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Versailles facing the degradation of its water supply from the Seine River: governance, water quality expertise and decision making, 1852–1894

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Abstract In 1852 a new machine to provide greater volumes of Seine River water to Versailles was decided. The new Marly Machine was operated by the Versailles Water Service (VWS), a 150-year old state-owned institution supervised by state ministries, managing the water supply over a vast domain that covered 32 towns in 1903. The VWS provided financial, technical and administrative resources to the city of Versailles, but the city council had no word in decision-making. Soon after the installation of the Machine in 1859, the city of Paris started to collect its wastewaters and discharge them untreated into the river, 16 km upstream of the Marly Machine. In 1874 the Seine River was officially declared infected by Paris sewers. The VWS reacted in 1877 by asking several French chemists, pioneers of river surveys, to assess the quality of the Versailles waters by innovative chemical approaches that had been developed on the Seine River since the Boudet ammonia river profile in 1861. In 1874 Gérardin's oximetric profiles revealed the severe depletion of oxygen in the Seine at Marly in the summer, explaining the fish kills. This degradation of Versailles water intake in the Seine River mobilized local, regional and national actors over the coming 20 years. Finally, the VWS was forced to gradually use (1880–1895) groundwater to supply the Marly Machine. In 1892, another new water quality criterion was considered, the bacteriological survey, and in 1894 the Seine River water was completely excluded as a water source, ending a multidecadal debate in which scientific expertise played a prominent role.

Keywords Water supply · Versailles · Marly Machine · Seine River · Water quality analysis

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Introduction

« Sans jeu de mots, il s'agit bien des eaux de Versailles; non des grandes eaux, bien entendu – ceci ne nous regarde pas, mais de celles qui servent à l'alimentation des habitants de la ville royale par excellence, aujourd'hui siège du gouvernement républicain. Les appeler potables, pour les distinguer, eût été faire mentir cet adjectif, car ces eaux de Seine ne le sont réellement plus; ce sont des eaux impures, insalubres, malfaisantes, délétères au premier chef. La situation est donc des plus graves aujourd'hui que le premier magistrat de la République, son gouvernement et tous nos honorables sont à l'usage de cette eau » (La Santé Publique 1873)

"No pun intended, we are speaking of Versailles water; not the fountain water shows […] but about drinking water for the dwellers of this royal city par excellence, which is today the seat of the republican government. To call it drinking water, to distinguish it from the water of the royal park, would belie this adjective, because the Seine water can no longer be honestly called drinking water; it is unclean, unhealthy, nefarious and primarily harmful water. Consequently, the situation is of utmost gravity today, given that the first magistrate of the Republic, its government and all our honorable citizens are using this water" (La Santé Publique 1873)

During the nineteenth century in France, cities' demand for water rose considerably, due to urban growth, the development of hygiene measures (Goubert 1986) and the increase in per capita water use: the quantity of water supplied to Versailles was multiplied by more than 10 between 1804 and 1900, while the population only doubled. Polluted wastewater was often discharged into rivers with no prior treatment, leading to their progressive degradation during the second half of the century despite attempts to reduce this degradation (Barles 1999; Bellanger 2010; Frioux 2013). Paris urban development and its impact on infection of the Seine water, the "metabolic interaction between Paris and the Seine" (Barles 2007, p. 1757), has already been the subject of several studies (Barles 1999, 2007; Barles et al. 2016; Barles and Guillerme 2014; Deutsch and Gautheron 2013; Lestel and Carré 2017). It is much less well known that Versailles, the world-famous former capital of France and the king's residence, was also impacted by the Seine's pollution because this river supplied the city with drinking water by the means of the Marly Machine (Soullard 2011; Siaud 2012; Quenet 2015), which was renovated in 1859. Meanwhile, Paris was constructing large sewer collectors discharging untreated wastewater directly into the river, thus extending the Seine's pollution downstream of the capital over dozens of kilometers. The state-owned Versailles Water Service (VWS), a specific institution, rooted in the Ancien Régime, was the main actor managing the delivery of safe drinking water to the royal city and its suburbs. Local (the city of Versailles) and regional institutions (Hygiene Board) were the other stakeholders. The VWS was finally forced to shift from its river water intake to groundwater wells, then to definitively stop its intake of Seine River water in 1894, nearly 200 years after its beginning.

The history of water supply and sanitation has been explored in detail by scholars such as Martin Melosi (1990), Theodore Steinberg (1991) and Joël Tarr (2002) for the United States, Nicholas Goddard (1996) for Great Britain, Simone Neri Serneri (2002) for Italy and Sabine Barles for France (2005). However, less is known about the role of the chemical analysis of water by scientists (Hamlin 1990), developed in the second half of the nineteenth century in Paris for the Seine (Lestel 2005; Meybeck et al. 2017), and bacteriological analyses, developed in the late 1880s, in support of sanitation policies and techniques. Paris was a pioneer in that matter for France, and Versailles, with a much smaller population, closely followed the capital. The aim of this paper is to address two

issues: (1) the history of local water management and its complexity and (2) the water quality expertise in local water policy and technical choices at the local level.

The article is based on sources from different VWS archives, the Regional Hygiene Board and documents on water and sewers at the local, *département*[1] and national levels. The deliberations of both municipal and *département* councils were specifically scrutinized. The technical or hygiene periodicals in which the members of administrative and scientific institutions published, such as the *Annales d'hygiène publique et de médecine légale*, were also consulted.

After having presented the specificity of Versailles and its waters supply in the second half of the nineteenth century, largely inherited from the chateau's construction period, we detail the complex Versailles Water Service (VWS), a state-owned institution, unique in France, and its relation with other actors from the local to national levels. We then address how the VWS met the increasing water demand, first by the renovation of the Marly Machine in 1852–1859, then by shifting from a river water supply at Marly to groundwaters, in 1880–1895. Finally, we develop how the chemical and bacteriological analyses of Versailles waters made by experts played a prominent role in the decision-making process. These historical analyses are reworked with contemporary tools and/or references, as developed in earlier studies on water use and water quality from the nineteenth to the twenty-first centuries (Lestel and Carré 2017; Meybeck and Lestel 2017).

Versailles' specificity and its water supply

Versailles, the former royal city

Versailles had a specific status among French cities. The city had many facets: the chateau with its gardens (8 km^2); the city around it (26 km^2); the prefecture of the former Seine-et-Oise *département* bordering the Seine *département* on the west (including Paris)[2]; the capital of France: from 1682 to 1715, when Louis XIV made his residence there, from 1722 to the 1789 Revolution, when the royal family stayed in the chateau, and from 1871 to 1879, when the government's major institutions were located there during and after the Paris Commune.

After the 1789 Revolution, the city was transformed into a holiday and tourist resort. It was famous for its large wooded streets, its fresh air, its alleged immunity to epidemics and the exceptional longevity of its dwellers (Rabot 1882, p. 4). The Versailles population was mostly composed of landlords and wealthy people, rose from 27,574 in 1800 to 35,367 in 1851, and continued growing to reach the maximum of 61,686 inhabitants in 1872, following the events of the Paris Commune. At the end of the nineteenth century, the number of city dwellers had stabilized at around 55,000 (Fig. 1). Versailles had no major industries that would have disrupted its harmony: the census of polluting industries made in 1875 listed 182 small enterprises among which 83 laundries.[3]

[1] In the administrative divisions of France, the *département* is one of the levels of government between the national level and the town.

