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Small wastewater treatment plants in Italy: situation and case studies of upgrading with advanced technologies

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ABSTRACT

The choice between centralization and decentralization of wastewater treatment depends on many factors and requires a case-specific approach. In Italy, 92% of plants have a potentiality of less than 10,000 p.e., but altogether they treat 31% of total pollutant load. They must comply with different local regulations and they have higher specific costs than larger plants. This paper reports some examples of upgrading small overloaded plants with advanced technologies such as lamellar settlers, dissolved air flotation (DAF), moving bed biofilm reactors (MBBRs), and membrane biological reactors (MBRs). In plant nr. 1, nitrification was improved by converting part of the aerated tanks into hybrid MBBRs. Plant nr. 2 was upgraded by converting an out-of-use tank into a tertiary MBBR. Plant nr. 3 was upgraded by introducing lamellae into the settler and converting a thickener into a tertiary MBBR. In plant nr. 4, a DAF unit was installed as a primary treatment to remove Total Suspended Solids and part of Chemical Oxygen Demand. In plant nr. 5, a DAF unit was installed as a secondary treatment to work in parallel with the existing settler during rainy days. Plant nr. 6 is in a touristic locality and was upgraded with a new treatment line based on MBR.

Keywords: Small plants; Upgrading; Flotation; Lamellar settlers; Moving bed; Membrane

1. Introduction

The choice between centralization and decentralization of wastewater treatment depends on many factors and must be evaluated with a case-specific approach [1]. In a centralized plant complex, wastewater treatment technologies, sludge digestion, and thermal drying may be economically justified. Moreover, continuous monitoring and automatic regulation systems can be conveniently installed. But centralization also has disadvantages. A big plant is served by a long branched sewer network and many pumping stations involving high costs for realization, exercise, and maintenance. Moreover, a centralized plant usually treats industrial wastewater as well [2]. With many decentralized small plants, the impact of residual pollutants is distributed over a wide territory, consequences of a failure in one plant are limited and local reuse of treated water is favoured [3]. So the choice between centralization and decentralization is still an open question. This paper briefly describes the situation of small plants in Italy and focuses on some case studies of upgrading with advanced technologies such as lamellar settlers, dissolved air flotation (DAF), moving bed biofilm reactors (MBBRs), and membrane bioreactors (MBRs).

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Lamellar settlers are a well-known technology [4,5]. The effective settling area is increased by inclined plates or multiple tubular channels adjacent to each other and sloped at 50–60° from horizontal, so that particles have laminar flow and travel a short distance before settling. Raw wastewater or mixed liquor flows upwards between plates; here particles hit the surface of plates, agglomerate, settle, and slide downwards. Many applications of these clarifiers are reported in the literature. In [6], it is reported that inclined plates were introduced in a conventional settler with a surface loading rate of $4.17\,m^3/m^2h$; the effective surface loading rate became $1.59\,m^3/m^2h$ and Total Suspended Solids (TSS) removal efficiency was 90%. Lamellae have been successfully used in large plants as well by introducing them directly into activated sludge basins [7,8].

In MBBRs, biomass grows as a biofilm on plastic floating carriers; mixing is done by aeration in aerobic tanks, and mechanically in anoxic tanks. In pure MBBR reactors, biomass grows only as a biofilm on carriers; in hybrid reactors it grows both as a biofilm and as suspended sludge. Several processes and carriers have been developed [9]. The AnoxKaldnes^{TM} MBBR has the largest number of applications (more than 400) in the world. Technical literature on MBBRs reports specific nitrification rates of $0.8–1.0\,g_N/m^2d$ at 15°C and 5 mg/L O_2 with secondary effluent [10]. The process is negatively affected by organic load and is almost inhibited if the organic load is higher than $5\,g_{BOD}/m^2d$, BOD = Biological Oxygen Demand [11]. For denitrification, different specific rates are reported: $0.4–0.7\,g_N/m^2d$ at 15°C for pre-denitrification with raw wastewater, $1.2\,g_N/m^2d$ at 15°C for post-denitrification with sodium acetate as an external carbon source [12,13].

