks or a single tank where effluent is subjected to accelerated aerobic breakdown (Figure 2). A final effluent is produced using various combinations of pumps, fans, airblowers, contact media for bacterial growth, and settlement and chlorination chambers. With the required management and maintenance (including periodic sludge removal), the final effluent produced should be clear and non-odorous and should meet quality criteria approved by the State Department of Health.

The number of AWT systems has increased substantially in recent years and there are approximately 20,000 units in New South Wales alone. However, they are not always suited to widely varying hydraulic loads and shock loadings which may periodically occur. Australian Standard 1547 [13] has recommended quality criteria for the final effluent from these systems which should not be higher than 20 mg/L BOD_5 and 30 mg/L SS. It should not contain more than 10 organisms per 100 mL for thermotolerant coliforms (that is, faecal coliforms) nor have a free residual chlorine concentration of less than 0.5 mg/L.

After chlorination, effluent from these systems is typically land applied using surface or sub-surface irrigation. In general, a minimum area of 200 m^2 should be used and the land area should be appropriately landscaped and used solely for the purpose of irrigation.

With the increase in the number of these systems, local government has been finding their administration and management difficult. Apart from maintenance, there are also reported difficulties with the effectiveness of the chlorination system, and the adequate sizing of the landscaped area for irrigation in relation to hydraulic and nutrient loads. Surveys of the disinfection performance of aerated systems[14] suggest that a high percentage of systems fail to meet the residual chlorine and faecal coliform requirements, while others recommend disposal areas larger than 200 m^2 to reduce the risk of nitrate leaching to groundwaters.

Sand mounds containing about 12 m^3 of well sorted sand are an alternative to AWT systems with the advantage that they are less susceptible to shock loads and require minimum maintenance by the householder.

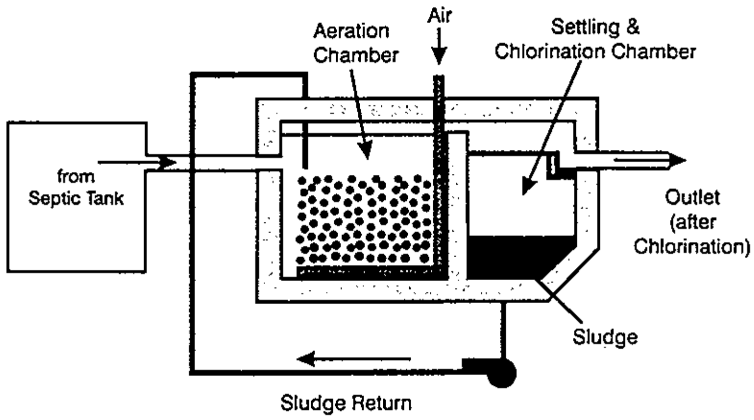
12 P Geary and E Gardner, "On-Site Disposal of Effluent" (1996) *Invited Lectures on Land Management for Urban Development*, Australian Society of Soil Science, Brisbane, pp 291–319.

13 Australian Standard—1547, "Disposal of Sullage and Septic Tank Effluent from Domestic Premises" (1994), Standards Australia, Strathfield, NSW.

14 L Rawlinson, "Review of On-Site Wastewater Systems" (1994), Report prepared for Environment Protection Authority, Southern Tablelands Region, NSW.

FIGURE 2

Schematic of an Aerated Wastewater Treatment System



Nutrients and secondary treatment

Aerated wastewater treatment systems supplied with septic tank effluent operate on the same general principle as the unsaturated zone beneath absorption trenches on sandy soils. That is, the organic material present in effluent (as measured by BOD_5 or Volatile Solids) is oxidised to CO_2 in unsaturated conditions, whilst the ammonium is nitrified to nitrate, and the remaining organic P to orthophosphate.

Data in Table 1 compare the concentration and nutrient forms of effluent from various typical treatment processes. It is evident that BOD_5, SS and Faecal Coliforms are (usually) many fold lower in the aerobically treated effluent, but that Total N and P maximum concentrations are only marginally reduced. There is much wider variation in the N and P levels in the AWT and sand mound effluent reflecting the potential for NH_3 volatilisation, NO_3 denitrification during resting times in the aerobic reactor, and PO_4 phosphorus adsorption and precipitation (and removal) in the sludge.

