INNOVATIVE SUSTAINABLE DESIGN APPROACHES FOR ONSITE SEWAGE TREATMENT

Chia Shun "Rocky" Shih[1], G. Alberto Arroyo[1], and Anna Maricel Doro-on[1]

[1]*Department of Civil and Environmental Engineering, University of Texas at San Antonio, 6900 N. Loop 1604 West, San Antonio, Texas 78249,USA*

The On-Site Sewage Facilities (OSSF), commonly named as Septic Tank Systems, is supposedly to provide adequate treatment for individual private dwellings. In reality, because of its poor efficiency and lack of sound engineering design, the OSSF has become a modern façade to pollute the land and groundwater resources legally and unethically. The objective of this paper is to present an innovative design approaches for OSSF based on land treatment principles and new evapotranspiration bed design formulations to provide the needed sustainability for land and local environment where the OSSF is situated.

Keywords: OSSF, land treatment, evapotranspiration bed.

INTRODUCTION

On-site sewage facilities (OSSF) have been widely used to treat wastewater from individual residence and community facilities in unsewered area. In many classic literatures, it is named as septic tank systems. Currently, there are about 20 to 30 percent of the population in Europe and North America utilizing OSSF for domestic wastewater disposal. Whereas, there are 17 million housing units, or 1/3 of all housing units, dispose of domestic wastewater through the use of septic tank systems in the US. It has become an open and unethical means to pollute our landscape legally. This paper will illustrate new design approaches to eliminate such pollution based on the sustainable carrying capacity of our soil and environment.

INADEQUACY OF OSSF

Different alternatives of OSSF systems have been devised because of the demand of protecting the public health and water resources since 1980. However, different states have admitted in their 1998 Clean Water Act reports that designated uses (e.g. drinking water, aquatic habitat) were not met for 5,281 water bodies because of pathogens and nutrients associated with OSSF (USEPA, 2002:section 303(d)). The most common water-quality problems created by different OSSF are summarized in Table 1.

In reality, all OSSF design is not standardized, regulated and engineered properly. In fact, the sewer contractors without any formal engineering training and knowledge are normally the one who sizes and installs most OSSFs. Consequently, most OSSF systems become the septic or anaerobic waste holding tank, the source of concentrated pollutant discharge, the pollution for the land and groundwater legally, the most inefficient and illogical treatment system for domestic wastewater and the sources

[1] cshih@utsa.edu

Shih, C S R, Arroyo, G A and Doro-on, A M (2004) Innovative sustainable design approaches for onsite sewage treatment. *In:* Khosrowshahi, F (Ed.), *20th Annual ARCOM Conference*, 1-3 September 2004, Heriot Watt University. Association of Researchers in Construction Management, Vol. 2, 785-94.

unaccountable amount of pollution to the American landscape. Figure 1 illustrates different ways of wastewater OSSF to pollute groundwater and surface water.

Figure 1. Fate of wastewater discharge from OSSF (USEPA, 2002)

