Technical Note: T20-3

SIZING AN EFFLUENT TRENCH: CALCULATION OF AREA REQUIRED FOR HYDRAULIC AND NUTRIENT ASSIMILATION AREA AROUND AN EFFLUENT TRENCH

Dr Robert Patterson

FIEAust, CPSS(3), CPAg

15th December 2020

Sizing an Effluent Trench: Calculation of area required for hydraulic and nutrient assimilation around an effluent trench

1. Introduction

When on-site wastewater systems are planned and constructed, the effluent must be returned to the environment in a sustainable way for the two major components, water and nutrients. The calculation of the hydraulic load is modelled using monthly rainfall, evapotranspiration, deep drainage and soil water storage for the locality and specific soil profile. The nutrients are assimilated by plants, soil biota and immobilisation mechanisms in the soil. An understanding of each of these components will assist in better planning for longevity of the soil system.

This document reviews the science of soil properties in sizing an effluent trench and identifies limitations apparent in the Australian/New Zealand Standard AS/NZS 1547:2012 *On-Site Domestic Wastewater Management* herein referred to as the Standard. The NSW *Environment and Health Protection Guidelines: On-site sewage management for single household* (DLG et al., 1998), referred to as the Guidelines, provide some valuable insights into on-site disposal for septic systems but with some bizarre set-backs, water balance modelling and nutrient assimilation constraints that do not model the real world.

2. Water in the Soil Environment

We must differentiate between the terms *infiltration* and *permeability*. **Infiltration** is simply the movement of water from the surface into the soil. Throw a bucket of water over the soil and watch how quickly, or slowly, the free water disappears: that is a measure of infiltration rate. We know, of course, that depending upon the prior 'wetness' of the soil, the infiltration may be rapid, slow or the water ponds on the surface. We can measure that infiltration capacity knowing the loading rate (litres per square metre) and time, usually reported in mm/h, as one litre over one square metre (L/m^2) is one millimetre (mm) depth of water. By sampling the soil we can measure its starting moisture content, the moisture content immediately after infiltration and then some future time.

Once the water enter the soil, the term *permeability* is used to measure and report the movement of water **through** the soil, that is, the rate of movement of water through the soil in response to flow through large channels in response to gravity and in very small pores in response to capillary actions, as shown in Figure 1. Water only moves through the soil in the spaces between the solid particles and the types of spaces are dependent upon soil texture, soil structure, bulk density (compaction) and whether the soil profile is uniform or otherwise a mix of horizons with differing permeable properties, as set out in Figure 2. The terms *infiltration* and *permeability* do not have the same meaning as each conveys a specific meaning to the movement of water into or in the soil. The words are not interchangeable, although in some references it is confusing as to which term is correct.

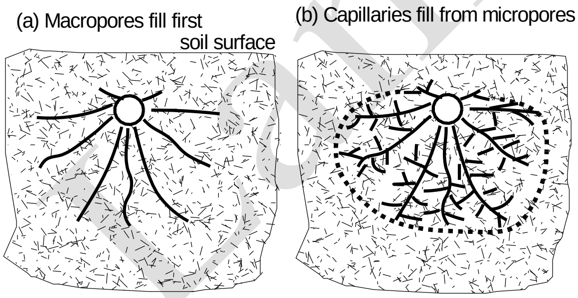


Figure 1 Movement of water in soil

Sand, for example, has large pore spaces in which capillary flow is difficult to achieve and maintain, so water flows mainly in the macropores by gravity, as in Figure 1(a). In clay, where there are mostly very small spaces between the solid particles, the surface tension of the water acts very strongly and so water can move large distances in very small pores by capillary action, as in Figure 1(b). Clays hold water more strongly than sands so that upon rewetting, the capillary actions in the clay are revived quickly.

Two terms that become important in the movement of water in the soil are *adhesion* and *cohesion*. **Adhesion** occurs when water sticks to something else such as soil particles, plant roots or container wall. **Cohesion** occurs when water molecules stick only to themselves. We can easily demonstrate both properties at the same time.

Simply, take a bath towel and throw one end into the water in the bath tub and the other end on the floor outside the bath (near the floor waste preferably). The towel in the water gets wet: adhesive forces in play. Then the towel gets wet above the surface of the water as the capillaries in the towel slowly fill by forces of adhesion (water molecules sticking to cloth particles) and cohesion (water molecules attracted to other water molecules) and a wetting front will quickly become obvious, creeping up the towel against the forces of gravity. The towel will continue to pull water up over the side of the bath and by gravity and adhesive and capillary forces combined deliver the water to the floor. When left over a long period the towel will completely empty the bath until the capillary force is broken. The towel may still be wet, but the small capillaries become broken and the flow ceases. The same processes happen in the soil, and we can benefit from those actions.

When the capillaries in the soil are dry, the actions involved in evapotranspiration cease as there is no passage of water through the dry soil, or through the soil to plant root hairs. Water cannot jump across the dry spaces, nor can new roots grow through a dry soil. Water in soil moves as a wetting front, filling capillaries as it moves by gravity, but capillary forces require those capillary passages to be full. A wick in a kerosene lamp works the same way, drawing kerosene in response to a loss at the flame.

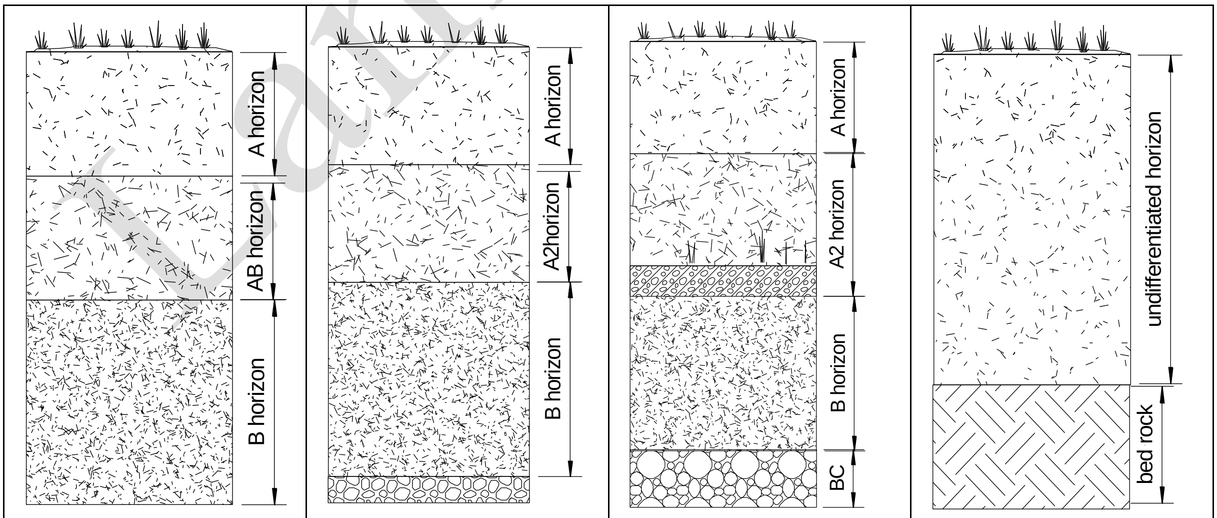
Two terms are in common use: *saturated hydraulic conductivity* (K_{sat}) and *unsaturated hydraulic conductivity* (K_{unsat}). When using the term *hydraulic conductivity* we must differentiate between saturated and unsaturated conditions. Water flows faster in saturated flow conditions because of the continuum, forces of cohesion and adhesion working to pull the water along the capillaries. A system designed using saturated hydraulic conductivity will have the highest conductivity rate possible, except under flooded conditions. The problem with flooded conditions in the soil is that air is displaced to the disadvantage of soil aerobic micro-organisms; the ones that transform or consume the nutrients and other bacteria, becoming anoxic or anaerobic.

