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APPENDIX
A August 9, 2005 and August 12, 2005 Meeting Minutes
In August 2005, Wayne Lorenz and intern Phillip Wolfram traveled to southern France for the purposes of visiting and further studying the ancient Roman water system sites of Barbegal. Fieldwork was conducted by Wayne and Phillip from August 4 to August 12, 2005. Wayne also returned to the area on August 19, 2005.

The purpose of this report is to document the field activities and interviews that were conducted during the August 2005 field visit. This report presents only the small portion of the field measurements that were obtained for the aqueduct and mill structures that are relevant for the initial observations and discussions presented in this report. Further study of the information that was gathered during this August 2005 field visit will be carried out. The results of these further studies will be presented in separate, more detailed papers and articles.

1.0 INTRODUCTION

The ancient Roman engineers had the knowledge, management skills, and resources to design and build a complex water supply and industrial system at Barbegal. Like most great engineered structures, the useful life of the Barbegal mill and aqueduct system was extended by reconstruction and rehabilitation. One can imagine how valuable this flour mill was to the populace and how it was frequently repaired and restored to maintain its usefulness over time, perhaps for over three centuries.

The engineering aspects of the Barbegal water system are fascinating for many reasons. The overall study of Barbegal, including this field visit, is an investigative process, from an engineering perspective, to learn about Roman engineering and to pass on what we learn. It is intended that, through this process, we become better engineers.
The fieldwork during August 2005 included observations, measurements, and photos of many sites that had not been previously visited by the Wright Paleohydrological Institute (WPI) team. The work also included research visits to the Musée de L’Arles (Museum) and meetings with several leading researchers of the Barbegal sites.

There were many highlights of the field visit with much new information obtained. These highlights include:

- Interviewing researcher Etienne Blanchet and obtaining his two-volume report that addresses the painstaking work of documenting the north and south aqueduct remnants.
- A meeting and discussion on the mill site with leading researcher Professor Philippe Leveau, and his colleague Professor Bruce Hitchner.
- Taking detailed horizontal and vertical measurements of sections of the mill site and aqueduct system.
- Discovering modern day springs in the starting areas of the ancient aqueducts and taking water samples for laboratory analysis.
- Discovering the Simian Bridge as a mostly intact structure that passed stormwater flows below the aqueduct.

2.0 OBJECTIVES OF THE FIELD VISIT

Planning for the August 2005 field visit included the following major objectives as organized by the physical categories of the mill site, aqueducts, and water sources. During planning, it was recognized that some of the objectives could be attained during the field visit, while others would need additional study after field observations and data were obtained. The objectives that were attained as a part of the field visit are addressed in the “Observations and Discussion” section of this report.
2.1 Objectives Regarding the Mill Site

- Perform observations and measurements to describe whether or not there was a uniform or consistent design layout of each waterwheel and millstone system.

- Assess the overall dimensions of the site to make observations regarding the design of the mill. If uniform design is evident in the individual water wheel and millstone systems, then could the site actually hold 16 systems?

- Investigate the dimensions of a specific water wheel and millstone system to envision plausible arrangements of the wheel, type of gearing, location of the millstone, and worker access to the system.

- Make general observations of the construction, geology, and foundation of the site.

- Obtain measurements of the arches along the Le Vallon des Arcs to determine the uniformity of design.

2.2 Objectives Regarding the Aqueducts

- Acquire a better understanding of the extent of the aqueduct systems that brought water to the mill site by investigating existing remnants and meeting with experts.

- Define, to the extent possible, the aqueduct alignments and research the extent of vertical survey previously performed on these remnants by meeting with experts.

- Visit and inspect as many existing remnants and locate these using global positioning system (GPS) methods.

- Identify an aqueduct site location to perform independent study of how the Roman engineers designed culverts/arches to pass storm flows under the aqueduct.

- Begin acquiring the data needed to perform the above independent study.
2.3 Objectives Regarding the Water Sources

- If possible, determine the location of water sources that fed the aqueducts (north and south) by meeting with experts.

- If possible, visit the locations of possible water sources and locate these using GPS methods.

- If springs exist today, obtain water samples for water quality analysis specifically to describe the calcium carbonate (total hardness) condition of this spring water. This information will be used to explain the calcium carbonate deposition that is observed in the aqueducts.

3.0 OBSERVATIONS AND DISCUSSION

Much of our time in France was spent in the field performing observations and measurements of the physical remnants and geography of these sites. In addition, we made three visits to the Museum that houses many exhibits of Roman artifacts and history from throughout the local area. In particular, we were able to inspect, in detail, the model of the Barbegal mill that is on display, as well as the millstone fragments.

3.1 Interviews with Experts

The visits and interviews with Barbegal experts were also highlights of the August 2005 field expedition.

We conducted two major interviews with Barbegal experts. Individual meeting minute reports have been prepared for each of these interviews and are presented in Appendix A. Following are summary discussions of the most important aspects of the interviews.
3.1.1 Etienne Blanchet

In our initial meeting at the Museum, we met with the librarian, Michael Martin. He produced a two-volume library copy of a detailed field survey of Barbegal aqueduct remnants. Since the location of the aqueduct and remnants was one of the objectives of our journey, this was a major discovery for us. We inquired whether or not we could obtain our own copy and perhaps meet with the author of the work.