In DAF, suspended solids are separated from water by air micro-bubbles that lift them up to the surface. Part of the clarified water is pressurized, saturated with air at 5–6 bar in an air saturation reactor (ASR), sent together with wastewater into the flotation tank and rapidly depressurized. Air micro-bubbles develop, adhere to solids and lift them up to the free surface; flocculation is improved with a polyelectrolyte. Solids are collected by a rotating scraper, and clarified water is extracted through a holed annular pipe. DAF has been applied in water and wastewater treatment with several aims [14]. DAF as a primary wastewater treatment removed 92% of TSS, 78% of Chemical Oxygen Demand (COD), and 95% of phosphorus with surface loads of $5–10\,m^3/m^2h$; DAF in biological plants after fixed biofilters or MBBR reactors removed excess biofilm with surface loads of $3–6\,m^3/m^2h$ [15].

In membrane bioreactors (MBRs), biomass is separated from treated wastewater by a microfiltration (pore size 0.01–20 μm) or ultrafiltration (pore size 0.002–0.02 μm) membrane which is submerged in the oxidation tank or in a dedicated tank. MBRs can treat higher pollutant loads with a higher sludge concentration in smaller tanks than traditional activated sludge plants with final settlers. Moreover, effluent water can be reused with ultrafiltration MBRs if it meets the chemical and microbiological limits for irrigation. MBRs have been successfully applied to treat municipal wastewater [16,17] both with plane and hollow fiber membranes. In treated effluents, COD is normally less than 40 mg/L and BOD is less than 10 mg/L, while nitrification is related to sludge age (in [18] efficiencies of 80% for 10 days and 99% for 50 days are reported). An MBR with a retention time of 14 h, a sludge concentration of $9\,kg_{TSS}/m^3$, and a plane membrane with a pore size of 0.4 μm removed 97% of BOD, 98% of ammonium, and 8-log total Coliforms, but the same reactor with 5 μm pore size membranes achieved only 5-log Coliforms reduction [19]. MBRs are also used for greywater treatment: with residence times between 10 and 18 h, removal efficiencies were 92–95% for TSS, 85–95% for COD, 94–97% for BOD, and 63–92% for TSS [20–22].

2. General situation in Italy

According to a study published by the Italian Statistic Institute [23] focusing on 11509 wastewater treatment plants, 78% of plants have a potentiality of less than 2,000 person equivalent (p.e.), most of these having only a primary treatment; 14% of plants have a potentiality between 2,000 and 10,000 p.e., most of these having a secondary treatment. The smallest plants treat only 6% of total pollutant load, while plants with a potentiality of 2,000–10,000 p.e. treat 25% of total pollutant load (Figs. 1 and 2).

Plants that serve isolated buildings have only a primary treatment and are generally Imhoff tanks. Plants with a secondary treatment are generally based on activated sludge reactors with different schemes

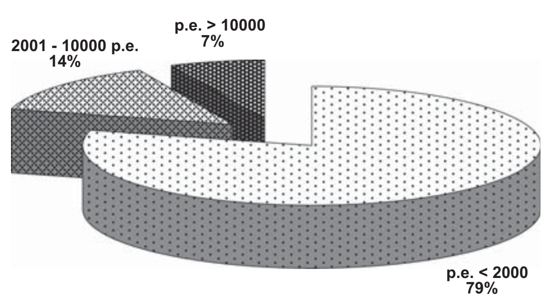

Fig. 1. Distribution of Italian plants for potentiality.

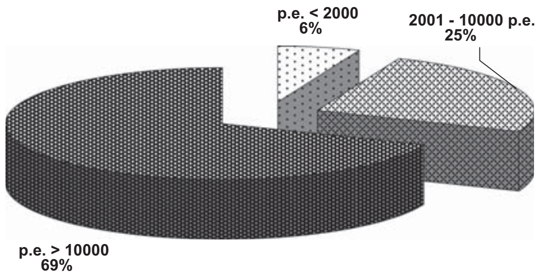

Fig. 2. Distribution of Italian plants for treated load.

