WINERY HIGH ORGANIC CONTENT WASTEWATERS TREATED BY CONSTRUCTED WETLANDS IN MEDITERRANEAN CLIMATE

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ABSTRACT

Three different multistage constructed wetland plants for wineries wastewater treatment, located in central Italy, have been monitored and designed by the IRIDRA Ltd engineering firm. The three treatment systems are: 1) Casa Vinicola Luigi Cecchi & Sons (Siena): single stage horizontal subsurface flow system (SFS-h) followed by a Free Water System (FWS); 2) Azienda Vitivinicola "Tenuta dell'Ornellaia" (Leghorn): vertical flow constructed wetland (SFS-v) as a first stage followed by a second SFS-h stage with recirculation to the first stage and then by a single FWS; 3) Azienda Agricola La Croce (Siena): a single stage SFS-h constructed wetland. This paper presents the principal design specifications, a description of the plant operations and the analyses of influent and effluent characteristics (pH, COD, BOD_5, TN, TP, TSS). The comparison of the performances of these three different plants is of the great interest, given that they have been designed with different layouts and are set in the same geographical region in Italy, where the wine industry represents a very important economic sector. The mean COD concentration in the three plants, after a primary anaerobic treatment and equalization, is in the range of 1000-4000 mgO_2/l, while pH varies from 4.8 to 6.9. The preliminary data indicates that constructed wetlands have great potential for treatment of this kind of wastewaters: so far, the BOD_5 and COD removal as high as 92-98% and 87-98% have been achieved, respectively. Suspended solids (TSS) were removed with up to 70-90% efficiency, neutralization of the pH in the effluents contributed to the increase from 6.5 to 7.5, total nitrogen (TN) removal was 50-90% and total phosphorus (TP) 20-60%.

KEYWORDS

Multistage constructed wetlands, winery wastewater, high organic load, reed beds, BOD removal, COD removal

INTRODUCTION

Winery wastewaters are characterised by the high content of organic material and nutrients, high acidity, and large variations in a seasonal flow production. Consequently, their treatment requires particular attention and demands careful consideration of all available options. Furthermore, the wine industry in Italy includes several hundreds of small producers, whose

yearly wastewater production and financial resources may not be sufficient to warrant advanced technological treatments. In the current common practice, effluent is often stored in evaporation ponds and then sprayed over open land for evaporation/irrigation purposes. With the increasing pressure from the environmental regulations and the growing awareness of the negative impacts of concentrated, seasonal discharge of waters containing high nutrient and organic loadings in the nearby water courses, this industry is facing greater restrictions related to the discharge of their wastewater. Constructed wetlands may offer an efficient, low-cost, low-maintenance and energy alternative for wineries that have sufficient land area available for a wetland creation. Constructed wetlands also have the advantage of being able to accept seasonal flows without adversely affecting the functional aspects of the treatment system. The engineering firm IRIDRA Ltd, based in Florence, has designed most of the first operating constructed wetlands for winery wastewater treatment in Tuscany. The performance of three different constructed wetlands designed by IRIDRA have been monitored during the last year by IRIDRA and ARPAT (Agenzia Regionale per la Protezione dell'Ambiente), the regional public authority responsible for environmental monitoring.

The three treatment facilities schemes are shown in Figure 1 (As=surface area; Qmn= mean daily flow):
1) Casa Vinicola Luigi Cecchi & Sons (Castellina in Chianti - Siena): winery wastewater treatment and reuse for irrigation using a single stage horizontal subsurface flow system (SFS-h; As=480m^2) followed by a free water system (FWS; 850m^2) – Qmn=35m^3/d;
2) Azienda Vitivinicola "Tenuta dell'Ornellaia" (Bolgheri - Leghorn): winery wastewater treatment and reuse for irrigation using two parallel vertical flow constructed wetland as a first stage (SFS-v; As=90m^2 each) followed by a second SFS-h stage (As=86m^2) and then by a single FWS (As=148m^2) and a final Pond (As=338m^2) with recirculation to the first stage – Qmn=10m^3/d;
3) Azienda Agricola La Croce of F.lli Zari (Castellina in Chianti - Siena): winery wastewater treatment by a SFS-h constructed wetland (As=216m^2) and discharge in a fresh water receiving body – Qmn=8m^3/d.

