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ENVIRONMENT & HEALTH PROTECTION GUIDELINES

On-Site Sewage Management for Single Households

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Evapotranspiration Bed Designs for Inland Areas

Dr Robert A. Patterson

Lanfax Laboratories, Armidale

Introduction

The use of an evapotranspiration bed (ET) for the return of the water component of domestic wastewater to the hydrologic cycle has an advantage because of its low profile, and is suitable for effluent disposal in shallow soils or areas of high water table. Essentially, an ET bed is a large constructed sponge of sand and gravel, sealed from the surrounding soil, with an inbuilt water storage capacity and a vegetated surface from which evapotranspiration is maximised. When the base of the bed is used for soil absorption (percolation) of effluent in addition to the evaporative demand of the surface, the system is called an evapotranspiration/absorption bed (ETA). The term ET/A is used to describe both an ET bed and an ETA bed.

The success of any wastewater system is dependent upon not only the appropriate design and siting of the system, but upon continued vigilance of wastewater quantity and quality in the house and regular inspections and maintenance of the operating in-field system. This paper addresses the simple design factors of evapotranspiration systems and considers the appropriate actions required for system maintenance.

Definitions

The design and operation of evaporative type systems are dependent upon the appropriate choice of design criteria and materials. However, before we start it is necessary to understand the terminology used in describing these criteria.

Crop factor (Cf) is the coefficient expressing the proportion of open-water evaporation transpired by a crop under the same energy gradient, varying with stage of growth, plant type, plant density, sunlight, wind and soil conditions. For vigorously growing well-watered plants a coefficient of 0.7 to 0.9 may be used.

Capillary water exists as a continuous film around soil particles, held by surface tension, that drives the water through very small pores. Movement of water laterally (sideways) and upwards works like a wick and is of interest in ET bed design. The sponge effect allows water to move in all directions by capillary flow.

Evaporation (E) is the movement of water from the surface of a body (water, soil, plant) into the atmosphere in response to a lower humidity gradient.

Evapotranspiration (Et) is the total loss of water from the surface of the soil and the transpiration losses from plants, increasing with increasing air temperature, sunshine intensity and wind speed and decreasing humidity.

Field capacity (FC) is the soil moisture status when a saturated soil is allowed to freely drain and is the upper limit of available water storage capacity.

Gravitational water is the water stored in the soil between field capacity and saturation when all the soil pores are filled with water.This water drains away under normal circumstances but cannot drain from a sealed ET bed.

Humidity gradient, or vapour pressure gradient, indicates the direction and intensity of evaporation, moving from the higher to the lower humidity. This gradient is influenced by temperature, solar radiation, wind and surface conditions.

Infiltration is the downward movement of water from the surface into the soil with a reduction in the soil's storage capacity. Infiltration is influenced by rate of precipitation, surface soil condition, vegetation cover and amount of water already in the soil. The infiltration rate, measured in mm/h, is higher when the soil is dry and decreases with increasing soil moisture.

Pan evaporation (Eo) from a Class A Pan is the index used to measure loss of water from an open water surface. Units of measure are mm/day.

Percolation (hydraulic conductivity) is the movement of water downwards through the soil profile in response to gravity and is a function of soil permeability.

Precipitation (P) is rainfall. A proportion of rainfall may be intercepted by plants and never reach the soil, a proportion may fall at a rate greater than infiltration capacity and run-off from the land, the remaining proportion infiltrates the soil and contributes to a change in soil moisture status.

Void ratio (*e*) is the ratio of volume of voids to volume of solids in a given mass of soil. The voids may be filled with air or water.

Porosity (*n*) is the ratio of volume of voids to the total volume of a given mass of soil, sand or gravel. The voids may be filled with air or water.

Run-off coefficient (Cr) is the proportion of rainfall which is lost as run-off and occurs when the precipitation rate exceeds infiltration rate. High intensity storms lead to high proportion of runoff. The rainfall retained is P x (1 - Cr)

Soil absorption (D) is the drainage of water through the soil profile, usually downwards towards the water table and relates to the water moving through the profile and the maintenance of a high stored water content.

Soil hydraulic conductivity (K) is a measure of the rate of downward movement of water through the soil and depends upon soil moisture, soil texture, soil structure, effective diameter of the soil pores, and connectivity of soil pores. The highest soil K is when the soil is saturated (Ksat) and declines with decreasing soil moisture.

