Desalination and Water Treatment
www.deswater.com

4 (2009) 98–102

1944-3994 / 1944-3986

A comparison of different methodologies for designing land application systems: Case study at the Redueña WWTP

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Received 23 April 2008; Accepted in revised form 3 July 2008

ABSTRACT

The conventional treatment of wastewater in small populations is unfeasible. Therefore, non-conventional methods have to be applied in these cases, including land application systems (LAS) also called “filtros verdes” in Spanish. Nowadays, there are many methodologies applicable to the design and sizing of land application systems: the flow/EH, the hydraulic load based on the permeability of the ground, the hydraulic load based on the nitrogen balance, and the hydric balance calculation. A comparative analysis of these methods, which have been applied to the wastewater treatment plant (WWTP) at Redueña (already in operation and sized with parameters flow/EH), is presented. It can be observed how the plant was oversized (18,000 m^2) with the parameters with which this filter was designed firstly (1 ha/200 EH), so during the summer there was not enough flow to keep the irrigation of the forest species used and, as a result, most of them died. To calculate the necessary dimensioning surface, a comparison of diverse methods has been carried out according to different parameters: the ground permeability, calculation of the hydraulic load based on the nitrogen balance, and the hydric balance calculation. The surfaces obtained respectively by these methods were 1,600 m^2, 20,000 m^2, and 8,000 m^2. The results obtained by means of the experimental works in the WWTP at Redueña, point out that the hydric balance is the best method to apply in this plant, because it optimizes the required surface and the water purification yields.

Keywords: Land application systems; Sewage treatment plant design

1. Introduction

Land application systems are low-load wastewater surface application systems. Their main goal is to purify the wastewater applied in the smallest possible surface to reuse the water treated, to obtain biomass and, when the water quality is good enough, for recharge. In these systems, the treatment takes place through the natural action of the ground, the microorganisms, and the plants through physical, chemical, and biological mechanisms.

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Presented at the 2nd International Congress, SMALLWAT '07, Wastewater Treatment in Small Communities, 11–15 November 2007, Seville, Spain

This technique has a wide field of application given its economical advantages, its flexibility and operativeness in small communities.

The land application system at Redueña (a small town located to the NE of the Madrid Region, Spain) was constructed in 1988 throughout the valley Arroyo de las Huertas. To plant 1 ha of *Populus euroamericana* by each 200 EI (equivalent inhabitants) was its design criterion, whose resulting surface was 18,000 m^2, where the wastewater was first pre-treated and subsequently distributed by an open 20×30 cm canalization that crosses the parcel. Different areas of the filter, irrigated with furrows, were controlled by several floodgates.

Using these design parameters, the WWTP was oversized, so wastewater flows were not enough to keep the hydric necessities of the system. To solve the problem, it was necessary to design a pilot plot, in which hydric conditioning in the design method [1] was taken into account (Fig. 1). A multistage LAS concept that includes two stages was established. A first stage is with hydrophilic vegetation of trees and grassland that will work during the summer period and with maximum wastewater flows, and a second stage is covered by grassland, which will work during winter and with lower wastewater flows.

Nowadays, there are many methodologies applicable to the design and sizing of land application systems: the flow/EH, the hydraulic load based on the permeability of the ground, the hydraulic load based on the nitrogen balance, and the hydric balance. Here we present a comparison between the aforementioned methods for determining the one that better optimizes the size of the necessary surface.

The main objective of this study is to determine the best methodology to be applied for the designing calculations of a land application system.

2. Methods

Firstly, when a land application system is designed, it is necessary to consider the water to be added, with some variable pollution loads which willmodify the natural hydric balance [1]. Other parameters to be considered are the hydric needs of the vegetation based on the vegetative period, and the final purification degree must fulfil the quality objectives.

Based on the results obtained from the first experiments carried out at the Redueña WWTP, four different methodologies were compared in order to estimate the necessary area.

2.1. Methodology 1: calculation using the equivalent inhabitants unit

This methodology consists in calculating a filtration surface of 1 ha by each 200 equivalent inhabitants. This