(classical, extended aeration or pre-denitrification–oxidation, with static settler or with scraping bridge settler, sludge recirculation by pumping or gravity, turbine or diffused aeration). Biofilm processes are also applied in trickling filters (TFs), rotating biological contactors (RBCs), and in constructed wetland. The Italian national law D.Lgs. 152/2006 (which applies the European Directive nr. 271/91) requires emission limits for plants serving 2,000 p.e. or more, while for smaller plants an "appropriated treatment" is required, and for isolated buildings regions are required to provide suitable treatments.

Each Italian region has its own local wastewater regulation. Local emission limits depend on potentiality (p.e.) and type of final receptor (sea, river, lake, or soil in the few cases in which it is allowed). Moreover, some regions divide their territory into areas with different sensitivities, meaning that limits are different for plants with the same potentiality and type of final receptor. Others have technical norms for projection of small wastewater treatment plants.

A study was conducted in 2010 on 463 Italian plants [24] in cooperation with eight water service companies. Imhoff tanks had low and very variable performances: removal efficiencies were 30–70% (average 50%) for COD and 10–80% (average 50%) for TSS. Activated sludge plants had much better performances, but within this large category there were significant differences. With classical scheme, extended aeration, and pre-denitrification–oxidation plants, average removal efficiencies were 85% for COD, 81% for TSS, 86% for ammonium, and 58% for total nitrogen (with pre-denitrification–oxidation schemes, values of up to 85% were encountered). Gravity-recirculation plants on average removed only 54% of COD and 38% of TSS (no data were available for nitrogen). TFs removed 62% of COD, 71% of TSS but only 28% of total nitrogen. Similarly, RBCs removed 77% of COD, 82% of TSS, and 33% of total nitrogen. Constructed wetland on average removed 86% of COD, 91% of TSS but only 36% of total nitrogen. Plants of less than 2,000 p.e. had higher specific costs than larger plants (28€/p.e.·year vs. 20€/p.e.·year), caused mainly by transfer of personnel and transportation of sludge to bigger plants. Common difficulties with small plants included wide variations of hydraulic and pollutant loads, infiltrations in sewers and the need to transport sludge to bigger plants for aerobic/anaerobic stabilization and dewatering (local treatment is often limited to thickening).

3. Case studies of upgrading

Plant nr. 1 was originally built for 3,000 p.e. and was made up of a pumping station, a screen and a biological section with pre-denitrification (150 m^3), oxidation (470 m^3), and settling (310 m^3). Emission limits were stated by D.Lgs. 152/2006 and by the local Regional Plan of Water Resanitation of Veneto (Table 1). The plant was overloaded: the effective hydraulic load corresponded to 3,800 p.e., the organic load to 4,500 p.e., and the nitrogen load to 5,800 p.e. Ammonium was the most critical pollutant as its concentration in effluent was often close to the emission limit. Pollutant concentrations in influent and effluent over a period of 8 months are listed in the first part of Table 1. The plant was upgraded by compartmenting the aerated tank: 2/3 of the volume was kept as an activated sludge reactor and 1/3 was converted into a hybrid MBBR. Here, Anox-Kaldnes^{TM} polyethylene carriers (specific surface 500 m^2/m^3) were placed with a filling degree of 60%. The hybrid MBBR receives air by a 1,400 Nm^3/h blower and medium bubbles diffusers. After the restarting phase, the activated sludge concentration was 3.8 kg_{TSS}/m^3, and biofilm concentration as Total Solids (TS) reached 1.7 g_{TS}/m^2 (0.5 kg_{TS}/m^3) in 3 months, 2.6 g_{TS}/m^2 (0.8 kg_{TS}/m^3) in six months, and 4.0 g_{TS}/m^2 (1.2 kg_{TS}/m^3) in one year. With an average hydraulic load of 850 m^3/d and pollutant loads of 370 kg_{COD}/d and 60 kg_{TKN}/d, TKN = Total Kjeldahl Nitrogen, removal efficiencies were 90% for COD, 99% for TKN, and 87% for total nitrogen. Pollutant concentrations in influent and effluent over a period of 6 months (temperature range 22–28˚C) are listed in the second part of Table 1. The investment cost of this upgrading was 200,000 €. This plant was the first hybrid MBBR in Italy. More details on pilot-scale tests and starting a full-scale plant are reported in [25].

