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Aqueduct Architecture: Moving Water to the Masses in Ancient Rome

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by Ralph Russo

Introduction

This unit seeks to raise awareness of basic, yet, historic principles of architecture as they apply to the provision of water to an urban center. Exploration of Roman aqueducts should serve this goal. It fits the study of classical civilizations in the ninth grade world civilizations curriculum. Moreover, it lends itself to interdisciplinary teaching, a great way for students to see things in context. Studying aqueduct architecture encourages proficiency in quantitative skills, language arts, and organizational skills. Quantitative activities such as measuring, using scale, and calculating volume facilitate developing math skills. Critical reading of primary and secondary sources, document based questions, discussion, reflective writing, descriptive writing, and persuasive writing teach and/or reinforce language arts skills. Readings and activities can also touch on the levels of organization or government necessary to design, build, and maintain an aqueduct. The unit is not a prescribed set of steps but is meant to be a framework through which objectives, strategies, activities, and resources can be added or adjusted to meet student needs, address curriculum goals, and help students to make connections between the past and contemporary issues.

The inhabitants of Rome satisfied their need for water first from the Tiber River. Rome grew from a small farming community along the Tiber into the capitol city of an empire with almost one million inhabitants. Like all urban centers of the past and present, and future, Rome had to deal with the challenges of gathering and maintaining enough freshwater to provide for a suitable level of health, nourishment and hygiene for its inhabitants. The people of Rome met this challenge through the adapting and refining aqueduct architecture from the Assyrians, Etruscans and others. Yet the Romans not only emulated others but raised the bar of accomplishment through the sheer quantity of aqueduct construction throughout its empire. The effectiveness of their work is evident in the almost 2,000 year-old remains of the grand edifices such as the arches of the Porta Maggiore in downtown Rome and in the ruins of the 12km arcade that supported the Aqua Claudia across the Campagna. Similar technology is also still apparent in water authorities across the United States today. The Catskill Mountains a historical source of Manhattan's drinking water is tethered by aqueduct. Los Angeles uses aqueducts to bring water and carry it away from the city. These modern examples show that principles of aqueduct design used by the Romans continue to serve large urban centers. To help students make connections between the past and present as well as prognosticate what challenges lie ahead for the future, the unit references local water authority infrastructure issues as well as global freshwater supply and demand problems. This unit can be used as an interdisciplinary unit with the support of a math teacher or as a component of the study of classical civilizations.

Rationale

Water is an essential resource for health and survival. We are as dependent on having clean water as the Romans were 2000 years ago. Growing demands on our water supply challenge us to be conscious of how we consume water and ensure a healthy standard of water quality. Because we face some of the same challenges to providing clean water to our cities as did the Romans, having students make connections to how we provide clean water to our urban centers makes sense.

When one more closely examines the situation of both the Romans and we, common needs between our civilizations become apparent. First, all societies must be able to sustain their basic human needs. Like the ancient Romans, we understand the need for a clean and steady water supply. We also know the difference between good and bad tasting water. We make great efforts at times to at least drink water we find most potable. For the ancient Romans this meant being lucky or persistent enough to obtain water from the Anio Valley brought by the Marcia Aqueduct as opposed to settling for water from the Lake Alsientinus on Alsientina Aqueduct. For us it may be buying a particular brand of bottled water or drinking water treated by home filtration systems. Another shared characteristic is that our methods of obtaining clean water developed in a technological, scientific, and at times in an artistic way. Roman aqueduct design and construction evolved from almost completely hidden subterranean channels to more grandiose constructs which grandly entered the city walls. Early Romans were often threatened by invasion; hence the need to hide their water supply lines from enemies. As Rome secured and expanded its borders, Rome's political leaders seized the opportunity to create more open and grandiose waterworks.

The innovation and improvement of the Roman's water distribution has parallels in our culture. While our water delivery system is mostly hidden in an array of subterranean water mains connected to tentacles of copper pipe, it nonetheless evolved from tapping local sources and expanded outwards to serve spreading metropolis. When pre-20th century well and pump technology is compared to current home bathroom and kitchen décor as well as infrastructure for heating, chilling, and filtering water, we see a remarkable improvement in technology in a relatively short period of time.

