1 INTRODUCTION: WATER SUSTAINABILITY

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INTRODUCTION

History has been a continual ebb and flow of civilizations. Ancient civilizations faced many severe problems associated with water as a means for their existence. I attempt to examine similarities of water resources sustainability development issues between our present and past civilizations. In the title I use sustainability; however, *unsustainability* may be more appropriate because it better reflects what I am attempting to accomplish. The Brundtland Commission (Brundtland, 1987) presented the following definition: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable development has also been referred to as the process in which the economy, environment, and ecosystem of a region develop in harmony and in a way that will improve over time.

As pointed out in Chap. 3 "sustainability is both a vague and politicized term, yet it is precisely because the world community has rallied around sustainability and sustainable development as normative goals of ecological-economic performance that the stakes are high for defining the concept in a manner that is true to its spirit." How sustainable is it to live in a world where approximately 1.1 billion people lack safe drinking water, approximately 2.6 billion people lack adequate sanitation, and between 2 and 5 million people die annually from water-related diseases (Gleick, 2005)?

The *United Nations Children's Fund's* (UNICEF) report, "The State of the World's Children 2005: Children under Threat," provides an analysis of seven basic "deprivations" that children feel and that powerfully influence their futures. UNICEF concludes that more than half the children in the developing world are severely deprived of one or more of the necessities essential to childhood:

- 640 million children do not have adequate shelter
- 500 million children have no access to sanitation
- 400 million children do not have access to safe water
- 300 million children lack access to information
- 270 million children have no access to health-care services
- 140 million children have never been to school
- 90 million children are severely food deprived

There are approximately 2.2 billion children (with 1.9 billion living in the developing world and about 1 billion living in poverty) in the world, so approximately one in five children in the world do not have access to safe water.

Certainly, fresh water has emerged as one of the most critical natural resource issues facing humanity. The world's population is expanding rapidly, yet we have no more fresh water on earth than there was 2000 years ago, when the population was less than 3 percent of the current 6 billion. This is one of the most important topics facing society today and will continue to be so well into the future.

While we all may have heard of the crisis and tragedies occurring in Darfur from the news media, with world headlines in early 2003, we may not have been made aware of the extent to which the problems are related to the water resources. The crisis in Darfur can be traced back to the early 1970s, when desertification in the northern part of Sudan and drought in Darfur led to increased competition over water resources and fertile land. The quest for food and water led pastoral groups from semidesert areas in the north to move south, where tension soon arose with farmers. Over the past 30 years there have been increasing disputes over the region's dwindling resources.

Threats to drinking water systems during conflicts have plagued humans since the dawn of history. Water has always been a strategic objective in armed conflicts. Many historical conflicts have caused flooding by diversion or eliminated water supplies by building dams or other structures. In Mesopotamia a great system of canals were dug but had to be cleaned of silt. Stoppage of canals by silt depopulated villages and cities more effectively than invading armies. The Romans had a long history of developing alternate water supplies to Rome for the expanding water supply and security.

The Bible mentions conflicts over the Jordan River since inhabitants moved to the area in ancient times: "And Gideon sent messengers throughout all the hill country of E'phraim, saying, 'Come down against the Mid'ianites and seize the water against them as far as Beth-Bara'ch, and also the Jordan'." More recently, a primary cause of the 1967 Arab-Israeli war was the struggle for fresh water. The struggle for fresh water in the Middle East has also contributed to other military disputes in the region (see Gleick, 1993, 1994, 1998, 2000, and Lilach, 1997 for additional information).

The events of September 11, 2001 have significantly changed our approach to the management and protection of water supplies, with the threat of terrorist activities toward these systems. These present-day threats include cyber threats, physical threats, chemical threats, and biological threats. Chapter 10 includes discussions on water supply security issues.

Natural disasters such as drought and flooding have plagued civilizations throughout history and continue to do so today. We continue to build new infrastructure in urban flood plains and develop new areas without regard to the downstream effects. Houston, Texas is one of many examples, with approximately $5 billion of damage due to flooding during Tropical Storm Allison, in June 2001. A large portion of the flooding damaged infrastructure was built in the past three decades. Then there was Katrina!

WHAT IS WATER RESOURCES SUSTAINABILITY?

The concept of sustainable resources has been around for a long time, as water resources managers had been taught the principles of sustained yield management long before publications such as *Limits to Growth* (Meadows et al., 1974) and *Our Common Future* (Brundtland Commision, 1987). Loucks (2000) defined sustainable water resource systems as "water resource systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity." Most definitions of sustainable water resources are so broad that they defy any measurement or quantitative definition. Other attempts at defining water resources sustainability have been by ASCE (1998).

When invited to broadcast a talk on soil conservation in Jerusalem in June 1939, Dr. W. C. Lowdermilk (1953) gave for the first time what has been called an "Eleventh Commandment," which could also be a definition for water resources sustainability:

> Thou shalt inherit the Holy Earth as a faithful steward, conserving its resources and productivity from generation to generation. Thou shalt safeguard thy fields from soil erosion, thy living waters from drying up, thy forests from desolation, and protect thy hills from overgrazing by thy herds, that thy descendants may have abundance forever. If any shall fail in this stewardship of the land thy fruitful fields shall become sterile stony ground and wasting gullies, and thy descendants shall decrease and live in poverty or perish from off the face of the earth.

The definition of water resources sustainability used in this text is consistent with that of the Brundtland Commission report (Brundtland, 1987) and that of Dan Rothman:

> Water resources sustainability is the ability to provide and manage water quantity and quality so as to meet the present needs of humans and environmental ecosystems, while not impairing the needs of future generations to do the same.

Another definition of sustainability is:

> Water resources sustainability is the ability to use water in sufficient quantities and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life, and to protect humans from the damages brought about by natural and human-caused disasters that affect sustaining life.

Because water impacts so many aspects of our existence, whichever definition is used, there are many facets that must be considered. These are summarized as:

- Water resources sustainability includes the *availability of freshwater supplies* throughout periods of climatic change, extended droughts, population growth, and to leave the needed supplies for the future generations.
- Water resources sustainability includes having the *infrastructure* to provide water supply for human consumption and food security, and to provide protection from water excess such as floods and other natural disasters.
- Water resources sustainability includes having the *infrastructure* for clean water and for treating water after it has been used by humans before being returned to water bodies.
- Water sustainability must have adequate *institutions* to provide for both the water supply management and water excess management.
- Water sustainability can be defined on a local, regional, national, and international basis.

Sustainable water use has been defined by Gleick et al. (1995) as "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it." The following seven sustainability requirements were presented:

- A basic water requirement will be guaranteed to all humans to maintain human health.
- A basic water requirement will be guaranteed to restore and maintain the health of ecosystems.
- Water quality will be maintained to meet certain minimum standards. These standards will vary depending on location and how the water is to be used.
- Human actions will not impair the long-term renewability of freshwater stocks and flows.
- Data on water resources availability, use, and quality will be collected and made accessible to all parties.
- Institutional mechanisms will be set up to prevent and resolve conflicts over water.
- Water planning and decision making will be democratic, ensuring representation of all affected parties and fostering direct participation of affected interests.

FRAMEWORKS FOR CIVILIZATIONS TO COLLAPSE

Tainter (1990) outlines how civilizations historically tend to collapse precisely at the moment levels of increasing complexity are not sustainable. His eleven major themes of societal collapse are (a) depletion or cessation of vital resources; (b) establishment of a new resource base; (c) insurmountable catastrophe; (d) insufficient response to circumstances; (e) other complex societies; (f) invaders; (g) class conflict/societal contradiction/elite mismanagement or misbehavior; (h) social dysfunction; (i) chance concatenation of events; (j) mystical factors; and (k) economic factors.

There are many different theories as to why ancient civilizations failed (Linden, 2006). Gill (2000) found over a hundred different theories for the collapse of the Mayan civilization in researching material for his book, *The Great Maya Droughts: Water, Life, and Death.* Desertification, climate change (Alley, 2000), and deforestation (Perlin,1989) have been somewhat unappreciated factors, in addition to the factors given in Diamond (1997), *Guns, Germs, and Steel,* to the collapse of societies.

Tainter (1990) is skeptical that collapses of ancient civilizations were due to the depletion of environmental (natural) resources. He feels that complex societies were not likely to allow collapse through failure to manage their resources. In Chap. 2, I use the Teotihuacans, the Xochicalcoans, the Mayas, the Chacoans (Anasazi), and the Hohokams as examples of societies that have failed as a result of at least partial depletion and misuse of environmental (natural) resources, and climate change. The Mohenjo Daro in the Indus Valley (Pakistan) declined after 2000 BC, possibly due to climate change, river shifts, and water resources management problems. Droughts possibly caused or attributed to the collapse of the Akkafdran Empire in Mesopotamia around 2170 BC, the collapse of the Moche IV civilization on the Peruvian coast around AD 600, and the collapse of the Tiwanaka civilization in the Andes around AD 1100. In other words *the ancient ones have warned us.*

Diamond (2005) proposed a five-point framework for the collapse of societies:

- Damage that people inadvertently inflict on their environment
- Climate change
- Hostile neighbors
- Decreased support by friendly neighbors
- Society's responses to its problems

I refer to this framework throughout the discussions in Chap. 2. There is no doubt that the ancient societies in Mesoamerica and the southwestern United States discussed in Chap. 2 did collapse at least partially as a result of water sustainability issues from the misuse and depletion of natural resources and climate change. This depletion of natural resources then led to other events that caused the eventual collapse. Diamond (2005) points out that he does not know of any case in which a society's collapse can be attributed entirely to environmental damage as there are always other contributing factors.