Thanks to Mr. Martin’s assistant, Patrick Heurley, we met with Etienne Blanchet on Monday, August 8, 2005 (see Photo 1). He brought along a signed copy of the two-volume report entitled *Aqueducs Romains Trajet de Barbegal à Arles* and *Aqueducs Romains Essai de recherche détaillée du trace de l’aqueduc nord des Alpilles*. We purchased this reference from Mr. Blanchet for a total of $110 euros.

![Photo 1. Etienne Blanchet (center), Patrick Heurley (left), and Phillip Wolfram (right) at the Museum.](image-url)
Mr. Blanchet is an elderly gentleman (88 years old) who retired from the French military. The work that he has done on the aqueducts was apparently done out of personal interest. He stated that it took approximately five years of work to produce the two-volume report. He was very happy that we were expressing interest in his work.

The work includes detailed (and what apparently are very accurate) maps of the aqueduct remnants for both the north and south aqueducts and the aqueduct from Barbegal to the City of Arles (City). The maps were at the back of each report.

The reports were used in the next several days to locate and photo document aqueduct remnants. They were also used to guide us to specific areas for water sources of the aqueducts.

The reports contain a limited amount of vertical survey data on the south aqueduct. The vertical survey data is one area that is incomplete in the reports. Nevertheless, we can use this data in the future to plot a profile of the south aqueduct and refine the hydraulic calculations associated with the aqueduct.

**3.1.2 Philippe Leveau and Bruce Hitchner**

A remarkable opportunity was presented to us when Philippe Leveau offered to meet with us at the Barbegal site. He had made plans to have lunch with a cousin in Maussane and would be in the area. Dr. Leveau brought along Bruce Hitchner, which was very fortunate for us since Dr. Hitchner is very fluent in both English and French and served as a translator during our visit with Dr. Leveau.

Dr. Leveau is the leading researcher on the Barbegal mill and the aqueducts coming into the mill system. Other than the researcher F. Benoit, Dr. Leveau is the only other researcher to publish work on excavations he performed at the mill site. He has also published many other papers regarding the mill.
Dr. Hitchner is the chairman of the Classics Department at Tufts University in Boston. He has performed research in collaboration with Dr. Leveau at the nearby Roman farm site of Merindole and the Simian Bridge.

The meeting with Drs. Leveau and Hitchner occurred on August 11, 2005 at the Barbegal mill site, see Photo 2. Many details regarding the mills and aqueducts were discussed and are in the meeting minutes presented in Appendix A.

Dr. Leveau’s research shows that the aqueduct and mill system were constructed in several phases. Dr. Leveau believes that the south aqueduct was constructed prior to the north aqueduct and that the aqueduct system was initially constructed to bring potable water into the City. This initial aqueduct system was constructed in the 1st Century AD and included an initial aqueduct from the convergence basin on arches across Le Vallon des Arcs to the Roche de Penne. He then contends that the water quality in the south aqueduct was deemed to be nonpotable, and this was a driving force in the planning/construction of the mill—an industrial use of this seemingly nonpotable water. He bases his theory on recent work done by a researcher on the calcium carbonate deposits in the convergence basin. He then gave us prepublication copies of two
articles that address this water quality component. These articles are in French and need to be translated.

The construction of a second parallel aqueduct along Le Vallon des Arcs to carry this water to the mill was in the 2nd Century AD. Therefore, Dr. Leveau maintains that the mill was constructed in the late 1st Century to early 2nd Century. Dr. Leveau then believes that the initial aqueduct was rehabilitated and reconstructed during the time of Trajan, 3rd Century AD. He showed us archeological evidence of the reconstruction at the site.

One of the aspects to the above planning/construction phasing theory is that it is difficult to believe that the Roman engineers would have used this aqueduct alignment to carry only potable water to the City. It would seem that a convergence basin located to the west would have resulted in a shorter aqueduct alignment to the City if there was no preconceived plan to construct a mill at the Barbegal site. The Barbegal mill site appears to be the optimum site in the area when considering such things as available head, consistency of slope, access, etc. When a civil engineer looks at the entire Barbegal system, it appears that this system was planned from the start for providing water first to the Barbegal mill site and then to the City. It is difficult to imagine that the Barbegal mill site was a coincidence after the aqueducts were laid out. This is one aspect that we plan to follow up with Dr. Leveau.

Another fundamental aspect of the Barbegal system that was learned from Dr. Leveau is that to explain the specific function and history of the mill will be an extremely complex undertaking. During our site visit, Dr. Leveau pointed out many examples and locations of reconstruction of the mill that presumably occurred over several centuries. Dr. Hitchner reported that there is absolutely nothing in the ancient literature that addresses the operation and maintenance of the Barbegal mill. Dr. Leveau even doubts that all of the mill’s waterwheels and millstones operated at the same time.

Dr. Leveau is also of the opinion that any further explanation of the Barbegal mill system would need to be done by engineers. He stressed that this would be extremely complex and would take years to research properly. Drs. Leveau and Hitchner understood that this was not one of the goals of the WPI at this time.
We also learned that Drs. Leveau and Hitchner did not know of any complete field survey of the mill site. Dr. Hitchner believes he has portions of the site surveyed and volunteered to look into this for us. He will also provide an article on research he knows about at the Simian Bridge. Dr. Hitchner was not aware of any research to address the Roman stormwater engineering aspects of the aqueduct design.