Plant nr. 2 was originally built for 400 p.e. and was made up of a pumping station, a screen, an activated sludge oxidation tank (volume 55 m^3) with temporized aeration (14 h/d), a static settler (volume 9 m^3), a small tank (8 m^3) out of use, a sludge thickener (20 m^3) out of use, and a final constructed wetland. Emission limits were stated by the local Regional Plan of Water Resanitation of Veneto (Table 2). The plant was

Table 1
Pollutant concentrations in the influent and effluent in Plant nr. 1 before and after upgrading

Plant nr. 1		Influent			Effluent			Emission limit	Removal (%)
		Min	Average	Max	Min	Average	Max		
Before upgrading	COD (mg/L)	232	374	880	23	58	75	125	84
	TKN (mg/L)	37	68	124	2.6	8.5	22		87
	NH_4–N (mg/L)				2.6	8.5	22	23	
	NO_2–N (mg/L)				0.11	0.60	1.82	2	
	NO_3–N (mg/L)				0.8	4.7	9.0	30	
	Tot-N (mg/L)	37	68	124		12.8			82
After upgrading	COD (mg/L)	181	435	710	10	44	71	125	90
	TKN (mg/L)	35	71	106	0.05	0.70	1.2		99
	NH_4–N (mg/L)				0.05	0.70	1.2	23	
	NO_2–N (mg/L)				0.01	0.08	0.26	2	
	NO_3–N (mg/L)				3.3	8.7	19.8	30	
	Tot-N (mg/L)	35	71	106		9.5			87

overloaded: the effective hydraulic load corresponded to 413 p.e., the organic load to 371 p.e., and the nitrogen load to 549 p.e. In this plant, ammonium was the most critical pollutant and its concentration was often close to the emission limit. Pollutant concentrations in influent and effluent over a period of 4 months are listed in the first part of Table 2. The plant was upgraded as follows: the thickener was converted into a pre-denitrification tank, the aeration time of the oxidation tank was increased to 18 h/d and the small tank ($8\,m^3$) was transformed into a pure biofilm MBBR. In this reactor, Anox-Kaldnes™ polyethylene carriers (specific surface $500\,m^2/m^3$) were placed with a filling degree of 50%. A screen was installed to keep carriers in the tank; air was supplied by a $50\,Nm^3/h$ blower and medium bubbles air diffusers. After the restarting phase, the activated sludge concentration in the first two tanks was $3.5\,kg_{TSS}/m^3$, and biofilm concentration in the tertiary MBBR reached $4.4\,g_{TS}/m^2$ ($1.1\,kg_{TS}/m^3$) in three months. With an average hydraulic load of 100 m^3/d and pollutant loads of $46\,kg_{COD}/d$ and $6\,kg_{TKN}/d$, removal efficiencies were 82% for COD, 81% for TKN, and 66% for total nitrogen. Pollutant concentrations in influent and effluent over a period of 4 months (temperature range 10–15°C) are listed in the second part of Table 2. The investment cost of this upgrading was 30,000 €.

Plant nr. 3 was originally built for 500 p.e. and was made up of a pumping station, a coarse screen, an activated sludge oxidation tank (volume $100\,m^3$), a static settler (volume $11\,m^3$), and a sludge thickener ($18\,m^3$). Emission limits were stated by the local Regional Plan of Water Resanitation of Veneto (Table 3). The plant was overloaded: the effective hydraulic load corresponded to 1,160 p.e., the organic load to 765 p.e., and the nitrogen load to 820 p.e. The most relevant problem was the hydraulic load as this plant treated wastewater from a combined sewer. Moreover, frequent nitrogen peaks in the influent were encountered. Pollutant concentrations in influent and effluent over a period of 6 months are listed in the first part of Table 3. The plant was upgraded as follows: the coarse screen was replaced with a fine screen, an anoxic zone ($20\,m^3$) was created in the oxidation tank, inclined plates (60° from horizontal, surface $30\,m^2$) were installed in the settler, the old thickener was converted into a pure biofilm MBBR, and a prefabricated sludge thickener was installed. In the tertiary MBBR tank, Anox-Kaldnes™ polyethylene carriers (specific surface $500\,m^2/m^3$) were placed with a filling degree of 50%. A screen was installed to keep carriers in; air was supplied by a $180\,Nm^3/h$ blower and medium bubbles air diffusers. After the restarting phase, the activated sludge concentration in the first