MODERN DAY EXAMPLES OF UNSUSTAINABILITY

To talk about sustainability of water we must first talk about unsustainability and look at examples. One example of unsustainable development in our present time has been the region of the Aral Sea, resulting in many detrimental effects to the population of that region. The decision by the former Soviet Union that water from the rivers of the Aral Sea basin should be used for growing cotton instead of sustaining the fourth largest inland sea resulted in an environmental disaster rivaling Chernobyl (Postel, 1997).

Aral Sea

The Aral Sea is located in Central Asia between Uzbekistan and Kazakhstan (both countries were part of the former Soviet Union) as shown in Fig. 1.1. The Amu-Darya and the Syr-Darya (dar'ya means river in Turkic) flow into the Aral Sea with no outlet from the sea. Over more than 30 years, water has been diverted from the Amu-Darya and the Syr-Darya to irrigate millions of acres of land for cotton and rice production, which has resulted in a loss of more than 60 percent of the sea's water. The sea has shrunk from over 65,000 km^2 to less than half that size, exposing large areas of the lake bed. From 1973 to 1987 the Aral Sea dropped from fourth to sixth among the world's largest inland seas. The satellite photos in Fig. 1.2 show the Aral Sea in 1985 and 2003; and Fig. 1.3 illustrates the decrease in size of the Aral Sea from 1957 to 2000.

The lake's salt concentration increased from 10 percent to more than 23 percent, contributing to the devastation of a once thriving fishing industry. The local climate reportedly has shifted, with hotter, drier summers and colder, longer winters. With the decline in sea level, salty soil remained on the exposed lake bed. Dust storms have blown up to 75,000 tons of this exposed soil annually, dispersing its salt particles and pesticide residues. This air pollution has caused widespread nutritional and respiratory ailments, and crop yields have been diminished by the added salinity, even in some of the same fields irrigated with the diverted water. Additional reading material includes Ellis and Turnley (1990), Ferguson (2003), and Perata (1988, 1993).

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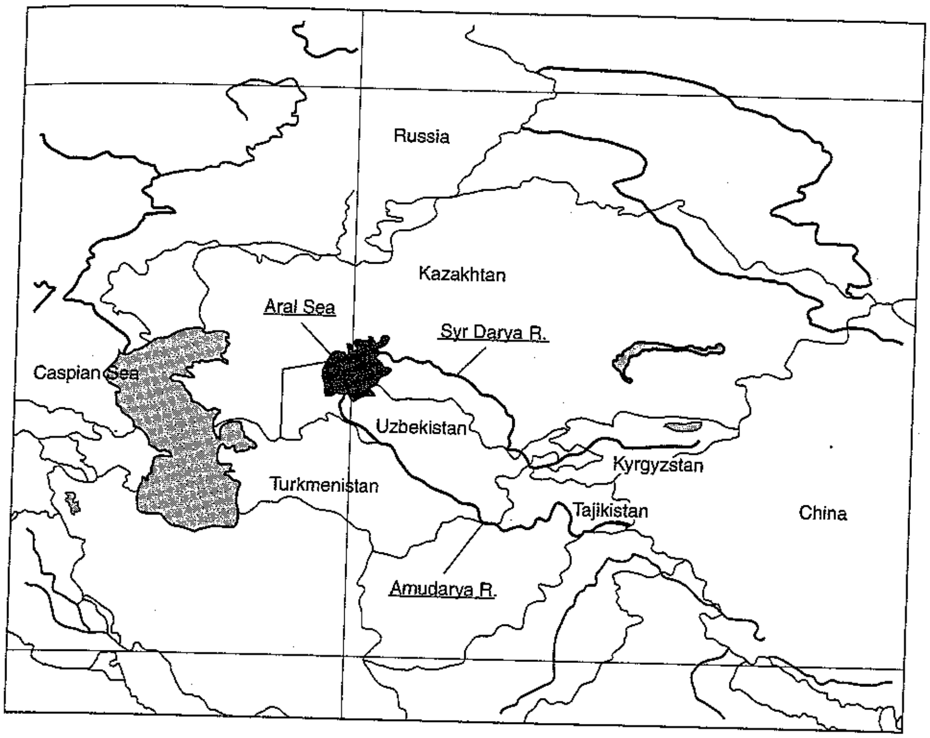

Figure 1.1 The Aral Sea basin. (*Courtesy of McKinney, 1996*)

The major consequences of the continuous desiccation of the Aral Sea since 1960 are summarized as follows:

- Climatic consequences such as mesoclimatic changes, increase of salt and dust storms, shortening of vegetation period
- Ecological/economic consequences including degeneration of the delta ecosystems, total collapse of fishing industry, decrease of productivity of agricultural fields

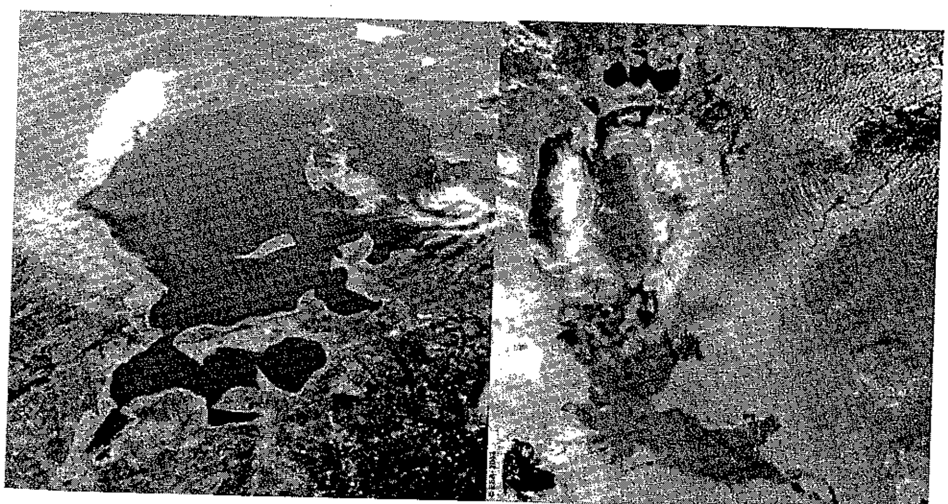

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Figure 1.2 Comparison of Aral Sea 1985 and 2003. (*Courtesy of NASA*)

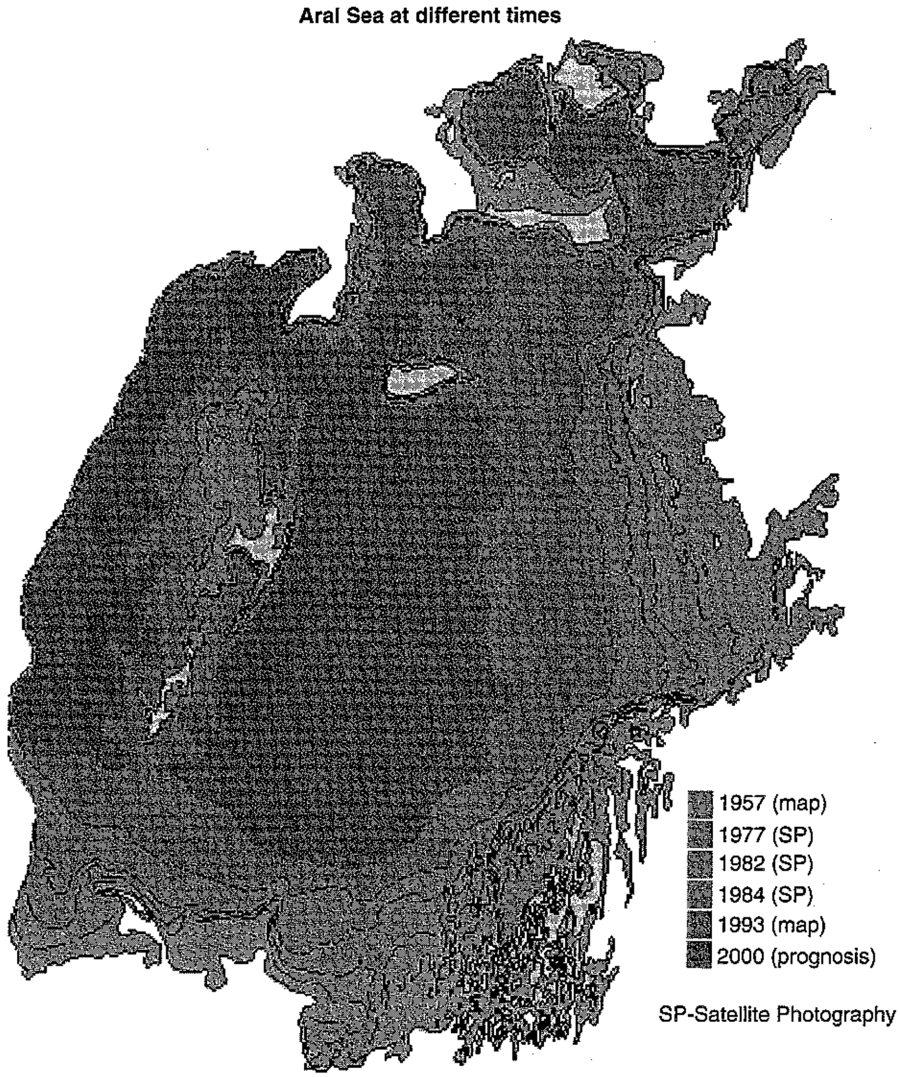

Figure 1.3 Aral Sea from 1957 to 2000 from the report Environment State of the Aral, developed by the International Fund for the Aral Sea (IFAS) and the UN Environment Programme (UNEP) under financial support of the Norway Trust Fund at the World Bank. Co-ordination from the side of IFAS was held by the Executive Committee of IFAS, and from the side of UNEP-UNEP/ GRID-Arendal. (*Courtesy of http://enrin.grida.no/aral/aralsea/english/arsea/arsea.htm#2*)

- Health consequences such as increase of serious diseases, birth defects, and high infant mortality

People of the region did not make the decision to use the rivers of the Aral Sea basin but they have certainly suffered the consequences. As stated at the Conference of the Central Asian region ministers, "States of Central Asia: Environment Assessment," Aarhus, Denmark, 1998:.