I would like students to gain an awareness and appreciation of our water supply. I think that we often have the fortune of taking clean water for granted. While many in the global community see a growing water crisis, our outlook reflects expectation that clean water will always be available. Evidence provided by the United Nations World Health Organization indicates that the status of the world's water supply may well be in danger. The United Nations reports that water related deaths and diseases are an increasing human tragedy. More than 5 million people each year - 10 times the number killed in wars die in water related deaths. Furthermore, about 2.3 billion people (more than a third of the world's population) suffer from diseases linked to dirty water. Some 60 per cent of all infant mortality worldwide is linked to infectious and parasitic diseases, most of them water-related. (1)

Of specific importance is the notion that the citizens of ancient Rome and us share the experience of living in rather dense urban areas where sanitation is paramount. Interestingly, because of more or less efficient systems of water supply and sewers, both, the classical city of ancient Rome in general and our cities today can be said to have a rather high standard for supplying clean water and disposing of sewage. Actually by comparison, the Romans may have outdone us in terms of the quantity of water delivered to the city proper and in the efficiency of disposing waste water. In Roman Roads and Aqueducts Don Nardo calculates that the flow of the eleven Roman aqueducts to service Rome's population of over one million could potentially deliver about 250 gallons of water per day per person compared to about 125 gallons per day that a typical water authority can supply the average American town. (2) Both societies have also demonstrated how to efficiently facilitate water disposal; Romans also constructed crowned roads with raised sidewalks. Covered sewers large enough to walk in were common in busy areas of the city. The Cloaca Maxima, part of a drainage system built by the Etruscans still drains storm run-off from a modern Roman Road into the Tiber. It can be viewed from the Ponte Palatino. (3) Perhaps it is worth saying that these standards are high compared to woeful accounts of the unsanitary conditions of crowded European cities in the Middle Ages, where sewage flew from apartment windows and waste water pooled in the streets. So aqueducts are a useful avenue to explore how a civilization maintains a high standard of health - more health than the monarchies that arose following Rome's decline.

Additionally, study of the Roman aqueducts exemplifies how technology is adapted to suit a society's need. For in building these aqueducts, a progression is evident. From the hidden and rather crude Aqua Appia to the grand length and volume of Marcia to the directness of Alexandria one can see the refinement of Roman skills in both style and scale. The Roman aqueducts are a great subject to study because they incorporate architecture, math, and history with the study of necessary life resource- water! As is true both in ancient times and in the present, the community without an adequate supply of clean water for drinking and sanitation experiences high rates of disease and mortality. The Romans effectively yet imperfectly delivered sufficient amounts of water to Rome from the surrounding countryside. They improved upon their building technique by developing better ways to gather spring water in constructed basins, include settling tanks, and transverse distances of markedly different elevations. They also improved concrete to seal and strengthen aqueducts. The infrastructure became so vast that the remains of their aqueduct system are still revered for the scope of their form and function.

Today shortages of clean water for drinking and sanitation plague many communities in parts of the world often described as the developing world. By declaring 2003 the international year of clean water, the UN raised awareness to the fact that approximately over 1/3 of the world's population lack access to adequate supplies of clean water. (4) In a curriculum unit written in 2004, I explored the prevalence of this water crisis. Some facts regarding water crisis and health can be found in appendices 1 and 2. In this unit I seek to address how Roman technologically and architecturally satisfied its need for water and invite students to draw parallels to how society today satisfies its need for water.

My goal in developing and teaching the unit transcends the desire to have students understand the fundamental principles of how the Roman Aqueducts were constructed. Given the global inequities of access to clean water and the emerging challenges of maintaining the vitality of the water supply in developed areas, wanting students to gain awareness, appreciation and respect for practices that allow for the sustainable use of water makes sense. I carry this idea forward from being a fellow in John Wargo's 2004 YNHTI seminar on Water in the Twenty-First Century. The seminar crystallized some developments which are becoming apparent to everyone. Inequities in supply, growing populations, threats to the health of water supplies, and mismanagement of water supplies pose serious health risks to a significant part of the world population. With the price of bottled water making clean water now not just a resource but a valuable commodity, it is necessary that clean water not be taken for granted.

