Effect of Different Vadose Zone Depths on the Purification Process of an Aggregate Laden Soil Infiltration System.

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ABSTRACT

This study investigated the wastewater effluent quality from a soil purification system, considering the influence of the vadose depth. A wastewater soil infiltration system was designed and fabricated. It consisted of 10 compartments, each with $12x12cm^2$ surface area. The system had two different soil vadose zone depths of 60cm and 90cm to the ground water level. Loamy sand soil (water content of 18.8%, bulk density of 2.51 and saturated hydraulic conductivity of 0.051cm/s) was used as the infiltration medium. The wastewater filtrate is meant for both domestic and irrigation purposes.

For 24 weeks, the soil infiltration system was dosed 4 times daily with raw wastewater. The filtrates were collected weekly over a 24 hour period. The raw wastewater, the control potable water, and the filtrate were analyzed weekly. The trend indicated purification improved gradually over the 24- week period. Considering the two vadose depths of 60 and 90cm the BOD values of (69.86 and 76.82mg/l), COD (71.28 and 71.79mg/l), TSS (65.31 and 66.22mg/l) and TBC (165/100 and130/100ml) respectively are within the FAO standard for irrigation, but TSS and TBC both exceeded the WHO water quality standard for consumption. NO_3 (14.36 and 7.85 mg/l), PO_4 (8.48 and 3.50mg/l), C (8.11 and 3.39 mg/l) and K (1.82 and 0.98mg/l) are within the limits for both domestic and irrigation purposes. The pH and temperature level (7.6 and 30^oC respectively) are also suitable for both these purposes. Soil vadose depth of 90cm had better purification efficiency on TDS with the filtrate concentrate of 283.2mg/l being within both WHO and FAO standards, while soil vadose zone depth of 60cm had a range of 560.3mg/l. This exceeded Nigeria NAFDAC standard of 500mg/l but falls within FAO standard for irrigation purpose. There was significant difference ($p < 0.05$) in purification performance attributable to the soil vadose zone depth. 90cm depth had a stronger influence on the purification system than that of 60cm.

(Keywords: wastewater purification, infiltration, soil filtration, Nigeria)

INTRODUCTION

Domestic wastewater can be treated using soil infiltration system and recycled for domestic and agricultural usage. Wastewater in this study refers to all the water used in the home that goes down the drain or into the sewage collection system; such as water from baths, showers, sinks, dishwashers and water closets. In arid and semi-arid areas, where surface water is scare and rainfall distribution poor, recycling wastewater will go a long way in ameliorating the problems caused by clean water scarcity and also improves hygienic standard of the people. Nature has provided a means of treating wastewater as it percolates through the soil and plant can serve as a living filter which is capable of renovating the wastewater for groundwater recharge or disposal to receiving water courses. Since good water is scare, wastewater can be recycled with minimal treatment for both domestic and agricultural usage.

Wastewater systems for onsite and small-scale applications are commonly designed for application of primary treated wastewater into natural soil where it infiltrates and percolates through the vadose zone before it recharges the underlying groundwater. Such systems are widely used because of their high purification performance with respect to organics, solids and nutrients, with relatively low cost and limited operation and maintenance requirements

(Siegrist and Cuyk, 2001). A system's physical features, operational parameters and environmental conditions can determine its hydraulic and purification behaviors. The infiltration surface character and the soil vadose zone depth are two system features that are commonly determined during design (Cuyk et al., 1999).

Long time contact between wastewater constituents, the soil matrix and associated biofilms occur during unsaturated flow. This can be achieved by intermittent dosing (e.g., 4-24 times per day) of daily loadings, limited to a small fraction of the soil's saturated hydraulic conductivity (Cuyk et al., 2000).

The infiltration rate in these systems is critical to system design and the resulting performance achieved in terms of both hydraulic and purification aspects. The infiltration behavior experienced during treatment of wastewater effluents in soil is extremely complex and even after decades of study it is still not fully understood. While it is clear that wastewater effluent composition and loading characteristic can impact infiltration rate behavior during wastewater purification, the underlying phenomena have not been fully elucidated for different designs and environmental conditions (Siegrist and McCray, 2006).

Performance data related to the extent of soil clogging in systems with gravel on the infiltrative surface (Aggregate-laden) led to infiltration system design that have an open surface (Aggregate-free), the most common of which is the chamber system (May, 1996). Gravel on an infiltrative surface can reduce infiltration zone permeability by becoming embedded in the soil matrix, yielding fines that are deposited in pore entries thereby blocking them and by attracting wastewater constituents to itself as a result of the reduced permeability due to the effects of the factors above (Jenssen and Siegrist, 1990).

