Operation and effluent quality of a small rural wastewater treatment plant (WWTP) receiving discharges from an abattoir WWTP

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Abstract

The objective of this study was to evaluate the impact of effluent and sludge discharges of an abattoir wastewater treatment plant (WWTP) on the operation of a municipal aerated pond WWTP. Experiments were carried out in Cervera WWTP, located in north-eastern Spain, which comprises four ponds operating in series. Cervera WWTP treats a flow rate of 3 100 m^3/d of urban sewage mixed with the effluent and the sludge discharged by an abattoir WWTP. Prior to September 1993, the effluents of Cervera WWTP showed poor quality (70 mg TSS/ℓ and 58 mg BOD_5/ℓ) because the abattoir sewage was discharged directly into the municipal sewer. Since September 1993, when the abattoir WWTP was established, effluent quality has improved considerably (24 mg TSS/ℓ and 15 mg BOD_5/ℓ). The sludge discharges of the abattoir WWTP into the municipal sewer did not significantly affect effluent quality of Cervera WWTP, even when the TSS and BOD_5 loading rates were 800% and 60% higher than the design loadings respectively. Cervera WWTP clearly had higher sludge production per treated flow (3 to 6 ℓ/m^3 with a percentage of dry matter of 4.8 to 6.8%) than other similar WWTPs. In conclusion, sludge discharge to WWTPs with high retention times to allow for sedimentation and high capacity for storing does not affect effluent quality. However, these discharges increase sludge management costs.

Keywords: operation and maintenance, abattoir wastewater, aerated ponds, waste stabilisation ponds

Introduction

Catalonia (north-eastern Spain) currently has 23 urban wastewater pond systems in operation under the supervision of the Catalonian Water Agency (Departament de Medi Ambient, 2001). Altogether these wastewater treatment plants (WWTPs) receive a load equivalent to wastewater from approximately 160 000 inhabitants (1.3% of the total load of the region) and most of these are aerated ponds. To assess the potential of pond systems as an economic and technically viable alternative for wastewater treatment in the rural areas of Catalonia, an evaluation of the existing pond systems was conducted in 1997-1998. The evaluation included a description of the facilities of each WWTP, an analysis of the available performance data, and an evaluation of complementary data and information obtained from additional sampling surveys (García et al., 2000).

All the pond systems currently operating in Catalonia have been constructed over the last 17 years. Agriculture and cattle-raising are the main economic activities in the areas served by ponds. Aerated ponds are used for small to medium-sized communities (1 200 to 16 000 inhabitants, 230 to 4 700 m^3/d; note that these flows may include industrial effluents), while stabilisation ponds are used for small communities (90 to 2 800 inhabitants, 20 to 800 m^3/d;). Most of the pond systems comply with the European Union standards contained in Directive 91/271 (Council of the European Communities, 1991), despite the inadequate level of operation and maintenance (O & M) often applied to these types of facilities. Aerated ponds produce effluents with a better quality than stabilisation ponds in terms of TSS and BOD_5 (average effluent TSS and BOD_5 of 31 mg/ℓ and 22 mg/ℓ for aerated ponds, and 100 mg/ℓ and 67 mg/ℓ for stabilisation ponds respectively; note that the effluent BOD_5 of the stabilisation pond systems is analysed using raw samples, while the European Union standards state that the stabilisation pond effluents should be analysed using filtered samples).

Aerated ponds require a significant energy supply per treated water volume (0.25 to 1.62 kWh/m^3). High electricity consumption in many of the WWTP is mainly due to the lack of dissolved oxygen (DO) control devices, which require continuous operation of the aeration systems. On the other hand, the ratio of water surface to population equivalent (p-e) is clearly lower for aerated ponds (1.3 m^2/person-equivalent (p-e)) than for stabilisation ponds (9.6 m^2/p-e). Aerated ponds produce much larger amounts of sludge than stabilisation ponds. Furthermore, during the evaluation it was observed that some aerated ponds received sludge from industrial WWTP (mainly from the abattoir), which discharged into the municipal sewer. This obviously increases the necessary sludge-wasting activities and O & M costs. A specific study was carried out to evaluate the impact of effluent and sludge discharges of an abattoir WWTP into the municipal sewer and its influence on the operation and the effluent quality of a small municipal aerated pond system.