But not taking water for granted means undertaking practical action to manage water efficiently. Moving water efficiently means constructing a suitable infrastructure for water quality and distribution. Knowing something of constructed space and the materials needed to build properly is just as essential as desiring a designed space. My understanding of the necessity of creating architecturally sound structures for moving water to the masses greatly increased due to my participation this year in the seminar *Math in the Beauty and Realization of Architecture.* Martin Gehner, our seminar leader shared copious amounts of his expertise as an architect and educator. Not only did he model excellent teaching practices through his weekly organization at seminar sessions, but he encouraged a supportive and collegial setting through which all fellows could come to learn fundamental principles of architecture and apply them to our curriculum units. Professor Gehner facilitated a view of the aqueducts as architectural structures that conform as do all constructed space to general architectural principles. We explored these principles through weekly readings and three projects. Through our projects I discovered that each material used in constructed space has its own set of qualities that favor its use in particular situation. For instance, a steel I-beam can span a greater length due to its ability to accept more tension and compression, than a concrete beam. Subsequently a modern skyscraper can reach to higher heights with much less material than can be achieved through concrete or mortar. Compare an early medieval church to the Sears Tower or any skyscraper and you will begin to understand the implications of building with different materials. Professor Gehner certainly encouraged us to never take the material of a structure for granted. I learned why stone and a primitive form of concrete were preferred materials for the construction of aqueducts; these materials were effective and available as was a large pool of semi-skilled labor.

So I understand better now how the Romans became master builders of stone structures that served the needs of Roman society well; they built magnificent roads, buildings, and aqueducts on a grand scale.

Standards

The unit both directly and indirectly addresses a number of local, state, and national standards. The harnessing and management of sufficient amounts of clean water for a large urban population requires a close connection between humans and their environment. As Rome grew from a small community on the banks of the Tiber River to a major urban center of over one million people, innovation was needed to tap into additional sources of water. Reliance on the Tiber as the primary source of fresh water and waste water depository diminished during the 4th century as Romans constructed its first aqueduct, the Aqua Appia. The story of the Aqua Appia shows the marvel of moving water over long distances of varied terrain- discreetly. It also shows how those who lived in the Roman countryside masterfully utilized the fresh water springs.

Study of the story of constructing the discreet and crude Aqua Appia, the bold Marcia, or the majestic Claudia will allow students to make connections that will help them understand the development of human culture and its relationship to geography and environment. (Content Standard One) One story has it that even the talented Roman engineers trying to find the source of a spring to build the Aqua Virgo needed the help of a local village child who had been born there (5)

The body of work that comprises the construction of Rome's eleven aqueducts and other aqueducts throughout its empire is an important legacy that continues to influence water supply technology today. Although temporarily obscured during the Middle Ages, the principles and techniques employed by Roman builders are fundamental for today's engineers. Building on the technology learned from the Etruscans, Roman engineers sufficiently mastered moving water through different elevations through building techniques that showed a mastery of hydraulics. The siphon and arch allowed builders to transverse steep ravines. Raised tanks limited head and controlled the velocity and inertia of water. Tools such as the t-bar and chorobates, or water level for leveling, the groma and dioptra for determining site lines were all essential for surveying. There function is still practiced albeit with advanced electronic and mechanical tools. Today fresh water is transported to New York City from upstate New York over a distance of many miles. In 1837 work on a 125 mile Catskill Aqueduct project began the tradition of bringing clean water to Manhattan from watersheds in the Catskills. (6) In California, open aqueducts move storm water away from roads and population centers. Others bring clean water to cities from outlying mountains. Students who explore even the most general characteristics of the development of aqueduct architecture from the Assyrians to the Romans and beyond will see the global impacts of classical civilization at work (Content standard three)

By examining the achievements of the Romans and our modern society in regard to harnessing and managing access to clean water, students will be able to evaluate the impact of these achievements for the future. Students should be able to make connections from the past to the present and to the future particularly when they are exposed to the growing challenges of providing access to clean water for everyone in all parts of the world. This challenge has been clearly annunciated by the United Nations in their Year of Fresh water campaign of 2003.

The use of Roman engineering techniques to build aqueducts in what are now France, Spain, Israel, and Britain shows the political and economic structures of empires (Content Standard Four). Having students examine examples of Roman aqueducts across Europe and the Middle East will allow students to examine the impact of cultural diffusion from Empires into surrounding cultures and vice versa (content standard five)