Vinten et al. (1983) who worked on the effect of suspended solids in wastewater on soil hydraulic conductivity and vertical distribution of suspended solids discovered that clogging was influenced by the amount of suspended matter and pore size distribution. This resulted in decrease in hydraulic conductivity for finer textured porous media. Siegrist and McCray (2002) worked on principles and behavior of infiltration process during onsite wastewater treatment in soil systems. They found that long-term decrease in infiltration rate is due to the deterioration of soil structure, partial sealing of profile, particle relocation, and air entrapment within the soil structure.

According to Siegrist et al. (2000), an estimate of the time required for effluent to infiltrate and percolate to a given depth based on the daily flow, area of infiltrative surface, and an effective porosity for the soil (loamy sand soil) is based on the following relationship:

$$Tr = \frac{(A_{IS})(D)(N_e)}{Q} \quad \textbf{(1)}$$

where: T_r = travel time required for effluent to reach the depth of interest (days)
D = depth of interest (m)
A_{IS} = infiltrative surface area (m^2)
Q = daily flow (m^3/day)
N_e = effective porosity (v/v)

This relationship assumes uniform application and infiltration into the absorption system. Unsaturated zone thickness beneath a soil infiltration system and the depth to ground water can affect hydraulic function and in turn purification by influencing the soil water content, aeration status, media surface area, and hydraulic retention time. Usually, the thickness of the unsaturated zone for the soil infiltration system ranges from 0.6 to 1.2m and for intermitent sand filters, from 0.6 to 0.9m (US EPA, 1980; Anderson et al, 1985; Crites and Tchobanoglous, 1998).

A high degree of treatment normally occurs in the infiltration zone as soil clogging develops. However, at high hydraulic loading rates and with non-uniform distribution methods, constituents of concern that would normally be treated can be transported through the vadose zone to groundwater.

The objective of this study was to determine the effect of different vadose zone depths on the purification quality of wastewater through an infiltration system using loamy sand soil as the filtration media.

MATERIALS AND METHODS

Study Area

The study was carried out in the Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria. Makurdi lies between latitudes 7°45'and 7°52'N of Equator and longitude 8°35' and 8°41'E of Greenwich meridian. The physical characteristics of loamy sand soil sample used as the filtration media are water (18.8%), bulk density (2.51) and saturated hydraulic conductivity (0.051cm/s).

The Purification Chamber

A soil purification system made of fiberglass was designed and fabricated consisting of 10 compartments, each with 144 cm^2 surface area. The filtration media was loamy sand and the chamber comprised of two vadose depths of 60 and 90cm of five compartments each. Washed gravel (2 to 4mm diameter) was used both as envelope material over a screen ($1mm^2$) at the bottom of all the compartments and as aggregates over the surface of the compartments.

Dosing

The study which was in three replications was run for 24 weeks. During the 24 weeks of continuous operation, each compartment of the system was dosed 4 times daily with wastewater from same source. Physical and biochemical analyses were carried out weekly on the potable water (control) and wastewater before dosing. Wastewater effluents were collected in one–liter cans and stored in a refrigerator until the analyses were completed. Filtrate was collected over a 24-hour period at the end of every seven days (and stored in a refrigerator) for laboratory analysis. The essence of this was to keep the filtrate in a stable state pending completion of the laboratory analyses.

Analysis

Soil and Water Quality laboratories of the Abubakar Tafawa Balewa University, Bauchi, Nigeria was used for water and wastewater analyses while Soil and Water Laboratory of the Department of Agricultural and Environmental Engineering University of Agriculture, Makurdi, Nigeria was used for soil analysis. The GenStat 7.2 (2007) soft ware package was used for the statistical analysis of the raw data generated. The results are presented in tables and graphs. Percentage removal of the wastewater constituents was adopted as the measurement of the filtrate quality and the index of purification efficiency. This was because the aim of the study was to investigate the amount of the constituents that has been removed from the raw wastewater. The higher the quantity of constituents removed, the higher the quality of the filtrate and the more its acceptability.

