Water Science and Technology **Vol 44 No 2–3 pp 181–188** © IWA Publishing 2001

Septage dewatering in vertical-flow constructed wetlands located in the tropics

T. Koottatep*, C. Polprasert*, N.T.K. Oanh*, U. Heinss, A. Montangero** and M. Strauss****

* Urban Environmental Engineering and Management Program (UEEM), School of Environment, Resources and Development (SERD), Asian Institute of Technology (AIT), P.O. Box 4, Klong Laung, Pathumthani 12120, Thailand

** Department of Water and Sanitation in Developing Countries (SANDEC), Swiss Federal Institute for Environmental Science and Technology (EAWAG), Ueberlandstrasse 133, CH-8600 Dübendorf, Switzerland

Abstract Constructed wetlands (CWs) have been proven to be an effective low-cost treatment system, which utilizes the interactions of emergent plants and microorganisms in the removal of pollutants. CWs for wastewater treatment are normally designed and operated in horizontal-flow patterns, namely, free-water surface or subsurface flow, while a vertical-flow operation is normally used to treat sludge or septage having high solid contents. In this study, three pilot-scale CW beds, each with a surface area of 25 m^2, having 65 cm sand-gravel substrata, supported by ventilated-drainage system and planting with narrow-leave cattails (*Typha augustifolia*), were fed with septage collected from Bangkok city, Thailand. To operate in a vertical-flow mode, the septage was uniformly distributed on the surface of the CW units. During the first year of operation, the CWs were operated at the solid loading rates (SLR) and application frequencies of, respectively, 80–500 kg total solid (TS)/m^2.yr and 1–2 times weekly. It was found that the SLR of 250 kg TS/m^2.yr resulted in the highest TS, total chemical oxygen demand (TCOD) and total Kjeldahl nitrogen (TKN) removal of 80, 96 and 92%, respectively. The TS contents of the dewatered septage on the CW beds were increased from 1–2% to 30–60% within an operation cycle. Because of the vertical-flow mode of operation and with the effectiveness of the ventilation pipes, there were high degrees of nitrification occurring in the CW beds. The nitrate (NO_3) contents in the CW percolate were 180–250 mg/L, while the raw septage had NO_3 contents less than 10 mg/L.

Due to rapid flow-through of the percolates, there was little liquid retained in the CW beds, causing the cattail plants to wilt, especially during the dry season. To reduce the wilting effects, the operating strategies in the second year were modified by ponding the percolate in the CW beds for periods of 2 and 6 days prior to discharge. This operating strategy was found beneficial not only for mitigating plant wilting, but also for increasing N removal through enhanced denitrification activities in the CW beds. During these 2 year operations, the dewatered septage was not removed from the CW beds and no adverse effects on the septage dewatering efficiency were observed.

Keywords Cattails; constructed wetlands; dewatering; operating strategies; septage; vertical-flow

List of abbreviations

BOD = Biochemical oxygen demand
CW = Constructed wetland
N = Nitrogen
NH_4 = Ammonium
NO_3 = Nitrate
SLR = Solid loading rate
TCOD = Total chemical oxygen demand
TKN = Total Kjeldahl nitrogen
TS = Total solids
TVS = Total volatile solids

Introduction

In most rural and urban areas of developing countries, where sewerage systems are not available, human excreta are commonly disposed of in on-site systems such as septic tanks, cesspools, or pit latrines. Septage and other types of faecal sludges produced in these units need to be periodically removed. They are characterized by high solid, organic and enteric microorganism contents, often with large quantities of grit and grease, a great capacity to foam upon agitation, and often poor settling and dewatering characteristics (Polprasert, 1996). Discharge of the untreated septage to watercourses or land may result in environmental degradation and serious public health risks (Strauss *et al*., 1997).

CWs are man-made systems aiming at simulating the treatment processes in natural wetlands by cultivating emergent plants e.g. reeds (*Phragmites*), bulrushes (*Scirpus*), and cattails (*Typha*) on sand, gravel, or soil media. Based on investigations of pilot and field-scale systems, CWs have been proven to be a promising treatment alternative characterized by low investment, operation and maintenance costs (Kadlec and Knight, 1995 and Cooper *et al*., 1996). Therefore, utilization of CWs in waste treatment and recycling is currently of interest, including their ancillary benefits such as supporting primary production and enhancement of wildlife habitats. For several years, a number of CW systems have been employed to treat various kinds of wastewaters including, more recently, sludge from conventional treatment plants (Heinss and Koottatep, 1998).