Objectives

Objectives for this unit will include having students rationalize the need for a clean and consistent source of water for all civilizations both past and present. Exploration in this area will include having students demonstrate the general historical developments in irrigation and water delivery systems from civilization to civilization over time. Thus the unit will credit the influences of the Etruscans (the Arch) and the Assyrians (aqueduct construction) for inspiring the Romans to go beyond their predecessors in both scale and function. Students will be able to name and describe the components of a typical Roman aqueduct and be able to name and describe two of these aqueducts in detail. The unit will contain opportunity for students to demonstrate how a fundamental understanding of mathematical concepts such as volume, slope, and gravity is essential to completing a successful aqueduct. Further objectives will allow students to explore the aqueduct in the eco-social-political context of Roman Civilization. Readings and presentations which associate the building of aqueducts with the people (engineers, laborers, and political figures) who made the aqueducts a reality will be included. We are fortunate to have primary source material from Marcus Vitruvius Pollio a practicing Roman architect from about 46 to 30 B.C., who compiled his knowledge of into a ten book treatise called *On Architecture* and from Sextus Julius Frontinus, a governor and distinguished military leader, who was appointed *curator aquarum* (water commissioner) of Rome in A.D. 97. Students will examine primary and secondary source material regarding these people to understand some of the whys and hows of Roman aqueducts: Why were aqueducts needed? How was an aqueduct constructed? How did an aqueduct function? How much water could be moved and how far could it be moved? Who benefited from the water? What problems did aqueduct builders and maintenance workers face? These questions may be posed under an overarching essential question such as "How did Roman aqueducts work?" that will entice students to think about how an urban center such as Rome could provide enough clean water to its populace.

Additionally, students will compare how our own community gets its water supply delivered to the system of aqueducts that the Romans used. We are fortunate to have a drinking water treatment plant and a damned reservoir within a mile of Wilbur Cross High School. Students will visit the plant and learn how water is delivered from the reservoir to homes throughout New Haven. Students should also realize how their own use of water is part of the community's consumption of water. In order to gain an awareness of their own water use, students will keep a log of water consumption for two days. Students will record how much water they consume, use for personal hygiene (bath/shower, hand washing, laundry, toilet flushes, lawn garden, washing and cleaning around the house or school). From the data that they report, we will be able to construct some crude calculations as to the amount of water usage that occurs in the school community. If students were to conduct a household water consumption survey, we could then prognosticate water consumption for the community at large.

Strategies

Strategies to address the questions will include posing the objectives in the forms of essential questions, thus encouraging inquiry into historical, technological, mathematical, and practical subject matter. The unit will begin with a brainstorming session in which students will be asked to think about what an aqueduct is and scribe their interpretation in a drawing or in writing. Discussion will be encouraged throughout the unit. Reading strategies outlined in the text Subjects Matter will be employed for assigned readings. The subject matter of aqueducts will be dealt with first chronologically. Students will understand the chronological overview of the development of aqueduct systems from general readings. Reading from the primary sources of Vitruvius Pollio and Frontinus will be utilized to give students insight into first how the aqueducts were constructed and second how they were maintained. Introducing a slide show of modern aqueducts such as those in use in California today will allow students to see that the notion of the aqueduct is still very viable in providing water delivery or flood/wastewater control in certain environments. Incorporating student descriptive, reflective and persuasive written responses to brainstorming, photographs/slides, primary source material, and secondary works will be encouraged through classroom activities.

Experiential learning through simulation and field study will enhance the learning activities of this unit. Simulation will also be employed as a strategy to have students experience the thought process and considerable factors that were necessary for aqueduct building. In my experience students of grades nine and ten particularly enjoy simulations and role plays in which they have to work with other factions to come up with consensus or write resolutions. A simulation of aqueduct building will allow teams of students to develop a position. It will also allow students to present their position, defend it before others, and integrate it into the position of others. In this case, groups of students will be given a set of data and be challenged to develop, present, defend, and refine a proposal for constructing an aqueduct that will successfully overcome the challenges set forth in the data. Students will employ basic math skills, select materials from the palate of Roman resources and, utilize Roman building and architectural techniques.

Field study will occur through a trip to the water processing plant and through a personal water consumption study.

Classroom Activities

Classroom activities will start with a brainstorming session. Students will be asked to think about what an aqueduct is and draw or descriptively write their interpretation on paper. Presentation and discussion of student interpretations will follow. Many students will undoubtedly describe the arcades, or arch-supported channels that are often mistaken to be the definitive aqueduct. However, in the slide show that follows, students will view examples of the many components of a typical Roman aqueduct: water sources, open and closed cement channels, siphons, arcades, pipe material, valves, fountains, baths, and cisterns. Students will react to this activity with reflective writing in their journals. For homework students will complete an assigned reading about the history of aqueducts and answer a few comprehension questions in their notebooks. On day two students will first review the homework and then view sides of aqueducts sites or ruins from Rome, Europe and the Middle East. Students will be assigned to teams and draw the names of Roman aqueducts. Students teams will be allowed a class period to research their aqueduct and prepare a brief PowerPoint presentation of their work. For homework students will be given primary source readings of Vitruvius and Fontenius and be given some comprehension questions (perhaps the assignment could be for students to come with five comprehension questions and answers from the reading). Students will present their presentations on the aqueducts in the next class session. (Perhaps groups of five could present on two aqueducts each) Students will have a chart to complete for each presentation.

