The greatest water reservoirs in the ancient Roman world and the "Piscina Mirabilis" in Misenum

G. De Feo, S. De Gisi, C. Malvano and O. De Biase

ABSTRACT

The aim of the present study was to investigate the greatest water reservoirs in the ancient Roman world and, in particular, the "Piscina Mirabilis" in Misenum, in Southern Italy. In our study, we considered the reservoirs with a volume in the order of thousands of cubic metres, storing flowing water, set low in the ground or actually underground, and roofed over. In general, a Roman aqueduct was not built to provide drinking water, nor to promote hygiene, but either to supply the baths or for military aims. As a matter of fact, the population of Rome at the end of the 1st century AD had an average water supply of 1,550 L/d per capita especially used for baths. This circumstance required reservoirs of huge capacity. The reservoir of the Baths of Caracalla in Rome could contain over 80,000 m^3 of water. The use of columns in a Roman reservoir was introduced in the ancient Constantinopolis and the Yerebatan Saray with a maximum capacity of almost 85,000 cubic metres can be considered the biggest Roman reservoir. While for military aims, the Piscina Mirabilis in Misenum can be considered the biggest Roman resevoirs used for military aims ever known until now (provide the Classis Praetoria Misenensis) with a volumetric capacity of 12,600 m^3 of water.

Key words | Miseno, Naples, Piscina Mirabilis, Roman aqueduct, Serino

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INTRODUCTION

Roman engineers realized effective and durable aqueducts that have survived through time. As a matter of fact, Rome is famous all over the world for its aqueducts, with its water supply system being considered one of the marvels of the ancient world (Hodge 2002; De Feo & Napoli 2007). In general, the Roman aqueducts were not built to provide drinking water, nor to promote hygiene, but to supply the baths (Hodge 2002) or for military aims (De Feo & Napoli 2007). Other "secondary" purposes were domestic supplies, garden irrigation, aquatic shows, flour mills, decorative fountains and public fountains (Hodge 2002; Tolle-Kastenbein 2005; De Feo & Napoli 2007). Typically, a Roman aqueduct was composed of the following components: source (the so called *Caput Aquae*), steep chutes (dropshafts), settling tank (the so called *Piscina Limaria*), tunnel and shafts, covered trench, aqueduct bridge, inverted siphon, ground channel (*substruction*), arcade, distribution basin (*Castellum Aquae Divisorium*) or reservoir and, finally, water distribution system (Passchier & Schram 2005; De Feo & Napoli 2007). The water in the aqueducts descended gently through concrete and masonry channels. Multi-tiered viaducts were used to cross low areas, while inverted siphons were employed (sparingly) when valleys were particularly deep. Tunnels, burrowed through hills too difficult to skirt, were equipped with vertical shafts for inspection and cleaning while debris cleaned from the tunnels was dumped beside the openings to the vertical shafts (Passchier & Schram 2005; De Feo & Napoli 2007).

At the end of its route the aqueduct channel flowed either into a distribution basin (the *Castellum Aquae*) or a reservoir. The Castellum Aquae was a partitioning tank subdivided into basins and channels with masonry walls

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and weirs. The partitioning function was planned to regulate the waters flowing into the urban pressure pipes, made of lead, terracotta or wood (Hodge 2002; Monteleone *et al.* 2007).

Before discussing the reservoir, it is important to clarify the difference between the terms "reservoir" and "cistern". In fact, a "cistern" was constructed in order to store rain water for domestic use (private houses). Moreover, a cistern had a limited volume, in the order of dozens of cubic metres (Tolle-Kastenbein 2005).

On the other hand, a reservoir was a more important structure with a volume in the order of thousands of cubic metres. Moreover, a reservoir stored flowing water (not stagnant as in the cistern) for different subsequent uses (Tolle-Kastenbein 2005).

This paper is focused on Roman reservoirs. In particular, after a review of the principal reservoirs in Roman times, the paper deals with the study of the "Piscina Mirabilis" in Misenum: one of the marvels of the ancient Roman world.

THE ROMAN RESERVOIRS

Roman reservoirs were usually set low in the ground, or actually underground, and roofed over, typically by means of concrete vaulting. In the plans, they appeared like what one could only call a kind of subterranean hypostyle hall. Moreover, the roofing vaults were supported by rows of columns, piers, or wall pierced with doors to allow the water to circulate. In some cases (e.g. at Lyon) the floor was slightly concave with a drain in the middle, to permit cleaning (Hodge 2002).