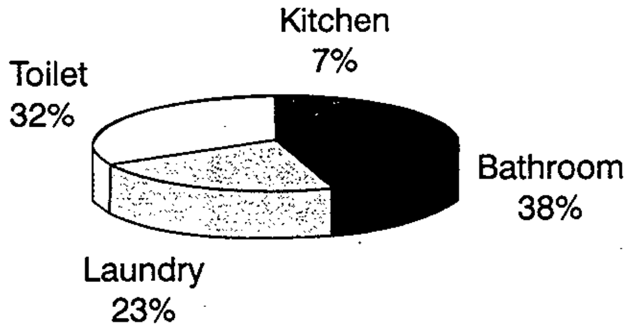
However, a distinguishing characteristic of the aerobically treated effluent is the dominance of the NO_3 form comprising between 80 and 95 per cent of Total N, compared with ammonium dominance for the septic tank effluent. In all three effluents (septic, AWT, sand mound), there is little difference in the predominance of the soluble orthophosphate (between 85 and 90 per cent of Total P). Consequently, when aerobically treated effluent is irrigated onto dedicated disposal areas, nitrate leaching can be expected if the hydraulic loading rates are considerably in excess of the irrigation demand.

Composting toilets with greywater treatment

Composting toilets are the modern day analog of the old pit toilet where no water is added to the system and aerobic decomposition (and odour control) is facilitated by electric fan assisted aeration. When the system is operating satisfactorily an earthy smelling humus, largely free of pathogens, is removed from the bottom of the system every year or so. A carbon source such as sawdust is usually added to the system a few times each week to aid the microbiologically moderated composting process, although various management practices are required with different proprietary systems. Toilet cleaning products must be chosen with care to prevent disinfection on the aerobic microbiology.

Liquid wastes from the kitchen, laundry and bathroom are usually not added to composting toilets and alternative treatment systems are needed for these domestic wastes. These could include septic tank and/or grease trap pre-treatment followed by subsurface disposal, further polishing in wetland systems or land application of this greywater. Domestic reuse of greywater is often favoured by residents in local authority areas with insufficient potable water supply capacity, but there is considerable concern by regulatory authorities about the pathogen levels in bathroom and laundry wastewater. A recent report discusses the microbiology of greywater and refers a number of possibilities for reuse in Australia.[15] Figure 3 shows the partitioning of domestic wastewater from the different sources and it is evident that black water from the toilet system is only one-third of total household production.

FIGURE 3
Typical In-House Effluent Generation



[15] B Jeppesen and D Solley, "Domestic Greywater Reuse: Overseas Practice and its Applicability of Australia" (1994) Research Report No 73 Urban Water Research Association of Australia.

Does on-site effluent disposal do environmental harm?

There is considerable evidence of pathogen and nutrient export from underperforming septic absorption trenches and AWT systems in Australia. For example, a study of 12 catchments in Sydney[16] reported that nitrogen and phosphorus exports in surface runoff from septic system catchments were between 50–90 times higher than that in catchments with different effluent disposal practices (Table 2). Bacterial contamination was also higher in the septic system catchments indicating direct contamination, presumably from surcharging septic trenches in the shallow (<1m) soils.

TABLE 2
Combined Flow Weighted Pollutant Loads (kg/ha/yr) Leaving Catchments with Different Effluent Disposal Practices

Parameter	Control†	Sewered	AWT	Septic
	kg/ha/year			
NH_3*	0.00	0.01	0.06	1.70
TKN*	0.01	0.04	0.10	1.91
TP	0.00	0.01	0.03	0.86
BOD_5	0.04	0.53	0.28	4.90

* TKN—Total Kjeldahl Nitrogen; NH_3—Ammonia
† Non-urban, partly cleared catchment

The poor performance of different systems and the potential for environmental harm have also been reported in a number of other studies.[17, 18] Monitoring by Coffs Harbour City Council of faecal coliforms in creeks showed a 10-fold increase in E.coli for a rural residential catchment compared with a rural catchment, which in turn was similar to a reticulated sewerage catchment.[19]