Critical thinking and persuasive writing will be included in the unit activities. Students will work individually and in teams to problem solve on how to move fresh and clean water to a city that is 50 miles away and behind hilly terrain. Throughout the simulation students will be introduced to practical challenges that will require them to read for information, conduct research, make calculations, write descriptively and write persuasively. For instance students can be assigned to write reflectively in their journals about the process of measuring and calculating the resources and methods needed to construct the aqueduct. For instance, students can write about whether or not lead pipe, clay pipe, buried conduit, a siphon system, tunnels and/or arches should be incorporated. Students will also have to write a persuasive essay in which they must persuasively propose a particular aqueduct technology to overcome a problem and defend that choice with supporting evidence. In addition to acting as instructor, the teacher will play the role of arbiter and introducer of new challenges. The goal of the simulation will be to complete an aqueduct that will successfully move enough clean water over distance to supply each citizen with a defined unit of water. A full description of the model aqueduct building activity is included in this unit.

Students will be assessed according to a rubric. Rubric guidelines will contain scoring for their descriptive and persuasive writing, their calculations, and their ability to work cooperatively and individually.

The unit will be culminated with a field trip to the Regional Water Authority's water learning center in Hamden, Connecticut.

Figure 1

The anatomy of an aqueduct

Most components of an aqueduct were underground. Yet, the architecture of the visible components is still stunning. Water seepage from high ground, a spring, river, or lake, would be collected through feeder lines into a catch basin. Water might them proceed through a number of components- a covered trench, a bridge, inverted siphon, a tunnel, substruction, and an arcade before reaching the city distribution system (see figure 2) Sketches may not be included in the online version. For sketches please consult hard copy of the curriculum unit or refer to illustrations in Aicher or Hodge

Figure 2

Distribution System

Water flowed from the incoming aqueduct into a main castellum or settling tank (sometimes there was a second settling tank.). From there water traveled through underground piping to homes of the wealthy, places of business, public baths, and public fountains. Illegal tapping into the system was common but punishable offense.

Model Aqueduct Building Project

The goal of having students construct a model aqueduct will be to have students understand the concepts of basic design, scale, volume, and gravity. Students will also experience the coordination of various components of the building process. In order to introduce the conditions that Romans had to work under, the project will work off of gravity and employ the components of a typical Roman aqueduct. These components will include four components: 1) a device for tapping and gathering water from a source, 2) a covered subterranean channel 3) a channel through mountain rock 4) a siphon 5) an arcade, and an endpoint fountain or pool. Teamwork and cooperation will ultimately facilitate the challenges of creating a working model.

Objectives: Student teams will create a working component of a Roman aqueduct that when connected with the other components will allow for the provision of a calculated volume of water from one point to another. Students will write reflectively pre-during and post project. Students will be assessed according to a rubric

Material List:

I gathered my materials from a home improvement store and from an arts and crafts store. I bought some material but later found some things around the house such as paint stirrers) that were free and substituted equally as well as bought materials.

I used 1'x 3'x 1" pieces of Styrofoam as a base. Any lightweight rigid material would serve equally as well. Listed below are materials I used as well as other materials I foresee could be used to complete this project or a project like this.

Balsa wood

Paint stirrers

Popsicle sticks

Tongue depressors

Styrofoam blocks

Styrofoam circles (cut in half for arches)

Small square pieces of tile

Thinset

Glue

Straws

Rubber tubing

Plastic bowls

Pipe cleaners

Toy building blocks such as Lego, Brio arches

Clamps

Valves

1/4 inch pvc pipe

small level

ruler/tape measure

Activity:

1. Show class pictures, diagrams, photographs of the different components of aqueducts- the source, subterranean channel, mountain channel tunnel, siphon, arcade, endpoint fountain or pool.
2. Organize the class into design and construction teams.
a. Water source catch basin
b. Subterranean channel
c. Mountain channel/tunnel
d. Siphon
e. Arcade
f. Endpoint fountain or pool.
3. Assign scale and rough dimensions. Show materials to work with.
4. Allow one day for designing. Then before construction have each group present their design and discuss how the designs will integrate. Students should write reflectively on how they see the design of each team fitting together.
5. Allow 90 minutes for construction. Troubleshoot as necessary
6. Connect all parts and test.
7. Have students write reflectively on whether the project turned out as they had expected. What

happened as expected? What happened that wasn't expected.

