WET-WEATHER STORAGES FOR ON-SITE WASTEWATER SYSTEMS

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Abstract

Since the release of the NSW Department of Local Government guidelines for on-site effluent management in early 1998, one of the major concerns has been the determination of where and when wet-weather storage facilities should be implemented. The possible requirement for a wet-weather storage facility, in association with an on-site wastewater management system, is both something radically new in terms of on-site management, but also something with which the industry has found very difficult to come to terms. There are numerous options which can be considered, technical difficulties to overcome, increases in cost and methods of determining the relevant size and management of the storage facility.

This paper provides some clear guidance regarding the numerous difficulties associated with the concept of wet-weather effluent storage. It considers a range of technical approaches and numerical methods for evaluating the most suitable, from both an environmental and economic perspective, method of applying wet-weather storage to on-site facilities. Included in the analyses, are detailed reviews of daily versus monthly modelling approaches, implications of 'design soil percolation' rates, in-ground and above ground storage's, soil moisture monitoring, and the implications for maintenance and scale of works (ie. hydraulic load of the sewage treatment facility), location and ownership on the wet-weather storage facility.

Keywords

on-site sewage management, percolation rates , water balance, wet-weather storage,

1 Introduction

For the past three years, there have been significant initiatives to implement on-site detention (OSD) of treated effluent during periods of wet-weather for on-site wastewater management (OWM) systems. The move towards OSD has come, at least in NSW, from a number of government agencies including the NSW Department of Health (DoH), the NSW Department of Land and Water Conservation (DLWC), the NSW Environment Protection Authority (EPA), the NSW Department of Urban Affairs and Planning (DUAP) and the NSW Department of Local Government (DLG). This initiative has recently culminated with the release of the NSW DLG (1998) guidelines for on-site effluent management which indicate that water balance assessment and determination of suitable levels of OSD during wet-weather storage should be considered for most OWM systems.

Fundamentally, the movement towards OSD stems from the notion that there is greater risk of effluent leaching and / or effluent runoff during wet-weather and in some instances, for some period after wet-weather where soil profiles are at or near to saturation, thereby increasing transmissivity or propensity for surface runoff. Through the OSD, government has attempted to force the home owner to comply more fully with the principles of ecologically sustainable development and comply with effluent re-use guidelines more traditionally associated with larger re-use facilities.

In NSW, the initiative has forced the regulatory community to be faced with essentially something radically new in terms of OWM. The community, including local government, residents and indeed also the supportive regulatory authorities, have encountered numerous difficulties with the actual implementation of the concept of effluent storage during and often for some period after wet-weather. The primary difficulties associated with implementation of the initiative include:

1. Determining suitable levels of storage.
2. Where to store effluent.
3. Choosing methods of monitoring soil moisture.
4. Suitable soil moisture levels when effluent storage should begin.
5. Dealing with extended or prolonged wet-weather.
6. Maintenance of the wet-weather storage facility.
7. Monitoring of the wet-weather storage facility.
8. Comparisons with common effluent schemes.
9. Costs of implementing storage.

Each of these items has to date presented local government, who are essentially at the implementation end of the plan, with considerable difficulty. The community is generally not in acceptance of the OSD philosophy, and most certainly severely criticises the often substantial additional costs and approval / management / monitoring requirements of the storage facility and associated infrastructure such as soil moisture monitoring probes and other assorted electrical equipment.

This paper presents discussions which hopefully shed some light on the issues which are outlined above. Importantly, substantial discussions are provided regarding the method of calculation of the size of the storage facility, as this in fact has over-riding influence on most of the other issues mentioned. Badgerys Creek, the possible site of Sydney's second airport in Sydney's western suburbs, is used as a case study to illustrate many of the points in the paper.