Drs. Leveau and Hitchner had several comments regarding the local politics and control of the Barbegal site as a tourist stop. The Town of Fontvieille’s business people think that the site is too far away from the town’s cafes and stores and do not want to promote the site as a tourist stop. The people of Arles (being approximately 7 kilometers away) also feel that the site is too far away from the city and will draw tourists away from the businesses and shops. Drs. Leveau and Hitchner believe these are reasons why the site is not better maintained and tourists are not controlled.

3.1.3 William Hildebrand

Wayne met with William Hildebrand on August 19, 2005. Mr. Hildebrand had just returned from a visit to southern California with his son.

Mr. Hildebrand described a rainstorm that occurred in September of 2003 resulting in the flooding of his property and partially into his home. Mr. Hildebrand’s home is located several yards from Le Vallon des Arcs. The storm washed away some sediment in the front of his yard to reveal a rock wall that appeared to be the south boundary of his property. It did not appear to be Roman.

Mr. Hildebrand explained that the town performs the weed/brush control only on Le Vallon des Arcs. The last cutting was probably about one and a half years ago. There has been no such maintenance on the mill site for a long time since the mill is on private property.

The town has also purchased, within the last two years, the property just to the west of Mr. Hildebrand’s property. He believes that the town may eventually construct a parking area for visits to the Barbegal site and probably charge for parking.
3.2 Barbegal Mill Site and Les Vallon des Arcs

Upon our first arrival on the mill site on August 4, 2005, we were somewhat dismayed that the vegetation around the mill site ruins had not been cleared for some time. In fact, the vegetation had not been cleared since our last visit in July 2002. This is evident by inspection of the photos taken in July 2002 compared to the August 2005 photos (see Photos 3 through 10). Note also that there is a fig tree that has grown up in Waterwheel Box No. 5 (see Photos 6 and 8). This fig tree is fast growing since it is not evident in the July 2002 photos (see Photos 5 and 7).

The vegetative cover was unfortunate since many of the details that would give us clues to the function of the waterwheel/millstone systems are in the lower portion of the mill. This is where the vegetation was most prolific. WPI should investigate the possibility of removing this vegetation prior to future visits.

Much of the top portion of the mill site has been taken down to the foundation walls, and what is left is the sturdiest portions of the mortar/rubble and brick that is tied into the limestone rock foundation. The very lower portion of the site has an accumulated depth of sediment that has protected a portion of the structure walls to a greater height. Again, this is the area that has the most vegetation, and most of it was inaccessible to us (either because of the thick, thorny vegetation or the accumulated sediment). However, we were able to identify one area within the mill site that has definition of the rooms and waterwheel boxes and we were able to access them for horizontal and vertical measurement. We have identified this area of the mill site as the East Waterwheel Boxes Nos. 3 and 4 in the associated millstone room complex. The location of this area is shown in Photo 11. This photo shows a plan of the mill site that is located in the Museum with Wayne showing the area of study (Waterwheel Boxes Nos. 3 and 4).


The horizontal and vertical dimensions of the East Waterwheel Boxes Nos. 3 and 4 and associated millstone room complexes were measured on August 5 and 6, 2005. Vertical dimensions were obtained by using a hand level and a makeshift survey rod.

The Waterwheel Boxes Nos. 2, 5, and 6 on the east side were also measured.

Our observations show that the waterwheel boxes appear to have rather uniform dimensions; approximately 4.9 meters (16.1 feet) in length by 1.3 meters (4.3 feet) in width by 2.5 meters (8.2 feet) in depth. Based on this assumed uniform design, it appears that the overall site dimensions could have indeed accommodated 16 waterwheel boxes.

We are further investigating the dimensions of the millstone and room systems to envision plausible arrangements of the gearing, millstone, and access.
In the July 2002 visit, we obtained measurements of the channels along the Le Vallon des Arcs. During the August 2005 visit, measurements were obtained on three major arch sections to begin to understand the structural and architectural design used by the Roman engineers. The three arch sections had dimensions at the base of the arches that range from 4.6 to 4.8 meters (15.1 feet to 15.8 feet). The radius of each arch was approximately 2.1 meters (7.0 feet). These dimensions were taken on the west arch structure. The width of the bridge structure at the arch is approximately 1.9 meters (6.2 feet). This arch supported an aqueduct channel with a width of approximately 0.9 meters (approximately 3.0 feet). A portion of the section of the Le Vallon des Arcs that was measured is shown in Photo 12. According to Dr. Leveau, this is the rebuilt aqueduct that dates from approximately the 3rd Century AD.

We also made two very interesting discoveries along Le Vallon des Arcs. First, we observed an emblem carved into a limestone block that was near the foundation of the west aqueduct. This emblem, shown in Photo 13, appears to be a flower or some type of vegetation. It could also be a symbol for wheat.
Also observed was a dovetail shape carved into several of the foundation blocks. These blocks appear to have been the first aqueduct, located on the west side. This dovetail carving is shown in Photo 14. We know of one reference that states that these dovetail marks were used to hold connecting stonework in place, and some authors hold the opinion that this way of connecting stonework died out during the 1st Century AD.
3.3 North and South Aqueducts

One of the main objectives during the field visit was to acquire a better understanding of the extent and location of the aqueduct system, both north and south aqueducts, based on the evidence of remnants and meeting with experts.

