will cause a jog, either below or above, in the supplementary horizontal line representing the crosshead path, and will indicate, beyond all question, where the lost motion commences, how long it lasts, in which direction it is from the normal, and when and where it stops.

By the aid of this rig, its inventor effectually cured the hitherto incorrigible engine.

New York, September 8, 1883.

THE WATER SUPPLY OF CITIES IN ANCIENT TIMES.

By WALTER ATLEE, C. E.

It would seem to be particularly interesting at the present time to give some account from ancient authors of the manner in which the famous water supplies of Rome and other cities, celebrated in antiquity, were conducted.

Ever since men have increased in numbers, and have dwelled together for a more or less time in one locality, great attention has always been given to obtain a permanent and abundant supply of pure water.

Among pagan nations water was regarded with such reverence that it was customary to give names to fountains and springs, and to place them under the protection of the gods.

The ancient Egyptian priests, in order to show that all things could subsist only by the virtue of this element, carried solemnly, with religious respect, into the temple where their god was supposed to reside, an ornamental vase filled with water, and there prostrating themselves on the earth, with their hands raised, gave thanks to the divine goodness for his admirable inventions.*

In ancient Rome was celebrated annually on the III Ides of October (October 13), the feast of the fountains, under the name of Fontanalia. During the half day which the celebration lasted, the fountains and wells were crowned with flowers, and wreaths were thrown into the springs of running water.

The Germans, even a long time after the introduction of Christianity, continued in certain districts to make pilgrimages to several fountains consecrated to pagan gods.

If history furnishes but few and scattered accounts of the art of

* Vitruvius lib. 8, preface.

furnishing cities with water, we find in national traditions and monuments the proof that the science of hydraulics dates back to the most remote antiquity.

We know that Persia possesses canals for irrigation, the origin of which is lost in the "night of ages," and which nevertheless continue at the present day to perform their functions.

In the province of Anachosia ruins of canals attest the former existence of a vast system of irrigation.

At Memphis is the ancient aqueduct of Sestorius.

Semiramis constructed at Babylon her celebrated aqueduct.

The city of Jerusalem was supplied by water through an aqueduct built by Solomon. The whole plain at Persepolis was at one time traversed by hydraulic constructions, the ruins of which show that conduits made of stone and pottery large enough for a man to enter were supported by masonry above the level of the plain.

The traveler Tavernier went from Aleppo to Ispahan by the route of the Great Desert, and arrived at a large abandoned palace before the entrance to which was a reservoir communicating with a canal, then completely dry, the bottom and the roof, which latter was level with the surface of the ground, were constructed of bricks. The Arabs who accompanied Tavernier said that the canal had served to bring water from the Euphrates, which was at least fifty miles distant.

Joseph's well, at Cairo, although of more recent date, is probably the most wonderful subterraneous work ever performed by man. A brief and clear account of this structure is given by Ewbank.

There is also at Cairo a long aqueduct, built of masonry, which for its greater length is supported by arcades, constructed about the same time as Joseph's well.

The engineering skill of the ancient Greek is shown by the celebrated aqueduct constructed by Eupalinos, of Megara, which Herodotus mentions as one of the wonders of the Island of Samos;* this exceedingly interesting object for the archæologist pierces, for two and a half miles, the heart of the mountain back of the town, whose inhabitants it supplied with water from a perennial spring.

From an article in Macmillan's Magazine for August, 1883, we learn that a priest named Cyril, from the monastery of the Holy Trinity, last spring, while plowing, discovered the long lost southern entrance of this aqueduct. At a cost of 20,000 francs the Samiotes

* Herod. lib. 3, ch. ix.

have now almost completed the restoration of the ancient channel with the view of again utilizing it, in supplying the town with water. Amongst the ruins of the aqueducts of ancient Greece that of Patara, in Lycia, is most interesting. It consists of a syphon constructed with cut stones supported by an arch in cyclopean masonry, dating to the most remote antiquity.

But it is, above all, the Romans who particularly attract our attention by their hydraulic constructions, the magnificence and daring of which surpass those of all other nations.

Rome is the only city of antiquity of which we have any detailed account of the administration of the collection, conveyance and distribution of water.

The Romans, enabled by their enormous wealth to gratify their love of display and indulgence in luxurious habits, constructed those monuments of hydraulic engineering which Frontinus speaks of as being "worthy of the greatest care, since they are a principal testimony of the grandeur of the Roman empire," "*rem enixiore cura dignam, cum magnitudinis romani imperii id præcipuum sit indicium.*"*

At the fall of the Republic, 45 B. C., Rome, according to Frontinus, possessed four aqueducts. The Appia, constructed in 442 Roman era, by the emperor Appius Claudius. The Anio Vetus, built in the year 481 Roman era; the Marcia and the Tepula.

