Hypogea 2015

Proceedings of International Congress of Speleology in Artificial Cavities
Italy, Rome, March 11/17 - 2015

EDITORS

Mario Parise
Carla Galeazzi, Roberto Bixio, Carlo Germani

TRAJAN AQUEDUCT: THE SANTA FIORA BRANCH

Carlo Germani [1], Vittorio Colombo [2]
[1] Centro Ricerche Sotterranee Egeria – www.speleology.it
[2] Roma Sotterranea – www.romasotterranea.it

Reference Author: Carlo Germani, Via degli Opimiani, 21 – 00174 Roma, carlo.germani@gmail.com

Abstract
The *Aqua Traiana* aqueduct, built by Emperor Trajan in 109 A.D., was the tenth of the eleven aqueducts of ancient Rome. It collected water from many aquifer sources in the hills around the volcanic basin of Lake Bracciano, in the Sabatini Mountains, and reached Rome with a mostly underground conduit. One of the *caput aquae* of the aqueduct was located SE of Oriolo Romano, in an area that is today known as Santa Fiora. From here a duct descended to the lake to join a similar duct coming from the Grotte Renara Valley. Unlike the latter, the Santa Fiora branch was cut sometime in the past between the sixth and ninth centuries and never restored, thereafter forgotten. By carrying out a thorough investigation on the territory, the authors found and explored it, reconstructing the route in detail. Here we try to explain the construction characteristics of the duct, including its wells and creek crossing. Finally we discuss the way in which the water could drop the considerable difference in height between the sources and the lake.
Keywords: artificial cavities, underground aqueducts, roman aqueducts, Traiano, *Aqua Traiana*.

Riassunto
L'acquedotto Traiano, realizzato per volere dell'imperatore Traiano nel 109 d.C., è il decimo degli undici acquedotti di Roma antica. Raccoglieva le acque di molte sorgenti attorno al lago di Bracciano, sui monti Sabatini, e raggiungeva Roma con un percorso in gran parte sotterraneo. Uno dei caput aquae *dell'acquedotto era situato a SE di Oriolo Romano, in una zona nota oggi come Santa Fiora. Da qui un condotto scendeva verso il lago per ricongiungersi con un analogo condotto proveniente dal fosso di Grotte Renara. Diversamente da quest'ultimo, il ramo proveniente da Santa Fiora fu tagliato in un'epoca imprecisata tra il VI e il IX secolo e mai più ripristinato, tanto da essere del tutto dimenticato. Gli autori, effettuando una accurata indagine sul territorio, hanno potuto ritrovarlo ed esplorarlo, ricostruendone dettagliatamente il percorso. Vengono illustrate le caratteristiche costruttive del condotto, dei pozzi e degli attraversamenti dei fossi. Viene infine discusso del modo con cui le acque superavano il notevole dislivello esistente tra le sorgenti e il lago.*
Parole chiave: *cavità artificiali, acquedotti sotterranei, acquedotti romani, Traiano,* Aqua Traiana.

Introduction

The *Aqua Traiana* aqueduct, built by Emperor Trajan in 109 A.D., is the tenth of the eleven aqueducts of ancient Rome. It collected water from many aquifer sources in the hills around the volcanic basin of Lake Bracciano. With an overall length of 57 km, it reached the city with a largely underground path along the Triumphal and Clodia streets, leading to arches along the Via Aurelia and finally entering Rome on the Janiculum hill, on the right bank of the Tiber River (Fig. 1).
Thanks to Sextus Julius Frontinus, superintendent of the aqueducts at Rome and author of the famous *De aquaeductu Urbis Romae*, we know many information about the previous nine aqueducts. The successors of Frontino, who died in 104 A.D., did not edit any further update unfortunately, so that historical information related to the Trajan aqueduct is very scarce.
After the fall of the Roman Empire, the aqueduct was broken and repaired several times, to be completely abandoned around the ninth century. In the seventeenth century, Pope Paul V had it completely rebuilt, and renamed it *Acqua Paola*. During the work, led by architects Giovanni Fontana and Carlo Maderno, most of the sources of Trajan were recovered, except those from the area that is today known as Santa Fiora, because the owners of the area - first the Orsini and later the Odescalchi - reserved the rights of possession: at the beginning they needed the water for their mills at Vigna Grande (Fea, 1832), and since 1698, to power the aqueduct Bracciano Orsini – Odescalchi, which reached the town with a route partly underground and partly on arches.
As a consequence, the overall amount of collected spring water turned out to be insufficient: to increase the flow rate, water from lake Bracciano was added to the spring water, at the expense of the quality of the water, which degraded to so little value, as to become proverbial.

The sources at Santa Fiora

The outermost sources of the Trajan aqueduct from Rome were located along the Grotte Renara Valley, E of Manziana. SE from here a branch of the aqueduct reached the lake and circumvented it clockwise, intercepting water from other sources along its way.
Another branch of the aqueduct originated SE of Oriolo Romano from a rich source area that is today known as Santa Fiora. It descended to the lake, too: along the left bank of the Santa Fiora ditch initially, then pointing

Fig. 1: path of the Trajan aqueduct.
Fig. 1: tracciato dell'acquedotto Traiano.

NE until it connected to the branch coming from Grotte Renara. This duct, therein called "Santa Fiora branch", had never been either identified or described, and is the object of this study (Fig. 2).

It seems the ancient spring area was made of several capture systems involving a number of monumentalised hydraulic relics such as the Nymphaeum of Santa Fiora and the Nymphaeum Carestia (Italian for "Famine").