Table 1 reports some examples of Roman reservoirs with the indication of their volume and water use. All the considered reservoirs only contained a volume of water useful for the demand of something over a days' supply (Hodge 2002).

The reservoirs could have two specific functions. On the one hand, a reservoir could be a reserve for use when the aqueduct ran low, by adding in a little from the tank every day to supplement supplies until the aqueduct discharge picked up again. On the other hand, when the daily consumption exceeded what the aqueduct could bring in, at least in the hours of daylight, the reservoir was topped up every night to meet the next day's demands (Hodge 2002).

The storage function of a reservoir apparently could contradict the philosophy of water supply based on the continuous off-take principle of the Roman aqueducts. It would imply the acceptance of storage against future needs and something akin to the recognition of peak and off-peak hours: an un-Roman philosophy, but they might have been driven to it by an actual lack of water. Certainly the widespread use of cisterns and reservoirs, some even aqueduct fed, in minor and rural sites, must have accustomed the people living in Roman colonies, especially North Africans, to the idea of drawing upon

Table 1 | Volume and water use of the principal Roman reservoirs

Roman reservoir	City, Country	Volume (m^3)	Water use
Bordj el-Djedid[a]	Zaghouan, Tunisia	30,000	Baths
Ain el hammer, Ain mizeb[a]	Thugga, Tunisia	15,000	Baths
Baths of Caracalla[a]	Rome, Italy	80,000	Baths
Baths of Trajan[a]	Rome, Italy	10,000	Baths
Baths of Diocleziano[b]	Rome, Italy	–	Baths
Binbirdirek[a, c]	Istanbul, Turkey	32,500	–
Yerebatan Saray[d, e]	Istanbul, Turkey	85,000	Imperial Palace
Sultan's cistern[f]	Istanbul, Turkey	–	–
Cisternone (Big cistern)[g]	Formia, Italy	8,000	Baths, Fountains, Domestic Supplies
Piscina Mirabilis[a]	Bacoli, Italy	12,600	Military

Sources: [a]Tolle-Kastenbein (2005); [b]Ball Platner (1929); [c]Mymerhaba (2008); [d]Lendering (2008); [e]Kültür (2008); [f]Kumbaraci (2008); [g]CulturalWeb (2003); Prugnola (2003).

a store as required, and filling it up as opportunity offered (Hodge 2002).

As shown in Table 1, an outstanding example is the Bordj Djedid reservoir at Carthage in Tunisia, into which the Carthage aqueduct emptied after a run of no less than 90.43 km from its source (Hodge 2002). This great reservoir was oblong, 39.0 × 154.6 m, the size of an entire city block, and subdivided into eighteen transverse compartments (Hodge 2002). Its capacity was 25,000–30,000 m^3, but, to put this into context we should note that this represents about a day and a half's discharge for the aqueduct (Hodge 2002).

Remaining in Tunisia, in the centre of the city of Dougga/Thugga, there are two considerable reservoirs. The first one is the Ain el hamman reservoir with five aisles. While the second one is the Ain mizeb reservoir with seven aisles. Globally, the two reservoirs have a volume of 15,000 m^3 (Tolle-Kastenbein 2005).

As it is well known, great reservoirs were not only realized in Northern Africa but also in Europe, especially in Italy and in Turkey.

A Roman aqueduct was normally constructed in order to supply baths. In fact, it is well known the huge amount of water needed by the Roman Baths for constant and vast supplies (Hodge 2002). As a matter of fact, total discharge of the ancient aqueducts in Rome (excluding Aqua Traiana and Aqua Alexandriana, whose data are missing) was 24,360 *quinariae*, corresponding to 1,010,258 m^3/d (11.69 m^3/s). The population of Rome at the end of the 1st century AD was about 500,000. Consequently, a mean of 1,550 L/d per capita was available (Bono & Boni 1997).

As shown in Table 1, the reservoir of the Baths of Caracalla (located in an area of over 100,000 m^2) could contain over 80,000 m^3 in the numerous cells, situated into two parallel aisles and onto two floors (Tolle-Kastenbein 2005), while the oldest Baths of Traiano took water from a reservoir of around 10,000 m^3 (Tolle-Kastenbein 2005).