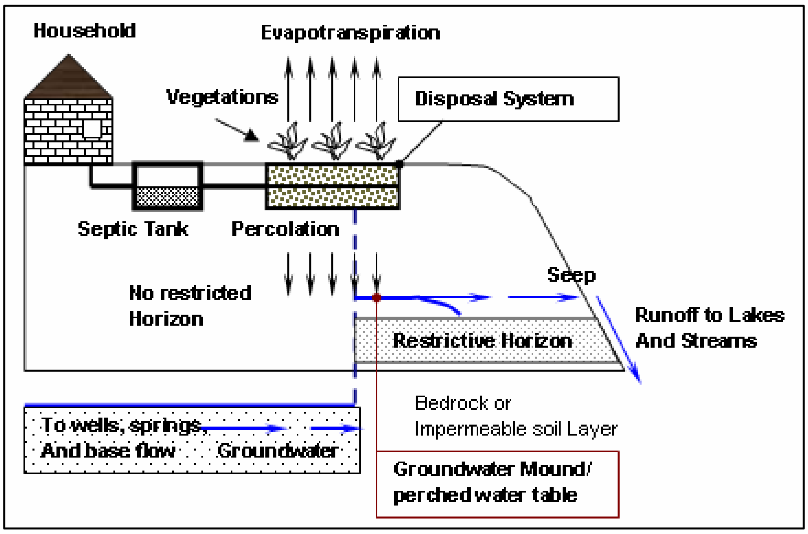


Table 1. Common water quality problems of conventional OSSF

Alternative OSSF	Problem Description of OSSF
Mound System and Intermittent Sand Filters	Sever problems occurs when there is power outage, also during prolonged rainfall will create wastewater generated accumulated in that dosing facility and septic tank. Also, increasing potential odors
Continuous Flow, Suspended-Growth Aerobic Systems (CFSGAS)	Sensitive to temperature, interruption of electricity, influent viability or shock loading of chemicals. The blowers of CFSGAS creates noise that will cause major irritant. Produce potential Odors during organic loading.
Fixed –Film Processes	It may create public health hazard through production of poor quality effluent during worst weather condition.
Vegetated Submerged Beds(VSBs), and Other High-Specific-Surface Anaerobic Reactors(HSSARs)	Nagging problem associated with odor (hydrogen sulfide) and corrosion development.
Evapotranspiration bed/Infiltration Field (ET)	Unsatisfactory performance due to overflow, during continuous rainfall or worst weather condition.

INNOVATED INFILTRATION FIELD SYSTEM DESIGN

The existing design approach for the infiltration field for the OSSF has been arbitrary and lack of scientific basis. Scientifically, the infiltration field should be based on the concept of land treatment for its field sizing and considerations of the vegetative coverage. It is recognized that the total non-operating days due to adverse climatic situations for vegetation growth must be included in the computation for the infiltration field requirement. Meanwhile, a storage pond must be added to hold the wastewater generated during non-operating days. The formulations for the design of infiltration field is proposed as follows:

When Precipitation (Pr) is greater than Evapotranspiration Bed (ET): Pr>ET

$$A_F = \frac{([365q/7.48][365/(365-t_{NO})]\} + Vs}{L_{WD} - \{(\Pr - ET)(365/(365-t_{NO})\}}$$

B. When ET≥Pr:

L_{wn} = 0.37U /{(1-f) C_n} = (ET – Pr)

Where, Max. C_n = 0.37U/[(1-f)(ET-Pr)]

$$A_F = \frac{([365q/7.48][365/(365-t_{NO})]\}}{L_{WD} + \{(ET - \Pr)(365/(365-t_{NO})\}}$$

In most cases, $L_{WD} = L_{wn} = (ET\text{-}Pr)$

Thus,

$$A_F = \frac{([365q/7.48][365/(365-t_{NO})]\}}{\{(ET - \Pr)[1 + (365/(365-t_{NO})]\}}$$

Where: t_{NO} =Number of non-operating days per year, day

A_F = Infiltration Field, acre

L_{WD} = Designed hydraulic loading rate , in/yr

L_{wn} = Allowable hydraulic loading rate on annual nitrogen loading rate, in/yr

q = Wastewater flow, gal/day

C_n = Nitrogen in wastewater, mg/L

P_r = Design precipitation rate, in/yr

U = Nitrogen uptake by crop, Ib/ acre·ft

f = Fraction of applied total Nitrogen removed by denitrification and volatilization, 15-25%

Vs = Volume, cu.ft./yr

THE ILLUSTRATIVE EXAMPLE FOR THE DESIGN OF INFILTRATION FIELD

Problem Description

The site is located in central Missouri in an area characterized by fertile soils and intensive farming. Additionally, rainfall is more abundant than is needed for most crops, but is distributed unevenly during the year. Likewise, area is subjected to periodic changes in weather with no lengthened periods of seriously cold or greatly hot weather. The last freeze is usually in late March and the first freeze in early November. Climatic data obtained from the National Oceanic and Atmospheric Administration's Weather Center of the United States, is summarized in the table below. Determine the Hydraulic-loading rate based on Nitrogen (U.S. Army Corps of Engineers, 1982). Total N = 40mg/L. Preliminary design assumes forage grass based on nitrogen uptake rate 400 lb /(acre-year) and the limiting soil permeability is K = 0.60 in/hr, considering, there is no drainage system toward the site.

Solution

Maximum daily Percolation rate (P_w) computation: for the soils of relatively uniform and sandy, limiting soil permeability is K≥0.2 in/hr, thus,

P_w (daily) = (permeability of soil, K-inch/hr)(24 hr/day)(4%-10%),in/day

Normally, only a small percentage of the vertical permeability is used to account for the needed drying time between applications, considering the variability within a site, and the potential reduction with time, the percentage ranges from 4% to 10% of the saturated vertical permeability is recommended (Crites, Reed & Bastian, 2000). A value of 4% is used here in order to be conservative for preliminary design.(U.S. Army Corps of Engineers, 1982).