The Nymphaeum of Santa Fiora, whose name dates back to the eighteenth century, is a rather complex structure to date little studied although of great charm and historic and artistic interest. It probably originated from a large underground construction dedicated to a local Nymph or Deity, upon which, during the Renaissance, a chapel with a now lost bell tower was erected and dedicated to the Virgin Mary (for further details see QUILICI, 2009).

The Nymphaeum "Famine", whose name dates back to the Middle Ages, is located approximately 500 meters NE of the above and is completely ruined. Its connection with the catchment tunnels upholstered with *opus reticulatum*, originating from the neighboring spring called "del Gatto", is uncertain. This was a large construction, perhaps bigger than the nympheum of Santa Fiora. At present, no extensive study or excavations have been carried out yet.

Existing literature about the Santa Fiora branch

The literature on the Paula aqueduct is pretty large, and all aspects of the structure have been extensively analyzed since the Renaissance. Therefore we know sources and path in detail for the branch of the Trajan aqueducts that originates from Grotte Renara, because it was rebuilt into the Paula Aqueduct. Regarding the Santa Fiora branch, despite the field research carried out by some authors, not much is known instead, mainly because it was completely abandoned since the ninth century at least.

Alberto Cassio, an archaeologist from the eighteenth century, in his work *"Corso dell'acque antiche..."* (1756), wrote: "*At the time of Trajan, springs were located in three areas; they were more than present, because those who came from the Fiora valley are lost*" (CASSIO, 1756, XXI, 6). In 1756 the aqueduct Orsini-Odescalchi, which in S. Fiora had and still has its well-springs, was already operational. It is therefore likely that Cassio did not relate the word "lost" to the sources, that were well known at the time, but to the duct leading from the sources to the other branches of the aqueduct around the lake.

In 1825, Antonio Nibby (1792-1839), historian, archaeologist and academic in ancient topography, tried to trace the sources that Cassio had mentioned. While surveying the area between Oriolo, Bracciano and Vicarello together with his friend Giacomo Palazzi, Nibby identified many sources, especially around the Fosso di Grotta Renara valley. The Fosso della Fiora valley is described as "a stream of clear water" (NIBBY, 1849).

A few years later, Thomas Ashby (1874-1931), well known archaeologist and photographer, went to the area to find the source of Trajan (ASHBY, 1935). At Santa Fiora he found a "ruined chapel" (now known as the Nymphaeum of Santa Fiora) and, some hundred meters to the E, a ten meters long stretch of *specus* that the Santa Fiora river had cut (see note 1). Ashby *"could find no further fragment of the aqueduct in going down the valley of the Fosso di Fiora"*. Ashby explains the absence by the fact that the Fosso di Fiora is cut by no side valley in which the channel might come out to daylight, so the channel remains hidden. He draws the conclusion that it might be worth searching further, especially at the junction of the Santa Fiora branch with the present main line, which he assumed to be in Vigna Grande. We now know that this assumption was wrong. All other authors, both "classic" and contemporary, only quote the sources we described above.

Genesis of the project

In the introduction to "The triumphs of water" Dr. Giuseppina Pisani Sartorio writes: *"... very few bothered to go over the path of the ancient aqueducts again, in order to analyze them with more updated and accurate techniques, before it's too late: because either time, the carelessness or the habitual lack of resources of the responsible organizations will let them be destroyed completely ... There is still much to learn, discover, excavate, measure, draw, detect, photograph and understand, before these traces disappear permanently"* (PISANI SARTORIO, 1986). Since 1986, the year in which these words were written, little seems to have changed unfortunately, in the context of knowledge about the ancient aqueducts of Rome. The current activity is a response to this plea, in an attempt to fill some of the many gaps.