> The Aral crisis is the brightest example of the ecological problem with serious social and economic consequences, directly or indirectly connected with all the states of Central Asia. Critical situation caused by the Aral Sea drying off was the result of agrarian economy tendency on the basis of irrigated agriculture development and volume growth of irrevocable water consumption for irrigation.

Mexico City

Now let us look at present-day Mexico City (see Fig. 1.4), a very large urban center, as another example of water resources unsustainability. Mexico City is the cultural, economic, and industrial center for Mexico. This city is located in the southern part of the Basin of Mexico, which is an extensive, high mountain valley at approximately 2200 m above sea level and surrounded by mountains of volcanic origin with peak altitudes of over 5000 m above sea level.

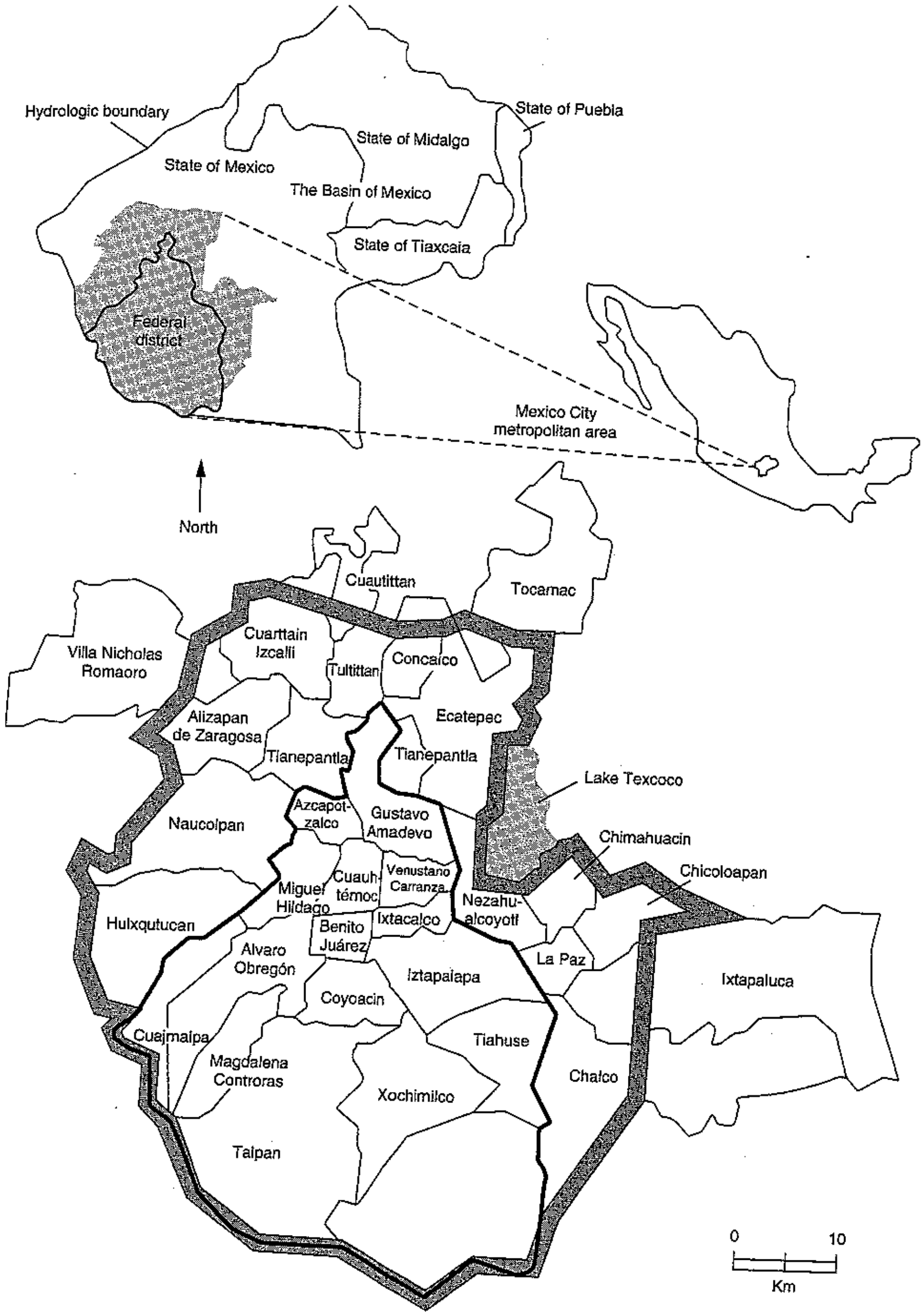

Figure 1.4 Basin of Mexico and the Mexico City metropolitan area. (*Courtesy of NRC 1995*)

Beginning in the fourteenth century, the Aztecs made use of a system of aqueducts to convey spring water from the higher elevations in the southern portion of the Basin of Mexico to their city, Tenochtitlan. This ancient city was built on land reclaimed from the saline Lake Texcoco. The Spaniards defeated the Aztecs in 1520, after which they rebuilt the aqueducts and continued to use the spring water until the mid 1850s. Potable groundwater, under artesian conditions, was discovered in 1846. Over the next century, the increased groundwater extraction and the artificial diversions to drain the valley resulted in the drying up of many of the springs, the draining of lakes, loss of pressure in the aquifer with declining groundwater levels, and the consequent subsidence.

Because Mexico City is located on the valley floor, it has always been subject to flooding. Subsidence has worsened this problem by lowering the land surface of Mexico City below the level of Lake Texcoco, resulting in increased flooding. Drainage systems had to be dug deeper and Lake Texcoco had to be excavated. By 1950 dikes had to be built to confine stormwater flow, and pumping was required to lift drainage water under the city to the level of the drainage canals. By 1953 severe subsidence resulted in the closing of many wells that had to be replaced with new wells.

The *Mexico City metropolitan area* (MCMA) has become a magnet of growth, being the cultural, economic, and industrial center for Mexico, with an estimated population approaching 22 million people. A continual migration of people from rural areas to the city has occurred, with many of the people settling illegally in the urban fringe with the hope of eventually being provided public services. Providing water supply and wastewater services for Mexico City is a formidable challenge. Imagine that the city has the largest population in the world living in an enclosed basin with no natural outflow to the sea. The water supply situation has reached a crisis level, with the continued urban growth and poor system of financing by the government. The consequences include an inability to expand the water supply network to areas that are underserved or not served at all, repair leaks, and provide wastewater treatment. Mexico City cannot meet the water demands of its population.

Homero Aridjis, a successful novelist and journalist and one of Mexico's leading environmental figures, has stated "Mexico City, founded on water, may die of thirst." (Kunstler, 2001). The water problems in Mexico City are insurmountable. Aridjas has said that "the city is an urban disaster." James Kunstler in his book, *The City in Mind: Meditations on the Urban Condition*, describes Mexico City as a "hypertrophied metastasized organism destined to devour itself." In the preface to his book he referred to Mexico City as "a prototype of hypertrophic 'third world' urbanism, plagued by failed social contract, lawlessness, economic disorder, and a wrecked ecology."

The present-day water problems are summarized:

- Mexico City receives approximately 70 percent (55.5 m^3/s) of its water supply from the underlying aquifer system, with natural springs and runoff from the summer rains from the surrounding sierras and mountains supplying water to the aquifer. The other 30 percent (19 m^3/s) of the water supply comes from the Lerma River through a 15 km long aqueduct and the large-scale Cutzamala River project, which transfers water 120 km over a 1200 m elevation change. Skaggs et al. report 51 m^3/s are withdrawn from the aquifer and 23 m^3/s are imported from outside the city.

- An estimated 40 percent of the water supplied is lost through leaks in the aging municipal water supply system and through ineffective coordination between the various levels of government.
- Overexploitation of the aquifer has caused subsidence, which has been a problem since the early 1900s as a result of draining of the lake water (Lake Texcoco) from the basin floor. The subsidence has caused damage to the many parts of the infrastructure, including serious damage to the city's water supply and sewage system.
- Subsidence has also worsened the city's flooding problems as the city has sunk below the natural lake floor. The continuing subsidence has caused such a serious problem that now the pumping stations must run 24 hours a day year round to keep the summer rains from washing sewage and runoff back to the city (Morgan, 1996a).
- Only about 10 percent of Mexico City's wastewater is treated, with the remaining 90 percent being untreated, and diverted out of the Basin of Mexico through an extensive network of drainage. The primary destination of the untreated wastewater is the Mezquitl Valley (largest area in the world, irrigated with wastewater) in the state of Hidalgo, where it is eventually discharged into the Tula-Moctezuma-Panuco River system, which flows to the Gulf of Mexico. Wastewater is mixed with surface water from reservoirs for irrigation purposes.

