WASTEWATER RECLAMATION AND REUSE IN FRANCE

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INTRODUCTION

Assuming climatic stability, France total annual renewable freshwater capacity is estimated equal to 185 Billion (Bn) m^3 but decreases to lower figures during dry periods. As an example, the total annual renewable freshwater capacity dropped below 120 Bnm^3 between 1988 and 1992. Based on a country's population of 58 M, the per capita water availability (PCWA) value is around 3,190 m^3/year. France's PCWA will decrease steadily towards 2025 when the country's population is expected to stabilise.

After the records of the Ministry of Environment (MoE), the overall water consumption was around 40 Bnm3 in 1994, of which 70% was accounted for by industry, mainly power station cooling. Both municipal supply and agriculture accounted for some 15% (6 Bnm3) each. Though agriculture consumption might be underestimated, the country is unlikely to face any major water shortage over the next decades.

In spite of the high PCWA values, all regions do not share an equal access to water resources and regional chronic droughts appear in different parts of the country every year. However, even during the driest years, rain hardly falls below 600 millimetres per year in the least watered parts of France. To compensate for the lack of resources of some regions, major hydraulic constructions such as the Durance canal and the Bas Rhône canal have been built. But only ten percent of the capacity of the Bas Rhône canal, constructed 40 years ago for irrigation purposes, is utilised. Therefore, there is no real water scarcity, except for local or exceptional situations, which can be considered as niches for water reuse development (Faby *et al*., 1999).

In 1995, 85% of the French population (urban and rural) was connected to sewerage systems and around 70% to a wastewater treatment plant (WWTP). Most WWTP achieve a secondary treatment. However, the quality of French ground and surface water resources have steadily deteriorated to the extent that many rivers were recently reported to be affected by excessive eutrophication. The main factors of water quality deterioration are pollution from agricultural origin, wastewater treatment deficiencies due to undercapacity and unreliable WWTP infrastructure, insufficient nutrient removal (in 1995, municipal plants performing a tertiary treatment were less than 5%) and sewer discharge during storm events. Many wastewater reuse projects are driven by the aim of protecting receiving waters from microbial pollution and recovering rivers affected by eutrophication.

In the late 1980's wastewater reuse was limited to the sewage farms of Achères and Reims, relics of the treatment practices of the XIXth century, and to 4 recently set up small projects, three of which are located on islands off the Atlantic and Mediterranean coasts (Rodier and Brissaud, 1989). Despite the poor development of wastewater reuse, the Ministry of Health (MoH) started the elaboration of regulations on irrigation wastewater reuse in 1989. Guidelines issued in 1991 (CSHPF, 1991) are currently used as a provisional regulation.

Wastewater reuse was acknowledged as a means of disposal of treated wastewater and a recommended approach to serve small communities along the coastline in the Water Law and application decrees released by the Ministry of Environment (MoE) in 1992 and 1994. A survey ordered by the Ministry of Health showed that more than 15 new projects were in operation in 1996 (Figure 1). The characteristics of these new projects, i.e. location, goals, irrigated area, irrigated crops and wastewater treatment before reuse, allow to depict the situation and main trends of wastewater reuse in France.

