Sewer sediment management: some historical aspects of egg-shaped sewers and flushing tanks

J.-L. Bertrand-Krajewski
URGC Hydrologie Urbaine, INSA de Lyon, 34 avenue des Arts, 69621 Villeurbanne cedex, France
(E-mail: jlbk@urgc-hu.insa-lyon.fr)

Abstract This paper presents a historical review of some concepts and techniques used to manage sewer sediments and to cleanse sewers. Two aspects are illustrated: i) the use of egg-shaped and similar types of sewers in order to ensure self-cleansing velocities even during low flow periods, and ii) the use of flushing tanks to scour deposited sediments and keep sewers free of deposits. After a brief survey of antecedent periods, the paper focuses on the evolution since the middle of the 19th century. Mainly based on French and English complementary examples, because both countries were leaders in the development of urban drainage in the period 1840–1880, the paper also provides information from Germany and the USA and shows that some aspects remained rather unchanged during 150 years while other have been completely revised during the same period.

Keywords History of sewers; sewer cleansing; sewer flushing; sewer sediment; urban drainage

Introduction
Urban drainage and sewer systems characteristics not only depend on scientific and technical knowledge, but also on cultural, social, political and economical conditions and constraints. As a consequence, some concepts and techniques, or the context and the conditions of their use, may change with time. But sewer systems and their associated operational practice constitute a significant heritage that cannot easily be modified according to changing contexts. Considering that the management of sediments in sewer systems is a permanent and still not fully solved problem, it appeared interesting to investigate its historical evolution. This paper presents some historical aspects of two elements allowing us to manage sewer sediments and to cleanse sewers: i) the use of egg-shaped and similar types of sewers in order to ensure self-cleansing velocities even during low flow periods, and ii) the use of flushing tanks to scour deposited sediments and keep sewers free of deposits. After a brief survey of antecedent periods, the paper focuses on the evolution since the middle of the 19th century.

Some milestones before the middle of the 19th century
Since their appearance around 7000 BC in the first cities in the Middle-East region, like in El-Kowm (Cauvin, 1987; Stordeur, 2000), located in Syria, sewer systems suffer from deposition of various types of solids leading to blockages, premature overflows and floodings, odours and gas emission. In Mohenjo-Daro (Pakistan), a large city from the ancient Indus civilisation built around 2500–2000 BC with impressive sewer systems, sewers were equipped with settling chambers very similar to the present grit chambers, deeper and larger than upstream and downstream reaches (Jansen, 1988).

Some centuries later, during the Roman Empire, many cities had been equipped with sewer systems suffering from deposition (Malissard, 1994). In Rome, Marcus Vipsanius Agrippa (63–12 BC), son-in-law of Augustus, decided to cleanse the large Cloaca Maxima, built by an Etruscan engineer under the reign of Tarquin the Elder (Tarquinius Priscus) around 550–500 BC. Agrippa visited the Cloaca Maxima by boat and asked to flush it by
discharging simultaneously the water coming from seven aqueducts of Rome. Storage tanks were also built in order to create periodic flushes (Malissard, 1994). Sextus Julius Frontinus (35–104 AD), also named Frontin, curator aquarum of the city of Rome, recommended in his famous treatise about aqueducts that a fraction of the water from aqueducts and runoff “should be discharged into cloacas in order to cleanse them” (Frontin, 98 AD, chapter CXI, p. 54 in the French edition of 1961). settling chambers were also used: Malissard (1994) quotes the example of the Chiavica della Rotonda which was 4 m wide and 3 m deep. But usually cleansing was carried out manually, which was considered as a “punishing and shameful labour” (Reid, 1993), as stated by Pliny the Elder in his Natural History.

During the Middle Ages, constructed sewer systems were really not a priority for municipalities, and even the Roman heritage was not kept and maintained. However, the German city of Bunzlau is a very interesting exception, where the sewer system, built in 1531, was periodically flushed by discharging drinking water to keep it without deposits, as reported by Sickert (1999). This system was still in use at the beginning of the 20th century.

In Paris (France), Jean-Baptiste Colbert (1619–1683), surintendant of King Louis XIV (1638–1715), created the first sewer cleansing service in 1663. Approximately one century later, in 1737, the prévôt des marchands de Paris Michel-Etienne Turgot (1690–1751), during the reign of Louis XV (1710–1774), replaced an old broken sewer by a new one, with smooth paved walls and invert, equipped with sluice gates, which was periodically flushed by emptying a 6,930 m³ reservoir located at the Filles-du-Calvaire Place (Bechmann, 1900; Imbeaux, 1911). “In a rare display of royal interest in sewers, Louis XV and his entourage attended the initial release of water from the reservoir in 1740; the king remained a good half-hour, chattering on about the beauty of the project” (extract from Reid, 1993). But cleansing sewers was not routine before the 18th century. This unpleasant and dangerous task was frequently carried out by prisoners or convicts.