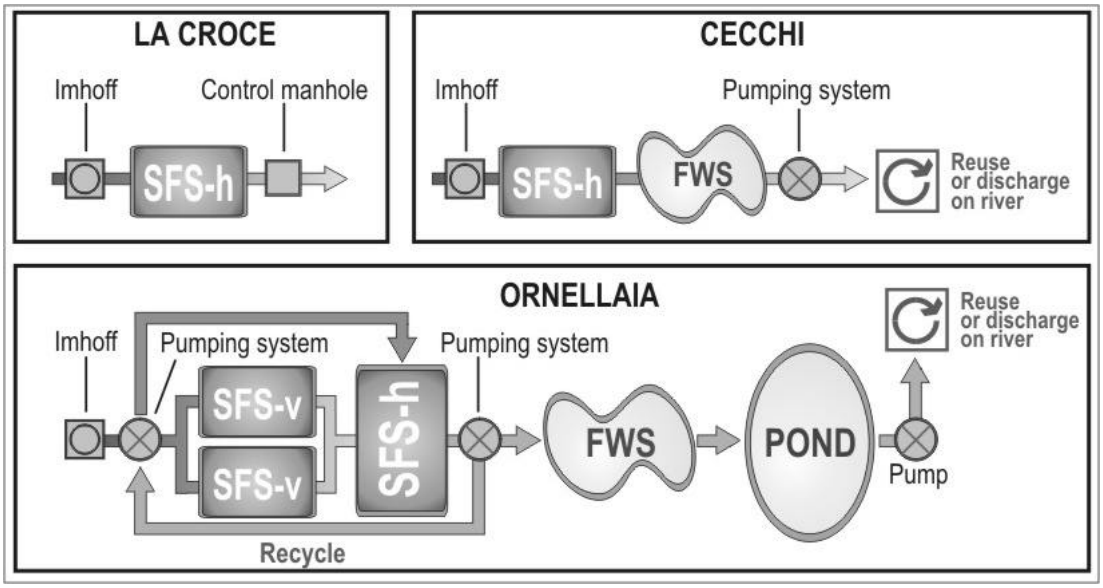

Fig. 1 – Schematic presentation of the three facilities

METHODS AND MATERIALS

The dimensioning tools utilised for the design of the three systems were based on published criteria from the following publications: E.P.A. [1], IWA [2], Platzer [3]. The superficial area and basin dimensions were designed on desired effluent characteristics, the daily average hydraulic loading, organic load, fill depth and gravel size and the basin slope. The population equivalent (p.e.) values have been calculated assuming 60 gr BOD_5/pe.day.

Table 1 – Main features of wineries wastewater treatment facilities

	Cecchi	***Ornellaia***	***La Croce***
Load (p.e.)	730	370	127
Surface Area 1st stage (m^2)	480 (SFS-h) 30 m (W) x 16 m (L)	2 x 90 (SFS-v) 5 m (W) x 18 m (L)	215 (SFS-h) 21,5 (W) m x 10 m (L)
Surface area 2nd stage (m^2)	850 (FWS)	102 (SFS-h) 17 m (W) x 6 m (L)	-
Surface area 3rd stage (m^2)	-	148 (FWS V=128 m^3) + 338 (Pond V=440 m^3)	-
SFS-h Beds depth (m)	0,7	0,7	0,7
SFS-h Gravel size (mm)	5-10	8-12	5-10
SFS-v filling media (sand+gravel)	-	Top 5 cm ∅ 8-12mm 20 cm sand ∅ 0/4 20 cm ∅ 4-8 mm 15 cm ∅ 8-12 mm 10 cm ∅ 12-18 mm Bottom 10 cm ∅ 30-40 mm	-
SFS-v Beds depth (m)		0.9	
HLR (cm d^{-1})	2,6	2,3	3,7
Organic loading rate (Kg COD ha^{-1} d^{-1})	329	236	352
Flow (m^3/d)	35	10	8
Primary treatment	Imhoff	Imhoff	Imhoff + Degreasers
Operating since	2000	2000	2000

The outlet standards for industrial wastewater were established in the Italian National Law D.Lgs. n.152 of 1999 (Table 2).