P_w (daily) = (0.6 in/hr)(24hr/day)(0.04) = 0.57 in/day

$P_{w\ (monthly)} = (P_{w\ DAILY})$ x (Number of operating days/month)

For instance, in January, the designed percolation rate per month will be,

P_w (Jan) = (0.57)(11 operating days) = 6.2 in/month,

Table 2, illustrate the computation of hydraulic loading (L_w) based on Pr and ET.

Table 2. Monthly hydraulic loading computation.

1	*2*			*3*	*4*	*5*	*3+5*
MONTH	ET, in	Operating days	Non-Operating days	Monthly Percolation P_w(in)	Monthly Precipitation, (Pr) in	Monthly Net ET – Pr in	Hydraulic Loading (L_w) inch
Jan	0.1	11	20	6.22	3.98	-3.9	2.36
Feb	0.3	13	15	7.36	4.09	-3.8	3.54
Mar	0.8	19	12	10.8	5.94	-5.1	5.67
Apr	2.2	30	0	17.0	6.22	-4.0	13.00
May	3.8	31	0	17.6	6.85	-3.0	14.5
June	5.3	30	0	17.0	5.63	-0.4	16.7
July	6.2	31	0	17.6	5.55	0.63	18.2
Aug	5.5	31	0	17.6	4.84	0.63	18.2
Sept	3.5	30	0	17.0	5.79	-2.3	14.7
Oct	2	27	4	15.3	3.9	-1.9	13.4
Nov	0.7	18	12	10.2	5.83	-5.1	5.08
Dec	0.2	14	17	7.95	5.12	-4.9	3.07
Annual	31	285 days	80	161	63.8	-32.8	128

In general, infiltration operation will stop during days when the average temperature is less than – 4^{o}C or 25 ^{o}F based on the climatic data from the NOAA shown in Table 2, non operating days due to cold weather are estimated for the months between October and March. (U.S. Army Corps of Engineers, 1982)

DETERMINATION OF HYDRAULIC LOADING BY MONTH

Using the following formula below, the monthly allowable hydraulic loading(L_w) in ft/yr is determined:

$L_w = P_w$ + ET (Evapotranspiration) – Pr (Precipitation)

L_w = (K x 24 x 0.04) + (ET - Pr)

K = Permeability of Soil = in/hr

As shown in Table 2, Pr – ET = 63.8 – 31 = 32.8 in/yr

$$L_{wn} = \frac{(10mg/L)(32.8/12) + 0.37(400)}{(1-0.15)(40)-10} = 7.31\,ft/yr \text{ (Based on Nitrogen)}$$

Loading Rate: L_{wD} = is found to be minimum loading rate of ($L_{w,} L_{wn}$)

Thus, L_{WD} = 7.31 ft/yr

Infiltration Field Area (A_F) Computation:

t_{NO} = 80 non-operating days ; t_O (operating days)= 365-80 = 285

$$A_F = \frac{(900)(365)}{7.48[7.319(285/365)-(32.8)/12]} = 14{,}748.00 sq.ft. = 121.44\,ft x 121.44\,ft$$

Considering safety factor, recommend infiltration field area is A_F = 125 ft x 125 ft
The design layout for the OSSF with infiltration field is shown in Figure 2.

