

Sewage treatment in the greater Paris area: from an indispensable hygienist approach to an environmental protection approach

Summary: The sewerage system that has been progressively constructed in the greater Paris area has enabled some very considerable progress to be made: eradication of water borne diseases, progressive restoration of the quality and the uses made of the river (leisure activities and drinking water supply), effectively combating the consequences of rain related events (floods and spillages of pollutants), restoration of the biological potentiality. However, there are still challenges that need to be faced, such as the management of by-products from waste water treatment and improving treatment in periods of heavy rainfall. The solutions being envisaged call for innovation within a framework of increased awareness of the challenges involved in sustainable development.



The Seine river banks have been classified as world UNESCO patrimony

The greater Paris area is located at the centre of the river Seine catchment area. The climate is oceanic and temperate, with annual rainfall of 750mm. The population of greater Paris is 10 million. This includes Paris itself (2.1 M inhabitants) and the surrounding departments, to which must be added around 200 urban districts, covering a total surface area of around 2300 km². The average population density is very high (8000 inhabitants/km²). Situated at the crossroads of European exchanges, the greater Paris area lies within the principal economic region of France, which generates nearly 30% of national wealth. Only 10% of the surface of Europe is located in the catchment basin of a river that supports a population density higher than that of the Seine basin, which has low median flow (60 m³/s at the low water mark). One can thus assess the load that the greater Paris area exerts on its river. This considerable load is reflected in water withdrawal that extends well beyond the region itself and by its discharges, the influence of which can be felt as far away as the estuary in the North Sea.

The objective of this communication is to outline the benefits of the progressive development of the sewage treatment system of the greater Paris area. The different steps of this development will be presented, the way it is managed, the way its development is planned out and the benefits obtained.

1. Waste water treatment in the greater Paris area: the adoption of a hygienist approach

For many centuries, household and other waste water from Paris was discharged into the street, where it stagnated until washed away by rain. The first waste water treatment measures go back to the paving of certain streets under the reign of King Philippe Auguste in 1186. At the beginning of the 19th century, buildings and houses had septic tanks that were rarely leak tight, which polluted the soil and any wells in their vicinity. When emptied, their contents were transported to municipal waste discharge sites. In 1800, there were only 25 km of sewers for a city covering 3 500 hectares and 700 000 inhabitants.

Repeated epidemics only underlined the acuteness of sanitary problems due to this method of sewage treatment. The cholera epidemic of 1832, which led to 18 400 deaths, was the most important. It was followed by other typhus and cholera epidemics: 1849, 1854, 1865 and 1892, which was the last major cholera epidemic. These epidemics, at the same time as improved knowledge, led to an acceleration of transformations to the city's sewerage system.

During, the 19th century Paris was marked by a demographic explosion (fivefold increase in its population). Very extensive works were carried out to bring water to Paris from faraway sources and to set up industrial means for producing drinking water from surface water. Thanks to these works, water consumption, which stood at 4l/inhabitant/d in the 18th century jumped to 120l/inhabitant/d (it now stands at 300 l/inhabitant/d).