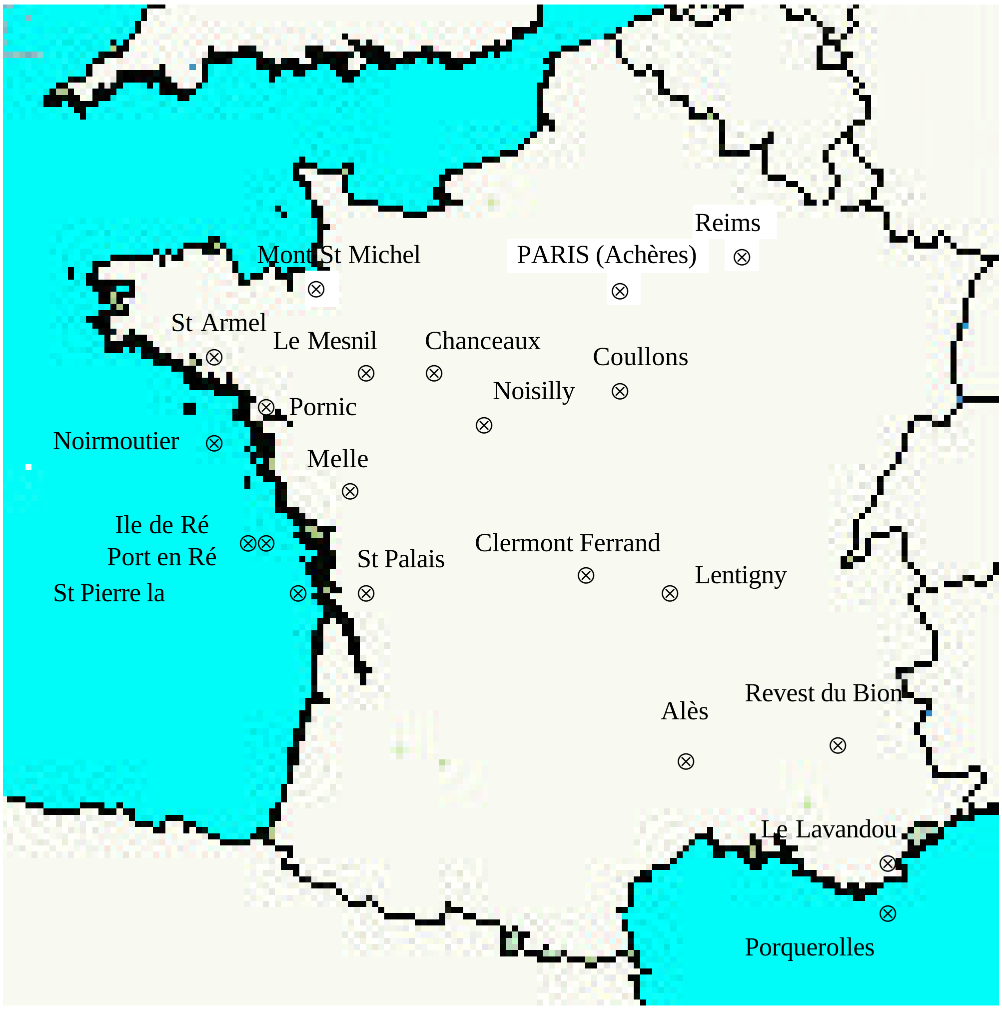

Figure 1. Water reuse projects in France in 1996

A final draft of the regulations of the use of wastewater for irrigation was drawn up by the MoH at the end of the year 2000.

LEGAL FRAMEWORK

January 3, 1992 France's water law required each city to define the zones to be served by public municipal sewerage, storage, treatment and disposal or *reuse of wastewater*. This was the first time wastewater reuse appeared in a French regulation. Wastewater reuse was thus acknowledged not as a marginal water supply but as an alternative solution to wastewater discharge. A June 3, 1994 decree provided the basis for water reuse rules in France. First, it clearly stated that treated effluents can be used for agricultural purposes, but only if water reuse projects are operated without any risk for the environment and public health. Second, wastewater treatment requirements, irrigation modalities and monitoring programs must be defined after an order of the Ministries of Health, Environment and Agriculture. This order is still being prepared (in June 2002) by the Inter-ministry Water Mission and the National Council for Public Health (CSHPF).

The idea that water reuse can be a viable alternative to the disposal of treated effluents in rivers and coastal waters was repeated in a May 12, 1995 order of the MoE. It encouraged the use of alternate solutions to the discharge of wastewater in sensitive areas, where advanced tertiary treatments are not affordable; in those cases the order recommends that cities evaluate other alternatives, such as, among others, land application. The reuse of the treated wastewater of small seaside resorts is also recommended, together with infiltration and other appropriate solutions, in order to put an end to the disposal of wastewater in bathing waters, shellfish breading areas and other receiving waters, the quality of which must comply with stringent sanitary regulations.

The order which is prepared by the Inter-ministry Water Mission and the CSHPF will result from a revision of the *Recommendations about the use, after treatment, of municipal wastewater for the irrigation of crops and landscape areas* drawn up by the CSHPF (1991). These recommendations refer to the A (nematode egg content < 1/L, faecal coliform content <1000/100 mL), B (nematode egg content < 1/L, no bacteriological criterion) and C (no microbiological criterion) categories of water reuse defined by the World Health Organisation guidelines (WHO, 1989). But, as stressed by Bontoux and Courtois (1996), additional requirements on irrigation management and the prevention of health risks related to human exposure made the first French recommendations more stringent than the WHO's guidelines.