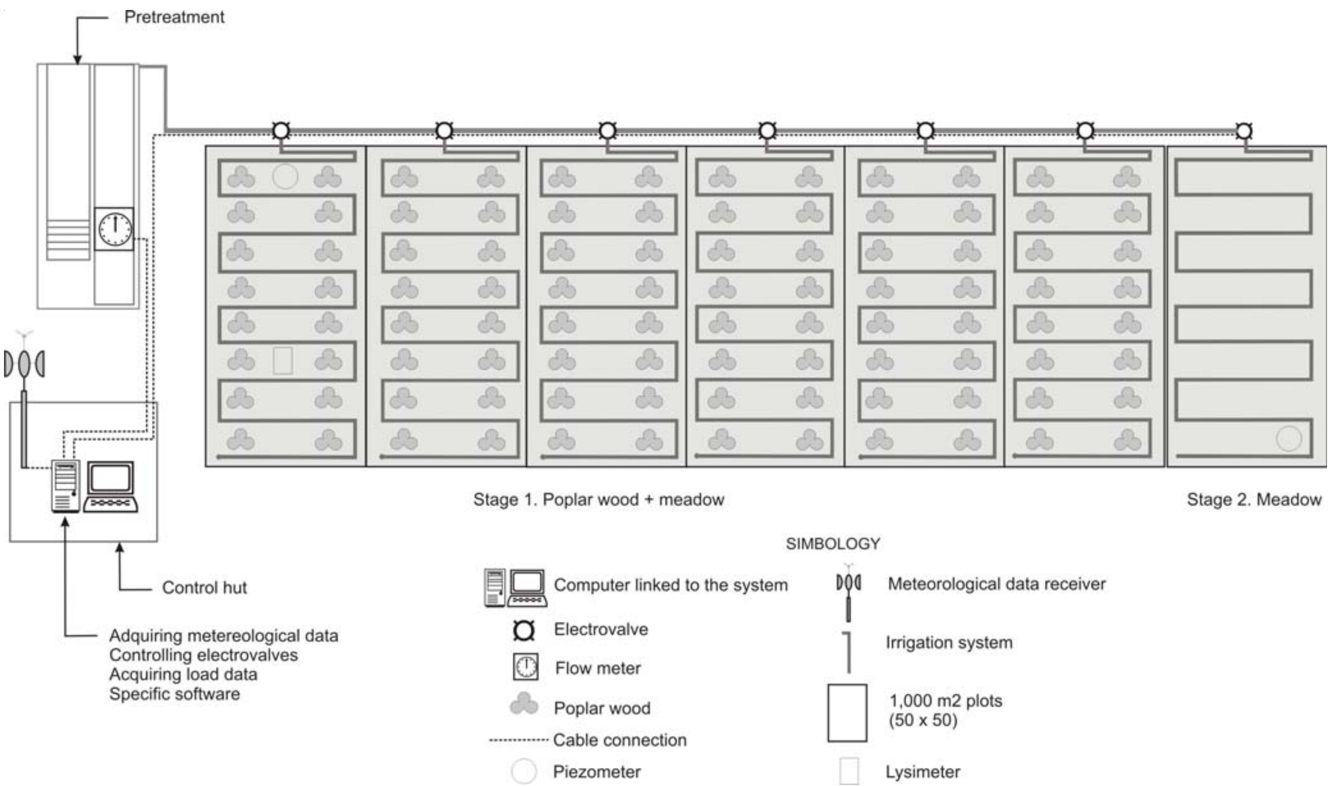

Fig 1. Scheme of the land application system of Redueña.

method only considers the organic matter load but not the climatology, a limiting factor for agriculture techniques. The results obtained by this method are far away from the real necessities of the system because they generally overestimate the required surface.

2.2. Methodology 2: calculation of the hydraulic load based on the soil permeability

This method is based on the soil infiltration capacity, a parameter that depends on the soil texture. The design hydraulic load (amount of water that can be given to the ground without reaching the saturation) is calculated from the measured infiltration rate, and the surface required for the WWTP is calculated from the input of wastewater [2].

$$S = \frac{365 \cdot Q}{10 \cdot L_{pm}} \quad (1)$$

where S — necessary surface; Q — daily average volume of wastewater (m^3/d); L_{pm} — design hydraulic load.

$L_{pm} = \mathrm{ETP}_m - Pr_m + P_{wm}$

where ETP_m — monthly potential evaporation (cm/month); Pr_m — monthly precipitation (cm/month); P_{wm} — monthly infiltration rate (cm/month).

2.3. Methodology 3: calculation of the hydraulic load based on the nitrogen balance

This methodology, though very similar to the previous one, uses both the precipitation and the evapotranspiration as limiting factors. The difference lies in including the nitrogen balance as a key element when determining the required surface [3].