Table 2 - Outlet criteria for industrial wastewater - Law 152 (1999) Tab. 3 Annex 5

Parameters	Max effluent acceptable concentration
$B.O.D._5$	40 mg/l O_2
C.O.D.	160 mg/l O_2
TSS	80 mg/l
$N\text{-}NH_4^+$	15 mg/l $N\text{-}NH_4^+$
P-total	10 mg/l P
N-total	35 mg/l N

The monitoring of each stage of the plant took place during the second year of establishment, with the aid of the Regional Environmental Protection Agency (ARPAT – Dept. of Prato). Most of the analyses have been made in the vinification period (September-November), when the wastewater production is most intensive and its organic contents at the highest level. Standard analysis methods IRSA/CNR were used for chemical measurements in all cases (IRSA/CNR - Water Research Institute of National Research Center – is the Governmental Research Institute that provides the analytical standards for Italy: standard methods are almost the same as provided by APHA [4].

RESULTS AND DISCUSSION

The average concentrations of parameters monitored at the input and at the output of the three treatment facilities are summarised in Table 3. Table 3 shows that, considering average results, the effluents of the three Constructed Wetlands systems are always well within the Italian quality standards regarding discharge of industrial wastewater in the environment. The average removal efficiencies obtained during the monitoring periods show a high reduction level for all the different analysed parameters. The Total Suspended Solids (TSS) overall average removals were 89,1 % for the Cecchi treatment system and 74,7% for the Ornellaia one. About or more than 90% of organic load is removed by the three systems (respectively: Cecchi 97,8% COD and 98,4% BOD_5, Ornellaia 92,2% COD 93,3% BOD_5, La Croce 87,5% COD and 91,6% BOD_5). As regards Total Nitrogen, the average overall efficiencies are higher where the raw wastewater contains more organic substances: the Cecchi facility shows a value of 82,2% and the Ornellaia combined system, with a vertical flow bed followed by a horizontal one, reaches 90%, while the La Croce plant shows a more common efficiency of about 54%.

These results are parallel to the common removal percentages that we find on similar horizontal flow reed beds located in the same region and reported by Conte et al. [5], Masi et al. [6], Pucci et al. [7] and more particularly to the figures reported by Grismer et al. [8] and Shepherd et al.. [9] about wineries wastewater treatment by SFS-h CWs.

Table 3 - Mean concentrations of overall inputs and outputs of the three treatment facilities

		Cecchi			***Ornellaia***			***La Croce***		
		IN	**OUT**	n° samples	**IN**	**OUT**	n° samples	**IN**	**OUT**	n° samples
pH		6,0	7,4	3	6,4	7,5	10	6,6	7,2	3
TSS	mg/L	221,8	24,3	5	102,7	25,3	10			
COD	mg/L O_2	4044,9	90,6	8	1003,2	78,6	10	721,7	90,0	3
BOD_5	mg/L O_2	1792,7	29,4	7	424,9	28,6	10	353,7	29,7	3
Total Nitrogen	mg/L N	14,7	2,6	5	26,6	2,65	10	65,2	27,5	3
Total Phosphorus	mg/L P	4,9	1,3	5	1,92	0,12	10			

Figure 2 provides all the results obtained for BOD_5 and COD in the **Cecchi winery facility**. The quantity of wastewater produced in this industrial cycle is constant enough during the whole year (about 35 m^3/d) and even the organic content is similar; the only exceptions in the observed period were two particular episodes of very high concentrations in the inlet (7660 mg/l COD and 14100 mg/l COD) caused by bad mantainance of the primary treatment (Imhoff tank). It can be observed that the biggest part of removal takes place in the first horizontal flow

reed bed (SFS-h), with an HRT of about 3.5 days.The average removal efficiencies in this stage are, in fact, 96,2% for COD and 96,6% for BOD_5.

