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Ancient Pompeii Water Supply: Sources, Routes, Hydraulics of the Aqueducts

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Abstract The aim of this paper is to study water sources, routes and slopes of aqueducts serving ancient Pompeii. In particular, the main focus of the research was to perform a study of the topography between Avella and Pompeii by means of field GPS investigations to validate the hypothesis of the existence of an own aqueduct of Pompeii coming from the mountains due north east of Avella. When the Aqua Augusta was built under Augustus (between 33 and 12 B.C.), it crossed the course of the older Avella aqueduct between the Apennines and Mount Vesuvius, and both aqueducts were united into a single system. Based on historical accounts, archeological sites, chemical/mineralogical analysis, and topographical study we conclude that the existence of an Avella Aqueduct that carried water from the Avella springs to Pompeii prior to the construction of the Aqua Augusta is highly likely.

Keywords Aqueducts; Pompeii; Roman; Serino Aqueduct; Slopes; Water Supply

INTRODUCTION

The Aqua Augusta, also known as the Serino Aqueduct, is the largest aqueduct system constructed in the Roman Empire. The Augusta was an ambitious and grand Roman civil engineering achievement that had a main conveyance channel with branches to the settlements in the present day Campania region, including a branch to Pompeii. Just like major public works projects constructed today, the Aqua Augusta was fundamental in the economics of Pompeii and this area of the Roman Empire.

Prior to the construction of the Aqua Augusta there was a different water supply to Pompeii. It is known that groundwater wells and harvested rainwater provided Pompeii with water prior to Roman occupation. When Pompeii became a Roman colony under General Lucius Cornelius Sulla, in about 80 B.C., the Roman social life of the City became established. The settlement of Roman families in the Pompeii region and the expansion of the Pompeii baths, corresponded to the construction of major water facilities in the City. These aspects, plus other evidence, show that there was an aqueduct conveyance of water to the City and that the City enjoyed an outside source of water during this early First Century B.C., prior to the construction of the Aqua Augusta. Thus, the water supply to Pompeii during the Roman occupation can be addressed in two historic periods: 1) Pre-Augustan era from 80 B.C. when an aqueduct delivered water to Pompeii and 2) Aqua Augusta Period which began between
33 to 12 B.C. and continued to provide Pompeii with water until the time of the great earthquake of 62 A.D. and after repair, until the eruption of Mt. Vesuvius in 79 A.D., a period of service to Pompeii of at least 129 years. The likely routes of the aqueducts are both shown in Figure 1.

**Figure 1.** Major likely routes of the aqua augusta (serino) and avella aqueducts.

The Pre-Augusta era Aqueduct was constructed between 80 B.C. and 33 B.C. Even though the archeological record of this older aqueduct is rare, we can look at the engineering aspects at specific locations of these aqueducts to estimate the alignments and slopes of these water supply structures. These criteria can be applied to calculate the hydraulic characteristics and flows of the aqueducts.

The Aqua Augusta was constructed during the Augustus period, between 33 and 12 B.C. When the Augusta was constructed, it intersected the older aqueduct and provided water to Pompeii.

Like other Roman Aqueducts, the Augusta was restored in many areas and many times over the centuries. A written record of a major restoration was discovered in the 1930’s in the form of an epigraph at the site of the Aquaro Pelosi spring, near Serino, Italy. From this epigraph we know that a major restoration project was performed in 324 A.D. during the reign of Constantine. Vestiges of this restoration survive at a few locations like the Ponte Tirone and Mura d’Arce, located near Sarno.

**THE PRE-AUGUSTA AQUEDUCT HISTORICAL FRAMEWORK**

**Water Source**

The water source for the Pre-Augusta water supply to Pompeii has long been the subject of research. There are springs in the Pompeii area today that existed in ancient times and used as water sources to the City. For example, the series of springs near Sarno are quite prolific (up to 1000 liters per second) and are approximately 13 kilometers northeast of Pompeii. There were also springs on the northern slope of Mt. Vesuvius including the Olivella and the Chianatelle Springs (Madonia, et. al., 2008).
In the historic literature, there is evidence that an aqueduct supplied Pompeii from springs to the northeast of the Municipality of Avella. Avella is located approximately 25 kilometers to the north of Pompeii at the foot of the Apennine Mountains. A poem by Paulinus of Nola written in 407 A.D. addresses the repair of an aqueduct that conveyed water from the mountains near Avella to the south toward Pompeii. Murano (1894) recognized the possible water source of the Pre-Augusta supply to Pompeii as being from the Fontanelle region located just northeast of Avella, see Figure 2. Finally, using chemical and mineralogical means, Ohlig (2001) agreed with Murano that the initial aqueduct water supply was from the Avella Springs. Today, these springs provide drinking water for Avella and its neighboring area.