Another NSW North Coast study[20] of four river systems draining catchments variously served by septic tanks, rural residential and reticulated sewerage, all showed violative levels of faecal coliform, but with the highest per capita level occurring in the two septic tank catchments. A study at Benalla, Victoria, found groundwater contamination in areas where septic tank density exceeded 15 tanks/km^2 (that is, >1 tank/6.7 ha).[21] Nitrate levels were up to 17 mg/L in the upper aquifer (10 m deep) and appeared to contribute about 20 per cent of the nitrogen load in the nearby Murray River in low flow periods. Unacceptably high levels of faecal coliforms were also recorded in the nitrate contaminated aquifer. In studies of the leachate composition beneath septic absorption trenches located on sandy soils in Western Australia, nitrate levels were invariably high (about 30–50 mg/L) for a number of metres beneath, and next to the trench.[22, 23]

There appears to be little opportunity for nitrate rich leachate beneath septic absorption trenches to denitrify because of an inadequate labile carbon source to feed the denitrifying bacteria as most of the organic carbon in waste water is consumed by aerobic oxidation in the soil profile at approximately the same rate that nitrate is created. Consequently, the nitrate is leached unchanged to the groundwater where concentrations greater than 10 mg/L will exceed potable water standards.[24] Flowing

16 D Martens and R Warner, "Impacts of On-Site Domestic Wastewater Disposal in Sydney's Unsewered Areas" (Department of Geography, University of Sydney, NSW, 1995).

17 P Geary, "Diffuse Pollution from Wastewater Disposal in Small Unsewered Communities", (1992) 5(1) *Aust Journal of Soil & Water Conservation*, 28–33.

18 R O'Neill, G Roads and R Weise, "On-Site Wastewater Treatment and Disposal in NSW" (Report prepared for the Department of Water Resources & the University of Technology, Sydney, 1993).

19 Rawlinson, op cit n 14.

20 J Beard, T Sladden and G Sullivan, "Effluent Disposal and Waterway Contamination", (1994) (Aug/Oct) *Environmental Health Review—Australia*, 15–18.

21 Rural Water Corporation, "Groundwater Pollution from Septic Tank Effluent and the Potential Impact on Adjacent Watercourses", (Report prepared by Hydro Technology for the Murray Darling Basin Commission, Armadale, Victoria, 1993).

22 B Whelan and N Barrow, "The Movement of Septic Tank Effluent through Sandy Soils near Perth I. Movement of Nitrogen, II. Movement of Phosphorus", (1984) 22 *Australian Journal of Soil Research* 283–302.

23 B Whelan and Z Titammis, "Daily Chemical Variability of Domestic Septic Tank Effluent" (1982) 17 *Water, Air and Soil Pollution*, 131–139.

24 ANZECC, "Australian Water Quality Guidelines for Fresh and Marine Waters", Australia and New Zealand Environment and Conservation Council, 1992.

groundwater can dilute the nitrate concentration in the leachate, but if the aquifer flow is small relative to recharge rate, and aquifer dispersion ability is small (for example, a coarse textured aquifer) leachate from subdivisions can cause increases in downgradient nitrate concentrations. Analytical and numerical groundwater models can estimate these contaminant concentrations as a function of housing density and aquifer hydraulic characteristics.[25]

Nutrient loading rates

The nutrient loading rate from septic/absorption trenches or dedicated irrigation areas can be estimated from the N and P production per household and the allotment density. Perhaps not surprisingly, the per capita production of organic material and nutrients from various household sources has not been well studied. The best available Australian data[26] use an average production of 3.8 kg N/person/year and 0.6 kg P/person/year. For an average 3.5 person household, this is equivalent to 13.3 kg N/year and 2.1 kg P/year.

If an average allotment density of 8/hectare (1000 m^2 allotments after 20 per cent allowance for roads) is assumed, the equivalent loading rate over the whole subdivision is 106 kg N/ha/year and 17 kg P/ha/year. Whilst these values are not particularly high by agricultural standards, the specific loading rate per unit area of absorption trench (assume a 50 m x 1 m wide trench) is 2,600 kg N/ha/year and 420 kg P/ha/year.

As there is apparently little loss of nitrogen after it exits the absorption trench, and minimal plant N uptake from the trench itself, these specific N loading rates are exceptionally high by agricultural standards and are likely to lead to contamination of groundwater, and in some cases, surface water.