A further increase in water quality is obtained in the following stage, the free water system, that also works as a reservoir for water reuse and which offers an important environmental value to the treatment plant itself for its high biodiversity and naturalistic aspects (Figure 3). In the hot season a light increase of organic content was observed in this stage due to algal bloom. To reduce this problem we have inserted a small gravel bed (Figure 4 - Section D - planted with *Typha*) in the very final stage of the FWS which permits a very efficient water filtration before the last deep water zone (planted with *Nymphaeas*) in which a submerged pump is placed. Despite the fact that the SFS-h system shows a good removal performance, in the two cases in which the output from the SFS-h system was over the standard (dec-2001; jan-2002), the FWS was able to "buffer" the effect. After the start-up of the plant we have observed a gradual increase in performance, as shown in the graph. Also the purple colour of the inlet water started to disappear after five months, when reeds showed a well developed population in the bed.

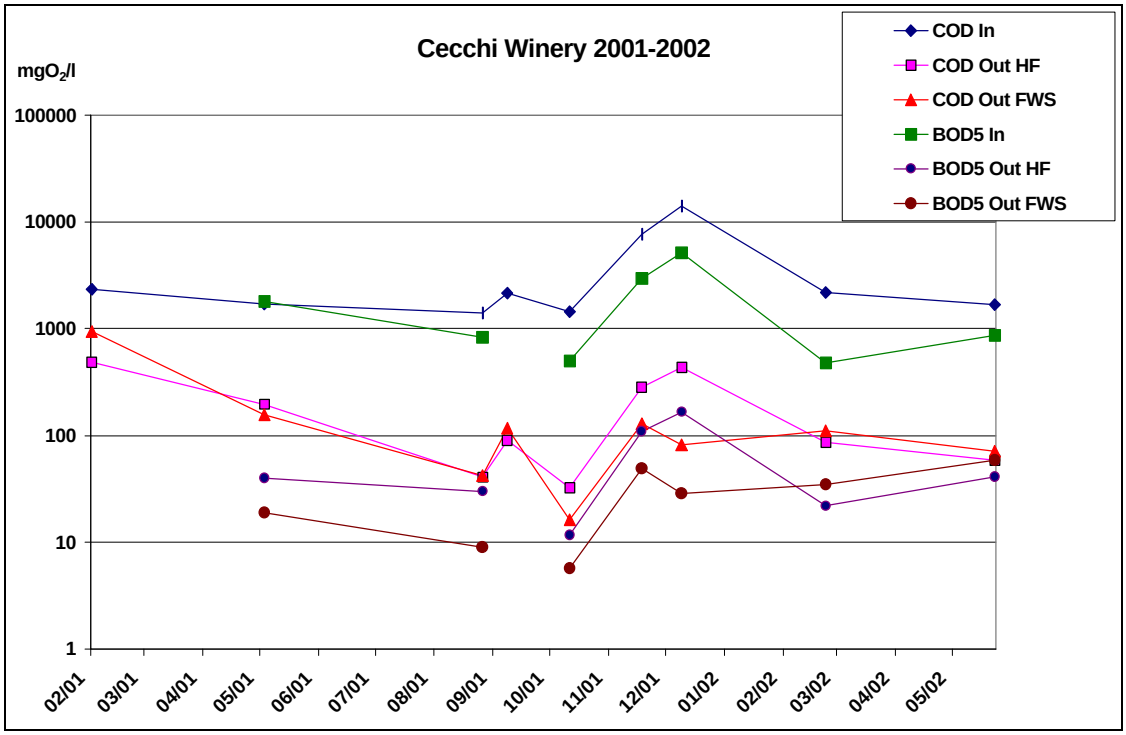

Fig. 2 – COD and BOD_5 concentration values in the inlet and HF + FWS oulets of the Cecchi Winery CW plant

Fig. 3 – Cecchi winery treatment facility during realisation (left), SFS-h after reeds growth (middle) and well developed FWS (right)

The Free Water System has been realized inside the old pond used for wastewater storage. It is subdivided in five zones, all 0,4 m depth, but Zone E that is 1 m. After about one year from the plantation (0.4-0.3 plants/m^2) the system appears definitely well developed. Macrophytes distribution in the system is described in Figure 4. As regards emergent and submerged macrophytes (*Typha latifolia*, *Phragmites australis*, *Elodea canadensis*, *Ceratophyllum demersum*, *Nymphaea alba* and *Nymphaea rustica*), these have reached a high and uniform growth, a strong development of the emergent parts and a rich blossoming season. Even the shore species (*Caltha palustris*, *Epilobium hirsutum*, *Epatorium cannabium*, *Iris pseudacorus*, *Botumus umbellatus* and *Juncus effusus*) have shown a good growing rate and blossoming during spring and summer.