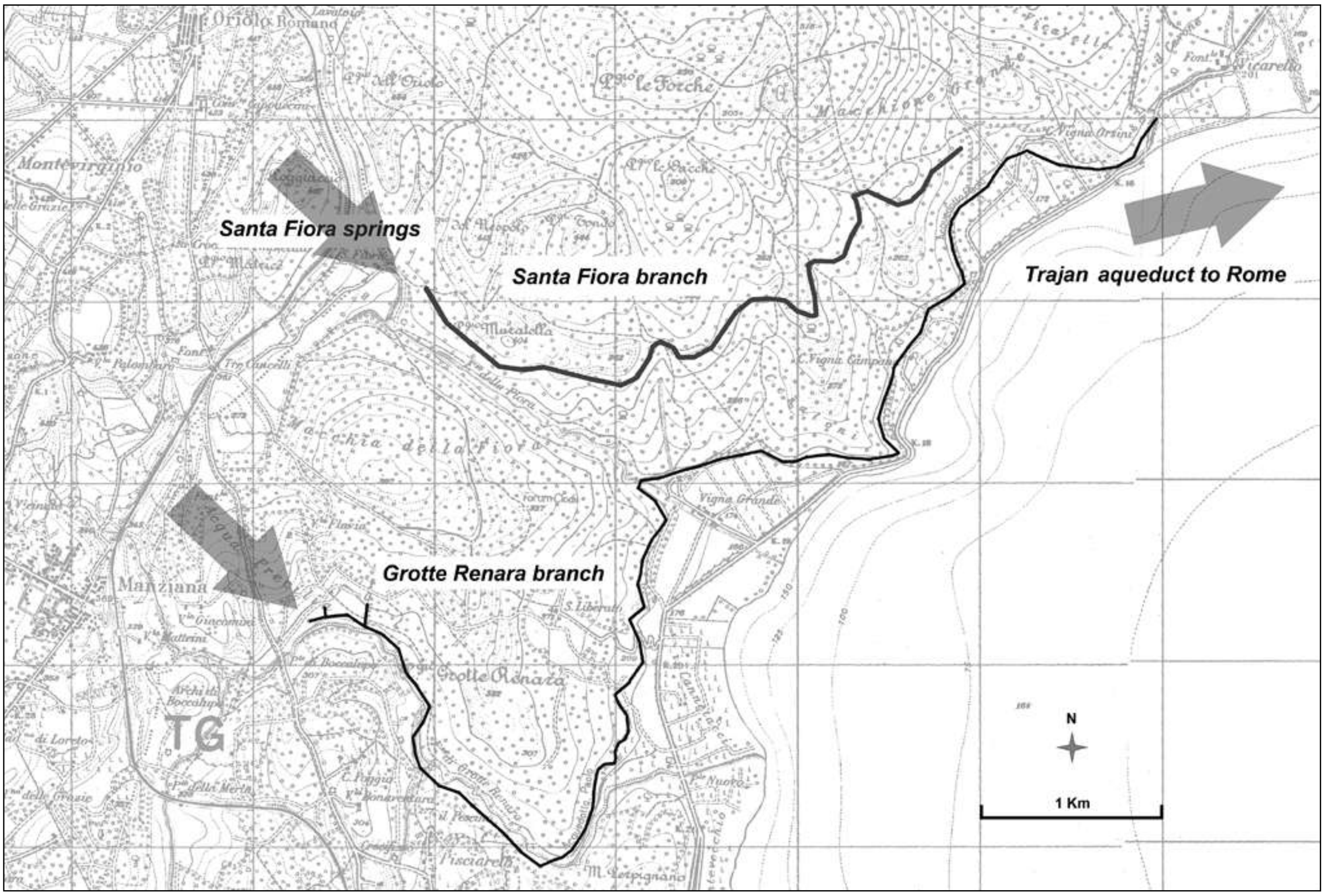

Fig. 2: area of the main sources of the aqueduct Trajan.
Fig. 2: area delle principali sorgenti dell'acquedotto Traiano.

Due to the same lack of knowledge that Pisani Sartorio reports, until now the Trajan aqueduct has been conventionally represented on map by a very approximate path, almost faithfully tracing the path of its modern replacement, the Aqua Paola. How good this assumption is, is still to be verified; anyway such a path does not include the springs at Santa Fiora, that are recognized as the main springs. How were the sources in Santa Fiora connected to the rest of the aqueduct?
Since summer 2012, a group of cavers of the Underground Research Centre "Egeria" (CRSE) and Underground Rome (*Roma Sotterranea*, RS) has conducted a thorough investigation on the territory, that has led to the rediscovery and exploration of this forgotten branch of the aqueduct, which runs mostly underground, and was up until now unknown.
The beginning of the "rediscovery" originated from a joint exploration in the footsteps of Tullio Dobosz, who had identified a stretch of wall in *opus reticulatum* immersed in the valley of Santa Fiora. It soon became clear that we were facing the outer cover of an ancient Roman aqueduct: due to location and altitude, it could only be the branch of Santa Fiora of the Trajan aqueduct. In the following months a careful and laborious exploration of the woods has enabled us to reconstruct in detail the location of the lost branch.
It was not easy, as the aqueduct runs almost entirely underground and the undergrowth and bushes are very thick, with compact brumbles. We had to look, one after another, for well holes and collapses, making our way with difficulty through the undergrowth (Fig. 3).
During one year in the field more than one hundred datum points were numbered and identified with plastic tags. Each feature was localized by GPS, with a margin of error generally within a few meters (Fig. 4).
In overall, 25 substantially intact wells were identified (squares in Fig. 4), while the remaining datum points identify other entry points to the channel, such as ceiling or side walls or well collapses - sometimes unidentifiable.

Fig. 3: one of the entrances to the duct located in the wood (photo C. Germani).
Fig. 3: uno degli accessi al condotto individuato nel bosco (foto C. Germani).