2 Determining Storage Volume

2.1 Monthly water balance approach

The DLG (1998) guidelines recommend that a monthly water balance approach be implemented to determine firstly the size of the OSD facility required, and secondly, the actual period of detention. Generally the approach can be described as follows (note median monthly values are used given that the effluent is domestic and low strength):

$$WB = R - ET - P - E_f \qquad \textbf{(1)}$$

where; WB = Monthly water balance (in mm).
R = Median monthly rainfall (mm) from local rainfall records.
ET = Median monthly evapotranspiration (mm) from local evaporation records and crop coefficients.
P = Monthly design percolation rate (mm) nominated by designer.
E_f = Monthly effluent load (mm), determined from hydraulic load and application area size.

Effluent (E_f) can only be applied where (R - ET - P) is negative and there is therefore 'capacity' to accept effluent for any given month. If 'capacity' is ≥ 0 or if after effluent is added 'capacity' ≥ 0, then any excess effluent should be stored and added to any previous storage from the previous month's storage. The storage volume (L) is determined by multiplying the application area (m^2) by the maximum storage (mm) determined from the analyses.

The monthly method is applied to the Badgerys Creek site which has an average annual rainfall of 903.2 mm/year and median annual rainfall of 886.5 mm/year. The simulation scenario is described in Table 1 with results of the assessment given in Figure 1.

Results of the monthly modelling indicate that a maximum storage depth of 82.5 mm is requires, which translates over the 800 m^2 disposal field into minimum OSD facility of 66 m^3.

Several comments can be made regarding this approach. Most important is that the approach is water balance orientated and does not include any soil parameters such as soil permeability or water storage capacity. Secondly, the approach does not allow for any runoff of rainfall during wet-weather. Thirdly, the percolation rate has no physical meaning and is consequently almost always arbitrarily determined.

Typically percolation rate is set at a nominal 5 mm/week, although it may be set to 0 mm/week where local environment is deemed to be sensitive.

Table 1: Monthly water balance data and wet-weather storage assessment for Badgerys Creek, NSW.

Re-use Field Factors			
Disposal field size (m^2)			800
Effluent load (L/day)			900
Design percolation (mm/wk)			5
Crop Cover Factors			
Crop Type	Coverage	Summer	Winter
Grass	80%	0.80	0.65
Shrubs	20%	1.20	0.80
Design values	100%	0.88	0.68