The research and discovery of the work discovered by Blanchet resulted in a much more precise map of the alignment of both the north and south aqueducts. Based on guidance from the Blanchet work, we were also able to visit and observe many sections of both the north and south aqueducts and obtain GPS readings to verify the mapping in the Blanchet reference. The result of this work is a map of the Barbegal aqueduct system, shown in Figure 1.

We learned many things regarding the aqueduct system from the Blanchet work and the visit to numerous locations of the remnants. For example, we determined that the north aqueduct went through the southern part of modern Fontvieille, and we located remnants that demonstrate this alignment. We also learned that one of the upper sections of the north aqueduct was on a different alignment than what we had previously assumed.

When confronted with crossing a drainage tributary with the aqueducts, the Roman engineers apparently used several techniques, specifically for the Barbegal aqueducts. For smaller and narrow tributaries, it appears that they followed the contours of the natural topography (e.g., Vallon des la Barjolle, Points 37 and 36 in Blanchet). For larger, wider tributaries, they used an arched bridge or culvert crossing (e.g., La Vallon des Simian, Point 49 in Blanchet). This aspect of Roman engineering is subject to further study.

One of the major aspects of the study of the aqueduct system is the water flow carrying capacity of the aqueducts.
Field measurements of channel width and estimates of the depth of water carried in the channels were compiled for the aqueduct section in the Les Vallon de Arcs, north aqueduct, and south aqueduct. This channel cross section information is presented in Tables 1, 2, and 3. The information presented in these tables should be supplemented by information obtained in future visits. However, we have sufficient information for key observations:

- The aqueduct through the Les Vallon des Arcs that carried water to the mill had a width of approximately 900 to 1,000 millimeters (mm) and a water depth of approximately 500 mm.

- The width of the north channel ranged from 510 mm to 940 mm. The north aqueduct had sections of open, rectangular channel and closed (tunnel) trapezoidal shaped channel.

The other important component of determining the hydraulics of the aqueducts is slope. Previously, we have used an assumed slope of approximately 0.001 (0.1 percent). This was based on the inspection of the topographic maps and investigation of the literature regarding Roman engineering.

Although we did not perform additional surveying during this visit, Blanchet provides additional information and insight regarding the aqueduct slopes. Blanchet’s work presents data that result in the following:

- North Aqueduct Entire Section \( S = 0.00064 \) (0.064 percent)
- South Aqueduct Lower Section \( S = 0.00066 \) (0.066 percent)
- South Aqueduct Upper Section \( S = 0.0084 \) (0.84 percent)

Although these field need to be verified, they can be used to refine our hydraulic calculations of aqueduct capacity.
TABLE 1

Aqueduct in Les Vallon des Arcs
Channel Cross Section Information

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance From Convergence Basin (m)</th>
<th>Width of Channel Bottom (mm)</th>
<th>Width of Channel Top (mm)</th>
<th>Estimated Depth of Water (mm)</th>
<th>Open Channel or Covered Section</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone cut</td>
<td>300</td>
<td>900</td>
<td>900</td>
<td>Open</td>
<td>Sediment filled.</td>
<td></td>
</tr>
<tr>
<td>Fallen section</td>
<td>190</td>
<td>880</td>
<td>460</td>
<td>Open</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Williams home</td>
<td>25</td>
<td>1,020</td>
<td>530</td>
<td>Open</td>
<td>South of convergence basin.</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2

North Aqueduct
Channel Cross Section Information

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance From Convergence Basin (km)</th>
<th>Width of Channel Bottom (mm)</th>
<th>Width of Channel Top (mm)</th>
<th>Estimated Depth of Water (mm)</th>
<th>Open Channel or Covered Section</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>East of D33</td>
<td>0.4</td>
<td>510</td>
<td>940</td>
<td>930</td>
<td>Covered</td>
<td>Channel is trapezoidal.</td>
</tr>
<tr>
<td>Simian Bridge</td>
<td>2.2</td>
<td>720</td>
<td>1,000</td>
<td>Open</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In town east of D33</td>
<td>4.7</td>
<td>880</td>
<td>1,000</td>
<td>Covered</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In town at Daudet Hotel</td>
<td>4.9</td>
<td>860</td>
<td>Covered</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3

South Aqueduct
Channel Cross Section Information

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance From Convergence Basin (km)</th>
<th>Width of Channel Bottom (mm)</th>
<th>Width of Channel Top (mm)</th>
<th>Estimated Depth of Water (mm)</th>
<th>Open Channel or Covered Section</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>West of D5—south of bridge</td>
<td>9.6</td>
<td>380</td>
<td>465</td>
<td>375</td>
<td>Covered</td>
<td>This is upper section only. Blanchet shows covered.</td>
</tr>
</tbody>
</table>
3.4 Water Sources and Water Quality Sampling

Since the Romans went to the expense of building the Barbegal aqueduct and mill system, we are assuming that the Alpilles Mountain springs were a good water resource in that they provided a reliable and adequate flow. The water quality aspects of the Barbegal system are intriguing since the water quality may have had something to do with the phasing of engineering and construction of the system. In addition, the calcium carbonate concentrations in the water resulted in significant deposits in the aqueduct channel that are still visible today. As hydraulic engineers, we wonder about the operations and maintenance resulting from these deposits and also questions whether or not the deposits had an impact on the water flow that was received at the mill.