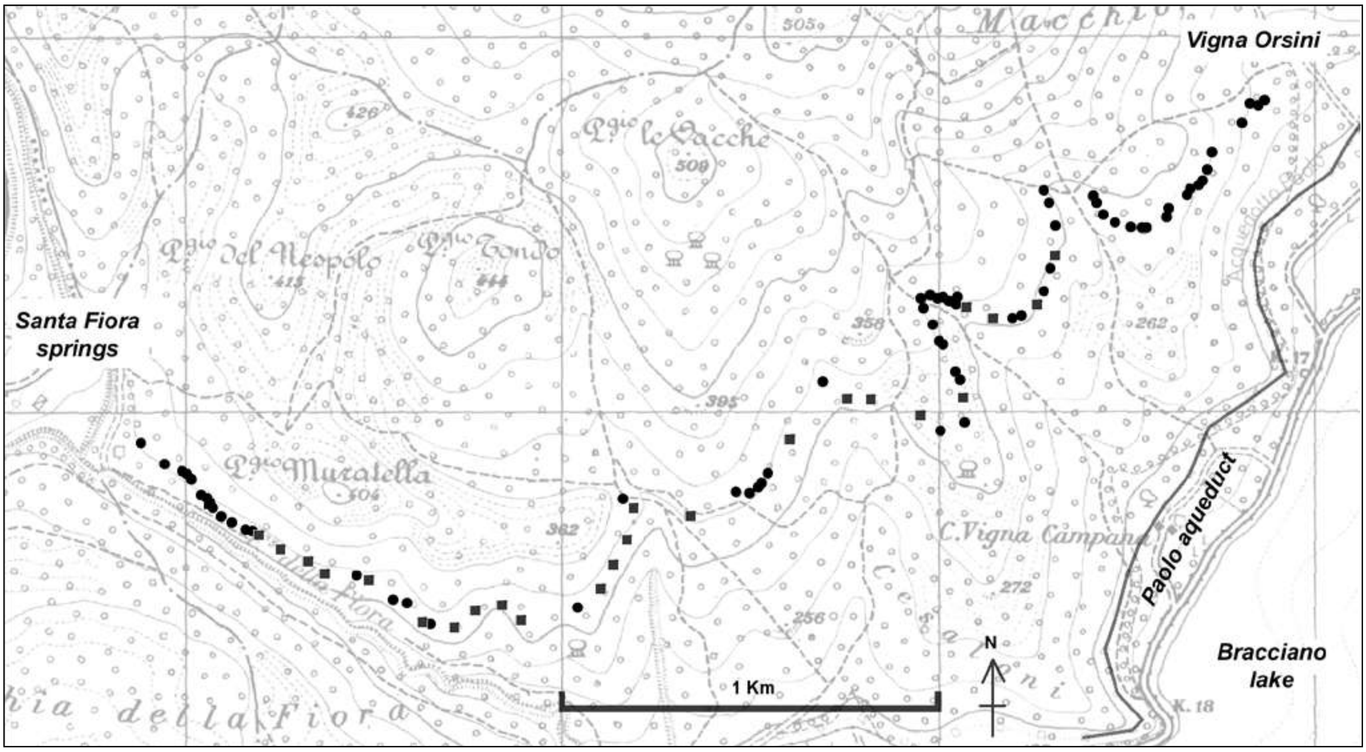

Fig. 4: sequence of points received from GPS. Squares indicate the wells definitely identifiable as such, the other points are sinkholes of various origins.
Fig. 4: serie dei punti rilevati tramite GPS. I quadrati indicano i pozzi sicuramente identificabili come tali, gli altri punti sono sprofondamenti di varia origine.

Description of the path

The path of the branch of Santa Fiora winds through the woods between the springs and Vigna Orsini, on the shores of Lake Bracciano, adapting to the geomorphology of the area and substantially following the contour lines around 300 m a.s.l. (Fig. 5).

Starting from the springs, the first remains of the duct can be seen today about 500 m SE of the Santa Fiora nymphaeum, at an altitude of about 320 m a.s.l., at the entrance of a large underground hypogeum carved into the tufa, probably made for agricultural or pastoral usage. As the cave cuts the channel, it evidently originated after the last use of this branch of the Trajan aqueduct. The conduit is accessible and runs 70 m SE with a slight slope before a first interruption. By continuing on the surface while maintaining altitude and direction we are soon able to find a new stretch of the underground aqueduct that was accessible for 40 m, and so on in a similar sequence for the entire length of the channel.

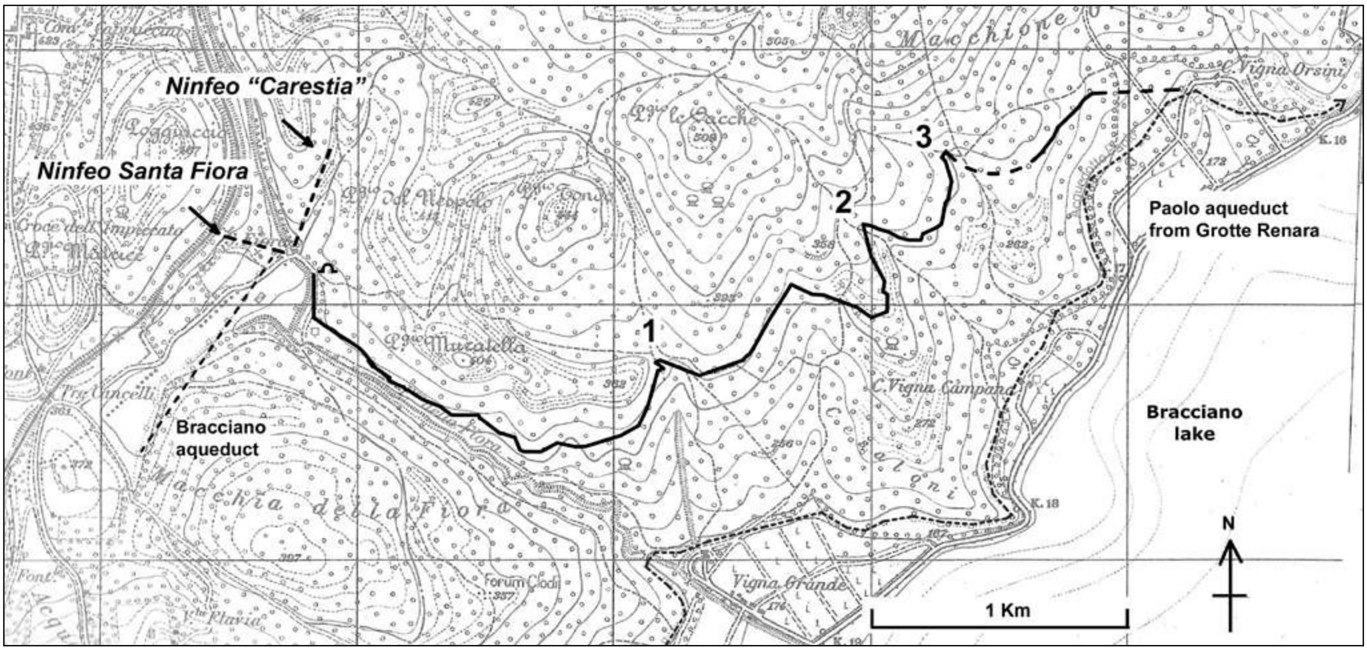

Fig. 5: path of the branch of Santa Fiora.
Fig. 5: tracciato del ramo di Santa Fiora.