[2] These two departments were reorganized in 1968 into the smaller *départements* Yvelines and Paris and the creation of five new *départements.*

[3] The *department* archives of Yvelines, 7 M 98: *The state of unsanitary, inconvenient or dangerous industries in the city of Versailles in 1875.*

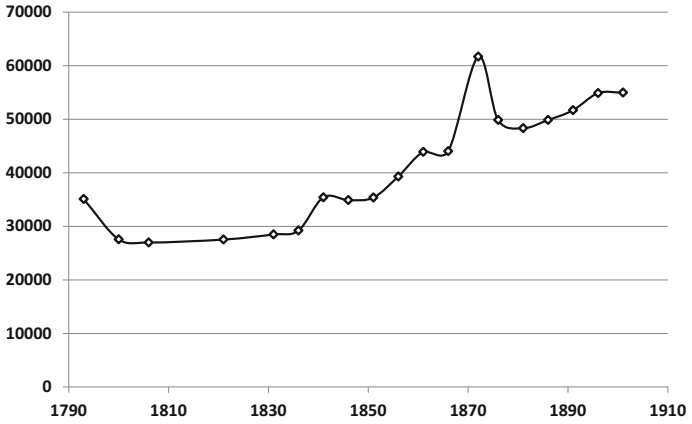

Fig. 1 Versailles population, 1793–1901 (Statistics on the population of Versailles, yearbook of Versailles City Hall, 2016)

The Ponds and Marly waters

Before the construction of the chateau by decision of King Louis XIV in the seventeenth century, there were very few water resources on the Versailles plateau, about 100 m above the Seine River valley, between the headwaters of the Bièvre River on the east side and those of the Mauldre River, on its west side, respectively upstream and downstream tributaries of the Seine (see their schematic positions in Fig. 2a). The chateau was built exactly on the headwaters of a small catchment, the Ru de Gally, a tributary of the Mauldre River.

Since its establishment, Versailles had been subjected to an extraordinary water demand for the royal city, the gardens and their magnificent fountain shows. The royal residence had to generate its own water supplies through two remarkable hydraulic systems, the Ponds water (*Eaux des Étangs*) and the Marly Machine, the famous hydraulic structure located on the Seine River, 16 km downstream of Paris, along the meanders (Evrard 1935; Dauphin 2004) (Fig. 2b). With these major water works Versailles quickly became a kind of "hydraulic laboratory" for all kinds of water supply projects (Dollfus 1918, p. 97).

Water from the Ponds, termed white waters ("*eaux blanches*"), was first used to supply the gardens and the garrison horses in water, but could also replace the Seine waters when they could not be supplied if the river froze, for example, which occurred for up to 3 months in the colder climate of that period (Barbet 1907). Before the mid-nineteenth century, the Ponds water was considered lesser quality than the Seine River water at that time, due to its fine particle content, eroded from local soils, probably clays, therefore their name. In the late seventeenth century, the original hydrological features of the plateau had been modified over a total area of 150 km^2 equipped with eight major ponds divided into the Upper Ponds and the Lower Ponds (see their position further in Fig. 4), acting as reservoirs, totaling 6.85 km^2 and a nominal capacity of 8 million m^3 (Gavin 1892). The actual water supply generated by the Ponds has gradually decreased since the eighteenth century: some of them began to be cultivated, but the pond system is still in operation today and is used for watering the chateau gardens and supplying its fountains.

The impressive hydraulic Marly Machine and its related water supply network were built in 1680–1686. The giant hydraulic mechanism, an engineering marvel of the time,

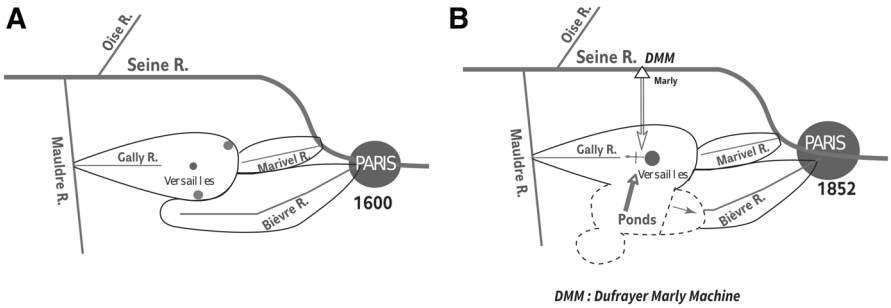

Fig. 2 **a** Schematic position of the initial hydrology of the Versailles plateau at the pre-royal period (1600) on three hydrological basins. Rivers are represented with their basin limits. **b** The Versailles water supplies in 1852 with their hydrological impacts and interactions. The hydrological limits of the Gally basin are expanded by the Ponds system. *DMM* Dufrayer Marly Machine

was located at Bougival on the left bank of the Seine about 16 km downstream from the northwestern limits of Paris (Fig. 2b). It was used for the drinking water supply of Versailles only after 1758, because private wells had become polluted and caused epidemics (Siaud 2012).

During the First Empire, Versailles was not favored by Napoléon I, who preferred Fontainebleau for his residence, and the Marly Machine deteriorated, reaching a minimal yield of 600 m^3 per day in 1804 (Barbet 1907). After 1816 several renovations were attempted, the original hydraulic machine was replaced, but never lifted more than 1000–1500 m^3/day between 1830 and 1855 (for volumes delivered by the Marly Machine during the nineteenth century, see Fig. 8).

Both the Ponds waters and the Marly Machine waters had their own sets of reservoirs, canals and pipes, converging to a third set, the Versailles reservoirs (Fig. 3). The Marly waters were first stored in a set of three reservoirs, the Deux-Portes reservoirs. From there they went to the Louveciennes aqueduct, followed by an underground aqueduct, 6.3 km

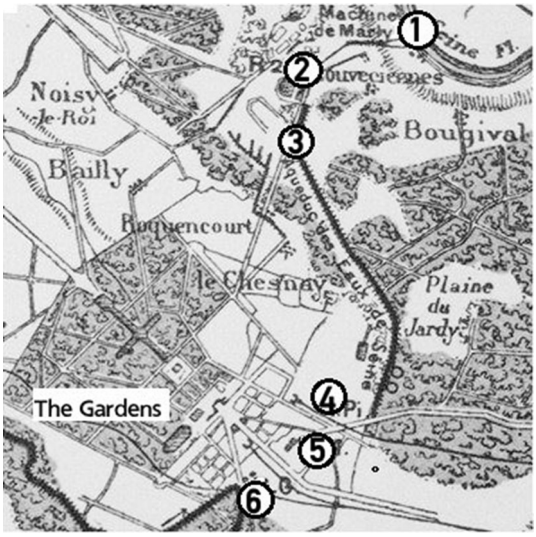

Fig. 3 The Marly water system from the Seine River to Versailles: *1* the Marly Machine on the Seine and the groundwater wells (after 1892), *2* Deux-Portes reservoirs, *3* the Seine water aqueduct, *4* Picardie reservoir, *5* Montbauron reservoirs, *6* Gobert reservoirs (Lacour and Gavin 1896)

long and 10 m deep (Gavin 1892), and were stored in the Versailles reservoirs: Picardie, Montbauron and Gobert. The Picardie reservoir (13,000 m^3; Lacour and Gavin 1896), was only filled with Marly water while the two Montbauron reservoirs (116,000 m^3) received both Marly and Ponds waters. The two Gobert reservoirs (45,000 m^3) were only connected to the Ponds. The underground pipelines of the two systems totaled 54.4 km. It was then a mix of Seine water and Ponds water that finally came out of the taps.

The Versailles Water Service, a hydra with three heads

A unique governance

The VWS was initially created to supply the Chateau of Versailles, its gardens and fountain displays. Since its beginning in 1685, it also included three other royal residences and hunting grounds: Marly, Meudon and Saint-Cloud. It was nationalized after the 1789 Revolution by the law of 1794, May the 5th, and declared an integral part of the inalienable and imprescriptible domain owned by the state. Under the Second Empire (1852–1870), the water service was inscribed on the civil list[4] and directly assigned to the Ministry of the Emperor's House and Fine Arts (Report of the commission 1892[5]).

The water service was gradually extended to supply other suburban communities, west of Paris, also deprived of important natural water courses and/or exposed to frequent droughts, contamination of private wells and epidemics.). At the beginning of the nineteenth century, the population of Versailles accounted for 85% of the population served by the water service, and by the end of the century this figure dropped to less than 50%, since the VWS provided water to 32 nearby cities and towns[6] (Fig. 4), covering a territory of 230 km^2 and totaling about 133,000 inhabitants (1901 census). It had to manage and maintain 856 ha of ponds and lakes scattered over a 15-km^2 area, 158 km of pipes, canals and aqueducts, and half a dozen major reservoirs.

The governance of the state-owned VWS was complex (Fig. 5). It was managed by the Ministry of Fine Arts, but other ministries such as the Ministry of Public Works or the Ministry of Agriculture could interfere in water service management to address bureaucratic, financial or engineering issues. For this reason, the Versailles water service was called sometimes "a hydra with three heads" (Le Matin 1905).