Table 2
Pollutant concentrations in the influent and effluent in Plant nr. 2 before and after upgrading

Plant nr. 2		Influent			Effluent			Emission limit	Removal (%)
		Min	Average	Max	Min	Average	Max		
Before upgrading	COD (mg/L)	494	608	678	55	62	72	380	90
	TKN (mg/L)	57	77	94	8.2	12.3	22.5		84
	NH_4–N (mg/L)				8.2	12.3	22.5	23	
	NO_2–N (mg/L)				0.28	0.60	0.90	2	
	NO_3–N (mg/L)				2.5	4.6	6.0	30	
	Tot-N (mg/L)	57	77	94		17.5			77
After upgrading	COD (mg/L)	301	456	616	58	82	120	380	82
	TKN (mg/L)	36	50	87	8.0	9.5	16.5		81
	NH_4–N (mg/L)				8.0	9.5	16.5	23	
	NO_2–N (mg/L)				0.01	0.40	0.90	2	
	NO_3–N (mg/L)				0.6	7.3	11.8	30	
	Tot-N (mg/L)	36	50	87		17.2			66

tank was 2.9 kg_{TSS}/m^3, and the biofilm concentration in the tertiary MBBR reached 1.0 g_{TS}/m^2 (0.26 kg_{TS}/m^3) in three months. The effective average hydraulic load of the settler was 0.44 m^3/m^2h, while without lamellae it would have been 2.2 m^3/m^2h. No sludge loss was encountered. With an average hydraulic load of 244 m^3/d and pollutant loads of 68 kg_{COD}/d and 10 kg_{TKN}/d, removal efficiencies were 87% for COD, 87% for TKN, and 46% for total nitrogen. Pollutant concentrations in influent and effluent over a period of four months (temperature range 22–27°C) are listed in the second part of Table 3. The investment cost of this upgrading was 100,000 €.

Plant nr. 4 was originally built for 3,500 p.e. and was made up of a screen, a pumping station and an activated sludge biological section with an anaerobic selector (25 m^3), an oxidation tank (412 m^3), and two settlers (total volume 115 m^3). Excess sludge was treated in a thickener and a filter press. Emission limits were stated in a program agreement between a province of Toscana and the water service company, and are listed in Table 4. The plant was overloaded: the effective hydraulic load corresponded to 5,000 p.e., the organic load to 5,716 p.e., and the nitrogen load to 6,333 p.e. Emission limits for COD and nitrogen were often exceeded. Pollutant concentrations in influent and effluent over a period of 6 months are listed in the first part of Table 4. The plant was upgraded as follows: a flow divider was built to send 80% of the incoming load to a new equalization tank (20 m^3) and then to a new DAF Deltafloat® tank (16 m^3); wastewater coming from the flotation tank and the remaining 20% of raw wastewater was sent to the existing biological section. Primary sludge from the DAF tank was treated together with secondary excess sludge. After the restarting phase, with an average hydraulic load of 1,000 m^3/d and pollutant loads of 693 kg_{COD}/d and 80 kg_{TKN}/d, the flotation tank removed 60% of incoming COD and 16% of incoming TKN. Activated sludge concentration in the biological tanks was 4.2 kg_{TSS}/m^3, and the whole plant removed 95% of COD, 99% of TKN, and 68% of total nitrogen. Pollutant concentrations in influent and effluent over a period of 6 months (temperature range 18–22°C) are listed in the second part of Table 4. The investment cost of this upgrading was 140,000 €.