Based on the August 2005 field visit, the Alpilles Mountain springs still exist. Based on the Blanchet work, we visited several locations where the French inhabitants have used these sources over the years. We have found no documentation of archaeological study of the sites that we visited during this trip. Therefore, we cannot say that any of the sites that were visited are Roman in origin, or that they were sources of the Barbegal system.

One of the objectives of the field visit was to obtain water samples for laboratory analysis, particularly for hardness and the potential for calcium carbonate deposits.

Following is a summary of the sites that were visited and relevant information regarding each site.

- Le Baux Golf Course—Based on Blanchet’s work, we visited both the Le Baux Golf Course and the Mas St. Berthe—both located in the Manville area (Point 4 in Blanchet’s work). To our untrained eye, the remnants on the Le Baux Golf Course appear to be a major spring collection gallery site. Although the site did not have water during out visit, it was evident that spring water occurred here. This is an area of a major limestone bed plain surfacing, a perfect conduit for groundwater. We observed remnants of rock and mortar with the appearance of older construction. There was also a “newer” looking
cistern-type structure at this location. We also observed what appeared to be aqueduct remnants from this source traversing the golf course.

- Mas St. Berthe—This location is at a farmhouse located upstream of the Le Baux Golf Course. We met with the residents of the farmhouse (Anne Rolland and her mother). The spring empties into a cistern located just in front of the farmhouse. We visited this spring on two dates, August 10 and August 19. On August 10, the spring was not running. On August 19, the spring was running at a flow of between 5 to 10 gallons per minute (gpm). A sample of water was taken on August 19, as shown in Photo 15. There was no evidence of older construction at this site.

![Photo 15. Sampling at Mas St. Berthe Spring.](image)

- Mas de la Dame—This location is also on the upper reaches of the south aqueduct. We observed two manhole-like structures, side by side, made of rock and mortar. These structures were of more recent construction, not Roman. One of the structures had a pump installed at the bottom, but there was no water at the time of the visit.
• Manville Spring—This site is also located in the upper, south aqueduct area, downstream of the Le Baux Golf Course. We visited this site because it is a modern day, flowing spring located in the vicinity of sources shown in the Blanchet work. On August 6, 2005, the springs resulted in a flow in the range of 40 to 60 gpm. The springs are located just upstream of a pump/chlorine station that serves the Town of Maussane. Nearby homes had placed portable pumps with suction hoses in the pool created by the spring. We obtained water samples from this spring.

• Les Arsacs Lake—When we informed Mr. Blanchet that we wanted to obtain water samples from an Alpilles Mountain groundwater sources, he suggested that we visit the Les Arsacs Lake. This lake was created by an open pit, bauxite mine. It is located in the area of origin of the south aqueduct in the Vallon Rouge. We obtained a water quality sample from the surface of the lake (southeast corner).

• Souneques Spring and Lavoir—This spring site is the only site that was visited on the north aqueduct system. It is located near the Town of Eygalieres. This spring had a structure of stone and mortar. On August 19, 2005, there was no water evident, but damp conditions were observed. Spring water is conveyed across a road through a pipe to a basin where the locals do their laundry. The age of the structure is unknown to us.

• William Hildebrand Well—We obtained water quality samples from Mr. Hildebrand’s well to obtain additional data from an Alpilles Mountain groundwater source. William reported that his well is approximately 75 meters deep, and that the water is filtered through a cartridge filter. There is no disinfection of the water.

The locations where water quality samples were obtained, along with the results of the water quality analyses, are presented in Table 4. The water quality parameters were selected to address the calcium carbonate chemistry and the potential for calcium carbonate deposition. The following is a summary of observations of the water quality data:
### TABLE 4

Barbegal Water Quality Analyses
August 2005

<table>
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<tr>
<td>pH</td>
<td>7.55</td>
<td>7.28</td>
<td>7.42</td>
<td>8.08</td>
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<tr>
<td>Temperature (Deg C)</td>
<td>15.5</td>
<td>24</td>
<td></td>
<td></td>
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<tr>
<td>Calcium</td>
<td>110</td>
<td>110</td>
<td>100</td>
<td>69</td>
</tr>
<tr>
<td>Magnesium</td>
<td>9.5</td>
<td>9.9</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>Sodium</td>
<td>10</td>
<td>8</td>
<td>14</td>
<td>5.3</td>
</tr>
<tr>
<td>Bicarbonate Alkalinity (mg/L as CaCO3)</td>
<td>269</td>
<td>245</td>
<td>171</td>
<td>149</td>
</tr>
<tr>
<td>Total Hardness (mg/L as CaCO3)</td>
<td>310</td>
<td>320</td>
<td>300</td>
<td>200</td>
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<tr>
<td>Specific Conductance</td>
<td>583</td>
<td>545</td>
<td>595</td>
<td>368</td>
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<tr>
<td>Total Dissolved Solids</td>
<td>366</td>
<td>340</td>
<td>390</td>
<td>230</td>
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<tr>
<td>Total Suspended Solids</td>
<td></td>
<td>U</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Chloride</td>
<td>10.3</td>
<td>13.5</td>
<td>20.1</td>
<td>10.2</td>
</tr>
<tr>
<td>Sulfate</td>
<td>38.4</td>
<td>39.6</td>
<td>115</td>
<td>29.1</td>
</tr>
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The total hardness concentration in the groundwater samples ranges from 300 to 320 milligrams per liter (mg/L) as calcium carbonate. This is a “very hard” degree of hardness according to the American Water Works Association. A total hardness of 200 mg/L was measured in the Les Arsacs Lake.