For sludge or septage dewatering, a vertical-flow mode of operation with a percolate-drainage system beneath CW beds is required. An advantage of CWs over conventional, unplanted sludge drying beds is the much lower frequency of dewatered sludge removal from the bed, allowing for several years of sludge accumulation prior to bed emptying. Furthermore, the percolating liquid is subjected to microbial reactions within the CW beds, enabling nitrification and higher removal efficiencies within the liquid. Septage treatment in CWs was conducted in laboratory-scale experimental units at Cemagref in Lyon, France (Liénard and Payrastre, 1996), showing the promising treatment performance and ease of operations. Since 1996, the EAWAG and AIT have jointly undertaken research collaboration on “Septage Treatment by CWs and Attached-growth Waste Stabilisation Ponds” to test the feasibility of this treatment option and to establish design and operational guidelines. This article presents the 2 year experimental results of the CWs employed to dewater septage.

Materials and methods

Experimental setup

Configurations and dimensions. Based on the site and literature surveys of the CWs treating sludge in Europe (Heinss and Koottatep, 1998), it was evident that performances of these CW units were not dependent on length to width ratio, but more on distribution of sludge onto the bed surface. The AIT pilot-scale CWS were then figured to be square in shape in order that septage could be uniformly distributed by a feeding system. The AIT CWs comprise of three vertical-flow units, each with a surface area of 5 × 5 m and lined with ferro-cement as shown in Figure 1.

Substrata and vegetation. Based on the suggestions of Cooper et al. (1996), the substrata of CW units planting with reeds should have a depth of 80 cm with a 70cm graded gravel layer and topped off with 10 cm coarse sand. Because length of the cattail roots is only about 30–40 cm, relatively shorter than reeds (50–60 cm), the substrata depth in these experiments was designed to be 65 cm. A 10 cm layer of fine sand, 15 cm layer of small gravel, and 40 cm layer of large gravel from top to bottom were used as substrata in each CW unit. A free board of 1 m was allowed for accumulation of the dewatered septage. On top of the

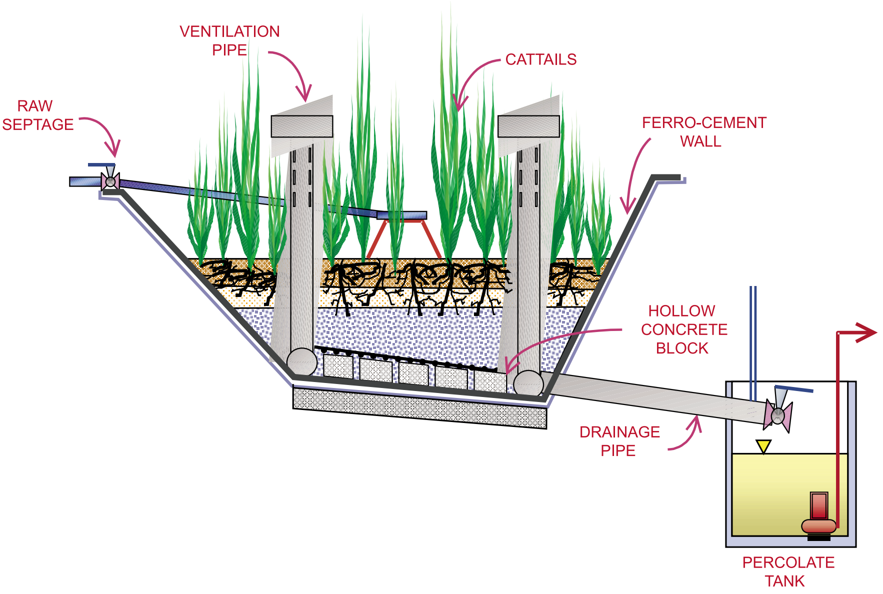

Figure 1 Schematic diagram of pilot-scale CW units

sand layer, narrow-leave cattails (*Typha augustifolia*), collected from a nearby natural wetland, were planted in each CW unit at the initial density of 40–50 shoots/m^2. Cattails were selected because they are indigenous species and evidently growing better than reeds in most wetland areas of Thailand.

