

## Constructed wetlands effluent for streamflow augmentation in the Besòs River (Spain)

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### Abstract

There is nowadays a tendency in the south of Europe to recover the natural features of urban rivers as much as possible. The final part of the Besòs River (Spain) flows inside a heavily industrialized area in greater Barcelona. Following a classical model in the 1970s, the river was canalized, theoretically to reduce the high flow impact but in practice to gain flat areas where building was easy. The result was many artificially created impervious areas which made infiltration difficult, and the invasion of the river-related high-flow zones by industrial facilities and urbanized areas. Additionally, for several decades, the Besòs River was the most altered fluvial basin of Catalonia. Trying to improve the really bad conditions of that section of the river, a big conversion of part of its final section was undertaken in the 1990s. There, the low flow concrete channel was re-naturalized, bending it, and in the reclaimed bed surface an urban park and a tertiary wastewater treatment system were implemented. After treatment, the effluent directly enters the river, thus improving water quality. Water from the tertiary treatment, constructed wetlands, has the following percentage of removal if compared with the effluent of the activated sludge facility: 40% for suspended solids; 62% for COD; 20% for  $\text{NH}_4^+\text{-N}$ ; 58% for P; and 1.1 log U/100 mL for fecal coliforms.

*Keywords:* Constructed wetlands; Subsurface horizontal flow; River bed; Re-naturalization; Urban parks

### 1. Introduction

Re-naturalization of man-modified landscapes became a usual practice in the north of Europe

several decades ago, but in the Mediterranean the practice appeared during the 1990s. Before it, river flood plains and low-flow channels were among the most altered natural structures. The tendency was to restrain rivers to concrete boxes,

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eliminating meanders and existing vegetation. The reason was to reduce flood-related hazards, guaranteeing a maximum flow calculated for several years [1]. Nevertheless, the hazards related to heavy rains, and hence maximum flows, were exacerbated through processes in the whole basin, namely deforestation and urbanization, which created many impervious areas. The result was an increase of flowing water speed, thus increasing the water kinetic energy in the whole basin and the capability of causing damage [2].

In the lower parts of the basin's flood plains, all types of natural wetlands and meanders can be found. Almost all these structures usually disappeared in the small- and medium-size rivers in the studied area, being occupied by buildings or infrastructure.

On the northern border of the Barcelona municipality flows the Besòs, a Mediterranean-type river. Although the Besòs draining basin is small (1,039 km<sup>2</sup>), the Mediterranean climatic conditions, many artificially created impervious areas which made difficult the infiltration in the lower basin, new buildings and infrastructure of the river-related high-flow zones, and the encasement of the bed made heavy-rain episodes dangerous for the surrounding areas. Additionally, the surroundings of the mouth were occupied by energy production and waste management structures, apart from industries in the northernmost part of the Besòs delta. In the south, old residential areas were mixed with industry. In any case, no flood inundation plan existed.

The related aquifer usually carries more water than the river, and groundwater can be found easily. During many years, the aquifer was exploited for tap and industry supply, and the water table was maintained at a certain depth. Due to the implementation of a supply network with external resources and the displacement of industries to other locations, groundwater was no longer pumped out, and the water level rose. The final result was the flooding of several under-

ground infrastructures, like parking lots or the Metropolitan subway, which increased the costs of water elimination. This water had to be disposed of into the sewerage system and was treated as wastewater.

For several decades, the Besòs River had the most altered fluvial basin of all the hydrographic network of Catalonia (an autonomous region of Spain) and was considered the second-most contaminated river of Europe, after the Rhine. During the last decades, water resources quality was impaired due to the excessive exploitation and heavy contamination of the river. Also, during heavy rain episodes in the 1960s, an important number of casualties were registered because of the violent flooding of housing areas.

The final part of the river flows among several towns (Barcelona, Montcada i Reixac, Santa Coloma de Gramanet, and Sant Adrià de Besòs) in a heavily populated — more than two million inhabitants — and industrialized area. The river has an extreme variation of flows, from violent flooding episodes up to 2000 m<sup>3</sup>/s a few times per year, to no flow except the one from treated wastewater disposal all year round. There used to be a concrete channel for the low-water flows, which suffered a transformation recently to re-naturalize partially the river bed.

Due to all the mentioned circumstances, wildlife disappeared from the river ecosystem. Aquatic plant species were no longer abundant and the existing vegetation could be defined as degraded.

Water demands in the basin increased heavily after the 1960s and clearly exceed the available resources. Furthermore, it was discovered that part of the river-related aquifers were heavily contaminated with chemicals buried illegally in old, abandoned gravel pits inside the river bed. Consequently, an important resource was no longer available for water supply.