The percentage removal was computed by using the following equation:

$$\%\,\mathrm{Re}\,moval = \frac{W_r - W_f}{W_r} \text{ X } 100 \qquad \textbf{(2)}$$

where w_r = Concentration of constituent in the raw wastewater before dosing
w_f = Concentration of constituent in the filtrate after dosing

RESULTS AND DISCUSSION

Physical Parameters

Removal of the key constituents from the wastewater is shown in Table 1. Summary of the treatment means, Coefficient of Variation (CV) and the Least Square Deviation LSD $_{(0.05)}$ of the parameters are given in Table 2 while Table 3 shows the comparison of the values got with the internationally accepted standards.

The CV less than 10 % indicates a good degree of precision in the study (Gomez and Gomez, 1984). At the end of the study (i.e 24 weeks), the depths of 60cm and 90cm, had mean percentage removal of total suspended solids (TSS) as 65.91% and 64.98% respectively (Table 1). This shows that 60cm depth (though shorter distance of travel) performed better in the filtration process throughout the 24 weeks with respect to TSS.

The filtration medium might have introduced some solids in the 90cm vadose zone depth. Vadose depth of 60cm had a treatment mean of 65.34mg/l while 90cm depth had 66.22mg/l (Table 2).

TABLE 1: Means of the Parameters monitored over a 24-week Period of the Study.

Parameters	Before Dosing		After Dosing (WW)			
	PW* (mg/l)	WW** (mg/l)	Retained (mg/l)		% Removal	
			60cm Depth	90cm Depth	60cm Depth	90cm Depth
TSS	28.49	288.03	98.20	100.88	65.91	64.98
TDS	139.78	1130.91	734.49	380.00	35.13	66.44
BOD	8.07	79.33	21.15	18.69	73.32	76.42
COD	33.94	305.55	87.83	84.48	71.24	72.34
NO_3	4.06	27.08	15.68	8.61	41.91	68.10
PO_4	0.05	14.93	11.61	4.80	22.23	67.88
C	5.92	178.51	35.54	14.92	80.10	91.65
K	0.76	21.05	6.90	3.81	67.17	81.85
TBC	125	8627	1789	1413	79.25	83.6
EC	1.78	4.16	2.29	2.261	45.10	45.64

**PW = potable water (control); **WW = Wastewater.*

Table 2: Treatment Means of the Analyzed Parameters.

PARAMETER		TSS	TDS	BOD	COD	NO_3	PO_4	C	K	TBC
TREATMENT MEANS	60cm	65.34	560.3	69.86	71.28	14.36	8.48	83.07	66.27	78.70
	90cm	66.22	283.2	76.82	71.79	7.85	3.50	92.42	82.22	83.60
$LSD_{(0.05)}$		0.0997	1.140	0.725	0.1404	0.434	1.451	1.228	1.692	0.724
CV %		0.4	5.7	2.4	0.5	2.1	8.0	3.4	5.6	2.2

Table 3: Comparing Values of Monitored Parameters with Water Quality Standards at end of Experiment.

S/N	Parameter	60cm	90cm	W.H.O. Max. Acceptable Conc.[1]	NAFDAC Max. Acceptable Conc.[2]	FAO[3]	Allowable limit for reuse in irrigation[4]
1.	Colour	-	-	5TCU	-	-	-
2.	pH range (units)	7.6	7.6	7.0 – 8.5	6.5 – 8.5	6.5 – 8.4	6 – 9
3.	BOD (mg/l)	69.86	76.82	-	500	<100	30 – 300
4.	TSS (mg/l)	65.34	66.22	30	100	18	50 – 150
5.	TDS (mg/l)	560.3	283.2	1000	500	450 – 2000	1500
6.	Potassium (K) mg/l	1.82	0.98	1 – 2	10	12	-
7.	Nitrates (NO_3) mg/l	14.36	7.85	50	-	50	30 – 45
8.	COD (mg/l)	71.28	71.79	-	-	65	100 – 500
9.	TBC (MPN/100ml)	165	130	Must not be detectable in any 100ml per sample	1 (max)	1 (max)	100 – 1000
10.	Phosphate (PO_4) mg/l	8.48	3.50		10	-	30
11.	Carbon (C) mg/l	8.11	3.39	100	-	-	-
12.	EC (dS/m)	2.1	2.08	-	120	0.7 – 3	-
13.	Temp(°C)	30	30	25	-	-	-

[1]WHO, 1988 Guidelines for drinking water
[2]NAFDAC, 2004: Water quality standard for consumption
[3]FAO, 1985 Standard for irrigation
[4]Ministry of Water & Irrigation, Jordan, 2006.