In 1678, Sir Christopher Wren suggested to the ancient Westminster Sewer Commission in London that the “new sewer in Westminster” should “. . . receive a flush of water from the Mill ditch, by means of the says sluice, for the scouring and cleansing of the says sewer” (quoted in Bazalgette, 1865).

Around 1789, the total sewer length in Paris was equal to 26 km, and some flushing reservoirs were used to cleanse some reaches (Bechmann, 1900; Mondon, 1934).

In 1805, the Frenchman Pierre-Emmanuel Bruneseau (1751–1819), appointed as General Inspector of Salubrity, created the sewer department of Paris and started his seven years’ long first exploration, cleansing and repair of the old Parisian sewer system. Bruneseau himself and his work have been described in a grandiloquent and epic way by Victor Hugo (1802–1885) in his famous “Les Misérables” published in 1862.

In the first half of the 19th century, old sewers inherited from the Roman period and from the Middle Ages were used mainly for runoff water. Due to the bad state of streets and to the practice of the inhabitants to throw all their domestic solid wastes in the streets (before 1870, in Paris and in many other cities, it was legally authorised to throw in the streets all domestic dry wastes between 19:00 and 07:00), surface runoff transported very large amounts of various mineral and organic solids which entered and settled in sewers where the flow was not sufficient to transport them. “Until the 1820s, [. . . Parisian] sewers had rectangular bases and silted up quickly” (Reid, 1993). The sewers were not maintained and were frequently blocked (Mondon, 1934). Where maintenance was not carried out (the most frequent case . . .), deposits could “reach the ceiling of the sewer” (Reid, 1993). In Paris, “the sewers were still not cleansed; filth, which was accumulating [in sewers], was blocking the flow and spreading infection into the atmosphere. During the slightest rainfall, runoff could not flow and low parts of districts in the city were flooded. Water was invading
cellars and ground floors of buildings up to a depth of 1 meter in some locations” (Bechmann, 1900). In London, the old sewer system was discharging the effluent into the Thames only during low tides, and, as reported by Joseph William Bazalgette (1819–1891), the great sanitary engineer who created the modern London sewers during the Victorian period (Foulkes, 1993; Halliday, 1999), as the effluent was stored in sewers 18 hours a day until low tide, “during that period, the heavier ingredients were deposited, and from day to day accumulated in the sewers; besides which, in times of heavy and long-continued rains, and more particularly when these occurred at the time of high water in the river, the closed sewers were unable to store the increased volume of sewage, which then rose through the house drains and flooded the basements of the houses” (Bazalgette, 1865).

In 1826, the hygienist Alexandre Jean-Baptiste Parent-Duchâtelet (1790–1836) supervised and participated himself in the cleansing of the sewer in Amelot Street, which was reputed as a clogged, foetid and stinking dangerous sewer that nobody wanted to cleanse. During six months of exhausting work, the workers extracted manually approximately 2,400 m³ of sand, and pushed three times this volume of muck into the Seine River. They created some artificial dams by means of a wooden manual tool named a rabot, which is the ancestor of the mechanical gates introduced some decades later by Eugène Belgrand (Cebron de l’Isle, 1991). Parent-Duchâtelet himself wrote a very detailed report on these cleansing works (Parent-Duchâtelet, 1824, 1826).

To facilitate sewer maintenance and cleansing, Henry Charles Emmery de Sept-Fontaines (1789–1842), head of the Paris sewer department from 1832 to 1839, re-discovered some of the ideas of Frontinus and “placed fountains at the head of streets in north-eastern Paris and redid these streets so that water no longer flowed down a channel in the middle but went into gutters under sidewalks, which emptied periodically into a sewer” (Reid, 1993). This system and its design are extensively explained by Emmery, who set as a basic principle that “giving the maximum flow by means of a minimum number of fountains is a necessary condition to have a flush, and, consequently, not only submersion, but effective cleansing and scouring of deposited sediments” (Emmery, 1834). Fountains were flowing twice a day during one hour (Bechmann, 1900).

After the middle of the 19th century, sewer systems were built in all major European and North American cities (see e.g. Gerhard, 1899a, b, c). Sewer sediment was accounted for by means of two complementary approaches, which are still applied today: i) how to avoid or at least limit deposition in new sewers by means of appropriate rules based on sewer shapes, slopes and flow velocities, and ii) how to cleanse deposits by means of appropriate flushing and mechanical devices. The following sections give information about two aspects: the shape of sewers and flushing tanks.

**Self-cleansing sewer shapes**

Inherited from the Middle Ages period, ancient sewers, especially in Paris, had shapes with rather flat inverts, as shown in Figure 1. These shapes were similar to those used in the ancient Roman Cloaca Maxima. In conjunction with very low slopes, these shapes facilitated sediment deposition.