The lack of available water was somewhat improved by diverting water from more northern

river, thus adding some 5 m<sup>3</sup>/s to the existing, poor-quality, groundwater resources. This implies that the water quality of this final section of the river does not reflect the theoretically natural water quality conditions, especially with respect to chemistry. The only free, non-urbanized, surface is the river bed.

Wastewater treatment plants (WWTP) became operative in the basin in the 1990s. Afterwards, all the flowing water, except from rain episodes, was wastewater, mainly treated up to a secondary level by activated sludge. Liquid and solid industrial wastes thrown into the river were also controlled, and other solid waste disposal from urban origins was nearly eliminated. Nevertheless, during the previous three decades, much organic matter was disposed of into the river; and in hot and dry summers, anaerobic fermentation processes appeared, generating odour problems. The odorous substances were transported up and down the river basin by the prevailing winds, and many complaints were issued. Then, after several summers of odour problems attributed to the river and full degradation of the bed, several actions were planned.

Until the 1998, an aerial electricity transport infrastructure was inside the high-flow bed, completing the degradation picture. Using FEDER and local funds, a large conversion of part of the final section of the river was undertaken. In part of the modified section (among Montcada i Reixac and Santa Coloma de Gramanet by one side, and Montcada i Reixac and Barcelona on the other side), the low-flow concrete channel was re-naturalized, bending it, and in the high-flow bed surface, a tertiary wastewater treatment system was implemented. In the rest of the river bed, between two of the towns (Santa Coloma de Gramanet and Barcelona), turf surface was installed, together with a small road for bicycle riding and service cars. An alarm system was installed to announce flooding episodes with time enough to evacuate people and

close access to the urban park. Apart from this, into the straight low-flow channel, inflatable polyethylene barriers were installed. The purpose of the barriers is to have water pooled in the surface, in this way increasing the aesthetic value of the river. In case of flooding or other adverse circumstances, the barriers are deflated and do not offer resistance to the water. The grass area is spray irrigated using groundwater, thus contributing to lower the aquifer level.

Initially, this transformation into an urban park was done along 3 km approximately; in mid-2004 an additional part of the river bed, downstream and up to the mouth, was also transformed, this time between the municipalities of Sant Adrià del Besòs and Barcelona.

The success of such installations has been enormous. The naturalists very much enjoyed the upper part where the wetlands tertiary system was installed because of the reappearance of wildlife; people from the municipalities enjoy the new park, using it for bicycle riding, running, and walking in a more natural area, or for picnics.

## 2. Materials and methods

From now on only the area devoted to wastewater tertiary treatment is considered. The effluent to be treated is supplied by the Montcada i Reixac activated sludge classical secondary wastewater treatment facility, with a peak capacity of 0.5 m<sup>3</sup>/s. The facility treats mainly urban wastewater, with some industrial effluents usually pretreated to legally fixed levels before reaching the sewerage system.

Part of the effluent (0.2–0.3 m<sup>3</sup>/s) is diverted to subsurface flow constructed wetlands, acting as a tertiary treatment. The wetland effluent enters directly into the river through pits where a device to control the wetlands water level is located. River water quality is theoretically improved with the tertiary-treated wastewater. At the same time, the re-creation of natural areas caused an

improvement of the landscape and subsequently wildlife (reptiles, amphibious, birds, etc.) re-appeared because of the implementation of refuge and nesting areas. Wetlands planted vegetation (mainly reed, but also cattail, water lily, etc.) is typical of river beds and can resist high floods, just bending and recovering afterwards. Part of the old degraded vegetation remains but is slowly disappearing.

Usually, constructed wetlands are designed as a soft technology to treat wastewater in small communities. Nevertheless, the system is also described as a tertiary treatment or as a way to manage run-off or industrial wastewater. A sub-surface horizontal flow was the chosen design for the Besòs wetlands. This type of flow typically avoids odour problems and the appearance of mosquitoes. The selection was made in order to reduce at a maximum the problems with the neighbours living less than 100 m apart from the wetlands in several places. Nevertheless, several complaints were issued because of insects, birds, frog croaks, and the like.

Subsurface flow constructed wetlands, with macrophytes, present a complex aerobic–anoxic–anaerobic underground system. Around substrate, roots, and rhizomes bacterial colonies, biofilms are installed. The implied wastewater treatment mechanisms are complex and include filtration, sedimentation, chemical precipitation, and bacteriological oxidation. The treatment is mainly based on the relationships among vegetation, substrate, and soil saturated with water.