Rubric for aqueduct model building activity.

(table available in print form)

Figure 1: Anatomy of an aqueduct

(image available in print form)

Figure 2: Water distribution

(image available in print form)

Cross section of an aqueduct.

(image available in print form)

Map of Rome's Eleven Aqueducts: Adapted from Aicher

(image available in print form)

Table 1: The Eleven Aqueducts that serviced the city of Rome (Compiled from Van Deman and Aicher)

(table available in print form)

The Eleven Aqueducts of Rome

The Aqua Appia

Built in 312 B.C. by Appius Claudius Caecus and Caius Plautius Venox, the Aqua Appia had very little of the grandeur of later aqueducts. Most of the 16 km aqueduct is underground. Most authors attribute this to security concerns. Due to warfare with the Samnites, Romans feared poisoning of the supply if it were detected. Aicher describes it as having more similarities with the first drainage systems than later aqueducts.

It is believed that springs (now covered) were the source. (7) Van Deman describes it as having " a square passage with a rounded roof cut in the soft tufa of the hill and lined with cut-stone walls with a broad shelf on both sides...The technique so far as reported was very crude" (8) She believes it was used for about 150 years before it fell into disuse and was subsequently modified and abandoned and modified again.

The Anio Vetus

Built between 272- and 269 B.C., the second of Rome's aqueducts drew its water from the river above Tivoli. Like the Appia, most of the original Vetus was underground. Funding for the aqueduct came from the spoils of victory over Pyrrhus. Apparently, the water was often muddy after storms and clouded in good conditions. (9)

Van Deman devotes 38 pages to Anio Vetus. She summarizes the archaeological record of its remains. (10)

The Aqua Marcia

The first of the aqueducts to make an architectural statement, it sat atop substructures and arches for the last 10km into Rome. Having defeated Carthage and Macedonia, security to the water supply was not a serious threat. Still 80 km of the aqueduct was underground. It is the longest of the aqueducts and with many restorations it was used into the 10th century. It collected subterranean spring water in small channels which led water to a holding basin which flowed into a main aqueduct. (11)

Van Deman's 80 page chapter on Aqua Marcia describes the history of renovations done by Agrippa, Augustus, and Trajan. She includes some excellent photos. (12)

The Aqua Tepula

While nothing remains of the original aqueduct, the waters are still known to be warm (60 degrees F.) Agrippa stopped using the channel and directed its waters to the Aqua Julia. It was one of the smaller aqueducts in terms of length and volume. (13)

The Aqua Julia

Agrippa built Julia and mixed the waters of the Tepula with Julia. He put Julia on top of the larger Marcia for their entrance in to Rome. (14)

The Aqua Virgo

Built to supply Agrippa's public bath near the Pantheon, the Aqua Virgo was unique in that it had feeder channels of drinkable water connected to it along its path. Although the water is chlorinated, portions of it are still used today for fountains. It was once used as a tunnel by the Goths who were planning an attack. In the 16th century ruling popes rediscovered the sources of water and modified the aqueduct so it could be used again. (15)

The Aqua Alsietina

One of two aqueducts that have sources other than the Anio watershed; it begins at the Southern side of Lake Martignano. The water was not of high quality which raises questions as to why it was built. Aicher offers Frontinus' suggestion that the aqueduct provided emergency water when other aqueducts were closed for repairs, filled a basin for Augustus' mock sea battles and watered gardens along its path. [16]

The Aqua Claudia

The emperor Claudius completed the aqueduct in A.D. 52; 14 years after Caligula had started its construction. It was known for the purity of its water and for the fact that it ran for 14 km (the longest run) on arches. It was the second highest aqueduct to enter the city. As a result it could supply all of Rome's fourteen districts after it was modified by Nero. [17]

The Anio Novus

Also started by Caligula and finished by Claudia, the Anio Novus was the highest of the aqueducts. The source was modified by Trajan which greatly increased the quality of the water. It not only tunneled through mountain, it rode atop of Claudia's channel as it entered Rome. [18]