The greatest Baths of Diocletian occupied about the same area as those of Caracalla (a rectangle of about 356 × 316 m) and closely resembling them in the plans. The reservoir by which the baths were supplied was fed by the aqua Marcia, the volume of which was increased by Diocletian. It was trapezoidal in shape, 91 m in length, with an average width of 16 m (Ball Platner 1929). This reservoir, called "Botte di Termini" ("Barrel of Termini), was destroyed during 1876 in order to realize the Termini railway station, whose name derives from that of the baths.

In the three centuries of the Roman imperial age, the reservoirs were realized in almost all the architectural forms and in almost all the techniques of masonry known: arcs (especially transversal arcs), turned (especially barrel vault), carrying pillars or groups of pillars, walls of stones and bricks, *opus caementicium*. However columns were not still used. In fact, the columns were introduced by architects famous for their works of hydraulic engineering in the present day Istanbul. They realized a "host of columns" hidden in the heart of the capital of the Roman empire (Tolle-Kastenbein 2005). As a matter of fact, the name of the first reservoir we consider means "with a 1001 pillars". It is the Binbirdirek reservoir which was built under the order of Philoksenos, a Senate member in the Constantinus I period of the 4th century. During the Roman period, Istanbul's water requirements were met by water brought from distant parts of Thrace. For this reason, the Byzantines built large reservoirs in order to be able to withstand long sieges (Mymerhaba 2008).

The Binbirdirek reservoir covered an area of 3,640 m^2 and had a capacity of around 32,500 m^3 of water. It measured 66 × 56 m and was carried by 224 columns consisting of 16 rows each one having 14 columns all of which are equal in length, and every column carries the signature of its master ("1001" was used to emphasize the great number of columns). There is a thick overlapping astragal running round the columns carrying the vaults and arches and they are in the form of a truncated pyramid and are without decoration. The relief cross on one of the columns is good proof that the reservoir was built in the 4th century, after the Byzantines accepted Christianity. In order to construct ceilings 14–15 m high, a second layer of columns were fixed over the marble rings on the first layer of columns. When the palace was destroyed in the 6th century the cistern was restored. After the Ottoman conquest of Istanbul in 1453, new reservoirs were built and the Binbirdirek was no longer used (Mymerhaba 2008).

One of the magnificent historical constructions of Istanbul is the Yerebatan Saray (or Basilica Cistern), located near the south-west of Ayasofya (Hagia Sophia).

This huge reservoir was rebuilt by the emperor Justinian (527–565) after the Nika revolt (532). It is a large, vaulted space, the roof rests on twelve rows of twenty-eight marble columns, which are about 9 m high. As the total surface is 65 × 138 m, the maximum capacity is almost 85,000 cubic metres, which was brought to this cistern from a well about twenty kilometres away with a new aqueduct, also built by Justinian. It was used to provide water to the imperial palace (hence the name, "imperial cistern"). The 336 columns (246 are still visible) were brought to the Basilica Cistern from older buildings. Again, it is narrated that 7,000 slaves worked in the construction of the cistern. In fact, the cistern borrowed its name from Ilius Basilica in the vicinity (Kültür 2008; Lendering 2008).

Another huge Roman reservoir in ancient Constantinopolis (today's Istanbul) is the Sultan's Cistern. We do not have any verifiable scientific evidence for its construction date at the earliest it could be late 4th century AD judging by the presence of crosses carved into the upper parts of the column heads. It has a rectangular plan and the whole is divided into five equal rectangular parts by the use of 28 columns, with 7 in granite and 21 in marble, placed equidistant from each other, also supporting the roof with vaulted arches (Kumbaraci 2008).

During 2003, in the Lazio Region, in the District of Formia (the ancient *Formiae*) the restoration of a considerable ancient Roman reservoir was completed. It is the so called "Roman Cisternone" ("The Big Roman Cistern"). It has a regular shape, 65 × 25 m, with 60 pillars, 6.5 m in height (CulturalWeb 2003; Prugnola 2003). The first detailed news about this reservoir as well as technical description are due to Formia's Podestà F. Tonetti in 1930 (Prugnola 2003). The reservoir was realized on the top of Arce (the present day Castellone area) along the internal side of the defensive circuits. From the reservoir, by means of a distribution network, water was furnished for public (baths, public fountains, nymphaeum) and private (private houses, commercial activities, etc.) uses (CulturalWeb 2003).

