Use of reclaimed water in the recreation and restoration of aquatic ecosystems: practical experience in the Costa Brava region (Girona, Spain)

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Abstract. Where there is water scarcity, the situation is dramatic for aquatic ecosystems. In many Mediterranean basins the exploitation of water resources has gone clearly beyond renewable level and affects aquatic ecosystems. Thus, they may benefit from the recycling of high-quality effluents that can be used to cope with environmental water demands instead of being discharged. Their reclamation with natural technologies produces an improvement in quality based on the development of trophic webs built upon nutrients still dissolved in the reclaimed water. The main project in the Costa Brava area is that of the Empuriabrava constructed wetland system, where nitrified effluent is further treated to reduce the concentration of nutrients in the water and is reused for environmental enhancement. This facility is also an interesting site for bird-watching. Other projects where water recycling produces indirect benefits on the aquatic ecosystems are those in Tossa de Mar, affecting the "temporary" Tossa Creek (a watercourse which flows on temporary basis according to rainfall patterns), and in the Aro Valley, affecting the also "temporary", but slightly bigger, Ridaura River. This document summarizes these projects and proposes practical recommendations for the use of treated effluents in the recreation and restoration of aquatic ecosystems.
Keywords: wastewater reclamation; environmental reuse; ecosystem recreation and restoration

INTRODUCTION

In recent decades, the evolution of the overall water demand in the Mediterranean has increased. According to official EU statistics (Eurostat, 2004), Spain, for instance, has seen a 20% increase in overall water consumption between 1993 and 2002, the same percentage of increase as Cyprus between 1998 and 2003. Available data for Greece only provide information for the period 1992-1997, in which there is an 8% increase in water demand. Data for Turkey show a 32% increase between 1995 and 2001 and Italy only gives the figure for 1998, so no trend can be established. Since the Mediterranean is an area prone to droughts, the increase in water consumption has meant more water extraction from the environment and thus lower ecological flows. In such a context, complying with the European Water Framework will sometimes represent a tremendous challenge, and maybe even an impossible one under certain circumstances.

This situation needs a careful evaluation of how the demands should be met. Extraction of natural flows to cover certain kind of demands (landscape irrigation, street cleaning, etc.) should be revised and changed, especially in situations of stress, such as in drought periods. Water used to cover these non-potable demands can be reclaimed water: it has already been extracted from the environment once to produce drinking water and it is given a second use, something that avoids both a second extraction and a discharge. In order to recover water flows to be used for environmental uses or to restore the biological potential of aquatic ecosystems, the highest priority has to be given to flow substitution, so that natural flows –usually the ones with the best quality- can remain in the environment. However, this optimal situation is not always possible. In some cases it may be better to use an alternative resource such as reclaimed water than not to do anything at all, which may cause greater disruption (even including complete drying-up) than the one caused by the use of this resource. Domestic use of water is a non-consumptive activity, at least in a very high percentage, which means that the extracted flows do not disappear but instead are discharged again into the environment with a lower degree of quality compared to that of the water at the point of extraction. Given the fact that we all use water on a daily basis, even in periods of drought, when referring to volumes, reclaimed water is a limited resource but it is quite constant in time and predictable, which allows a good degree of planning for its subsequent use. Moreover, wastewater is nothing but drinking water plus the pollutants added by human activity; if these substances have an organic origin and are not toxic, quality can be restored to a level close to that of the original, so this water can be used for the restoration and/or recreation of aquatic ecosystems in those areas in which they are affected either by low flows or by pollution.

Obviously, reuse projects for ecosystem restoration and/or recreation require a high-quality secondary effluent, otherwise unwanted problems could arise (i.e., eutrophication). Instead, if land is available and affordable, these effluents can be further treated and purified through natural technologies producing an improvement in the quality of water because of the development of trophic webs, based on the nutrients still remaining in the water and that, if discharged, would cause eutrophication. This is the idea lying behind those projects that combine the additional treatment of secondary effluents with environmental recreation and/or restoration. In the Netherlands, Kampf & Claassen (2005) have developed this concept and have given it the name of Waterharmonica (www.waterharmonica.nl), in the sense that this system acts as a transition zone between the point of discharge and the receiving environment. In parallel, in the Consorci de la Costa Brava area (Girona, NE Spain), several similar projects have been put into operation in order to restore and/or recreate local aquatic ecosystems and which are also based on the Waterharmonica idea, despite the fact they were initially developed independently (Sala *et al.*, 2006).