The aim of delivering effluent to the soil environment is to maximise the slow movement of water to allow capillary flow to root hairs (hence uptake by plants) and the general soil microbial population in an aerobic environment. Water (effluent) in the soil is dispersed widely into the atmosphere (by evapotranspiration), more widely into the soil surrounding the trench, and to deep drainage under the forces of gravity.

3. Capillary Forces in a Soil Profile

A soil profile is typically an arrangement of soil horizons (layers) from the surface to an arbitrary depth, usually about 1.0 m in the case of effluent disposal sites. Only in certain landscapes is the soil the same, in colour, texture, structure, bulk density and permeability from the surface to that depth. Generally, a soil profile is made up of several horizons, layers of soil that have different physical, chemical and biological attributes; some obvious, others more subtle. For our discussion here, the important soil attributes for effluent disposal are the physical properties related to texture (as in proportions of sand, loam, clay), soil structure (as massive or well-structured with favourable aggregate sizes and shapes), properties of the various soil horizons, internal drainage mechanisms (or impediments) and slope of landscape (gravity in play). Plant root systems provide the biological mechanisms for returning water to the atmosphere through transpiration and for utilising nutrients provided by the effluent.

Depending upon the diameter and continuum of the soil capillaries, water may be 'pulled' to the surface, from where evaporation can occur, in the same manner that water flows from the roots to the leaves by capillary flow to be lost to the atmosphere as transpiration. The two processes together are called evapotranspiration.



2a. Gradual change in horizons, poor differentiation	2b. Three different horizons, strong differentiation	2c. Strong differentiation with concretions at base of A2 horizon	2d. Poor differentiation, uniform throughout soil profile

Figure 2 Various natural configurations of horizons within soil profile

In each of the examples in Figure 2, the behaviour of percolating effluent and capillary movement will be different, even when the loading rates are the same because of the differing permeability as the water passes through one horizon to the next, more likely a slower rate with increasing clay content.

The shape of the plume of percolating effluent (Figure 3) will be different for different soil profiles because of: (a) the changes in soil permeability down the profile; (b) ease of movement sideways in both the large soil pores and the capillaries; and (c) capillary forces drawing effluent to the surface.

In our soil sampling procedures, we endeavour to understand the soil profile and the attributes that either enhance movement of water through the soil, or those conditions that change the permeability in the various horizons. While we may see the various horizons when using a soil auger and setting out the soil in order of extracted material, a soil pit is the ideal exposure to see the horizons *in situ*, their relationship to one another and their lateral orientation. Much more can be said about horizons and movement of water, a topic of its own.

In Figures 3 (a) & (b), the uniform percolation of the effluent in response to gravity is disrupted by the different hydraulic properties of the soil horizons. Water moves easier as gravity flow through sands, than it does through loam and more slowly through clay. As percolating water reaches a less permeable zone, water will pond on the surface of the B horizon and spread laterally. Ponding will continue while loading rate exceeds percolation rate. The term used for identifying the horizon has specific meaning in soil profile description, but will not be discussed here. The reader needs to refer to appropriate soil references.

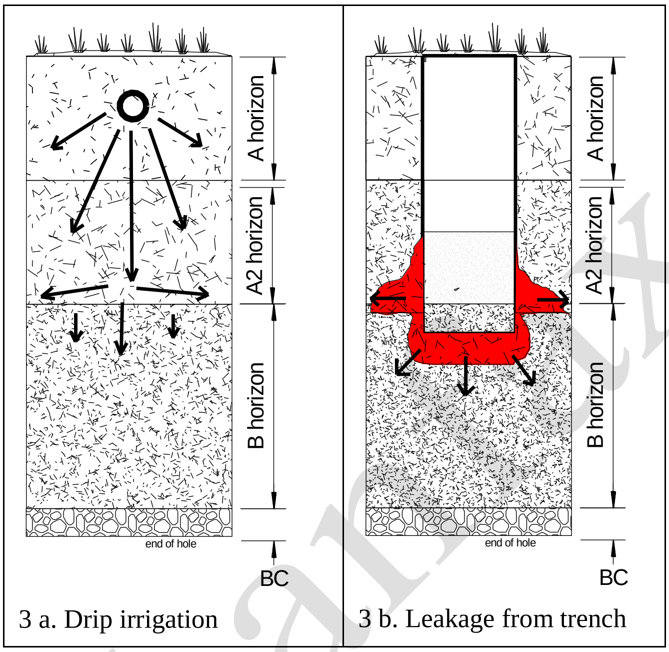


Figure 3 Restriction in the movement of water from a trench

In Figure 3 (a) the water passes quickly through the loam A horizon into the A2 horizon from where it may also flow quickly until the water ponds on the interface with the B horizon, because permeability of the clay is slower than for the soil above. Water may flow sideways (laterally) as the line of least resistance with only some of the water percolating into the B horizon, as shown by the arrows.

In Figure 3 (b) the water passes through the bottom of the trench at a rate determined by the *clogging layer* and the soil's permeability at that interface, in response to gravity and capillary forces. Water moves laterally into the sidewalls by both gravity flow and capillary actions. The higher the ponding of water in the trench, the higher the plume extends beyond the sidewalls. Where there is a distinct difference between the percolation rate in the horizons surrounding the trench, so too will the gravity and capillary actions be affected.