Fig. 6: one of the 25 wells detected (photo V. Colombo).
Fig. 6: uno dei 25 pozzi rilevati (foto V. Colombo).

Fig. 7: a sinkhole that allows access to the underground conduit (photo C. Germani).
Fig. 7: uno sprofondamento che consente l'accesso al condotto sotterraneo (foto C. Germani).

After about one km, the channel changes direction and heads NE, following the contour line at approximately 300 m a.s.l.
As discussed above, most of the route is recognizable either from the wells (Fig. 6), many of which have collapsed, or from sinking of various origins (Fig. 7) or from the remnant trench, whenever an entire section has collapsed. Between an opening and the other of the channel, regardless it is hazardous or due to a ventilation shaft, the tunnel is usually found intact. It shows all the charm of an "Imperial" hydraulic work, the result of a mature technology, made with a very high constructive standard that maintains uniform characteristics for tens of kilometers (Fig. 8).
In the accessible stretches the construction is intact: it seems just assembled and ready to be used again. The waterproof plaster is white and in perfect conditions, like the *opus reticulatum* coatings. The curbs at the base of the channel are steady and fast. The wells have a solid masonry still visible. The *pedarole* (footholds) which allowed access to the channel are well defined and still usable.

Fig. 8: the conduit aqueduct Trajan, branch of Santa Fiora (photo C. Germani).
Fig. 8: il condotto dell'acquedotto Traiano, ramo di Santa Fiora (foto C. Germani).

Fig. 9: the crossing of the first ditch with water streams (photo V. Colombo).
Fig. 9: attraversamento del primo torrente (foto V. Colombo).

In correspondence of ditches with water streams, the channel still follows the level curve at a shallow depth up to the point where it either crosses the water stream on a small bridge, or underpasses it at minimum depth. Then the duct continues along the other side of the ditch. We have identified three crossings (see fig. 5). The first raises particular interest as it is probably a bridge. The channel comes out of a hillside and flows into the opposite side, keeping the same section and remaining visible for 20-25 m. The outer wall is adorned on both sides with a decorative brick pattern that is repeated at regular distance (Fig. 9). The structure was almost invisible, completely surrounded by brambles: its study required a painstaking deforestation.

On the right hand side of the bridge, upstream, there is a square opening of 22 cm at the base of the channel, coeval to the bridge. The purpose of the hole is unclear, perhaps it is a side discharge used for the maintenance of the aqueduct.

The part of the bridge below the channel, and the arches, if any exist, are hidden by the landfill that has progressively raised the bottom of the valley. A brick facing is visible.

The second crossing would seem an underpass. The outer wall, faced in bricks, is visible for a couple of meters immersed in the mud of the stream that leaps over it like a weir.

The same probably applies to the third crossing, in a valley very altered by a forest track, on the bottom of which the aqueduct is visible, unfortunately uncovered and landfilled by bulldozers (Fig. 10).

For each of these three artifacts, further investigation would require excavation[1].

After more than 4 km at about 300 m a.s.l., the aqueduct reaches the esplanade of Vigna Orsini, situated a hundred meters below.

The duct maintains its construction properties and remains just below the surface, but it gradually increases its slope until an inclination of 18°, heading for what was to be the conjunction with the branch coming from Grotte Renara. The kinetic energy accumulated in this steep descent was evidently dissipated with the system of the steep chute (see below). Unfortunately, in the lower half of the slope there are no visible remains of either the channel or the hydraulic expansion chamber or the junction with the other branch. That is not surprising, since the physiognomy of Vigna Orsini has changed dramatically over time.

1) In addition to these, Ashby describes how, at the very beginning of the duct, the aqueduct passed the river Fiora by a structure that was to be impressive, with a wall of high support “10-15 meters”. Ashby locates it with unusual precision: “125 m due east of the ruined chapel of S. Flora [sic] and east of the railway (..) about 300 m south-east of casello 51.144” (Ashby, 1935, p. 300). Some authors have interpreted this as an indication of two separate features (e.g. Virgili P., Santolini R., 1986, p. 114) but we have verified that this is the same place, described in two different ways. This area, which encloses the *caput aquae*, is not included in our study because access is restricted, and it has been profoundly altered when building the water treatment plants of the modern aqueduct. We hope that we will be permitted to access this area in order to study it.

Fig. 10: the crossing of the third ditch with water streams (photo V. Colombo).
Fig. 10: attraversamento del terzo torrente (foto V. Colombo).

Built characteristics

The duct is made with a very high constructive standard that maintains similar characteristics for the entire length. Mostly built in covered trench, it flows for almost 5 kilometers at a depth ranging from just below the floor surface up to about 6 meters.

The channel (Fig. 11) is 150-160 cm high, 85 cm wide on average, faced with waterproof plaster (*cocciopesto*) on the bottom and up to an height of about one meter. The average thickness of the *cocciopesto* is 0.06 m but for long stretches thickness reaches 10 cm. The upper side of the cladding is rounded. There is a curb of 0.08 m at the base of the channel. On the *cocciopesto* slight traces of limestone are visible due to the passage of water up to an height of about 0.45 m.