The Aqua Trajana

Aqua Trajana successfully brought clear spring water to Rome from the hills North of Rome, (unlike the Alsietina which brought lake water from this region). There are no recorded data on the length, volume, and distance above ground due to its construction after the death of Frontinus. After being broken by the Goths in A.D. 537, it was repaired a number of times. In 1610, the Acqua Paola was built on the same route with some of the material of the Aqua Trajana. [19]

The Aqua Alexandrina

Built in A.D. 226, the last of the large aqueducts has some arches that are 20 m high in places. It supplied water to the baths of Alexander Severus. [20]

Appendix 1

Water Facts and Figures:

· 5 million people -Number of deaths each year related to water related disease (10 times the number killed in wars)
· 2.3 billion (1/3 of the world population) suffer from diseases associated with dirty water
· Most infant mortality worldwide is linked to infectious and parasitic diseases associated with water.
· Diarrhoel diseases have killed more children in the past ten years than all the people lost to armed conflict since World War II.
· UN-HABITAT's new report **Water and Sanitation in the World's Cities,** estimates that in Africa as many as 150 million urban residents representing up to 50% of the urban population do not have adequate water supplies, while 180 million, or roughly 60% of people in urban areas lack adequate sanitation.
· In urban Asia, 700 million people, constituting half the population, do not have adequate water, while 800 million people, or 60% of the urban population is without adequate sanitation.
· For Latin America and the Caribbean 120 million urban dwellers representing 30% of the urban population lack adequate water. Those without adequate sanitation number as many as 150

million, or 40% of the urban population.

From: Water and Sanitation in the World's Cities; Local Action for Global Goals

By Mrs. Anna Kajumulo Tibaijuka,

Under-Secretary-General of the United Nations and Executive Director of UN-HABITAT

Appendix 2: Four main categories of adverse human health effects from water

Four main categories of adverse human health effects from water

1. Water -born diseases are caused by water contaminated by human, animal, or chemical wastes. Examples include cholera, typhoid, shigella, polio, meningitis, hepatitis A and E and diarrhea, among others. Washing hands can often prevent these diseases from spreading.

2. Water-based diseases are aquatic organisms that live part of their life in the water and another in a host organism. Examples of water based diseases include guinea worm, paragonimiasis, clonorchiasis, and schistosmiasis (caused by flukes, tapeworms, roundworms)

3. Water related vector diseases are transmitted by vectors, such as mosquitoes and tsetse flies that breed or live in or near polluted and unpolluted water. About 90 percent of the annual global rate of deaths from malaria occur in Africa south of the Sahara.

4. Water -scarce diseases exist where freshwater is scarce and sanitation is poor. Trachoma and tuberculosis are two examples. To serve the additional 5 billion people expected to live on the planet by the year 2050, there is a need to provide sewerage facilities to 383,000 new customers a day.

From: International Year of Freshwater 2003. UN.org

Resources

Aicher, Peter. Guide to the Aqueducts of Ancient Rome. Wauconda, Illinois: Bolchazy-Carducci Publishers, Inc. 1995

Aicher's work is a concise, yet informative, guide to each of the eleven Roman aqueducts. At 183 pages it is a little less than one half the length of Esther Boise Van Deman's and Hodge's comprehensive endeavors. Like Van Deman, Aicher describes each of Rome's eleven major aqueducts. In addition to having photographs as visual aids, the work contains maps and figures which give informative schematic representations of tools and construction techniques.

Ashby, Thomas. The Aqueducts of Ancient Rome. Oxford: The Clarendon Press, 1935.

DG67 A83 1935A

Cairns, F. Future Currents in Aqueduct Studies. Leeds, Great Britain 1991

TD398 F88X 1991(LC)

I have yet to acquire these books. Nonetheless, they look promising and may be of interest to those looking for resources on the Roman aqueducts.

Hamey, J.A. and L.A. The Roman Engineers. Cambridge, UK: Cambridge University Press, 1981

A good resource for students and teachers to read. Chapter 2 is only 10 pages long and it contains the essential concepts to understanding Roman aqueducts. It focuses on the four Anio valley aqueducts which supplied Rome with its most highly regarded water. Photographs, maps, architectural sketches, and tables are included.

Harris, Robert. Pompeii A Novel. New York: Random House, 2003

This is a historical novel that includes characters that are involved in the everyday life of Pompeii, including road and aqueduct workers.

Hodge, A. Trevor. Roman Aqueducts and Water Supply. London, Gerald Duckworth &Co. Ltd.