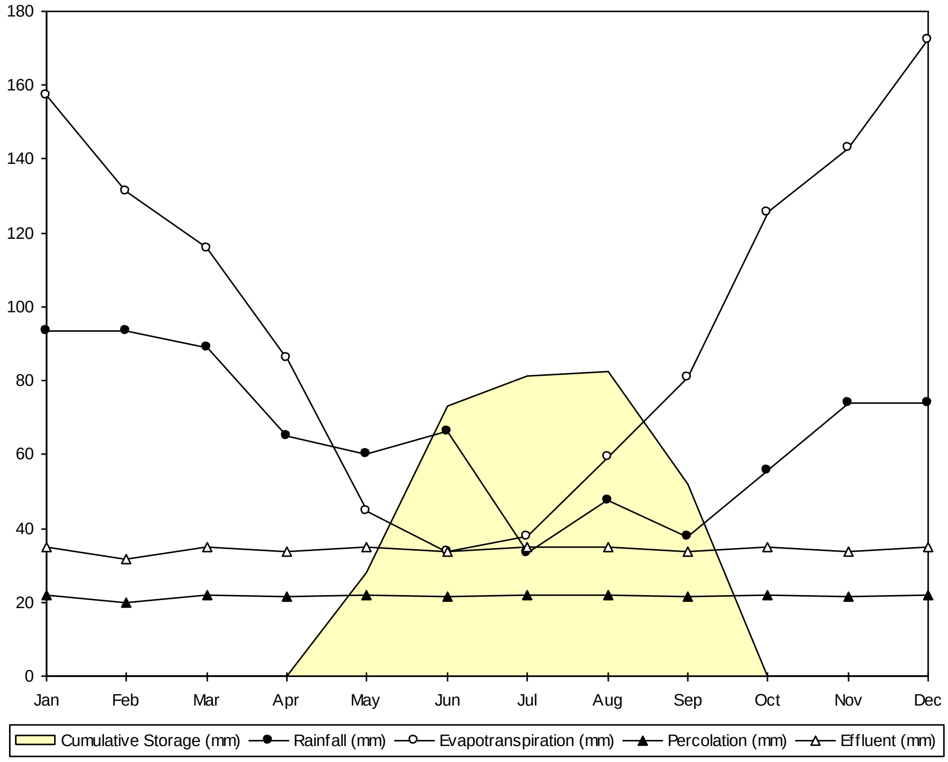

Figure 1: Monthly water balance and storage requirements, Badgerys Creek, NSW.

In fact, the monthly water balance approach is, upon closer inspection, extremely sensitive to both the effluent application area and the design percolation rate. A sensitivity analysis was conducted for these two parameters (based on input data for Badgerys Creek given in Table 1) varying percolation between 0 and 10 mm/week and effluent application area between 100 and 1000 m^2.

Results of the sensitivity analyses (Figure 2) indicate that for small disposal fields, very large OSD facilities are generally required (> 200 m^3) regardless of design percolation rate. However, for larger disposal fields, the approach shows considerable variation in estimates of OSD volume depending on percolation rate. This variability is of concern given that there is presently no guidance on determining suitable design values for percolation and that the ultimate number has no physical meaning. Indeed, given that the nominal percolation rate is typically never more than 5 mm/week, this indicates that for a large disposal field of say 600 m^2, the OSD facility would need to be 78.6 m^3 or almost 3 months of permanent effluent storage.

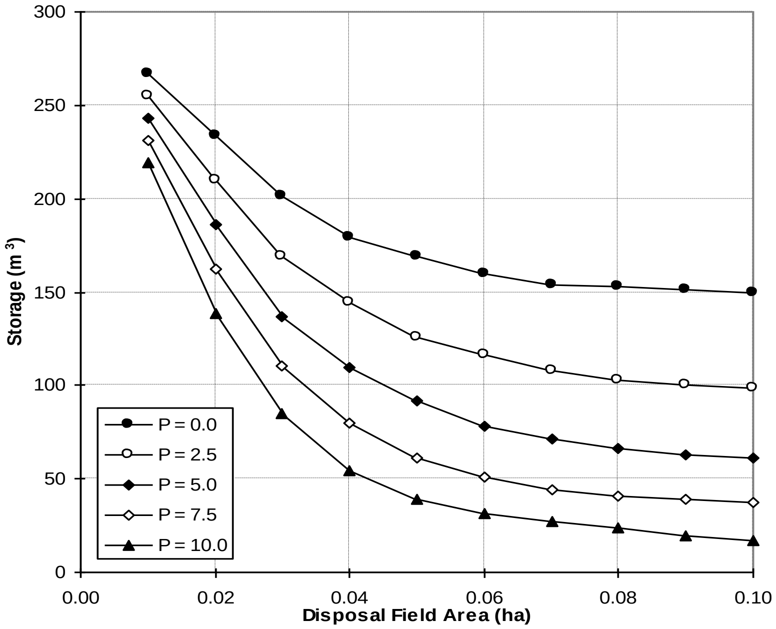

Figure 2: Storage requirements determined from monthly water balances varying with disposal field area and design percolation rate (in mm/week), Badgerys Creek, NSW.

In conclusion, the monthly water balance approach does not include any soil processes and is very sensitive to an arbitrarily chosen design percolation rate. In most instances, where say a percolation rate of 5 mm/week is chosen, OSD facilities become very large and impractical for domestic situations.