Soil water storage (S) is the amount of water that can be stored in the pore spaces of the confined ET bed and is made up of both the AWSC and the gravitational water.

Transpiration is the process of water vapour passing into the atmosphere through the tissues of living plants, driven by the humidity gradient and the soil moisture status. The water pressure gradient within the plant causes the extraction of moisture from the soil around the root mass. More water evaporates from the leaves when water at the roots is not limiting.

Available water storage capacity (AWSC) is the volume of water able to be stored in a given volume of soil and varies with porosity (soil texture, soil structure, organic matter content), thickness of the horizon and the amount of water already present. Water storage capacity may often be reported as depth of water for each metre depth of soil. Clay loams may store 185 mm/m while light clays may store 140 mm/m.

Application of Principles

The basic principle of ET bed design is to pass the effluent from a septic tank system through a distribution network in a specially prepared mass of suitable sand and gravel layers and that by capillary action and shallow rooting perennial plants water is lost by evapotranspiration. The bed allows for storage of excess effluent during periods of low evapotranspiration, acting like a large sponge, while the convex surface encourages the shedding a proportion of the rainfall.

By the same actions, solids, salts and other chemicals are retained in the bed and in a sealed system will eventually reach critical levels.

It will be seen during the discussion of the various aspects of the design criteria that it is critical to locate the bed to maximise solar radiation and wind eddies over the bed.

Figure 1 is a typical cross-section of an ET bed.

Collection of Data

Most of the design criteria for an ET/A bed can be sourced from local records and performed as a desk top study. Soil permeability must be assessed for the actual site of an ETA bed.

Rainfall and Class A Pan Eo rates are available from the NSW Climatic and Consultancy Section of the Bureau of Meteorology. Climate averages data for many Australian stations are available at http:// www.bom.gov.au /climate/averages/tables/ ca_nsw_names.shtml .

Only selected localities have pan evaporation data (usually the research stations) and the nearest station may not provide you with appropriate data. Beck (1979) stated that when water was high in the bed, the Et rate increased and in some instances can be up to 10 times Eo rates. This has not been proved to occur in Australia, but Et rates up to 2.0 are common in reed bed systems.