Constructed wetlands plots were distributed along 3.2 km of the basin. Wetlands are located in both banks for the upper 2 km, the following 1.2 km presenting plots only on the right bank. It is important to note that there are four types of plots, in total 60, described in Table 1.

Plots are established in 15 groups, which can include from two to five plots. Each group presents a valve to control the flow applied and another valve to control the pressure. The treated

Table 1

Types and dimensions of Besòs River wetland plots

Type	Width (m)	Length (m)	Number of plots
1	50.4	19.1	39
2	50.4	27.6	14
3	50.4	34.6	3
4	50.4	31.5	4

average flow is between 0.2 and 0.4 m<sup>3</sup>/s depending on the hydraulic regime implemented.

Impervious (using liners protected with geotextile) plots were filled with river gravel (granulometry between 8 and 25 mm) or with external granitic gravel (granulometry between 6 and 25 mm) because the existing material was not sufficient to fill all the plots. It should be noted that the depth of the plot at the inlet water side is 0.6 m, and 0.7–0.8 m at the outlet, with an approximately 0.5% slope.

Each plot presents an individual end pit where treated wastewater is collected before reaching the river. To control water height inside the reed bed, an adjustable pipe was installed inside the pit. A correct management of this system avoids the appearance of water on the wetland surface, thus minimizing any related risk of mosquitoes or odour appearance.

Sampling was done in a regular way in each outlet tank, and the following parameters were analyzed according to Standard Methods [3]: pH, EC, SS, COD, NH<sub>4</sub><sup>+</sup>-N, NO<sub>3</sub><sup>-</sup>-N, PO<sub>4</sub><sup>3-</sup> and fecal coliforms.

Several management problems appeared during the first 4 years after the implementation of the system due to construction defaults, public works in the area, and several accidents with pipelines crossing the river underground. Conversely to the beliefs of several people, the facility perfectly resisted the river floods with minor modifications in the first plots.

### 3. Results

The characteristics of the influent coming from the Montcada i Reixac activated sludge WWTP are presented in Table 2 as average values. The average results obtained for the plot's (60) effluent are shown in Table 3 (maximum, average, minimum, and standard deviation are the values chosen) for the years 2001, 2002, and 2003. The performances of the constructed wetlands changed during the 3 years of operation due to different factors: *Phragmites* development, wastewater quality of the WWTP (during this period of study, two episodes of high organic matter concentration were detected); climate (storms, temperature, etc.); construction along and inside the river basin, and others.

The average removal of organic matter (COD) was 62.4%. SS showed a reduction of 80%. It is to be noted that 75% of all the samples presented a SS concentration below detection limit.

In relation to nutrients, 20% of ammonia was removed. This reduction can be attributed to nitrogen transformation from ammonia to nitrates and nitrites. Results were lower than those indicated in other studies [4,5]. This fact could be explained by a low water residence time during part of the operation. Otherwise, a 58% of phosphorus removal was detected. Removal of phosphorus forms occurs mainly as a consequence of adsorption, complexation and precipitation reactions [6,7].

An additional sampling campaign during 2003 focused on the study of microorganisms removal, using fecal coliforms (FC) as an indicator. The FC average removal was 1.1 log cfu/100 mL, although maximum reduction attained was 3 log cfu/100 mL. As indicated, there was an improvement of river water quality. These data are given in Table 4.

As indicated previously, initially, several plant species were planted in the wetlands in order to enlarge the diversity and aesthetic characteristics of the plots. After several years of operation, the

Table 2

Quality of wastewater feeding the constructed wetlands

Parameter	Figures (wetlands inlet)
pH	7.4
EC ( $\mu\text{S}/\text{cm}$ )	1.59
TSS (mg/L)	6.9
COD (mg O <sub>2</sub> /L)	143.5
TKN-N (mg/L)	37.5
NH <sub>4</sub> <sup>+</sup> -N (mg/L)	34.2
NO <sub>3</sub> <sup>-</sup> (mg/L)	<2.0
P <sub>2</sub> O <sub>5</sub> (mg/L)	8.5
Fecal coliforms (log cfu/100 mL)	4.5

only plant species that lasts is *Phragmites*. The development of the plant is nearly perfect, covers all wetland surfaces and reaches a height of more than 3 m in almost all plots. In the areas without wetlands, degraded vegetation is still living and it is controlled in an ecological way, using the capabilities of goat and sheep flocks.

No problems were detected, as indicated, with the high flows. *Phragmites* bend, and in this way, the whole capacity of the river bed is reached. Afterwards, the plants immediately recover the upright position or, if sediment covers them, from any single knot a new stem appears. Once a year, after the vegetative season passes, the stems are cut. This practice is being reconsidered because of its high costs.