The Cisternone can be considered another Roman underground hydraulic marvel such as the Yerebatan Saray or Binbirdirek in Istanbul, or the spectacular "Piscina Mirabilis" in Misenum, in the Southern Italy (Adam 1988; Potenza 1996; Catalano 2003; Passchier & Schram 2005; De Feo & Napoli 2007). The next section deals with a detailed study of the "Piscina Mirabilis".

THE PISCINA MIRABILIS

The Piscina Mirabilis is located in the present day Municipality of Bacoli, in Miseno (the ancient Misenum), up the hill facing the sea in the bay of Naples (Figure 1). It was realized during the Augustan Age.

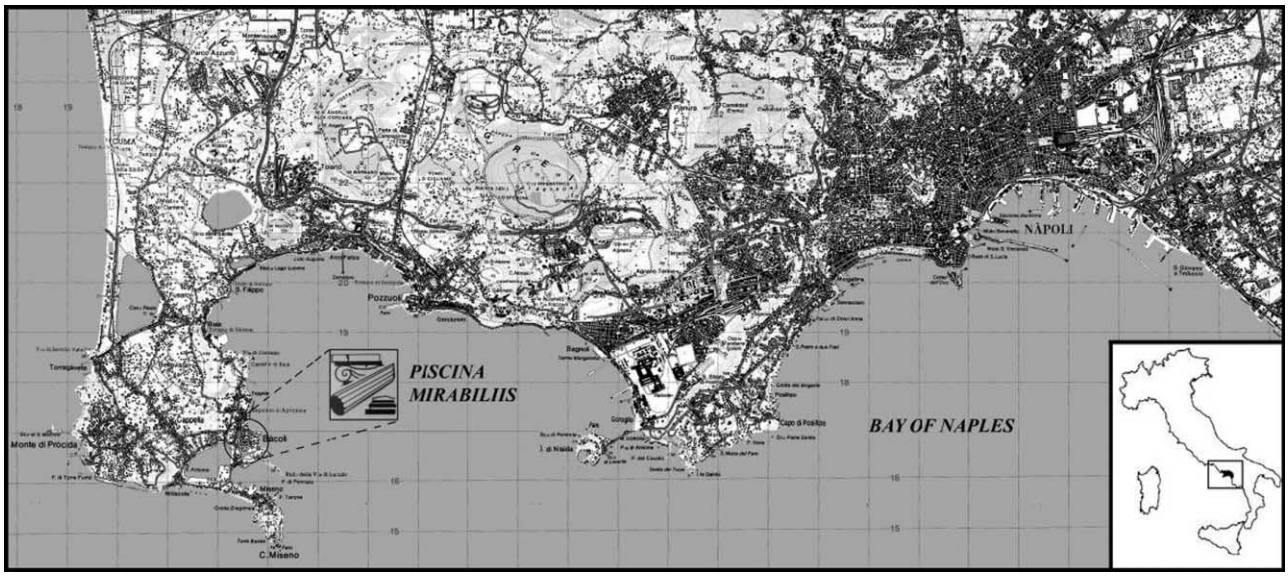

Figure 1 | The Piscina Mirabilis in Miseno, in the bay of Naples (Southern Italy).

In fact, during the war with Pompeius, Augustus ordered the construction of a harbour complex west of Puteoli (Pozzuoli), named Portus Julius (Figure 2), where an old Greek dam was restored to create an artificial lake, Lacus Lucrinus, which was then connected by a channel to another lake, Lacus Avernus, which was traditionally one of the entrances to the underworld. Later, this harbour was seen as less ideal, because of silting problems, and a new complex was built further west at Misenum, where two lakes were connected, becoming the base of the western Mediterranean war fleet (Passchier & Schram 2005; De Feo & Napoli 2007).

This major naval base needed large quantities of fresh water for the base itself and for the ships, which was the principal reason why Augustus had a new aqueduct built (Passchier & Schram 2005; De Feo & Napoli 2007). For this purpose, the "Serino aqueduct" was constructed, probably between 33 and 12 B.C., when Marcus Vipsanius Agrippa was *curator aquarum* in Rome. The *caput aquae* of the aqueduct was the Acquaro-Pelosi spring in the village of Serino, in the province of Avellino (the ancient Abellinum) (De Feo & Napoli 2007).

