Prominent features of the Augustan aqueduct in the Naples Bay area

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ABSTRACT

The great *Aqua Augusta* served the Naples Bay area with fresh water during the time of the Roman Empire. There are very prominent features of the *Aqua Augusta*, some that are extraordinary when considering other great aqueducts in the Roman Empire. For example, the deep tunnels allowed access to a spring water source from a separate watershed, which resulted in transbasin diversion of the water supply. Each one of the prominent features was engineered to provide water to the public for various uses. The prominent structures included other shallower tunnels (with two major types of construction), hydraulic chutes, arcades (one to an island), baths (located along a well-traveled road), and storage reservoirs. Also, there is the epigraph discovered at the water source. Important villas that may have influenced the alignment of the aqueduct are also discussed.

Key words | Aqua Augusta, aqueduct, Naples, Pompeii, Roman, water supply

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INTRODUCTION

The *Aqua Augusta* was one of the greatest of all of the aqueducts in the Roman Empire. It was exceptional in size and technical complexity. The main trunk of the aqueduct was about 103 kilometers (km) and the branches were an additional 60 km (Libertini *et al.* 2014). This grand public works project provided water to a large geographical area and, in doing so, crossed the boundaries of several natural watersheds in the Naples Bay area. The overall route of the *Aqua Augusta* and the prominent features addressed are shown in Figure 1.

The aqueduct is estimated to have been built between 33 and 12 BC, when *Marcus Vipsanius Agrippa* was *curator aquarum* in Rome (De Feo & Napoli 2007). The main goal of the aqueduct was to provide fresh water to two main harbors of the Empire, the civilian one of *Puteoli* and the military one of *Misenum*. However, the aqueduct provided water to many other areas in the Naples Bay region. This was attested to in an epigraph, discovered in 1936, regarding repairs of the *Aqua Augusta* that took place in the time of Constantine the Great (circa AD 324 to 326). In addition to *Puteoli* and *Misenum*, the cities of *Nola*, *Atella*, *Neapolis*, *Cumae*, *Acerrae*, and *Baia* are described as being served by the aqueduct (Miccio & Potenza 1994). As a Greek colony before the construction of *Aqua Augusta*, Neapolis was served by local aqueducts, one of the oldest of which was the Bolla Aqueduct (Albertini & Baldi 2008). After its construction, the *Aqua Augusta* became another supply and a main line to the City. Catalano (2003) and our research shows that a branch of the *Aqua Augusta* also served the coastal cities of *Pompeii* and perhaps *Herculaneum*.

Other important additional aims of the *Aqua Augusta* included the provision of water to colonies and many illustrious villas linked to the political power of the Roman

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Figure 1 | Naples Bay area and the route of *Aqua Augusta*. The main route and branches are indicated. The aqueduct features are: (1) Acquaro and Pelosi Springs (where the epigraph was found); (2) Forino tunnel; (3) Mt. Paterno tunnel; (4) Villa of Augusta; (5) great arcade of Pomigliano d'Arco; (6) *Crypta Neapolitana*; (7) baths of via Terracina; (8) Island of Nisida; (9) *Piscina Mirabilis*.

Empire. This helps to explain the considerable investment made in the aqueduct, estimated at between 150 million and 450 million *sestercii*. This cost was several times the cost of the massive baths (*thermae*) of Caracalla in Rome (Keenan-Jones 2010).

The main branch of the *Aqua Augusta* was about 103 km in length and carried plenty of water of great quality from springs in the area of Serino, south of the ancient settlement of *Abellinum*, to the end of the route in *Misenum*. The choice of the springs of the Serino area as the origin (*caput aquae*) of the aqueduct appears to modern engineers to be bold and extreme for the technical possibilities of the time. Tunneling and arcades were both used along the route, with tunnels comprising approximately 95% of the entire aqueduct length. The engineering feats that were accomplished are apparent by inspection and research of the special features along the path of the *Aqua Augusta*.

Several of the prominent features of the *Aqua Augusta* are presented and discussed in order of the alignment and flow of the channel. The data for the alignment shown on the figures are from field work by the authors and literature sources.

WATER SUPPLY AND INITIAL AQUEDUCT SEGMENT

In the planning for the *Aqua Augusta,* the Roman engineers identified the source of water as springs in the Apennine Mountains. Like much of the geology surrounding the Mediterranean Sea, these mountains are primarily comprised of limestone. The underlying geology has fissures and cavities that act as a sponge to store precipitation, a present day annual average of 150 centimeters (cm), that is released at several spring locations.