There was a significant effect of the depth on the filtrate quality. This meant that in this chamber the shorter the travel distance of the wastewater produced a more acceptable quality of the filtrate with respect to the TSS (though subject to verification with still shorter distances of travel).

The TSS values exceeded the WHO Standard of 30mg/1 and FAO value of 18mg/1 for domestic uses, but are within the limits of 50-150mg/1 for reuse in irrigation as recommended by the Jordan Ministry of Water and Irrigation Standard, as well as Nigerian NAFDAC acceptable concentration of 100mg/1 (Table 3).

Based on the TSS data and the guidelines, the effluent is suitable for irrigation and consumption under Jordan and Nigerian contexts (Table 3).

The mean percentage removal of the TDS in the 60cm vadose depth was 35.13% and in the 90cm vadose depth the mean percentage removal was 66.44% (Table 1). The TDS varied significantly with depths (Table 2). The value obtained from 90cm depth (283.2mg/1) is within WHO and FAO standards for domestic and irrigation purposes (Table 3). However, the value of 60cm depth (560.3mg/1) is above the 500mg/1 value of NAFDAC (Nigeria) for water consumption. TDS removal is achieved more when the wastewater traveled over a longer distance in the filtration chamber (contrary to that of TSS). The lower TDS value at 90cm indicates that the deeper the filtration chamber (vadose zone) the more time for the particles to attach to surfaces by electrostatic forces and chemical adsorption and the better the filtrate quality.

The average temperature of the filtrate was at 30^oC. The temperature varied from 34 – 38^oC in the wastewater and this could be as a result of the biochemical reactions resulting from the high level of pollution. The temperature later decreased due to reduction of reactions within the water medium and also due to the effect of the environment. From the Water quality standards used, temperature of the treated effluent is suitable for both domestic and irrigation purposes.

NAFDAC water quality guidelines recommend that the target pH range is 6.5 – 8.5. The mean values of 7.6 in both depths falls within the recommended range for both domestic and irrigation purposes. If pH values are below 6.5 or over 8.4 (FAO, 1985), there can be damage to crop leaves, reduced production, unavailability of some nutrients, corrosion and encrustation to the irrigation equipments.

Chemical Parameters

The mean percentage removal of BOD constituent is 73.32% and 76.42% for 60cm and 90cm respectively (Table 1). There was a general gradual increase in purification from the onset of first week. It was observed that in both depths the values were tending towards constancy. There was significant difference in the depths (Table 2). The values of BOD_5 from both 60cm and 90cm vadose depths were 69.86mg/1 and 76.82mg/1 respectively. These are within the Nigerian NAFDAC value of 500mg/l, FAO value of (<100mg/1) and Jordan allowable limit for reuse in irrigation of (30 – 3000mg/1) as shown in Table 3. This shows that the filtrate from this filtration media can be used for domestic purposes and irrigation comfortably. The value of BOD_5 in the 90cm vadose depth was higher than that of 60cm showing that purification efficiency increased with vadose depth in the whole process.

COD test is said to be an alternative test to that of BOD_5. It is used to measure content of organic matter of wastewater as well as natural waters. The measurement of COD level is used to determine the treatment efficiency and effluent quality. It also indicates the suitability of water for non-potable uses. The mean percentage removals of the COD were 71.24% and 72.34% respectively in the 60cm and 90cm depths. There was not much variation in the raw values with respect to vadose zone (depth of filtration) as in the case of BOD_5. In the 60cm and 90cm depths, the mean values were 71.28mg/1 and 71.79mg/1 (Table 2). The higher values of the COD compared to that of the BOD_5 could be as a result of the oxidizing materials such as fats and lignins which are only slowly biodegradable in the waste water (Punmia et al, 2005). Depth had a significant effect on the purification efficiency and a CV of 0.5% indicating a very good research result (Table 2). The COD filtrate quality of 71.28mg/1 (60cm) and 71.79mg/1 (90cm) falls above the FAO maximum limit of 65mg/1 and below Jordan Ministry of Water and Irrigation range of 100 - 500mg/1 allowable limit for reuse in irrigation (Table 3).

Nitrates (NO_3^{-2}) indicate the presence of fully oxidized organic matter; they indicate the most stable form of nitrogenous matter contained in wastewater. The mean percentage removal of the constituents was 41.91% for 60cm and 68.10% for 90cm (Table 1) showing that the removal of fully oxidized organic matter was more in a longer travel distance. Significant variation exists due to the depth factor. Based on the WHO (1988) and FAO (2005) standards value of 50mg/1 and the Jordan (2006) allowable limit for irrigation of 30-45mg/1, the NO_3 value range of (14.36mg/1) for 60cm depth and (7.85 mg/l) for 90cm depth is suitable for both domestic and irrigation purposes (Table 3).