The emperors Augustus, Caligula, Claudius and Trajan constructed at Rome other aqueducts, more magnificent than those of their predecessors, so that at the time of Frontinus (850 Roman era, or 97 B. C.) there existed nine aqueducts, namely, (in addition to the four already mentioned,) the Julia, the Virgo, the Alsetina and the Claudia.

The aggregate length of these most useful monuments was $267\frac{3}{10}$ miles. For $228\frac{3}{10}$ miles the channels were entirely underground, and for 39 miles above the surface of the ground, of the latter $34\frac{7}{10}$ miles were supported by arcades or ranges of arches.

The following brief account of the character and construction of the Roman aqueducts is mainly taken from "*Les aqueducts Romains*" by M. Belgrand.

The first aqueducts, the Appia, the Anio Vetus and above all the Marcia, bear the robust character of the masonry of the earliest ages, they were constructed of cut stone, very simply dressed, but adjusted

* Frontinus, ch. cxix.

with precision, so that we see that the engineer relied more upon the resistance of the stone than that of the mortar.

The Tepula aqueduct was built in 627 Roman era, or but nineteen years after the completion of the Marcia, nevertheless the mode of construction was different; during that time the Romans had become masons and understood that with good mortar and rough material, they could produce a construction as solid as with cut stone and at a much less cost.

The same mode of construction was employed in the other aqueducts, with the addition of the introduction of bricks, except in that of the Anio Novus, which, when it approached the city, surmounting the Claudia took a character of magnificence, the rough materials being abandoned and cut stone entirely employed.

The cross sections of the channels through which the water ran varied from 3 to 8 feet in height, by $2\frac{1}{2}$ to 5 feet in breadth, the bottom was horizontal and the sides perpendicular to it; the shape of the top or covering varied even in the same aqueduct, it being sometimes arched and at others peaked, and sometimes horizontal or parallel with the bottom.

The necessity of maintaining the aqueducts at a gradual inclination from their sources in the mountains to the place of delivery of the water in the city, forced the engineers, when they came to the numerous abrupt and deep ravines of the Apennines, to build sub-structures consisting of one or more arches; and often of several ranges of superposed arches where it was necessary to attain the required elevation.

In traversing the valleys it was often necessary to construct those arcades, the ruins of which are at the present day the wonder of all those who behold them, and no traveler considers that he has seen all the curiosities of Rome till he has visited at least the Plain Roma Vecchia, which is so remarkable for the ruins of the ancient aqueducts, especially for that of the Claudia surmounted by the Anio Novus, distinguishable by a high and exceedingly long line of arcades, extending beyond the power of vision.

The first four aqueducts constructed crossed the valley Degli Archi in the Apennines on magnificent arcades, the ruins of which are classed among the most curious of Italy.

There is an aqueduct bridge of the Anio Vetus composed of thirty-five arches, forming two ranges of arcades superposed, which traverses the valley now called St. John.

The aqueducts Anio Vetus and Marcia descended by regular grades the mountains Spaccato and St. Angelo, and crossed the first ravine of the Apennines on the same bridge, also composed of two ranges of arcades. This ruin, now called St. Anthony's bridge, is considered very beautiful.

The want, more and more pronounced, of water at a higher elevation obliged the Roman engineers, especially in crossing the plain near Rome, to support the aqueducts on higher and higher arcades. Thus the elevation of the Marcia water being insufficient, the Tepula, nineteen years afterwards, was constructed at a greater altitude. Ninety-two years later the Julia was built, at a still greater elevation, and eighty-four years after the completion of the Julia, the water still being too low, the high arcades of the Claudia were superposed on those of the Anio Novus, crossing the plain near Rome at an elevation of one hundred and nine feet above its surface.

Not only at the Eternal City, but wherever the Romans extended their conquests and established cities, they built those gigantic hydraulic monuments which prove to posterity the great importance they attached to the enjoyment of an abundant supply of water.

Amongst the ruins of these beautiful constructions with which Gaul was dotted after the Roman conquest, there still remain several aqueducts in active service. That called at present the "pont du Gard" supplies the town of Nîmes with water from the two springs, Aire and Airan. This aqueduct consists of a stone channel, 291 yards long, supported by three ranges of arches superposed and attaining an elevation of 160 feet.