There are several major springs in the area; however, the Roman engineers selected the Acquaro and Pelosi Spring as the specific source of water for the aqueduct. The engineering advantages for selecting this spring location were the elevation, at 378 meters (m) above sea level (asl), and the substantial flow rate. The elevation was needed to provide the gradient for the aqueduct for the required distance. Today, this spring flow ranges from 630 to 1,500 liters per second (l/s), which is sufficient for several hundred thousand people.

From the spring, the first segment of the aqueduct was also an area of mountainous terrain, where the aqueduct followed the contours of the hills in the present-day Aiello del Sabato and Cesinali areas. In this segment, the Roman

engineers used a tunneling feature known as 'cut and cover' where they could excavate into the slopes. These shallow (2-to-3-m-deep) sections were built with a concrete rubble framework to enclose the aqueduct section, with typical dimensions as shown in Figure 2(a). The 'cut and cover' construction was common in aqueducts throughout the Roman Empire. The time needed for construction of these sections was short when compared to deeper tunnel construction, shown in Figure 2(b), which was chiseled into limestone. However, the cut and cover sections were also subject to local land slips, especially in the steeper slope segments of the aqueduct. One such land slip occurred recently, exposing a tunnel that the authors inspected, shown in Figure 3(a).

This segment is also characterized as having the mildest channel gradient of the entire length of the aqueduct, at 0.027%. Since the next segment has a deep tunnel, the mild slope was desired to minimize the depth of the tunnel.

FORINO TUNNEL – TRANSBASIN DIVERSION

The length of the *Aqua Augusta* included four long and deep tunnels. These tunnels were exceptional by Roman aqueduct standards, as addressed in a comparison by Keenan-Jones (2010). The first featured tunnel is the Forino Tunnel, which was designed to take water from the Sabato River watershed to other watersheds along the route. A ridge divided the Sabato River watershed and the Sarno River watershed that the Roman engineers had to design to cross into the Naples Bay area. Therefore, the Forino Tunnel (see location in Figure 1) was unique because of the transbasin diversion of water. It is also remarkable because the tunnel had a length of approximately 6 km, which is one of the longest known ancient aqueduct Roman tunnels. It was also a deep tunnel, with an estimated maximum depth of about 70 m (Abate 1862). This transbasin diversion of water required that the design of the alignment of the aqueduct turn to the west in the area of Cesinali to follow the Vallone della Contrada and pass under the Monti di Forino.

A typical tunnel section is different to the cut and cover section, as shown in Figure 3(b).

The Forino Tunnel included an additional 1.5-km-long steep chute at the downstream end of the tunnel (*caduta della Laura*) that descended more than 150 m (a slope of 10%), which was a hydraulic transition that impacted flow. In 1840, the route of the *Aqua Augusta* was surveyed by Felice Abate in an evaluation commissioned by the City of Naples to investigate the restoration of the Augusta for a water supply to the City (Abate 1842). For the Forino Tunnel section, Abate identified only two shafts for the entire 6 km length of tunnel. The tunnel and access shafts were filled with sediment and were inaccessible when Abate performed his survey. Today, the Forino Tunnel remains unexplored.