- The total hardness is due primarily to the calcium concentrations in the groundwater (100 to 110 mg/L). There is also some magnesium that contributes to the total hardness, but only slightly.

- The total dissolved solids (TDS) concentration ranges from 340 to 390 mg/L in the groundwater.

- There is more sulfate and less bicarbonate alkalinity in the deeper groundwater well (Hildebrand) when compared to the surface, spring water.
The groundwater quality is typical of a limestone geology with high calcium hardness. We calculated the calcium carbonate deposition potential to determine if this water could result in significant deposition on the surfaces of the aqueduct channel.

The potential for calcium carbonate deposition is based on the conditions of the water as described by pH, bicarbonate alkalinity, calcium hardness, and TDS. The calcium carbonate deposition potential for the spring water (Mas St. Berthe and Manville Spring) is approximately 70 mg/L as calcium carbonate. This is a significant calcium carbonate deposition potential.

4.0 THE ARCHED BRIDGE AT LE VALLON DES SIMIAN

The arched bridge at Simian is an intact structure that the Roman engineers designed to cross the Les Vallon des Simian, see Photo 16. This structure probably is the only arched bridge that crosses a stormwater drainage that remains intact in the Barbegal aqueduct system. During some storm events, the arches probably still have water flowing through them. Note that the arches at the Les Vallon des Arcs cross over what is now a very dry area (once a marsh) even during storm events.

The Simian site is of specific interest since the Roman engineers would have had at least some understanding of the depth of the water that would occur in this small drainage during a storm event. Since stormwater hydrology and hydraulic structures are specialties of the WPI, the Simian site appears to be an opportunity for independent study on one aspect of the Barbegal system. Engineering references regarding the Roman engineering of hydraulic structures to address stormwater drainage are limited, which is another reason for proceeding with this independent study.

Les Vallon des Simian is a small watershed that has no base flow. However, because of the limestone geology and low soil permeability, there could be a significant flow during a storm event. On August 12, 2005, the drainage basin area was walked, and GPS measurements were obtained. Even though the brush was rather heavy in some areas, the ridgeline of the basin area was mostly accessible. Based on GPS measurements of the drainage, the area was determined to be approximately 0.15 square kilometers (36.3 acres) in area. The Simian drainage basin is shown on Figure 2.

Field measurements of the bridge and Simian were obtained on August 7, 9, and 12. The bridge consists of four arches supporting the aqueduct channel with a width of approximately 800 mm. One unique aspect of the bridge is that there is a slight bend at approximately the middle of the structure. The overall length of the structure is approximately 48 meters (158 feet).

Each of the four arches measure from 2.6 to 3 meters (8.5 to 9.7 feet) in length at the base with the radius of each arch ranging from 1.4 to 1.9 meters (4.6 to 6.2 feet). The width of the bridge structure at each arch ranges from 1.85 to 1.99 meters.
Another unique feature of this structure is the western arch. Construction at this location has resulted in “an arch within an arch” as shown in Photo 17. This work may have been done to repair a structural failure of the material at the top of the larger arch or to restore the structure.

Still another unique feature of the bridge at Simian is the use of large limestone blocks rather than rock and mortar in the construction of the columns between several of the arches (see Photo 18). We will investigate whether or not this construction was part of the original structure.
5.0 FUTURE STUDY AND ACTION PLAN

The research and data obtained during this field visit will be studied to develop the engineering perspective of the Barbegal mill and aqueduct system. The goal of this further study will be to publish papers and articles in civil-engineering related journals and magazines.

The action plan is presented in Table 5.

TABLE 5

Action Plan

<table>
<thead>
<tr>
<th>Priority</th>
<th>Paper Title or Subject</th>
<th>Author(s)</th>
<th>Targeted Journal</th>
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<tbody>
<tr>
<td>1</td>
<td>Water Quality Impacts to Aqueduct Hydraulics in the Second Century</td>
<td>Lorenz</td>
<td>Water Environment and Technology</td>
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<tr>
<td>2</td>
<td>Hydraulics of a Roman Aqueduct System in Southern France</td>
<td>Lorenz, Wright</td>
<td>ASCE, Hydraulics Division</td>
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<tr>
<td>3</td>
<td>Stormwater Hydrology and Engineering of an Ancient Roman Aqueduct Bridge Crossing in France</td>
<td>Lorenz, Wolfram</td>
<td>Journal of the AWRA</td>
</tr>
<tr>
<td>4</td>
<td>The Barbegal Flour Mill: Ancient Roman Civil Engineering</td>
<td>Lorenz</td>
<td>Civil Engineering Magazine</td>
</tr>
<tr>
<td>5</td>
<td>Ancient Roman Water Resources and Water Quality</td>
<td>Lorenz, Wolfram</td>
<td>Public Works Magazine</td>
</tr>
<tr>
<td>6</td>
<td>The “Les Vallons des Arcs” at Barbegal: Structural and Architectural Features</td>
<td>Lorenz</td>
<td>ASCE Bridge Engineering (or other)</td>
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</tbody>
</table>
MEMORANDUM