### 4. Discussion

For several years the Besòs wetlands system has been proving that such a facility can be implemented in a river bed, without risk of being destroyed, if the construction is performed properly and the low-flow river bed has a natural form. Nevertheless, several problems were detected, mainly related to the difficulty of

Table 3  
Quality of constructed wetlands effluent

Parameter	Year	Maximum	Average	Minimum	Standard deviation
pH	2001	8.3	7.5	7	0.2
	2002	8.1	7.5	7	7.5
	2003	8.2	7.5	6.8	0.3
EC ( $\mu\text{S}/\text{cm}$ )	2001	2167	1453	637	183.3
	2002	2930	1417	495	1417
	2003	2760	1490	659	204
Turbidity (NTU)	2001	100	5.7	0.5	13
	2002	45	5.3	0.6	5.3
	2003	49	5.1	0.6	7.8
TSS (mg/L)	2001	43	5.6	< 2.0	8.3
	2002	38	3.4	< 2.0	3.4
	2003	29	3.5	< 2.0	3.7
$\text{NH}_4^+$ (mg/L)	2001	46.6	25.6	1.5	8.8
	2002	55.7	25.2	1	25.2
	2003	48.9	31.7	0.2	11.4
$\text{NO}_3^-$ (mg/L)	2001	79.9	8.6	< 2.0	11.6
	2002	63.6	5.4	< 2.0	5.4
	2003	78.8	6.1	< 2.0	13.1
$\text{NO}_2^-$ (mg/L)	2001	10.1	0.6	< 0.5	0.7
	2002	10.8	0.7	< 0.5	0.7
	2003	26.6	0.9	< 0.5	2.3
$\text{P}_2\text{O}_5$ (mg/L)	2001	12.5	4.4	1	1.3
	2002	6.4	3	1	3
	2003	7.4	3.5	1	1.4
COD (mg/L)	2001	86	53.8	< 50.0	13.8
	2002	93	55.3	< 50.0	55.3
	2003	77	52.8	< 50.0	5.6

Table 4  
Quality of Besòs River for years 2001–2003 [8]

Parameter	Max.	Avg.	Min.
pH	8.6	7.7	7
E.C. ( $\mu\text{S}/\text{cm}$ )	2774	1957.7	1106
Turbidity (NTU)	47	18.5	3
TSS (mg/L)	116	30.7	<7.0
$\text{NH}_4^+$ (mg/L)	32.1	14.8	3.9
$\text{NO}_3^-$ (mg/L)	37	12.6	3
$\text{P}_2\text{O}_5$ (mg/L)	6.4	2.8	0.7
Fecal coliforms (log cfu/ 100 mL)	4.7	4.4	<2.3

financing and understanding the operation and management.

The two automatic control stations installed did not perform correctly because of several misconception problems. These are being transformed, and it is supposed that they will supply more continuous data. This will allow for better management because of more data and availability in real time.

Although the improvement of water quality and the river natural conditions improved dramatically from the aesthetic point of view, the final water quality in the river is not usually good

enough to support some types of aquatic wildlife, including fish, because of the high contents of nitrates and other contaminants.

There are currently several projects being undertaken in order to better manage the system. An agreement was reached between the Diputació de Barcelona and the University of Barcelona to perform research and change the operational way of the system once all the works in the bed are completed.

Future research and innovations will be related to operation and management. The residence time will be modified, trying to improve the nitrification and denitrification performance. Additionally, several plots will be emptied periodically, and the water height will be adjusted to a maximum to improve efficiency. The use of *Phragmites* cuts for composting sludge will be investigated. Small-scale wetlands located in the vicinity of the Montcada i Reixac facility will be used to test the full-scale changes. Several campaigns of wildlife identification were performed and will be continued during the next few years.

## 5. Conclusions

Constructed wetlands are usually considered as a wastewater treatment solution for small settlements or individual houses in suburban areas of large cities, as well as for rural settlements. After this experience and similar ones, it can be stated that constructed wetlands can be a good solution to improve urban river water quality using facilities inside the river bed.

*Phragmites* seems to be the best plant species to be installed in such a system, given its resistance to flooding and capacity to colonize and recover.

The construction of reed beds contributes to environmental reclamation of the final part of the Besòs River because they form an ecosystem which allows the recovery of potential wildlife habitats (food, nests, and protection zones) for

different types of fauna (reptiles, amphibious, birds, etc.).

By using this system, the landscape of nearly 4 km of a river, located in a heavily urbanized area, improved dramatically, and residents welcomed the change.

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