The aqueduct furnished the Roman fleet of Misenum and supplied water for the demand of the important commercial harbour of Puteoli as well as drinking water for big cities such as Cumae (Cuma) and Neapolis (Naples). The main channel of the aqueduct was approximately 96 km long, with 7 main branches corresponding to approximately 49 km. The total length of the Serino aqueduct was around 145 km. The Serino aqueduct is one of the largest aqueduct systems in the Roman world (De Feo & Napoli 2007). The Serino aqueduct filled several reservoirs in the section beyond Naples and, in particular, the Piscina Mirabilis. It was located up the hill facing the sea in order to easily refurnish of water the *Classis Praetoria Misenensis*.

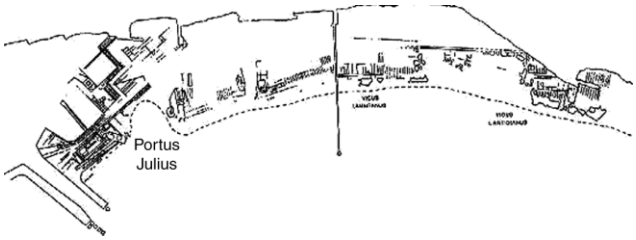

Figure 2 | The ancient Portus Julius.

The Piscina Mirabilis is a gigantic reservoir 72 m long and 27 m large (Hodge 2002; Tolle-Kastenbein 2005; De Feo & Napoli 2007), which gets its name from the eighteenth century antiquarian tradition, with clear reference to the impressiveness of its plan as well as the remarkable architectonic effect. It is dug in a tufa hill and has two step entrances in the northwest, the Ancient Roman entrance (Figure 3) and southeast corners, the latter closed. Forty-eight pillars, arranged on four rows serving as a support to the barrel vault, divide it into five principal aisles on the long sides and thirteen secondary aisles on the short sides, lending to it the majestic look of a cathedral (Figures 4 and 5). In particular, one of the five principal aisles and one of the thirteen secondary aisles (constituting the ancient Roman reservoir) are respectively shown in Figures 5i and 5m.

The Piscina Mirabilis can be considered one of the biggest Roman reservoirs ever known until now with a volumetric capacity of 12,600 m^3 of water (Potenza 1996; Hodge 2002; Tolle-Kastenbein 2005; De Feo & Napoli 2007). The water coming from Serino flew into it near the northwest entrance, as shown in Figures 3. In particular, in Figure 5h, the zone interested by the entry of the water is shown, near the northwest staircase. The long walls were realized in *opus reticolatum* (reticular work) with brick bonding courses and by the technique of the tufa stone pillars, both covered with a thick waterproof layer of *opus signinum* (pounded terracotta).

From Figure 5l, the different material used in the construction of the ancient reservoir can be observed, with tufa used as a base material (widely present in the area of *Campi Flegrei*) and a layer of terracotta used for the waterproofing of the structure.

There is a basin of 1.10 m, probably a polishing pool, that is a waste-bath for the maintenance of the reservoir, in the floor of the nave (Figures 4c, 4d and 4e). It was used as a *Piscina limaria* for the periodical cleaning of the reservoir (Potenza 1996; Hodge 2002; Tolle-Kastenbein 2005; De Feo & Napoli 2007).

The water, through a series of doors opening in the vault along the central nave, was raised through hydraulic engines on the covering terrace of the reservoir, which was also floored with *signinum* and from there, canalized towards the built-up area. In Figures 4m and 5f, two