To: Barbegal Research File
From: Wright Paleohydrological Institute
       Phillip J. Wolfram and Wayne F. Lorenz, P.E.
Date: August 15, 2005
Re: August 9, 2005 Meeting at the Musée de l’Arles et de la Provence antiques (Arles Museum) With Etienne Blanchet—Arles, France

Wright Paleohydrological Institute (WPI) researchers Wayne Lorenz and Phillip Wolfram met with Patrick Hourly, assistant curator of the Arles Museum, and Etienne Blanchet, independent researcher, at 4:00 P.M. on August 9, 2005. Mr. Blanchet’s wife was also in attendance.

The meeting was initiated after Michel Martin, curator at the bibliothèque of the Arles Museum, brought to the attention of WPI’s researchers Mr. Blanchet’s two relevant reports on the Barbegal mill site. Mr. and Mrs. Blanchet were kind enough to drive from their home in Avignon to meet with us at the museum.

Mr. Blanchet is the primary author of a two-volume report entitled Aqueducs Romaines Tour de Barbegal à Arles and Aqueducs Romaines Essai de recherche détaillée du trace de l’aqueduc nord des Aptilles.

These reports address the vestiges and locations of the north and south Barbegal aqueducts (volume 1) and the aqueduct leading from the Barbegal mill into the City of Arles (volume 2). We purchased a copy of both volumes for 110 Euro.

Mr. Blanchet stated that he spent four to five years of his life in preparation of these reports. He was assisted in the fieldwork (i.e., surveying) by students.

The salient points of the meeting are as follows:

- Mas Crema is considered by Mr. Blanchet the beginning of the north aqueduct (see map is Blanchet’s Aqueducs Romaines)
- Mr. Blanchet used an aerial photograph as the basis to determine the course of the aqueduct leading into Arles. Vegetation and coloration differences were noted by him and assumed indicative signs of the aqueduct’s subterranean route.

To further the knowledge of our civilizations through the study of ancient water management and practices.
The National Forestry Service archives aerial photographs of the Alpilles region every 10 years. These photographs have been archived. Note: Google Earth likely uses the latest version of the forestry photographs explaining the high level of detail apparent in the photographs.

Mr. Blanchet compiles these papers by himself, with some help by students. It was his "personal work," and he has presented at conferences.

Mr. Blanchet sold Dr. Leveau a copy of his work. Dr. Leveau was alerted to the work by one of his students who attended a conference where Mr. Blanchet presented. He contacted Mr. Blanchet and purchased it. They never personally met.

The director of the museum is supposed to have written some articles on this subject. His name is Jean Maurice Rouquette.

The north springs are dry.

There is still water in the south aqueduct region.

- Mines for bauxite in southern region.
- Lake of subterranean water formed through mining.

There is a little lake at the top of the most southeastern aqueduct. This originates from about a century ago (likely caused by bauxite mining).

The Les Baux Golf Course is watered from ancient spring water. It is near Le colombier.

The Kaistic limestone benefited the creation of springs. (Since it also fractures a lot, too, the possibility of springs increases.)

The region is full of water. This is one reason the site was chosen.

Between Le Rougas and west of St. Remy, the aqueduct is full of water until the chateau (see 20 in Blanchet's work).

A modern windmill raised water from the aqueduct via a pump.
According to Mr. Blanchet, the north aqueduct extension shown in Mr. Leveau's schematic is nonexistent.

The little river that is congruent with the extension was used to irrigate farming.

La Durance feeds the existing canal to the south of the mill. The canal is modern.

The north aqueduct following the topo due to steepness (west side of Alpilles).

In the south aqueduct, arches were used because the depth was less steep than in the north. Following the contour would have been more costly than building a bridge and would have increased the aqueduct's length.

On Mr. Blanchet's map, triangles indicate the elevation of the south aqueduct.
MEMORANDUM

To: Barbegal Research File

From: Wright Paleohydrological Institute
Wayne F. Lorenz, P.E.
Phillip J. Wolfram

Date: September 12, 2005

Re: August 11, 2005 Meeting With Dr. Philippe Leveau and Dr. Bruce Hitchner at the Hotel Val Major and the Barbegal Mill Site

WPI researchers Wayne Lorenz, P.E. and Phillip Wolfram met with Dr. Philippe Leveau and Dr. R. Bruce Hitchner on August 11, 2005 at 4:45 P.M. Dr. Leveau is retired from Aix de Provence University and is the leading researcher on the Barbegal mill. Dr. Hitchner is the head of the Classics Department at Tufts University. Dr. Leveau’s wife and Hitchner’s wife were in attendance for the first couple minutes, in addition to Hitchner’s children. Shortly after arriving, Lorenz, Wolfram, and Drs. Leveau and Hitchner went to the Barbegal mill site for discussions. After approximately an hour and a half at the site, they met back up with the Leveau and Hitchner families at the hotel.