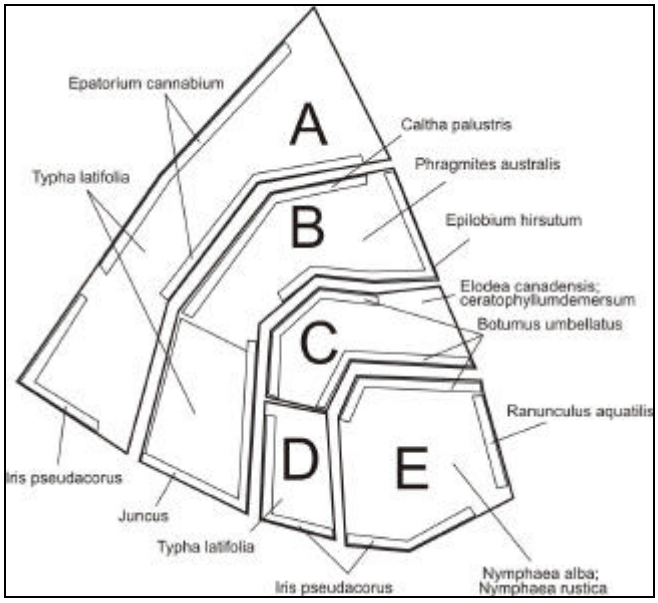

Fig. 4 – Macrophytes present in the Cecchi winery FWS: Zone A inlet – Zone E outlet

The **Ornellaia winery facility** shows an higher Ammonium content in the inlet (due to some mixed domestic wastewaters) which is efficiently removed in the first stage vertical flow reed beds, as shown in Figure 5. The mean removal within the SFS-v can be estimated to be 90 per cent (range: 50 to 99,9).

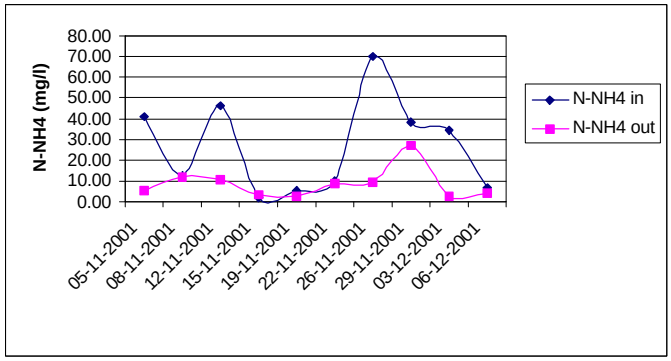

Fig. 5 – Ammonium concentration values in the inlet and oulet of the Ornellaia Vertical Flow Reed Bed

Figure 6 shows the inlet and outlet concentrations for each stage of the plant. It can be easily

noticed that the good performance obtained in the last tertiary treatment by the FWS, where the high retention time (up to 13 days) helps the final removal of the remaining organic substances. This stage had moreover a really low cost in realisation because the winery already had the pond for their wastewater storage. In our design we simply transformed a small part of the pond in the FWS and mantained, after restoration and cleaning, the remaining part as a reservoir for irrigation purposes (green areas and green roofs of the factory). There is a strong relation between inlets and outlets behavior due to the strict correspondance between the total HRT in the first and second stage (submerged flow systems) and the sampling time. The monitoring phase started about 2 months after the beginning of the winemaking period (sept 2001). The observed values at the FWS outlet have to be considered as related to a 12 day HRT. In this first year of activity we decided not to monitor the pond water quality for the presence of fresh water. The dilution effect doesn't permit any observation of the degradation processes that occurs within. During the next production season the pond efficiency will be controlled too. The median BOD removal rates that we found in the three stages were: SFS-v 21%, SFS-h 15%, FWS 65%. About median COD removal rates, they were: SFS-v 31%, SFS-h 38%, FWS 82%.