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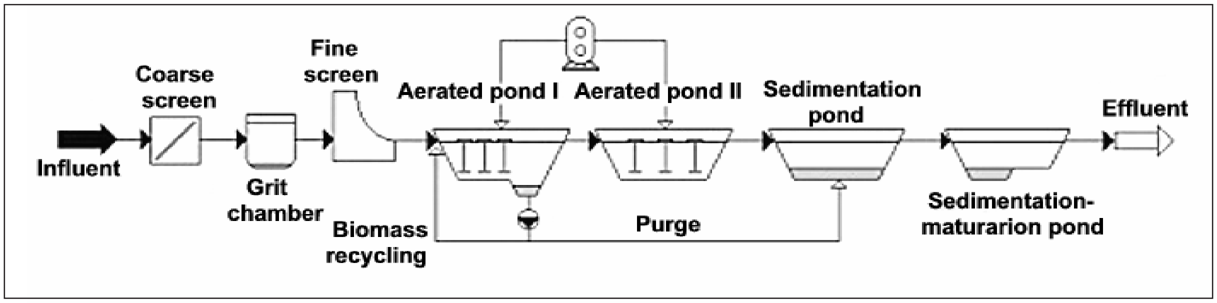

Figure 1
Flow diagram of Cervera WWTP

TABLE 1
Actual and design values of the operating parameters of Cervera WWTP. Actual values are averages of data obtained from March 1989 to January 1998. The population equivalent was calculated taking a theoretical unit mass emission rate of 60 g BOD_5/p-e.d.

Parameter	Actual value	Design value
Population served	6 950	6 750
Population equivalent, p-e	30 000	30 900
Average daily flow, m^3/d	3 100	2 900
Peak hourly flow, m^3/h	290	290
Hydraulic retention time, days	14	14
Influent TSS, mg/ℓ	490	520
Effluent TSS, mg/ℓ	45	30
Influent BOD_5, mg/ℓ	580	640
Effluent BOD_5, mg/ℓ	35	30
Organic load, kg BOD_5/d	1800	1 860
Surface organic load, kg BOD_5/ha.d	1 200	1 230
Electricity consumption, kWh/m^3	0.65	0.78
Surface/p-e ratio, m^2/p-e	0.50	0.49

Experimental

The study was carried out at the Cervera WWTP, which was established in 1989 (Fig. 1). The WWTP is made up of four ponds operating in series:

- the primary and secondary ponds are aerated ponds
- the tertiary pond functions as a sedimentation pond
- the quaternary pond is a sedimentation-maturation pond.

The primary and secondary ponds both have a surface area of 4 050 m^2 and a depth of 4 m. The tertiary pond also has a surface area of 4 050 m^2 with a depth of 3.5 m. The surface area of the quaternary pond is 2 950 m^2 and the depth is 3.5 m in the sedimentation area and 1 m in the maturation area (each area occupies approximately half of the pond). The primary pond has a small sedimentation area equipped with three pumps that can provide biomass recycling to the head of the pond; these pumps also allow the settled sludge to be conveyed to the tertiary pond. After the fine screen there is a Parshall flume equipped with an ultrasonic level transmitter for flow-rate measurement. The WWTP receives an average daily flow of 3 100 m^3/d of urban sewage from approximately 7 000 inhabitants, mixed with the effluents and sludge discharged by a conventional activated sludge WWTP of an abattoir (up to 3 000 pigs processed per day). Table 1 shows actual and design values of the main operating parameters of the WWTP.

The reliability and performance of the Cervera WWTP was evaluated using the data provided from the Catalonian Water Agency. These data were obtained from grab samples of the influent and the effluent taken with a monthly periodicity from March 1989 to January 1998. The data were evaluated considering two periods: before and after September 1993. This is because, prior to September 1993, the abattoir sewage was dumped directly into the sewer. From September 1993, the abattoir constructed and operated an activated sludge plant that discharges the effluents and the sludge into the municipal sewer. The technical services in charge of O & M activities provided the data on sludge wasting activities used in this paper.