Similar calculations can be done for the secondary treated effluent from AWT or sand mounds, where BOD_5 and pathogen reduction make it acceptable for surface or near surface irrigation of dedicated areas. For a 200 m^2 disposal area (the minimum required by many local authorities), the specific loading rates are 650 kg N/ha/year and 105 kg P/ha/year.

TABLE 3
Nutrient Uptake from Effluent Irrigated Eucalypts, Pine Trees and Grass Pasture

	N	**P**	**Time Period (years)**
	(kg/ha)		
Eucalypts	180	20	2.5
Pines	350	35	4.0
Pastures	300	30	0.5

Nutrient uptake

For a system to be sustainable, the loading rate should be balanced by the allowable sinks—for nitrogen, allowable sinks are denitrification and plant uptake. Plant uptake of nitrogen depends on the plant yield (or biomass) and the nitrogen concentration in the various plant parts. Table 3 compares nitrogen uptake for trees (eucalypts and pines) and pasture. For trees, net uptake of nutrients reduces substantially (to about 20–30 kg

[25] D Anderson, J Rice, M Voorhees and R Kirkner, "Groundwater Modelling with Uncertainty Analysis to Assess the Contamination Potential from On Site Sewage Disposal Systems in Florida", *Proceeding of 5th National Symposium on Individual and Small Community Sewage Systems*, American Society of Agricultural Engineers, 1987, pp 264–273.

[26] Whelan and Titammis, op cit n 23.

N/ha/year) when the leaf biomass stabilises at canopy closure. This stage occurs in 2 to 4 years in effluent irrigated eucalypts and pine trees respectively.[27] Grass pasture on the other hand closes its canopy within weeks and grows vigorously provided it does not become rank. N uptake of 300 kg N/ha can be expected in the six warmer months of the year.[28]

Provided the plant material on the effluent disposal area is harvested and removed on a regular basis (years for trees, months for pasture), it will provide a sustainable and recurrent sink for nitrogen.

Nitrogen

Using mass balance principles, it is relatively straightforward to calculate the amount of excess nutrients applied in the effluent to a disposal area. After allowing for 20 per cent losses due to denitrification,[29] the net load to the soil becomes (650 x 0.8) or 520 kg N/ha/yr. If trees are growing in the disposal area, annual N uptake is about 100 kg N/ha/year (Table 3). Hence the nitrogen (potentially) available for leaching is about 420 kg N/ha/yr.

Assuming there are 8 allotments per hectare, the spatially averaged catchment scale leaching is approximately:

$$\doteq 420 \ \frac{kg}{ha.yr} \left(\frac{200 * 8\ m^2}{10{,}000\ m^2} \right)$$

Catchment scale leaching then becomes approximately 67 kg N/ha/year.

If the allotment density/hectare was halved or the disposal area size doubled, the (potential) catchment scale N leaching would be reduced to about 34 or 26 kg/ha/year respectively. It is unlikely that the above rates are environmentally sustainable if the groundwater resources of the subdivision are used for potable or agricultural purposes. On this basis there is potential for contamination of groundwater from nitrogen in effluent.

Commenting on a related problem of groundwater contamination in American subdivisions, it was argued that the major method for controlling the impact of septic systems is the density of on-site systems.[30] This argument applies equally well to nutrient loading from effluent irrigation areas.

An alternative to trees (and shrubs) is pasture, and assuming an annual uptake of 400 kg N/ha, the potential N leaching loss is reduced to 120 kg N/ha/year on the disposal area. At subdivision scale, the values are 10–20 kg N/ha/year depending on allotment density.

Clearly, regularly harvested and removed grass in the disposal area will have considerably less environmental impact than trees, shrubs or landscaped gardens which are either not harvested, or done so on an irregular basis (for example, branch pruning).

Practical application of this advice would require a change in some local government rules which currently require dedicated landscaped areas for effluent irrigation because of concern about the health hazards. These concerns are well founded, and before grass irrigation could be generally recommended, disinfection efficacy of aerobically treated effluent must become more reliable, or alternatively, subsurface irrigation considered.

27 B Myers, W Bond, W O'Brien, P Polglase, C Smith and S Theiveyanathan, "Wagga Effluent Plantation Project" (Technical Report, CSIRO Division of Forestry, User Series No 17, Canberra, 1994).

28 E Gardner, "Concepts and Practices for the Reuse of Effluent Using Irrigation" in Wastewater 1995—IIR Conference, Sydney, 1995.