The soil profile will dictate the depth to which the trench is best suited to discharge the water by both gravity flow and capillary actions into the surrounding landscape as well as connecting capillaries to the surface and plant roots. For that reason, there is no universal ideal depth of an effluent trench if the horizons suggest a more rational approach. However, it is generally accepted that shallow trenches (<450 mm) favour gravity flow (downwards and sideways) and capillary flow to shallow root systems as a pathway to evapotranspiration.

4. Water Movement in Trenches

4.1 Basic water movement

Effluent from a wastewater treatment system may flow by gravity or be pumped into a drainfield (trench) to dispose of that effluent back to the environment through actions of evapotranspiration and drainage (gravity flow). Treatment for nutrient assimilation and bacterial die-off also occurs, but is discussed elsewhere.

Evaporation from the surface of the soil moves water into the atmosphere, replenished by capillary processes; in this case towards the surface. The rate of evaporation depends upon the difference in the humidity in the soil compared to the humidity in the air; as measured by relative humidity. The same process occurs when we *perspire*, water moves from our skin to the atmosphere, working as a cooling mechanism. If the relative humidity is high, perspiration ponds on our skin as sweat. When the relative humidity is low, we do not really notice that we perspire.

The *transpiration* component is the water lost by plants transpiring through their leaves, actively drawing water from around their roots by capillary and osmotic actions and moving the water to the stomata on the leaves. Depending upon the humidity difference, water is lost from the leaves to the atmosphere. Moisture moves from the higher humidity environment in the soil to the lower humidity in the atmosphere.

The combination of these two pathways is termed *evapotranspiration*.

Figure 4 Transpiration of leaves in response to solar energy

To show that plants draw water from the soil, simply tie a plastic bag around some leaves and watch the solar energy drive the response by the plants, as shown in Figure 4. Slowly water moisture will be seen to condense, in the plastic bag, on the cooler plastic surface.

That water came from around the plant's root system, so the grasses over and around a trench are part of the hydrologic cycle, returning water to the atmosphere. At the same time, the moving water is translocating soluble nutrients from the soil to the plant.

Water moves from the trench in all directions. Water moves downwards in the *macropores* (large spaces between soil particles) under the force of gravity, aided by movement of a wetting front with capillary forces in play in the *micropores* (very small spaces between soil particles).Water moves through the soil adjacent to the sides of the trenches (sidewalls) both by gravity flow and capillary action. Water flows from the 'wet' soil to the 'dry' soil by these two forces and that movement ceases once the availability of the water is restricted. Water cannot 'jump' across dry soil; it moves as a continuum only. A dry soil horizon may also be a restrictive barrier as it must first become wet to restore the capillary flow, as explained below.

The processes of evaporation and transpiration at the surface cause a 'drawing' effect upon the capillary water that continues until this action is halted, either by reduced evaporation from the surface, disconnection of capillary flow from below (empty capillaries), breakage of capillaries by loss of soil compaction or death of the plants. This action is similar to the bath towel example above. Some water evaporates from the soil provided there is a link with a continuum of soil moisture and an evaporation deficit. Farmers 'fallow' the ground to reduce vegetative cover (reduce transpiration) and break-up the soil to disrupt the capillaries of a compact soil; hence maintaining soil moisture for the following crop.

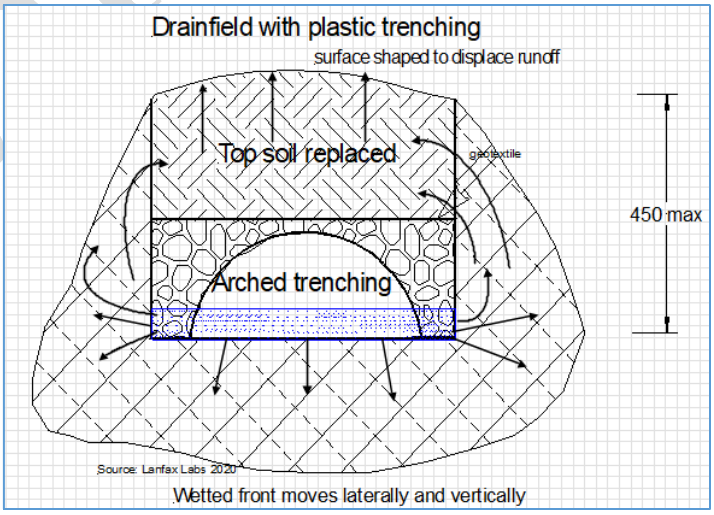


Figure 5 Wetted perimeter around a trench

Similar to Figure 3 (b), Figure 5 shows a small depth of effluent ponded in the trench because the loading from the septic tank is greater than the hydraulic conductivity of the soil to dispose of rapidly; so water ponds for a time. That ponded water is now moved by gravity flow in a downward direction (deep drainage) and by capillary flow sideways and upwards through the connection with the sidewall. The air-gap in the tunnel and the large pores in the gravel surrounding the tunnel take NO part in the water transfer process; there is no continuity of flow through air. The impact from the humidity in that confined space is negligible. The soil above the trench can only become ‘wet’ from the capillary flow through the sidewalls and in the undisturbed soil outside the trench. By capillary flow, water will ‘wick’ into the soil from the sidewalls of the trench, spreading the water across an area wider than the trench. The only time water will wick up through the soil above the tunnel is when the tunnel is full of water, an event that may occur infrequently if the water balance is conservative.

It is not accurate to consider only the base of the trench as the pathway for movement of water out of the trench as the Standard suggests. Enlarging the basal area, without considering the potential of the sidewalls to move the water simply creates an unnecessary larger trench with higher costs, as set out in Section 4.4.

4.2 Safety factor in design loading

It is absurd for the Standard to have adjusted the capacity of a trench to limit the movement of water only through the base of the trench (Section L4.1, page 143) without any justification of the significance of soil type, soil horizons, soil texture for the relevant horizons, soil structure, soil structural stability or potential ponding depths. Based upon the previous section, how does water move from the trench to the soil above the trench if it does not move through the sidewalls? The only continuum with the surface is the sidewall. The Standard notes that the values used for *design loading rates* (DLR) already account for the sidewalls, but offers no justification or scientific reference as to how this recalculation has been reconciled with real soil activity. The definition of *design loading rate*” (Standard, page 13) states that *the DLR is equivalent to the long term acceptance rate (LTAR) reduced by a factor of safety*.

The *factor of safety* is defined (Standard, page 14) as ‘*the proportionate increase in designed capacity or performance of a system aimed at reducing the risk of adverse impacts on public health or the environment* without saying how that factor is derived or how its implementation ‘reduces risk’; a vague statement indeed! To complicate interpretation further, under clause C5.5.5.4 (Standard, page 56) ‘*Evapotranspiration can thus provide an additional factor of safety for the operation of soil absorption systems, helping the soil to dry out and promoting aeration and biological treatment of the effluent.’* Unless something is missing from this interpretation, the water balance relies heavily on the evapotranspiration component, as set out in the Standard (Appendix Q Informative, page 181) so this additional factor is already installed. Without the continuum of the sidewalls, there is no pathway to the evaporative surface.