The impact of effluent and sludge discharges of the abattoir WWTP on the operation and the effluent quality of Cervera WWTP was evaluated by means of 2 sampling campaigns. The first campaign was carried out in March to April 1997 and the second in January to February 1998. In each campaign a Philips PW9815 composite sampler was installed after the fine screen device to collect influent 24 h flow-weighted composite samples. Using a disproportionate increment in the instantaneous flow as an indication, daily influent samples were discarded until such time as a substantial discharge was observed. In the first campaign, a substantial discharge was observed on March 10^{th}, and the second on January 13^{th}. The sampling periods began on these days. The first campaign finished on April 2^{nd} and the second on February 4^{th}. During the two sampling periods, daily water temperature in the primary pond ranged from 10 to 12°C. Rain and evaporation may be considered negligible in both campaigns with respect to the influent flow rate (accumulated rain of 1 and 3.5 mm was measured in the 1^{st} and the 2^{nd} campaigns respectively; maximum evaporation during winter in the area is approximately 0.5 to 1 mm/d). In each campaign three to four samples of the influent and the effluent were collected weekly. All influent samples were 24 h flow-weighted composite samples and these were taken until the third week after the discharge. Effluent grab samples were collected until the 4^{th} week after discharge (approximately twice the theoretical hydraulic retention time). Samples were refrigerated and analysed 1d after collection. TSS, COD and BOD_5 analyses were carried out using conventional methods (*Standard Methods*, 1995).

Results and discussion

Reliability and performance of the WWTP

Figure 2 shows the changes of TSS and BOD_5 in the influent and the effluent of the WWTP from March 1989 to January 1998. As can be seen, influent TSS and BOD_5 concentrations had extreme

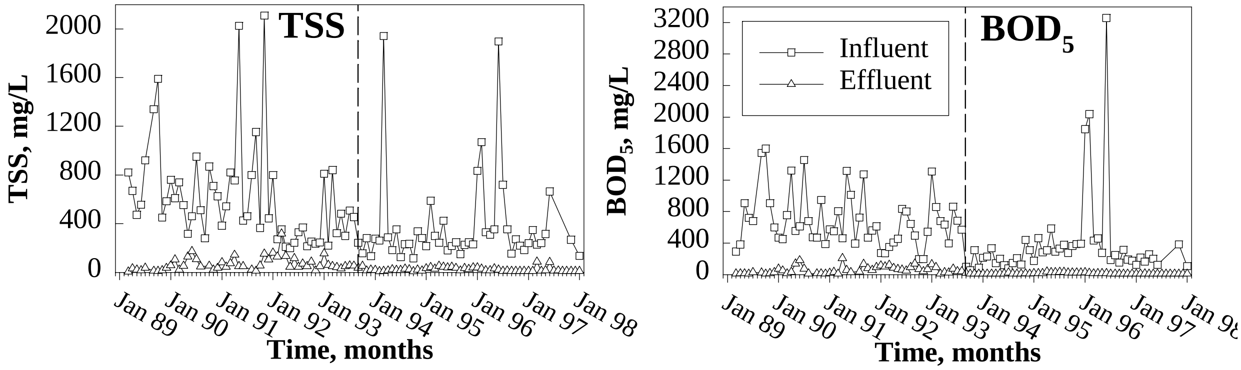

Figure 2
Changes in concentration of TSS and BOD_5 in the influent and the effluent of Cervera WWTP from March 1989 to January 1998. The dashed line indicates the start-up of the abattoir WWTP operation.

values in some samples. This was due to the fact that when sample collection was carried out, there was a simultaneous abattoir discharge. TSS and BOD_5 showed a certain tendency to decrease in the influent and the effluent over time. Thus, each time series may be divided into two different parts separated by September 1993 (dashed line in Fig. 2), when the abattoir WWTP was established.

Table 2 shows the average, standard deviation and range of the water quality parameters of Cervera WWTP before and after the establishment of the abattoir WWTP. As can be seen, before September 1993 when the abattoir sewage was dumped directly into the sewer the average influent TSS and BOD_5 were clearly higher than after September 1993. On the other hand, before September 1993 the effluents showed poor quality with average values exceeding the standards established in Directive 91/271 (Council of the European Communities, 1991). In fact, only 30% of the samples had a TSS and BOD_5 concentration of lower than 35 and 25 mg/ℓ respectively. However, since September 1993, 70% of the samples have had a TSS concentration lower than 35 mg/ℓ, and in 80% of the samples a BOD_5 lower than 25 mg/ℓ. It is clear that from September 1993, the effluents improved considerably in terms of quality and reliability (note that the variation coefficient of TSS and BOD_5- standard deviation divided by the average expressed as a percentage - was higher before September 1993 (79% and 82% respectively) than after (70% and 47% respectively).