At Metz the Moselle river is crossed by the aqueduct of Segovia, which brings water from the valley of Gorge, 23 miles distant.

A part of the water of Paris is still supplied by the Roman aqueduct passing near Arceuil.

Nothing gives a higher idea of the ancient splendor of the city of Lyons (Lugdunum) under the Roman emperors than the remains of the ancient aqueducts erected under Augustus, Tiberius, and Claudius to furnish the city with water.

But no country shared so well in grand Roman hydraulic monuments as Spain, where aqueducts and baths, or their remains, are found in most of the large towns. Those of Merida, Toledo and Tarragona are worthy of being compared to those of Rome itself. The aqueduct of Segovia, in spite of the ravages of time, of civil and political disturb-

ances, has never ceased to fulfil its ancient purpose, and to-day still furnishes the city with all the water necessary for its consumption. This aqueduct, nineteen miles in length, is justly celebrated for its admirable arcades, 700 yards long, composed of 109 arches supporting the channel at an elevation of 107½ feet above the valley.

Constantinople, the Rome of the East, was also justly celebrated for its water-supply brought to the city by the renowned aqueducts of the emperors Valens and Justinian.

The magnificent Carthaginian aqueduct carried its supply of water through mountains and over valleys for seventy miles; near the town of Undena it was supported by an arcade of more than a thousand arches, the elevation of the channel exceeding in some cases 100 feet above the surface of the ground.

Rome was long celebrated for the purity and freshness of its water. The Romans knew that spring and well waters alone were suitable for drinking and culinary purposes; that river water should be reserved for watering and washing streets and parks, to supply the needs of industry, ornamental fountains, and the celebrated amphitheatres where they were so fond of witnessing the famous naval sham-combats.

They knew that water to be good should be limpid, of a moderate temperature in winter and summer, inodorous and above all of an agreeable taste. Vitruvius* tell us "that we can, by means of several observations, know the quantity of the water of a district. If it flows along the surface of the ground, it is necessary before enclosing it in conduits to consider the physical condition of the inhabitants, if they are robust and have good color, and are not subject to diseases of the limbs or runnings from the eyes, the water may be considered fit for use. To test the quality of the water of a newly discovered spring it is necessary to throw several drops of it on Corinthian brass; and if it leaves no spots it is a sign that the water is excellent. It will be the same if, after having been evaporated, no mud or muddy deposit remains, and if vegetables boiled in this water cook quickly. Finally, we shall know that the water is light and very healthy if, being clear and beautiful in its source, it deposits in the places by which it passes neither moss, rushes, nor other impurities."

Until the 442d year after the foundation of Rome, or 310 years before the Christian Era, the inhabitants of the Eternal City contented themselves with water from the Tiber and from the most agreeable

* Lib. 8, ch. iv.

springs of the locality. They had at the foot of Mount Coelis the fountain of Mercury ; on the Palatin Hill the fountain of Saturn ; from the famous grotto of the Louvre still flows the Lupercale water ; in the same neighborhood is also the spring of Castor and Pollux.*

A. Cassio speaks also of four other springs—those of Lantulus, of Picius and Faune, of Cybele and of the nymph Egeria. For the waters of these springs and fountains the Romans had a profound veneration.

When Rome became powerful and rich she knew of no better manner in which to employ the plunder and slaves procured by her victorious arms than by constructing monuments as remarkable for their daring in architectural design as for their utility. She therefore constructed her famous aqueducts and thus availed herself of the remarkable advantage of being situated on seven hills at a distance not too great from the Apennine mountains which contain at a much greater altitude innumerable springs and lakes of pure water, by bringing for the health, comfort and luxury of her inhabitants this pure liquid to the summit of these hills by means of gravity through aqueducts, and thence distributing it throughout the city. The sources of the water of the Marcia and of the Claudian aqueducts are each 1030½ feet above their respective locations of delivery.

The water of the Marcian spring on account of its remarkable purity and agreeable taste was reserved by an edict of the Emperor Nerva for drinking.

Frontinus considered it a sort of profanation to have used this beautiful water for ordinary purposes.

The Romans having decided upon the springs or lakes from which they wished to augment the supply of water for the Eternal City, and having assured themselves that the sources were situated at an elevation sufficiently greater than that of the locality where they wished to deliver the water, first collected the water into reservoirs from which it ran through a channel built of masonry on a regular incline so that the water might run by the action of gravity to the storage reservoirs from which it was distributed, sometimes the water was made to pass through intermediate reservoirs for the purpose of purification by permitting the water to remain at rest long enough for the mud and other impurities carried along by the force of the motion of the water, to fall and be deposited on the bottom of the reservoir.