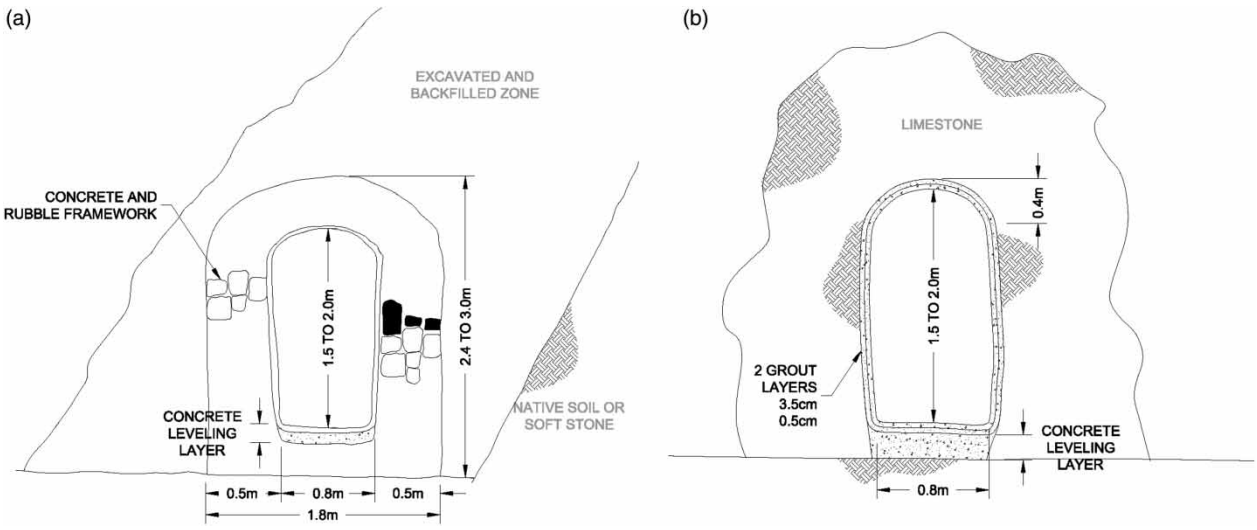

Figure 2 | (a) Cut and cover bench into hillside section. (b) Deeper tunneled section.

Figure 3 | (a) A cut and cover section exposed by a small landslide near the municipality of Cesinali (in the province of Avellino). (b) Photograph of the hydraulic chute tunneled section at Mt. Paterno Tunnel. Photographs by Wayne Lorenz.

The *Aqua Augusta* continued from the exit of the Forino Tunnel in a much shallower section (although there are no archaeological remnants in this section) through the area of present-day Mercato San Serverino. Then the aqueduct turned west towards Castel San Giorgio with the 'cut and cover' shallower tunnel sections following the contours along the side of the hills in the area. It then reached the area of Mount Paterno (before and after this mountain, there are various archaeological remains as directly observed by the authors).

MOUNT PATERNO TUNNEL AND HYDRAULIC CHUTE

The Mount Paterno was a barrier to a direct route of the aqueduct to the Sarno plain. The Romans constructed a tunnel of about 1.5 km under this barrier, descending an elevation difference of about 13 m, from 83 to 70 m asl (Vv. Aa. 1883).

One of the unique aspects of this section is that there was a hydraulic chute at the end of the tunnel where the slope of the channel was at least 15%, which created a hydraulic jump in the water flow. This resulted in a 'full flow' section where the flow constantly filled the channel section. The authors have observed a section of the chute, see Figure 3(b). Thick calcium carbonate deposits up to the top vault of the channel section are shown, indicating the full flow conditions that persisted. This hydraulic condition controlled the flow capacity of the aqueduct in this segment in the range of 1 to 1.5 l/s.

BRANCH TO POMPEII AND HERCULANEUM

There were several known branches of the *Aqua Augusta*; however, one of the most significant is the branch to *Pompeii*, because *Pompeii* has such a special place in archaeological history. The branch headed south, turning gently around the Vesuvio (*Vesuvius mons*), in the direction of *Pompeii*, where the supply by an aqueduct sufficient for the needs of the town is well documented (Catalano 2003). It is probable that the aqueduct did not point directly towards *Pompeii*, but that it remained on a higher altitude and continued towards *Oplontis*, where the present-day Torre Annunziata, and *Herculaneum* (now Ercolano), are

located, and the channel served several villas set along the path on the south side of *Vesuvius*. The remains of an aqueduct near *Herculaneum* and of a *castellum aquae* in the town were found (Catalano 2003).

Some researchers have judged that the alignment of the main channel of the *Aqua Augusta* should have followed this southern route on its way to *Neapolis* rather than being located on the northern slopes of *Vesuvius mons*, shown in Figure 4. However, this hypothesis cannot be proven. In fact, a path south of *Vesuvius* would have been a technically very demanding undertaking with prohibitive costs. To reach *Neapolis* at an altitude of about 41 m asl (i.e., that of Ponti Rossi and of the arches near via Vergini, the main remains of the ancient aqueduct in modern Naples) it would be necessary to overcome the valley of the *Sarnus* River with a series of arches over 14 km long and the valley of the *Sebethus* River with another arcade with a length of almost 10 km. Moreover, the two long arcades would have had a considerable height, up to 40 m in the central parts of the valleys. In addition, a path south of *Vesuvius* did not allow the aqueduct to serve the towns of *Nola*, *Acerrae*, and *Atella*.

In contrast, the path chosen by the Romans first ran just below the surface on the divide between the valleys of *Sarnus* and *Clanius* Rivers and, after going on the north side of the slopes of *Vesuvius*, then ran on the divide between the river valleys of *Sebethus* and *Clanius* Rivers with an arcade of approximately 3.6 km and of limited height. Moreover, this route allowed for opportune branches to provide water to the aforementioned towns (Figure 4).