TABLE 2
Average, standard deviation (s) and range of the water quality parameters of Cervera WWTP before and after September 1993. *n* is the number of data used for calculation. For the flowrate, *n* is the number of monthly averages obtained from daily flowrates.

Parameter	*n*	Average	s	Range
Before September 1993				
Flowrate, m^3/d	17	3 100	570	1 800-3 900
Influent TSS, mg/ℓ	53	620	410	200-2 100
Effluent TSS, mg/ℓ	50	70	55	6.0-320
Influent BOD_5, mg/ℓ	53	690	340	200-1 600
Effluent BOD_5, mg/ℓ	50	58	48	9-210
After September 1993				
Flowrate, m^3/d	51	3 000	340	2 000-3 900
Influent TSS, mg/ℓ	48	370	380	120-1 900
Effluent TSS, mg/ℓ	53	24	17	9.0-86
Influent BOD_5, mg/ℓ	48	385	560	56-3 300
Effluent BOD_5, mg/ℓ	53	15	7	9-35

TABLE 3
Average, standard deviation (s) and range of the water quality parameters of Cervera WWTP during the 2 sampling campaigns for the evaluation of sludge discharges (March-April 1997 and January-February 1998). *n* is the number of data used for calculation.

Parameter	*n*		Average		σ		Range	
	1997	1998	1997	1998	1997	1998	1997	1998
Flowrate, m^3/d	17	18	2 800	3 600	640	1 200	1 100-3 500	1 400-5 700
Influent TSS, mg/ℓ	10	10	390	500	100	900	270-550	180-3 100
Effluent TSS, mg/ℓ	14	13	10	10	6	2	1-22	7-14
Influent COD, mg/ℓ	9	10	570	800	130	990	400-830	350-3 600
Effluent COD, mg/ℓ	14	13	72	70	30	55	30-110	20-200
Influent BOD_5, mg/ℓ	10	10	240	220	88	170	150-410	120-680
Effluent BOD_5, mg/ℓ	14	13	3	7	2	8	1-9	2-13