Near the seventh mile stone from Rome, on the Latin road, six of

* Belgrand, *Idem* p. 17.

the aqueducts emptied their supply of water into covered wells or reservoirs, from which the water continued its journey through aqueducts to the walls of the city, where it was received in "castelli,"* or water-towers, which were structures built of masonry enclosing a basin, near which were three reservoirs fed from the basin by three pipes which distributed the water equally.

These reservoirs were so placed that the centre one would receive in times of abundance the surplus water of the other two. From this reservoir of the centre the water was distributed to the public fountains and amphitheatres. The public baths were supplied with water from one of the other reservoirs. Private establishments obtained from the third reservoir their supply of water.

The water towers of the Julia and Claudia aqueducts were very important monuments, the ruins of which still remain.

Besides the public water towers there were private and special towers, which in the time of Frontinus numbered in the city of Rome 247. The public towers received the water directly from the aqueduct or from a branch of it, from which a portion of the water ran continuously through leaden pipes into the public fountains of the vicinity from which most of the people obtained the water necessary for domestic purposes.

The inhabitants of those portions of the city more distant from the public water towers into which the aqueducts emptied, were supplied with water from special towers to which the water was brought by conduits from the public towers. Private dwellings were supplied directly from the nearest water tower, or when situated at a too remote distance, the wealthy inhabitants were accustomed to build private towers for their special use. These towers and the dwellings were each supplied by their special conduits in lead or pottery; each conduit receiving its amount of water from an opening in the water tower, to which was attached horizontally a bronze pipe or gauge of a diameter and length, regulated by law, in proportion to the amount of water to be supplied; this diameter was maintained for a distance of twelve digits or nine inches, for if the opening alone were of the required diameter and a larger pipe were attached, immediately the pressure on the water would cause it to fill the larger pipe and thus supply a greater amount of water than that granted by the concession. This bronze pipe was therefore a sort of meter, which, if properly placed

* Vitruvius, lib. 8, ch. vi.

and the water of the reservoir maintained at a certain elevation, would indicate the amount of water supplied. From this gauge or meter the water was conducted through conduits in lead or pottery under the paving of the streets to the dwelling of the consumer, where it ran continuously, day and night, from a fountain, into a sort of basin or reservoir called the "impluvium," which occupied the centre of the interior court or "cavaedium," forming a part of the "atrium" or vestibule characteristic of the dwellings of the wealthy Romans.

This arrangement can be seen in all the larger houses at Pompeii; the smaller houses were not supplied with water, the artisan dwelled in his shop and procured the necessary supply from the public fountain.

The houses were thus supplied by water through special conduits directly from the reservoir, the water ran continuously in the court of the dwelling, and not through a large conduit, distributing the water to all the houses near which it passed, nor was the water distributed throughout the dwellings as is customary at the present day.

This mode of distribution rendered the expense of a private supply of water very great, for in addition to his portion of the expense of the maintenance of the tower of the district, the proprietor was obliged to bear the expense of laying the pipe, repaving the street, and maintaining in repair this conduit which was often necessarily of great length.

Through this custom of permitting the water to run continuously, much the greater quantity distributed for public and private service ran to waste.

The Emperor Nerva ordered this surplus water to be so used as to continuously flush the sewers and wash the streets; through some of the latter it ran continuously, a system so inconvenient that it would not be tolerated at the present day. Indeed, it would seem that the Eternal City would have become uninhabitable but for this abundant supply of water.

Frontinus considered this employment of the surplus water as one of the benefits of the reign of the Emperor Nerva, he says, "that the super-abundant water was no longer useless, the sanitary condition of the city was already changed, the air purer, the causes of that pernicious air, of that infamous air of the city of our forefathers were destroyed."

Vitruvius has left us a detailed account of the manner in which very long valleys could be crossed by means of the syphon; but the

Romans were only able to employ the syphon where but a small quantity of water was required, for they had not made sufficient advance in the working of metals to be able to economically employ any but lead pipes, and these were of such an inferior quality that the force of the water would often burst the pipes, especially in the curves.

According to the very careful calculations of M. Belgrand,* the water entering the nine aqueducts existing at the ascension of the Emperor Nerva, amounted to 252 million gallons each twenty-four hours, corresponding to about 252 gallons for each inhabitant of the city; about 27 million gallons of water were extracted inside and as much outside the city, in the name of Cæsar for the use of Imperial property, but much the larger quantity estimated at $83\frac{1}{2}$ million gallons was extracted by fraud.