THE VILLAS OF THE EMPEROR AUGUSTUS

The Emperor *Octavianus Augustus* was often in Campania and had several properties in the Naples Bay area. It is noteworthy that several of these properties were in *Pausilypon*, *Baiae*, and *Nola*. Since the *Aqua Augusta* was planned and constructed during the reign of *Augustus*, some researchers have inferred that the path of the *Aqua Augusta* was influenced by these property locations.

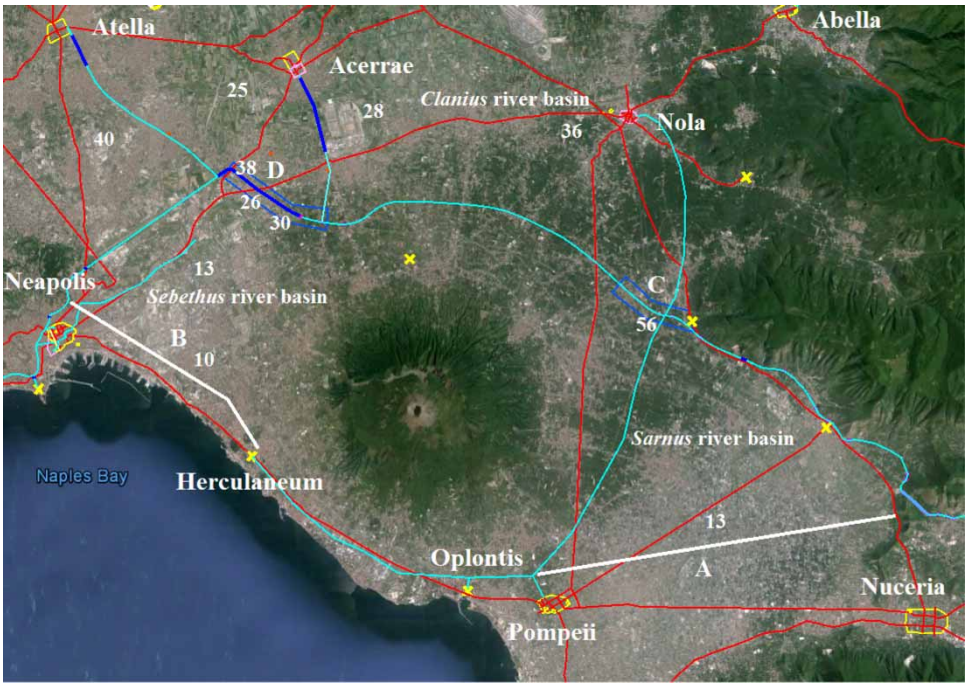

Figure 4 | A hypothetical path south of Mount Vesuvius would have required the construction of two long and expensive arcades (A and B). In contrast, the path built by the Romans passed on the divides (C and D) between the valleys of the small river *Clanius* on the north and of the small rivers *Sarnus* and *Sebethus* on the southern side. These valleys have slopes so subtle as to be visually imperceptible. However, the heights of the divides were another story, with the Campania plain reaching *Neapolis* with an elevation of 41 m asl. The elevations of some areas are indicated in m asl.

In the segment of the aqueduct in the vicinity of the north slopes of Mt. Vesuvius near *Nola*, the elaborate front part of a *villa* was found under several metres of volcanic deposit. Ongoing archaeological excavations have led to the interpretation that it was the famous villa owned by *Augustus* (by inheritance from his natural father, *Gaius Octavius*). However, the *villa* was located about 80 m above the level of the aqueduct in that area.

The *villa* was surrounded by *civitates* and places where *Augustus* had assigned lands to loyal veteran soldiers, as shown in Figure 5. These other lands held by the veterans were located at lower elevations that could have been served water from the *Aqua Augusta*. Therefore, the Roman engineers may have been influenced in the planning of the alignment of the aqueduct by these political considerations.

POMIGLIANO D'ARCO ARCADE

There were three major stretches of arched construction, or arcades, in the *Aqua Augusta*. Together, these three account for 3.6% of the total length of the main channel of the aqueduct.