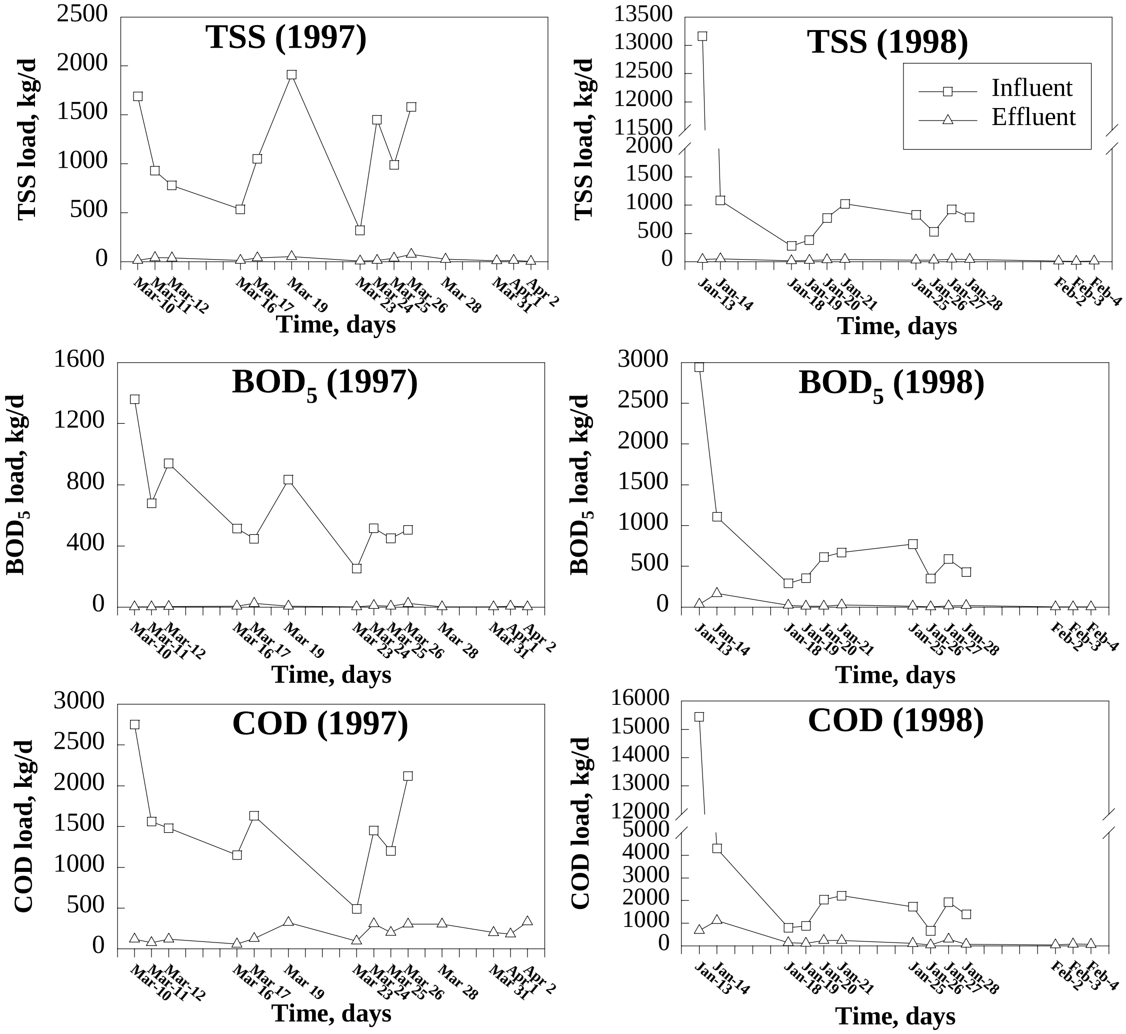

Figure 3

Changes in TSS, BOD_5 and COD loads in the influent and the effluent of Cervera WWTP during the sampling campaigns of March and April 1997, and January and February 1998. Note that the ranges of the ordinate axis scales are different.

Impact of the sludge discharges on water quality

Table 3 shows the average, standard deviation and range of the water quality parameters of Cervera WWTP during the two sampling campaigns. As can be seen, the average values are similar to the average concentrations observed after September 1993 in Table 2. Only influent TSS during the 2nd campaign (1998) had an average value more similar to that observed before September 1993. This is related to the extreme high influent TSS detected on the day of the sludge discharge (3 100 mg/ℓ). BOD_5 influent concentration values in the two campaigns were systematically lower (40 to 45%) than the values obtained from the grab samples collected monthly by the Catalonia Water Agency. These grab samples are usually taken in the morning, and from this study it is clear that they are not representative of the influent actual water quality. The calculation of the BOD_5 efficiency removal of the WWTP based on the data obtained through these grab samples is greater than the actual efficiency because of the lower concentrations observed in flow-weighted composite samples.

Figure 3 shows the changes of TSS, BOD_5 and COD loads in the influent and the effluent of the WWTP, in the two sampling campaigns. As can be seen, the highest influent loading rates are mainly those of the first sampling day because of the sludge discharge. Only the TSS loading rate observed on March 19th (1st campaign) was greater than that detected on the first day and this was related to another sludge discharge. Contaminant loading rates were clearly higher in the discharge of the 2nd campaign (1998). In fact, TSS and BOD_5 loading rates observed in the discharge of the 1st campaign were quite similar to the design loads (1 500 kg TSS/d and 1 860 kg BOD_5/d). However, the TSS and BOD_5 loading rates in the 2nd discharge were 800% and 60% higher than the design loads.

As can be seen in Fig. 3, the changes in the effluent loads of the three water quality parameters evaluated do not show any significant tendency according to the discharge event, even exactly 14 d from the discharge coinciding with the theoretical hydraulic retention time. Note that during both campaigns the effluent quality was excellent and reliable (Table 2). In conclusion, the sludge discharge on Cervera WWTP does not affect effluent quality sufficiently to bring the water quality parameters above the requirements established in European Union Directive 91/271 (Council of the European Communities, 1991).

TABLE 4
Sludge volume wasted, annual flowrate and sludge production of Cervera and Guissona WWTP from 1992 to 1997. (a) These values have been calculated taking into account that in previous years accumulated sludge was not wasted.