For instance, irrigation of vegetables to be eaten raw with quality A water is allowed, but methods that reduce the direct contact of irrigation water with vegetables and fruits are highly recommended. Irrigation of public green spaces with the same quality of water is tolerated, provided it is done by short range sprinklers outside opening hours. Also, sprinklers should be more than 100 m from houses, sports and recreational areas. This last requirement applies also to aspersion of cereal, fodder crops, nurseries, ... with B quality water. The most prominent restrictions added to the WHO's guidelines are mainly aimed at protecting people from aerosol risks. Reuse of C quality water by drip or underground irrigation is limited to areas closed to public access.

The CSHPF recommendations also concerned the chemical quality of the reclaimed water used for irrigation. Wastewater of mainly domestic source (as defined by the French standard NFU 44041) can be used, after treatment, for the irrigation of crops and green spaces. Because of potential excessive concentrations in mineral and organic micro-pollutants, permission to use wastewater of non-domestic source depends on the analysis of each particular wastewater. When the wastewater quality is not suitable, reuse is not authorized.

According to water police regulations, every authorization request to dispose of treated wastewater must include :

- comprehensive information about the nature and quantity of compounds brought by industrial wastewater discharged to the public sewerage system,
- at least one analysis of the treated effluent for SS, BOD_5, COD, NK, heavy metals and organic compounds of concern,
- one analysis of the sludge produced by the treatment plant (according to NFU 44041).

When, for at least one parameter, heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) concentrations measured in sludge exceed the standard, treated wastewater quality must be more thoroughly analyzed. This supplementary examination is particularly recommended when treated wastewater is to be used for the irrigation of market gardening, cereal, industrial and fodder crops and pastures.

Disposal authorization, which has been previously delivered, will be submitted to a new examination when :

- reclaimed wastewater shows increased concentrations in toxic substances,
- maximum amounts of heavy metals that can be added to cultivated soils (NFU 44041 standard) are exceeded.

Moreover, each new wastewater reuse project must be authorised by the representatives of the MoH and monitored on a permanent basis.

The order of the Ministries of Health, Environment and Agriculture is expected to be issued before 2005. According to its last draft, the new regulation is likely to be more stringent than the 1991's guidelines. The main changes are listed thereafter.

- Performing a secondary treatment before any irrigation reuse will be mandatory.
- Four water reuse categories will be introduced, instead of three in the WHO's guidelines:
    - A' (*Escherichia coli* content <1000/100 mL, no *Salmonella*, no Taenia egg) : irrigation of vegetables and small fruits to be eaten raw, irrigation of pastures, aspersion of fruit trees, public parks, sports areas and golf courses,
    - B' (*Escherichia coli* content <1000/100 mL): irrigation of vegetables and small fruits to be cooked or pasteurised, aspersion of flowers, nurseries, cereals and fodder crops,
    - C' (*Escherichia coli* content $<10^4$/100 mL): irrigation – at the exception of aspersion – of flowers, nurseries, cereals and fodder crops,
    - D' (no microbiological criterion): irrigation – with the exception of aspersion – of forests with controlled admittance to the public.

Restrictions on aspersion will be maintained, diversified and adjusted to the water quality.

PARIS'S SEWAGE FARMS

The construction of water supply and sewer networks in Paris, initiated in 1856, resulted in a heavy pollution of the river Seine. After experiments performed at Clichy, it was decided that sewage farms would be the appropriate solution to dispose of wastewater. The first sewage farms were at Gennevilliers in 1872, handling a small part of Paris wastewater flow rate. Then, a project aiming at the disposal of the wastewater of the whole town was designed in 1875 and implemented in 1895. At the beginning of the last century, sewage farms reached their maximum extent, with 4 different areas: Gennevilliers, 900 ha, and the 3 Achères districts (Achères plain, 1400 ha, Pierrelaye, 2,010 ha and Triel, 950 ha) supplied with raw wastewater by the Colombes pumping station (Figure 2). The whole sewage farms could not treat more than 160 hm^3 a year; thus 250 hm^3 had to be disposed of to the Seine river downstream from the town. The disposal of untreated wastewater to the Seine started to decrease with the construction of the first activated sludge treatment plant at Achères in 1940. The treatment capacity of Achères WWTP was augmented over the years. The Colombes WWTP came on stream in 1998. Since then, raw wastewater is no more used for irrigation and the 3 Achères districts, still 2,000 ha, are provided with wastewater which has gone through an advanced primary treatment (flocculation + settling) in the Colombes WWTP. In summer, secondary treated water is added when necessary.