However, better shapes were possible and had been used in the past. As an example, in the Minoan city of Knossos, in Crete, some water pipes, dated approximately 1700–1500 BC, had a parabolic shape “with the purpose of increasing the speed of flow of the water and thus helping to flush any sediment through the pipe” (Graham, 1987). Similar shapes were used for surface runoff sewers, associated with settling traps built at various distances (Bonnin, 1984).

During his technical visit in the United Kingdom, the French engineer Hippolyte Mougey (1813–1838) observed that egg-shaped sewers were used in London, especially in
Holborn and Finsbury districts, and also in Scotland (Mougey, 1838). But the origin of such shapes was not quoted, and the concept was not imported into France. In 1848, Henry Austin, consulting engineer to the First Metropolitan Sewers Commission of London, had been asked to conduct a survey of the sewers. From his report, it appeared that “it was the practice in many areas to construct egg-shaped sewers with the narrow end downwards so that, when the flow was small (for example at night or in dry weather) the liquid would be concentrated in a narrow area and thus speed the flow” (quoted by Halliday, 1999). The reduction of section and increase of flow velocity obviously facilitated solid transport and reduced deposition. Rawlinson (1852) indicated that “small sewers and drains [i.e. less than 2 feet or 0.6 m in diameter] should be circular; large ones should be oval, or egg-shaped”. This argument has then been re-used in almost all textbooks and manuals since the middle of the 19th century. The egg-shaped geometry of sewers is sometimes attributed (but of course he did not invent it) to John Phillips, Chief Surveyor of the Metropolitan Sewers Commission of London, who suggested a way to design them: his drawings have been reproduced by Imbeaux (1911) and later by Koch (1967). As shown in Figure 2, it is a geometrical combination of circles. In the first case (left figure), the smallest circle corresponds to the gutter, and the largest circle, twice as large as the smallest one, corresponds to the roof. The walls correspond to circles three times larger than the smallest one. In the second case (right figure), the invert is narrower in order to get a more concentrated flow during low flow periods. Such sewers were usually used for medium size sewers, with depth ranging from 0.6 to 0.9 m. For larger sewers, especially interceptors, the flow was always considered as sufficient to avoid deposition. Such medium size egg-shaped sewers were widely used in Europe, especially in the United Kingdom, the USA (Brooklyn, Washington, New York) and Germany (KölN, Dresden). In the latter country, this shape has been introduced by the English engineer William Lindley who built the sewer system of Hamburg from 1842 (Sickert, 1999; Büker, 2000). But Lindley slightly modified the original egg-shape profile into an O-profile with a wider invert in order to facilitate the walking of the sewermen (quoted by Sickert, 1999). Egg-shaped sewers were standardised in Germany between 1920 and 1940.

Figure 1 Some shapes of old Parisian sewers (extract from Bechmann, 1900, p. 18)

Figure 2 Egg-shaped sewers by John Phillips (extract from Koch, 1967, p. 99)

Figure 3 Egg-shaped sewers adapted by Mille (extract from Koch, 1967, p. 99)
Egg-shaped sewers were introduced in France by the French engineer Adolphe Mille (1812–1894), 13 years after Mougey published his paper. Mille, who discovered the ovoid profile adopted in England during his visit to the London Exhibition in 1851, strongly supported its use in Paris, but for man-entry sewers with height ranging between 1.8 and 2.0 m, where, like Lindley, he flattened the invert to facilitate the walking of sewermen (Figure 3).

François Eugène Belgrand (1810–1878), who is the most famous sewer system builder of the French capital during the period 1856–1878, decided to build large man-entry sewers in order to facilitate their maintenance and cleansing. Indeed, Belgrand, considering that, due to low slopes and limited dry weather flows, deposition could not be avoided, decided to built large sewers where sewermen could easily access and remove sediments manually. However, in order to facilitate sewer cleansing, he promoted the development of sewer shapes with *cunette* (i.e. gutter) and single or symmetric lateral *banquettes* (i.e. sidewalks) where sewermen could walk along sewers, as illustrated in Figure 4. The large size of these sewers was also appropriate to install drinking water pressure pipes, which could then easily be inspected to detect leakage. This was among the first applications of the concept of a technical gallery, extended later to gas pipes, industrial water, pressurised air and telephone networks. This concept had also been proposed in Hamburg by Lindley (Sickert, 1999).

*Cunette* and *banquette* were an adaptation to the Parisian context of the egg-shaped geometry imported by Mille. According to Bechmann (1900), it has been first invented in 1851 by Arsène Jules Emile Juvénal Dupuit (1804–1866), who was the predecessor of Belgrand in Paris from 1850 to 1855. During the construction of the new large sewer along Rivoli Street (see Figure 4, left), Dupuit used the lateral *banquettes* as a track for small wagons used to transport sediments removed from the sewer. According to Bechmann (1900) and Imbeaux (1911), sewers with *cunette* and *banquettes* were then further developed by Alfred Durand-Claye (1841–1888), who worked in the Design and Construction Unit of the Seine Sewer Department created by Mille in 1867 (Cebron de l’Isle, 1991).