29 G Monnett, R Reneau and C Hagedorn, "Effects of Domestic Wastewater Spray Irrigation on Denitrification Rates" (1995) 24 *Journal of Environmental Quality* 940–946.

30 M Yates, "Septic Tank Density and Groundwater Contaminations' (1985) 23 *Goundwater*, 586–591.

Phosphorus

As a rule of thumb phosphorus uptake by plants is 8 to 10 times less than nitrogen uptake (Table 3). However, Australian soils are notorious for their ability to immobilise P. This capacity varies widely from low levels in many sandy soils to high levels in strongly weathered clay soils (for example, red earths) or calcic soils (for example, black earths).

Hence the P storage capacity of the soil, and the design soil depth are the major determinants for assessing the sustainable life for phosphorus.[31] For a sandy soil, the P front moves downwards at a rate of about 20 years/m of soil depth for an effluent P concentration of about 10 mg P/L of effluent.

The environmental consequences of these leaching rates (when reduced from disposal area to subdivision scale levels) are site specific, depending on the depth to the water table, the beneficial use of the aquifer, and the separation distance (from the disposal area) to a surface stream. For example, a study of septic tank leachate on a calcareous soil from Western Australia reported soil solution concentrations of 15 mg P/L at 8m depth,[32] with similar levels occurring in the underlying aquifer. The ANZECC (1992) standard for phosphorus concentration in potable water is 0.1 mg/L.[33]

In a study on lateritic derived sandy and duplex soils in Western Australia, it was found that the high P adsorption capacities would limit P travel times to multiple decades for distances of 5 to 30m.[34] Moreover, the orthophosphate levels in the surface streams of the subdivision were very low (<0.005 mg/L) suggesting no adverse effects of septic effluent.

In summary, where shallow aquifers adjoin environmentally sensitive freshwater bodies, considerable care should be paid to the phosphorus budget. However, the many adsorption sites for phosphorus in soils and aquifers suggest that adverse groundwater consequences of P leaching are likely to be the exception rather than the rule.

Water balance and salinity

Any change in land use which alters the amount of water moving in the landscape has the potential to lead to secondary salinisation. If significant areas of trees are removed in the process of subdivision, especially in sensitive catchments, salinity hazard should be assessed.

There are three potential sources of excess water from a completed subdivision which must be disposed of in some manner. The most obvious is the effluent generated from domestic residences. Another source of excess water is the additional hard surface runoff generated from roofs, roads and paving. This hard surface runoff is generally diverted as run-on onto grassed areas, and in effect is the same as irrigation. The third source of water is the extra water added to a system from the irrigation of gardens and lawns. The supply of mains pressure reticulated water to subdivisions encourages the establishment of irrigated gardens and lawns. Due to inefficiencies in every irrigation system, there will be an increase in deep drainage from landscaped blocks in comparison to "native" gardens where watering is minimal.

Secondary salinisation occurs over 1.2 million hectares of farming and grazing land in (southern) Australia. In some urban areas, capillary rise of

31 Geary and Gardner, op cit n 12.

32 B Whelan, "Disposal of Septic Tank Effluent in Calcareous Sands", (1988) 17 *Journal of Environmental Quality* 272–277.

33 ANZECC, op cit n 24.

34 R Gerritse, J Adeney, G Dimmock and Y Oliver, "Retention of Nitrate and Phosphate in Soils of the Darling Plateau in Western Australia: Implications for Septic Tank Systems" (1995) 33 *Australian Journal of Soil Research* 353–367.

water and salt are causing significant structural damage to roads and buildings. In salinity sensitive catchments, the objective of on-site effluent disposal and storm water management on new subdivisions should be to minimise increases in deep drainage.

Implications of on-site disposal on allotment size

Septic absorption trenches and AWT systems are the most common methods of effluent disposal in unsewered areas. The evidence to support the environmental sustainability of septic absorption trenches is meagre. Catchment scale studies have almost invariably shown much higher nutrient and E coli levels in surface streams compared with those draining catchments using other forms of effluent disposal. If these excessive impacts are due to trench surcharge from inadequate design and maintenance, then improvements in site assessment and trench design are likely to make a substantial improvement in stream water quality. Alternatively, septic density must decrease to allow sufficient dilution of effluent leakage by natural runoff and/or groundwater flow.