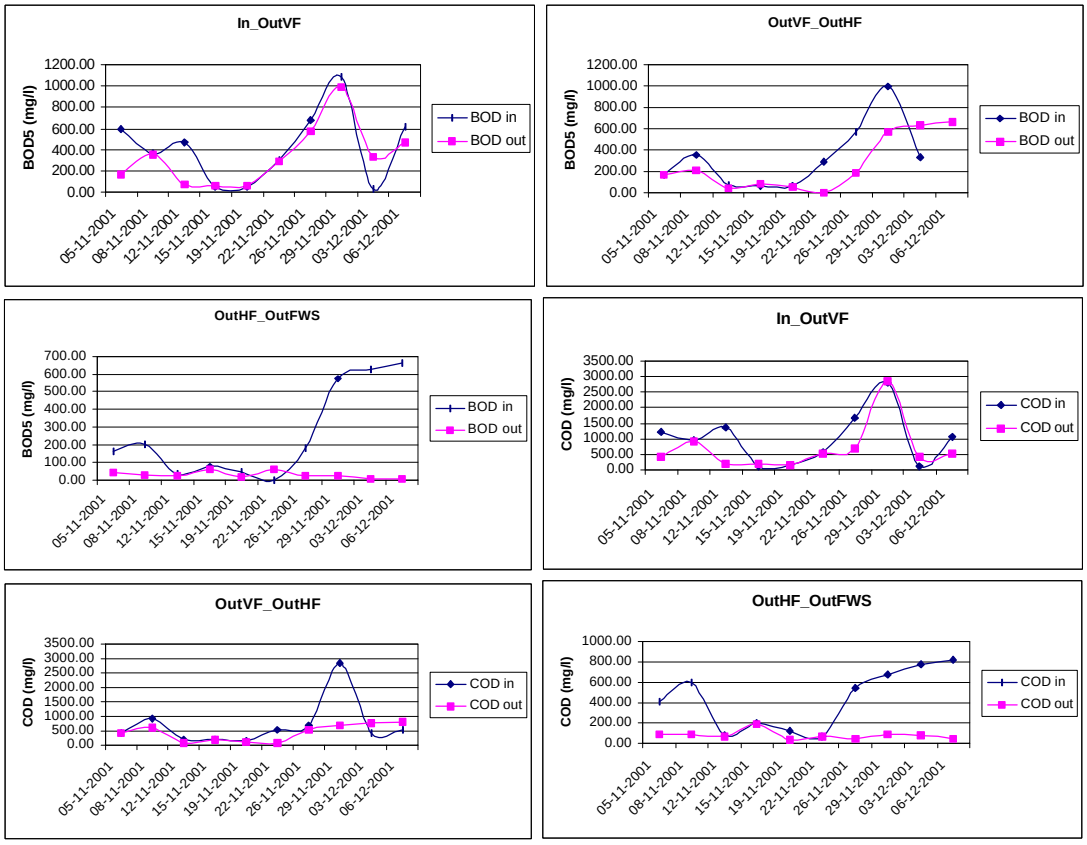

Fig. 6 – BOD_5 and COD concentration values in the inlet and SFS-v (VF), SFS-h (HF), FWS outlets of the Ornellaia Winery CW plant

As reported in Fig. 7, Total Suspended Solids are mainly reduced in the submerged flow systems, both vertical and horizontal. The same behaviour was observed in the Cecchi SFS-h, with an average removal rate equal to 93% (this value is higher than the overall average removal rate due to some events of light TSS self-production in the final FWS).