The outer walls and the ceiling are made of concrete with ashlar. The vault is about 0.40 m thick and plastered internally. The outer walls are 0.65 m thick, faced with bricks and tufa *opus reticulatum*. The tufa *reticulatum* cubes are 0.07 m square.

Looking at the uncovered parts, starting from the bottom, there is, first, a layer of *opus reticulatum* lining the concrete base resting on the bottom of the excavation trench, followed by a triple row of bipedales that provide leveling of the bottom of the duct. The walls are built upon this layer and faced with a six brick cornice, then *opus reticulatum*.

The construction sequence seems to involve a first excavation of the trench, then building the concrete platform, appropriately leveled, and finally the duct, including wells and coatings. All was eventually covered. The well size is 1.00 x 0.85-0.90 m on average, with the long sides aligned with the duct. Depth varies from 1 up to a maximum of 8 meters (Fig. 12). They are 2 *acti* distant (240 feet or 71 m), following the Vitruvian rule. They have two sets of footholds, which allowed access for maintenance. It is interesting to note that these were shaped by using a special brick with a custom shape (Fig. 13). The two shorter sides, at the opening of the duct, are structured as a arch of brick.

At the base of the wells debris is always present, with variable thickness, so that access is often prevented to either or both the stretches of channel. In many cases

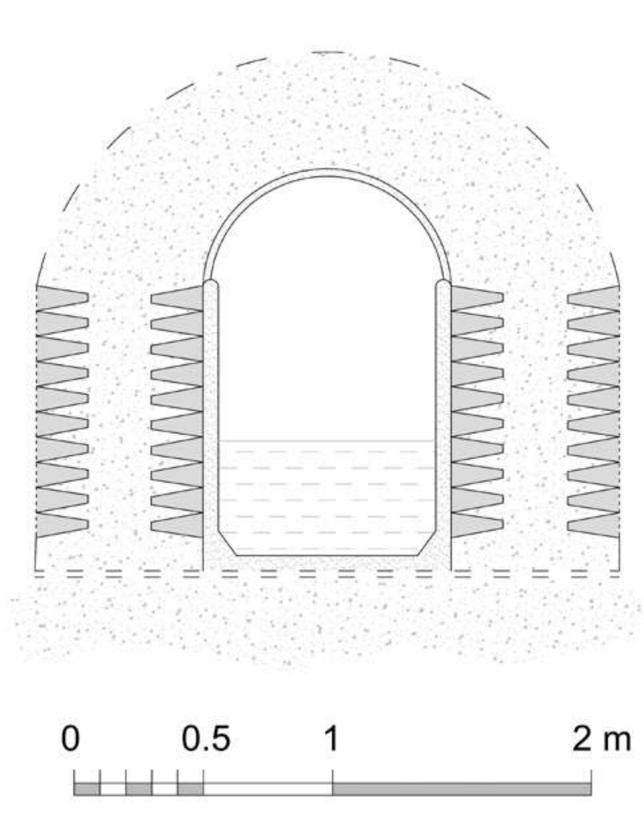

Fig. 11: section of the conduit in the underground sectors.
Fig. 11: sezione del condotto nei tratti interrati.

the gap between the debris and the vault has been used by the animals as a den. We have found no stone markers, or pit closure slabs.

Flow rate of the branch of Santa Fiora

The calculation of the flow rate of an open channel requires a significant number of parameters which, at present, are unknown. In particular, no topographic survey has been carried out for providing detailed data; consequently, the exact elevation profile is not available. Nevertheless, starting from what is so far available, it is still possible to try to make some assumptions about the flow rate of this branch of the aqueduct Trajan.

To calculate the approximate flow rate the following formula can be used:

$$Q = S * V$$

(Q = flow rate, S = wetted section, V = flow velocity)

To calculate the wetted section area we apply an average channel width of 0.84 m and an average water height of 0.45 m, that is less than the observed height of the different *cocciopesto* coatings and corresponds to the level of the slight visible traces of limestone. Therefore:

$$S = 0{,}45 * 0{,}84 = 0{,}378 \text{ m}^2$$

Similar considerations apply to the wetted perimeter (see below)

$$P = 0{,}45 + 0{,}45 + 0{,}84 = 1{,}74 \text{ m.}$$

Fig. 12: a deep wells: the tunnel is accessible from the base of the shaft, passing the pile of debris (photo C. Germani).
Fig. 12: un pozzo profondo: il cunicolo è accessibile dalla sua base, superando il cumulo di detriti (foto C. Germani).

Fig. 13: the footholds made by special bricks (photo V. Colombo).
Fig. 13: le pedarole realizzate mediante mattoni appositamente formati (foto V. Colombo).

Mean flow velocity can be obtained from the Chézy rule:

$$V = C * \sqrt{(R * I)}$$

(C = Chézy coefficient, R = hydraulic radius, I = slope)

Several formulas are known for the calculation of the coefficient C, such as the Bazin equation,

$$C = 87 / (1 + y/R)$$

where y = 0.10 is the roughness coefficient for smooth concrete, while R is calculated as:

$$R = S / P = 0,21 \text{ m}$$

where S is the wetted section, and P the wetted perimeter.
The channel slope has greater uncertainty, because we do not have, at present, an exact elevation profile. However, excluding the final drop, and assuming a total channel length of 4.5 km and an height drop of 25 meters until the beginning of the final drop to Vigna Orsini, we get:

$$I = 25 / 4.500 = 0,0055$$

This is a quite high value, but still in the slope range that is known for Roman Aqueducts.
Solving with the known numerical values we get C = 59,18; from which (rounded):

$$V = 2 \text{ m/s} , Q = 0,75 \text{ m}^3\text{/s}$$

As mentioned earlier, the value of 0.75 m^3/s is merely indicative; provided it is confirmed by further studies, it would prove to be very interesting, as it amounts to more than half of the estimated flow of the entire Trajan aqueduct, that carried about 1360 liters/s, or 1.36 m^3/s.