In the last 10 years, in the Costa Brava area several environmental enhancement projects in which reclaimed water has played a key role have been implemented. Among them all, possibly the best-known is that of the Empuriabrava constructed wetlands, where a nitrified and partially denitrified effluent is further treated in a 7 ha wetland which has a great interest not only from the point of view of nutrient removal but also from an ornithological point of view. Moreover, effluent from this wetland facility is also reused for other environmental purposes at the Aiguamolls de l'Empordà Natural Park. Other ongoing projects in the Costa Brava area with indirect benefits on local aquatic ecosystems are those affecting the temporary Tossa Creek, and in the Aro Valley (central Costa Brava), and the also temporary, but slightly bigger, Ridaura River (Ordeix *et al*., 2005; Sala *et al*., 2005). This document summarizes the main characteristics of these projects and proposes practical recommendations for the use of treated effluents in the recreation and restoration of aquatic ecosystems.

THE RECLAMATION PROCESSES

Whereas for most of the conventional uses of reclaimed water (irrigation, cooling, street cleaning, etc.) the treatment processes will be aimed at protecting public health and thus be based on filtration and disinfection, in the case of environmental uses reclamation may be more adequate if some kind of natural treatment is used. When reclaimed water is intended to be used for environmental recreation or restoration, eutrophication prevention should be the project's priority target, bearing in mind that the natural treatment itself will remove indicator and pathogenic bacteria and also that water will usually be allocated in remote places inaccessible to humans. Constructed wetlands are an excellent option as reclamation treatment for environmental reuse, since their high productivity ensures that nutrients will be removed from the water and a portion of them will be used in the development of a trophic web and will be turned into biomass, some of which can be of high ecological value (i.e., waterfowl feeding on hydrophita or on crustaceans, insects or amphibians).

Table 1. Statistical summary of the quality of reclaimed water produced by four of the Consorci de la Costa Brava facilities during 2006.

Kind of facility (in brackets, year of construction)	Reclamation plant							
	Empuriabrava		Pals		Castell-Platja d'Aro		Blanes	
Wastewater treatment	Extended aeration (1995) (c)		Extended aeration (1995)		Activated sludge (1983)		Extended aeration + chemical phosphorus removal (1998)	
Reclamation treatment	Constructed wetlands (1998)		Chlorination (2000)		Filtration, disinfection (UV + chlorine) (1998)		"Title-22" (d) (2002)	
Treated volume 2006, m^3	661.000		263.000		982.000		3.155.000	
Statistical parameters (a)	Average	P90	Average	P90	Average	P90	Average	P90
SS, mg/l	5,5	12,4	4,4	8,7	3,5	5,8	1,8	2,4
Turbidity, NTU	9,2	20,0	1,2	2,8	2,0	3,8	1,8	2,5
Faecal coliforms, cfu/100 ml	85	310	2	6	3	24	< 1	4
Total nitrogen, mg N/l	3,2	8,2	4,4	6,1	28,7	46,6	7,1	9,8
Phosphorus, mg P/l (b)	1,9	2,7	3,8	5,8	3,2	6,0	1,6	2,4

(a) Annual arithmetic mean for all the parameters, except for the concentration of faecal coliforms, which is a geometric mean. P90 corresponds to the percentile 90 of the annual set of data.
(b) In Empuriabrava, values correspond to soluble phosphorus; for the rest, the values correspond to total phosphorus.
(c) Except in the peak of summer. In 2007 a new biological reactor has been put in operation in order to be able to completely remove ammonia from the treated effluent all year round.
(d) "Title-22" treatment process includes coagulation, flocculation, clarification, filtration and disinfection (UV + Cl_2).