Plant nr. 5 was originally built for 2,500 p.e. and was made up of a pumping station, a screen, an activated sludge tank (anoxic volume 100 m^3, aerated volume 192 m^3), a settler (volume 100 m^3), a sludge thickener, and a belt filter press. Emission limits were stated by D.Lgs. 152/2006 and by the local Regional Plan of Water Resanitation of Veneto (Table 5). The plant was not overloaded for pollutant loads but

Table 3
Pollutant concentrations in the influent and effluent in Plant nr. 3 before and after upgrading

Plant nr. 3		Influent			Effluent			Emission limit	Removal (%)
		Min	Average	Max	Min	Average	Max		
before upgrading	COD (mg/L)	105	280	662	12	28	50	380	90
	TKN (mg/L)	4.8	33.9	83.1	1.3	2.9	5.4		91
	NH_4–N (mg/L)				1.3	2.9	5.4	23	
	NO_2–N (mg/L)				0.05	0.41	1.70	2	
	NO_3–N (mg/L)				3.5	6.8	19.7	30	
	Tot-N (mg/L)	4.8	33.9	83.1		10.1			70
After upgrading	COD (mg/L)	196	278	344	23	35	56	380	87
	TKN (mg/L)	24.3	39.6	49.1	0.7	5.1	8.4		87
	NH_4-N (mg/L)	13.1	22.4	28.2	0.05	0.06	0.09	23	
	NO_2–N (mg/L)				0.02	0.14	0.44	2	
	NO_3–N (mg/L)				14.0	16.1	22.2	30	
	Tot-N (mg/L)	24.3	39.6	49.1		21.3			46

Table 4
Pollutant concentrations in the influent and effluent in Plant nr. 4 before and after upgrading

Plant nr. 4		Influent			Effluent			Emission limit	Removal (%)
		Min	Average	Max	Min	Average	Max		
Before upgrading	TSS (mg/L)	146	385	2,100	14	82	634	173	79
	COD (mg/L)	331	788	1,610	27	132	456	218	83
	TKN (mg/L)	32	76	122	8.9	27.4	81.5		64
	NH_4–N (mg/L)				0.1	17.7	71.6		
	NO_2–N (mg/L)				0.01	0.74	5.39		
	NO_3–N (mg/L)				0.5	15.0	27.0		
	Tot-N (mg/L)	32	76	122		43.1		32	43
After upgrading	TSS (mg/L)	138	319	630	8	19	35	173	94
	COD (mg/L)	333	693	1124	14	37	82	218	95
	TKN (mg/L)	248	279	315	0.1	2.5	26		99
	NH_4–N (mg/L)				0.3	0.9	2.7		
	NO_2–N (mg/L)				0.01	0.40	2.77		
	NO_3–N (mg/L)				5.5	23.1	37.0		
	Tot-N (mg/L)	40	80	107		26.0		32	68

during rainy days with 10 mm rain or more, the hydraulic load reached 780 m^3/d (3,900 p.e.) with hourly peaks of 60 m^3/h. This was 1.5 times the maximum projected value of 40 m^3/h. Pollutant concentrations in influent and effluent over a period of 6 months are listed in the first part of Table 5. The plant was upgraded as follows: a DAF Deltafloat® tank (12 m^3) was installed to work in parallel with the existing settler during rainy days to separate treated water from sludge, which was (and is) recirculated to the biological tank. After the restarting phase, during six rainy days (10–20 mm), the plant treated an average hydraulic load of 44 m^3/h. The DAF tank treated an average hydraulic load of 17 m^3/h (maximum value of 25 m^3/h) with an average sludge concentration of 3.5 kg_{TSS}/m^3. The recirculated effluent load was 25 m^3/h. Therefore, the surface hydraulic load was 4.66 m^3/m^2h and the surface solids load was 6.6 kg_{TSS}/m^2h. Sludge was separated from treated water with an efficiency of 99%. The effluent always met emission limits, particularly the TSS limit. Pollutant concentrations in influent and effluent over a period of 6 months (temperature range 13–20°C) are listed in the second part of Table 5. The investment cost of this upgrading was 130,000 €.