2.2 Daily soil moisture modelling

A daily water balance is frequently recommended as a means of providing a more detailed method of determining wet-weather storage. In principle, this involves determining daily variations in soil moisture, and in doing so, determining when soil moisture levels exceed design values and effluent is required to be stored. Implementation of a daily soil moisture balance is, from a practical perspective, frequently very time consuming, costly and requires significant user expertise. To overcome these problems, a modelling package called ***ReCycle*** produced by Martens & Associates Pty Ltd was used which conducts daily soil moisture calculations and allows for the determination of soil moisture, drainage and contaminant leaching [from for example, effluent biosolids application schemes], surface runoff and OSD facility volume determination.

ReCycle has been developed over the past year in an attempt to address the substantial problems associated with the monthly water balance approach. It consists of a Windows™ environment with a number of input dialogues (for examples see Figure 3, Figure 4 and Figure 5) which allow relevant soil, climatic, crop cover, hydraulic load and effluent properties to be entered into the system. The model requires both daily rainfall and daily evaporation as variables on which calculations are based.

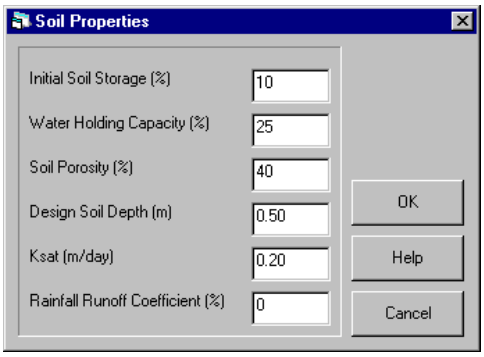

Figure 3: Soil parameters for ***ReCycle*** soil moisture and wet-weather storage modelling system.

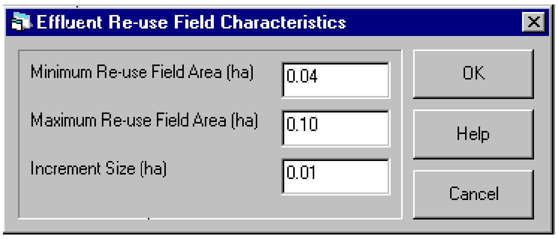

Figure 4: Re-use field dialogue for *ReCycle* soil moisture and wet-weather storage modelling system.

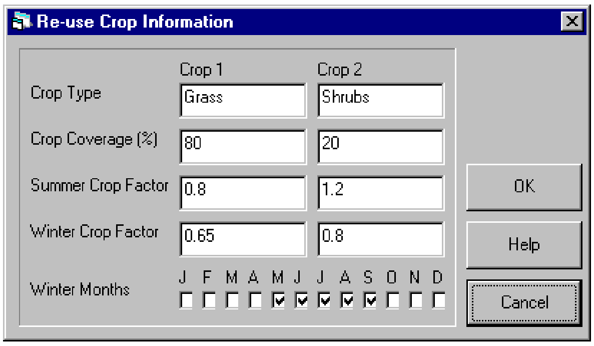

Figure 5: Crop cover dialogue for *ReCycle* soil moisture and wet-weather storage modelling system.

Daily soil moisture was modelled for the period of record at the Badgerys Creek site. Relevant input parameters to the model are summarised in Table 2.

Calculations were conducted over a range of effluent disposal field sizes (100 - 1000 m^2) for both a loam (K_{sat} = 0.20 m/day) and a fine-medium sand (K_{sat} = 2.50 m/day). The sand was chosen to indicate a lower or 'worst case' scenario for effluent application. Calculations were also conducted for a range of design soil depths (for both the loam and the sand) with depth for each scenario ranging between 0.25 and 1.00 m.

Results (Figure 6) indicate that for small effluent disposal fields (≤ 300 m^2) very large storage facilities are required [of greater than 100 m^3] which compares well to those predicted by the monthly modelling methods. What this means is that, in fact, no realistic solution can be found for these areas and that there will be some surface runoff during and possibly after wet-weather. However, when fields exceed say 300 m^2, the required storage falls substantially to below 10 m^3 which is significantly lower than OSD volume estimates based on the monthly methods (which would be > 50 - 100 m^3).