Surely, when the water balance is designed for an appropriate return interval on rainfall, for accurate interpretation of the soil properties likely to enhance or reduce percolation and drainage, for average evaporation for monthly modelling, and full occupancy for the dwelling based upon number of bedrooms, surely an undisclosed ‘safety factor’ imposes unnecessary enlargement of the soil based system. Systems cannot be constrained by the ‘never fail’ imposition otherwise the design would be based on the wettest year we have ever had and a full occupancy all the time. An absurd assumption; we don’t even design billion dollar highways on such contingencies!

The finite life of a soil based system is based upon maintaining an alternating anaerobic/aerobic environment in the trench system (trench plus sideways and bottom area), receiving effluent after adequate primary treatment, minimising the carry-over of solids from the tank to the trench, limiting the use of chemicals that may reduce the hydraulic capacity of the soil, or chemicals that may be detrimental to the in-trench biota. Many soil based systems have been in operation for more than half a century. Notwithstanding the need to regularly monitor performance and provide appropriate servicing, an imposed ‘safety factor’ is purely based on guesswork, or the need to apply the *worst case scenario* to all systems.

4.3 Sidewall or no sidewall allowance

Figure 5 suggests that the sidewalls contribute significant draw on the water in the trench and distribute the water in all directions by capillary and gravity flow. If you are not convinced, dig a small hole and pour some water into the hole. Now inspect the sidewalls of the hole when all the water has disappeared (infiltrated). The soil is likely to be wet a few millimetres into the soil body in the side of the hole. Try it yourself!

That only the bottom area is acceptable for the DLR value for designing the dimensions of the trench (L4.1) is contradictory to the Standard’s Equation 3 (Appendix Q3, page 181) where *the effective area of infiltration* (A) is calculated from the *wetted bottom and sidewalls*. It is not possible that water in a trench passes only through the base and not the sidewalls. Even if the trench is only loaded to a depth of 5 mm, then 5 mm of effluent is in contact with the sidewalls and subjected to the capillary and gravitation forces exerted. It may be that the biomat reduces permeability at the sidewalls, but does not prevent percolation. The Standard (CL4.1, page 143) states that the biomat plays a part in the water movement; the biomat does not exclude water movement.

The biomat is a film of anaerobic (living in the absence of oxygen) and facultative (surviving in low and fluctuating oxygen environment) bacterial oozes and slimes, varying in thickness depending upon the length of time that the soil/trench interface remains in contact with the effluent and the quality of the effluent. While the biomat has been shown to reduce the percolation of effluent in sandy soils to more moderate levels of permeability, the biomat may also influence the permeability in finer textured (clayey) soils. However, one function of this biomat clogging layer is that it provides a bacterial population that 'consumes' some organic solids and nutrients in the effluent and acts as a filter protecting the sidewalls and base of the trench. The clogging layer is only active when it is submersed in effluent, otherwise it dries out and shrinks (exfoliates) to expose the soil face of the trench.

It is important to note that the trench is merely a conduit to link the effluent with a soil interface, to provide storage of effluent excess to the infiltration capacity at the trench interface (sidewalls and bottom area), and provide rudimentary treatment and filtration in the biologically active gelatinous mass (slime) of the biofilm. It is wrong to size the absorption trench on the volume of the trench, or only on the bottom area.

The Standard (CL4.1, page 143) states "*It is recognised that in permeable and freely draining soils, absorption through the bottom area and sidewall biomat (clogging) zone in trenches and beds is the significant absorption mechanism under **adequate** design loading rates. During extreme hydraulic loadings to trenches in permeable soils, the sidewall area above the biomat zone is the significant absorption pathway.* So what is **adequate** and where is this magical zone that starts **above** the biomat zone? Where does the biomat zone stop? The level of ponded effluent in a trench is highly variable, based upon intermittent loading and the losses as combined drainage and capillary flows. That the biomat never degrades to become more permeable defies logic as the biomat cannot persist where the effluent does not pond for significant periods.

The same clause (CL4.1) states *"The DLR values in Table L1 are to be used to size the land application system on the bottom area only, the effect of the sidewalls being already included.* How the *sidewalls being already included* and have been calculated into the DLR is anyone's guess! It would be relevant that such calculations or assumptions were presented in the Standard.

Without knowledge as to how one converts from LTAR to DLR given all the combinations and permutations of soil texture, soil structure, wetting front, highly variable depth of water in the trench, effects of effluent chemistry on the soil, CL4.1 appears to be a 'smoke and mirrors' interpretation.

Let's look at the rationale of using only the bottom area as the mechanism by which water moves back to the environment; seepage and evapotranspiration. Figure 6 indicates an impervious sidewall interface with the soil landscape, the effect of negating the sidewalls as the Standard asserts. Water ponds on the bottom of the trench but does not seep into the sidewalls, a practical impossibility but not according to the Standard when calculating trench loading rate.

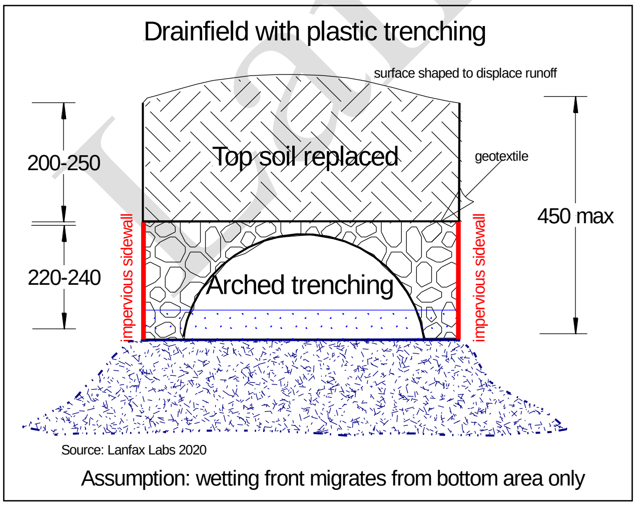


Figure 6 Theoretical impediment to water migration

The open space within the tunnel trench and the large pores between the gravel backfill prevent movement of water to the soil above the tunnel until the tunnel is completely filled with effluent. The result is that the soil above the tunnel has no access to the water in the trench.

So, for the design calculations to satisfy the Standard, water only moves through the bottom, as in Figure 6.