Year	Cervera WWTP			Guissona WWTP		
	Sludge volume, m^3	Annual flowrate, m^3/year	Sludge production, ℓ/m^3	Sludge volume, m^3	Annual flowrate, m^3/year	Sludge production, ℓ/m^3
1992	4 760	828 915	6	0	923 085	-
1993	0	1 169 095	-	0	657 000	-
1994	5 890	1 024 190	3 (a)	3 200	687 660	1 (a)
1995	5 030	1 111 425	5	0	927 100	-
1996	3 770	1 150 480	3	0	1 067 625	-
1997	6 440	1 107045	6	4 090	1 101 570	1 (a)

Sludge production

Sludge wasting is a common operational activity that has to be conducted in aerated pond systems. To evaluate the influence of the abattoir WWTP discharges on sludge production in the Cervera WWTP, a comparison was made with a similar aerated pond WWTP located 15 km away. This plant treats the wastewater of the town of Guissona and was designed for a flow rate of 2 000 m^3/d and a population equivalent of 10 000. It is also made up of four ponds operating in series:

- the primary and secondary ponds are aerated ponds
- the tertiary pond functions as a sedimentation pond
- the quaternary pond is a sedimentation-maturation pond.

The Guissona WWTP also receives industrial treated effluents but not sludge discharges (at least not to a significant degree, as is the case with Cervera). Sludge wasting in the Cervera and Guissona WWTPs is carried out in tertiary and quaternary ponds. Table 4 shows the comparative sludge production at the Cervera and Guissona WWTPs.

The results shown in Table 4 indicate that the Cervera WWTP has a clearly higher sludge production per treated flow than the Guissona WWTP. These sludge production data are comparable because the percentage of dry matter in the sludge of both plants is very similar: 4.8 to 6.8% for Cervera and 3.3 to 7.5% for Guissona. If the sludge production at the Guissona WWTP is considered a typical situation for the area (according to the data shown by Crites and Tchobanoglous (1998) sludge production in aerated ponds usually ranges from 1 to 3 ℓ/m^3), then the sludge production at the Cervera WWTP is 200 to 500% higher than the usual values. From these comparative data we conclude that the discharge of sludge at the Cervera WWTP increases the sludge production, which in turn increases the sludge wasting operation activities. In fact, from Table 4 it can be observed that sludge wasting is more frequently undertaken at the Cervera WWTP than at the Guissona WWTP.

The O & M costs of the Cervera WWTP per volume of water treated are estimated at 0.11 •/m^3. If the cost of the sludge wasting activities is 0.006 •/ℓ (of sludge), and the sludge production is 3 to 6 ℓ/m^3 (instead of 1 ℓ/m^3), then the O & M costs of the Cervera WWTP increase by approximately 10 to 30% because of the sludge discharges.

Conclusions

After the establishment of the abattoir WWTP in September 1993, the effluents of the Cervera municipal WWTP clearly improved in quality and reliability. Before September 1993, only 30% of the effluent samples of the Cervera WWTP complied with the TSS and BOD_5 standards established in European Union Directive 91/271. Since September 1993, 70% of samples have complied with these requirements.

The present study shows that sludge discharges of the abattoir WWTP into the municipal sewer do not significantly affect the effluent quality of the Cervera WWTP. In fact, we have observed that after severe discharges, the TSS and BOD_5 of the effluents are still well below the requirements of Directive 91/271(Council of the European Communities, 1991). The great capacity of the Cervera WWTP to absorb sludge discharges without influencing its effluent quality may be related to the nature of the discharges and the type of plant. The sludge discharges originate from activated sludge purged in the abattoir WWTP, and are characterised by high TSS and low BOD_5 concentrations. This sludge can easily settle in the tertiary pond, which acts as large clarifier with a low hydraulic surface loading (1.3 m/d considering a flow of 3 100 m^3/d) and with a high hydraulic retention time (4.6 d considering the same flow and the nominal volume of the pond without sludge). Sludge can also settle in the quaternary pond. On the other hand, the results indicate that decomposition of the settled sludge does not seem to represent a significant internal source of organic matter for increasing the BOD_5 of the final effluent. Settled sludge is discharged together with the sludge produced in the same plant. In short, the Cervera WWTP based on aerated ponds has excellent characteristics for allowing sludge sedimentation and a high capacity for sludge storage.

The Cervera WWTP has a sludge production that is clearly higher than other similar WWTPs because of the sludge discharges. As a result the Cervera WWTP needs more intensive sludge-disposal operating activities, thus increasing the annual O & M costs by approximately 10 to 30%.

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