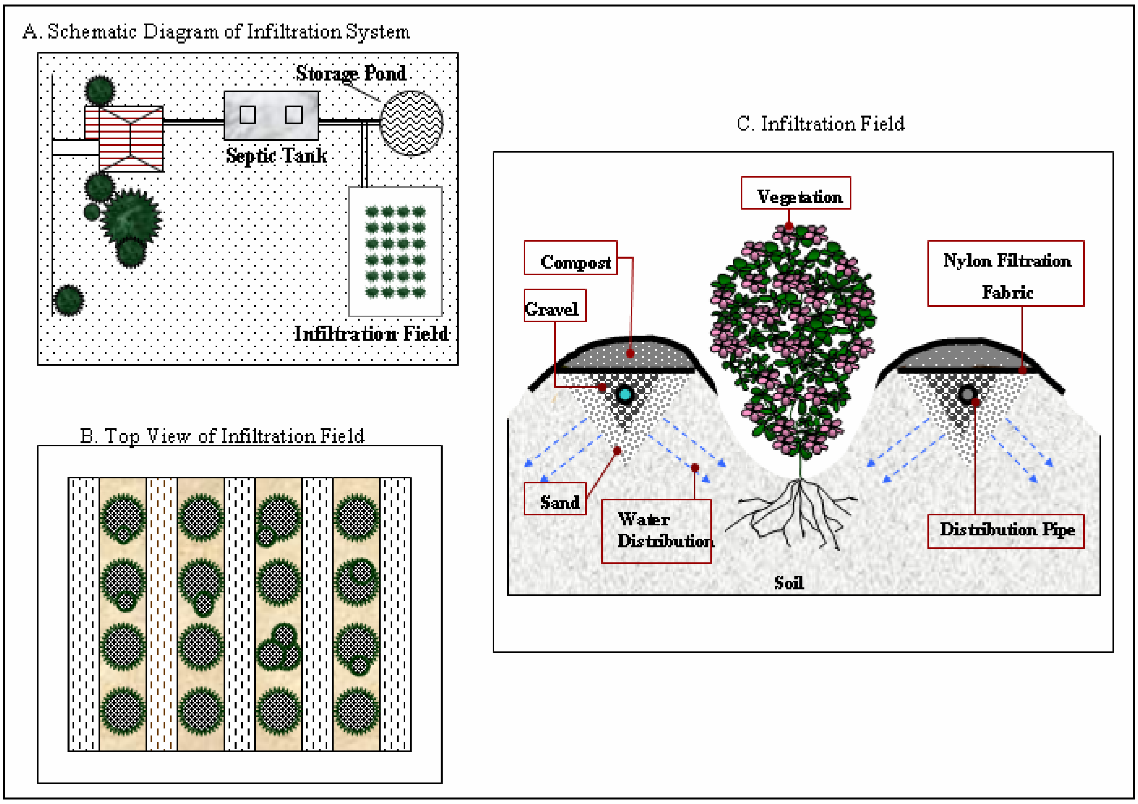


Figure 2.Schematic diagram of innovative design of infiltration field for OSSF.

EVAPOTRANSPIRATION BED SYSTEM DESIGN

For the OSSF using evapotranspiration bed (Figure 3), the design consideration must include the following: the highest accumulated rainfall with the consecutive storm cycles, the porosity of the soil and the vegetation coverage. It should be noted that the innovative design for the evapotranspiration bed must also include the storage requirements for the rainy days as well as the selection of vegetation based on the soil and climatic characteristics. In fact, the choice of vegetation coverage is the same as that for infiltration field. The optimum choice of vegetation vs. soil and climatic conditions has been suggested by Crites, Reed and Bastian as shown in the Table 3 (Crites, Reed and Bastian, 2000). In addition, the installation of evapotranspiration bed must include a layer of geosynthetic membrane placed under the soil and an evenly distributed piping systems for the gas venting with the commercially available compost (CAC) adapted for the absorption of poisonous gases. It should be noted that, the separation by the use of a concrete or steel walls for the evapotranspiration bed from the surrounding soils must be installed to prevent the siphoning and/or the water infiltration from ground soil.

Table 3. Nutrient uptake rates for selected crops (Crites, Reed, and Bastian, 2000)

Crop	lb/acre.year		
	Nitrogen, N	Phosphorus, P	Potassium, K
FORAGE CROPS			
Alfalfa	200-600	20-30	155-200
Bromegrass	115-200	35-50	220
Coastal Bermuda grass	350-600	30-40	200
Kentucky Bluegrass	175-240	40	175
Quack grass	210-250	25-40	245
Reed canary grass	300-400	35-40	280
Ryegrass	160-250	50-75	240-290
Sweet clover	155	18	90
Tall fescue	130-290	27	270
Orchard grass	220-310	18-45	200-280
FIELD GRASS			
Barley	110	13	18
Corn	155-180	18-27	100
Cotton	65-100	13	36
Grain Sorghum	120	13	60
Potatoes	200	18	220-290
Soy beans	220	10-18	27-50
Wheat	140	12	18-50