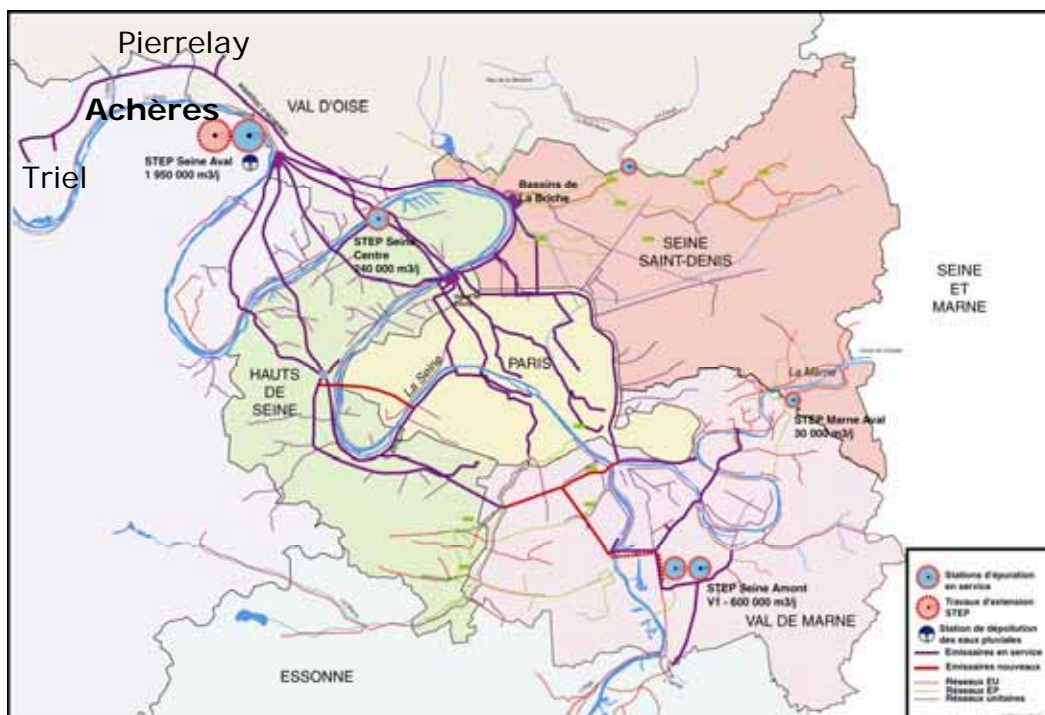
In 1856, Eugène Belgrand became head of the water and sewage service and the following principles were adopted during major construction works in Paris: the construction under each street of a gallery housing water lines, connecting up houses to evacuate domestic waste water and run off water into the gallery and discharging the water thus collected downstream of Paris. As a result, 400 km of new galleries were excavated (a threefold increase) during these major works. Four major collectors formed the backbone of this unified network. However, despite appearances, it was still a long way off from the sewerage network that exists today. Waste water (apart from domestic waste water) was still channelled into septic tanks. In fact, the network designed by Belgrand was only meant to collect domestic waste water and rain water, with the exclusion of solid matter. Numerous commissions had to meet before the networks were also able to collect solids from the septic tanks and pressure from the cesspit emptiers was not without effect in causing this delay. It was at the outcome of these debates that *"tout à l'égout"* (everything goes into the sewer) was first recommended before being imposed throughout the city in 1894 by an Act brought about as a result of pressure from the forthcoming Universal Exhibition of 1900. The network then became a combined sewerage system: it collected waste water, household waste water and run off water.

The transfer and the concentration of the discharge of effluents into the Seine downstream of Paris (in Clichy) led to serious pollution problems. To overcome these problems, sewage fields were brought into service on land purchased by the city of Paris 28km downstream. The Achères aqueduct enabling the waste water to be conveyed to these fields was constructed. In 1910, 5 000 hectares absorbed 180 millions m³ each year.

The population of the greater Paris area rose sharply after the 1914-18 war reaching 4.5 million inhabitants in 1933. In 1927, a sewage treatment programme was adopted. It provided for the construction of a waste water treatment plant in the town of Achères. The first phase of the Achères treatment plant (220 000 m³/d) entered into service in 1940 and a second one in 1966. In 1968, the waste water treatment programme was updated. The new programme will allow the construction of two supplementary phases of the Achères waste water treatment plant (representing 1 500 000 m³/d) and the creation of the Noisy-Le-Grand and Valenton plants upstream of Paris.

2. Sewage treatment in the greater Paris area today

2.1 Institutional organisation and principal sewage treatment works



The greater Paris area sewerage network

Management of the sewerage network of the greater Paris area is divided into three administrative levels. Collection is under the responsibility of each community (around 150). The collected waste water is channelled into departmental networks, the outlet of which is the interdepartmental network of the S.I.A.A.P (Wastewater Treatment Authority for Greater Paris). This authority is responsible for the transport and treatment of waste water produced by 8,3 million inhabitants.

The collection infrastructure is made up of a network of around 4500 km of structuring collectors. The outfall sewers of S.I.A.A.P (combined water transport lines of 2.5 to 4m diameter located at a depth of between 10m and 100m) constitute a 160 km transport network that ends up at the different waste water treatment plants. To this must be added the communal collection networks. A large part of the greater Paris area is equipped with a sewerage network equivalent to that of Paris, in other words a combined, gravity based system. However, certain communities in greater Paris, particularly in areas of low rise housing, have separate networks.