Table 1 shows a summary of the quality of the reclaimed water produced during 2006 by four of the reclamation plants operated by the Consorci de la Costa Brava. It is interesting to compare the quality of the Empuriabrava constructed wetlands with the other facilities, which range from a chlorinated, N/DN secondary effluent (Pals) to a N/DN Title-22 effluent (Blanes). Concentrations of faecal coliforms are lower in those systems in which there is a disinfection process compared to the natural disinfection provided by the constructed wetland system, but it takes well designed and well operated extended aeration plants (Blanes and Pals) to approach the concentrations of nutrients in the effluent of the wetland system.

KEY CRITERIA FOR THE RECLAMATION AND REUSE OF TREATED WASTEWATER ON ENVIRONMENTAL ENHANCEMENT

Water quality

As mentioned above, the quality of effluents to be used for environmental enhancement has to be high. The classical limits used to evaluate the quality of a secondary effluent, such as BOD < 25 mg/l or SS < 35 mg/l, are not useful for this purpose. Instead, practical experience from the Empuriabrava constructed wetland project has revealed that a key parameter is the concentration of ammonia in the secondary effluent. The system performs as expected when ammonia levels are low and operation of the WWTP is aimed at having less than 1 mg NH_4-N/l in the effluent. A limit of 5 mg NH_4-N/l has been established as set point for the online probe, so effluent is allowed to enter the constructed wetland system only if this criterion is met, otherwise water is discharged into the nearby Muga river, which was intended to be the original discharge point for all the secondary effluent. Such an approach means that the effluent has to be oxidized, with nitrate being the main nitrogen component. Even though this means a greater energy consumption compared to a situation in which only BOD and SS are taken into account for the removal of pollutants, the advantages of working with nitrified effluents clearly pay-off. First, the oxidized effluent will pose little or no oxygen demand on the receiving discharge point, either a constructed wetland facility or the point of use, which is the key for the development of a healthy ecosystem; otherwise, undesired anoxia-related phenomena, such as botulism, can appear. Secondly, little or no ammonia in the effluent will prevent the development of phytoplankton in the water column which, if present, would turn the water green, decrease light penetration, alter pH and oxygen cycles and decrease biodiversity. Instead, by using nitrified effluent, the water remains transparent and allows the growth of both filamentous algae and submerged plants (hydrophyta such as *Zannichelia palustris* or *Najas minor*), which provide oxygen throughout the water column. These plants also act as shelter for zooplankton organisms, such as Cladocera, an order of Crustaceans that include water fleas, that feed by filtering particles in water and that produce notable improvements in its quality in terms of suspended solids, turbidity and indicator bacteria. Once the nitrification has been achieved, anything that happens spontaneously seems to improve the water quality; on the other hand, if ammonia is the main nitrogen species in the effluent, some extra retention time will have to be allowed in order to achieve its removal before these processes can start. Since ammonia stimulates the growth of phytoplankton, its presence in the secondary effluent produces an increase in the deposition of organic sediments, which, in turn, may impair the efficiency of the treatment in the mid to long term.