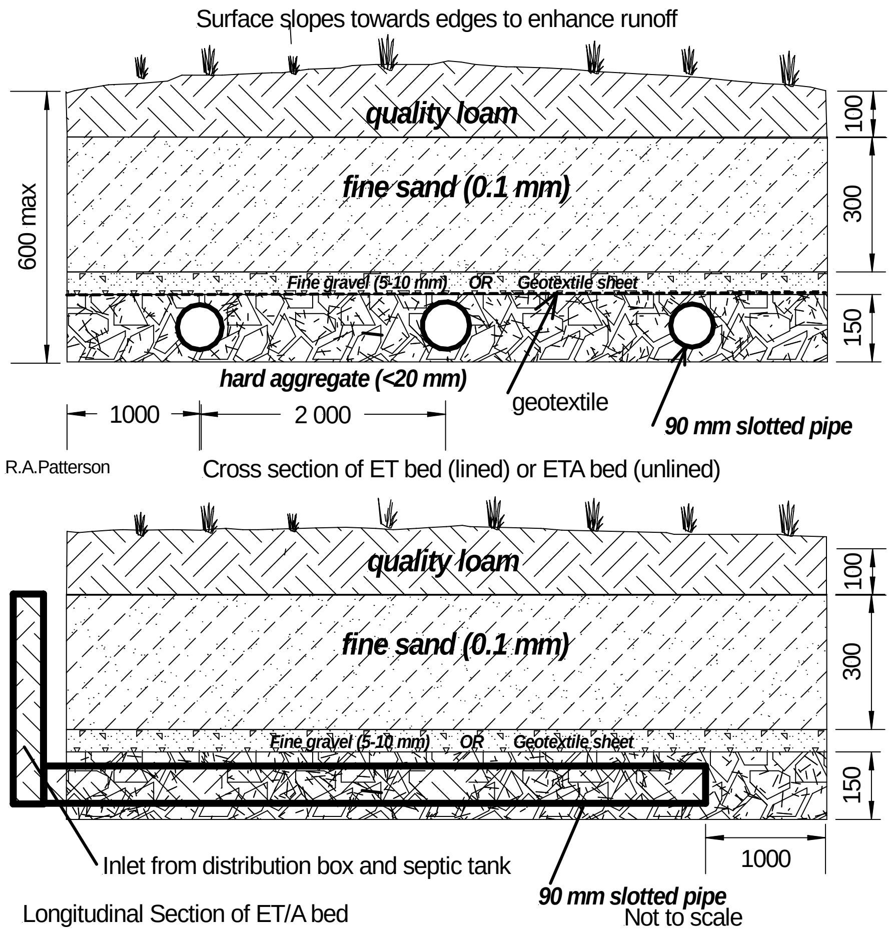

Figure 1. Typical cross-section of an ET bed

While it is inevitable that some months will have higher than average rainfall, a water balance for each month over a whole year will often provide adequate in-bed storage of water for those higher events into the drier months. Crites and Tchobanoglous (1998) recommend a 15-20% increase in area to account for variations in rainfall and effluent flows.

There are several models available for a more accurate determination of evaporation however, for the purposes of ET bed design such calculations are unwarranted.

The void ratio (***e***) of the sand and gravel media used in ET/A beds can be obtained from published data. The following void ratios are suitable: 0.45 for dense uniform sand, 0.3 for gravels and 0.6 for light clays 0.6 (Das, 1985).

The crop factor (**Cf**) and the interception component of the rainfall can be taken from theoretic values for the vegetation. It is usual to use a Cf value between 0.75 and 0.85.

The runoff coefficient (**Cr**) can be related to the proposed shape and surface compactness of the ET bed for which a value of 0.35 is acceptable. Beck (1979) suggests the top of the bed has a cross fall of at least 13 mm/m from the centre to shed rain.

The effluent quantity (**Qe**) produced by the household can be determined from data published in AS/NZS 1547:2000 (Standards Australia and Standards New Zealand, 2000) or from a knowledge of typical local values for similar households. There is no advantage in understating the daily production rate as the integrity of the design of the ET bed depends on accurate inputs.

Water Balance

The basic function of the ET/A bed is to return all the water from the on-site system to the hydrologic cycle through evapotranspiration or the combined evapotranspiration/absorption. This objective requires that the daily volume of effluent from the septic tank (Qe) and the rainwater infiltrating the surface of the bed (rainfall minus interception and runoff) must always be less than the actual loss of water from the bed. A sealed ET bed of this size would be prohibitively large. Hence, the bed must provide a storage capacity within the matrix of the sand and gravel to accommodate excesses for evaporation during drier periods.

The output, therefore, is the loss by evapotranspiration and the change in storage of excess effluent within the bed. The variable D is zero for an ET bed and will depend upon soil permeability for an ETA bed.

Input		≤	Output	Equation 1
Effluent	+ rainfall retained	≤	Et + D + change storage	
Qe	+ { Px (1-Cr)}	≤	(E o x Cf) + D + Δ S	

(the Greek symbol *delta* (Δ) is used to denote "change")

A suitable model for the water balance is given in Appendix G of AS 1547-1994 (Standards Australia, 1994). It is valuable to construct a computer spreadsheet for this model so that iterative (trial and error) calculations can be worked to determine an appropriate area of the ET or ETA bed based upon storage depth within the bed.

Typical ET/A bed design areas for a household of five persons producing wastewater at the rate of 700 L per day have been calculated using the AS 1547 model for several inland towns. The values indicated in Table 1 use average rainfall and evaporation data.

It can be seen in Table 1 that the higher evaporation deficits (P - Eo) do not necessarily translate to smaller areas for ET beds. In each of the budgets the constraint of low winter evaporation rates with winter rainfall meant that significant storage of effluent was required within the bed during the months of June to October. If no carry-over storage was available the areas would be prohibitively large. Even an ET bed of 2000 m^2 in Bathurst would still result in a storage of 86 mm of saturated bed in June to August each year.

Design criteria from water balance

The water balance provides not only the design surface area of the bed but also the constructed depth. By manipulating the proposed area of the bed, the depth of stored effluent will either increase or decrease. For a bed with a depth of 600 mm, the depth of stored water should not develop to within about 150 mm of the surface so that at no time may the saturation be detrimental to the roots of the plants. However, the reverse should also be considered that the water in the bed is within capillary reach of the surface. For the latter reason, the bed depth should not exceed 600 mm.

In Table 1, the iterative process was used to find the most appropriate area for a stored water depth of not more than 450 mm. Because of the void ratio, the actual amount of water is the water stored in the pores.