INNOVATED EVAPOTRANSPIRATION BED DESIGN

The innovated design approach for the evapotranspiration bed is based on the following formulas for the computation of Hydraulic Loading Rate and Field Area Requirements:

$$L_{wn} = \frac{0.37U}{(1-f)(C_n)} = [ET - \text{Pr}]$$

$$V = \frac{A_b d}{\phi} = (\sum_{i=1}^{M} R \text{ Total Rainfall}) + \{\Sigma N_i \times q\}$$

$$A_b = \frac{\{\Sigma N_i \times q\}}{\{(M \times d \times \phi) - \Sigma^M R\}}$$

Where:

$$d\phi \geq \Sigma^M R \quad \text{and} \quad Md \geq \Sigma^M R/\phi$$

Therefore:

$$M = \Sigma^M R / \phi d$$

$$\sum_{i=1}^{M} {}^M R = \Sigma R_i - \{[\Sigma N'_i \times ET]/365\}$$

Where:

L_{wn} = Allowable hydraulic loading rate on annual nitrogen loading rate, in/yr
C_n = Nitrogen in wastewater, mg/L
P_r = Design precipitation rate, in/yr
U = Nitrogen uptake by crop, Ib/ acre·ft
f = Fraction of applied total Nitrogen removed by denitrification and volatilization, 15-25%
V = Volume, cu.ft./yr
A_b = Area, sq. ft.
d = Depth, ft ~ design depth normally 3ft
ϕ = Porosity, %
N_i = Number of days of ith continuous rainfall in max. length of poured with consecutive rainfalls for specific location.
q = Wastewater flow, gal/day
$\Sigma^N R$ = Total stored water during the period of maximum consecutive rainfalls, ft
M = Multiplier for area estimation
N'_i = No. of dry weather days between ith and (i + 1)ith consecutive Rainfall
ET = Evapotranspiration, ft/yr
$\sum_{i=1}^{N} R_{Ni}$ = Total Consecutive Rainfall, ft

ILLUSTRATIVE EXAMPLE FOR THE DESIGN OF EVAPOTRANSPIRATION BED SYSTEM

PROBLEM DESCRIPTION

The site is in Houston Texas. The average monthly evapotranspiration rates are given below. The soil is deep clay loam with a permeability of K= 0.4 in/hr. Total N = 40 mg/L, C_p = 10 mg/L (as required by USEPA), and f = 20%. The crop is Alfalfa where U is 400. Annual potential evapotranspiration and precipitation data are base from

Texas-ET Network. The monthly hydraulic loading rate computations are illustrated in Table 4. The longest continuous rainfall is found to be 36 inches within 10 days. After 3 dry weather days, another consecutive rainfall within 8days resulted total precipitation of 12 inches, and after 4 dry weather days followed by a precipitation of 6 inches in 6 days, as illustrated in Figure 3.

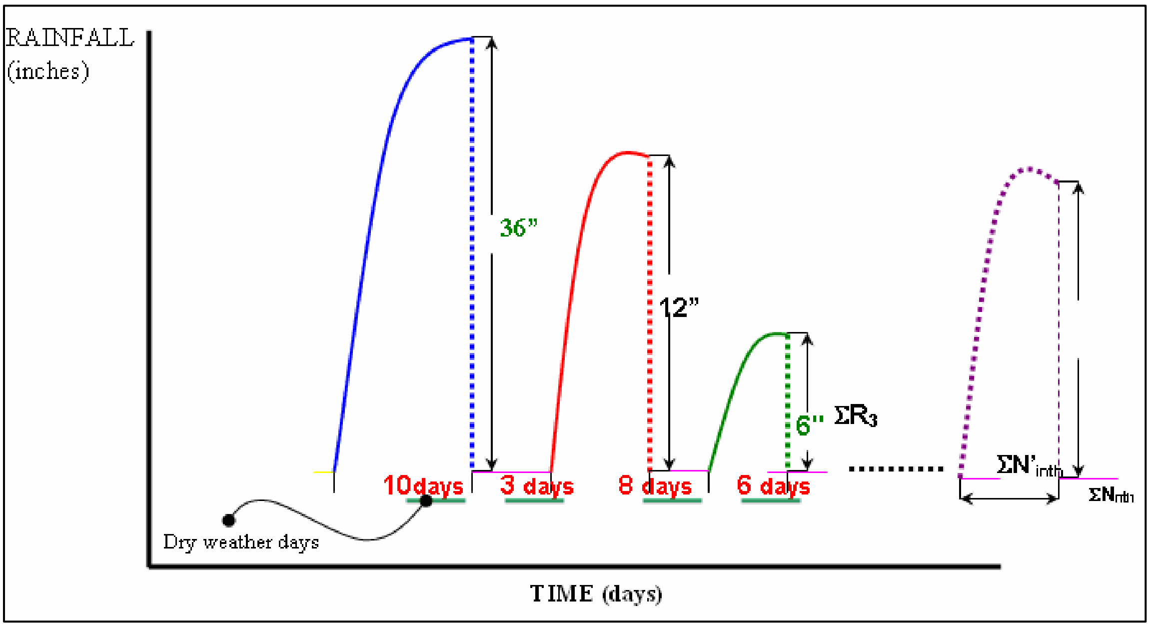
Table 4. Year 2002, monthly hydraulic loading rate computation of Houston Texas.