At present, the water is treated on 4 sites with a waste water treatment capacity of 2 520 000 m³/d. 80% of the water ends up at the downstream Seine waste water treatment plant in Achères, which reached its present capacity of 2 100 000 m³/d in 1978. Amongst the largest waste water treatment plants in Europe, it covers around one hundred hectares. The emission rate from this station (22.5 m³/s) is comparable with the five-year monthly low water flow rate of the Seine (60m³/s), and therefore the impact of the discharges from this plant on the natural environment is therefore considerable.

The Seine Centre waste water treatment plant in Colombes, located upstream of the Achères plant, has a nominal capacity of 240 000 m³/d. This plant uses modern treatment processes (lamellar settling, biofilter treatment) and is particularly compact since it covers an area of 4 ha. Finally, the downstream Seine waste water treatment plant located in Valenton (capacity of 600 000 m³/d) is located at the head of the structuring axis of the network. It intercepts and treats effluents upstream of Paris.

The treatment of sludge produced by waste water treatment is a very sizeable activity on the scale of the S.I.A.A.P, which has to dispose of 400 T/d of sludge (i.e. 50g/inhabitant/d), which is recycled for agricultural use.

A volume of around 3 Mm³ of waste water is transported by the outfall sewers of the S.I.A.A.P to the 4 waste water treatment plants. 44 % of this water is made up of infiltrated clear water, i.e. 140 l/inhabitant/d, which comes from various sources: small rivers that flow into the sewerage network, leaks from the drinking water network, mine drainage water, etc.

The "production" of waste water by the inhabitants of the greater Paris area is not regular. The infrastructures have to deal with sudden fluctuations between the night and the morning. In addition, variations in the flow of transported pollutants are very considerable in periods of wet weather. In order to regulate these variations and optimise the storage capacities of the outfall sewers, a centralised remote management system has been developed. This enables the flow rate of effluents going through the outfall sewers to be continuously monitored and regulated through the remote controlled opening of valves. Moreover, a decision aid system based on network measurements and a hydraulic model have been developed.

2.2 Planning the development of the waste water treatment system

Once the sanitary problems had been overcome, those responsible for waste water treatment and inhabitants progressively became aware of the necessity of safeguarding the Seine. Various waste water treatment schemes (1929, 1968) orchestrated by the French government and then the S.I.A.A.P enabled a gradual development of the sewerage system, since the waste water treatment facilities were not sufficient to meet the requirements of the population. In 1990, with the completion of the fourth phase of the Achères waste water treatment plant, dumping of untreated raw water into the river Seine in dry weather finally ceased. Since then, everyone has been able to observe the disappearance of white froth, an improvement in water quality and the return of many species of fish.

However, after heavy storms, tonnes of fish died because although storm overflows protected Paris from its networks overflowing, large quantities of water were then discharged into the river without being treated. This fish mortality was not readily accepted by a population increasingly aware of environmental issues.



Fish mortality, 1968



Storm water treatment plant (30 m³/s)

Following numerous discussions, it was decided in 1994 by the then *Ministre de l'Environnement* (French Ministry of the Environment) to launch a greater Paris waste water treatment study under the aegis of the French State and financed by the State, the Ile-de-France region, the S.I.A.A.P. and the *Agence de l'Eau Seine Normandie* (Seine Normandy Water Agency). The objective of this study was to propose improvements making it possible to set out future waste water treatment in the greater Paris area by integrating the requirements resulting from new urbanisations and limiting the impact of heavy rainfall periods on the Seine. This waste water treatment development plan should also take into account the necessity of limiting the capacity of the principal waste water treatment plants of the greater Paris area and the necessity of eliminating any nuisances for those living in the vicinity of the treatment works.

The methodology employed in this study consisted in the construction of 4 possible development scenarios entitled scenarios A to D, each comprising more or less centralised treatment facilities and storage volumes spread out as a consequence. In order to enable a choice to be made between these different scenarios, a multi-criteria analysis was carried out, which took into account environmental performance, reliability, cost and integration within the environment of the different scenarios.