Stopping wastewater reuse had been envisaged by health authorities; however it was not the final decision. The goals for keeping sewage farms in operation are to:

- maintain a 2,000 ha green area in an otherwise heavily built up zone,
- prevent heavy metal release to aquifer and river waters should irrigation cease,
- alleviate the load of the biological treatment plant, thus preserving the quality of the Seine river, especially in Summer when the daily volume of reclaimed water used for irrigation reaches up to 300,000 m^3 (Védry et al., 2001).

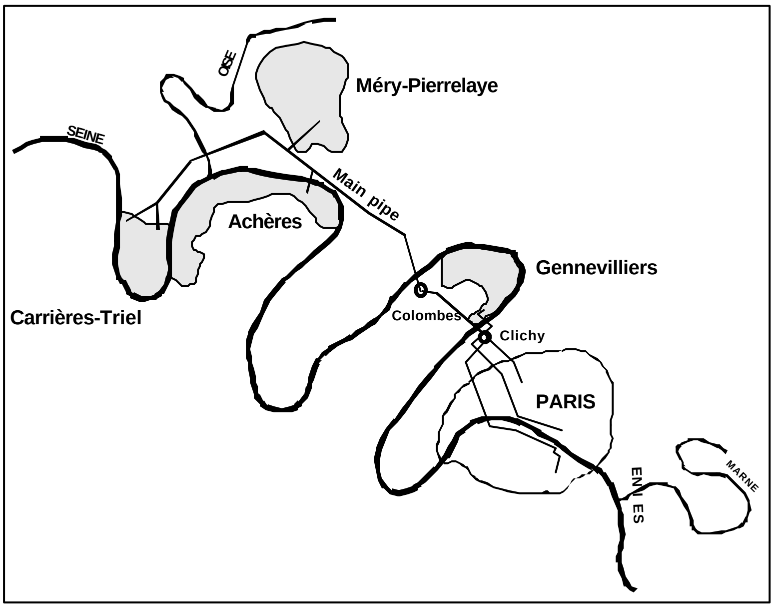

Figure 2 : Irrigated fields of Paris in 1900

Originally, in the Pierrelaye area, high sewage loads were applied to the lands owned by the city of Paris, which accounted for 1/3 of the irrigated surface and were devoted to corn or industrial crop cultivation. On the remaining 2/3, which are privately owned lands, farmers used wastewater to irrigate vegetable crops. Irrigation of vegetables to be eaten raw was not allowed, but the rule has not always been obeyed. Possible health hazards, related to pathogens and to heavy metals accumulated in the soil for decades, have recently led to abandon the traditional cultivation of vegetables in the Pierrelaye fields. From now, cultivation of corn seeds will be favoured.

PROJECTS DEVELOPPED FROM 1981 TO 1997

Location

Among the 19 projects developed since 1981, six are located on the Atlantic coast, five in three islands off the same coast (Figure 1), only one on the Mediterranean coast (a golf course irrigation), and another one on the Porquerolles island. The remaining six are scattered in the hinterland. As expected from the MoE's recommendations, most projects serve communities and tourist resorts situated along the coastline of Vendée, Brittany and Normandy. In the south of the Gironde mouth, wastewater of tourist resorts is not reused but infiltrated into a 5 km wide dune sand string stretched along the shore line.

Driving factors

Every single island off the French coast is experiencing water shortage, which is mainly due to increasing tourism. In several cases, water is supplied from the mainland and its marginal cost is soaring. The first objective of wastewater reuse is to provide water for the irrigation of food crops and corn, thus allowing to maintain a profitable agricultural activity and a permanent population in these islands (Noirmoutier, Ré, Porquerolles). Treated wastewater is also supplied to golf courses (Oléron, Port en Ré), which are part of the tourist economy. The second objective is to prevent the pollution of bathing waters, shellfish breeding areas (Noirmoutier, Ré, Oléron) and aquaculture water (Noirmoutier, Ré). At Porquerolles, wastewater is entirely reused. In several other cases where the amount of wastewater exceeds the irrigation needs, disposal to the sea is interrupted during the tourist season and wastewater stored in reservoirs (Ré, Noirmoutier). Moreover, the treatment performed to match the water quality standards required for agricultural reuse allows complying with the current microbiological criteria of bathing and shellfish breeding waters.