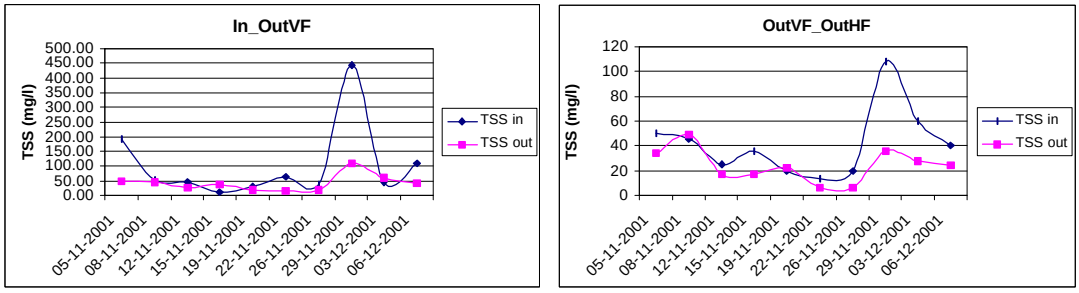

Fig. 7 – Total Suspended Solids (TSS) concentration values in the inlet and SFS-v (VF), SFS-h (HF) outlets of the Ornellaia Winery CW plant

The design of this plant has allowed us to highlight the alternate feeding method as well as to investigate the clogging potential of the vertical beds to a greater extent. During the winemaking period, due to the very high hydraulic load (about 55 l/m^2.d) and organic load (56 gCOD/m^2.d) both the vertical beds presented light clogging problems, with black sludge sedimentation on the top of the beds. As a positive factor, all this sludge has been digested during the period January-June 2002, in which a very low quantity of water was loaded in the treatment system (about 1-2 m^3/d with OLR of about 2-6 gCOD/m^2.d). The good developmnent of the reeds community is moreover increasing the vertical beds' permeability and the superficial sludge decomposition.

Also in this case, the Free Water System has been realized within the existing storage pond. It is subdivided into three zones, with increasing depths and a final filter zone filled with gravel. Macrophytes distribution in the system is described in Figure 8. Due to the very recent plantation (last spring) there is very little information to report: 1) the submerged flow systems are showing a normal growth rate of *Phragmites*, that seem to tolerate the acidity of the inlet waters very well; 2) the emergent part of the FWS macrophytes is already consistent and all the inserted plants are still alive.

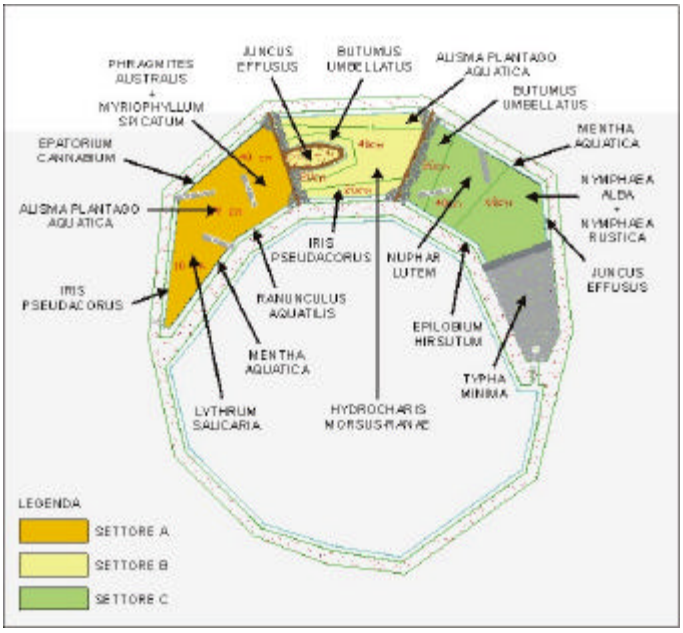

Fig. 8 – Macrophytes present in the Ornellaia winery FWS: Zone A inlet – Zone C outlet

The total costs (realisation and design) for all the facilities are:

	Cecchi	Ornellaia	La Croce
Realisation and design costs (euro)	59.470,00	77.300,00	23.080,00

CONCLUSIONS

All three CWs facilities obtain the design objectives, with easy maintenance and an elevated improvement regarding economics and naturalistic and environmental aspects. Further reasearch will be done to assess better the different behavior over a longer period of time.

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