Underdrain and ventilation system. The bed support and drainage system consists of hollow concrete blocks, each with a dimension of 20 × 40 × 16 cm (width × length × hollow space), and perforated PVC pipes with a diameter of 20 cm at the bottom. Mounted on the drainage system are ventilation pipes of the same diameter and extending approximately 1 m over the top edge of the units. Natural draught ventilation is required to avoid anaerobic conditions in the root zone and, hence, plant damage. The percolate of each CW unit was collected in a 3 m^3 concrete tank for sampling and analysis.

Operating conditions

Cooper *et al*. (1996) suggested solid loading rates (SLR) for reed beds treating excess sludge from a wastewater treatment plant in Europe to range from 30–80 kg total solids (TS)/m^2.yr and sludge loading frequency should be once a week. In tropical regions, it is expected that CWs could be loaded at the higher SLRs.

Septage used in these experiments was transported from Bangkok city. To remove garbage and rags, the raw septage was passed through a bar screen and then homogenized in two 4 m^3 mixing tanks before feeding to the CW units. The CW units were subjected to the operating conditions as shown in Table 1.

In Runs I–V, the CW percolates were allowed to flow freely into the percolate tanks soon after septage feeding. For Run VI, the percolate ponding conditions were maintained by closing the outlet valves according to the designed ponding periods.

Samples collected from the CW units at different operating conditions were analyzed for the contents of TS, total volatile solids (TVS), suspended solids (SS), biochemical oxygen demand (BOD), TCOD, dissolved chemical oxygen demand (DCOD), TKN, ammonium (NH_4), NO_3, and helminth eggs. Analytical methods for these parameters were according to *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, WPCF, 1992).

Table 1 Operating conditions of pilot-scale CW units

Run	SLR (kgTS/m²·yr) CW-1	CW-2	CW-3	Percolate ponding*	Frequency of septage application	Periods of operation
I	250	125	80	No	twice a week	Apr. 97–May 97
II	250	125	80	No	once a week	May 97–Jul. 97
III	250	125	80	No	twice a week	Aug. 97–Dec. 97
IV	500	250	160	No	twice a week	Dec. 97–Jan. 98
V	500	250	160	No	once a week	Feb. 98–Mar. 98
VI	250[a]	250[b]	250[c]	Yes	once a week	Apr. 97–Feb. 99

* Percolate was retained 10 cm below dewatered septage layers in CW units

[a] ponding period = 6 days, [b] ponding period = 2 days, [c] no ponding

Results and discussion

Characteristics of Bangkok septage

During the 2 year observations, the Bangkok septage showed the characteristics as given in Table 2.

The Bangkok septage had solid and organic contents in the same ranges as those reported by U.S. EPA (1995), but having relatively higher N contents. The low ratio of BOD to TCOD concentrations in the Bangkok septage showed the biodegradable fractions were mostly decomposed in the septic tanks. Because public hygiene and sanitation in Thailand, especially in the capital city, have significantly improved, the numbers of helminth eggs in the septage samples were evidently lower than those observed in other developing countries. Therefore, the Bangkok septage could be classified as type “B” or low-strength fecal sludge as suggested by Strauss *et al.* (1997).

First-year results: Run I–IV experiments

The results obtained from the first year operation during Run I–IV showed removal efficiencies of TS, TCOD, TKN, and NH_4 to be higher than 80%, while the average NO_3 concentrations increased from 2–5 to 150–200 mg/L (Table 3). Analyses of the CW performance are given below.

Solid removal and sludge drying. Based on the results of Runs I–III, which had the same ranges of SLR, the frequencies of septage application did not have significant effects on the TS removal efficiencies. The TS removal efficiencies achieved in the CW beds were similar to those of the sand drying beds treating the septage, which were studied in parallel for comparison (Pinsakul, 1997; Limsuwan, 1997). At the end of the 4 month operation of Run II, the TS contents of the dewatered septage increased from 1–2% to 30–60% after about

Table 2 Characteristics of Bangkok septage samples*

Parameter	Range	Average	Standard deviation
PH	6.7–8.0	7.5	0.6
TS (mg/L)	2,200–67,200	19,000	12,500
TVS (mg/L)	900–52,500	13,500	9,400
SS (mg/L)	1,000–44,000	15,000	10,100
BOD (mg/L)	600–5,500	2,800	1,400
TCOD (mg/L)	1,200–76,000	17,000	15,000
TKN (mg/L)	300–5,000	1,000	800
NH_4 (mg/L)	120–1,200	350	170
NO_3 (mg/L)	1.0–11	4.5	3.5
Helminth eggs, no./g of sample	0 – 14	4	1