Plant nr. 6 was originally built in a touristic locality for 4,000 p.e. during winter and 12,500 p.e. during summer. It was made up of a pumping station, a screen, an activated sludge biological section with two predenitrification tanks (total volume 104 m^3), three oxidation tanks (total volume 590 m^3) and two settlers (total volume 255 m^3), and a disinfection tank (70 m^3). Sludge was treated in a thickener (60 m^3). Emission limits were stated by the local Regional Plan of Water Resanitation of Veneto (Table 6), as the final effluent was (and is) discharged into the sea. During summer, the plant was often overloaded: the effective hydraulic load corresponded to 9,400 p.e., the organic load to 19,900 p.e., and the nitrogen load to 17,450 p.e. Moreover, an increase in hydraulic load was expected. Pollutant concentrations in influent and effluent over a period of four months are listed in the first part of Table 6. The plant was upgraded by building a new biological line with membrane reactors. This new line is made up of a pre-denitrification tank (225 m^3), an oxidation tank (800 m^3) in which there are also Kubota membranes, and a deoxygenation tank (150 m^3). Membranes have a pore size of 0.4 μm, a normal permeate flux of 20 L/m^2h and a maximum exercise transmembrane pressure of 20 kPa. In this plant, membranes have a total surface of 2,500 m^2 and are kept clean by local aeration. When necessary, they are washed with sodium hypochlorite 0.6% solution. In the old line activated sludge concentration is 4 kg_{TSS}/m^3 and in

Table 5
Pollutant concentrations in the influent and effluent in Plant nr. 5 before and after upgrading

Plant nr. 5		Influent			Effluent			Emission limit	Removal (%)
		Min	Average	Max	Min	Average	Max		
Before upgrading	TSS (mg/L)	270	360	440	18	22	25	35	94
	COD (mg/L)	560	625	725	42	59	68	125	91
	TKN (mg/L)	62	73	81	3.7	5.2	7.5		93
	NH_4–N (mg/L)				3.7	5.2	7.5	23	
	NO_2–N (mg/L)				0.13	0.33	0.50	2	
	NO_3–N (mg/L)				2.9	4.4	5.6	30	
	Tot-N (mg/L)	62	73	81		9.9			86
After upgrading	TSS (mg/L)	155	302	689	18	20	22	35	93
	COD (mg/L)	181	632	1092	25	32	50	125	95
	TKN (mg/L)	46	66	84	0.5	1.3	6.7		98
	NH_4–N (mg/L)				0.5	1.3	6.7	23	
	NO_2–N (mg/L)				0.36	0.67	1.04	2	
	NO_3–N (mg/L)				1.8	7.7	16.1	30	
	Tot-N (mg/L)	46	66	84		9.7			85

Table 6
Pollutant concentrations in the influent and effluent in Plant nr. 6 before and after upgrading

Plant nr. 6		Influent			Effluent			Emission limit	Removal (%)
		Min	Average	Max	Min	Average	Max		
Before upgrading	COD (mg/L)	815	1,217	1,700	<25	<25	<25	160	98
	TKN (mg/L)	76	112	136	<0.5	<0.5	<0.5		99
	NH_4–N (mg/L)				<0.5	<0.5	<0.5	11	
	NO_2–N (mg/L)				<0.01	<0.01	<0.01	0.6	
	NO_3–N (mg/L)				14.6	18.9	19.5	20	
	Tot-N (mg/L)	70	112	209		18.9			83
After upgrading	COD (mg/L)	152	386	587	<25	<25	<25	160	94
	TKN (mg/L)	20	28	35	0.5	1.0	2.9		96
	NH_4–N (mg/L)				0.5	1.0	2.9	11	
	NO_2–N (mg/L)				<0.01	0.10	0.33	0.6	
	NO_3–N (mg/L)				2.5	11.4	19.3	20	
	Tot-N (mg/L)	20	28	35		12.5			55