It seems there is some logic missing from this assertion. Short of placing an impervious barrier on the sidewalls, water must move through the sidewalls in response to gravity and capillary forces.

Further, outside the excavation of the trench the sidewalls are integral to the bottom area, there is no distinction, that interface has not be disturbed during the excavation. Figures 3 (b) and 5 show that connectedness quite clearly. The Standard (Section Q3, page 181) refers to *the effective area of infiltration* as the *wetted bottom area and sidewalls* being used in the water balance. So why the confusion between this statement and that in the Standard (Section L4.1, page 143) where *the selected DLR value, is applied to sizing of the bottom area only of trenches and beds*"? Some justification needs to be given, preferably by explanation as to how '*design loading rate (DLR)' and 'long term absorption rate (LTAR)*' vary independent of soil variability, climate and other impacts on effluent assimilation. Section A3 (page 71) advised that *providing for an increased sidewall area enables relief of the bottom area loading on which DLR is based, thus avoiding breakout*". Confusion reigns!

Take the example that a full load (150 L) from a top loading automatic washing machine is dumped to the septic tank. An equivalent volume passes out of the septic tank to the trenches. Assume the first trench is 25 m long and 0.6 m wide, a bottom area of 15 m^2. The dump from the washing machine will, therefore, cause a 10 mm rise in the water in the trench. Thus, not only is the bottom area exposed to the water, but also the sidewalls. It is logical that the water will also percolate through the sidewalls. An hour later another washing machine load arrives in the trench, raising the ponded height to 20 mm, less say 1 mm percolation over the hour (24 mm/day).

However, be aware that the appendices (pages 71 to 208) are only ***informative***, except that regulators may interpret them differently. A search for 'design loading' in the ***normative sections*** of the Standard does not shed any light on the source of the 'safety factor', its origins or its application based upon any one or more of the soil properties; nothing more than an unqualified guess.

What is known about the science of movement of water in a trench, is that both the bottom area and all the four sidewalls, to the wetted depth, contribute to the movement of water out of the trench, into the surrounding soil. A biofilm may develop on the sidewalls where the water ponds for long period, but sloths off as the water levels fall. It is planned that the depth of the trench allows for storage of water to account for large volumes in excess of the percolation rate and that over time the trench will return to very low levels of storage. In many instances, water is stored in the trench over the low evapotranspiration months of winter, with potential storage up to the depth of the tunnel trenching. Table 1 provides storage capacities for several size tunnel trenches.

The Standard (Section A2, page 71) further complicates the interpretation of the use of the sidewall by the statement *Providing for an increased sidewall area enables relief of the bottom area loading on which DLR is based, thus avoiding breakout.* Thus, it is clear that not only is the DLR extremely conservative as indicated above, but that an additional sidewall component needs to be considered as a 'belt and braces' approach, a stated 'risk reduction measure' further increasing the size, and cost, of the trench system for no actual benefit. When a rational model is employed, using higher probability monthly rainfall to design the length of trench required, based upon sidewalls and bottom area, one does not need to distinguish between a LTAR and a DLR to account for 'vagaries' in the modelling. Is it that the without an adequate water balance model, as is the case in the Standard, one has to rely upon 'safety factors' being plucked from the air?

The Standard (Section 6.2.4.1, page 60) states that installation instructions shall cover *b) the preparation of the bottom and sides of any excavation*. If the sidewalls play little or no part in the return of the effluent to the soil landscape, then there is no need to 'prepare' the sidewalls, whatever is inferred by 'preparation'. Under normal construction processes any smeared surface on the bottom area and the sidewalls would be raked to remove the smeared soil.

The Standard (Table K2, page 138), the installation practice suggested by the Standard is to *avoid smearing sides and bottoms of trenches and beds* for *soils with low permeability (Category 5 and 6 soils)*". Avoiding is not rectifying, so what does the Standard mean? In effect, the sidewalls are considered an important passage way for water into the surrounding soil otherwise there would be no 'preparation' required. It is obvious the sidewalls play a significant role is the passage of water into the soil as the depth of water varies in response to loading and drainage.

4.4 Variables in sidewall and bottom areas calculations

So, what are the variables in the bottom area and the sidewalls that have not been considered as a pathway for effluent to diffuse into the surrounding soil?

Let us assume that a trench of 600 mm wide is appropriate, since the width is suited to digging using a 600 mm bucket on the excavator. How do the sidewalls and bottom areas combine to provide an absorption area? Figure 7 shows four different configurations of the cross-section of a trench, depending upon the proposed depth of the trench and the appropriate tunnel trenching or pipe distribution.

If one assumes that the only wetted volume of the trench is to the extent of the gravel, then the variations of in-trench storage and wetted perimeter can be calculated, as set out in Table 1. For the purpose of this example, the wetted perimeter is only the combination of the bottom and each side of the trench, and not the interface with the gravel. The interface of the back-filled topsoil with the gravel only comes into play when the depth of the tunnel and gravel section is full of effluent. Then, and only then is there additional capillary flow to the surface. At all other times the upward water movement is through the soil at each side of the trench; the sidewalls, as shown in Figure 5.

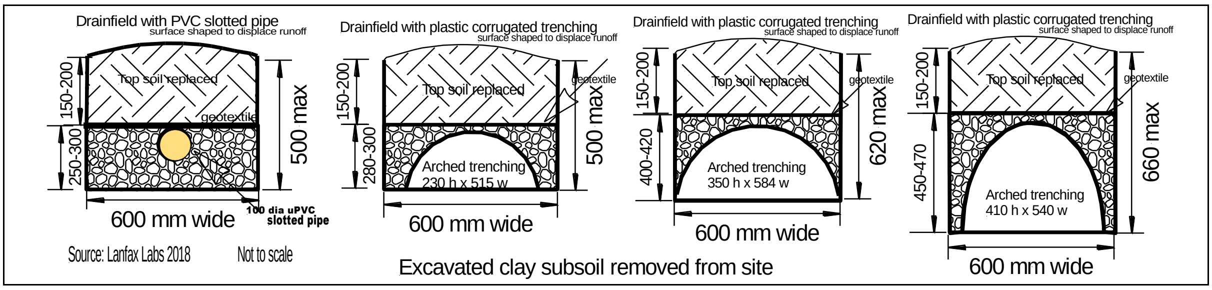


Figure 7 Variations of a 600 mm wide trench

Table 1. Calculations for dimensions, storage capacity and wetted perimeter for several trench configurations

Calculations for pipe and arched trench dimensions and properties				
Property	Pipe trench	Standard tunnel	Large tunnel	Jumbo tunnel
Height (mm)	250	230	350	410
Width (mm)	600	515	584	540
Tunnel storage (L/1.5 m)	nil	120	227	260
Excavation width (mm)	600	600	600	600
Trench storage (L/ m)	60	115	187	212
Wetted perimeter (m)	1.1	1.16	1.4	1.5
Ratio Wetted Perimeter/width	1.8	1.9	2.3	2.5