One specific featured arcade, the Pomigliano d'Arco, seems to have been one of the longer continuous stretches of *opus arcuatum* in an ancient Roman aqueduct (Keenan-Jones 2010). There are very few archeological remnants of this arcade; however, it has been shown to have a length of about 3.6 km and a maximum height of over 12 m. Although it does not exist today, this arcade bridge long survived the deactivation of the aqueduct. This is known because, in the early Middle Ages, many towns were known for their locations beyond the arches of the aqueduct (in the perspective from *Neapolis*), such as *foris arcora* (beyond the arcade; e.g. *Pumilianum foris arcora*, present day Pomigliano d'Arco, *Licinianum foris arcora*, Licignano, part of present day Casalnuovo di Napoli, *Mascarella foris arcora*, extinct medieval center) or also *a foris arcora* (likely, present day Afragola) (Libertini 2011).

TUNNEL AT THE CRYPTA NEAPOLITANA

In the first century BC, the communities of *Neapolis* and *Puteoli* were divided by the *Pausilypon* hill. Therefore, the road that connected these locations was long and

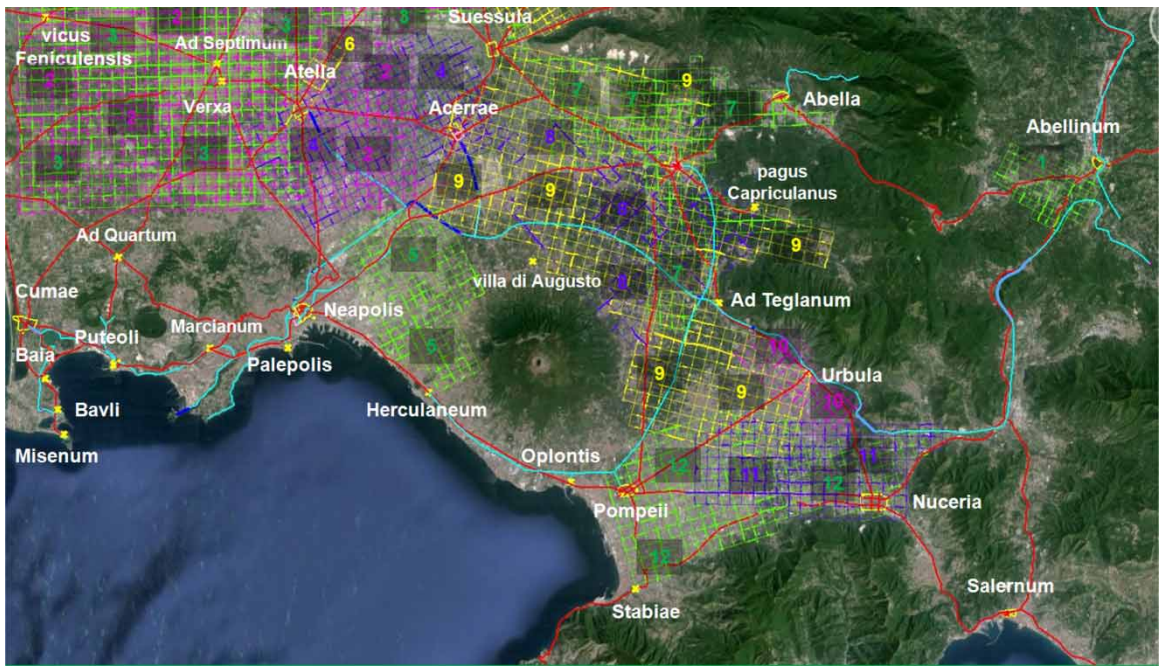

Figure 5 | The *villa* of *Augustus* (villa di Augusto) surrounded by the centuriations ordered by Augusta and where many of his veterans were allocated properties. Centuriations are identified as follows: 1 = *Abellinum*; 2 = *Ager Campanus I*; 3 = *Ager Campanus II*; 4 = *Acerrae-Atella I*; 5 = *Neapolis*; 6 = *Atella II*; 7 = *Nola I-Abella*; 8 = *Nola II*; 9 = *Nola III*; 10 = *Nola IV-Sarnum*; 11 = *Nuceria I*; 12 = *Nuceria II* (Chouquer *et al.* 1987; Libertini 2013).

traversed steep hills, and it was a long journey. At the end of the first century BC, a major road tunnel was constructed, the *Crypta Neapolitana*, at 5 m high, 4.5 m wide and 705 m long.

The aqueduct tunnel at the *Crypta Neapolitana* is the third major tunnel in the route of the aqueduct. The aqueduct tunnel was constructed parallel to the road tunnel at a height of 50 cm from the base of the tunnel on its north side. One of the advantages of this parallel alignment was that maintenance access to the aqueduct tunnel was made efficient by manholes from the road tunnel rather than from the surface (Keenan-Jones 2010).