Selection of suitable material

The gravel for the base of the bed should be a hard clean material of about 20 mm average diameter. The volume of gravel, in cubic metres, is 0.15 x area of the ET/A bed .

The fine sand of 0.1 mm diameter is desirable as it provides a large void ratio and a high capillarity (50% by weight smaller than or equal to 0.1 mm) (USEPA, 1980). The volume of sand required, in cubic metres is 0.35 x area of bed. A layer of geotextile laid over the gravel will prevent the sand moving into the larger spaces in the gravel, or a layer of finer gravel may be used.

The surface soil should be a loam to provide a suitable supporting medium for the vegetation. The volume of top soil required, in cubic metres is 0.1 x area of bed.

Membranes for lining ET beds should be at least 200 μm thick and the joins overlapped and sealed with a high quality waterproof tape to ensure water tightness over many years. Ideally, a 50 mm layer of sand should be laid on the floor of the excavation to prevent puncturing the membrane during construction.

Distribution System

A distribution box provides a mechanism for evenly dosing each of the pipes in the base of the bed. The inverts (bottom of the pipe) of the outlets must be higher than the designed stored water depth in the bed otherwise the system will not gravity feed.

Table 1 Variations in design criteria for ET/A beds in inland towns of NSW.

Town	Annual Rainfall (P) (mm)	Annual Eo (mm)	Area for ET bed (m2)	Max. depth of storage (mm)	Area for ETA bed (m2)	Max depth of storage (mm)
Armidale	790.9	1331.7	500	375	75	346
Bathurst	634.4	1325.6	600	416	77	384
Cowra	640	1352.1	700	436	79	366
Inverell	807.1	1602.9	375	420	72	361

The long term absorption rate was set at 8mm per day for the ETA bed.

The pipe system at the base of the bed needs to distribute the effluent evenly over the whole area. Pipe diameters of at least 90 mm slotted PVC (normal stormwater pipe) are firstly laid on 50 mm depth of gravel and the gravel filled to a total depth of 150 mm. The lateral spacing of the pipes should not exceed 2.0 m.

Location of Bed

The ET/A beds need to be positioned so that the effluent from the septic tank can gravity flow to the distribution box then to the ET/A bed. Where gravity flow cannot be achieved, a pumped system is appropriate.

Either a single bed, or a number of beds totalling the design area, are to be constructed. The bed is formed in an excavation of the appropriate area and to the design depth. The floor of the bed is to be level in all directions. Figure 1 shows the cross-section of a typical ET bed. Where the landscape is more than 5% slope, it may be necessary to step several narrow beds, each parallel to the contour, down the slope.

All opportunity should be taken to maximise solar radiation falling on the surface of the bed for long periods each day. As evaporation is dependent upon a negative humidity gradient over the surface of the bed, ensuring that air flows freely over the surface and that trees or shrubs do not reduce wind velocity over the bed are important local considerations.

Management

Longevity of the ET/A beds is dependent upon the salinity tolerance of the vegetation unless households minimise high salinity and highly sodic chemicals. The ET bed will slowly accumulate salts and other nutrients as there is no mechanism for flushing these salts from the system. ETA beds do benefit from salts being flushed from the system during periods of high rainfall.

The grassed surface of the ET/A bed must be maintained to maximise evapotranspiration and encourage rainfall runoff. Some additional interception of rainfall is accomplished by leaving the grass at least 50 mm long. Bare spots within the grassed surface must be repaired because the grass transpires more water than a bare earth surface.

During very dry periods it may be necessary to irrigate the surface to keep the grasses in prime condition. Only small amounts of clean water should be used.

Conclusion

The area of a lined ET bed is significantly larger than the area for an ETA bed, because the latter has the additional benefit of absorption of effluent into the surrounding soil. The relative cost of the ET bed will be higher by up to six times that of the ETA bed. However, there are instances such as sites with very shallow subsoils, high water tables, close to permanent water that the ET bed provides an environmentally acceptable means of disposing of domestic effluent on-site.

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For More Information

Author Contact Details

Dr Robert A.Patterson
Lanfax Laboratories
PO Box W90
Armidale NSW 2350
Phone: 02 6775 1157
Fax: 02 6775 1043
Email: rob@lanfaxlabs.com.au

Septic Safe Program

Department of LocalGovernment
Locked Bag 3015
Nowra NSW 2541
Phone: 02 4428 4179
Fax: 02 4428 4199
Email: septicsafe@dlg.nsw.gov.au
Website www.dlg.nsw.gov.au