Table 2: Input data for daily water balance and wet-weather storage assessment for Badgerys Creek, NSW, using ***ReCycle***.

Re-use Field Factors			
Disposal field size (m^2)			100 - 1000
Effluent load (L/day)			900
Soil Factors		Loam	Clean Sand
Porosity (n, %)		40	40
Water Holding capacity (WHC, %)		25	4
Nominal initial moisture content (%)		10	2
Soil depth (m)		0.25 - 1.00	0.25 - 1.00
Saturated hydraulic conductivity (K_{sat}, m/day)		0.20	2.50
Surface runoff coefficient (%)		0	0
Crop Cover Factors			
Winter period		May to September	
Crop Type	Coverage	Summer	Winter
Grass	80%	0.80	0.65
Shrubs	20%	1.20	0.80
Design values	100%	0.88	0.68

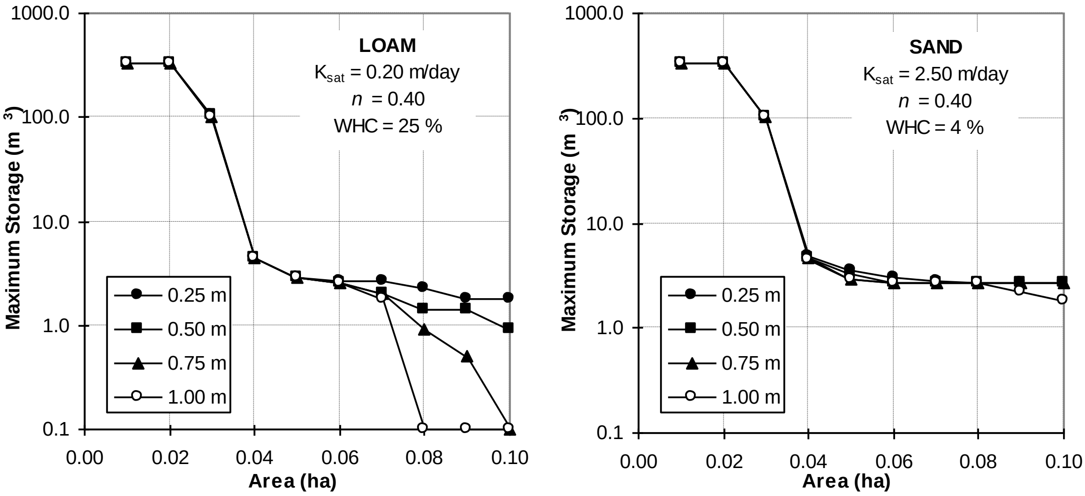

Figure 6: Wet-weather storage requirements (median values) based on daily soil moisture budeting determined through ***ReCycle***.

The analyses show considerable differences between loam and sand. In particular, increasing the effluent disposal field results in substantial reductions in storage volume for the loam but limited reductions in the sand.

ReCycle also allows for the determination of annual drainage to soil layers below the surface layer of interest (Figure 7). In the loam, drainage significantly decreases with the effluent application area and depth of soil, ultimately to zero. However, for the sand, substantial drainage of both rainwater and effluent continues throughout the year regardless of the size of the effluent application area. For very large effluent application fields (say > 800 m^2), drainage would primarily consist of rainwater given that much of the effluent is prevented from being applied to the soil when soils exceed field capacity, being temporarily held in the OSD facility.