Durand-Claye proposed to adopt such a shape after the decision made in 1883 to accept domestic sewage (i.e. urine and faeces) in the Parisian sewers, in association with flushing tanks whose discharges were more efficient through such reduced invert sections to cleanse sediments and avoid deposition (Bechmann, 1900). However, for smaller non man-entry sewers, circular shapes, eventually modified with egg-shaped elements put over the invert, were proven to be more appropriate than traditional shapes to limit sediment deposition. Imbeaux (1911) and Mondon (1934) describe various shapes of sewers and discuss their respective merits from the solid transport point of view. According to Imbeaux (1911), sewers with *cunettes* and egg-shaped inverts are strongly recommended to increase the solid transport capacity and to facilitate self-cleansing. Old galleries with large and almost flat inverts are not recommended and should be advantageously improved by building *cunettes* as done by Durand-Claye after 1885.

Imbeaux (1911) indicates that egg-shaped sewers are the most frequently used in London, while in Paris large sewers with low *cunette* and lateral *banquettes* as designed by Durand-Claye are preferred. There are many reasons explaining the different approaches used in London and Paris. In Paris (and also in Lyon, Marseille or Besançon where similar types of sewers had been built), it had been decided by Belgrand to have large man-entry sewers, and to use them only to drain surface runoff which contain high loads of settleable solids (including street sweeping debris) that enter the sewers by means of open street inlets without gully pots facilitating grit removal (in the beginning, it was forbidden to discharge domestic sewage into Parisian sewers). In conjunction with low slopes of about 1 to 3 per 1000 and low flows, deposition could not be avoided. This is the reason why various
mechanical devices had been created to facilitate manual sewer cleansing (see Hederstedt, 1865). In London, where both domestic sewage and a limited fraction of surface runoff were taken away, Bazalgette decided to promote non man-entry egg-shaped pipes for small sewers and rather circular shapes for large interceptors, designed with slopes allowing minimum velocities of 1.5 mile per hour (0.67 m/s) and ensuring self-cleansing as much as possible. Bazalgette (1865) noted: “[in Paris] it would appear that instead of constructing the sewers so as to carry off the deposit, great ingenuity had been expended in inventing appliances to cleanse them by artificial means”. Rawlinson (in Bazalgette, 1865) also made similar conclusions and claimed that “sewers large enough for men to enter, merely to cleanse them, were not necessary, and . . . believed it to be possible so to deal with different districts by constructing small or egg-shaped sewers. . . . Where sewers had been made of sufficient capacity for men to enter them, and with flats inverts, it had been found in practice that such sewers required to be regularly cleansed, because the excessive dimensions and flat inverts retained all solids, until removed by hand-labour at great cost”. A little bit ironically, Lemon (in Bazalgette, 1865) observed, “as to the form of the French sewers, it was curious that a nation, which has produced some of the most eminent authors on hydraulics, should have lost sight of one of the first principles, that of obtaining the maximum hydraulic mean depth of flow in the sewers in dry seasons: for which purpose the egg-shape was one of the best forms”. These criticisms had been given before Durand-Claye proposed his modification of inverts by adding cunettes and banquettes. New interceptors after 1890 have been built with minimum slopes of 5 per 1000 ensuring self-cleansing velocities of 1.0 to 1.5 m/s.

However, due to the French centralism and to the strong influence of the Parisian paradigm, the problem was not definitively solved during the following decades, as recognised e.g. by Bechmann (1900, p. 333) who nevertheless noticed that the Parisian streets were cleaner than in any other European cities and that sewer slopes were rather similar in all European large cities. Egg-shaped sewers with a height less than 1.7 or 1.8 m were not really accepted. For example, Durand-Claye, in his report to the Hygienists Congress in Vienna in 1887, wrote: “It is recommended to avoid at any cost small galleries which are too large to be a good pipe and too small to be a good sewer” (quoted by Koch, 1935). However, due to the increase of dry weather flows, many banquettes were progressively submerged and became slippery for sewermen. The consequence was that some banquettes have been removed and that sewermen walked in the cunette, which was finally “a simple

Figure 4 Shapes of Parisian sewers with cunette and banquettes(s) (extract from Bechmann, 1900, p. 26 (left) and Imbeaux, 1911, p. 277 (right))
transposition of the English egg-shape sewers” (Koch, 1935, 1967). Many other French municipalities built small circular sewers, mainly because they were less expensive than large man-entry sewers.