AQUEDUCT ARCADE TO AN ISLAND

Immediately after the tunnel at the *Crypta Neapolitana*, a branch of the *Aqua Augusta* was constructed to run along the side of the hill to a unique section of the *Aqua Augusta* system. This section included an arcade bridge that crossed over sea water and provided water to the small island of *Nisida* (Lettiero 1560) where there were lavish villas, in particular that of *Lucullus* (D'Arms 1970) and also that of *Marcus Iunius Brutus*, in which *Brutus* and *Gaius Cassius Longinus* plotted to assassinate *Julius Caesar* in 44 BC (Lancaster 2005).

There is little in the way of archaeological evidence of this constructed section, other than piers that were identified as of Roman construction (Cardone 1992).

This section is unusual in that it appears to be one of only two examples of a Roman aqueduct crossing saltwater, with the other at Cadiz, the ancient port city in southwest Spain (Keenan-Jones 2010).

BATHS OF VIA TERRACINA

The building of the Roman aqueducts provided water in quantities that promoted the proliferation of bath complexes. The baths were central to the Roman social life, and their importance grew from the late first century BC into the first century AD. There were several baths in the *Neapolis* region before the construction of the *Aqua Augusta*. However, there were many other baths built likely because of the construction of the *Aqua Augusta*.

There were frequent travelers on the Roman road system in the Naples Bay region, because the area was known for the resorts and villas of the Roman elite. At the end of the *Crypta Neapolitana*, the new road bent to the north and reconnected with the old road. Here, there was a resting place for travelers with a thermal spa complex. The remnants of the *Aqua Augusta* have been excavated near the baths of *Via Terracina*, indicating that the aqueduct provided the water used in the bath complex.

The baths of *Via Terracina* are extraordinary, since the complex appears to have been located specifically for traveling clientele, rather than located in a community for residents. It was a major complex with three principal baths: the *apodyterium*, the *frigidarium*, and the *caldarium*. The complex included a semi-circular latrine that was flushed with the water from the aqueduct. The complex is an archaeological site today.

STORAGE RESERVOIRS – PISCINA MIRABILIS

The *Aqua Augusta* finally reached *Misenum* and its military port, as shown in Figure 1. The port was one of the main goals for the construction of the aqueduct. The Misenum area needed imported water. In particular, the military port needed large quantities of water for supplying fresh water to the fleet.

There are many surviving fragments of cisterns in this area, suggesting that water storage was needed since the aqueduct may not have had continuous flow at this end of the long journey. Therefore, the water needed to be captured for later use when there was flow occurring in the aqueduct. Examples of cisterns that may have been fed from the *Aqua Augusta* include the *Dragonara* near Cape Miseno, *Cento Camerelle*, and *Lusciano*.

One of the largest storage reservoirs that is known to have existed in the Roman Empire was located here, the imposing *Piscina Mirabilis*, see Figure 6. This reservoir was excavated into the hillside, into tufa, with a liner consisting of concrete/brick (*opus reticulatum mixtum*) on the exterior walls, which were covered with a layer of hydraulic cement (*cocciopesto*). The concrete top of the reservoir is supported by 48 cruciform columns and the ceiling was

Figure 6 | Photograph of the interior of the *Piscina Mirabilis*. Photograph by Wayne Lorenz.

constructed in double vaulted sections between the columns. The reservoir has approximate dimensions of 66 m long by 25 m wide. It has a depth of about 15 m and a volume of 12,300 cubic m, or about 10,700 cubic m if the volume of the columns is considered.

CONCLUSIONS

There are many prominent features of the *Aqua Augusta*. The technical characteristics of the work, author observations, and the documentation of classical texts and archaeological evidence tell the story of a magnificent water conveyance achievement by the Romans.

The prominent features and extraordinary engineering aspects of the *Aqua Augusta* include the water supply at the Acquaro and Pelosi springs, Forino Tunnel, Mt. Paterno tunnel, the branch to *Pompeii* and *Herculaneum*, *Octavianus Augustus*' villa, the Pomigliano d'Arco arcade, the *Crypta Neapolitana* tunnel, the baths of *Via Terracina*, and the great reservoir of the *Piscina Mirabilis*. These features of the *Aqua Augusta* demonstrate how unique this aqueduct was regarding engineering in the Roman Empire.

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