The results of the simulations estimated in terms of impact by means of the environmental quality model led to scenario C being chosen. The key features of this scenario are as follows: improvement in the level of waste water treatment in periods of dry weather, reduction in the throughput of the downstream Seine site (Achères), storage and treatment of storm water (1 600 000 m³ of storage tunnels).

Scenario C should be completed by 2015, by which date the good ecological quality objectives of the Seine imposed by the European Framework Directive on Water also have to be attained. A study is currently underway to update this water treatment development plan.

2.3 Means of financing waste water treatment

The first investments made to construct the backbone of the waste water treatment system of the greater Paris area were borne by the French State. Present funding is principally borne by users through their drinking water bills according to the general principle: "water pays for water". Within greater Paris, the price of water for domestic purposes is around 3€ per cubic metre. 40% of this is used for the production and the distribution of drinking water and 30 % for the treatment of waste water. The remainder corresponds to royalties and taxes, including in particular the royalty paid to the Seine Normandy Water Agency, which is around 250 M€/year for the greater Paris area. This royalty, the calculation of which is based on the quantity of pollution produced, is then redistributed to local authorities with projects in the drinking water and waste water treatment sectors in the form of loans and subsidies. This mechanism brings into play the principle "the polluter pays and the de-polluter receives aid", while at the same time allowing solidarity and consistency throughout the basin, since the Water Agency's actions are carried out on the scale of the Seine catchment basin as a whole. It should be noted that water represents less than 1% of household budgets (the health budget represents around 21%).

Improvements in collection and treatment throughout the greater Paris area necessitates some considerable investments by the principal owners of works in the greater Paris area. Treatment works (not including the work carried out by each community on the collection networks) represents nearly 10% of the total amount of public works contracts in the Ile-de-France region. Over the last ten years (uniquely works supported by the Water Agency), they have stood at around 280 M€ each year (45% of the total financial support for pollution treatment on the Seine Normandie basin).

The annual operating budget of the SIAAP, which is responsible for assuring the transportation and treatment of the waste water of the greater Paris area was 1 billion Euros in 2004 (of which 65% went into investment).

In order to implement the waste water treatment scenario chosen in 1997, a Contract known as a Basin Contract tying together the SIAAP, the Ile de France region and the Seine Normandie Water Agency was signed on the 6th March 2000. This contract, which extends for 6 years, concerns the completion or the modernisation of the principal water treatment works, the construction of retention structures and pollution treatment in periods of heavy rainfall, as well as the completion of major collection structures. This contract involves a sum of 2500 M€ (not including tax) for the period 1999-2006, i.e. 340 M€/year. The estimations for the next period of investment concerning the improvement of the treatment plants (2006-2012) are around 2000 M€.



Storm water storage tunnel



Seine amont treatment plant extension

3. New issues and challenges for waste water treatment in the greater Paris area

3.1. Storm water management

Due to the fact that a very large majority of its network is organised into a combined sewerage system, the greater Paris area has to face two major problems in terms of storm water management: managing network overflows that lead to local flooding and the adverse affect on the quality of water in the river Seine brought about by urban discharges in periods of heavy rainfall.

In order to meet these twin challenges, numerous storage structures have been put in place, constituting a storage volume of more than 1.5 Mm³. One third of these involve storage structures on combined sewerage networks that return the water to the waste water treatment plants, while two thirds concern storm water structures that return the water to the natural environment after settling. For example, the basin of La Plaine in Saint-Denis, which is the largest storage basin in greater Paris with a volume of 165 000 m³, was built within the scope of the construction works of the Stade de France for the football world cup in 1998.

In order to better protect the natural environment against discharges from the combined sewerage system during periods of heavy rainfall, tools have also been developed for remotely managing devices such as valves, pumps, etc. allowing the system to store the water. Finally, specific means for treating combined water in periods of heavy rainfall have been commissioned. This involves treatment plants such as the one installed in Achères in 1998, which can deal with 22.5 m³/s of waste water, which it treats by physical / chemical settling. Moreover, the new waste water treatment plants have been designed to be able to accept much higher throughputs in wet weather than in dry weather. For example, the throughput of the Colombes waste water treatment plant goes from 2.8 m³/s in dry weather to 12 m³/s in periods of heavy rainfall.