A study[35] estimated phosphorus export from septic trenches during surcharge events (climate plus trench failure driven), scaling the phosphorus mass upwards by septic tank density, and the phosphorus concentration downwards by dilution from catchment runoff, to arrive at a designated stream water quality. Using this approach on a sandy clay at Landsborough (Queensland) and slowly permeable clay at Wauchope (NSW) returned minimum acceptable allotment sizes of 4,500 m^2 and 17,000 m^2 respectively.

At the other end of the spectrum, groundwater contamination in aquifers underlying permeable soils has frequently occurred if septic tank density exceeded 15/km^2 (1 per 7 ha). However, other investigations suggest an acceptable density of 25 septic tanks/km^2 (1 per 4 ha) for potable groundwater protection, increasing to 100 tanks/km^2 (1 per 1 ha) where land use values exceed the need for protection of groundwater quality.[36] Whether groundwater contamination is acceptable depends on the beneficial use of the aquifer. In catchments where groundwater contamination is not an issue, an environmentally sustainable size for allotments using septic tanks is probably in the range 4000 m^2 to 10,000 m^2 (that is, 1 ha).

Alternative on-site systems include transpiration beds and AWT systems. However, local authority surveys almost invariably show an effluent quality failure rate of about 50 per cent or higher of the AWT systems examined. A recent survey in Campbelltown in New South Wales indicated that final effluents from the majority of systems tested did not meet standards set down for almost all the parameters.[37] Whilst many of the BOD_5 and pathogen problems are probably resolvable using an enforceable maintenance program, the problem of excessive water and nitrogen application to too small a disposal area (for example 200 m^2) remains.

On nutrient and hydraulic loading criteria, an irrigation area of at least 500 m^2 is required. Combining this with hard surface areas of about 500 m^2 (that is, roofs, driveways etc) and statutory set-back distances gives a minimum allotment size of about 2,500 m^2. If the soil is likely to generate substantial runoff from the effluent irrigation area (for example, cracking clay or impermeable texture contrast), then an additional

35 P Jelliffe, "Procedure for Determining Pollution from Unsewered Development" in *Domestic On Site Wastewater Treatment and Disposal Seminar*, Bundaberg, Queensland Department of Primary Industries & Institution of Engineers Australia, 1995.

36 Rawlinson, op cit n 14.

37 M Khalife and H Dharmappa, "Aerated Septic Tank Systems: Field Survey of Performance" (1996) 23(5) *Water* 25–32.

20–30 m of downslope buffer distance is required to dilute transported effluent.[38] This is equivalent to about an additional 1,500 m^2 giving a total minimum allotment area of 4,000 m^2.

Taken overall, an acceptable allotment size for AWT systems is likely to be in the 3,000–5,000 m^2 range, considerably smaller than the sustainable size for allotments using septic tanks (4,000–10,000 m^2).

Conclusions

The issues of nutrient and water management to ensure ecologically sustainable development are just as important in urban areas as they are in agricultural areas. But to date, these issues have largely been ignored by urban planners. Concepts of sustainable nutrient and hydraulic loading should be applied to on-site effluent disposal areas if the quality of our surface and groundwaters are to be preserved or improved. Invariably this means a lower density of septic trenches and an increase in the area for effluent irrigation areas if the assimilative capacity of the environment is not to be exceeded. This principle translates into larger and fewer allotments per hectare, if existing treatment methods continue to be used.

Local authorities should require urban developers to establish the nutrient, water and health sustainability of their proposed developments using rigorous scientific principles. This will probably involve matching allotment density to the biophysical resources of the area, modified by the choice of on-site effluent treatment technology.

Reticulated sewerage largely removes the onus for environmental sustainability from the developer and places it back on the local authority. Whilst new STP technology can certainly produce a clean, green treated effluent at a price, the challenge is to reuse effluent for beneficial purposes whilst maintaining public health standards, environmental sustainability and incurring minimum cost. Land dumping under the guise of effluent irrigation must not replace the current practice of dumping effluent to water bodies.

Many of the principles of sustainability are well understood. The challenges are to implement these principles at economic prices given increasing urban development pressures and to ensure that on-site effluent treatment systems do not contribute to environmental degradation.

38 Martens and Warner, op cit n 16.