Generally, this methodology is used as complement to the previous one in the cases in which it is desired to assure that the nitrogen values of the treated water do not exceed the established limits [2].

$$L_n = \frac{\mathrm{N}_i (P - \mathrm{ETP}) + 10C}{\left[(1-f)\mathrm{N}_a\right] - \mathrm{N}_i} \quad (2)$$

where L_n — hydraulic load based on the nitrogen limitations (mm/y); P — monthly precipitation (cm/y); C — annual consumption of nitrogen by the vegetation (kg/ha.y); F — eliminated fraction of nitrogen (%); N_a — nitrogen concentration average in the wastewater (mg/l); N_i — nitrogen concentration in the infiltrated water.

2.4. Methodology 4: calculation using a hydric balance

If we consider that the purifying plant for sewage to be installed is based on a forest system subjected to hydric conditioners, the estimation of its surface will have to be done by means of a hydric balance of the system. By taking into account the total volume of water to be applied to the ground (the sum of the natural precipitation and the wastewater), and the volume of water that returns to the atmosphere by evapotranspiration, it is possible to evaluate the volume of wastewater that can be applied without having an excess that would cause flooding or a deficit that would cause hydric stress. With the purpose of guaranteeing the sufficient water contribution for the maintenance of the plantation in the summer months, the surface (S) can be obtained by dividing the monthly total input volume between the maximum monthly evapotranspiration (ET):

$$S(\mathrm{m}^2) = \frac{Q_{\mathrm{efluent}}\ (\mathrm{L})}{\mathrm{ET}\ (\mathrm{L/m}^2)} \quad (3)$$

The expression used for the calculation of the potential evaporation (using the method of Blaney and Criddle), is proposed by FAO [4].

The Urbano Terrón's consumption coefficients are used for the calculation [5]. And for all those months in which there is a lack of data for the grasslands (November, December, January, February and March), values have been determined using the calculations of Blaney and Criddle in Pasadena (California). The former are slightly lower than the Spanish values due to the mitigation effect produced by the marine influence.

Considering the fact of season, there are great climatologic differences in many areas. Both aforementioned aspects can be overcome by introducing the concept of multi-stage wastewater land application system. This would include a first stage with hygrophile vegetation (which would need a constant annual hydric contribution), and a second vegetative stage or successive vegetation stages with lower water needs depending of the climatic variations. Thus, as soon as the volume contributions are becoming greater, the wastewater can be distributed within a wider surface.

From the environmental point of view, it is important that the highest possible volume of water gets infiltrated into the aquifer, because this contributes to the recharge, as long as the quality of the water is guaranteed. Otherwise, the plantation surface can be enlarged to get balance equal to zero. This is the methodology proposed by FILVER [6,7].

3. Results and conclusions

According to the methods described above, and using the data shown in Table 1, the necessary surface for the land application system at Redueña has been calculated. Results show that nitrogen balance method produces the bigger area (2 ha), followed by equivalent inhabitants method with 1.8 ha. The lower area, 0.16 ha, is obtained with the soil permeability method. The calculation using the hydric balance method presents an area of 0.75 ha (Table 2).

Table 1
Data of the land application system of Redueña

Month	*P* (cm/month)	ET (cm/month)	Infil. (cm/month)	L_n (cm/month)	*Q* (m³/month)	NUR %	kg N/ha	*Q*/ET m²
Jan	5.05	1.94	186	4.29	2.557	0.01	3.37	279.679
Feb	4.63	3.70	168	5.26	3.543	0.02	6.44	83.814
Mar	3.79	7.34	186	7.28	5.129	0.03	12.78	35.593
Apr	4.86	18.90	180	15.87	5.414	0.09	32.90	12.700
May	5.11	25.75	186	20.74	3.100	0.12	44.82	11.705
Jun	3.28	33.20	180	24.81	2.614	0.15	57.79	7.015
Jul	1.35	35.49	186	25.25	2.400	0.16	61.78	6.602
Aug	1.45	34.04	186	24.32	3.014	0.16	59.26	7.050
Sep	3.05	27.45	180	20.71	2.329	0.13	47.78	9.888
Oct	4.74	19.20	186	16.01	2.343	0.09	33.41	13.321
Nov	6.05	4.86	180	6.89	2.400	0.02	8.46	72.937
Dec	5.38	3.57	186	5.61	2.714	0.02	6.22	143.645
Annual total	48.74	215.43	2190	177.04	37.557		375.01	

Table 2
Results obtained for the land application system of Redueña

Methods	Surface
Equivalent inhabitant (350 EI design)	18,000 m² (1.8 ha)
Soil permeability	1,600 m² (0.16 ha)
Nitrogen balance	20,000 m² (2.0 ha)
Hydric balance	7,500 m² (0.75 ha) (6,500 of white poplar and grassland + 1,000 of grassland)

There is a great variability in the obtained results, depending on the methodology used for calculating the size of the surface required for the studied land application system.