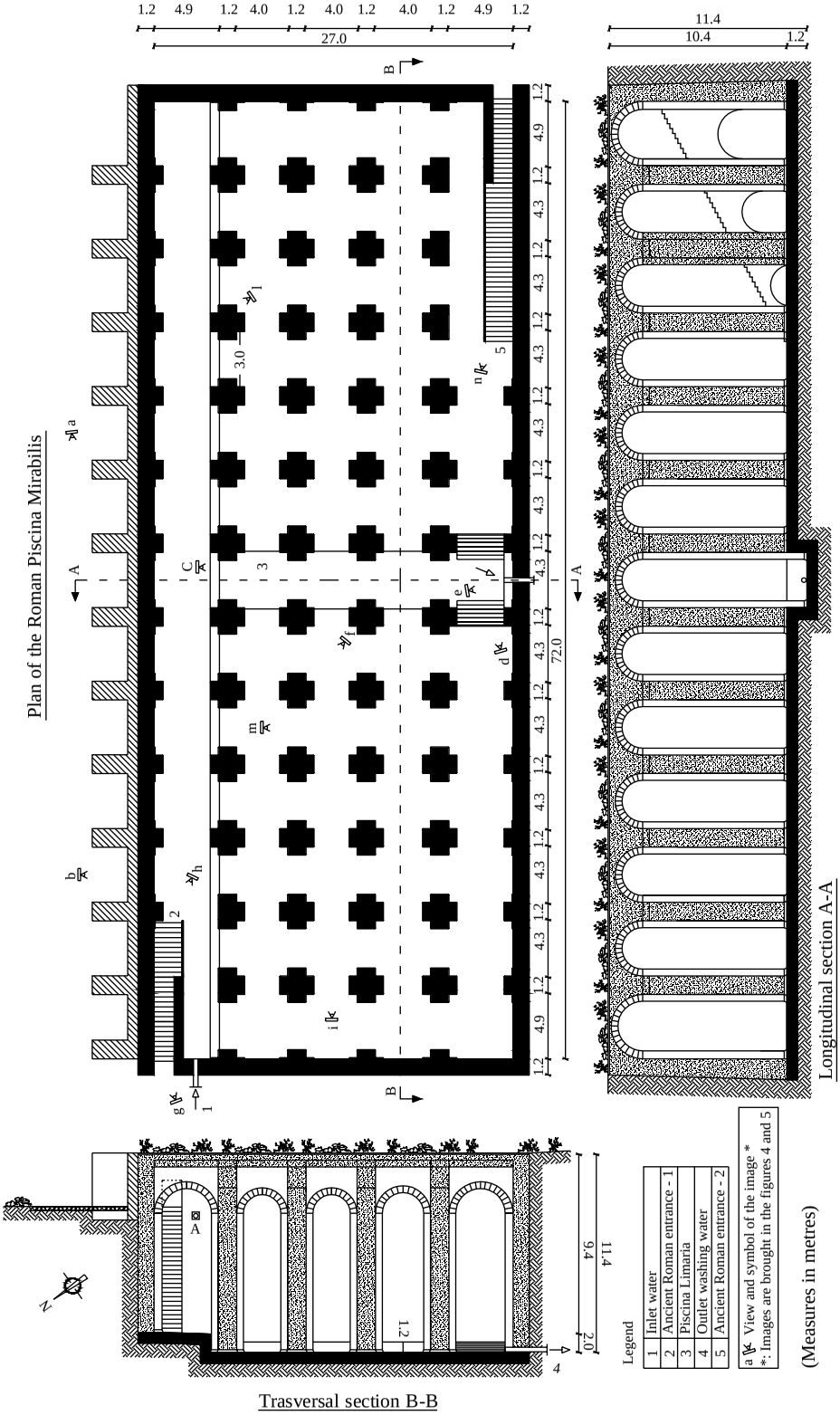

Figure 3 | Plan and sections of the Piscina Mirabilis.