Therefore it seems that most of the water of the Trajan aqueduct came from this branch, thus justifying the monumentality of the Nymphaeum of Santa Fiora (and maybe even of the "Carestia" one, now in ruins), being the *caput aquae* and the main sources of the entire system.
When considering the calculated flow rate of the Santa Fiora branch, it is easy to understand why, in the Renaissance, it was necessary to connect the waters of Lake Bracciano to increase the flow rate in the restored Paul aqueduct: the sources of Santa Fiora being unavailable at that time, the actual flow was "halved" compared to the structural capacity that was inherited from the Trajan aqueduct.

The vertical drop problem
Our research on the "lost" branch of the aqueduct has been made more complex by an obvious problem of loss of altitude. While the springs at Santa Fiora are located about 320 m a.s.l., the known branch of the Trajan-Paul aqueduct runs around the lake at an altitude of approximately 180 m a.s.l. Historical sources and topography guarantee that the union of the twos had to take place before Vicarello, few kilometers away[2].

2) The area of Vicarello is the furthest from the sources of Santa Fiora where it was reasonable to assume the point

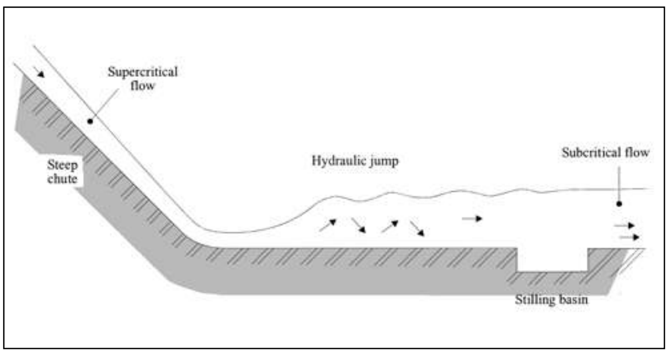

Fig. 14: steep "smooth" chute (modified after Chanson, 2000).
Fig. 14: dissipatore a cascata "liscia" (da Chanson, 2000, modificato).

Fig. 15: the segment of the 18° inclined duct (photo C. Germani).
Fig. 15: il tratto di condotto inclinato di 18° (foto C. Germani).

Therefore the Santa Fiora branch had to drop over 140 m in a relatively short distance: a drop considerably higher than you would expect from the average slope of the Roman aqueducts[3].

As no trace of the duct along the Fosso di Fiora exists, as Ashby himself annotated (1935), the alternative was necessarily a path through the woods at a height slightly less than the source, where we actually found it. However, a conduit with a mild slope would require at some point one or more structures designed to rapidly drop altitude while, at the same time, dissipating the kinetic energy of the water mass in rapid descent.

Similar structures are quite frequent in the Roman aqueducts across Europe (i.e. the aqueducts Beaulieu and Brévenne in France or Valdepuentes in Spain), but have never been seen on this scale in the eleven aqueducts of ancient Rome. Hence our interest and further stimulus in the search field.

We considered two possible designs: either "dropshafts" or "steep smooth chute"[4] (Chanson, 2000). In the first case, either one or a cascade of interconnected shafts are built, with an height that can reach about ten meters each. Dimensions are calculated so as to minimize scouring effects on the waterfall edge and on the walls.

In the second case, a stilling basin is made downstream of a steep chute in order to dissipate the kinetic energy and to restore calm water motion in the following stretch of channel (Fig. 14).

In the area immediately above Vigna Orsini, the last part of the conduit that we were able to explore shows a steep, growing slope, up to more than 18°, while no drop shaft has been observed: evidently the engineers chose the steep smooth chute design (Fig. 15).

Unfortunately, no trace could be found of the stilling basin - that may be hidden somewhere on private land. A remains of it might be identified in a pond which has now disappeared and that historical sources indicate precisely at Vigna Orsini[5].

Accurate measurement of the surviving stretches of the channel has allowed to gather a few characteristics of this steep smooth chute, such as:

- estimated length of the drop section: 365 m;

of confluence. Other possible areas were Vigna Grande (hypothesized by Ashby) and Vigna Orsini, both closer to the sources.

3) Dropping 140 meters with an average gradient of 2 ‰, that is typical of Roman aqueducts coming from the Apennines, would require a channel length exceeding 70 km.

4) A third method commonly used by the Romans, stepped channel, is not considered here as, being more sensitive to erosion, is not compatible with the huge flow rate originating from Fiora.

5) In the the website "Lago Sabatino - Archeologia, storia e storia dell'arte" (*www.lagosabatino.com/2013/acquedotto-di-traiano*), archaeologist Elena Felluca reports that, according to a print from early nineteenth century (ASO I F4), also described by von Hagen, in Vigna Orsini there was an artificial circular pond where five sources merged; then water entered into the channel coming from Grotte Renara.