The conclusion is obvious: the water resources situation in Mexico City is not sustainable by my definition or by any other definition. Additional sources of information include Mestre (1997), Paredes (1997), Perez de Leon and Biswas (1997), Tortajada and Biswas (2000), Skaggs et al. (2002), and *Mexico City: Opportunities and Challenges for Sustainable Management of Urban Water Resources* available at the Web site http://casestudies.lead.org/index.php?csp=15. We have very briefly examined two present day situations of water resources unsustainability, both resulting largely from unsustainable development.

THE PROBLEMS IN DEVELOPING NATIONS

The following press releases are only a couple of examples illustrating the threats associated with water sustainability in developing parts of the world such as Africa. The first is a UNICEF release (www.unicef.org):

Kenya: Worst drought in years threatens children

UNICEF Re-Issues Emergency Appeal for US$4 million

NAIROBI, 19 December 2005—UNICEF called urgent attention today to thousands of children in northern Kenya who face malnutrition due to deepening drought. The recent short rain season has been extremely poor in the northern and eastern pastoral districts. At a time of year when livestock should be healthy and feeding on new grass, carcasses are lying dead along the roadside. Many Government, UN and NGO experts meeting in Nairobi last week described the drought as the worst in years.

UNICEF Kenya Representative Heimo Laakkonen said in a statement today that rates of child malnutrition in districts like Wajir and Mandera may increase from the already alarming levels of almost 30 percent reported in assessments backed by the agency in October. "The dry weather is predicted to continue," said Laakkonen. "Given that situation can only get worse, it is imperative that all partners and the government act swiftly to protect the most vulnerable children and women." The World Food Programme has already more than doubled its estimate of the number of people needing food aid to about 2.5 million. It is estimated that about 560,000 people in 7 districts will require emergency supplies of water.

UNICEF has re-issued its October appeal which calls for US$4 million to assist more than 20,000 children estimated to be malnourished or at serious risk of malnutrition. The appeal also included programmes that aimed to keep children in school, ensure safe water supplies and provide emergency health care and protection.

Another news release of the Presbyterian News Service, August 22, 2005 is as follows:

Malawians face starvation, church leader says

Presbyterian cites drought, flooding as causes of famine in his homeland

by Toya Richards Hill

LOUISVILLE—If food isn't sent to the southern African nation of Malawi very soon, many people are sure to die, said the Rev. Winston Kawale, a leader of the Church of Central Africa Presbyterian (CCAP). . . .

"It's a pity, and I feel ashamed that we have hunger in Malawi," he said. "We have land, we have soil, we have water." The problem, he said, is a lack of expertise, especially in irrigation and water-resource management, which prevents year-round production. The country has no shortage of water—one of its greatest resources is Lake Malawi, the third-largest body of water in Africa, which covers almost one-fifth of the country. However, "At the moment, we only depend on the rains," Kawale said. With greater knowledge, he said, "hunger will no longer be there" and "poverty will be addressed."

These releases express the sadness associated with what is happening in Africa.

A Look at Sub-Saharan Africa

Sub-Saharan Africa has a history of poverty, war, and famine extending over millennia. What part has water sustainability played in the poverty, vulnerability, inequity, and threats to the social fabric in Sub-Saharan Africa? Only 45 percent of Sub-Saharan Africa's population has access to safe water (UNDP, 1994). As pointed out by Morgan (1996 b), the prospects of increased water scarcity are considerable, given the history of less precipitation in the past three decades and the reduction in volume of several water bodies, along with some evidence of worsening vegetation conditions or "desertification."

During the 1980s and the early 1990s, most of Sub-Saharan Africa witnessed serious economic decline or stagnation. The chief source of environmental degradation in Sub-Saharan Africa as a whole (including plant cover and species loss, destruction of fauna, climatic change, changes in water table levels and stream flow, and soil erosion) is deforestation, particularly when followed by overcultivation and overgrazing. The Sub-Saharan African economic and financial problems were made very much worse in the 1970s and in the 1980s by a combination of (Morgan, 1996 b):

1. An investment in growth and development that failed to earn the expected rewards
2. The international debt crisis, oil price hikes, and rising interest rates, plus the inadequacy of the aid programs that were meant to provide relief

3. Repeated drought, crop failure, and widespread famine
4. The failure of agricultural production to contribute significantly to growth and the increased dependence on imported food
5. Widespread warfare and civil unrest
6. The fact that *structural adjustment programs* (SAPs) have been only partially successful and that this success has been in terms of systems rather than people, who somehow have to survive in the hope that decisions linked to short- or medium-term deterioration based on theories that are unknown or unappreciated could solve their problems in the future

It is obvious that water sustainability issues have been a major factor in the poverty, vulnerability, inequity, and threatening of the social fabric of Sub-Saharan Africa.

FUTURE TARGETS FOR CURRENT GLOBAL WATER CHALLENGES

Current global water challenges and future targets are clearly stated in the "Millennium Development Declaration (2000)"—which includes the access to safe drinking water as one of its *millennium development goals*—and are strengthened and expanded in the plan of implementation of the world summit on sustainable development. The key role of sustainable water management for poverty eradication has been one of the key outcomes of the World Summit on Sustainable Development. The plan of implementation outlines several central statements related to freshwater and sanitation issues:

- Halve, by the year 2015, the proportion of people without access to safe drinking water
- Halve, by the year 2015, the proportion of people who do not have access to basic sanitation
- Combat desertification and mitigate the effects of drought and floods
- Develop integrated water resources management and water efficiency plans by 2005, with support to developing countries
- Support developing countries and countries with economies in transition in their efforts to monitor and assess the quantity and quality of water resources
- Promote effective coordination among the various international and intergovernmental bodies and processes working on water-related issues, both within the United Nations system and between the United Nations and international financial institutions

Global Climate Change

In December of 2005, I attended the International Water History Association meeting at the UNESCO headquarters in Paris, where I heard one of the most convincing talks by Robert Kandel (2005), Directeur de Recherche Emérite, CNRS—Laboratoire de Météorologie Dynamique—Ecole Polytechnique, France. The title of his talk was "Anthropogenic Global Warming and Water in the 21st Century." Dr. Kandel (also author of the book *Water from Heaven*) pointed out that for many observers, global warming of recent decades, although still modest, appears significantly stronger than climate variations of the previous thousand years, which is believed to result in part from anthropogenic intensification of the greenhouse effect, the trapping of thermal infrared radiation in the lower atmosphere. He emphasized that observers agree that anthropogenic alteration of atmosphere composition is dramatic in that the atmospheric concentration of carbon dioxide has increased by 30 percent since 1900, and methane has doubled. Climate modeling explains what is happening only when both natural forcing and anthropogenic forcing are included.

Because a major reduction of net carbon dioxide emissions is unlikely over the next few decades, a twenty-first century intensification of the greenhouse effect will occur, resulting in global warming. Dr. Kandel emphasized, "the coming rapid climate change will by necessity involve and depend on changes in the hydrological cycle, and some results suggest that it could be comparable to the strong climate changes of the past million years." He stated that, "what is new in the history of the planet is that this climate change will result from the activities of a species in part conscious of the consequences of its actions." Depending on the location of the acceleration and/or slowing of the hydrological cycle depending on location, the freshwater fluxes to the land biosphere can either increase or decrease.

We have tremendous advantages over past civilizations that were completely unaware of climate change. Figure 1.5, showing the decrease in the Arctic Sea ice boundary since 1979, gives us clear evidence of the oncoming climate change. Not only do we have the technologies to detect the oncoming of climate change, we are now able to date past climate events that the ancients faced. Now that we know the ancients have warned us, what will we do about this coming "strong warming"?

Can climate change spark international water wars? In recent years, we have seen water controversies among Israel, Jordan, and Palestine, between Turkey and Syria, between China and India, among Botswana, Angola, and Namibia, between Ethiopia and Egypt, and between Bangladesh and India.

Mega Water Projects: Can They Be a Partial Solution?

In Chap. 2 some of the ancient mega water projects are discussed, such as those developed by the Romans, the Mayans, and others. Presently, there are several mega water projects that are at different stages of development going on in the world. These include the southeast Anatolian project (GAP—*Guneydogy Anadolu Projesi*) in Turkey that involves the construction of 22 dams, 19 hydroelectric generation stations on the Tigris and Euphrates Rivers, and the irrigation of 1.7 million hectares of land; the great man-made river project in Libya, which is the construction of a massive conveyance system to transport over 6 million m^3 of water per day from aquifers in the southern parts of Libya to northern parts of Libya; the huge China south-to-north water project which includes three south-to-north canals, which will stretch across the eastern, middle, and western parts of China eventually linking the country's four major rivers—the Yangtze, Yellow, Huaihe, and the Haihe; and other smaller projects—the El Salaam project to divert Nile River water and irrigation return flows to the north Sinai and the Nile (Naga Hammadi) barrage that is 330 m long dam at Naga Hammadi in upper Egypt to divert water through a 1.1 km long canal. Are these projects the ultimate solution or are they simply bandages to the real problems associated with population growth and other societal concerns?