* Based on 120 raw septage samples during August 1997–February 1999

Table 3 Average TS, TCOD, TKN, NH_4, and NO_3 contents in CW percolate and removal efficiencies[+]

Sample	Run	Unit No.	SLR kg TS/m^2.yr	Frequency No./week	Parameter*, mg/L TS	TCOD	TKN	NH_4	NO_3
Raw septage**					16,300	16,000	830	340	8
Percolate	I	1	250	2	3,340 (81)	810 (97)	110 (95)	100 (90)	260
		2	125	2	3,610 (80)	570 (96)	62 (98)	44 (93)	190
		3	80	2	2,980 (83)	110 (98)	10 (99)	5 (98)	200
	II	1	250	1	2,640 (80)	300 (97)	62 (93)	46 (85)	180
		2	125	1	2,840 (80)	230 (98)	60 (96)	56 (80)	180
		3	80	1	3,640 (78)	210 (98)	45 (98)	32 (92)	210
	III	1	250	2	2,720 (88)	780 (95)	110 (94)	87 (88)	200
		2	125	2	2,700 (84)	460 (97)	100 (96)	36 (91)	190
		3	80	2	2,670 (86)	910 (94)	95 (99)	49 (79)	260
	IV	1	500	2	2,900 (81)	1,020 (93)	182 (87)	190 (69)	180
		2	250	2	3,600 (76)	800 (94)	140 (90)	100 (79)	220
		3	160	2	3,800 (80)	1,720 (88)	250 (79)	190 (52)	190

[+] Removal efficiencies as shown in parentheses depended on the characteristics of raw septage used in each experimental run

* Average data were based on 12 composite samples taken from each experimental run

** Raw septage data were averages of 72 samples of Run I to IV, during April 1997–January 1998

one week of dewatering. It was also observed that average heights of the dewatered septage layers were 1.5, 2.3 and 5.0 cm in the CW units operated at the SLRs of 80, 125 and 250 kgTS/m^2.yr, respectively.

From statistical analyses, the treatment efficiencies of Run III were higher than Runs I and II, probably because of the accumulated dewatered septage layers which contribute to better filterability and increased microbial reactions. It was also apparent from the results of Run IV that further increases in SLR resulted in decreased CW performance in term of TS removal. The high SLR corresponded to the large volume of applied septage, which was beyond the filtration capacity of the CW beds, hence the lower TS removal efficiencies. However, as a result of the filtering capacity, no helminth egg was found in the percolate samples of the CW units (Limsuwan, 1997).

Organic removal. During the first 8 months of Runs I–IV operations, the TCOD removal efficiencies ranged from 94 to 99%, resulting in the percolate TCOD concentrations of 105–805 mg/L (Table 3). Similar to the TS removal, the frequency of septage application did not have any significant effect on the TCOD removal efficiencies. It appeared that the TCOD removal depended on filtration capacity of the CW units rather than organic biodegradation at relatively short HRT. Another cause of the little biodegradation activity was the low biodegradability of the Bangkok septage, which had a BOD/COD ratio of 0.12.

N removal. Based on the results shown in Table 3, the TKN removal efficiencies of the CW units during Runs I–IV were greater than 93% and having percolate TKN concentrations of 45–250 mg/L, while the NH_4 removal efficiencies were found in the range of 80–92%. The percolate NO_3 concentrations were increased significantly from 8 to 200 mg/L, probably because of the nitrification reactions. Moreover, the percolate DO concentrations of 2–4 mg/L would support the growth of the nitrifying bacteria. This result revealed the beneficial effects of the vertical-flow mode of operation and the ventilated-drainage system that enhanced the nitrification reactions.

Effects on cattail growth. At the beginning of operation, the cattail plants in the constructed wetland units were 1.5–1.8 m in height. After two to three weeks of septage application, young roots and stems began to grow, but some cattail plants could not adapt to the septage, causing their leaves to turn yellow and died.

From observations, the cattail plants in the CW units showed a sign of water deficiency in Run I and were shocked during Run II, which was due to the once-a-week loading. From Run III, the plants could grow well because they became acclimated to the septage and septage loading was done twice a week.