The 90cm vadose depth performed better than the 60cm depth in the removal of Phosphate

(PO_4^{3-}) from the wastewater as presented in Table 1. The mean percentage removal of the constituent in the 90cm (67.88%) is higher than three times the value (22.23%) in the 60cm depth. This was also evident in the significant effect of depth on the quality of the filtrate (Table 2). The mean values of 8.48mg/l and 3.50mg/l for 60 and 90cm respectively fit in with Monwuba (2004), Agbejimi (2004), and Monwuba and Agbejimi (2004) NAFDAC value of 10mg/1 for water consumption and Jordan Ministry of Water and Irrigation (2006) value of 30mg/1 for allowable limit for reuse in irrigation (Table 3).

<u>Biological Parameters</u>

The Total Bacterial Count (TBC) is the most common bacterial indicator that is used to assess the microbial quality of irrigation water. Values of the parameter with respect to the depth of infiltration showed significant difference as shown in Table 2. The 60cm depth had a mean percentage removal of 79.25% and. For the 90cm depth, the mean percentage removal of 83.6% was achieved. The values of TBC at the end of the period studied was 130 and 165/100ml. The WHO, FAO and NAFDAC Standards recommend that there must not be any detectable trace (or at most 1 unit) in any 100ml per sample for drinking purposes while it should not exceed 1000 counts/100 ml for irrigation purposes (Jordan Ministry of Water and Irrigation). Although, the quality in terms of TBC is allowable for reuse in irrigation, it is definitely not suitable for domestic use.

The concentrations of a number of parameters studied in the filtrate meet the standards for domestic purposes, the data for TBC, which is an overriding parameter for domestic purpose, rules out the possibility of ever using the filtrate for domestic purposes.

CONCLUSION

From the results obtained in this study, it was very evident that the depth factor had an influence on the purification process and quality of the filtration chamber designed. Generally the depth of 90cm had better purification result than 60cm on all the parameters analyzed save for the TSS constituent. Further study is however recommended to determine the optimum vadose depth.

This could be as a result of the gravitational force exacting more pressure on the 90cm depth columns hence more filterable solids seeping through the envelope material and the screen. The recorded values of the parameters generally improved with time (weeks). This was because of void filling which created more advantage for filtration as the pore spaces become smaller.

A higher degree of treatment occurred in the infiltration zone as soil clogging developed. The study identified that the filtrate quality was generally within the standard value in terms of the NAFDAC and WHO recommended values. The concentration of TBC exceeded both standards. The TSS values exceeded the WHO and FAO guidelines for wastewater usage. For health reasons, the TBC is the most critical in considering the filtrate for domestic uses. Therefore the filtrate from both 60cm and 90cm depths were not suitable for domestic uses. They however could be used for irrigation because all the constituents were within the maximum allowable limit of the water quality for irrigation purposes.

The low concentrations of specific ions NO_3^{-2} and PO_4 will not damage the crop leaves if sprinklers are used. The treated effluent could be used for irrigation of crops that are not eaten raw, because of the TBC concentration. This study revealed that treated effluent from domestic wastewater could be used for irrigation where water is scare. In arid and semi-arid areas, farmers could treat wastewater (as an alternative source of water) using this simple filtration system and apply the effluent to irrigate crops.

The study showed also that domestic wastewater can be properly treated using this simple and affordable (low cost and low technology) infiltration system. This gives a relatively acceptable effluent of high quality for irrigation and discharge into the environment. This ttreatment process can also minimize the potential risks to the surface water and groundwater, as both crops and soilwill serve as natural filters. Production industries can also make use of this infiltration system to treat their wastewater before discharging them into the environment.

REFERENCES

1. Abejimi, P.A. 2004. "On Safe Drinking Water". Paper presented during NAFDAC National Conference, Abuja, Nigeria. 23.

2. Anderson, D.L., R.L. Siegrist, and W.C. Boyle. 1985. *Technology Assessment of Intermittent Sand Filters*. U.S. Environmental Protection Agency, Municipal Environmental Res. Lab.: Cincinnati, OH. 31.