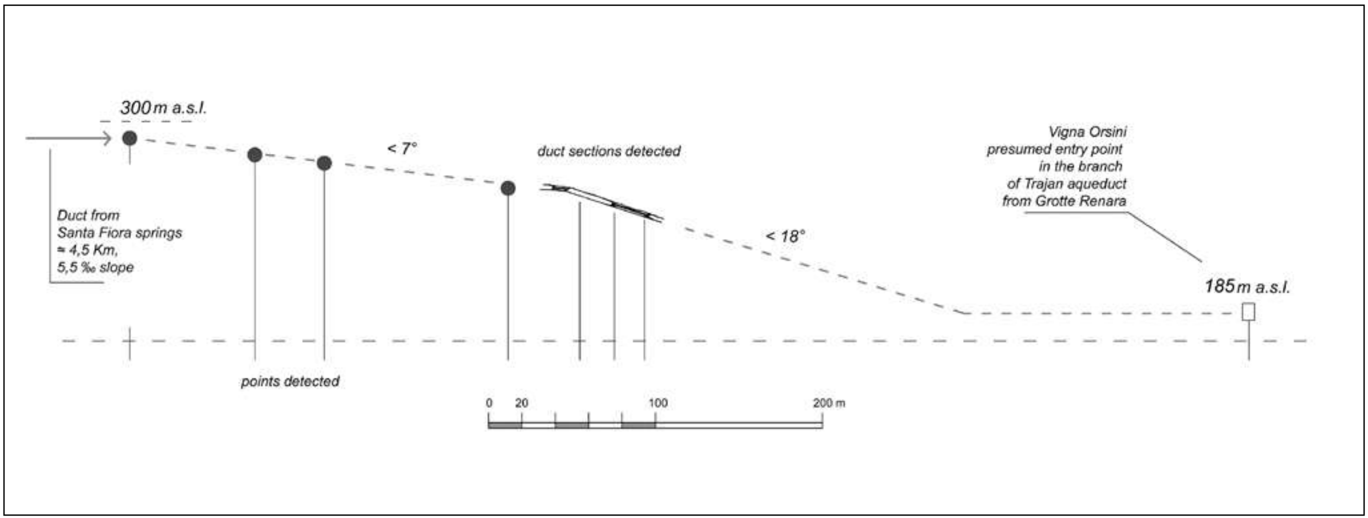

Fig. 16: section of the steep "smooth" chute previous entry of the duct from the springs of S. Fiora in the branch from Grotte Renara.
Fig. 16: sezione del dissipatore a cascata "liscia" precedente l'immissione del condotto proveniente dalle sorgenti di S. Fiora nel ramo da Grotte Renara.

- estimated drop height: 106 m;
- average slope in the drop section: 17°.

If confirmed by further studies, that are in progress, even considering errors due to limited measurements (Fig. 16), these numbers would establish the final stretch of the Santa Fiora branch among the major known drops in the world of Roman aqueducts (see Chanson, 2000).

Conclusions

The speleological surveys for research and study of the "lost" branch of the Trajan aqueduct, after a fortuitous start, merged into a rigorous project.

The path, that is now known in all its details, has turned out to be more than 4.5 km long. The conduit mostly fits into a trench that is a few meters deep. It originates from Santa Fiora and initially descends along the orographic left side of the Fosso di Fiora, then leaves it by heading towards NE, always keeping a slight slope. It roughly follows the contour line and thus remains above 300 m a.s.l. After a few km it begins a steeper descent towards the probable point of connection with the branch coming from Grotte Renara.

The method has been identified that allowed the masses of water, in their travel to Rome, to drop a considerable height along a very short distance; although all related remnants seem lost. Finally, the area, where probably the channel merged with the branch coming from Grotte Renara, was pinpointed as Vigna Orsini.

Survey campaigns, and more detailed studies on the structure of the aqueduct, on its complete path and on the construction techniques, are still on going. It is not inconceivable that this research may cause a new critical re-reading of what is today known about Roman hydraulics.

In addition to the authors, members of the "Underground Research Centre Egeria" and "Underground Rome" are actively involved in the project.

References

Ashby T., 1935, *The aqueducts of ancient Rome.* I.A. Richmond ed., Oxford.

Chanson H., 2000, *Hydraulics of Roman Aqueducts: steep chutes, cascades and dropshafts*. AJA, 104, pp. 47-72.

Cassio A., 1756, *Corso dell'acque antiche portate da lontane contrade fuori e dentro Roma sopra XIV Acquidotti e delle moderne, e in essa nascenti, con l'illustrazione di molte antichità...* Network.

Fea C., 1832, *Storia: I. delle acque antiche sorgenti in Roma perdute, e modo di ristabilirle, II. dei condotti antico-moderni delle acque, Vergine, Felice, e Paola, e loro autori*. Stamperia R.C.A. Roma.

Nibby A., 1849, *Analisi storico-topografico-antiquaria della carta de' dintorni di Roma*. Tipografia Belle Arti, Roma.

Pisani Sartorio G., 1986, *Premessa*. In AA.VV., Il trionfo dell'acqua. Acqua ed acquedotti a Roma dal IV sec. a.C. al XX sec. Paleani Ed., Roma, pp. 1-6.

Quilici L., 2009, *La Madonna della Fiora presso Manziana. La scoperta del caput aquae dell'acquedotto di Traiano*. In Orizzonti, rassegna di archeologia, X-2009, Serra Ed., Pisa-Roma, pp. 155-158.

Virgili P., Santolini R., 1986, *Aqua Traiana*. In AA.VV., Il trionfo dell'acqua. Acqua ed acquedotti a Roma dal IV sec. a.C. al XX sec. Paleani Ed., Roma, pp. 113-119.