The water service directors were often engineers, as was Xavier Dufrayer, who spent his entire career in the service, and François Victor Oscar Grille (1880–1883) and Edmond Honoré Berthet, both from the Ponts et Chaussées School. VWS headquarters were in Versailles and different inspectorates and sections were created at the local level for management and operation purposes: construction, repair and maintenance work for water

[4] A civil list is a list of State properties.

[5] The département archives of Yvelines, 2Q non coté 10 et 11.

[6] In 1870, the VWS supplied water to 13 cities in the Seine-et-Oise *département*. The cities of Saint-Cloud, Ville-d'Avray, la Celle-Saint-Cloud, Garches, Marnes and Sèvres were connected in between 1859 and 1860. In 1903, 32 cities depended on Versailles State-owned water service: Versailles, Marly, Meudon, Saint-Cloud, Le Chesnay, Rocquencourt, Buc, Toussus, Villiers-le-Bâcle, Châteaufort, Guyancourt, Saint-Cyr, Trappes, Le Mesnil-Saint-Denis, Coignières, Les Essarts-le-Roi, Bougival, Port-Marly, Louveciennes, Marly-le-Roi, Bailly, Noisy-le-Roi, La Celle-Saint-Cloud, Rueil, Vaucresson, Garches, Marnes, Ville-d'Avray, Sèvres, Viroflay, Clamart and Vélizy. Chaville, using local springs, was not connected to the VWS network. In 1980 the VWS was finally split into two entities: for the first time in three centuries the drinking water supply (Société des Eaux de Versailles et de Saint-Cloud (SEVESC) was separated from the Gardens water supply (Service des fontaines de Versailles).

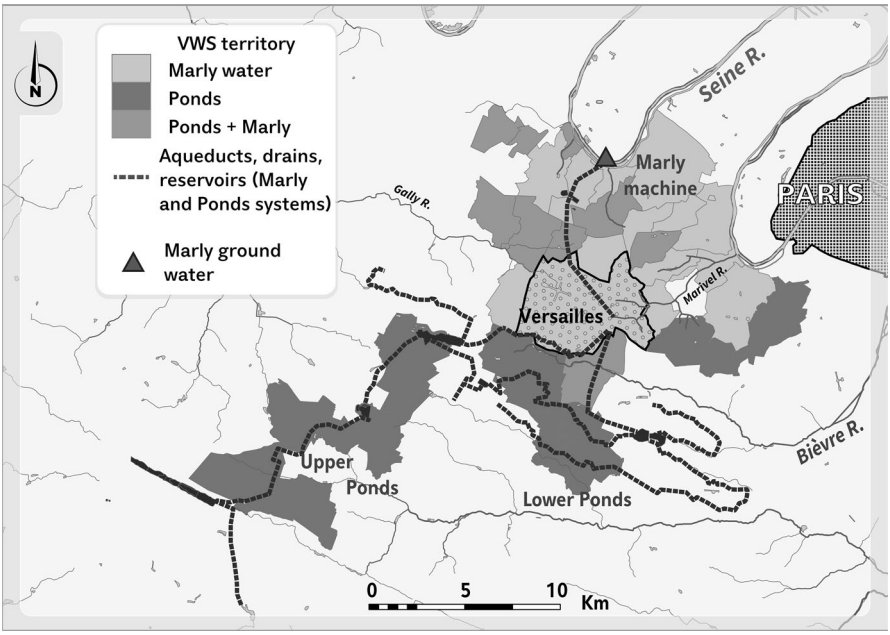

Fig. 4 Territories of the 32 municipalities supplied by the Versailles Water Service at the end of the nineteenth century (data from Imbeaux 1903)

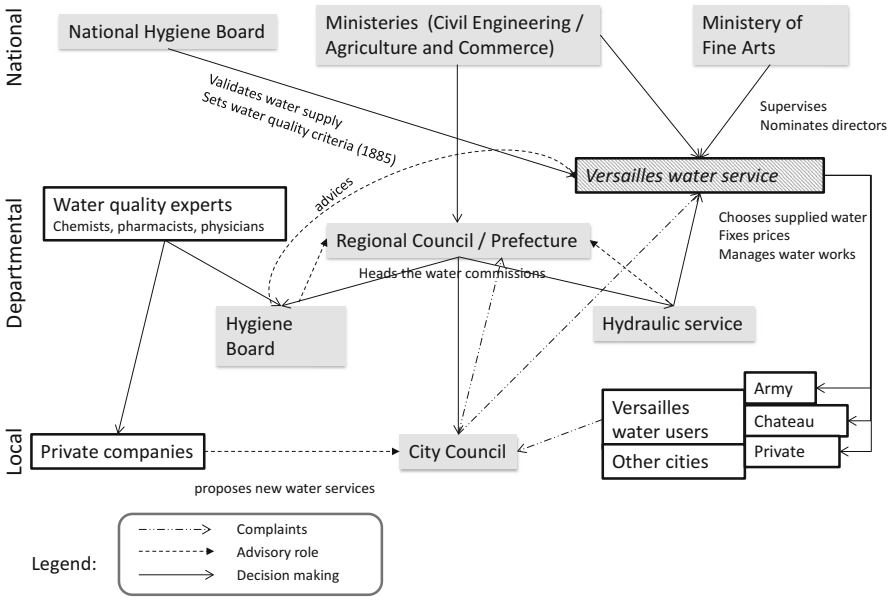

Fig. 5 Place of the Versailles water service VWS among different actors at local, regional and national levels, and their interactions

abstraction and distribution. Inspectors, designated at the head of each section by the water service director with ministerial approval, managed their team of assistants, workshop foremen, fountain keepers, workers and water guards. The Ponts et Chaussées chief engineers were not always efficient managers, as we can see with the example of Edmond Honoré Berthet. Assigned to the service at the end of 1890 in a water shortage period, he negotiated an expensive project for water filtration, finally refused, and took vacations in Asia Minor in spring 1894, a critical period in Versailles water supply, when ponds were dry and the Marly Machine lifted only some 3000 m^3/day of water.[7] The decisions were then made by water service inspectors. These inspectors have always played a very important role in the day-to-day service management, such as Maximilien Gavin, who spent his entire 40-year career in the service "without a day of vacation or sick leave",[8] or Douchain, who elaborated the project for taking water from the Marly-Croissy aquifer that completely cut the Seine's polluted water from the distribution in 1894.

The main interlocutor of the VWS at the local scale was the Seine-et-Oise prefecture, and two of its services: the Health Board and the Hydraulic Service. It had no administrative links with the Versailles town councils, nor with any of the other surrounding towns' councils. It therefore contrasted with the city-owned water service of Paris and with privately-owned services (Compagnie Générale des Eaux, Société Lyonnaise des Eaux), which equipped other Paris suburban cities at the time, which were also trying to obtain the Versailles water concession. Some argued that the VWS, by supplying public services and private concessions, had deviated from its initial goal, i.e., to serve royal, imperial or national residences and chateaus, and that the public water supply should be managed by municipalities. However, this had no effect: the service remained with its specific administrative structure, directly placed under the authority of the state.

During the nineteenth century (and after), solutions for urgent problems very often led to the creation of various commissions, at the local, regional or national levels and their combinations. The Versailles waters ad hoc commissions were established at the highest state level, including both representatives of scientific and administrative domains, and were chaired by the Seine-et-Oise prefect. A number of examples of water commissions can be given: in 1852, it discussed the installation of the new Marly Machine; in 1860, it examined the possibility of removing the Versailles Ponds from the water service, in 1874, it reviewed water concession prices, and in 1892 it ended the river water intake at Marly. The municipality was generally only an observer at these commissions. In contrast, municipal water commissions, much less efficient, discussed very local matters: a fountain installation, the choice of a filter for public fountains or extension of water pipes.

The quality of the water distributed by the VWS was controlled by the departmental and national Hygiene Boards, as for other water distribution institutions in France. The Versailles water users filed their complaints directly with the municipality, which in turn forwarded them to the Seine-et-Oise prefect and the VWS.

A difficult budget balance

The VWS found it difficult to balance its budget. In the 1850s, many water concessions were still free or proposed at reduced prices, particularly for the Versailles municipal services or certain privileged bourgeois. In 1874, a ministerial commission was established to ensure that the water service revenues exceeded its expenses. Thus, the commission

[7] The French National Archives: F/21/2877.