Therefore, it may be observed that after a hygienist approach that consisted in constructing networks to evacuate combined water as quickly as possible downstream of the greater Paris area, it is a "hydraulic" approach that has prevailed with the construction of storm water storage basins. This approach is now being questioned. In fact, if no action is taken to compensate for the increase in impermeable surfaces, it will be necessary to construct a storage volume of more than 100 000 m³ over the next ten years. In addition, treating storm water considerably increases the operating costs of water treatment managers.

The proper management of urban runoff in new urbanisation zones is now indispensable (source control, compensate the effects of impermeability, delimitation of zones where impermeabilisation has to be controlled ...).

2.3 The spreading of waste water from combined sewerage systems and its consequences

These sewage fields functioned since 1875 on a surface of 5000 ha of crop farming. Increasingly stringent regulations and the development of analytical means led to this technique of treating raw water to be abandoned in 1999.

In fact, analyses of soil samples in 1997 and later in grown vegetables (thyme) revealed the pollution present in certain plots of land. It is estimated that 10 000 tonnes of metals have accumulated on the 890 hectares of the Plaine de Pierrelaye.

For want of not being able to continue to use raw waste water, continued irrigation with treated water is recommended. Market gardening was replaced by single crop maize farming (on a surface of 600 ha). Since maize grains do not accumulate metal trace elements, no market restrictions got in the way of their commercialisation.

An outbreak of chrysomelids, insects that are destructive to maize, was detected in the summer of 2004 and the application of preventive methods aimed at restricting the development of this new pest has led to a reduction in single crop maize farming. Faced with this situation, the political authorities have decided to carry out a study of the possibilities and the conditions for producing non-food crops (for energy, textile, ornamental or biomaterials).

2.3 What is the future of sludge from waste water treatment plants?

The SIAAP currently produces 270 000 T of sludge, and is the biggest producer of sludge in France. Depending on the type of treatment employed and the sites, the methods currently used for disposing of this sludge are: re-use for agricultural purposes (50% of dry solids), specific incineration (30%) and storage in special waste landfill sites.

Over the last few years, these traditional disposal methods have run into difficulties. Storage in special landfill sites that are only designed for ultimate wastes is going to be restricted in the near future. In addition, this route is only of limited interest within the framework of a policy of sustainable development, since it rules out the possibility of waste reclamation (for example thermal reclamation). Incineration often has great difficulties being accepted on a local level (incinerators are regularly assimilated with household waste incinerators). Reuse for agricultural purposes is the most natural and the most ecological means of disposal and, in this respect, it is considered by the *Ministère de l'Ecologie et du Développement Durable* (French Ministry for Ecology and Sustainable Development) as a means for the future. However, in the context of the greater Paris area, some recent difficulties have called its perenniality into question (regulatory status of waste, farming and food processing industry rocked by recent scandals, etc.). These are major difficulties for the S.I.A.A.P given the extent of sludge spreading (40 000 ha).

Managers of waste water treatment plants therefore find themselves faced with some worrying problems: constantly increasing production of sludge, the consequence of a more and more efficient treatment of waste water and the treatment of waste water in periods of heavy rainfall with a partial rejection of traditional evacuation methods.

Consequently, it is necessary to seek new avenues of thought that take into account the challenges of sustainable development. In this framework, re-use for farming purposes could become sustainable with the abandonment of a "waste" logic and the accession of a "product" logic, which implies the implementation of new sludge treatment techniques.

For this reason, the S.I.A.A.P has opted for thermal drying as the processing step before reclamation within the scope of the extension of the new plants plants.

CONCLUSIONS: the benefits of sewerage treatment in the greater Paris area

The first benefit of the development of the sewerage system of the greater Paris area has been the disappearance of water-borne diseases. For example, 18 400 people died in the cholera epidemic of 1832. This was followed by numerous other typhus and cholera epidemics: 1849, 1854 and 1865. The last major cholera epidemic occurred in 1892 and now such epidemics have disappeared within the area.