Due to lower sludge loadings for nitrification, modern plants tend to have a higher sludge volume index, leading to a better removal of sludge particles (looser flakes trapping the smaller particles). Both at the full-scale plants of Empuriabrava (Costa Brava) and Everstekoog (Texel, The Netherlands) notable amounts of sludge are found in ponds and in the first part of the constructed wetland system, respectively (pers. obs. R. Kampf and L. Sala). Reality shows that this happens even in the best treatment plant, thus measures should be implemented to trap solids in the secondary effluent before letting them flow towards the next step. Sand filtration of the effluent is certainly an excellent solution to protect the constructed wetland system, but other simpler solutions could be used, such as sedimentation ponds or deeper areas near the inlet of the constructed wetland system; both these ponds or the deeper areas would require periodic cleaning, so they have to be engineered to allow for this kind of maintenance. Ponds also have the advantage of allowing the development of dense populations of Cladocera (mainly *Daphnia magna*), which feed on smaller particles and bacteria (Kampf *et al.,* 1999; Kampf *et al*., 2006). Filtration through the Daphnia leads to very effective removal of faecal coliform bacteria. In the new and more natural constructed wetland that further treats the secondary effluent of the Grou WWTP (The Netherlands) this observation is put into practice with the design of three Daphnia ponds (Claassen & Kampf, 2006). In the summer of 2007 an international research project has been started to study this phenomenon, with experiments being run in exactly the same mesocosms in the WWTP of Horstermeer (Water authority Waternet), to determine the influence of effluent filtration and perform food studies, in the WWTP of Grou (Wetterskip Fryslân), to compare their performance to the full-scale *Daphnia* ponds, and in the Empuribrava WWTP (Consorci de la Costa Brava) also to compare their performance to the full-scale *Daphnia* ponds and perform food and life cycle studies, with support from several universities in The Netherlands and Spain (more information on www.waterharmonica.nl).

As a key element of primary production, it is desirable that phosphorus concentrations in treated wastewater and/or in reclaimed water should be low. Reuse projects with an environmental purpose must not focus on production but on diversity, and the latter is enhanced when nutrients are scarce and specific organisms are able to develop in such an environment, as opposed to the blooming of a few opportunistic species which occurs in hypertrophic systems. The monitoring of the evolution of the reclaimed water quality in the Empuriabrava wetlands and in several storage facilities in the Costa Brava has shown that in these systems nitrogen is removed more easily from the water than phosphorus, which means that the ratio N/P decreases with the increase of the hydraulic retention time (Sala *et al.*, 2002). Despite the fact that in such a situation the development of cyanobacteria populations could be expected, these have never been observed to bloom and become dominant in the ponds. Instead, as mentioned above, it is filamentous algae and hydrophyta that develop as long as the water remains transparent.

Disinfection

Secondary effluents still have high concentrations of indicator microorganisms (i.e., faecal coliforms) and these are the target of most reclamation processes, so that water can be reused safely. When water is reused for environmental purposes, it is more likely to be used in areas with no public access, so that is the main reason why nutrient removal has been prioritized in the projects in the Costa Brava area. However, natural disinfection has been observed to occur both in the constructed wetland systems used for effluent polishing and in storage ponds if sufficient retention time is given. Kampf & Claassen (2005) have proved that the concentration of faecal coliforms in a N/DN secondary effluent stored in ponds decreases with the density of the populations of Cladocera (*Daphnia* sp. and other genera). Other factors that cause stress on faecal microorganisms in these kinds of environments are the variations in the concentrations of dissolved oxygen and pH due to metabolism of algae and submerged plants, as well as grazing by other organisms different from Cladocera. Whatever the importance of each of the factors is, the overall result is that a decrease in the concentration of faecal coliforms is observed at a level comparable to that of other disinfection processes. As an example, the limit of < 200 cfu *E. coli* in 100 ml required by Spanish guidelines for unrestricted irrigation is met at the Empuriabrava constructed wetland facility, even after the contribution of new faecal microorganisms provided by the droppings of wild animals, mostly waterfowl, and animals like horses, which until mid 2006 were introduced into the system to control the vegetation of the shallow pond.

Overall average faecal coliform inactivation in 2005 and 2006 –based on weekly samples- was between 2 and 3 log units between the secondary clarifier and the outlet of the shallow pond. Inactivation in the polishing ponds was 1 log unit greater in 2005 when compared with that of 2006, which possibly produced the slightly greater concentration at the outlet of the wetland system in the latter year. Data gathered from January to April 2007 in the absence of horses and low SS and turbidity values (average 5 mg/l and 1.7 NTU, respectively) prove that overall average inactivation can reach 3.9 log units, with the greatest removal (2.8 log units) actually occurring in the polishing ponds (where Cladocera grow best) and the additional 1.1 log unit removal occurring in the constructed wetland itself. Faecal coliform concentrations below 2 log units in the reclaimed water to be used for environmental restoration at the nearby Aiguamolls de l'Empordà Natural Park are of the same level or better than the quality of the waters naturally flowing into the area (Consorci de la Costa Brava, 1998). These observations are in compliance with the results of the full scale project at Everstekoog (Toet, 2003).