the new line activated sludge concentration is 8 kg_{TSS}/m^3. During the summer of 2010, the plant treated 2,400 m^3/d in the old line and 1,000 m^3/d in the new line. With pollutant loads of 1,312 kg_{COD}/d and 95 kg_{TKN}/d, removal efficiencies were 95% for COD, 99% for TKN, and 60% for total nitrogen. Moreover, treated water can be reused, as it complies with Italian regulations for reuse for irrigation purposes. Though influent is a combined sewage, no problems were encountered in the few rainy days during the summer of 2010. Pollutant concentrations in influent and effluent over a period of 4 months (temperature range 23–28℃) are listed in the second part of Table 6. The investment cost for this upgrading was 1,400,000 €.

4. Conclusions

The choice between centralization and decentralization of wastewater treatment requires a case-specific approach. Most Italian plants are small: 92% have a potentiality of less than 10,000 p.e. but together they treat only 31% of total pollutant load. Plants that treat less than 2,000 p.e. (including individual systems) often have only a primary treatment, while most plants with a potentiality in the range 2,000–10,000 p.e. have a secondary treatment. Small plants with different technologies have different performance levels. Imhoff tanks and gravity-recirculation activated sludge plants give the worst results; activated sludge plants with classical scheme, extended aeration, and pre-denitrification–oxidation remove COD, TSS, and nitrogen with respective average efficiencies of 85, 81, and 58%. Small plants have higher specific costs than bigger plants, mainly due to personnel transfer and sludge transportation. Common difficulties include wide load variations, infiltrations in sewers, and the need to transport sludge to bigger plants.

The case studies reported here demonstrate that overloaded small plants can be easily upgraded with advanced technologies with minimal additional space requirements and often simply by recovery and conversion of existing tanks.

- Plant nr. 1 (projected for 3,000 p.e.) was upgraded by dividing the aerated tank of each line into two sectors. The first sector was kept as an activated sludge reactor while the second was converted into an MBBR. The plant now treats a nitrogen load of 5,800 p.e. with a removal efficiency of 99% for TKN and 87% for total nitrogen.

- Plant nr. 2 (projected for 400 p.e.) was improved by transforming a sludge thickener into a pre-denitrification tank and a small tank into a tertiary nitrification MBBR. The plant now treats a nitrogen load of 549 p.e. with a removal efficiency of 81% for TKN and 69% for total nitrogen.
- Plant nr. 3 (projected for 500 p.e.) was upgraded by installation of lamellae into the existing static settler and transformation of a sludge thickener into a tertiary nitrification MBBR. The plant now treats a nitrogen load of 800 p.e. with a removal efficiency of 87% for TKN and 46% for total nitrogen. Sludge settles well without loss. The average hydraulic load is 244 m^3/d (1,160 p.e.).
- Plant nr. 4 (projected for 3,500 p.e.) was improved by installation of a DAF tank as a primary treatment. With pollutant loads of 5,716 p.e. as COD and 6,333 p.e. as nitrogen, the DAF alone removed 60% of COD and 16% of TKN. The whole plant removed 95% of COD, 98% of TKN, and 68% of total nitrogen.
- Plant nr. 5 (projected for 2,500 p.e.) was upgraded by installation of a DAF tank as a secondary treatment working in parallel with the existing settler on rainy days. During six days of intense rain, the DAF treated an average hydraulic load of $17\,m^3/h$ containing 3.5 kg_{TSS}/m^3, worked with a surface hydraulic load of $4.66\,m^3/m^2h$ including effluent recirculation and separated solids with an efficiency of 99.1%.
- Plant nr. 6 (projected for 4,000 p.e. during winter and 12,500 p.e. during summer) was improved by realization of a new biological line based on membrane bioreactors. In the summer of 2010, with pollutant loads of 10,933 p.e. as COD and 7,916 p.e. as nitrogen, removal efficiencies were 95% for COD, 99% for TKN, and 60% for total nitrogen. Moreover, treated water can be reused for irrigation, as it complies with Italian regulations for reuse.

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