[8] The French National Archives: F/8/205.

Table 1 Free and paid water delivered to the Versailles inner city and its outskirts in 1880 (Gérardin et al. 1882, p. 64)

Free water	m^3/year
Chateau, parks and gardens	340,054
Fountain displays	80,000
Military garrisons	96,680
City of Versailles (free supply)	379,149
Total	895,883
Paid water	
Concessions (at 0.27 F/m^3)	745,532
City of Versailles (reduced price 0.15 F/m^3)	107,066
Private (reduced price)	27,740
National road maintenance	16,000
Total	896,338
Overall total	1,792,221

reduced the number of free concessions, including Versailles public services, which caused the indignation of the Versailles Town Council, and priced all VWS waters (the Ponds and the Marly Machine) at the same level as water distributed in Paris: 0.27 F/m^3 (Cebron de L'Isle 1991, p. 376), with a few exceptions and reductions depending on water quantities and personal status (Table 1). Half of the water volumes distributed by the VWS were given for free to Versailles, the city, the chateau and gardens, and to the garrison.

Consequently, from about 150,000 F/year in 1870, the water service profit increased to more than 517,000 F in 1894 (Ville de Versailles 1897, p. 23). However, the VWS budget in the Versailles water infrastructure did not progress in the same way: from 1869 to 1892 investments were consistently reduced, from 449,000 F in 1869 to 300,000 F in 1892. A special ministerial commission, established in 1892, obtained a budget increase to 350,000 F after 3 years of discussion, an indication of the difficulties the VWS experienced with its ministerial supervision (Ville de Versailles 1897, p. 23).

The complex relation between the city and the water service

It should be noted that the city of Versailles benefitted in a number of ways from state control of its water supply. In 1882, there were 379,000 m^3/year of water given for free to the city. But this quantity, even when adding 107,066 m^3/year of water paid at a reduced price, was far from sufficient to meet the city's water demand: 120 L/capita/day in the 1880s, close to the situation in Paris, around 140 L/capita/day, but in Versailles around 25% of this volume was actually dedicated to the chateau and its fountains, so the real volume available per inhabitant was closer to 90 L/capita/day.

The Versailles City Council was placed in "a purely platonic contemplation"[9] regarding its water supply and did not always appreciate the state management. It complained about poor water service, insufficient water quantities and high water prices for industry, which they believed disturbed the city's development: "Placed in a very unique position, surrounded on all sides by the royal domain, the actions one might take to try to change this abnormal situation seem to be forbidden. […] Our city, as you know, gentlemen,

[9] The Versailles City Council deliberations file 1 D 61* 1875, City of Versailles Archives.

dependent on the system that governs its water, is far from being able to enjoy it at will; our most urgent needs are not met" (Fontaine 1865, p. 4). "There is at Versailles a service that reports directly to the State and has the monopoly of the administration and distribution of drinking water in this city […]. So far this service has watched over its prerogatives with jealous care and would not allow any authority to supervise its actions and monitor its administration. What could the municipal administration do without any authority over the staff, without any right to take measures in regards with the situation?".[10]

In 1892 the possibility of state withdrawal from the VWS governance was initiated by the state itself, which did not want to be responsible for the delivery of polluted Seine water to Versailles and its surroundings[11] and, as mentioned above, its budget at that time was insufficient to fund the new water intake facilities. The state wished to put an end to its unusual position as a water supply contractor. Three alternatives were then discussed: keeping the status quo, establishing a municipal water management organization or a private management structure. In this case the new manager would have to handle an extended service, supplying more than 30 communities, a task possible for a private company such as the Compagnie générale des eaux, already marketing the Seine water in Paris since 1861 and well established in some suburbs of Paris. The Versailles City Council, certainly aware of all the difficulties of city management, preferred to depend on the state, assumed to be more compliant, rather than on private companies, assumed to be more interested in profits than in public health. In addition, at that time the City Council absolutely refused to continue using the Seine water, even when taken upstream of Paris and treated: "let us not say that water taken from the Seine at the town of Choisy [upstream of Paris] is of good quality; if it were so, the city of Paris would not go far away at great expense and despite the strongest opposition, to get its drinking water, water which it had at its doors in a river where it was easy to draw".[12] The status quo was maintained (Ville de Versailles 1897).

Facing the degraded state of the Ponds water works and of the old Marly Machine and the increasing water demand from Versailles users and from nearby towns, in 1852 the VWS started to look for greater volumes of water, particularly those lifted at Marly. Unexpectedly, it was also forced to face the degradation of the Seine River quality. These were its major concerns for over 40 years.

How can the growing water demand be met?

The second Marly Machine accelerates the water supply (1859–1880)

According to Vallès (1864), a Ponts et Chaussées chief engineer in the Seine-et-Oise *département*, at the beginning of the Second Empire in 1852, the water supplied by both systems, the Ponds and the Marly Machine, amounted to 3979 m^3/day from the Ponds to Versailles (814 to private concessions, 2000 to public institutions, 1000 to the Gardens and the Trianon Chateau, 165 to the fountain displays); 1400 m^3/day from the Marly Machine (352 to private concessions, 968 to Versailles public institutions). In addition, 80 m^3/day were supplied from the Marly Machine to the cities of Marly and Louveciennes. Versailles wastewaters were directed to the headwaters of two local streams, the Ru de Gally on the west side and the Ru de Marivel on the east side (Fig. 2b).

[10] The Versailles City Council deliberations file 1 D 74* 1891, City of Versailles Archives.

[11] See below, paragraph Bacteriological analyses.

[12] The Versailles City Council deliberations in the city Archives: 1 D 74*, 1891.

The picture completely changed during the Second Empire, resulting from the personal funding of the emperor Napoléon III, because the Marly Machine also supplied the Saint-Cloud domain, the emperor's favorite residence. In 1852 the decision to redesign and refurbish the Marly Machine was made.[13] Conducted by an engineer from the Ecole des Arts and Métiers at Châlons, Xavier-Edouard Dufrayer, the future director of the VWS, it took only 5 years to construct a brand new machine. The severe decrease in water intake from the Seine lasted only 2 years, during which the Versailles inhabitants and animals were exposed to a water shortage: during 1858, the horses of the famous Versailles garrison had to be watered twice a day at the Reservoir des Suisses, a water body in the Gardens, away from their stables (Evrard 1935; Dauphin, 2004). "At last, on October 9th, 1859, the new hydraulic machine was put into service; the great waters gushed again, a show that had not been seen for over two years" (Damien and Lagny 1980, p. 99).

This second Marly Machine[14] allowed for a stepwise increase in the water supply by the Seine River, reaching 4000 m^3/day a few years after 1862, i.e., three times more than in the 1830s and 1840s. The water supply in 1863, according to Vallès (1864), is schematized in Fig. 6. The Rocquencourt spring supplied 100 m^3/day to local fountains. The city of Saint-Cloud and its chateau received 900 m^3/day from the Marly Machine and 800 m^3/day from the Ponds. The total abstracted Seine water was 3380 m^3/day, of which 2480 m^3/day was directed to Versailles, a marked increase. The Deux-Portes reservoirs could ensure the water supply for Versailles for a little more than 2 months. During the five summer months 10,000 m^3/day were delivered from the Ponds to the headwater of the Bièvre, the industrial—and heavily polluted-river—with high water demand throughout the year, which meets the Seine River within Paris (i.e., 4000 m^3/day annually on average) (Fig. 6). The hydrological balance of the Versailles plateau could be completed by the estimation of the discharge of the Ru de Gally, the outlet of the whole system (50 L/s or 4320 m^3/day), essentially composed of wastewaters.

The new supply of Versailles with the Marly-Croissy aquifer (1880 onwards)

It is important to note that, when the Dufrayer Marly Machine was commissioned in 1852, the city of Paris had not yet started its generalized sewer collection system with its discharge to the Seine at Clichy, upstream of the Marly River intake at Bougival. At that time the chemical and bacteriological water quality criteria had not yet been defined (Lestel 2005; see also below): it is probably on the basis of organoleptic criteria that the VWS concluded that the Seine waters were convenient for distribution, after simple storage and decantation in the Deux-Portes reservoirs.