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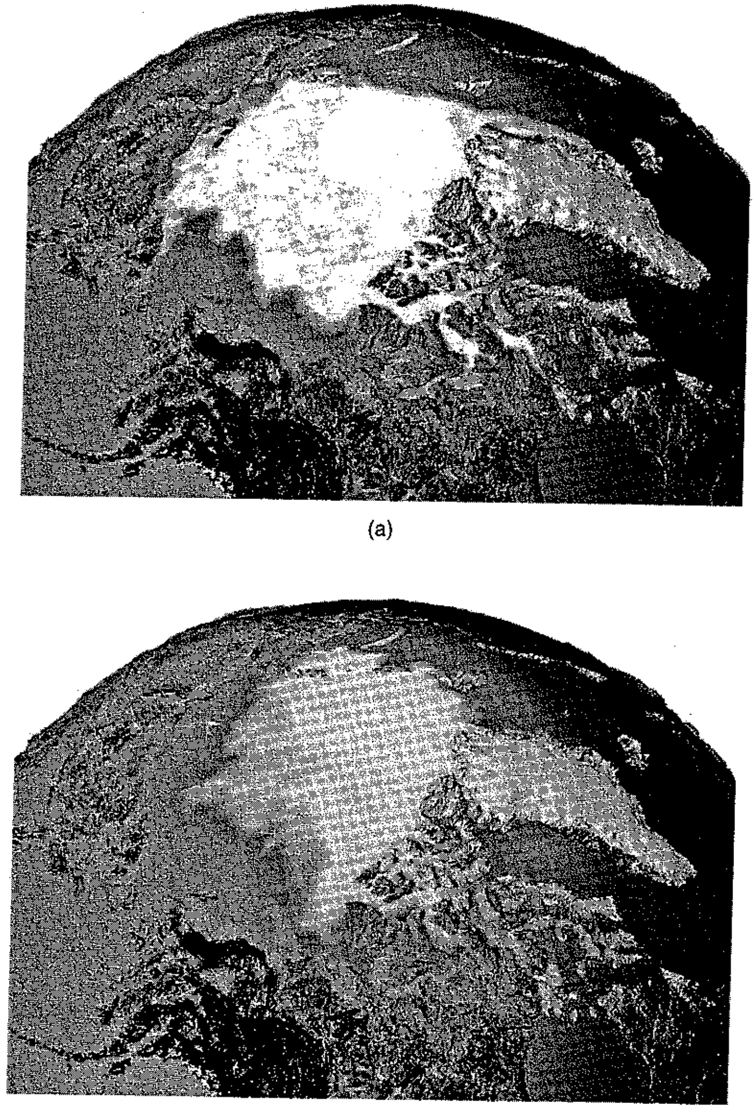

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(b)

Figure 1.5 Decrease in the polar ice cap from 1979 to 2003 (a) Polar ice cap in 1979 (b) Polar ice cap in 2003. (*Courtesy of NASA*)

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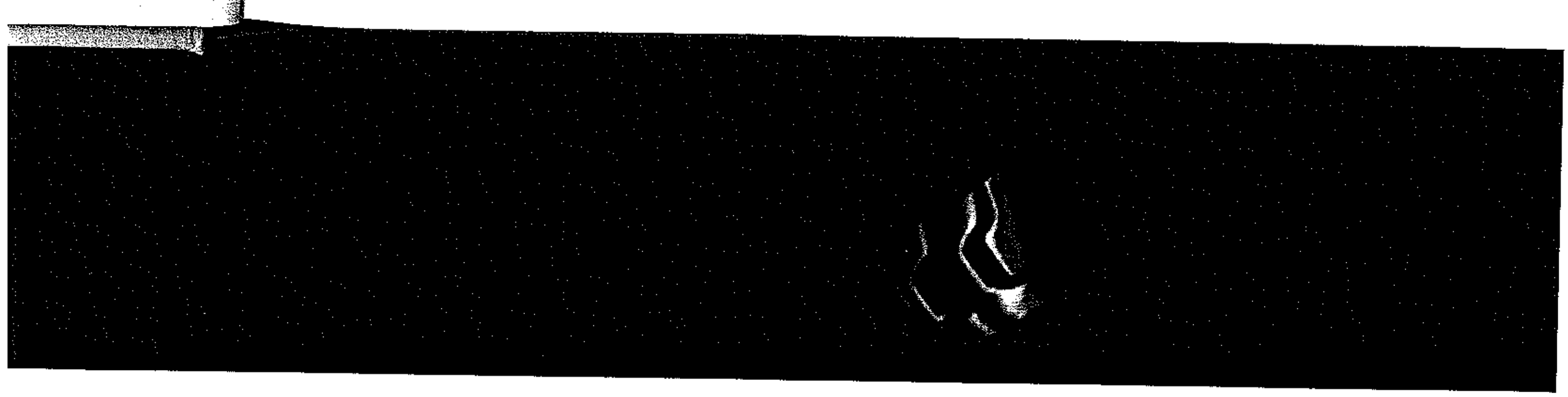

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2 WATER SUSTAINABILITY: PARALLELS OF PAST CIVILIZATIONS AND THE PRESENT

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INTRODUCTION

In this chapter, I discuss ancient civilizations that collapsed in the American southwest and Mesoamerica to further illustrate the concept of sustainability. Then I briefly discuss the relevance to modern societies of the collapse of ancient civilizations, particularly in the southwestern United States. Throughout history humans have struggled to find a lasting adjustment to the land and the natural resources; unfortunately though, civilizations have failed (collapsed) for various reasons; among those is the unsustainability of water resources.

The earliest known civilizations arose in the Tigris and Euphrates Valleys of the Fertile Crescent and in the Nile Valley of Egypt, where centralized political organizations or bureaucracies existed. The fertile alluvial plains of Mesopotamia and the valley of the Nile are the location where at least 7000 years ago, agriculture had its beginnings and where the first successful efforts to control the flow of water were made. Since these beginnings many civilizations made advances in the use of water. Water control systems appeared in many areas; including the Indus Valley, the Minoan civilization (Knossos on Crete), the Greeks, Mesoamericans, the Romans, the Nabataeans in present day Jordan, and many others. These ancient civilizations faced problems associated with sustainable development, particularly water-related issues. The challenges of the sustainability of water resources included many of the challenges that we face today, such as water supply security, climate variations, population growth, scarce natural resources, food security, and natural disasters such as floods and droughts.

Many civilizations, great centers of power and culture, were built in locations that could not support the populations that developed. Throughout history, arid lands seem to have produced more people than they could sustain. I will attempt to make comparisons between civilizations of the past and our present world in the context of water resources sustainability.

Water has always been a very important factor in the development and survival of societies. The collapse of societies for environmental and/or other reasons often masquerades as military defeats. The fall of the Western Roman Empire has been debated as a collapse, possibly masqueraded as barbarian invasions, with AD 476 as the year when the last emperor of the West was deposed. Was the fall a result of the barbarians becoming more numerous or better organized, having better weapons, or did the barbarians profit from climate change of the Central Asian steppes? Or were the barbarians unchanged and Rome became weakened by a combination of economic, political, environmental, and other problems?

ANCIENT MEGAWATER PROJECTS

Various ancient civilizations developed water projects that would have been considered as megawater projects during their times, and even today. Examples included the Romans throughout many parts of Europe, the Middle East, and northern Africa, the Hohokams and the Anasazi in the southwestern United States, the Egyptians, the Mesopotamians, and many others. I will use examples of Roman projects to illustrate ancient megawater projects.

Romans

The Romans built magnificent structures for water supply, including the following four that I will briefly describe: the water system of aqueducts and dams to Merida, Spain (see Fig. 2.1*a*); the system of aqueducts with various structures to Lyon, France (ancient Lugdunum) (see Fig. 2.2*a*); the system of aqueducts to Rome (see Fig. 2.3*a*); and the aqueduct of Nimes (ancient Nemausus) (see Fig. 2.4*a*).

In 25 BC, Emerita Augusta (Merida, Spain) became a colony and a century later the Romans had built a water supply system including three aqueducts (Fig. 2.1), two of which were supplied by dams (the Cornalvo dam and the Proserpina dam). The three aqueducts were the Cornalvo aqueduct (enters on the east side of Merida), the Proserpina aqueduct (enters on the northeast side of town), and the Las Thomas aqueduct (from springs on the north and northeast side of Merida).

The Cornalvo aqueduct was built first and was about 17 km long. Cornalvo dam (Fig. 2.1*b*) is an earthen dam approximately 194 m long, 20 m high, and has a 8 m dam crest width. A few remains of the aqueduct are visible as shown in Fig. 2.1*c* near the present day "bull ring."

The Proserpina dam (see Fig. 2.1*d*) is an earthen dam, 427 m long, 12 m high, located north of Merida, and supplied water to the 10 km long Los Milagros aqueduct. This aqueduct entered the town on the north side with an aqueduct bridge over the Rio Albarregas (see Fig. 2.1*e*), also referred to as the Los Milagros (the miracles) by the Spanish, with a maximum height of 30 m.