Biodiversity enhancement

Apart from the environmental improvement that will be achieved by the intended use of reclaimed water, the reclamation systems themselves, in the case of constructed wetlands, have a great potential for the enhancement of local biodiversity. The main criteria used at the Empuriabrava constructed wetland facility are:

Improvement of water quality: As stated by the ecological theory, biodiversity is greater in nutrient-limited environments (Margalef, 1983). The lower the concentration of nutrients, the greater the water quality and also the diversity of organisms, which leads to an overall environmental improvement in the area.

Diversity of environments. If different environments are provided, different species will be attracted, so biodiversity will necessarily increase. In the constructed wetland systems these environments could include areas with greater depth and shallow lagoons, which will attract different kinds of birds (divers in the former case, waders in the latter). Moreover, if the limits of the facility are planted with shrubs producing berries (hawthorn -*Crataegus monogyna*-, blackthorn –*Prunus spinosa*-, etc.), this will provide a very valuable environment to birds as a nesting site.

Water levels. If water levels in constructed wetlands can be regulated, apart from their use as an effluent purifying system managers may be able to establish the conditions to attract certain kinds of birds at different seasons of the year. If this aspect is not taken into account, water levels may sometimes be too high or too low for the birds that could have been attracted. Being flexible in the regulation of water levels is the best way to make sure that the goals are met.

Endangered species. Constructed wetlands for effluent reclamation are supervised and access to public areas is restricted, making them highly suitable as breeding areas for endangered species. Spanish toothcarp (*Lebias ibera = Aphanius iberus*), European pond turtle (*Emys orbicularis*) and amphibia in general can find a very welcome haven in these sorts of facilities.

PRACTICAL EXPERIENCE IN THE COSTA BRAVA AREA

The Empuriabrava constructed wetland system

Since 1998, the secondary effluent of the Empuriabrava WWTP has been further treated in a constructed wetland system specifically designed for additional nutrient reduction, mainly nitrogen. This wetland system has 3 parallel treatment cells with a surface of 8,000 m^2 each (160 m x 50 m), with an average depth of 0.5 m, followed by a shallow lagoon with a surface of 45,000 m^2 and an average depth of 0,2 m. These cells alternate macrophyte stands composed of *Phragmites australis* and *Typha latifolia* with free surface areas where sunlight is able to penetrate into the water column. Water flowing out of each of the cells is conducted to one single point from which it is then transported by the force of gravity to the shallow lagoon. Water enters this lagoon by a deeper canal surrounding the small island in the middle and then spreads and flows out of the system through a weir located in the lowest part of it (Romero and Sala, 2001; Sala *et al.,* 2004). This wetland system is fed with a nitrified and partially denitrified secondary effluent, with flows that vary between 1.000 m^3/day in winter and 6,000 m^3/day in summer. As explained before, water is allowed to flow into the system when ammonia concentration is below 5 mg NH_4-N/l, which is measured every 20 minutes by an on-line ammonia probe. In 2005, 82% of the total annual flow of the secondary effluent (903,000 m^3) was further polished in the constructed wetland system, whereas in 2006 the volume reached 62% (661,000 m^3). According to the estimation of mass balances for nitrogen, in 2005 and 2006 the system removed 70-85% of the inorganic nitrogen from the water (5,500-7,000 kg, about 1,100-1,400 kg N/ha.year) (Consorci de la Costa Brava, 2006a; Consorci de la Costa Brava, 2007).