While the Standard supposes to ignore the contribution of the sidewall, except as a 'belt and braces' approach, it is clear that depending upon the configuration of the trench, as shown in Table 1, there is a significant variation in the wetted perimeter. When the Standard ignores the sidewalls in the calculations, the consequence is that a 600 mm wide trench only has a 'wetted perimeter' of 600 mm, that is, the base of the trench. Compare that width to the wetted perimeter in each of the systems set out in Table 1. Even the modest pipe trench has a wetted perimeter of 1.1 m and the jumbo tunnel 1.5 m. The 'belt and braces' approach that the trench will be designed only on the bottom area (Section L4.1, page 143) is a poor excuse, by the Standard, for failing to consider the movement of effluent through the sidewalls. The consequences are a seriously over-designed and expensive trench system.

It is further interesting that the terms *sidewalls, bottom area* and *bottom area and sidewalls* are not once referred to in the ***normative*** section of the Standard. Except for a mention in the definitions, *safety factor* only appears in comments or in the ***informative*** pages. If we are to accept the Standard's use of the terms normative and informative, then the discussion on avoiding the calculation of the sidewall as just hot air!

4.5 Water balance and rainfall

Of course, the over-design of the trench may be appropriate when one uses the water balance approach in the NSW Guidelines (DLG *et al.,* (1998),p 159) where the 50th percentile (median) monthly precipitation rainfall is used. In many places, the sum of monthly median values may be less than the 30th percentile annual rainfall (http://lanfaxlabs.com.au/rainfall_statistics.htm); hence failure to appreciate the 'likely' rainfall is accounted for by overcompensating soil permeability in the 'belt and braces' approach by the Standard. Such a failure may lead to unnecessary costs on the home owner and is a poor alternative to science.

The Standard makes no mention of a rainfall statistic, either monthly or annual, suitable for the water balance as suggested in Appendix Q3 (page 181). Indeed, when mentioning '*rainfall*' the Standard uses the adjectives ***low***, ***moderate*** and ***high*** as meaningless descriptors without any further elaboration. When one can compile, from Bureau of Meteorology data (http://www.bom.gov.au/climate/data/index.shtml) a suite of return periods for almost anywhere in Australia, it is beyond belief that such simple modelling as suggested in Equation Q3 (page 181) finds its way into the Standard! Fortunately, Section Q3 is *informative* only!

For example, for Armidale (NSW 2350), the median rainfall (50th percentile monthly values) as suggested by the NSW Guidelines (DLG *et al.*, 1998, p 159) will always result in a smaller trench configuration than if the mean (average) or a higher return period is used in modelling. A range of values can be found at www.lanfaxlabs.com.au/rainfall_statistics.htm from which the data in Table 2 have been sourced.

The annual value is the recorded yearly total, while the 'Sum' is the summation of monthly values for that return period.

Table 2. Variations in sum of monthly rainfall to actual annual totals

Parameter	Armidale		Byron Bay		Narrabri		Port Macquarie		Camden	
	Annual	Sum	Annual	Sum	Annual	Sum	Annual	Sum	Annual	Sum
Median	769	684	1851	1538	636	490	1425	1234	702	537
Mean	788	784	1874	1872	646	644	1512	1540	743	747
60^{th} %ile	810	822	1966	1847	709	638	1520	1502	786	701
70^{th} %ile	859	946	2130	2318	751	800	1665	1873	867	884
Maximum	1508		2888		1312		3204		1631	
Median rank		30%		24%		23%		29%		22%

It can be seen in Table 1 that performing a water balance based on the median rainfall values, as ascribed by NSW Guidelines (DLG *et al*., 1998, page 158), results in a lower summation of the monthly total than the median 'annual' value. Since the water balance operates on a monthly calculation, the under-design of the system is easily explained but there is no single compensation figure that actually fits. Simply increasing the size of the trench, based upon guesswork, is nonsense.

The final row in Table 2 indicates the rank of the median in the overall rainfall data. That one would consider a rank of less than 30%, as an appropriate choice of rainfall values for a water balance, certainly shows that one does not understand statistics and will doom the performance in the field to failure. Perhaps it is because of a poor understanding of the implication of the most suitable choice of rainfall statistic that the Standard ascribes to a 'safety factor'. The choice of a higher return period, such as summation of the 60^{th} or 70^{th} percentile monthly totals will offer better performance in the field, but higher return periods will simply over-design for the low probability events; with just a disastrous higher costs for little benefit.

4.6 Permeability and DLR

The Standard (Appendix G) further confuses the understanding of water movement from an excavation into the surrounding soil. The section, prepared by Dr Robert van de Graaff, based on the Talsma method of measuring soil hydraulic conductivity, is a reliable and robust scientific method. When replicated to smooth anomalies in *in-situ* measurements, and when performed with a water of modified EC, the results are as accurate as one can be. Now compare this to the Standard's indicative permeabilities (Table L1, page 145, and M1, page 160), modified by an unknown factor to give long term acceptance rate (LTAR) then further modified by guesswork to derive a design loading rate based only on soil texture. The Talsma permeameter measures water movement into the sides and base of the hole, but the Standard nullifies the use of the sidewalls. How one does this recalculation for unknown soil factors is in Alice in Wonderland environs.

For a 75 mm circular hole (excavated using a 75 mm hand auger) and a testing water depth of 100 mm, the area of the sidewall (0.024 m^2) is six times greater than the area of the bottom (0.004 m^2). For a 100 mm auger hole and a similar depth of water, the area of the sidewall (0.0314 m^2) is four times the area of the base (0.0079 m^2). To negate the additional infiltrative value of the sidewalls ignores reality, measured with a Talsma permeameter, guessed in the Standard Tables L1 (page 145) and M1 (page 160).

For a trench of 25 m length and 600 x 400 mm cross section, the available sidewalls to a depth of 250 mm (maximum design depth of effluent), see Figure 5, is 12.8 m^2 compared to 15 m^2 for the bottom area. Thus, the sidewall is close to a duplication of the bottom area. Why is the contribution of the sidewalls ignored, or just seen as a 'safety factor of two'? The cost to the home owner is almost doubled because of the requirement to ignore the sidewalls.

If one was to consider the difference between the indicative permeability of a moderately structured clay loam as being 500-1500 mm/day (Table L1, page 145) (in itself a three-fold difference without explanation) and the design loading rate of 10-15 mm (about a 100-fold decrease) AND the use of only the bottom area (half the combined sidewalls and bottom area in the example above), the risk aversion is extreme. The unknown factor is that the difference between the indicative permeability and the DLR is not discussed, or referenced to published or recognised field research.