In 1874, the quality of the Seine River downstream of Paris was declared unfit for drinking, as developed in the last section of this paper, and the VWS was forced to shift from river water to groundwater, much safer but requiring new investments, in addition to those made for the Dufrayer Marly Machine, which was still used to lift water to the Marly reservoirs.

In 1879, excavation works, carried out on Bougival Island (also called Ile-de-la-Loge) by the Seine River navigation service, to establish a new lock, uncovered groundwater discharging 10,000 m^3/day (Rabot 1883, p. 100). In 1880, the first well B^1, 20 m deep, was drilled in the courtyard of the Marly Machine, on the left bank of the Seine at Marly (Fig. 7). This water was judged to be of excellent quality, but the abstracted volume did not

[13] Napoléon III donated about 2 million Francs.

[14] Dismantled in 1969.

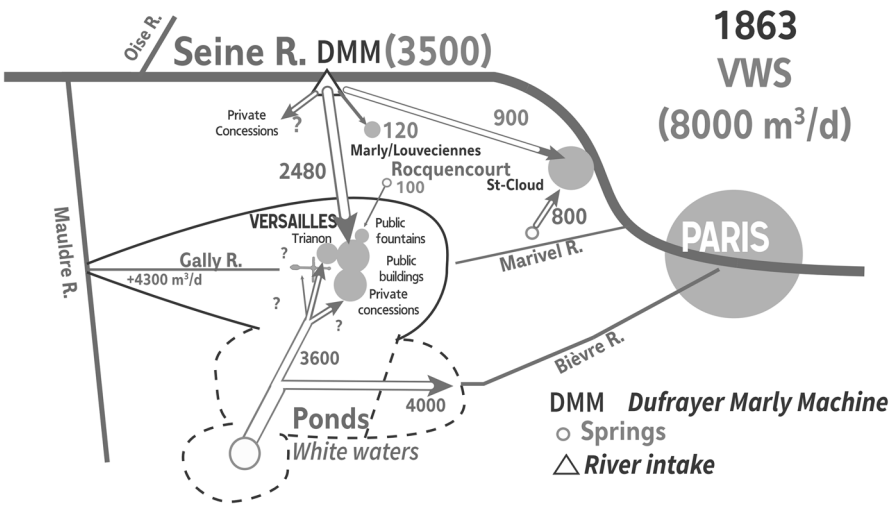

Fig. 6 Schematic representation of the average daily volumes (m^3/day) of water supplied by the VWS in 1863 by its two hydraulic systems: the Ponds and the new Marly Machine built by Dufrayer (DMM), which doubled the Marly Machine water supplied to Versailles. The outlet of the system was the Gally River, which collected all wastewaters

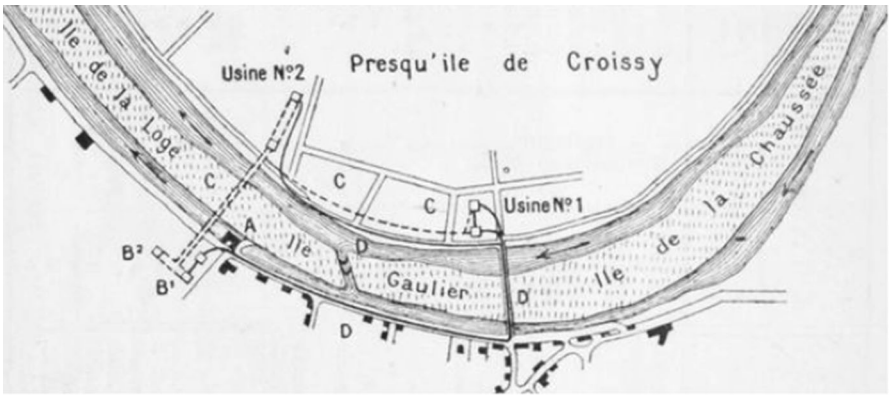

Fig. 7 The Marly waters after 1892, entirely fed by the Marly-Croissy chalk aquifer: *A* the Marly Machine, on the river bank at Bougival, *B* the Marly Machine courtyard, *B1*, *B2* left bank wells connected by a gallery, *C* an underground gallery, *D* a 4-km-long pipe conducting right bank waters from the Croissy no. 1 et no. 2 pumping facilities to the Marly Machine (Lacour and Gavin 1896)

meet expectations and in 1885 more wells (30 and 40 m deep) were drilled on both sides of the river in the so-called Marly-Croissy aquifer, in the Senonian chalk. The system of wells, on both sides of the river, was connected to and lifted by the Dufrayer Marly Machine (Fig. 6). In late 1893 when the commission recommended absolutely excluding the Seine water from the Versailles supply, the water quantity available for distribution did not meet demand: the Ponds had run dry following several years of drought. Subsequently, in 1895, two new wells (Fig. 7,C) were installed 30–40 m deep on the right bank of the Seine at Croissy. It remarkably increased the water supply to Versailles (Fig. 8).

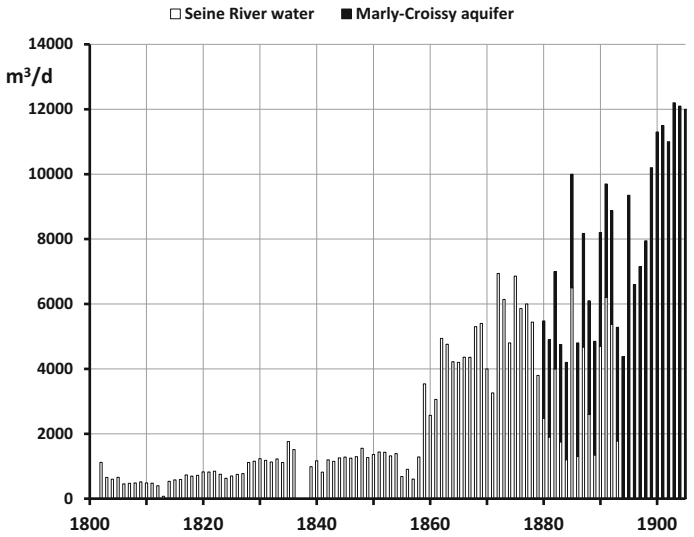

Fig. 8 Annual average water volumes (m^3/day), elevated by the Marly Machine, from the Seine River (1800–1892), then by the Marly-Croissy aquifer (1880–1906) (Barbet 1907). Key dates: *1859* first operation of the Dufrayer Marly Machine; *1874* June 8th, massive fish kills, official declaration of the Seine River infection, unfit for drinking water; *1875* May, fish kill; *1880–1885* chalk groundwater addition to the Marly Machine; *1892* major commission to resolve the Marly waters problem; *1894* definitive exclusion of Seine water from supply at Marly; *1895* two more wells at Croissy

This major shift of the VWS from a river to groundwater supply, a major expenditure only 25 years after the renovation of the Marly Machine, resulted from long debates between multiple stakeholders, the local users, the Regional Hygiene Board in charge of controlling the quality of distributed waters and the VWS.

This major technical rupture resulted from the far-reaching impact of Paris sewers on the Seine, unexpected in 1852, when the decision to change the Marly Machine was taken. The impact was gradually demonstrated from 1861 to 1892 by the development of a new scientific and technical field, water chemistry, by new actors, water quality experts.

The degrading Seine River quality at Marly and its observers

French pioneers of water quality and the Seine River

In the first half of the 19th century, the Seine River water was still considered better quality than the Ponds water and even sold at a higher price than spring water: "They swore by the Seine water at Versailles; and its quality, demonstrated by the analysis of that time, overshadowed white water and even spring water" declared one of the Versailles water service agents (Gavin 1892, p. 971). During that period Versailles was generally spared by epidemics. That alleged Versailles immunity was studied by several hygienists (Gemin 1866; Lacour 1899; Barbet 1907).