1 MONTH	2 Evapotranspiration, (ET)in	3 Percolation in	4 Precipitation, (Pr) in	5 ET – Pr in	3+5 Hydraulic Loading (L_{wD}),in
Jan	2.02	6.14	8.164	-6.144	0.004
Feb	2.71	7.296	9.238	-6.528	-0.768
Mar	4.03	9.984	11.33	-7.3	-2.684
Apr	5.23	11.5	16.75	-11.52	0.02
May	7.48	11.9	19.38	-11.9	0
June	8.08	11.5	19.6	-11.52	0.02
July	7.79	11.9	19.69	-11.9	0
Aug	7.78	11.9	19.68	-11.9	0
Sept	6.06	11.5	17.58	-11.52	0.02
Oct	4.90	10.8	15.65	-10.75	-0.05
Nov	3.06	6.91	9.972	-6.912	0.002
Dec	2.12	6.14	8.264	-6.144	0.004
Annual	61.26	117.45	175.3	-114.04	-3.41

(1) $\Sigma^{N}R$ = 36” + 12” + 6” – {15 (61.3)}/365 = 51.5”
ΣN_i = 10 + 8 + 6 = 24 days
$M = \{\Sigma^{N}R / \phi\}/d\phi$ = {(51.5 /0.4)/12}/3= 3.58
A_b = {24 x900/7.48 x (3.58)}/[(3/24) - 51.5/12] = 3181 sq..ft., field area requirement

(2) Storage Pond
The Storage pond is sized based on maximum freezing period of 67 days:
Minimum Depth of Infiltration Field = 3 ft
Distribution Pipe will be controlled by temperature triggered value @ 25 ^{o}F
Storage Pond Requirement = 900 x 67 = 60300 gal = 8061.49 cu, ft.
If depth of pond =6 ft, area of storage pond = 36 ft x 36 ft,
Diameter = 41 ft
The design layout for the OSSF evapotranspiration bed is shown in Figure 4.