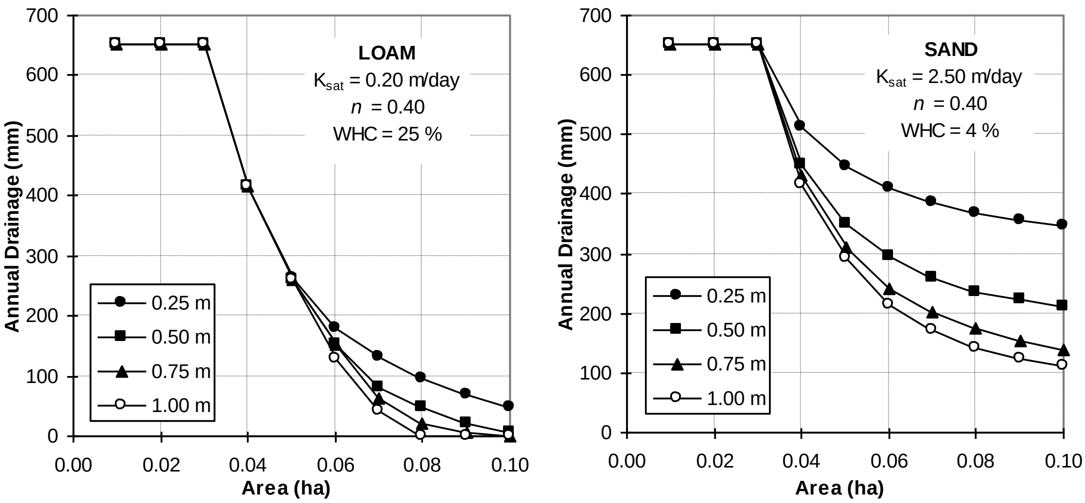

Figure 7: Total annual soil drainge to deeper layers (median values) based on daily soil moisture budeting determined through *ReCycle*.

2.3 Comparison of monthly and daily methods

Figure 8 compares median storage volumes between monthly and daily (loam and sandy soils), indicating that although there is some similarity of findings between the methods at low disposal field sizes (≤ 300 m^2), the monthly method grossly over-estimates the actual volume of storage required. From these analyses, it is concluded that monthly water balance methods are misleading and should not be employed when determining OSD facility volumes.

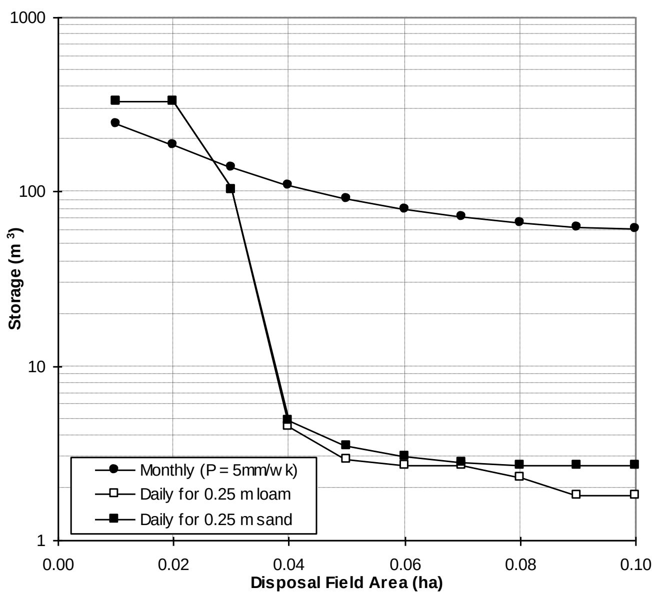

Figure 8: Comparison of storage volumes based on monthly methods (median values) and daily soil moisture analyses conducted using ***ReCycle***.

3 Storing Effluent

Two principal approaches to storing effluent are usually undertaken:

1. Provision of above-ground OSD facility; and
2. Provision of below-ground OSD facility as a part of the disposal system such as within gravel trenches

Until recently, above-ground facilities have been the only option available for the storage of effluent to managers. Below-ground storage has only been utilised where standard evapotranspiration beds have been implemented. Below-ground storage has not been utilised for sub-surface irrigation systems due to the very large volumes determined from the monthly water balance assessments.