Table 1 : Main wastewater irrigation projects developed in France for the last 20 years

Projects	Irrigated area (ha)	Date	Specific application	Wastewater treatment	Geographic location
Mont Saint Michel	265	1994	meadows and corn	3 lag.	Atlantic
Saint Armel	120	1997	market gardening	4 lagoons	coast
Porquerolles	35	1986	mark. gard. + orchards.	act. slud. + 3 lag.	Med. isl.
Noirmoutier - La Salaisière	220	1981	potatoes, cabbages, corn	act. sludge + 4 lag.	
Noirmoutier - Barbatre	35	1991	potatoes	aer. lag. + stab. res.	Atlantic
Ars en Ré	90	1985	corn, potatoes	act. slud. + chl. + res.	
Saint Pierre la Cotinière	25	1994		act. sludge + u.v.	islands
Port en Ré				underground irrigat.	
Pornic	34	1992	Golf	act. sludge + chlor.	
Baden	7	1989		2 lag. + stab. res.	Atlantic
Saintes			courses		coast
Saint Palais	55	1991		act. sludge + chlor.	
Le Lavandou	30	1994		Biofiltr. + ground filtr	Med. coast
Chanceaux sur Choisille	5	1993	sports areas; parks	act. slud. + lag.	
Le Mesnil en Vallée	85	1995	corn, nursery	aerated lagoon	
Clermont Ferrand	700	1996	corn	act. slud. + lagoon	Hinterland
Coullons	94	1994	corn	ph.ch + aer. lag + 2 lag	
Melle		1994	corn	act. slud. + 2 lag. + res	
Nouzilly	50	1993	corn, alfalfa	act. slud. + stab. res.	

( ) data not available

Most projects set up in the mainland along the Atlantic coast have the same two above-mentioned objectives. Supplying conventional water to Pornic golf course would have cost 0.9 €/m^3 instead of only 0.4 €/m^3 for tertiary treated urban wastewater. During the irrigation season, effluents of the Pornic treatment plant are no longer disposed of in the pretty old harbor. Thus the aesthetics of the very heart of the resort is greatly improved. The reuse of the wastewater of Le Mont Saint Michel and neighboring villages halted the disposal of wastewater in the bay, which is one of the most popular French tourist places and an area devoted to the breeding of mussels and oysters. Wastewater, treated and stored in a series of lagoons allows increasing the crop production of a polder zone.

Most hinterland projects were driven by the rehabilitation of rivers threatened by eutrophication. The main example is the Clermont Ferrand project; reusing urban treated wastewater aims at an overall improvement of river water quality and provides a reliable water resource to the farmers. The main goal of the Melle project was the rehabilitation of the stream that used to be a receiving body for wastewater treatment plant effluents. Projects of Le Mesnil en Vallée and Le Fuilet were mainly driven by the absence of streams capable of receiving secondary treated wastewater. Reusing wastewater was found to be a cheaper solution than sophisticated tertiary treatments; it allowed developing irrigated agriculture and increasing a few farmers income.

Irrigated crops

Most of the 17 projects set up since 1981 are small-scale projects (Table 1). The largest irrigated area is 700 hectares at Clermont Ferrand. The mean irrigated surface is just about 100 ha. Only 4 projects have an irrigated surface of more than 100 ha and 9 less than or equal to 50 ha.

In tourist areas located along the Mediterranean and Atlantic coastlines, the irrigated crops are : market gardening (potatoes, cabbages, carrots, onions, ..), orchards, meadows and corn, or lawns of golf courses.

According to CSHPF's recommendations, irrigation of meadows, corn and vegetables to be eaten cooked requires B quality water. Quality water A is required for the irrigation of vegetables to be eaten raw (aspersion of this category of vegetables is prohibited) and the aspersion of golf course lawns. Orchards can be irrigated with water of quality A, B or C, depending on the irrigation system.

Corn is the most frequent crop irrigated in hinterland projects. Alfalfa and nursery are exceptions and require water quality B and B or C respectively, depending on the irrigation technique.