After the Second World War, the French situation changed significantly, and the French engineer Albert Caquot (1881–1976) designed a series of egg-shaped sewers ensuring the minimum self-cleansing velocity for a very large range of flow rates. Finally, medium size egg-shaped sewers were standardised in 1949 in the French standards AFNOR NF P 16-401 and recommended for sewer heights between 1.0 and 2.0 m. The official French Technical Guidelines for Sewer Systems published in 1949 suggested to distinguish three categories: man-entry ovoid sewers with heights between 1.8 and 2.0 m, “semi man-entry” ovoid sewers with a 1.5 m height, and “exceptionally man-entry” ovoid sewers with heights ranging from 1.0 to 1.3 m. Smaller pipes had to be circular. It should also be observed that the Guidelines indicated that the above shapes of sewers were not applicable to the specific case of Paris, “where sewer shapes obey to specific objectives which could only be encountered in some very large cities” (Instruction Technique, 1949).

This distinction was maintained in the following manuals, e.g. Koch (1967), or Gomella and Guerrée (1986) who indicate in their manual that there exist “three types of sewer shapes: circular, normalised egg-shape as given in the standard NF P 16-401, and man-entry sewers with specific shapes for very large cities”. They also advocate egg-shaped sewers for heights above 0.60 m, because they facilitate the dry weather flow. However, as they are cheaper than prefabricated ovoid pipes, prefabricated circular pipes with diameters up to 1.6 m are frequently laid instead of ovoid pipes.

**Flushing tanks**

As already mentioned above, flushing has always been used to cleanse sewer systems since antiquity. This was particularly necessary in old sewers that were not appropriately designed (flat invert, insufficient volumes, slopes and velocities, rough walls, incoherent flow regime and depth, etc.) and because all debris and solids from the surface entered into sewers. In Paris (France), Parent-Duchâtelet (1824) (quoted by Koch, 1935) indicated that sewermen used provisory dams that they removed quickly to create flushes. In Strasbourg (France) in 1849, the Municipal Council for Hygiene asked inhabitants to flush sewers and gutters in order to scour deposits. The insufficient amount of water discharged in the sewer system and the low slopes were identified in 1864 as the main reasons for deposition in sewers, and the two engineers Stoeber and Tourdes suggested to flush streets and sewers with abundant water, as Emmery done some decades before in Paris (Claude, 1985). However, modern sewers rationally designed and built after the second half of the 19th century were not always effectively self-cleansing and flushing tanks were very frequently necessary to scour deposited sediment. Thanks to i) increasing water consumption (the volume per capita per day moved from less than 100 L in the 1850s to more than 200 L in the 1970s), ii) improved street surfaces with less debris and solids, and iii) better trapping of street solids in gully pots during rainfalls, flushing tanks progressively appeared less necessary.

In Paris, as reported by Bechmann (1900), the sewer system, at the end of 1899, had a total length of 1,100 km, with 3,500 flushing tanks. Most of these tanks had been built after 1885 at the upstream end of sewers, according to the recommendations of Durand-Claye (see Figure 5). These tanks, located either within or close to the sewers, were filled by means of a calibrated tap until a predefined water level. A siphon, derived from the type invented by Roger Field (see Figure 6) and used in the Waring separate sewer systems, then started to discharge the volume and created a rapid flush over a length depending on the tank volume and the sewer slope. The most typical siphons were the Geneste and Herscher (see Figure 7) and the Aimond types.
In the United Kingdom, some engineers advocated flushing tanks. Haywood (in Rawlinson, 1852) “explained that he had been careful, in all the pipe sewers he had constructed, to provide shafts at their heads, so as to have the power of flushing them periodically, with a considerable body of water. For the sake of experiment, this periodical flushing of the pipe sewers, had been discontinued for some time, and although most of them were laid with excellent gradients, some had accumulated deposits varying from 1 inch to 3 inches (2.5 to 7.5 cm) in depth, measured at their outlets”. Rawlinson (1852) recommended that “at each manhole there should be an arrangement for flushing (see Figure 8); and, in some instances, a depth of 7 inches (18 cm) of deposit had been flushed out of a pipe of 15 inches (40 cm) diameter, in ten minutes, leaving the pipe-drain perfectly clean”. However, in London, flushing tanks were apparently not significantly developed, despite some proposals to built flushing tanks at the upstream end of sewers to flush them at “about once a week during dry summers, but the oftener the better”, as suggested e.g. in 1854 by Hawkshaw or in 1865 by Grant (Hawkshaw and Grant, both in Bazalgette 1865).

In the USA, Hering (1881) explains that “in wrongly designed [combined] sewers [the] rain-water flushing is not sufficient to cleanse them, and even in rightly designed sewers, it cannot be solely depended on, and it will be necessary at times to clean sewers from substances too large or heavy to be removed by flushing water”.