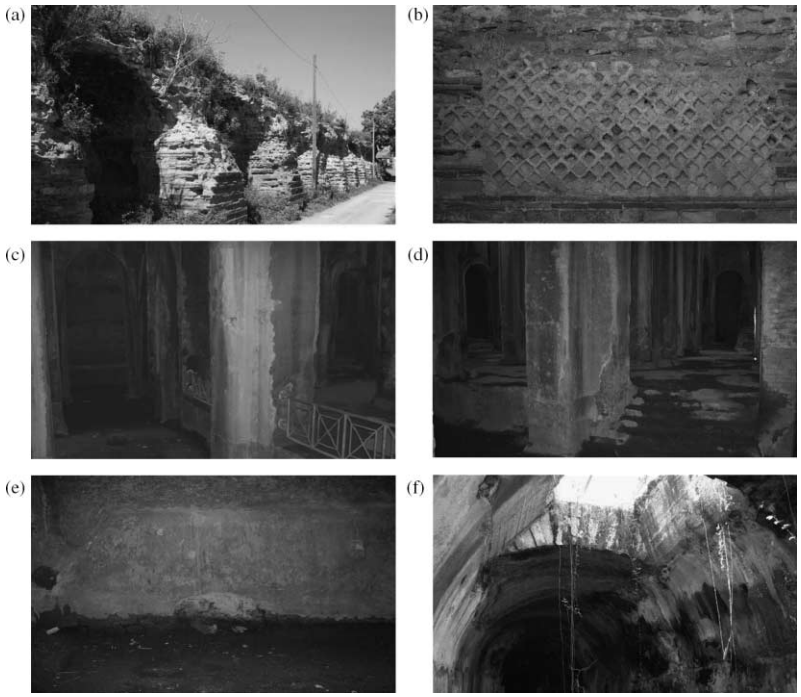

Figure 4 | Images of the Piscina Mirabilis: (a) outside barrel vaults; (b) particular of *opus reticolatum* of the wall of an outside barrel vaulted niche; (c) internal *Piscina Limaria*; (d) one of the two *Piscina Limarla* staircase; (e) discharge hole in the *Piscina Limaria*; (f) a hole in the barrel vaulted roof.

Figure 5 | Images of the Piscina Mirabilis: (g) the northwest entrance near the inlet water; (h) the northwest staircase (inlet water); (i) a longitudinal aisle; (l) a tufa stone pillar covered with a thick waterproof layer of *opus signinum* (pounded terracotta); (m) a cross aisle; (n) the northwest staircase (the ancient Roman entrance).

examples of openings in the barrel vault are visible. These doors appear casually opened in the roof, with an irregular realization being noted.

Along the north-west external side, in the course of the first century A.D. twelve vault-covered little rooms in *opus reticolatum* with angular brick bonding courses were added (Figures 4a, 4b), in the second of which is kept a *signinum* floor with labyrinth-sbaped mosaic *tesserae* and a central white inlaid panel with limestone polychrome tiles, which seems to date back to a more ancient phase (Adam 1988; Potenza 1996; Hodge 2002; Catalano 2003; Passchier & Schram 2005; De Feo & Napoli 2007).

Close to the Piscina Mirabilis there are two other large cisterns, probably belonging to large villas, the Grotta Dragonaria and Cento Camerelle (Nerone's jail). In Pozzuoli, the aqueduct served several cisterns, notably the Piscina Cardito (55 × 16 m) from the second century, and the Piscina Lusciano (35 × 20 m) from the first century AD. In Baiae, a tunnel with two cisterns, known as the Crypta Romana, was filled by the aqueduct (Adam 1988; Catalano 2003; Passchier & Schram 2005; De Feo & Napoli 2007).

CONCLUSIONS

In this paper we have presented and discussed the greatest water reservoirs in the ancient Roman world and, in particular, a detailed study on the "Piscina Mirabilis" in Misenum was described.

In our study, we considered the reservoirs with a volume in the order of thousands of cubic metres, storing flowing water, set low in the ground or actually underground, and roofed over. Therefore, the following general conclusions can be stated for the greatest Roman reservoirs:

- the population of Rome at the end of the 1st century AD had an average water supply of 1,550 L/d per capita especially used for baths;
- the reservoir of the Baths of Caracalla in Rome could contain over 80,000 m^3 of water;
- the use of columns in a Roman reservoir was introduced in the ancient Constantinopolis (today's Istanbul);
- the Yerebatan Saray (or Basilica Cistern), in Istanbul, with a maximum capacity of almost 85,000 cubic metres is the biggest Roman reservoir.

While, the following particular observations can be made on the Piscina Mirabilis in Misenum:

- the Piscina Mirabilis was probably constructed between 33 and 12 B.C. as the terminal reservoir of the Augustan aqueduct Serino-Neapolis- Misenum;
- it is a reservoir 72 m long and 27 m large which derives its name from the eighteenth century antiquarian tradition;
- it can be considered the biggest Roman reservoir used for military aims ever known until now (supplying the *Classis Praetoria Misenensis*) with a volumetric capacity of 12,600 m^3 of water;
- it was realized in tufa, a typical material of the *Campi Flegrei*.

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