The constructed wetland cells have turned out to be an excellent habitat for different kinds of birds, mostly dippers such as Mallards (*Anas platyrhynchos*), Common teals (*Anas crecca*), Coots (*Fulica atra*) or Little grebes (*Tachybaptus ruficollis*) among many others, whereas the shallow lagoon, called "Estany Europa", has proven to be an adequate habitat for wading birds, such as Black-winged stilts (*Himantopus himantopus*), Flamingoes (*Phoenicopterus ruber*), or different species of the genera *Tringa* and *Gallinago*. It is also frequent to see the Marsh harrier (*Circus aeruginosus*) flying over the area. Also, some endangered species have been detected breeding in the cells such as the Little Bittern (*Ixobrychus minutus),* Purple Gallinue (*Porphyrio porphyrio*) and Moustached Warbler (*Acrocephalus melanopogon*). Once treated, the water flowing out of the wetland system is used for other environmental uses at the Aiguamolls de l'Empordà Natural Park, either to feed the man-made Cortalet lagoon or recently for the recovery of the flooded meadows of the area, an ecosystem of high ecological value and now on the verge of disappearance due to the change in crops and traditional farming in the area.

The Sa Riera Park and the Tossa de Mar Creek

In 1997, a project was undertaken in order to turn marginal land located between the WWTP and the local creek (Tossa de Mar creek) into a park by using reclaimed water to help establish the newly planted vegetation. The Sa Riera Park was also completed with a wetland, which provides water to the creek by soil percolation, preventing its total desiccation in summer downstream of the Sa Riera Park. It has been observed that the slight flow gained is crucial for the survival of eels and also for the speedier recovery of macroinvertebrate indexes when natural flows run again (Consorci de la Costa Brava (2006b). In 2007, the municipality of Tossa de Mar has also started to supply reclaimed water for urban non-potable uses through specific distribution pipelines.

The Ridaura River and improved water resources management in the Aro Valley

Until 1993, all the drinking water supplied in the Aro valley came from the aquifer of the Ridaura River. This aquifer, with a renewable volume of 5 hm^3/year, became insufficient to cope with the demand for drinking water in an area with a high level of tourism, estimated as 10 hm^3/year. Water transfer from the Ter River started at a slow pace in 1993, but by the late 90's a change in the way the resources were managed was needed, so the Ter water became the baseline supply throughout the year. In 2005, the Ter river water made up 70% of the overall water demand, whereas local water extraction had been decreased to 30%. Reclaimed water supply for irrigation in the area also helped to reduce the aquifer exploitation and in 2006 almost 1,0 hm^3 was supplied and saved. Both activities, together with the abundant rainfall of 2002-2004, prompted the recovery of the natural water flows in the Ridaura River between 6 and 9 months per year, something that had not happened for many years. Macroinvertebrate analysis in several sampling points along the river have shown an ecological quality surprisingly good for a river that had suffered from a total desiccation upstream from the discharge point of the Castell-Platja d'Aro WWTP and the discharge itself in the lower portion, near the river mouth. Whereas the sampling points upstream of the discharge point of the WWTP have always fallen into the maximum category of the IBMWP index (except in summer due to the desiccation of the river), the points downstream of the discharge decrease one category all year round but the summer, when the decrease is of two categories due to the absence of natural flows to dilute the ammonia-rich effluent (Consorci de la Costa Brava, 2006c). This example of the Ridaura river shows how drinking water supply, wastewater treatment and water reuse can be organized as to produce a direct and measurable benefit to the local ecosystem.

CONCLUSIONS

The recent passing of the EU's Water Framework Directive will necessarily lead water bodies to introduce policies orientated towards the achievement of high environmental standards. Some of these policies will certainly require the implementation of wastewater reclamation and reuse projects that will help conserve water in the environment and reduce discharges. Environmental benefits will be achieved either directly, though the use of reclaimed water for restoration or recreation of aquatic ecosystems, or indirectly, through water substitution. Projects of this kind already in operation in the Costa Brava area may contribute to provide technical information for better protection and enhancement of aquatic ecosystems.

ACKNOWLEDGMENTS

The authors would like to acknowledge the collaboration of Eduard Marquès, Anna Huguet, Jordi Couso, Marc Ordeix and Jordi Sala, and the good advice and inspiration provided by Ruud Kampf.

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