Wastewater treatment

In most projects, wastewater is secondary treated through a biological process: activated sludge or aerated lagoons. An additional treatment is necessary to reach A quality and, even, B quality. It can be seen from Table 1 that the tertiary treatment applied to secondary effluents mainly depends on the cultivated crops.

When wastewater is used for market gardening irrigation, tertiary treatments are performed in series of 3 to 4 maturation ponds or in a stabilization reservoir. Chlorination is used in only one case (Ars en Ré). The relatively high number of ponds is intended to assure an appropriate disinfection level during the irrigation season. Monitoring of several projects have shown that the bacteriological quality of the irrigation water easily complies with the A category standard of the WHO's guidelines. At the outlet of Mont Saint Michel lagoons, the maximum fecal coliform content was found to be 20 CFU/100 mL and no helminth egg was detected. Carrots irrigated with reused water had a lower fecal coliform content (<10CFU/mL) than those irrigated with conventional water (90 CFU/mL). At the outlet of Porquerolles lagoons, where the water residence time is one month, fecal coliform contents are currently ranging from 100 to 1000 CFU/100 mL. Performances were significantly higher 10 years ago. The fecal coliform contents were measured twice a month during six years at the outlet of the Noirmoutier lagooning system before and after a new activated sludge plant has been put on line in 1997 (Figure 3). The average outlet concentrations were respectively 50 and 80 CFU/100 mL. Higher concentrations were observed at the end of summer, when the stored water volume has been depleted to meet the irrigation needs

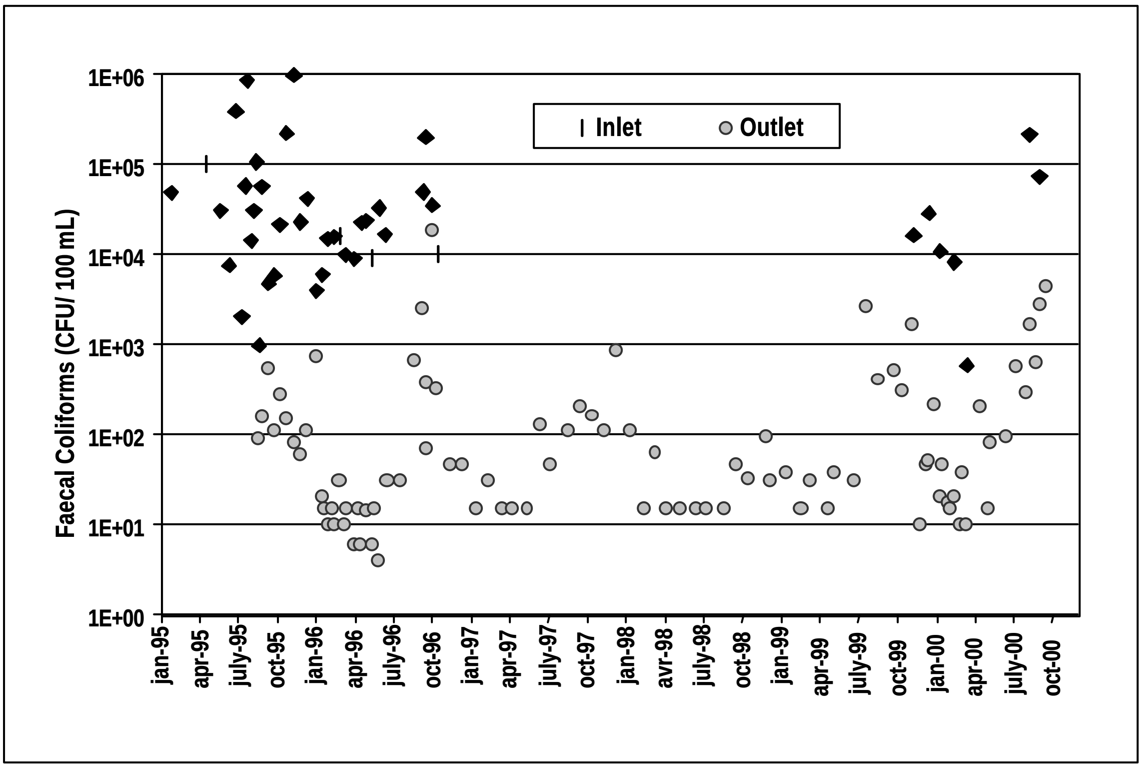

Figure 3. Faecal coliform content at the inlet and outlet of the polishing lagoons of Noirmoutier

Lagoons are also used as storage facilities, accumulating water to face seasonal irrigation needs and/or allowing to stop disposal of treated wastewater when the receiving bodies have to be protected. Then, water depths range between less than 1m and 3 m from one lagoon to another and vary along the year according to the irrigation needs (Mont Saint Michel, Murviel les Montpellier, Noirmoutier).