The Las Thomas aqueduct included an aqueduct bridge 1600 m long (across the Rio Albarregas), of which only three pillars (16 m high) remain (see Fig. 2.1*f*). Materials from this aqueduct bridge were used by the Arabs in the sixteenth century to construct

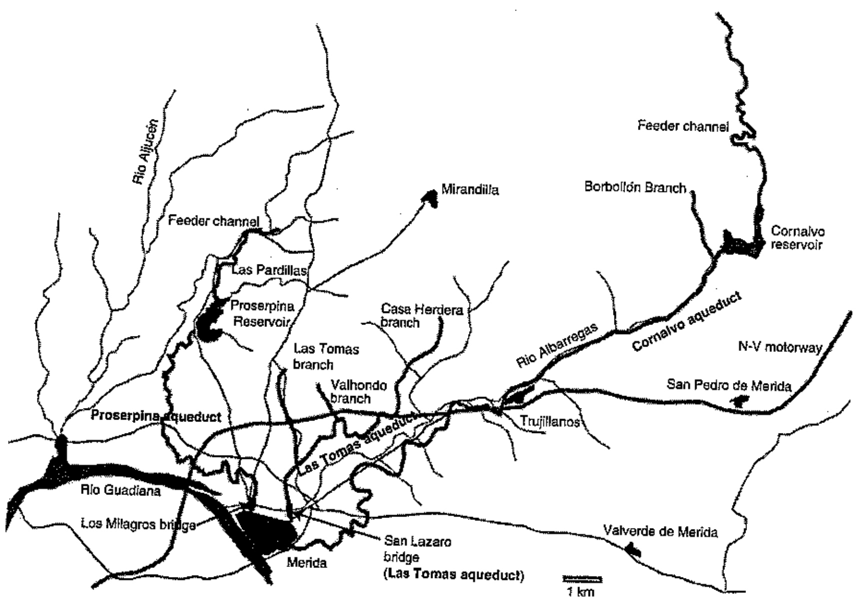


Figure 2.1 (a) Map showing the three Roman aqueducts in Merida, Spain. *(Courtesy of C.W. Passchier of Mainz, Germany)*

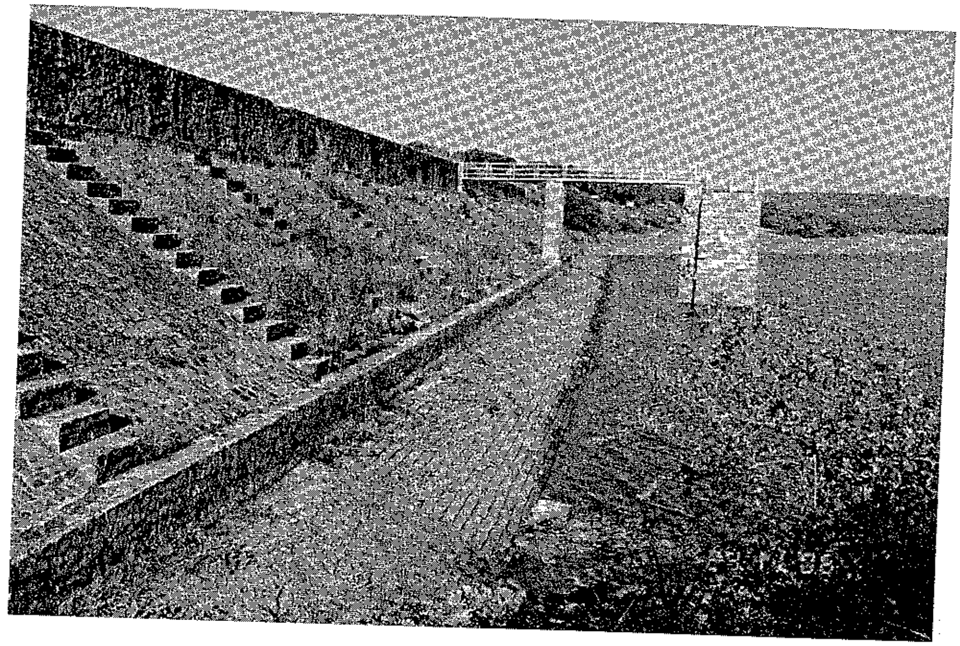


Figure 2.1 (b) Cornalvo dam near Merida, Spain. (*Photo copyright by L. W. Mays*)

the San Lazaro aqueduct bridge. Figure 2.1*g* shows the aqueduct near the Roman theatre and amphitheatre.

Four aqueducts were used to supply water to the ancient city of Lugdunum (Lyon, France). They were the Mont d'Or, the Yzeron, the Brevenne, and the Gier. Figure 2.2*a* shows the route of the aqueduct of the River Gier, which was the longest and the highest

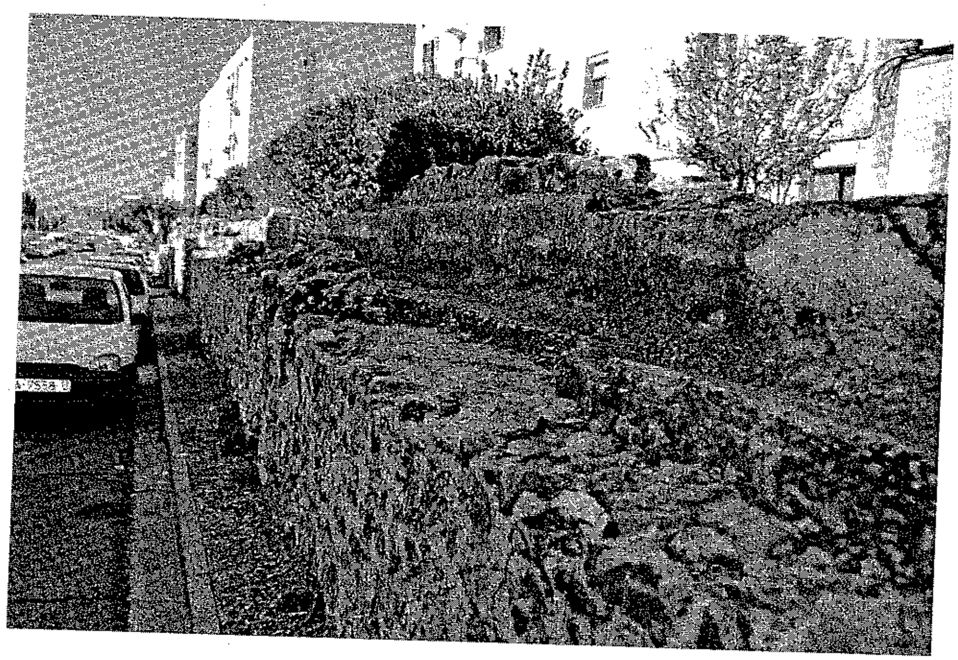


Figure 2.1 (c) Cornalvo aqueduct supplying water from Cornalvo dam to Merida. Only a few remnants of this aqueduct are still visible. (*Photo copyright by L. W. Mays*)

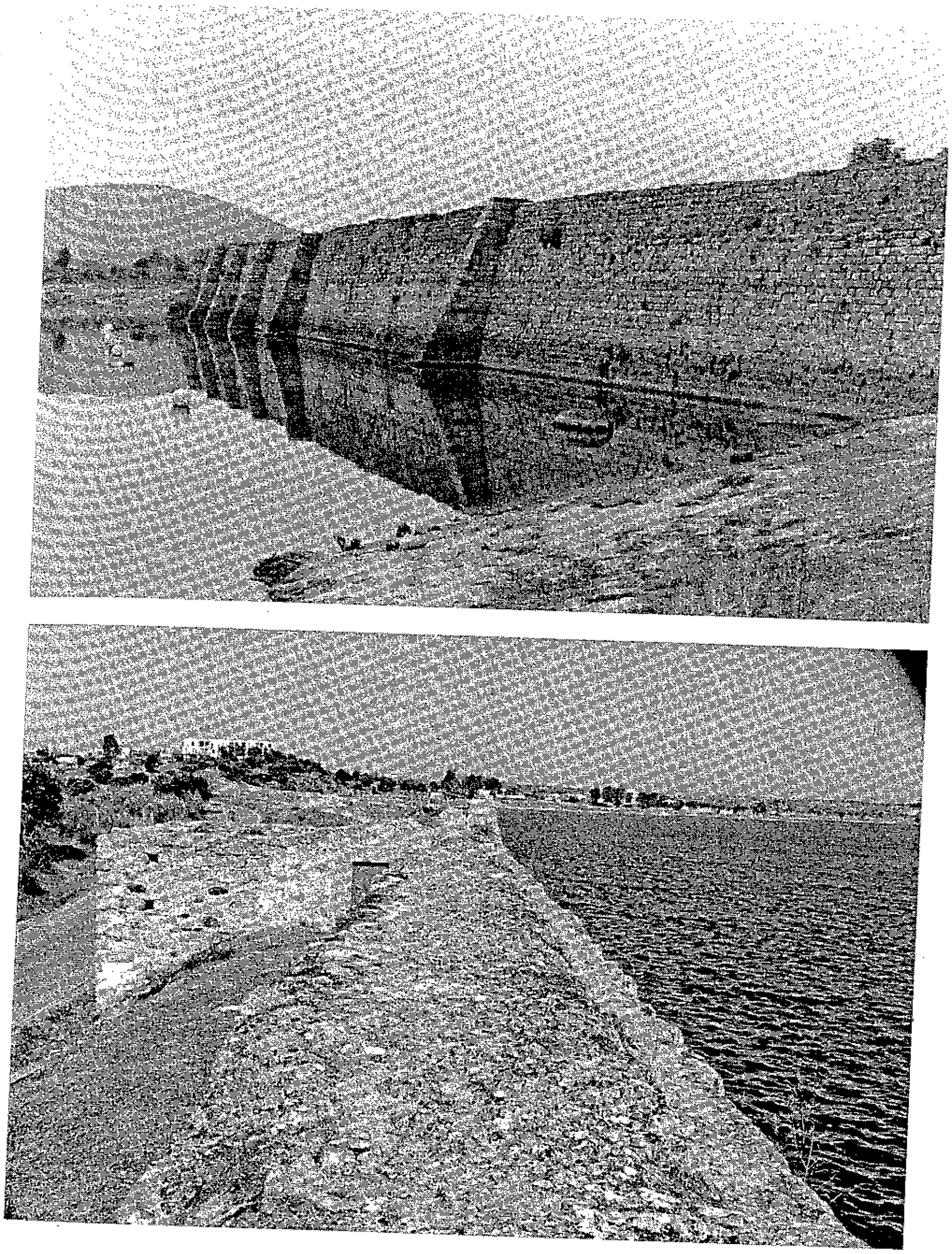


Figure 2.1 (d) Proserpina dam near Merida, Spain. (*Photos copyright by L. W. Mays*)

of the four aqueducts. Approximately half of the aqueduct was subterranean with at least nine tunnels and four siphons. Figures 2*b* and 2*c* are photos of the aqueduct near Chaponost. This aqueduct had four siphons and over 80 manholes.