After doubling the SLR to 160, 250 and 500 kg/m^2.yr in Run IV, serious wilting symptoms and plant die-offs occurred in all CW units. The cattail plants in CW units no. 1 and 2 were manually harvested without removal of the dewatered septage layers, while no plant harvesting was implemented in unit no. 3.

Second-year results: Run V–VI experiments

At the end of Run IV, heights of the dewatered septage layers were increased to 20–25 cm. The results obtained from the second year operation and beyond are shown in Table 4, and their analyses are given below.

Solid removal and mass balance. After maintaining the doubled SLR and septage application at once-a-week in Run V, the TS removal efficiencies were in the same ranges as those obtained from Run IV, asserting that the TS removal of CWs is independent of the septage application frequency. However, based on the results of Runs I–V, it was found that the SLR of 250 kg TS/m^2.yr resulted in the highest TS removal efficiencies. At the end of Run V (300 days of operation), the TS mass balances in each CW bed were analyzed as shown in Table 5. The accumulated TS inputs to CW units 1, 2, and 3 were 187, 115 and 112 kg TS/m^2, respectively. The average TS mass in dewatered septage amounted to 38–52% of the TS inputs, while about 11–12% of the TS inputs were in the percolate portion. The unaccounted TS of 36–50% was postulated to be due to biochemical reactions such as mineralisation, biodegradation, and TS accumulation in the CWs substrata.

Table 4 Average TS, TCOD, TKN, NH_4, and NO_3 contents in CW percolate and removal efficiencies[+]

Sample	Run	Unit No.	SLR	Frequency	Ponding	Parameter*, mg/L				
			kg TS/m^2.yr	No./week	days	TS	TCOD	TKN	NH_4	NO_3
Raw septage**						18,500	16,000	1,000	440	6
Percolate	V	1	500	1	–	4,960 (82)	1,880 (94)	240 (82)	170 (52)	250
		2	250	1	–	6,030 (77)	850 (96)	120 (87)	110 (70)	320
		3	160	1	–	4,320 (77)	1,250 (91)	150 (83)	110 (68)	270
	VI	1	250	1	6	2,000 (86)	270 (98)	100 (89)	80 (81)	20
		2	250	1	2	2,400 (84)	400 (97)	150 (85)	100 (77)	53
		3	250	1	0	2,700 (81)	620 (96)	200 (80)	140 (69)	120

[+] Removal efficiencies as shown in parentheses depended on the characteristics of raw septage used in each experimental run

* Average data were based on 12 composite samples taken from each experimental run

** Raw septage data were averages of 60 samples of Run V–VI, during February 1998–February 1999

Table 5 TS mass balance in CW units after 300 day of operation

Balance	Unit no. 1		Unit no. 2		Unit no. 3	
	kg TS/m^2	%*	kg TS/m^2	%	kg TS/m^2	%
Raw septage	187	–	115	–	112	–
Dewatered septage	93	50	60	52	43	38
Percolate	20	11	14	12	13	12
Unaccounted	74	39	41	36	56	50

* Percent TS in raw septage

The CWs operations in Run VI were maintained at the SLR of 250 kg TS/m^2.yr, while the CW percolates were withheld at the ponding periods of 6, 2 and 0 days in CW units 1, 2, and 3, respectively. It appeared from Table 4 that the percolate ponding periods did not have significant effects on the TS removal efficiencies, probably because the filtering capacity of the CWs did not increase via percolate ponding.

Organic removal. The data of Run V confirmed that the SLR of 250 kg TS/m^2.yr yielded the highest TCOD removal of 96–98%. For Run VI, similar to the TS removal efficiencies, the percolate ponding periods did not have any significant effects on the TCOD removal; sedimentation and filtration of organic particulate appeared to be the major mechanisms responsible for TCOD removal in these CW units.

N removal. The N removal efficiency of Run V at the SLR of 250 kg TS/m^2.yr was the highest. In Run VI, CW units 1 and 2 which had percolate ponding had higher TKN and NH_4 removal efficiencies than CW unit 3 without percolate ponding. This phenomenon was probably due to the denitrification reactions occurring in the CW beds. CW unit 1, having the longest ponding period of 6 days, achieved the highest TKN and NH_4 removal efficiencies, while the percolate NO_3 concentration was the lowest. The N plant uptake by cattail plants could be another N removal mechanism in the CW units, as reported by Kootatep and Polprasert (1997). However, because of the relatively high N loading of septage employed in these experiments, the N plant uptake rates of these CW beds accounted for only 5–7% of the total N input (Pinsakul, 1997).