More detailed information is provided by Imbeaux (1911) in his manual, which distinguishes different types of sewer systems.
Combined sewers

Imbeaux (1911) suggests that combined sewers are more affected by deposits than wastewater separate sewers, because minimum critical velocities of 0.6–0.8 m/s are not reached during dry weather periods, when the pipe filling level is very low. In his recommendations, flushing tanks are mentioned as one of the most important devices. Imbeaux reports that the sewer system of Paris, at the end of 1906, had a total length of 1,177 km, with 4,369 flushing tanks of various types. In Marseille in 1906, there were 190 km of sewers with 964 flushing tanks, with volumes ranging from 0.5 to 10 m³, which were functioning three times per day. At the same time in Berlin (Germany), the total length of the sewer system was 991 km and there were 1,220 flushing tanks. In Köln (Germany), three brooks (the main brook, named Duffesbach, with a mean flow of 2,000 m³/day) were discharged into a storage pond used to flush the sewer system of the west side of the old city and of the new city. Drinking water from the distribution network was also used to cleanse the sewers of the rest of the city, by means of 18 flushing tanks whose volumes ranged from 4 to 20 m³. It should be noted that the map of the Köln sewer system drawn in 1906 shows the sewer reaches and the location of all flushing tanks, which is an indication of the significant role of these devices. It is also interesting to note that all descriptions of sewer systems in cities across Europe and even out of Europe given by Imbeaux contain a description and a quantification of the flushing devices used to cleanse sewers. This shows that this type of problem was very significant.

Separate sewers

Imbeaux reports that the American Colonel George E. Waring (1833–1898), famous for having promoted very intensively separate sewer systems (see e.g. Cassedy, 1962), indicated among other technical guidelines that “a daily cleansing of the pipes by means of flushes, for which one uses the water accumulated in tanks located at the upstream end of the pipes” was necessary. In Memphis (USA), the city where Waring had first built a complete sewer system according to his views in 1879, the 68 km long sewer system was equipped with 180 Roger Field flushing tanks. Each tank, with a volume of 500 L, was emptied in 40 minutes. In 1883, the Waring system had been implemented and tested in the Marais catchment in Paris, around the Vieille-du-Temple and Rivoli streets. Five Field–Waring flushing tanks with volumes ranging from 425 to 700 L were emptied three times per day to maintain clean sewers. The Waring system was not further developed in Paris, but had been implemented in other French cities, like Cannes (in 1891, with approximately 60 flushing tanks of 0.5 to 2 m³, operated twice a day) or Privas (in 1911, with 30 flushing tanks of 0.5 m³ and 2 flushing tanks of 2 m³).
Mixed sewers

In a special chapter about mixed sewers, i.e. separate sewers but with wastewater pipes designed for small storm events, and stormwater pipes designed only for moderate to strong rainfall events, Imbeaux indicates that, in Rio de Janeiro (Brazil), there were 400 km of sewers in 1909, equipped with flushing tanks of both Field and R. de Brito types.

In his chapter on the conception, design and operation of sewer systems, which is 43 pages long, Imbeaux (1911) uses 14 pages to describe flushing tanks and tools for sediment removal, with 28 figures containing more 47 different drawings illustrating how the described devices function. He states: “if the flow velocity in sewers was always sufficient, there would be no deposits and one would have an automatic cleansing without [specific] devices. As it is not the case, . . . it is necessary to compensate, as we said, by flushings”. The starting point of Imbeaux consists in admitting that self-cleansing conditions cannot be obtained: this is the reason why he does not give detailed guidelines about minimum slopes or velocities to be maintained in sewers, but describes extensively the devices and tools for sediment transport and removal. He claims that “this is the best way to cleanse sewers”.

According to Imbeaux, the flushing volume should be proportional to the pipe diameter and to the length to be cleansed. He indicates that the minimum flushing volume should be equal to 1 m$^3$ and that the head should be between 0.80 and 1.50 m. Flushing tanks should be used between 2 and 4 times per day, depending on their volume. Imbeaux explains that very little experience is reported about the efficient length of flushing. He mentions experiments of Adams, Rosewater and Ogden in the USA who observed the water level, velocity and efficiency length under various conditions. Imbeaux concludes that the maximum efficiency length is between 200 and 300 m, and that flushing tanks should be located accordingly, and in all locations where the flow velocity falls below 0.6 m/s.

When water from a surface watercourse is available, Imbeaux recommends to use it instead of drinking water which is far more expensive. The use of natural water resources was very frequent at the beginning of the 20th century, especially in Germany where many cities were quoted as using the water from some of their brooks (Köln, München, Wiesbaden, Frankfurt, Stuttgart, Breslau, etc.). Seawater is sometimes used to fill the flushing tanks, as Imbeaux mentions for cities built along the coast in Tunisia.

Imbeaux describes many types of flushing tanks, depending on their conception: i) manual flushing tanks: these are the oldest ones – a gate or a valve was opened manually; and ii) automatic flushing tanks: there are various types of flushing tanks, depending on the technology used.