The aqueduct system in Rome evolved over a 500-year time period, with the first aqueduct, the Aqua Appia, being constructed around 313 BC. This system is illustrated in Fig. 2.3*a*, with 11 aqueducts that eventually supplied water to Rome from mostly springs, and two

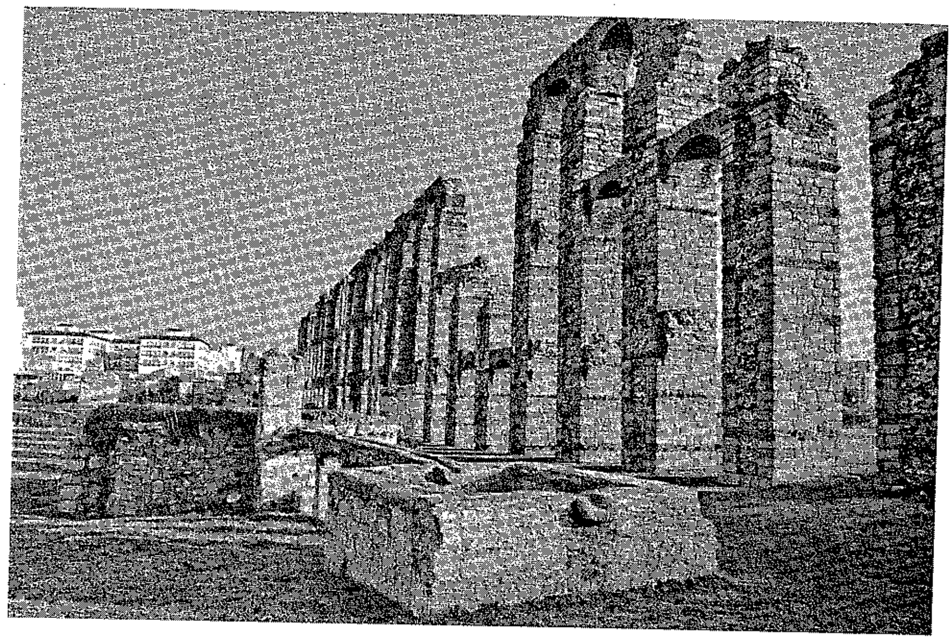


Figure 2.1 (e)
Los Milagros aqueduct bridge across the Rio Albarregas in Merida, Spain. (*Photo copyright by L. W. Mays*)

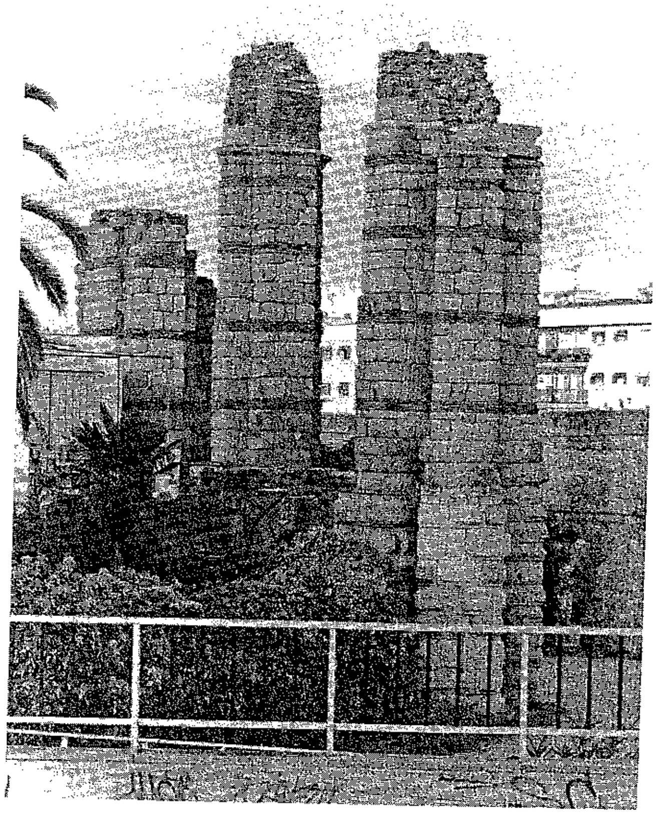


Figure 2.1 (f)
Las Thomas aqueduct bridge across the Rio Albarregas and located near the hippodrome. Only the three pillars remain of this aqueduct bridge. (*Photo copyright by L. W. Mays*)

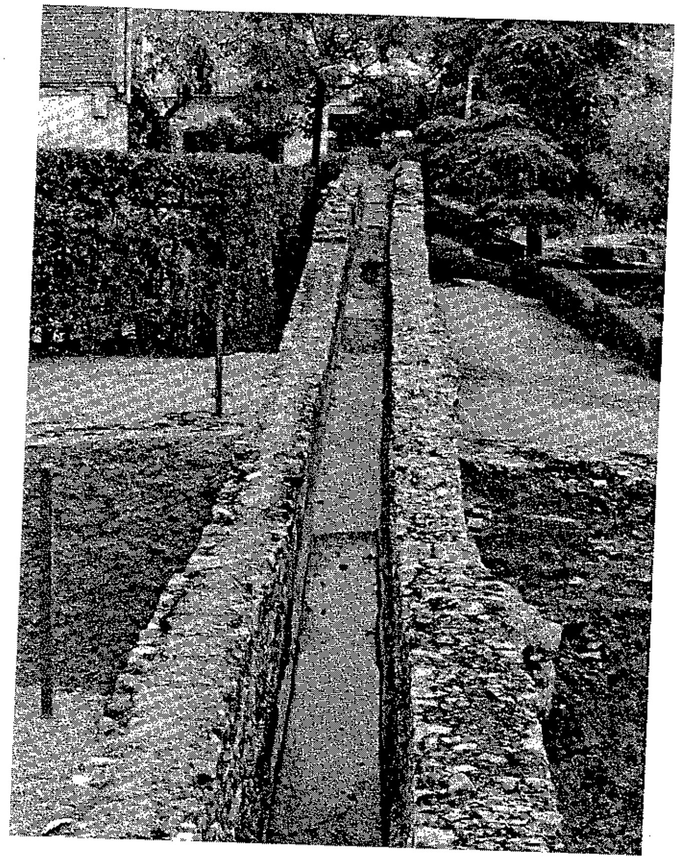


Figure 2.1 (g)
Las Thomas aqueduct in Merida near the Roman theater and amphitheater. Shown on the right side of the aqueduct is a lion head of stone which was used as a gutter spout. There are also remains of a castellum nearby. (*Photo copyright by L. W. Mays*)

were supplied from the Anio River and one from Lake Alsietinus. All the major eastern aqueducts entered Rome at the Porta Maggiore (see Figs. 2.3*b* and 2.3*d*).

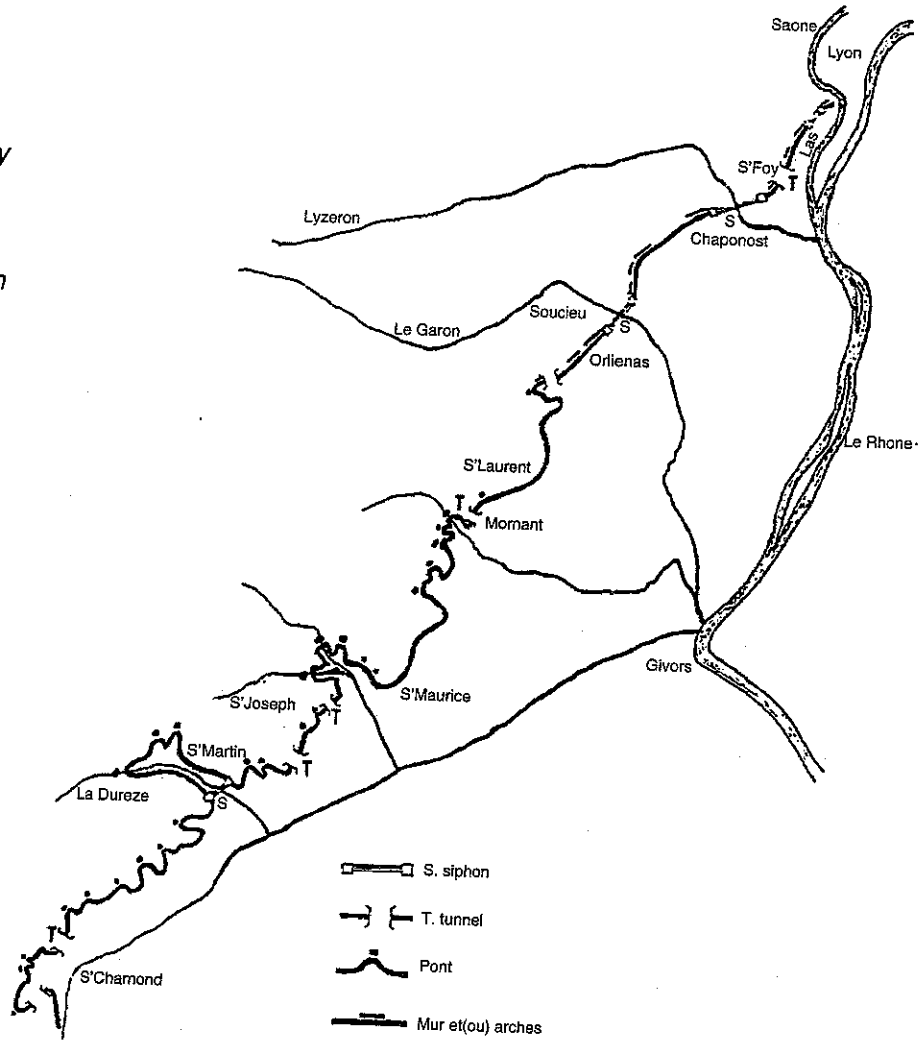
The aqueduct of Nemausus (built around 20 BC) conveyed water approximately 50 km from Uzes to the *castellum* in Nimes (see Fig. 2.4*a*). From an engineering point of view this was a remarkable construction project in that the elevation difference over the length of the aqueduct was only 17 m, making the slope only 0.0008.5 m/m, with the profile shown in Fig. 2.4*b*. The Pont du Gard, shown in Fig. 2.4*c*, is one of the most spectacular aqueduct bridges ever built and is the most photographed in the world. Figures 2.4*d* and 2.4*e* illustrate the *castellum divisorium* at Nimes.