Regarding the use of the equivalent inhabitants unit to calculate the surface (method 1), it was clear that the planted surface was much bigger than necessary. This was due to the fact that, firstly, most of the woodland did not receive enough water to survive during the dry season and, secondly, most of the plantation was lost during the first year of operation.

On the other hand, this methodology does not consider the climate, neither the ground nor the planted vegetation characteristics, these reasons being responsible for the lack of accuracy when calculating the size of this treatment system.

Although the methodology based on the permeability of the ground (method 2) provided the smallest surface, this was mainly due to the high infiltration rate. This method strongly depends on the percolation, thus being suitable for places with elevated infiltration rates. When permeability is very high it is not possible to guarantee acceptable results of pollutant elimination, as occurred in Redueña WWTP that has an infiltration velocity of 1,500 L/m²/d.

In the case of the results obtained by the methodology of the nitrogen balance (method 3), results similar to those from the first methodology were obtained, thus, the experience proved that the hydric contributions would not be sufficient for the survival of the planted vegetation during most part of the year. This can be because the method does not estimate, in a real way, all nitrogen losses that exist in the system, requiring a deeper estimation.

Therefore and in this case the methodology based on the hydric balance (method 4) is the most appropriate for this location since it guarantees the hydric contribution necessary to maintain the plantation.

The experiences carried out in a plot of the LAS of Redueña, in which this methodology was used for the sizing, show that the quality of the infiltrated effluents observes the in force legislation (Table 3).

Table 3
Treatment capacity in the land application system of Redueña [6]. Current regulation: UE Directive 91/271/CEE

Parameter	% reduction	[C_0]	[C_f]
BOD_5 (mg/l)	98	166	3.3
QO D (mg/l)	93	286	20
Suspended solids (mg/l)	85	64	30.6
N (mg/l)	70	51	15
P (mg/l)	80	10	2

Fig. 1 displays a scheme of the design made in this proposal, in which the first stage of *Populus* sp. and polyphitic grassland (of 6,500 m^2) is shown. This stage will be exclusively irrigated all year long with the volumes required by the vegetation. The second stage, with an area of 1,000 m^2 planted only with polyphitic grassland, will be irrigated with the remaining volumes.

The aquifer recharge is around 25,000 m^3/y, and it does not cause any problem because this value is within the limits established by the European Directive 91/271/CEE.

4. Symbols

C — Annual consumption of nitrogen by the vegetation, kg/ha.y
C_0 — Influent concentration
C_f — Effluent concentration
ETP_m — Monthly potential evaporation, cm/month
F — Eliminated fraction of nitrogen, %
Infil — Infiltration
L_n — Hydraulic load based on the nitrogen limitations, mm/y
L_{pm} — Design hydraulic load
N_a — Nitrogen average concentration in the wastewater, mg/l
N_i — Nitrogen concentration in the infiltrated water
NUR% — Nitrogen uptake rate
Pr — Monthly precipitation, cm/y
P_{rm} — Monthly precipitation, cm/month
P_{wm} — Monthly infiltration rate, cm/month
Q — Daily average volume of wastewater, m^3/d
S — Necessary surface

Acknowledgements

This research was funded by MEC under grants CSD2006-00044 and CGL2007-65712-C03.

References

[1] J. Mateos, I. De Bustamante, M. Dorado and J.M. Sanz, Geotemas, 1(3) (2000) 139–143.
[2] J.J. Salas, J.R. Pidre and I. Martín, Manual de tecnologías no convencionales para la depuración de aguas residuales, vol. 2, 2007, pp. 53–66.
[3] R.G. Smith, J.L. Meyer, G.L. Dickey and B.R. Hanson, In: R. Mujeriego, ed., Riego con agua residual municipal regenerada, UPC, Barcelona, 1990, pp.175–234.
[4] J. Doorenbos and W.O. Pruitt, Las necesidades hídricas de los cultivos, Estudios FAO, Serie Riego y Drenaje, No. 24, Ed. FAO Roma, 1986.
[5] P. Urbano Terrón, Tratado de fitotecnia general, Ediciones Mundi-Prensa, Madrid, 1992.
[6] I. De Bustamante, M. Dorado, S. Vera and C. Oliveros, Tecnoambiente, 79 (1998) 73–75.
[7] I. De Bustamante, S. Vera, J.M. Sanz, J. Alpuente, J. Mateos, V. León, P. López, J.L. Corvea and J. Larrañaga, Land application: design, performance evolution and control of groundwater pollution. International Meeting on Phytodepuration, 2005.