The research for my Ph.D. (Patterson, 1994) statistically replicated field measurements of soil permeability, on a range of soils, derived using a CSIRO disc permeameter, with an SAR/EC modified effluent to replicate domestic wastewater, on numerous soil types. It is not clear how the values in the Standard (Table L1, page 145) were derived, yet those values bear no relationship to what was measured in the field. For example, the permeability (K_{SAT}) of a moderately structured medium clay B horizon, subjected to SAR 8 water, was 5.1 $\pm$ 0.7 mm/h (Patterson, 1994, Table 5.4, page 122), equivalent to about 122 L/m^2.day. The Standard (Table L1, page 145) rates the 'indicative permeability' of a similar clay at 'less than 60 mm/day, but, by default, a DLR less than 5 L/m^2.day.

The Standard provides no insight and can be nothing more than informal estimates (guesses), and likely ultra-conservative ones at that. The use of terms such as *indicative permeability* and *design loading rate* as set out in the Standard (Table L1, page 145) offer no conversion from one measurement to the other. Is there a unique relationship one to the other? With so many variable physical characteristics of a soil profile (horizons, texture, structural forms, salinity, sodicity), it is hard to image how the relationship is as formal as the Standard portrays.

5. Assimilation Area Calculation

The practical application of knowledge of water movement in soil requires that both loss of water to the evapotranspiration cycle and the movement of water through both the sidewalls and bottom area are considered in designing the total trench length for a specific wastewater loading rate and water balance. The water balance has been discussed above in sufficient details for one to avoid using median rainfall values. See also the other references on this website (www.lanfaxlabs.com.au/rainfall_statistics.htm).

The setback (buffer) distance from trenches is 12 m if area up-gradient and 6 m if down-gradient from property boundary and 6 m if up-gradient and 3 m if down-gradient from swimming pools, driveways and buildings (DLG *et al*., 1998, Table 5, page 66). In other words, there is a buffer around the trench to protect assets further away. For a single 25 m x 0.6 m trench (total area 15 m^2), these buffers to the boundary would amount to close to 500 m^2 in total. This buffer is useable space in which effluent and nutrients can be assimilated. It is not an area where 'nothing' is allowed to happen; it is a buffer not an exclusion zone. The term 'exclusion' is not used in the Guidelines. The exclusion zone starts at the property boundaries, no effluent is to leave the property boundary.

If, under NSW legislation the set-back distance from boundaries is to be 5 m, then two assumptions can be made. Firstly, that the set back from the boundary is measured from the side of the trench closest to the boundary. In which case the assimilation area falls within this zone; all is okay.

The second assumption is that the set-back from the boundary is measured from the edge of the maximum wetted front from the trench closest to the boundary. In this case, another 5 m buffer needs to fall around the assimilation area. As such, we now have a set-back on a set-back; an absurd approach to the purpose of a set-back.

Unfortunately, AS/NZS 1547.2012, is quite vague with regards to the issue of an assimilation area being within the set-back. The Standard does not say that the set-back area is an 'exclusion' area, adding further uncertainty to its purpose. The 'exclusions' discussed in the Standard are in relation to site plans showing *flood-prone areas, setback, appropriate clearances between site features and intended on-site facilities* (B2.3 page 84). The interpretation that set-back areas are exclusion zones for effluent application cannot be made. The set-back area allows for the dispersal and assimilation of pathogens (bacteria and viruses) and nutrients (N, P, salts) in such a manner that at the boundary of the set-back distance, the risk of leakage of pathogens and/or nutrients is remote.

Since pathogens and nutrients can only move in a saturated soil environment, the larger assimilation area is more likely to have longer periods of unsaturated soil conditions; periods when neither pathogens nor nutrients can move.

In Figure 8, the total trench length is 60 m, set out as three separate 20 m trenches spaced 3 m apart, stepped down the landscape. The trenches are parallel to the contours of the landscape, not necessarily parallel to each other. The typical wetted area around the trenches includes 2 m upslope, 5 m at each end and 5 m downslope, well within the set-back (buffer) distances referenced in the NSW Guidelines (DLG *et al*., 1998, Table 5, page 66). That total area for the assimilation of the hydraulic and nutrient load is 420 m^2 and may, at some time, receive effluent by capillary or gravitation flow. The intention is that effluent does not move outside that zone or into a neighbouring property.

The 420 m^2 is considerably larger than the combined sidewall and bottom areas (31.2 m^2 and 36 m^2 respectively, totalling 67.2 m^2), all the nutrients can be assimilated in this area. Assuming 1 m depth of soil, 420 m^3 of treatment is available. Nutrients are not 'absorbed' in the trench. The trench is simply the mechanism for exposing effluent to soil in the sidewalls and base of the trench. It is absurd to consider the trench 'retains' any nutrients as there is generally only space in the tunnel and between inert gravel fragments, neither of which can absorb nutrients.

Nutrient balancing calculations are performed on the annual hydraulic and nutrient load, with the capacity of the vegetation and soil to adequately assimilate these loads within the nutrient absorption area.

That the only mechanism for hydraulic and nutrient absorption is within the trenches is to avoid understanding the complexity of movement of water and nutrients in a soil in response to capillary and gravitational forces. Nutrients and/or bacteria will only move in a continuum of a water environment.

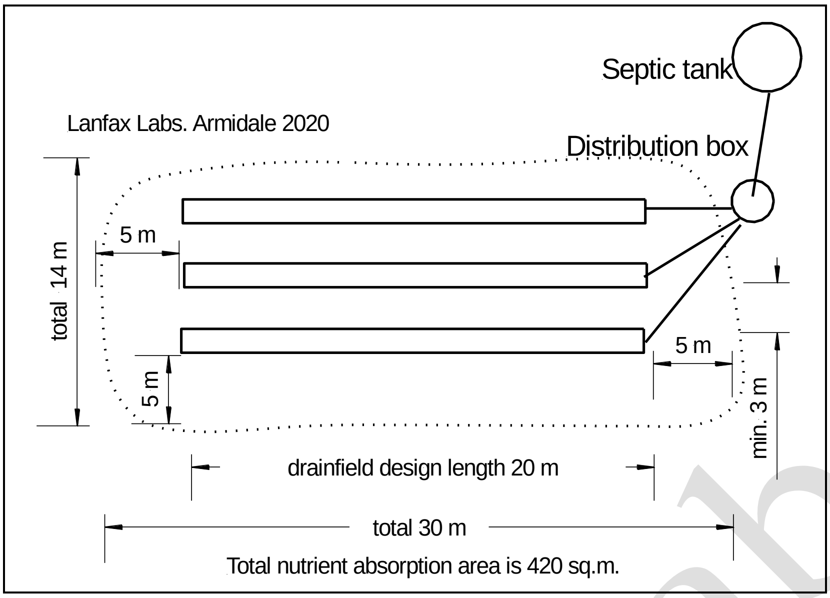


Figure 8 Assimilation area around three trench system

6. Nutrient Assimilation around a Trench

Let us assume for the purpose of this exercise that the septic tank produces an effluent of a quality such that it contains 70 mg/L as total nitrogen and 10 mg/L as total phosphorus. These values can be written 70 mg N/L and 10 mg P/L.