Hodge states in his preface that his aim of this book is to answer a simple question-"How did an aqueduct work? His comprehensive review (504 pages) of Roman aqueducts and water supply throughout the Roman Empire incorporates physics and math. This work is full of photographs of ruins with accompanying mechanical drawings and tables. Hodge is definitely not as concise as Aicher, or artistic as Van Deman, but he is by far the most technical and scientifically oriented. Chapter 2 The Predecessors of Rome is a detailed history of aqueduct technology that predates the Romans. Chapter 8- Hydraulics- relates principles of hydraulic engineering to the Roman aqueducts.

Leet, Kenneth. Fundamentals of Structural Analysis. Boston: McGraw Hill, 2002.

For a look at the structural analysis of an arch see Leets Chapter 7 pp. 227- 239

Macauley, David. City A Story of Roman Planning and Construction. Boston: Houghton Mifflin Company 1974.

Macauley portrays the planning and building of Verbonia, an imaginary Roman city that is based upon a composite of Roman planning and building techniques. Pages 37-53 describe the building of a complete aqueduct system (38 miles long) from mountain lakes through city reservoirs to public fountains, toilets, baths, and homes of the wealthy.

Nardo, Don. Roman Roads and Aqueducts. San Diego: Lucent Books, 2001

Published as part of a Building History Series, it is a concise (96 pages), very readable, and thorough resource for students and teachers to read. It contains chapters on how Roman roads and aqueducts were constructed, how water was distributed, how aqueducts were maintained, and specifically how bridges were built for roads and aqueducts. Nardo incorporates political and technological developments that accompany the development of aqueduct architecture in Rome. Another bonus, I found it in our school library!

Taylor, Raburn M. Public Needs and Private Pleasures. Water Distribution, the Tiber River and the Urban Development of Ancient Rome. 2000

DG 135.6.T39 2000 SML Stacks. Unfortunately, I wasn't able to get this resource. However, as the title suggests, one could explore the dimensions of water distribution in ancient Rome.

Van Deman, Esther Boise. The Building of the Roman Aqueducts. Washington D.C. Carnegie Institution of Washington D.C. Publication No. 423. 1934.

This is a classic and comprehensive work on Rome's eleven aqueducts. The 440 page text includes a chapter on each of the eleven aqueducts that serviced the city of Rome. Over one hundred black and white photographs of the remains of Roman aqueducts show the condition of the aqueducts as of 1934. The most artistically oriented of the works cited in my unit.

http://academic.bowdoin.edu/classics/research/moyer/html/intro.shtml

"Archaeology 291 The Roman Aqueducts and Water Systems" Bowdoin Classics Department. March 25, 2006

http://www.dl.ket.org/latin3/mores/aqua/intro.htm

http://aquaduct.hobbysite.info/links_sources.html

http://www.crystalinks.com/romeaqueducts.html

These are some of many online sites that contain useful background information on Roman Aqueducts. Some are college course material hosted by colleges. Some are part of college distant learning courses. I imagine that these sites may very well cease being hosted in the future; they nonetheless represent a sampling of information that can found through browsing the web.

http://www.hopefarm.com/ctytn1.htm

Water for New York City by Wendell Tripp. Hope Farm Press and Book Shop, Saugerties , NY

I used this source to access information on the history of how water is brought to Manhattan from the Catskills. Similar technologies used by the Romans are still in use today.

http://www.unesco.org/water/iyfw2/health.shtml Facts and Figures Page for the International Year of Fresh Water Website

A major campaign from the United Nation in 2003 was the International Year of Clean Water. These facts and figures are only a fraction of the material available online that has to do with global water distribution and water related crisis.

Endnotes

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1. http://www.unesco.org/water/iyfw2/health.shtml Facts and Figures Page for the International Year of Fresh Water Website

2. The Center For Public Integrity. The Water Barons United Nations International Year of Freshwater 2003 UN.org

3. International Year of Freshwater UN.org

4. p. 54 Nardo

5. p. 39 Aicher

6. p. 3 Tripp, Wendell

7. p. 35 Aicher

8. p. 28 Van Deman

9. Aicher p. 35

10. Aicher p. 35

11. Aicher p. 37

12. Van Deman p. 66- 146.

13. p. 38 Aicher

14. p. 38 Aicher

15. p. 40 Aicher

16. p. 41 Aicher

17. p. 42 Aicher

18. p. 43 Aicher

19 p. 44 Aicher

20 p. 45 Aicher