Frontinus tells us that he found fields irrigated, taverns and drinking places supplied by water, the proprietors having fraudulently turned the public water from the aqueducts.

Frontinus applied himself so assiduously to prevent these fraudulent extractions of water and with such success that he says, "the quantity of water recovered could be regarded as a new acquisition."† According to M. Belgrand, the amount of water was thus increased to 132 gallons for each person every twenty-four hours.

The water conceded for the public service in the time of Frontinus supplied 19 fields, 39 amphitheatres, 591 fountains and lakes, and 94 public establishments.

In the beginning the distribution of water for the city of Rome was very simple; all the water ran from the reservoirs into the public fountains, individuals could only use the water which fell from the inlet of the fountain into the basin. This water, after it had run from the basin of the fountain, was conceded to the public baths and for the use of fullers, they having obtained the right in consideration of paying an annual water-rent to the public treasurer.

Later, the water which escaped from the aqueducts through leaks was sometimes granted by concession to individuals. Frontinus‡ very justly remarks that these concessions favored frauds of many kinds, and were consequently very rarely granted by the emperors.

* *Les aqueducts Romains*, p. 98 and 105.

† Frontinus, ch. lxxvii.

‡ *Id.* chps. cx and cxl.

The administration of the water-supply was confided sometimes to those holding the office of "censor," and at other times to those holding the office of "edile." The maintenance of the aqueducts was ordinarily contracted for, and the contractor was obliged to keep a certain number of slaves employed on the aqueducts. The names of these workmen, their duties, and the location in which they were to be employed were inscribed on the public bulletins. Their work was subject to the approval of the official in charge of the administration of the water-supply. The administrator regulated all the details of the service. On the days of the great performances in the amphitheatres no one was permitted to use even the most necessary water without a special order from the administrator.

There were very severe laws against those fraudently turning the water from the aqueducts; fields thus irrigated were confiscated, and the public contractors who permitted the frauds were arrested.

Those convicted of wilfully impairing the quality of the water were fined 10,000 sesterces (\$280). To insure the execution of this two citizens in each district were chosen from among the inhabitants or property-holders in the neighborhood to oversee the public water.

These laws which punished so severely offences, which by public opinion were not considered dishonorable, were consequently very inefficacious, and must have been very little better than a dead-letter, for it would have required but little attention and care to have prevented the aqueducts from being opened and the water turned away, and to have prevented the planting of trees and the building of houses over the underground portions of the channels. Nevertheless, the most scandalous abuses are noted by Frontinus as being customary.

In the year of Rome 719 the supply of water became insufficient for the wants of the inhabitants. M. Agrippa, son-in-law of the Emperor Augustus, then holding the office of edile, completely restored the then existing aqueducts and constructed at his own expense two others, the Julia in the year 719, Roman era, and the Virgo thirteen years later. He reorganized and introduced admirable order into the administration of the water-supply of Rome, opened a regular account of the receipts and of the distribution of water for public and private concessions; he made laws to insure the preservation of the aqueducts and the maintenance of an abundant supply of water. He made out in detail the amount of water to be distributed to each water-tower and from which aqueducts the supplies should be drawn, the quantity to be employed

for public use and the amount to be distributed to individuals. He employed and maintained at his own expense a *family* of slaves, consisting of 240 men for the preservation of the water-supply, the care of the aqueducts, water-towers, and reservoirs.

Agrippa, having thus rendered his term of office when edile celebrated for the care he took to increase the water-supply by the restoration of the ancient aqueducts and by constructing two new ones, and above all, by the complete reorganization of the administration, so as to insure the preservation of these edifices and the abundant supply of water, was the first to be entrusted with the superintendence of the water-supply for life.

Those charged with the administration of the water-supply of ancient Rome were chosen from amongst the most illustrious citizens. Frontinus gives the names of his seventeen predecessors, who were all great personages or belonging to illustrious families; men distinguished for military or civic virtues, successful commanders, ex-consuls, and other dignitaries, were among those considered worthy and capable of being entrusted with the superintendence of the distribution of water and the preservation of the aqueducts. They alone were held to possess the talents, experience, and integrity necessary to properly conduct this most important department of the administration of the Eternal City.