Dr. Leveau is 68 years old and recently retired from the Aix de Provence University. He started work on Barbegal in 1990. Dr. Hitchner is past editor of the American Journal of Archaeology and is also Chairman of the Dayton Peace Accords Project and is helping to prepare a constitution should the Province of Kosovo attain their independence.

The information received at the meeting is as follows:

- We first met at the site on the location of the convergence basin (convergence of the north and south aqueducts). Dr. Leveau showed us where the excavation for the convergence box was performed in the early 1990s.

- Dr. Leveau explained how the south and north aqueducts came together at this place with the water being conveyed to the south in one aqueduct over the Vallon des Arcs. This first aqueduct was built in the First Century A.D. In the Second Century A.D., a second parallel aqueduct was constructed along with the Barbegal mill. The primary water source to the mill was from the south aqueduct. Then, probably in the Third Century, A.D., the original aqueduct over the Vallon des Arcs was rebuilt.

To further the knowledge of past civilizations through the study of ancient water management and practices.
Dr. Leveau said that the south aqueduct was constructed initially, then the north aqueduct was constructed when the south water was used less.

Dr. Leveau reported that there had been recent studies on the calcium carbonate deposition in the convergence basin. These studies have revealed that, at one time, the water from the south aqueduct was deemed no longer potable. Slow moving water was the problem and, evidently, the aqueduct ceased to be useful for potable water use. Therefore, the water was perfect for an industrial application like the Barbegeal mill.

Dr. Leveau was not as knowledgeable of the water sources, or springs. The “precise location of the sources is not known.” However, he did say that one source was at Paradeux at a small farm. Dr. Leveau was not sure of the spring structure that we had investigated several days earlier at the Les Baux Golf Course.

The convergence basin (and diversion functions) of the box was specifically constructed for the mill at Barbegeal.

The initial aqueduct (Vallon des Arcs) was made of poor limestone. Construction techniques were poor and there were foundation problems due to settlement of the limestone blocks. The rebuilt aqueduct (approximately Third Century) was built on the old foundations. Dr. Leveau pointed out several examples of this reconstruction.

At the mill site, we discussed how F. Benoit performed the initial, modern excavations of the mill in the late 1930s. During Benoit’s excavations, debris piles were made on either side of the current mill site. Dr. Leveau stated that this would be a good archaeological project in its own, sifting through the debris piles.

One of the evidences of the diameter of the water wheels was left by impressions into the calcium carbonate. According to Dr. Leveau, Benoit chopped away at the calcium carbonate at the site in the wheel boxes. Dr. Leveau also says that he knows the size of the waterwheels by the placement of connections in the boxes.

The mill use, operation, and maintenance simply are not known. There is nothing in the literature (emphasis on nothing).

Benoit discovered millstones and fragment of millstones from different stages.

The millstones that have been recovered had been the subject of testing, including study of the interior of the millstone. There were no traces of grain in the millstone: testing was inconclusive. Dr. Hichner stated that wheat and barley were likely ground at the mill. There was no corn (New World discovery).

All sediments were analyzed. No grain could be found for definitive analysis. Combinations of wet and dry periods have been destructive. Results of study are mediocre.
We had a discussion regarding the origin of the rock for the millstones. Published work shows a volvic source. Both Leveau and Hitchner said that the source of the basalt for the millstone is not sorted out. The sources of Longobard and Mass central have been eliminated as sources. Therefore, the precise location of the millstone source is still not known.

Dr. Hitchner is aware of some field surveying that has been done to show plan and sections of the mill site. He will investigate these surveys for the WPI.

The mill has been reconstructed in many different locations (and probably many times). Dr. Leveau pointed to a piece of calcium carbonate that was placed in the wall, presumably for repair. The calcium carbonate deposit came out of the wheel box.

There is no good sense of chronology on the aqueducts. Things were constantly “tapped and capped.”

Key questions attached to Leveau’s article designed to create a priority of importance in regards to research at Barbegal.

Site cannot be easily analyzed due to complexity. Necessitates a multidisciplinary study that puts bits and pieces together for understanding. “It is the work of engineers to do analysis.”

University of Braunschweig students did a basic study of hydraulics.

After the Fourth Century, the aqueducts were no longer used.

Excavation used to determine dating and water level at mill (at side and bottom).

It is hard to excavate any portion of the site since the mill is on private property.

Dr. Leveau has photos of his excavation.

The model of the Barbegal mill at Arler museum is based on Dr. Leveau’s vision.

- The structure at the top of the Rochers de la Pene was done by an architect who took things too far. There is no specific evidence for such a structure.

- The deepest part of the millstone room held the mechanism and gear shaft.

- The mill had different phases of activity.

  - Mill periods of use and their frequency are unknown.
The mill was not a “modern system” that had each part working faithfully. Things were not likely working all at the same time—sort of a patch job.

Archaeology reconstruction was difficult and evolutionary details of mill are unknown.

There are five or six smaller mills than Barbegal found in the region. Barbegal is the exception of Roman mills because of its size.

For an excellent research library visit the Mediterranean Center in Aix en Provence (http://www.mnash.univ-aix.fr/mediatheque/).

The meeting ended at approximately 7:00 P.M. Photographs were taken at the site with Drs. Leveau and Hitchner.