During the Second Empire the Seine River experienced major changes downstream from Paris. They resulted from the new sanitation plan proposed by Haussmann and its engineer Eugène Belgrand for Paris (Barles 1999). The main sewage collector, the

Table 2 The first water quality approaches in France: proposed indicators, experts, water qualification and threshold levels

Water quality criteria	Author (date of analyses)	Institutions	Water qualification	Indicator metrics
Hardness	Boutron and Boudet (1854) in Henry (1858)	National Hygiene Board	Pure	< 30 °F (French degree)
Organic matter	Fauré in Henry (1858)	French Academia of Medicine	Unhealthy	Organic matter < 10 mg/L
Ammonia	Poggiale (1853–1854) in Henry (1858), Boudet (1861)	National Hygiene Board	Altered	> 0.08 mg NH_3/L
Dissolved oxygen	Gérardin (1868, 1874) in Gérardin (1874)	Inspection of Insalubrious Industries	Healthy	O_2 > 7.5 mL O_2/L
Biological indicators	Gérardin (1868, 1874) in Gérardin (1874)	Inspection of Insalubrious Industries	Altered Corrupted	Biological criteria (fish, algae, molluscs)
Bacteria	Proust (1884)	School of Medicine	Pure Poor Infected	Tests on gelatin (18 days)

Asnières collector installed in 1858–1861, which combined domestic wastewater and street runoff during rain events, was discharged into the Seine at Clichy with no prior treatment (Fig. 6), 16 km upstream of the Marly Machine. Gradually the impact on the river and its fish could not go unnoticed by the riparian populations of many cities, so solutions were sought and tested. Chemical treatment of sewers was judged to be too costly, while treatment through agricultural soils in sewage farms concerned only very small volumes of sewage in the early 1870s (Barles 1999, 2007): the Seine River therefore received an increasing volume of untreated sewers. In 1873 an outburst of diarrhea cases was observed at Versailles and water analyses were requested by the City Council, carried out by the *departement* Hygiene Board by Edouard Rabot, its vice president, who sampled Versailles waters both from the Marly Machine and the Ponds. He consulted two decades of water quality analyses performed by several chemists, most of them using the Seine River for testing their new approaches and proposing water quality indicators; threshold values and related qualifications (Table 2).

The first water quality indicator, associated with a quality scale, was proposed by Boutron, a chemist and pharmacist, and Boudet, a chemist (1854). They used water hardness, expressed in French degrees (°F), also termed the hydrotimetric degree, which indicates the amount of carbonates and sulfates in water, to describe the suitability of water for various uses (e.g., cooking and laundry) and its potability (Lestel 2005; Lestel and Meybeck 2009). The water's hardness, more than 30 °F (French hardness degree) was considered "unsuitable" and the Seine River water reached the limit of "pure" water. In 1858 another chemist, Henry, published a study by Fauré, who used the measurement of organic matter by the oxygen taken from a permanganate solution.

For his assessment of Versailles waters, Rabot used the ammonia approach. It had been initiated by Poggiale, a military pharmacist (1853, 1854), then applied by Boudet in 1860 to assess the contamination of the Seine River by organic wastewater (Boudet 1861). Ammonia, which results from the transformation of urea nitrogen (albuminoid nitrogen),

an indicator of what would later be termed "organic pollution," was relatively easy to measure in very low concentrations (0.05 mgNH_3/L). Boudet sampled the Seine River upstream and downstream of Paris and generated a river ammonia profile. Then he considered the ammonia level measured at Ivry (0.08 mgNH_3/L), upstream of Paris, as a reference to define an unimpacted quality, an approach still used today by all river chemists. He used the ratio of the measured ammonia within Paris and downstream of the capital, over the reference ($R = NH_{3mes.}/NH_{3ref}$), as an indicator of the level of contamination by urban sewers: the maximum value (R = 28.7) of his indicator was found at Saint-Ouen, on the right bank, several kilometers downstream of Clichy, where the Asnières collector wastewater was injected. Based on ammonia, Rabot concluded that the Seine was permanently and increasingly contaminated by Parisian sewers at the VWS water intake. He also found that the Ponds water could be temporarily degraded following heavy rains that washed agricultural soils and organic manure.[15]

Auguste Gérardin's demonstration of the urban impact on the Seine River based on the oxygen profile

Auguste Gérardin, a chemist in charge of monitoring polluting industries of the Seine *département*, studied the effect of the organic wastewater discharged by industries on the Croult River, a small suburban tributary north of Paris, and the impact of the city of Reims on its river (Lestel and Meybeck 2009). He focused on measuring dissolved oxygen, which he greatly improved, an approach that he termed the "oximetric title," which differed from Boudet's ammonia approach. His analytical method allowed a rapid and accurate assessment of the water degradation level close to the field (Lestel 2005). He stated that the normal amount of oxygen dissolved in 1 L of water, in summer, should be 7.5 cm^3: below this quantity aquatic life could be disrupted. In his study of the Croult, he also compared the oxygen levels with aquatic biological indicators, fish, mollusks, different kinds of vegetation and the microorganisms visible under the microscope. He was therefore a precursor of the biological approach to water quality. He classified water into two types: blue water that could be kept for a long time before alteration, and green water, "dull and lusterless," easily corrupted (Barles 1999).

Gérardin used the same profile approach as Boudet and Rabot: in 1874 he took monthly oximetric measurements on the Seine over 150 km of river (Fig. 9). At each station he also measured the left and right banks and upper and lower layers. He was the first to establish the oxygen depletion profile, associated with the input of organic matter-rich wastewater, although it was demonstrated in a table, not in a figure.[16] The depletion lasted throughout the summer. Compared with contemporary criteria for the survival of the most sensitive fish (e.g., Cyprinidae), the profile shows that no fish could live over a 20-km reach. The Marly Machine intake on the Seine was indeed in the maximum impact zone of Paris sewage, despite its distance from Clichy, particularly in summer.[17]

Gérardin conducted his study at a critical state of the Seine River: during the summers of 1874 and 1875, massive fish kills were observed downstream of Paris: both newspapers

[15] The city Archives of Versailles: N3 1709.

[16] Until 1900 water quality graphics in technical reports were very rare.

[17] The minimum summer oxygen in the Seine River downstream of Paris sewer release, confirmed by annual surveys made by the Montsouris laboratory at Paris (Meybeck et al. 2017), was a permanent feature of the river; it lasted until the 1990s, until the wastewater treatment plant network was finally efficient (Meybeck et al. 2016).

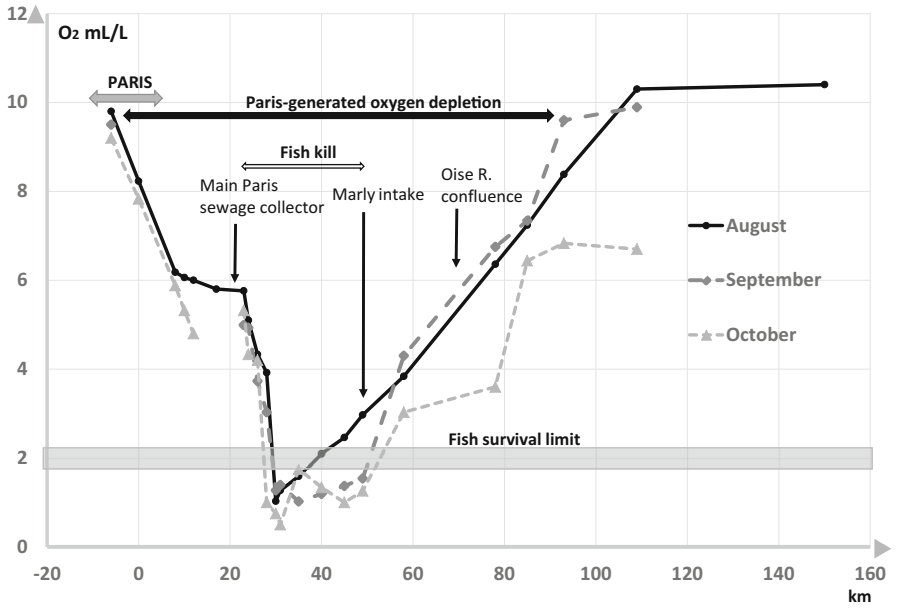

Fig. 9 Longitudinal profiles (x-axis in km, downstream of Paris center) of dissolved oxygen (mL/L) performed by Gérardin on the Seine River in summer 1874, downstream of Paris. Averages of several measurements at each location, left bank and right bank. The Marly Machine water intake was at the end of the zone of maximum degradation of the river quality, bordering the fish kill zone generated by the release of untreated Paris main sewage collectors, some 16 km upstream

and individuals sent complaints to municipalities and prefectures, denouncing the dangers of the situation: "if the fish themselves could complain, they would certainly, as many fish on the river bank were found suffocating" (Figuier 1873–1877, p. 144). The "infection of the Seine River" was officially declared in 1874 by the ministry of Public Works commission in a report published in the *Journal Official*, which meant that this water should no longer be used for drinking.[18] But Gérardin's oximetry was not much used by the authorities, which considered organic nitrogen and total nitrogen (mainly ammonia) as the main indicators of impacts, and dissolved oxygen only as a complementary indicator.