Until the death of Agrippa the administration of the water-supply of Rome had been regulated by special authority, and was subject to no general law. The Emperor Augustus confirmed by an edict the permits recorded in the registers kept by the order of Agrippa, and having inherited the slaves employed for the preservation of the aqueducts, he donated them to the State. He established the gauges by which the quantity of water was regulated and limited to 25, the number of openings permissible in each tower. He nominated Messala Corvus to exercise the functions of administrator of the water, and empowered him to make laws regulating the supply. He granted him two assistants, and to them were accorded the same marks of dignity as were given to magistrates. When they exercised their functions outside the walls of the city, they were surrounded by a numerous escort composed of two lectors, three public slaves, an architect for each of them, clerks, messengers, tipstaves and criers equal in number to those accorded to the functionaries who distributed the wheat to the people. When they exercised their functions inside the city the lictors were withdrawn.

We thus see that the dignitary in charge of the maintenance of the water-supply of Rome was empowered to exercise force in performing his duties. It was decreed that during the fourth part of the year they were to attend to the public and private demands relating to the distribution of water, but this order fell into disuse either from the negligence or from the inability of some of the administrators, although the public treasurer continued to pay the tipstaves and other employees, who ought during that time to assist the administrators.

The administrators were especially advised to prevent any distribution to individuals without an order from the prince, so that no one might obtain any public water that had not been granted him, nor any one receive more than was conceded to him.*

This law had been so much neglected that Frontinus tells us "that by enforcing it he would be able, with the quantity of water recovered, to establish new fountains, and to supply new permits of the prince, and that it was necessary at all times to prevent fraud, by an active superintendence; in order to do so successfully, the aqueducts outside of the city should be visited from time to time, and also the water towers and public fountains, to enable the administrator to become acquainted with the nature of the concessions and to insure the flowing of the water night and day without interruption."†

Frontinus, in his "*De Aquae Ductibus Urbis Romæ Commentarius*," says, "Everything confided to us by the emperor requires our greatest care, but I feel myself naturally disposed as much by duty as by taste to acquit myself well of the new functions with which the emperor Nerva, a prince as zealous as well-intentioned for the interests of the republic, has just charged me in confiding to me the administration of the water of Rome, both for their use and for their purity and safety; a function which has always been exercised by the first citizens of the State. I thought that the best way was to do in this as I have done in other circumstances, in order to well understand the object of my enterprise, and I do not believe in fact that there is a surer way to be able to judge well of what should be done and what should not be done, nor is there any thing more shameful for an administrator than to act only by the counsels of his agents, which must certainly occur when the chief, from want of experience, is obliged to have recourse to those who should be under his direction, and who, although neces-

* Frontinus, ch. ciii.

† Id. ciii.

sary, ought only to be regarded as the hands and instruments of the administrator. This is why I have followed in this the same method that I pursued in several of my other functions, in arranging in order all the information that I could obtain concerning this object, united in one body in this commentary to serve me as a guide during my administration."

Those who wished to have a concession of the public water, had to obtain permission from the prince by a letter, which, if approved, was presented to the administrator of the water supply. The latter placed the affair in the hands of his assistant, who designated to the guardians of the water tower from which the water was to be drawn, the location of the opening to be made and the size of the gauge to be attached in accordance with the quantity of water conceded.

A concession lasted as long as the person or persons lived in the locality for which the water was granted. This right could not be transferred to a purchaser of the locality nor could it be inherited with the property. But the public baths had the perpetual use of the water which had once been accorded to them.

These long concessions were rendered necessary by the expense required to conduct the water to the locality to be supplied, often a long distance from the aqueduct, and requiring the construction of a private water tower or reservoir.

When a concession became vacant through the death or removal of the proprietor, it was publicly announced.

The administrators had been accustomed to stop the distribution of water immediately on the expiration of a concession, and to sell the right to the new proprietors or to others, but the Emperor Augustus ordered thirty days to be granted, so as not to stop too suddenly so necessary a supply and to give time to make the customary demands for the renewal of the concession.

Concessions were afterwards made of the surplus water which ran from the reservoirs and from the leakage of the aqueducts. This last was very seldom permitted by the princes for it was easy to enlarge the fissure so as to supply any quantity of water desired, and this flow aided the rapid destruction of the aqueduct itself.

Frontinus having measured the quantity of water entering the aqueducts, and having ascertained that it greatly exceeded that which was registered as having been employed for public use, or granted by concessions, set to work to find by what negligence or fraud this great quantity was lost to the state and to understand how to prevent it.

He tells us that he found gauges of a diameter larger than was permitted by the concessions, some of which were not marked, which proved the dishonesty of the agent who controlled the placing of the gauges, he having been bribed to furnish more water than was justly due.