Contrary to vegetable crop irrigation, polishing of secondary effluents before golf course irrigation generally does not rely on extensive technologies but on conventional disinfection treatments: chlorination and ultra-violet irradiation. These treatments can ensure higher bacteriological quality than required by the MoH's recommendations provided they are properly managed and maintained, a task that golf course staff is usually able to cope with.

Most golf course owners and MoH representatives considered a conventional disinfection technology should be preferred in order to guarantee that the reuse is accepted by the public and to minimize the risks of microbe dissemination in the neighborhood, often high standing residential areas. Baden golf course is an exception : parts of the lawns, only 7 ha, are irrigated with wastewater treated in 2 lagoons and a storage reservoir. Underground irrigation, as practiced at Port en Ré, does not require any disinfection treatment.

Secondary effluents are also tertiary treated in lagooning systems or stabilization reservoirs before corn irrigation, thus providing a water quality higher than the B category standard. The reasons for improving the water quality beyond the MoH's guidelines are sometimes related to specific operations, such as in the Clermont Ferrand project. The general trend is to consider the MoH's recommendations as minimum requirements to be made more stringent according to local conditions. Lagoons are also used as storage means.

CLERMONT FERRAND: AN HINTERLAND PROJECT

A 400,000 p.e. secondary treatment plant serves the greater Clermont Ferrand. Effluents of the wastewater treatment plant used to be disposed of in the nearby Artière small river, thus heavily polluted (Figure 4). Moreover, farmers used to pump from polluted Ambène, Genzat and Bedat rivers to irrigate hundreds of hectares of corn plantation, which resulted in a large flow rate reduction and in a summer degradation of these water courses. A reuse project was designed in 1989 and authorized by national then local health authorities in 1995. It started to be implemented in 1996, when 50 ha were irrigated, and was completed in 1999. The final irrigated surface is 700 ha spread over 8 municipalities. Seed-corn is among the irrigated crops. Workers in charge of corn castration are in direct contact with plants aspersed with wastewater. This was the reason why health authorities required an A quality irrigation water.