In the simplest tanks, counterweights or floating valves are used to replace the manual opening. Two typical examples are the Colin and Poirier devices. Tipping devices are also among the oldest devices used in England, like the Duckett flushing tank, and in France, like the Berlier flushing tank (see Figure 9). These devices are the direct ancestors of the tipping tanks “re-invented” approximately one century later by Swiss and German companies to cleanse retention tanks.

Devices with automatic siphons and bells are presented by Imbeaux as the most recent and the most employed flushing tanks in the beginning of the 20th century. Most of them have been derived from the Field–Waring device shown in Figure 6. Among the various types manufactured in France, Imbeaux quotes the Geneste–Herrscher, Adams, Flicoteaux, Aimond, de Brito and Parenty devices.

Twenty years after Imbeaux, Mondon (1934) wrote a sewerage manual. In his 74 page long chapter on the conception and design of combined sewers, 21 pages deal with sedimentation problems, self-cleansing design and cleansing tools. In the next 53 page long chapter devoted to separate sewers, 16 pages concern these topics. Compared to Imbeaux, Mondon explains that, as much as possible, sewer should be designed and built to avoid
sedimentation (minimum slopes, smooth material, small angles for house connections and rounded shapes). But, despite all these efforts, sedimentation will occur and he admits that sewer cleansing remains necessary.

In combined sewers, increased flow rates during rainfall events contribute to the cleansing. But this action occurs only accidentally and it is necessary to cleanse the sewers periodically by means of flushing tanks. Compared to Imbeaux, there is no new information: all devices presented by Mondon were already presented by Imbeaux, with identical schemes. The only additional information provided by Mondon is the explanation about the adjustment of the tap discharging the drinking water into the flushing tank in order to have the required number of flushes per day. In separate wastewater sewers, if slopes are not sufficient, Mondon admits that flushing devices may also be necessary. But he is very sceptical about their actual efficiency. Indeed, due to very variable flowing conditions in sewers and to the poor reliability of existing devices, he considers that flushing devices should be used only where they cannot be avoided. He also estimates that their maximum length of efficiency is approximately 150 m. The flushing tanks may be filled with any type of water (river, groundwater, sewage, drinking water, etc.), but sewage should be avoided because settling occurs and odours are generated in the tank. One should preferably build flushing tanks using drinking water, located at the upstream end of each pipe whose slope is below 30 mm/m. The devices are similar to those used in combined sewers.

In the 6th edition of his famous manual “Taschenbuch der Stadtentwässerung” dated 1932, the German engineer Karl Imhoff recommends “to built flushing devices, especially in separate systems and in case of insufficient slopes at the upstream heads of sewer systems. The flushings could be made by means of a manual valve allowing to accumulate water in a manhole” (Imhoff, 1935).

In his first manual, Koch (1935, 1937) devotes a total of approximately 20 pages to flushing devices, with similar drawings to Mondon (1934). Tank volumes range from 250 L at upstream ends to 6–12 m³ in large Parisian sewers. Flushes are created at least once or twice per day. The length of efficiency is evaluated at some hundreds of meters in the most favourable circumstances. However, Koch indicates that, except for well designed separate wastewater sewers, flushing tanks cannot avoid any deposition, and that manual cleansing remains necessary, especially in combined sewers. He also mentions that water consumption may be very significant, especially with automatic flushing tanks.

In the French Technical Guidelines dated 1949 (Instruction Technique, 1949), it is indicated that “flushing tanks should be located at the upstream end of all sewers receiving domestic sewage; their volume should range from 250 to 500 L in separate systems, and from 500 to 1000 L or more in combined systems. Additional tanks should be built downstream along sewers only if the experience shows that they are necessary. They should nor-
mally flush automatically; however, in case of insufficient water resource, one should be able to operate them manually, especially during sewer cleansing”.

In his second manual, Koch (1967) devotes an 8 page long section with more than 10 drawings to flushing tanks. Observing that minimum velocities cannot be reached during low flow periods, especially in upstream sewers, Koch recognises that automatic flushing tanks may be necessary, despite their lack of reliability. He recommends to build adjacent tanks, filled with water from various sources, but drinking water should be avoided for obvious economical reasons. The volume should range from 250 L for upstream separate sewers up to 6 to 12 m³ for Parisian man-entry sewers. They should flush once or twice a day. Among his drawings, Koch gives a scheme for a siphon exactly identical to Figure 7 given by Bechmann 67 years before.

In the French Technical Guidelines dated 1977 (Instruction Technique, 1977), only one third of a page is devoted to flushing tanks. It is stated: “when it is not possible to periodically cleanse the sewers by means of hydraulic devices [like e.g. high pressure jetting], it is appropriate to build flushing tanks at the upstream end of the sewers in order to compensate the self-cleansing deficiency. It should be noted that the dynamic action of such devices is only exerted over short distances”. Flushing tanks could be implemented in the following cases: “i) in separate or pseudo-separate systems: at upstream ends where sewer slope is less than 2%, ii) in combined systems: at upstream ends where sewer slope is less than 1%, where there is no street inlets upstream the first house connection, in regions where there is no rainfall during many months”. The rest of the text is similar to the text published in 1949, except for an additional remark: “it should be noted that the water used in the flushing tanks represents a high cost for municipalities and that it may be a significant contribution to the hydraulic load in small wastewater treatments plants”. A footnote explains how to design a flushing tank: “the flushing tank volume could be set as equal to one tenth of the volume of the sewer reach to be cleansed, with a maximum length of 100 m”.