Xavier Dufrayer, the VWS director, expressed a concern about the water quality at Marly before the fish kills, as he wrote to the Versailles mayor on May 2nd, 1873: "Until now our greatest concern was the shortage of water; today we are forced to drop this thesis and to deal with water quality." In 1874, the VWS had to react but was without analytical facilities and trained chemists to perform and interpret water chemical analyses. Therefore, Dufrayer turned to Gérardin to assess the Versailles water quality. This took place in March 1877 in the presence of Dufrayer: Gérardin carried out the oximetry and microscopic analyses (microalgae and other benthic organisms) of the Marly Machine water intake, which proved its alteration, with dissolved oxygen quantities dropping to as low as 0.6 cm^3/L.[19] Meanwhile, he also undertook chemical analyses of the Ponds water at the request of the *département* administration. These waters were proven to be poor quality and he recommended their exclusion from the urban water supply. The decision was

[18] *Journal officiel de la République française*, 10 Avril 1875, N° 98, pp. 2583–2588.

[19] The Yvelines Archives: 2Q non coté 45 Gérardin's water analyses in Versailles, 1876–1877.

officially taken only four decades later in 1923: after this date it was assigned only to the Gardens and fountains.[20]

Other chemical assessments of Versailles' water quality

Following Gérardin's expertise, Maximilien Gavin, a major inspector in the Versailles water service, who also proved to be a sharp observer, between 1879 and 1880 measured the dissolved oxygen several times a month using Gérardin's method and reported it to the Parisian chemist (Gérardin et al. 1882). From June to August 1880, the oximetry of the Seine was again measured between 0.6 and 2 mL O_2/L, a confirmation of Gérardin's observation. The state of the Seine's water quality, long described by its users and the riparian population as disastrous, especially in summer, was at last monitored and scientifically quantified year after year, using a standard tested methodology, supervised by a well-recognized scientist.

Gavin also took oximetry measurements in the Versailles reservoirs (see location in Fig. 3) in August 1880, demonstrating that the oxygen level balance, measured between 0.6 and 2 mg O_2/L in the river, was fully restored in the reservoirs (7.3–9.2 mg O_2/L), where water was stored for a few weeks. He maintained that this increase was due to "the beneficial impact of vegetation, wind, sun and water movement" (and probably by the settling of the organic-rich particles in reservoirs). Gavin also noted that oxygen was increasing due to algal production: "the oxygen level has risen a great deal influenced by green vegetation activated by heat and especially by light; an excess of oxygen then occurs, which remains in solution in water" (Gérardin et al. 1882). This was one of the first mention of the correlation between the primary production of aquatic systems and the oxygen balance. He even considered the opening of a hydrologic observatory, which could become "the starting point for important discoveries, for example, improving water quality by ameliorative microscopic cultures such as *Zygogonium*, *Oscillaria*, etc." (Gérardin et al. 1882).

The water storage in reservoirs improved the water quality, as shown by oximetry. Despite this demonstrated improvement in water quality, the city of Versailles and other towns were not convinced and refused to continue drinking the Seine water, pushing the VWS to look for substitute water sources such as groundwater, but their quality and relation with the river had to be determined.

This required the water chemists to immediately study the groundwater quality and the possible connection between the infected Seine River and the wells drilled in the Croissy-Marly chalk aquifer (See well locations in Fig. 3). Samples of this new water were subjected to serious and detailed analyses by specialists such as Rabot, Gérardin, Dr. Remilly, a physician at the Versailles Hospital, and Gavin, who provided chemical analyses. They approved the new intake for public supply and wrote that its composition was as good as that of the water that feeds most big cities (Rabot 1882). The analyses were made public, to calm the local population and the numerous tourists who were visiting Versailles at that time.

In 1884 the hardness analyses were used as a tracer of the connection between the river and the aquifer, by Rabot, Durand-Claye, a prominent engineer at the Paris water works and Gérardin, in the presence of Dr. Remilly, Gavin and Vazou, another VWS inspector in charge of the Marly Machine. In this collective field study, Gérardin measured 30 °F (French hardness degree) in the Marly aquifer, Durand-Claye 49 °F, a level also found in

[20] The city Archives of Versailles: N3 5122.

local springs on the Marly slope, and Rabot 34 °F, the mean of several analyses.[21] The difference in the results was due, according to Gérardin, to the fact that his colleagues did not manage to have water only from the Marly aquifer but measured waters mixed with those feeding the springs from the Marly hillside. Confident in his results, Gérardin reported to the Versailles mayor that the difference between the Seine water (18–20 °F) and the Marly aquifer (30 °F) was compelling proof of the different origins of the two waters and the absence of any infiltration of the river into the abstracted groundwater. Contrary to Rabot's opinion, who considered the Marly-Croissy aquifer limited to the towns of Croissy, Le Vésinet, Bougival and Marly, Gérardin proved its extension over the entire Seine valley, as established on Delesse's hydrological map.[22] He explained that the Marly aquifer water was absolutely drinkable, because its hardness would be eventually diminished by passage through the canalization and air exposure in the Picardie reservoir (see Fig. 3), and he predicted the hardness in the distributed water would range between 24 °F maximum and 19 °F minimum, therefore meeting the water quality requirement of 30 °F[23] (see Table 2). For Gérardin and other experts, the Marly aquifer water was perfectly clean, comparable to the water of the Vanne and Dhuis, two major groundwater supplies going to Paris (Lacour and Gavin 1896) and to the water that feeds most major cities (Rabot 1882).

Hardness did not demonstrate an impact from Paris sewers, in contrast to ammonia and oximetry. In 1885 the National Hygiene Board issued the first official multi-criteria quality grid for distributed waters with six indicators[24] (Pouchet 1885), which applied to all distributed waters (Lestel 2005). The grid was not quite appropriate to assess the urban impacts on a river because it omitted the most sensitive chemical indicators of this contamination: ammonia and dissolved oxygen. It also omitted the new indicator developed by Proust, a physician (1884), bacterial counts, directly related to fecal contamination. The river was still used at Marly (see earlier Fig. 8), but not for long because the new water quality approach would soon be applied.

Bacteriological analyses definitively invalidate the Seine River for the Versailles water supply (1892–1894)

The decision to close the river water intake at Marly was finally taken by the 1892 commission. Established in August 1892 by the Minister of Public Works under the chairmanship of the Seine-et-Oise prefect, it brought together both national experts, such as Georges Bechmann, chief engineer of Ponts et Chaussées and chief of the Paris sanitation service, Gabriel Pouchet, director of the reference analytical laboratory at the National Public Hygiene Board, and those from Versailles, Edmond Honoré Berthet, chief engineer of Ponts et Chaussées and the VWS director, Douchain, senior inspector, and Edouard Rabot, vice president of the Seine-et-Oise Hygiene Board, to name just a few. It should be noted that the municipal administration was not part of this commission, but was encouraged to report any issue of particular interest to the city of Versailles.[25]

[21] The city Archives of Versailles: N3 1710.

[22] Achille Delesse (1817–1881) was a famous French geologist and mineralogist.

[23] The city Archives of Versailles: N3 1710.

[24] Chloride, sulfuric acid, organic matter, weight loss, two indicators of hardness.

[25] The Yvelines Archives: 2Q non-coté 10 and 2Q non-coté 11.