Effects on cattail growth and percolate flow. Due to inadequate water availability, severe wilting of the cattail plants was observed in Run V as a result of the doubled SLR and once-a-week septage application. The wilted cattails in CW units 1 and 2 were harvested prior to the start-up of Run VI. With percolate ponding in Run VI, the cattails in CW units no. 1 and 2 grew much better than those in CW unit no. 3, which, because of no plant harvesting, had interference from other weeds and dead cattails.

Even when the dewatered septage layers in the CW beds were 35–45 cm in height at the end of Run VI and the dewatered septage was not removed from the CW beds, there was no bed clogging as evidenced from the percolate flows during the course of operation. This phenomenon was presumably due to the continuous growth and distribution of the cattail roots and rhizomes in the dewatered septage layers and substrata, which helped to create porosity in the CW beds. It is obvious that the practice of septage dewatering in vertical-flow CWs without frequent removal of the dewatered septage should result in significant reduction of operating costs, confirming its advantage over conventional sand drying beds.

Conclusions

Based on the 2 year experimental results, suitable strategies for the vertical-flow CW system treating septage were found to be: (i) SLR of 250 kg TS/m^2.yr; (ii) once-a-week septage application, and (iii) percolate ponding period of 6 days. These strategies resulted in optimum performance of CWs with respect to septage dewatering and contaminant removal from the percolating liquid, healthy plant growth, and ease of operation in which removal of the dewatered septage was not required. The percolate ponding significantly promoted the nitrification/denitrification reactions essential for N removal. Although more long-term data are required, the results generated to date indicated the vertical-flow CW system to be a promising technology for septage dewatering with low investment and operation costs.

Acknowledgement

The authors would like to thank Mr. Narong Surinkul, Mr. Surasak Limsuwan, Mr. Anawat Pinsakul, Mr. Roongrod Jittawattanarat, and Mr. Suprachoke Uakritdathikarn, for their valuable contributions in the operation and maintenance of the experimental CW units as well as the parameter analyses. The generous support from the Swiss Agency for Development and Cooperation (SDC) through a grant to EAWAG is gratefully acknowledged.

References

APHA, AWWA, WPCF (1992). *Standard Methods for the Examination of Water and Wastewater*, 17th Edition, Washington, D. C.

Cooper, P.F., Job, G.D., Green, M.B. and Shutes, R.B.E. (1996). *Reed Beds and Constructed Wetlands for Wastewater Treatment*, WRc Swindon, Wiltshire.

Heinss, U. and Koottatep, T. (1998). *Use of Reed Beds for Faecal Sludge Dewatering*. EAWAG/AIT. Unpublished report.

Kadlec, R.H. and Knight, R.L. (1995). *Treatment Wetlands*, Lewis Publisher, New York.

Koottatep, T. and Polprasert, C., (1997). Role of plant uptake on nitrogen removal in constructed wetlands located in tropics, *Wat. Sci. & Tech.*, **36**(12), 1–8.

Liénard, A. and Payrastre, F. (1996). Treatment of sludge from septic tanks in a reed-bed filters pilot plants, *Pre Prints of the 5th International Conference on Wetland Systems for Water Pollution Control*, Vienna, 8 p.

Limsuwan, S. (1997). Operational criteria for septage dewatering in constructed wetlands, *Master Thesis*, EV-97-45, Asian Institute of Technology, Bangkok.

Pinsakul, A. (1997). Nitrogen removal in constructed wetland beds treating septage, *Master Thesis*, EV-97-2, Asian Institute of Technology, Bangkok.

Polprasert, C. (1996). *Organic Waste Recycling*, 2nd edition, John Wiley & Sons, Chichester.

Strauss, M., Larmie, S.A., and Heinss, U. (1997). Treatment of sludges from on-site sanitation – Low-cost options, *Wat. Sci. & Tech.*, **35**(6), 129–136.

United States Environmental Protection Agency (U.S. EPA) (1995). *Process Design Manual – Surface Disposal of Sewage Sludge and Domestic Septage,* Washington DC.