In their drainage manual, Gomella and Guerrée (1986) devote only 3 pages to flushing tanks, and reproduce nearly word-for-word the text of the 1977 Technical Guidelines, with a slightly modernised version of the figure given by Bechmann. They add some words about the difficulty in having a filling tap working reliably because of fur deposition, and quote a specific device to solve this problem which generally leads to over-consumption of water.

In the 2nd edition of their manual on urban drainage, Coste and Loudet (1987) again reproduce nearly word-for-word the text of the 1977 Technical Guidelines, but devote only one page and one figure to this topic and suppress the example of a design. Their figure is the modernised version of the schemes of the Adams siphon given by Imbeaux in 1911 and by Mondon in 1934. However, Coste and Loudet add that “many people would like to suppress such devices. As far as we are concerned, we think that this position should be adapted according to the general experience, and also according to economical constraints. The policy to be adopted will result from this global analysis”. It is a clear statement that, even if sewer sediments are not completely avoided in modern sewers which are supposed to be self-cleansing, other techniques and constraints should be accounted for.

In their manual published in 1995, Satin and Selmi (1995) devote only one page to the topic, with a once again modernised version of the figure given by Imbeaux in 1911, but with less detail in the text, so that the reader cannot have any practical and useful information. Their text starts with the following sentence: “Flushing tanks, which were used in wastewater separate sewers and located at the upstream ends of pipes with low slopes, are no longer recommended, because of their frequent leakage and their lack of reliability”. They strictly reserve the use of flushing tanks for cases where it has been clearly observed that appropriate cleansing devices cannot be used or where self-cleansing cannot be ensured. Coherently, Satin and Selmi, like Coste and Loudet, mention that “many would like to sup-
press such devices”. In Montpellier (France), Jeanjean (1998) reports that flushing tanks “had been abandoned since a decade. The engineers of the municipal sewer department think that flushing is expensive, and also useless because the increase of domestic water consumption led to an increase of flow in sewers. Flushing tanks remain only in private sewer systems”. Another explanation mentioned is the development of modern and efficient hydraulic and mechanical tools associated with high pressure and vacuum lorries.

But, surprisingly, Satin and Selmi (1995) add a last comment to report that “in combined sewers and in detention tanks, in Germany and Switzerland, flushings are made by means of Hydroself flushing tanks or elevated tipping buckets”. These devices correspond to the modernised versions of devices used at the beginning of the 20th century, but used in different contexts.

More recently, the draft of the future French Technical Guide, dated 2002, does not refer to either flushing tanks or flushing gates. Even modernised devices like Hydroself or Biggest flushing tanks, and Hydrass flushing gates (see e.g. Lorenzen et al., 1996, 1997; Lorenzen and Laplace, 1998; Pisano et al., 1999; Dettmar et al., 2001) are not mentioned in the sections devoted respectively to self-cleansing velocities and bed load sediment traps. Similarly, Butler and Davies (2000), in a very short paragraph about flushing, indicate that automatic siphons at the heads of sewers “are now rarely used” and that, obviously, they “merely move the dislodged material downstream and do not remove it from the system”.

Conclusions
The above brief historical review dealt with the evolution of two questions related to the management of sewer sediments. Concerning egg-shaped sewers, despite their obvious interest to obtain self-cleansing conditions and their wide use in the United Kingdom and in many other countries world-wide, the French context and the paradigm of the Parisian sewer system built with large man-entry sewers prevented their use in France for a long time. During many decades, sewers with cunettes and banquettes have been preferred, and specific mechanical tools for sewer cleansing have been developed. Concerning flushing tanks, their use was initially considered as one of the best solutions to manage sediments and to cleanse sewers. Thousands of them have been built since the 1880s. However, both technical conditions (better sewer design especially regarding self-cleansing velocities and conditions, higher volumes of water, less street sediments, development, especially since the late 1950s, of powerful hydraulic and mechanical cleansing tools like high pressure jetting, powerful vacuum lorries, etc.) and economical constraints (costs of maintenance, consumption of expensive water, etc.) changed progressively and led to the abandonment of flushing tanks, as observed in manuals and technical guidelines.

In order to complete the picture, other aspects should be investigated, concerning the definition of self-cleansing conditions (minimum slopes, velocities, shear stresses, etc.) and mechanical tools used to cleanse sewers (mobile gates, wagons and boat gates, balls, jetting, etc.).

References