Assume that the area available for assimilation is that set out in Figure 8 the total area of 420 m^2. It is expected that as the soil closest to the trench system saturates with nitrogen and/or phosphorus, those elements will move out into less saturated areas for assimilation. The same process occurs for sodium and other solubles in the effluent, including ionic forms as sulphates, chloride, ammonia and others.

The uptake of nitrogen by plants can only occur from nitrogen products in ionic form, ammonia-N (NH_4^+), nitrite-N (NO_2^-), and nitrate-N (NO_3^-), thus the total nitrogen value over-represents the mobile fraction. The organic form of nitrogen must be degraded by micro-organisms into the ionic forms otherwise the organic nitrogen is in an unavailable form and not freely moved with water moving through soil. In degrading the nitrogen in soil, a proportion is lost as gaseous nitrogen, a form that escapes to the atmosphere. If one assumes that 20% of the total nitrogen is in the unavailable form of organic N, then the 70 mg N/L can be recalculated as about 56 mg N/L of available N fractions. The NSW Guidelines (DLG *et al*., 1998, page 112) suggest that up to 40% of the total nitrogen may be in organic form, however, some of that will degrade to useful plant nutrients and some may degrade to nitrogen gas that is lost to the atmosphere. Some nitrogen will also be immobilised by its ingestion by soil microbes and microflora, an additional proportion will be lost by leaching.

The annual uptake of nitrogen by plants is generally accepted to be around 300 kg N/ha but may be as high as 500 kg N/ha in ideal, well irrigated soils. We need to calculate the load of nitrogen on an annual basis for a house discharging 600 L/day (5 persons at 120 L/person) at a total nitrogen concentration of 56 mg N/L. The annual load is 13.1 kg N/year. Assuming a nitrogen assimilation rate of 300 kg N/ha, then 0.0436 ha of assimilation area is required. The assimilation area in Figure 8 is 420 m^2, so there is a shortfall of about 16 m^2. Perhaps this shortfall is acceptable, given that the dwelling is unlikely to be working at capacity for all times.

The NSW Guidelines (DLG *et al*., 1998, page 153) indicates that *critical TN loading rate* is 25 mg/m^2.day, equivalent to 91.3 kg/ha.annum well below the 300 kg N/ha.annum considered necessary for maintain an actively growing pasture grass that receives additional water (effluent). That the Guidelines under-estimate plant requirements for this macro-nutrient simply enlarges the effluent application area unnecessarily.

The calculation of the uptake of phosphorus is a little more complicated because not only is there a plant uptake component there is a phosphorus adsorption capacity (P sorption) where soil compounds immobilise phosphorus. Plant uptake is estimated at about 30 kg P/ha annually. The P sorption capacity depends upon specific soil properties to immobilise the phosphorus. Such capacity is usually measured in a laboratory and reported as mg/kg or kg/ha, assuming a nominal bulk density and 1 m depth of soil.

For the purpose of this exercise, assume annual plant uptake rate is 30 kg P/ha and the P sorption capacity is 10 000 kg/ha over the estimated life of the land application area, say 50 years. On an annual basis that is 30 kg/ha from plants and 200 kg/ha from P sorption (10 000 kg / 50 years), a total adsorption capacity of 230 kg P/ha each year. The effluent at 10 mg P/L for 600 L/day equates to 2.2 kg P/annum. To calculate the assimilation area for phosphorus per hectare, divide the 2.2 kg P/year by 230 kg P/ha.annum to find 96 m^2 is required. As this calculated area is less than the area of 420 m^2 in Figure 8, phosphorus will not overload the soil system and its distribution will be sustainable.

Other chemicals in domestic wastewater influence the permeability of the soil and the vegetation that enhances evapotranspiration. Sodium can have a detrimental effect upon dispersion and loss of permeability as represented by the sodium adsorption ratio (SAR) of the effluent and the exchangeable sodium percentage (ESP) of the soil. These chemical interactions are addressed in detail under other technical papers by the author.

7. Conclusion

The movement of water away from a trench is dictated by the saturated hydraulic capacity of the particular soil, the varying characteristics of the soil horizons, the chemical interactions between effluent and soil, the effluent loading rate and climatic factors affecting rainfall and evapotranspiration.

That only bottom area of a trench system, as indicated in the Standard AS/NZS 1547:2012, can be used to develop an appropriate design loading rate is one that jumps from *indicative permeability* to *long term acceptance* rate to *design loading rate* without rationale. That sidewalls do not play in the everyday loss of water from a trench is contradictory within the Standard and defies common sense and observation. That the Standard is ultra-conservative is an understatement and as such imposes significant additional and unnecessary installation and maintenance costs for no apparent reason.

The NSW Guidelines (DLG *et al*., 1998) offer the legislators a tool to significantly restrict the use of the natural soil for the treatment and ultimate fate of domestic septic tank effluent, joining with the Standard to increase the area required for treatment. Neither document takes a decisive role in using science to meet the practical challenges and opportunities for low energy return of wastewater to the environment.

Throughout this document, the anomalies of both the Standard and the NSW Guidelines with the science of effluent interactions with soils are compared and contrasted with what occurs in the field.

8. References

Bureau of Meteorology Climate Data Online http://www.bom.gov.au/climate/data/index.shtml

DLG *et al*., (1998) *Environment and Health Protection Guidelines On-site Sewage Management for Single Households*. Depart. Local Gov't., NSW Environ. Protection Authority, NSW Health, Land & Water Conservation, and Depart. Urban Affairs & Planning Sydney.

Lanfax Laboratories Website www.lanfaxlabs.com.au

Patterson, R.A. (1994) *On-site treatment and disposal of septic tank effluent*. PhD thesis. Departments of Resource Engineering and Agronomy and Soil Science. University of New England. Armidale.

Standards Australia and Standards New Zealand (2012) AS/NZS 1547:2012 *On-site domestic-wastewater management.* Standards Australia, Sydney and Standards New Zealand, Wellington.