The 1892 commission requested that more analyses be carried out, this time in the new analytical laboratory of the National Public Hygiene Board, a facility created in 1889, in accordance with the 1884 law. It had the specific mission to examine all new drinking water resources at the request of municipalities with a population over 20,000 inhabitants. This national facility also performed systematic bacterial analyses, including the Versailles waters. Out of the 17 samples collected from all important points of the Versailles water distribution (the Ponds, springs, the Seine River and the Marly-Croissy aquifer), 16 were declared "dangerous or unsuitable for a good water supply," due to the presence of organic matter and *Bacillus coli*, and only one, from one Marly well, was considered satisfactory.

In 1894 use of the Seine River's water in public distribution for Versailles was closed for good, and two more wells were drilled in 1895. The Marly Machine continued to be used only as a driving force to raise groundwater. Some suggested not completely abandoning the Seine water but keeping it for the Gardens, fountain shows and city street washing. The more optimistic hoped that, if the Parisian program of sewage-irrigated farms was proved efficient and cleaned the Seine, the river could be used again for Versailles water supply (Gavin 1892; Barles and Guillerme 2014).

In 1895–1896, after the Seine water was cut off in the Versailles supply, Gavin and Lacour, a pharmacist in the Versailles Military Hospital, made another bacteriological assessment of all Versailles waters. In 1899 at Paris University, Lacour defended his thesis titled *Versailles Waters: Historical, Chemical and Bacteriological Study (from 1895 to 1899)*. Now both approaches were used: *Bacterium coli* and *Eberth bacillus* were not identified in the Ponds water; however, they were reported in large quantities in the Seine River water taken upstream from the Marly Machine. The regular monitoring of Versailles water quality was established in 1910, in a new facility at Versailles, the Municipal Laboratory, first directed by Edouard Rabot. Its analyst, Mr. Debains, performed weekly controls at the request of the city, the VWS and the army health service, with 7691 men and their 2695 horses now staying in Versailles, according to a memorandum signed between all parties.[26]

Conclusion

In 1852, the infrastructures, governance and management of the Versailles Water Service (VWS), were directly inherited from the establishment of the royal residence in the late seventeenth century. Two major hydraulic works were installed to meet the extraordinary water demand: the "white waters" originating from the Versailles Ponds, an extended water diversion scheme, and the Marly water, i.e., the Seine River water pumped by a complex hydraulic machine. In addition to this technical heritage, the VWS had a governance heritage. Originally covering the city of Versailles (27,000 people in 1810) plus three other nearby royal residences—Marly, Sèvres and Meudon—the VWS was "a very special service, unique in France," increasing service to 32 towns in 1903. The VWS, located in Versailles, was not a municipal institution but a state-owned service, supervised by state ministries (Fine Arts, Public Works), which nominated its director, allocated its budget and fixed the prices of the water delivered; half of the water was distributed at no cost to state properties. Water-related commissions were chaired by the prefect and made recommendations to the VWS supervising authority. The city of Versailles, which did not participate in the commissions, benefitted from exceptional financial, technical, scientific

[26] The département Archives of Yvelines: 2Q non coté 47.

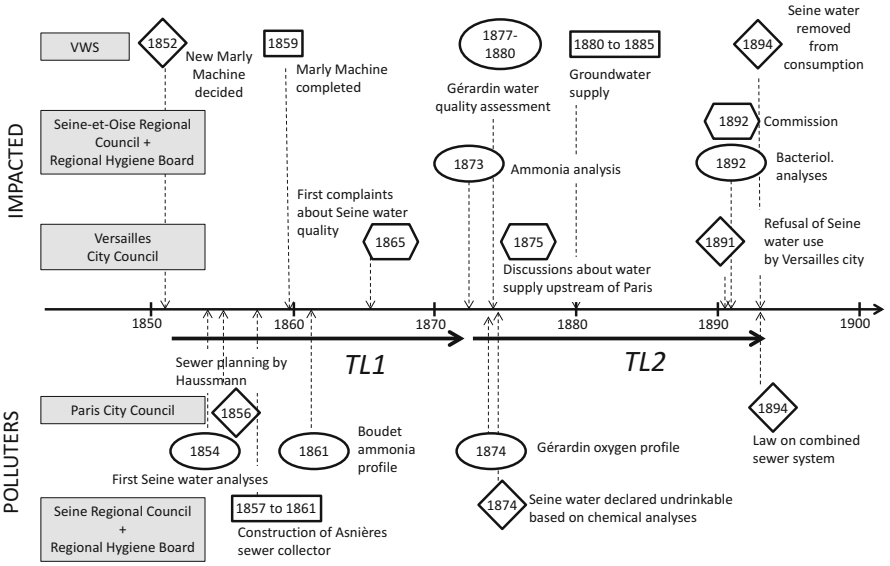

Fig. 10 Chronodiagram of the main conflicts, technical changes, administrative decisions and water quality assessments related to Versailles waters, between 1852 and 1894. *TL1* time lag lasting 22 years to declare that the Seine water was infected and unsuitable for drinking, *TL2* time lag lasting 20 years to exclude the Seine water from the water supply. *Diamonds* decisions, *Rectangles* technical actions, *Ovals* analyses, *Hexagons* discussions and complaints

and administrative support from the state, but could only forward suggestions and complaints to the VWS or the prefect.

The VWS's first major issue in 1852 concerned the volume of water supplied: the old Marly Machine was highly insufficient, and the Versailles Ponds were also poorly maintained. The construction of a new Marly Machine was decided and put into operation in 1859. It soon multiplied the quantity of water supplied by the Seine by a factor of three. This new facility was complemented between 1880 and 1895 by groundwaters abstracted from the chalk aquifer at Marly-Croissy. During the nineteenth century, the quantity of water supplied by the VWS to Versailles and its nearby towns increased by an order of magnitude. After 1894 no more water was pumped from the Seine River, ending a long-lasting and complex conflict with Paris.

This conflict began in 1861 when the Paris sanitation program, designed by Baron Haussmann, who was influenced by the Hygienist movement, resulted in the construction of the main sewer collector which released wastewaters at 16 river km upstream of the Marly Machine intake. The complex interaction between many stakeholders mobilized multiple commissions, at the local (Versailles water users), regional and national levels (Fig. 10). The river was increasingly impacted by untreated sewage because the technical solution chosen by Paris engineers, sewage farms, were never sufficient: Paris sewage water volumes increased more quickly than the area that would have been necessary for wastewater treatment.[27] It would take thirty years for the VWS to definitively end its pumping in the Seine at Marly: first the VWS had to be convinced of the problem, its

[27] For more information on Paris sewage treatment in irrigated farms and the Seine River sanitation, see Barles (1999, 2007). See also Lestel and Carré (2017).

amplitude and permanence—by repetitive water chemistry assessments—then an appropriate technical solution had to be found, groundwater use at Marly, a major break in water supply policy since 1680. Two major time lags can be put forward in this story (TL1 and TL2, Fig. 10).

The Versailles water history is a good example of the unequal power play between two unequal parties: Paris, the new capital city, and Versailles, the former capital, both supervised by the state. The state favored Paris, the cause of the water quality degradation, and forced the Versailles Water Service to adapt, causing a major technical shift from river water to groundwater. The chemical and bacteriological analyses, developed by prominent scientists, played a major role in raising awareness of the issue, its official acknowledgement and decision-making.

The first demonstration of the impact of the Paris sewer system on the Seine River was made by Boudet (1861), based on the ammonia indicator. From 1861 to 1899, all the chemical and then bacteriological approaches to assess water quality were applied to Versailles water, including the Seine at Marly. The oximetry developed by Gérardin over a 150-km river profile in 1874 clearly demonstrated the impact of Paris sewers in a pioneer water quality expertise. The same year, the Seine River was officially declared "infected" based on fish kills, odors and visual aspects, complemented by a set of chemical indicators, in which oximetry was secondary. In 1892 the bacteriological counts, established by the National Public Health Board as a new water quality criteria, were put forward to permanently exclude use of the river's water from the drinking water supply at Marly in 1894. The chemical approach, developed since 1854, was no longer the main criterion: in France too, "more medically qualified people took an interest in water quality, with more severe standards of accountability" (Hamlin, 1990).

The work of French chemists on Versailles waters led to important discoveries on the biochemical functioning of surface waters, such as Boudet for sewage tracing using the ammonia indicator, Gérardin for oxygen depletion downstream of urban sewers and Gavin on the re-oxygenation of reservoirs. Unfortunately, these pioneering works lacked followers during most of the twentieth century.

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