Figure 3. Diagram of consecutive rainfall in many days



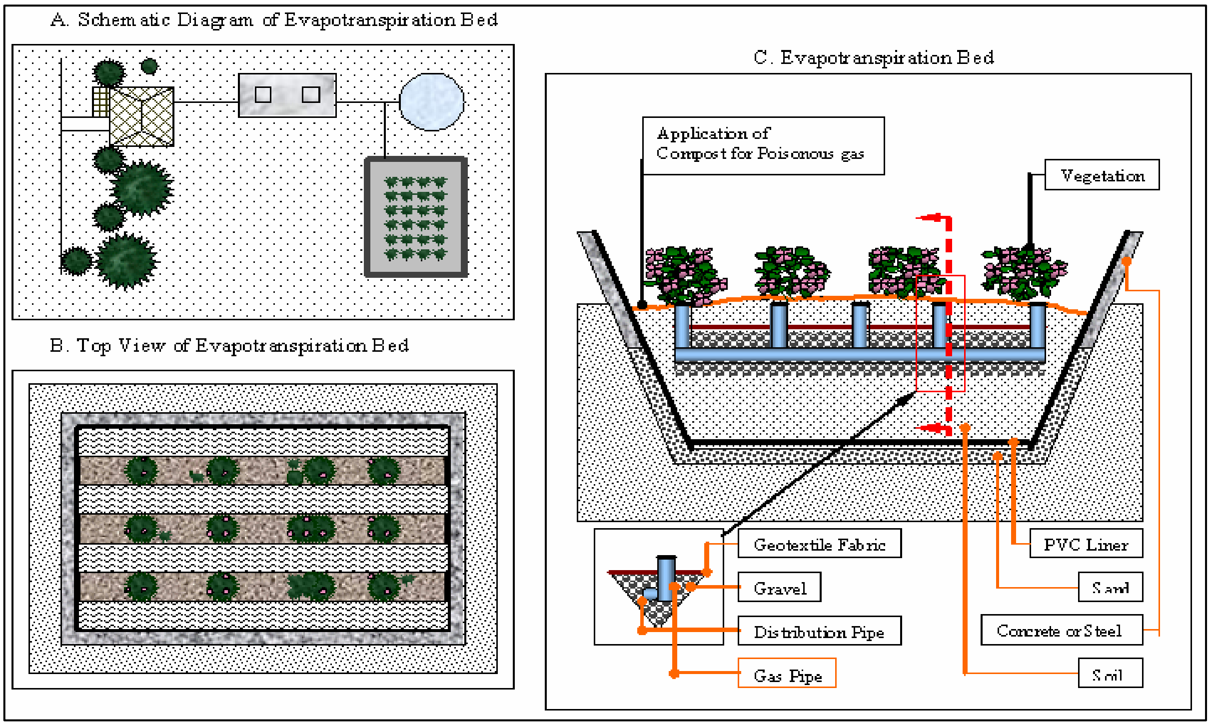


Figure 4. Schematic diagram of innovative design of evapotranspiration bed for OSSF.

CONCLUSIONS

The existing Regulatory Requirement related to OSSF design, installation, monitoring and the licensing, are grossly inadequate, especially for those located inside the recharge zone of a groundwater aquifer.

For the OSSF using infiltration field, a formula incorporating the principle of nitrogen utilization has been developed as follows:

$$L_{wn} = \underline{0.37(U\text{-}S)} + [Pr - ET] \quad (\textit{when } Pr>ET)$$

$$A_F = \frac{(1-f)(C_n)\, q[365]}{7.48[L_{wD}(t_O/365) - (Pr - ET)]} \quad \textit{(sq.ft.)}$$

For the OSSF using evapotranspiration bed, a set of design formulae has been developed based on the consideration of yearly maximum consecutive rainfalls, the soil porosity and the evapotranspiration characteristics of the site as follows:

$$V = \frac{A_b d}{\phi} = \left(\sum_{i=1}^{N} {}^{N}R \text{ Total Rainfall}\right) + (N \times q)$$

$$A_b = \frac{(\Sigma N_i) \times q \times M}{[(d/\phi) - \Sigma^N R]}$$

$$M = \{\Sigma^N R / \phi\}/d$$

$$\Sigma^N R = \sum_{i=1}^{N} R_{Ni} - [\Sigma N'_i \times ET/365]$$

The innovative methodology presented herein have incorporated the following considerations: sustainable carrying capacity of nutrient utilization and evapotranspiration rate of soil, protection against the contamination of groundwater and surface water, commercial viability, elimination of conventional septic leaching field, the application of land treatment principles, and the development of a new evapotranspiration bed design concept.

REFERENCES

Crites, R., Reed, S. and Bastian, R. (2000). Land Treatment Systems for Municipal and Industrial Wastes. McGraw-Hill, USA.

Doro-on, A.M. (2003), An Innovative Design Methodology for Onsite Sewage Facilities, Published MSCE Thesis, Department of Civil and Environmental Engineering, The University of Texas at San Antonio.

Doro-on, A.M., Shih, C.S. and Arroyo, G.A. (2003). An Innovative Design Methodology for Onsite Sewage Facilities, *NREP/INSTEP Annual Technical Conference and Pre-Conference Workshops and Certification Courses*, 17-21 November 2003, Rozen Plaza, Orlando, Florida, *http://instep.ws*.

Texas-ET Network (2003). Texas Potential Evapotranspiration & Rainfall. Texas Cooperative Extension-The Agricultural Program-The Texas A&M University System, http://www.texaset.tamu.edu//index.php

United States Army Corps of Engineers (20 May, 1982). Engineering and Design- Process Design Manual for Land Treatment of Municipal Wastewater. Publication No., EM 1110-1-501, Washington D.C.

United States Environmental Protection Agency-USEPA (Feb 2002). Onsite Wastewater Treatment Systems Manual. Office of Water, Office of Research and Development. EPA/625/R-00/008.