In certain water-towers the gauges were of the right size at the opening but instead of maintaining, this diameter for the distance required by law, a larger tube had been attached to the opening, thus furnishing more water than allotted by the concession as already described.

The locations of some of the openings were below that of others, thus on account of the greater pressure upon the lower openings they supplied a proportionately greater quantity of water.

In several towers, pipes were attached to the openings without any gauge, but were so arranged that they could be enlarged or contracted at the will of the guardian.

Another very reprehensible fraud on the part of the guardians was, when a concession changed hands, instead of using the old opening to supply the person obtaining the renewal of the concession, to pierce a new opening and to sell the water from the former for their own interest. Frontinus adds that the suppression of such a fraud should attract the especial attention of the administrator of the water, for it is his duty to take care not only of the water but also of the preservation of the towers for the latter would be very soon ruined if holes could be arbitrarily pierced.

In examining the condition of the different branches of lead pipes placed under the pavements, which circulated throughout the whole city, they were found to be pierced with holes in many places by an instrument called a "pointer," the water flowing from these holes was sold by the purveyor for his own profit to all those wishing to arrange with him, the water being lead from these openings by private tubes to the dwellings.*

A large quantity of water destined for public use was turned from its legitimate course in this manner as Frontinus† proved by the increased amount received at the outlet of several pipes after the holes had been closed.

The labor required to preserve the aqueducts and to maintain a

* Frontinus, ch. cxiv.

† Id. ch. cxv.

proper distribution of the water, was performed by the men of two families of slaves.

One family* belonged to the public, having been inherited from Agrippa by his father-in-law, the Emperor Augustus, who gave them to the State as already mentioned. This family comprised about 240 men.

The second family, consisting of 460 men, belonged to the family of Cæsar, and was established for this purpose by the Emperor Claudius when he built his aqueducts. These men were classified according to the work they were required to perform; into guardians of the water-towers, inspectors, pavers, pipemakers, and laborers. A certain number of these men were required to live outside the city, in order that they might be able to repair promptly any damage caused by accidents to the aqueducts, for although the damage might be slight at the time of occurrence the force of the running water would very soon increase very materially any crevice in the masonry through which it might escape, and thus not only delay the supply of water to the city, but destroy the foundations of the aqueduct. Some of the guardians were lodged in the water-towers. All the other men dwelt in the vicinity of the water-towers and amphitheatres which were supplied with water, and were expected to continually hold themselves in readiness to aid in abating any damage caused by accident, and when necessity required to aid in directing the supply of water ordinarily running to several districts at once into any special district requiring immediately a more abundant supply.

Frontinus tells us that he found that these men, through the negligence of the overseers, were accustomed to leave the duties required of them for the public good and to work for their own individual profit.

To re-establish and keep order amongst so great a number of men as composed these two families, Frontinus required that the work to be performed on the morrow should be designated the previous evening; he also kept a record of the work performed each day.†

These men were paid by the public treasurer, and this expense was defrayed by the money paid for concessions of water. This amounted, in the time of Frontinus, to 250,000 sesterces‡ annually; this revenue

* It will be remembered that *familia*, a family, means properly, the servants belonging to a common master.

† Fr., ch. cxxiii.

‡ This amounts to but \$8,500 of our money, but the great difference of relative value must be taken into consideration.

was often taken for other purposes. The Emperor Domitian used it for his own benefit; Nerva caused it to be returned to the public treasury.

The expenses of the supply of water for Imperial properties were paid from the public treasury, as were also those for pipes and all expenses relative to the maintenance of the aqueducts, water-towers, and reservoirs, or public fountains.

The maintenance of the aqueducts was the especial care of the administrator, for they were exposed to many and frequent causes of damage, which it was necessary to foresee and prevent.

Accidents were occasioned by the ravages of age, by exposure to intense cold and heat, by the violence of tempests, through the fault of badly constructed work, and by the dishonesty of the proprietors of the fields adjoining the aqueducts, who fraudulently caused the water to escape from the channels in order to irrigate their land.

Those portions of the aqueducts supported by arcades suffered most from the effects of age and the violence of the mountain storms. Where the arcades crossed the rivers the foundations were much exposed to the violence of the current in times of floods. The channels in masonry along the flanks of the mountains were exposed to landslides and many other causes of accident.

It was necessary to bring to the execution of all work required to prevent these accidents, and the consequent interruption of the supply of water, great activity, and to have the work performed with great care.