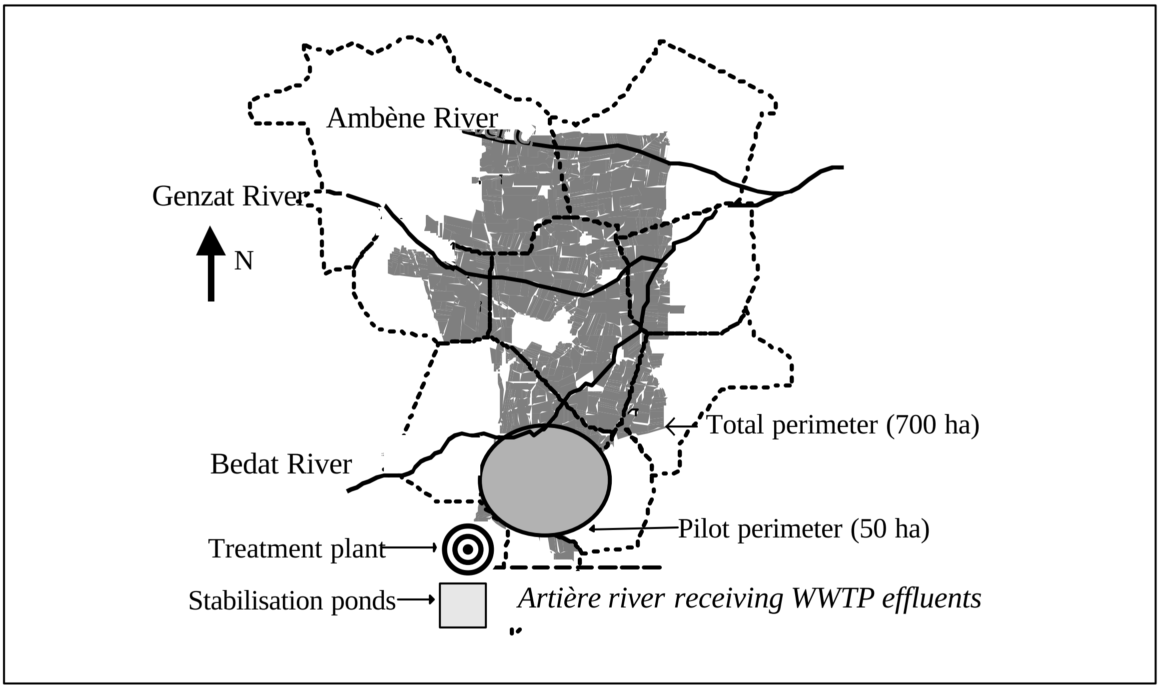

Figure 4 : Lay-out of the Clermont Ferrand irrigation scheme

Effluents of a sugar mill, set close to the wastewater treatment plant, are stored in 8 lagoons from October to June, The overall area and volume of the lagoons are 12 ha and 312,000 m^3.

Stored sugar mill effluents are spread over the fields in May and June. Then, empty lagoons are filled with secondary treated effluents in June. Pumping for irrigation starts one month later. The lagoons serve as a polishing treatment to meet the A standard.

Monitoring the microbial quality of the water withdrawn from the lagooning system between July 6 and September 8 of the year 1998 showed median content of 90 and 24 CFU/100 mL in faecal coliforms and *Enterococci*. *Salmonellae* were detected in 23 % samples (Devaux, 1999). The microbial quality of the irrigation reclaimed water was always higher than the one of the water pumped in Ambène, Genzat and Bedat rivers.

An epidemiological study was performed in 1996, 97 and 98 among the surrounding population, field workers and farmers. No epidemic event related to water exposure was identified (Devaux et al., 2001).

CONCLUSION

In spite of the excess water resource availability, water reuse projects have been steadily increasing since the 1980's. This trend is driven by water resource conservation in coastal and sensitive areas and by increasing water needs. This observation is particularly important in islands off the Atlantic and Mediterranean coast. Virtually all municipal water reuse projects are geared towards agricultural, golf course and landscape irrigation.

Conventional disinfection technologies are generally chosen for golf course irrigation, so as to meet public acceptance and for commercial reasons and also because golf courses are often closely surrounded by residences. When a high microbiological quality must be reached in an urban environment, conventional technologies are considered as more reliable than extensive ones.

On the contrary, lagooning and reservoirs are the most widespread tertiary treatment for agricultural applications of wastewater, whatever the irrigated crop: vegetables to be eaten raw or cooked, corn, meadows, nurseries, ...

Lagooning is very popular in France, where more than 2,000 facilities are operated (Racault *et al*., 1995). It is one of the most appropriate technologies for rural areas. Its advantages are :
- moderate investment costs,
- easy and cost-effective management and maintenance,
- reliability. Recent research has provided reliable tools for water quality prediction (Xu et al., 2002). No electric power failure can drop the treatment efficiency,
- lagoons may serve also as storage. Influence of storage on the performances has to be taken into account when designing and operating lagooning systems.

However, lagooning is land consuming; this main drawback prohibits it wherever land is expensive. A second important drawback is that temporary failures of microbiological performances have been often observed, due to preferential pathways related to specific wind conditions or to rainfall. Careful study of the influence of climatic conditions on water residence time distribution should allow improving the reliability of disinfection in maturation ponds.

The publication of the MoH's recommendations did not result in an outbreak of projects in France. The effect was more to slow down the development of wastewater reuse (Riou, 1996).

Anyway, in the future, new projects are expected to be worked out as alternative solutions to wastewater discharge in sensitive water bodies, as suggested by a 1994 decree of the Ministry of the Environment. Golf course irrigation is driving new projects.

MoH's recommendations are being revised ; they should not be made much more stringent, but more microbiological quality descriptors should be analyzed. A regulation is expected to be issued before the year 2005.

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SYMBOLS

CSHPF : French National Committee for Public Health
MoE : Ministry of Environment
MoH : Ministry of Health
PCWA : per capita water allocation
WWTP : wastewater treatment plant

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