With the implementation of a daily soil moisture budgeting approach, more realistic and physically sensible OSD volumes are derived. This therefore means that effluent storage within gravel trenches (to a design level such as median OSD volume required) can be provided.

To illustrate this, say a total of 5 m^3 of OSD was required and a disposal field of 600 m^2 was to be installed. Sub-surface trenches, spaced at say 0.90 m with a depth of 0.30 m and width of 0.30 m with the lower 50 % of the trench sealed or lined, would provide a total in-ground storage volume of approximately 15 m^3. This certainly accommodates the required 5 m^3 OSD, as well as significantly reducing site management and maintenance requirements and costs of installation.

In summation, provision of OSD storage is desirable. However, it is also desirable to reduce the maintenance of the OSD system by reducing the responsibility and interaction with the home owner. Below-ground OSD facilities, sized according to detailed daily soil moisture analyses, provide a means of achieving this approach.

4 Wet-weather Storage Facility Maintenance & Monitoring

With above-ground storage facilities, a soil moisture monitoring system is typically required to determine when and when not to irrigate or apply effluent. Soil moisture probes come in a variety of types such as hydrometer, capacitor and resistance based models, but each needs to be specifically calibrated to site conditions. Calibration may require some time and expertise before the optimal setting can be found.

As a part of the calibration exercise, suitable soil moisture levels need to be determined at which effluent application ceases and effluent storage begins. Ideally, the moisture probes should be set at field capacity, or the point at which soil drainage begins. This setting is required to ensure that effluent is not applied to the site when soil drainage is occurring.

5 Extended or Prolonged Wet-weather

During extended or prolonged wet-weather, soil moisture levels increase and drainage from the soil to groundwater occurs, particularly in higher rainfall areas and on permeable soils. In the design of the OSD facility, it is important to consider the strength (in terms of say $BOD_5 < 50$ mg/L, TN < 50 mg/L, and TP < 10 mg/L, see NSW EPA, 1995) of the effluent being applied to the site. In general for domestic installations, it is appropriate to allow the OSD facility to 'fail' once every 2 years, failure being taken as effluent being applied to the site under wet-weather where soil moisture is in excess of the field capacity and some drainage is occurring. However, under the daily soil moisture modelling approach, better performance can be guaranteed.

The ***ReCycle*** program calculates the maximum OSD volume required for each year of record. Yearly maximum data are then assessed to determine median, mean, 75th percentile, 90th percentile and maximum storage OSD volumes for the entire record. Using this approach, a suitable OSD volume can therefore be chosen depending on effluent strength to be applied to the site.

6 Common Effluent Schemes

In the case of common effluent schemes (CES) where the scale of effluent disposal or re-use is significantly larger, the daily soil moisture approach is also recommended as it provides a physically correct estimate of OSD volume required for the scheme. Because of the economies of scale associated with CES's, higher safety margins (eg. using 90th percentile results) can be applied to provide for additional OSD volume catering for 1 in 10 year failure.

7 Conclusions

Several conclusions are drawn from the discussion provided in this paper.

1. The water balance monthly method grossly over-estimates the actual volume of storage required. It is concluded that monthly water balance methods are misleading and should not be employed when determining OSD facility volumes. Historical daily soil moisture analyses should be undertaken to determine the OSD facility volumes.

2 It is desirable to reduce the maintenance of the OSD system by reducing the responsibility and interaction with the home owner. Below-ground OSD facilities, sized according to detailed daily soil moisture analyses, provide a means of achieving this approach.

3 In general for domestic installations, it is appropriate to allow the OSD facility to 'fail' once every 2 years, with failure being taken as effluent being applied to the site under wet-weather where soil moisture is in excess of the field capacity and some drainage is occurring. However, under the daily soil moisture modelling approach, better performance can also be guaranteed.

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