The second benefit of improved sanitation has been to allow a fundamental use for water, namely the production of drinking water. Thanks to the sewage treatment system, the waters of the Seine and the Marne, which are the two rivers that cross the greater Paris area, are of sufficient quality to allow the production of drinking water. In fact, surface water intended for the production of drinking water must meet very precise quality requirements in accordance with the European Directive (98/83/CE), re-transcribed in the French code of public health. Two thirds of the volume (i.e. 1 million m³/d) of drinking water produced for the greater Paris area comes from river water treated in drinking water production plants.

The constant efforts of local authorities and industry, financially supported by the Seine Normandy Water Agency, demonstrate another benefit of improved sewage management: restoring the quality of river water. In 1880, Dr. Bourneville, who was making his way to Clichy, (the place where the Parisian sewerage network discharged in dry weather without any treatment) described a Dantesque landscape: "a continual fermentation during the summer, which causes the water of the river to bubble, causing refuse to rise from the bed to the surface and releasing marsh gas in the form of enormous bubbles, sometimes attaining a diameter of one meter". Nowadays, after a long pursuit race, all of the waste water in dry weather from the greater Paris area is treated and the concrete results of this may be seen. For example, monitoring of ammonium concentrations in Paris by means of continuous measurements shows that the Seine is of very good quality (<0.5 mg/l) 100% of the time. This concentration in Paris has dropped by a factor of 10 over the last fifteen years. This progress is very important because ammonium, which is a characteristic pollutant in urban effluent, is the source of nitrites that are toxic for fish and its consumption by river bacteria cuts the oxygen level, which is indispensable to aquatic life. This improvement has been obtained by installing waste water treatment plants upstream of the capital.



Paris, September 2001, the 48th World Fishing Championship



Recreational uses of water

The benefits of improved sewage treatment are also felt well downstream of the greater Paris area. Sizeable algal blooms develop, particularly in estuaries and fjords, coastal areas on the eastern side of the North Sea, the Wadden Sea and to the east of the Skagerrak. These algal blooms are due to the significant input of nutrients, which come in particular from the Seine. In fact, with regard to nitrogen containing pollutants, the different communities within the greater Paris area contribute between 20 and 40 % of the annual amount flowing into the North Sea. As for phosphorous, the same communities account for around 70 % of the amount discharged into the North Sea. In the Oslo - Paris Convention (1988), France committed itself

to cutting nutrient discharges into the North Sea by 50%. This objective has already been attained for phosphorous but efforts still have to be made for nitrogen. Improvements have already been observed in the North Sea.

Improved sewage treatment has also enabled water quality compatible with recreational uses governed by the European Directive 2002/0254 to be obtained. Recreational use firstly comprises activities that are in indirect contact with the water: pleasure boating and angling. In the 1960s, there were 3 species of fish in the river Seine. The physical and chemical quality of the water and the very abrupt de-oxygenations due to discharges in periods of heavy rain led to considerable fish mortality (500 T in 1992 for example). The efforts that have been made in terms of waste water treatment have meant that, today, 29 species of fish are present in the greater Paris area. In September 2001, the 48th World Fishing Championship took place, with 40 participating countries. The second type of recreational use concerns activities that are in direct contact with the water: swimming, wind surfing, canoeing, water skiing, etc. The quality of the Seine water in the greater Paris area is not compatible with the standards in force. Although the water of the Seine and the Marne in particular upstream of Paris are periodically "fit for swimming", the threshold limit is only complied with 30% of the time as regards the bacteriological quality. Storm water discharges arising from run off from urban surfaces and overflows of sewage networks are very important factors in the degradation of the microbiological quality.

In terms of benefits, the progress that has been made is already considerable. In 1970 only 25% of the waste waters were treated during dry weather. The totality of waste waters is now treated. Though, new challenges now need to be faced. These challenges concern the efficient management of storm water and the improvement of water treatment performance. The water treatment development plan described in this communication will contribute to this. These changes fall within the scope of an ambitious and restrictive European legislative framework: attaining a good ecological potential for the Seine in 2015. The solutions being considered call for innovation within a framework of increased awareness of the challenges raised by sustainable development.