Figure 2. Location of the avella springs in the fontanelle region northeast of avella.

Roman aqueduct sections have been unearthed in the Fontanelle region during the construction of modern public works projects. There has also been archeological evidence that supports the use of the Avella Springs as a water source to Pompeii. The Avella Springs are located at elevations of between 746 meters and 400 meters. There are other locations of aqueduct remnants in this area, including the majestic Roman Aqueduct, single arch, bridge that spans the Clanio River just north of Avella (see Figure 3). Therefore, it is known that the Romans used these Fontanelle region springs for a water supply.
Aqueduct Alignment

One proposed alignment of a Pre-Augusta aqueduct from Avella to Pompeii has been researched and documented by Ohlig (2001). Ohlig’s work was based on earlier work by Murano. We performed a study of the topography between Avella and Pompeii and carried out field GPS investigations to validate and refine the Ohlig alignment. We have developed a refined alignment based on our research as shown on Figure 4.

The aqueduct alignment begins in the Fontanelle area where the water was collected from several springs. The aqueduct flowed from the Bocca dell’Acqua east to west in the valley following the surface water tributary that eventually becomes the Clanio River. The route turns to the southwest at Fusaro and passes by the Avella Roman Amphitheater and goes through the village of Avella. Continuing west to the area of the existing area of Schiava, the topography begins to be less steep and dictates the specific route that the aqueduct followed. The route would have had to follow a path south through Casamarciano and on the east side of Nola. The route also had to follow the topography along the hill in San Paolo Bel Sito and continue south toward Palma Campania.
Figure 4. Refined alignment of the avella aqueduct.
The major point along the Avella Aqueduct route is in the area of the Ponte Tirone. This is a small area that was a "pinch point", or low area (approximately 50 meters elevation) in the topography of the region that lies between Mt. Vesuvius and the Sarno Mountains. The aqueduct remnants at Ponte Tirone, shown in Figure 5, were a part of the later Aqua Augusta; however, this location is in the area where the Avella Aqueduct route and the Aqua Augusta route must have intersected. The location of the intersection is dictated by the topography, even when considering there has been volcanic deposition of material in the area.

![Aqueduct archeological site at ponte tirone.](image)

The total length of the aqueduct from the Sambuco Springs to Pompeii is approximately 37 kilometers. Based on our investigations, it is feasible to engineer an aqueduct from the springs near Avella in the Fontanelle region to the south and to Pompeii. In fact, there are chemical and mineralogical data, historical data, archeological sites, and engineering details that would support the existence of the Avella Aqueduct that followed the alignment shown in Figure 4.

**Aqueduct Slope and Hydraulics**

The alignment of the Avella Aqueduct shown in Figure 4 was divided into segments to investigate the range of channel slopes that comprised the overall route from Fontanelle region to Pompeii. The estimated lengths and elevations for each segment, along with the range of slope for the segment, are shown in Table 1.
The steep average channel slope in the first segments from the Sambuco Spring to the Roman Bridge (0.09 or 9 percent), and from the Roman Bridge to Avella (0.05 or 5 percent) resulted in hydraulic energy that was used to turn waterwheels and mill grain. There are at least four mill ruins along the aqueduct alignment in this upper section of the aqueduct.

The slope becomes much milder as the alignment turned southward, just east of Nola, at Casamarciano. The change in slope would have resulted in varying hydraulic conditions, going from supercritical flow to subcritical flow as the channel slope changed from relatively steep to mild.

The hydraulic capacity of the aqueduct into Pompeii would have been defined by the mild slope that is evident from Ponte Tirone to the Castellum Aquae located at the Vesuvius Gate in Pompeii. This channel slope would have been 0.0004 (or 0.04 percent), or less.

The hydraulic capacity of this last segment (13,900 meters) into Pompeii was estimated using the slope of 0.0004 and taking the cross-section of the Avella Aqueduct to be that as it entered the Castellum Aquae. Measurements of the aqueduct section entering the Castellum showed a width of 52 centimeters (cm) and a height of 140 cm. There is a smaller channel section at the bottom of the aqueduct that measures 23 cm wide and 30 cm deep. The resulting flow in the smaller, bottom section was calculated at 15 liters per second (L/sec). However, the flow could have been 100 L/sec, or greater, if the depth of water was just 50 centimeters in the main channel.

**AQUA AUGUSTA**

**Water Source**

The great Aqua Augusta was constructed with the goals of providing spring water to the Roman Navy fleet located at the port of Misenum and to supply water for the increasing demand of the Puteoli harbor (De Feo and Napoli, 2007). The source of water for the aqueduct was the Acquaro Pelosi springs located in the village of Serino, in the Apennine Mountains, to the east of Pompeii as shown in Figure 1. This spring area was productive in ancient times, as it is today. The karst geology provided a spring flow of 600 l/sec in ancient times. Today, the modern infiltration gallery springs provides a flow that ranges from 400 to 1,400 l/sec, depending on the time of year (Fiorillo, et. al., 2007).