The channels underground suffered less, not being exposed to the effects of intense cold or heat. Accidents to the channels could sometimes be repaired, while still maintaining the supply of water, by carrying it across or around the break through a temporary channel made of lead pipes held at the proper elevation.

A frequent obstruction to the passage of the water was the gradual deposit of mud on the bottom and sides of the channel, which formed in time hard and thick incrustations, and which gradually narrowed the channel till the passage of the water was finally entirely prevented. Sometimes the mortar would drop out and permit the water to escape, which would damage the walls of the channel and the masonry supporting it.

Only those repairs that were absolutely necessary were permitted during the heats of summer, so as not to interrupt the distribution of water

at the season when its use was the most required. Spring and autumn were recommended for this work, as the season most suitable, when the fresh masonry would not be exposed to the intense cold of winter, which would freeze the mortar before it was "set," nor would it be exposed to the heats of summer, which would absorb the moisture in the mortar and thus prevent it from forming a solid mass with the stones; for intense heat is as injurious as intense cold to fresh mortar. Moreover, there is no work which demands as much skill, precision and care as masonry required to prevent the escape of water; each piece must fit exactly according to the rules which most masons understand and few observe.* By preparing in advance all material required, and working with the greatest celerity, the passage of water was interrupted for the shortest possible period, and by working on but one aqueduct at a time, the city was not deprived of too great a quantity of water at once.

The administrators were empowered by the Senate when repairs were to be made to the aqueducts, to procure earth, clay, stone, sand and wood from the adjoining fields and have them transported across the fields if necessary, the damages having been previously appraised.

Fifteen feet were ordered by the Senate to be reserved on either side of the channels, no buildings nor trees being permitted within that space except where the aqueducts were entirely under ground, when the space was reduced to five feet. This law had fallen into such disuse that proprietors often enclosed this ground within their fields and used it for their own convenience, building and planting upon it as they pleased, and making roads over it, and even going so far as to prevent the employees of the administrator of the water supply from visiting those portions of the aqueducts, and thus these constructions were, from want of proper and timely attention, gradually destroyed. The real and prime cause of the destruction of the aqueducts was the negligence of the administrators entrusted with the care of the preservation of these magnificent testimonials of the civilization of ancient Rome; the workmen appointed to attend to the repairs profiting by the negligence, and following the examples of their masters, neglected their allotted work and attended to private affairs.

Pliny tells us that long before his time the City was deprived of the benefit of the water from the Marcia, the Julia, and Virgo aqueducts that the proprietors of the land adjoining the aqueducts had turned all the water to their own use; nevertheless, the water from these aqueducts

* Frontinus, ch. ex

continued to figure on the public register as amounting to 2242 quinaires daily, exactly as if it were regularly received and distributed.*

It is evident from what has been said in regard to water-supply that modern cities have not advanced beyond ancient Rome; indeed, in regard to abundance, no city has ever yet even contemplated supplying to its inhabitants such a large quantity. There, there was an abundant supply for every purpose; that which was used for drinking purposes was brought from a great distance and its freshness was retained by bringing it through conduits of stone and keeping in covered reservoirs, where it was exposed to the action of the air and at the same time protected from the rays of the sun. Great care was taken to prevent any pollution. As to the abuses in ancient Rome of the public water, it is not the place of the writer, nor his object, to remark upon them, or to make any comparison with those of modern times.

Many of the larger cities of both the old and new world have either recently imitated ancient Rome or are now contemplating so doing, by procuring their supply of water from long distances, from localities removed from all causes of pollution, and bringing it to the inhabitants by means of gravity through aqueducts.

OIL DRESSED BELTING.

By JOSEPH SHARP.

[Read at the Stated Meeting of the Franklin Institute, September 19, 1883.]

Transmission by belting is the rule, rather than the exception, in American manufactories and shops.

It has the advantages of high shaft speed, wide shaft distance, cheapness, and lightness, and of slipping in case of a clog in the machinery, thus preventing serious loss and accident by breakage.

One thing which sometimes stands in its way is that it is not as sure, under very heavy work, as gears are, and requires for such heavy work very great pressure on bearings, to prevent slipping.†

The very principle of its action demands a certain amount of slipping, say from 2 per cent. as a minimum, to 15 per cent. or 20 per cent. as a common occurrence.

This cuts it out from many applications where regularity and proportion of velocity-ratio are necessary.

* Pliny, lib. 31, ch. xxv.

† The minimum slippage, with one belt, is 2 per cent.; where there are several belts between the motor and the machine there is proportionately more slip.