3. Cuyk, S.V., R. Siegrist, A. Logan, S. Masson, E. Fischer, and L. Figueroa. 1999. "Purification of wastewater in Soil Treatment Systems as Affected by Infiltrative Surface Character and Unsaturated Soil Depth". 72nd Water Environment Federation Exhibition and Technical Conference, October 9-13, 1999. New Orleans, LA.

4. Cuyk, S.V., R. Siegrist, A. Logman, S. Masson, E. Fischer, and L. Figueroa. 2000. "Hydraulic and Purification behaviours and their Interactions during Wastewater Treatment in Soil Filtration Systems". *Wat. Res*. 35(4):953-964.

5. Crites, R.C. and G. Tchobanoglous. 1998. *Small and Decentralized Wastewater Systems.* McGraw-Hill: Boston, MA. 19.

6. FAO. 2005. "Agricultural Drainage and Water Management in Arid and Semi-Arid Areas". Irrigation and Drainage Paper 61. FAO: Rome, Italy. (Accessed July 2009). http://www.fao.org/documents/show_cd.asp?url_file=/DOCREP/005/Y4263E/y4263e00.HTM.

7. FAO. 1985. "Water Quality for Agriculture". Irrigation and Drainage Paper 29. FAO: Rome, Italy. 137.

8. Gomez, K.A. and A.A. Gomaz.1984. *Statistical Procedures for Agricultural Research (2nd Edition)*. John Willey and Sons Inc.: New York, NY. 680.

9. Jenssen, P.D. and R.L. Siegrist. 1990. "Technology Assessment of Wastewater by Soil Infiltration Systems". *Water Sc. Technol*. 22: 83-92.

10. May, R. 1996. "Problems Associated with the Use of Gravel in Septic Tank Leach Field Systems". *J. Environ Health*. 59(2):6 – 11.

11. Ministry of Water & Irrigation, Jordan. 2006. http://www.mwi.gov.jo/mwi/JS-893.aspx (Accessed July 2009).

12. Monwuba, P.C. 2004. "Guidelines on Registration of Regulated Products". Paper presented during NAFDAC National Conference: Abuja, Nigeria. 12.

13. Monwuba, P.C. and P.A. Agbejimi. 2004. "Guidelines on Registration of Regulated Products". Paper presented during NAFDAC National Conference: Abuja, Nigeria. 2004.

14. Punmia, B.C. and A.K. Jain. 2003. *Soil Mechanics and Foundation*. Laxmi Publ. LTD: London, UK. 968.

15. Siegrist, R. L. and S.V. Cuyk. 2001. "Wastewater Soil Absorptions Systems: The Performance Effects of Process and Environmental Conditions". ASAE Paper No. 148, 41-51 in *On-Site Wastewater Treatment, Proc. Ninth Natl. Symp. on Individual and Small Community Sewage Systems*. Fort Worth, TX. ASAE 701P0009

16. Siegrist, R.L. and J. McCray. 2006. "Infiltration Rate Behaviour During Wastewater Treatment in Soil Systems". *J. Environ. Qual.* 16(2):181-187.

17. Siegrist, R.L. and J.M. McCray. 2002. "Infiltration – Process Principles and Behaviour During Onsite Wastewater Treatment in Soil Systems". National Onsite Wastewater Recycling Association 2002 Annual Conference and Exposition presentation.

18. Siegrist, R.L., E.J. Tyler, and P.D. Jenssen. 2000. "Design and Performance of Onsite Wastewater Soil Absorption Systems". *Proc. Decentralized Wastewater Management Research Needs Conf*. Washington Univ.: St. Louis, MO. May 19-20. Electric Power Research Institute, St. Louis, MO.

19. Siegrist, R.L. and W.C. Boyle. 1987. "Wastewater Induced Soil Clogging Development". *J. Environmental Engineering*. 113(3):550-566.

20. USEPA. 1980. *Design Manual Fero-on site Wastewater Treatment and Disposal Systems.* US Environment Protection Agency Municipal Environmental Res. Lab.: Cincinnati, OH.

21. Vinten, A.J.A., U. Mingelgrin, and B. Yaron. 1983. "The Effect of Suspended Solids in Wastewater on Soil Hydraulic Conductivity: II. Vertical Distribution of Suspended Soils". *Soil Sci. Soc. Am. J.* 47:408-412.

22. WHO. 1988. "Health Guidelines for the use of Wastewater in Agriculture and Aquaculture". Technical report series No 778. World Health Organization: Geneva, Switzerland. (http://www.who.int/water_sanitation_health/wastewater/en/wastreusexecsum.pdf)

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