**Aqueduct Alignment**

The route of the Aqua Augusta to the intersection of the Avella Aqueduct near Ponte Tirone began at the Acquaro Pelosi springs, see Figure 1. From the springs, the aqueduct crossed the Sabato River on a bridge to the west to Aiello del Sabato. It passed below Contrada in a tunnel, then through the plain of Forino through Petruro, Pandola, Tor di Marcella, Castel S.
Giorgio and Taverna di Lazzaro to a tunnel (1,903 meters in length) below Monte Paterno towards Sarno. Through Episcopio, it continued to Mura d’Arce and then to Torricella and finally to Ponte Tirone. There are no archeological remnants of the junction boxes, although we know that the Roman engineers used hydraulic junction and control boxes in many of the existing aqueducts in the empire.

**Aqueduct Slope and Hydraulics**

Similar to the Avella Aqueduct, the Aqua Augusta was segmented to show the range of channel slope over the length from the Acquaro-Pelosi Springs to the intersection of the Avella Aqueduct, shown in Table 2.

**Table 2.** Aqua augusta from the acquaro pelosi springs to the intersection with the avella aqueduct at pt. tirone - segments and channel slopes.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Approx. Length (Meters)</th>
<th>Elev. Difference (Meters)</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquaro Pelosi Spring to Miranda</td>
<td>910</td>
<td>6.7</td>
<td>0.007</td>
</tr>
<tr>
<td>Miranda to Contrada Valley</td>
<td>12,800</td>
<td>3.4</td>
<td>0.0003</td>
</tr>
<tr>
<td>Contrada to Caduta della Laura</td>
<td>5,950</td>
<td>11.2</td>
<td>0.002</td>
</tr>
<tr>
<td>Upper to Lower Caduta della Laura</td>
<td>1,450</td>
<td>145</td>
<td>0.099</td>
</tr>
<tr>
<td>Caduta della Laura to Petruro</td>
<td>1,000</td>
<td>15.4</td>
<td>0.015</td>
</tr>
<tr>
<td>Petruro to San Severino</td>
<td>4,700</td>
<td>48.2</td>
<td>0.010</td>
</tr>
<tr>
<td>San Severino to San Giorgio</td>
<td>5,000</td>
<td>47.2</td>
<td>0.009</td>
</tr>
<tr>
<td>San Giorgio to Monte Paterno Upper</td>
<td>1,500</td>
<td>11.8</td>
<td>0.008</td>
</tr>
<tr>
<td>Monte Paterno Upper to Lower</td>
<td>1,900</td>
<td>12.6</td>
<td>0.007</td>
</tr>
<tr>
<td>Monte Paterno Lower to Sarno 1</td>
<td>5,750</td>
<td>15.7</td>
<td>0.003</td>
</tr>
<tr>
<td>Samo 1 to Samo 2</td>
<td>2,710</td>
<td>1.1</td>
<td>0.0004</td>
</tr>
<tr>
<td>Samo 2 to Mura d’Arce</td>
<td>1,260</td>
<td>1</td>
<td>0.0004</td>
</tr>
<tr>
<td>Mura d’Arce to Ponte Tirone</td>
<td>780</td>
<td>0.3</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

The segment with the maximum slope is from the upper to lower Caduta della Laura at 0.099, or 9.9 percent. This is a very steep grade for a channel and would have resulted in supercritical flow hydraulic conditions requiring some form of energy dissipation.

The channel slope of 0.0004 in the lower segments as the Aqua Augusta approached the Avella Aqueduct intersection approximates the slope in the lower section of the Avella Aqueduct. The dimensions of the Aqua Augusta at Ponte Tirone are a width of 71 cm and a total height of 220 cm. Even with the mild slope, the flow through this section of the Aqua Augusta was at least 1000 L/sec.

**CONCLUSIONS**

Based on historical accounts, archeological sites, chemical and mineralogical investigations, and engineering study, it is likely that there was an Avella Aqueduct that carried water from the Avella springs to Pompeii prior to the construction of the Aqua Augusta (the Aqua Augusta built probably between 33 and 12 B.C.).

Based on topography and GPS, the slope of the Avella Aqueduct that served Pompeii was on the order of 0.0004 (0.04 percent). Although this is a mild slope, the channel dimensions could have accommodated a flow of 100 L/sec, or greater.

The Aqua Augusta, in the area of Ponte Tirone, had a flow of at least 1000 L/sec even at the mild slope of 0.0004.
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