I use the Teotihuacans, the Xochicalcoans, the Mayas, the Chacoans (Anasazi), and the Hohokams to illustrate that the ancient ones have warned us.

Mesoamerica

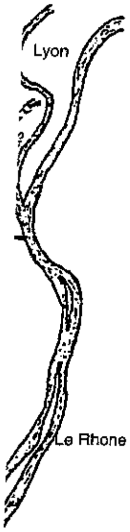
Many Mesoamerican civilizations developed and failed for various reasons. The period or era from about AD 150 to AD 900 (called the *classic*) was the most remarkable in the development of Mesoamerica (Coe, 1994). Figure 2.5 shows Mexico during the classic period. During the classic period the people of Mexico and the Maya area built civilizations comparable with advanced civilizations in other parts of the world. In Mesoamerica

Figure 2.2 (a)
Route of the aqueduct on the River Gier to Lugdunum (Lyon, France). (*Courtesy of Les Aqueducs Romains de Lyon, L'Araire, Le Borg, 69510 Messimy en Lyonnais*)



Les ouvrages d'art de l'aqueduc du Gier

the ancient urban civilizations developed in arid highlands where irrigation (hydraulic) agriculture allowed high population densities. In the tropical lowlands, however, there was a dependence on slash-and-burn (*milpa*) agriculture, which kept the bulk of the population scattered in small hamlets. Sanders and Price (1968) suggest that the nonurban lowland civilization resulted from responses to pressures set up by the hydraulic, urban civilization. Teotihuacan (city of the Gods) in Mexico is the earliest example of highland urbanism.



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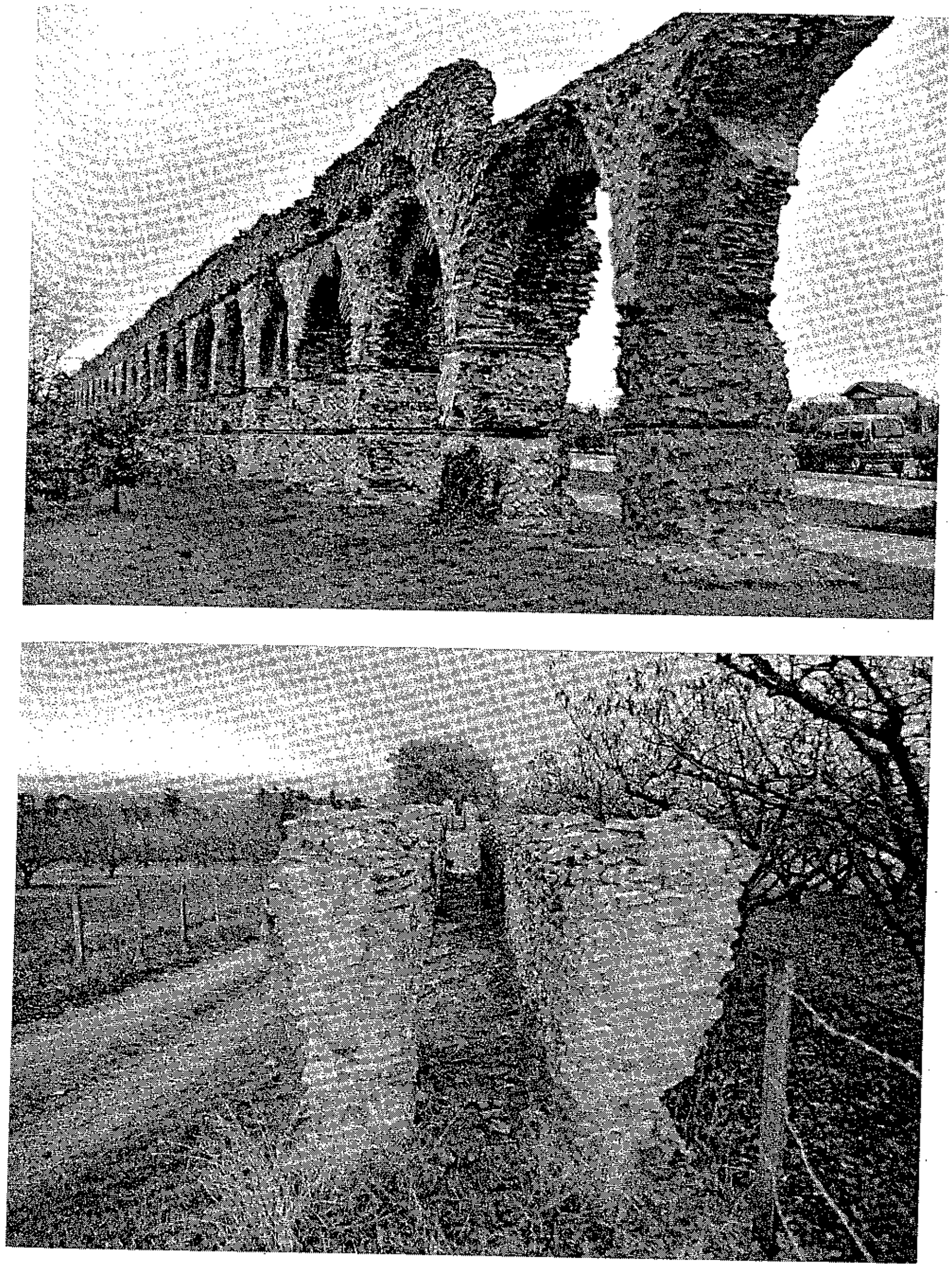

Figure 2.2 (b) and (C)
Aqueduct of the River Gier near Chaponost, France. (*Photo copyright by L. W. Mays*)

Teotihuacans

Teotihuacan was a very impressive civilization, which evolved about 25 mi north of Mexico City around the same time as Rome. Prior to 300 BC, Teotihuacan valley had a small population spread over the valley and was the dominant urban center in Mesoamerica throughout the classic period. By AD 100, Teotihuacan covered an area of 12 km^2, which has been linked to the development of so-called hydraulic agriculture (Haviland, 1970).

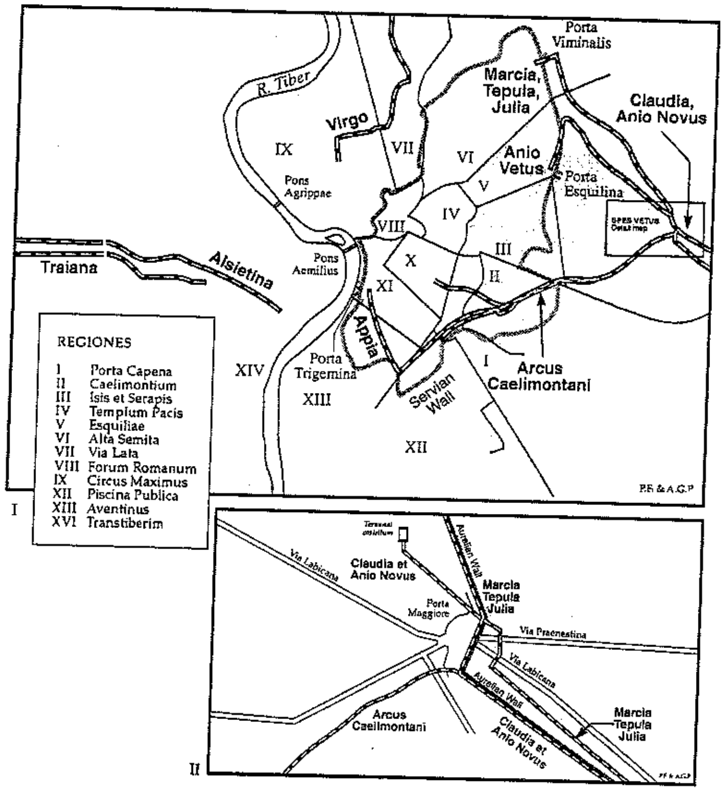

Figure 2.3 (a) Aqueducts in ancient Rome. (I) Termini of the major aqueducts (*from Evans, H.B., Water distribution in Ancient Rome: the Evidence of Frontinus, University of Michigan Press, Ann Arbor, 1999*) (II) The area of the Spes Vetus showing the courses of the major aqueducts entering the city above ground (*from R.Lancianni, Forma Urbis Romae, as presented in Evans, 1994*)

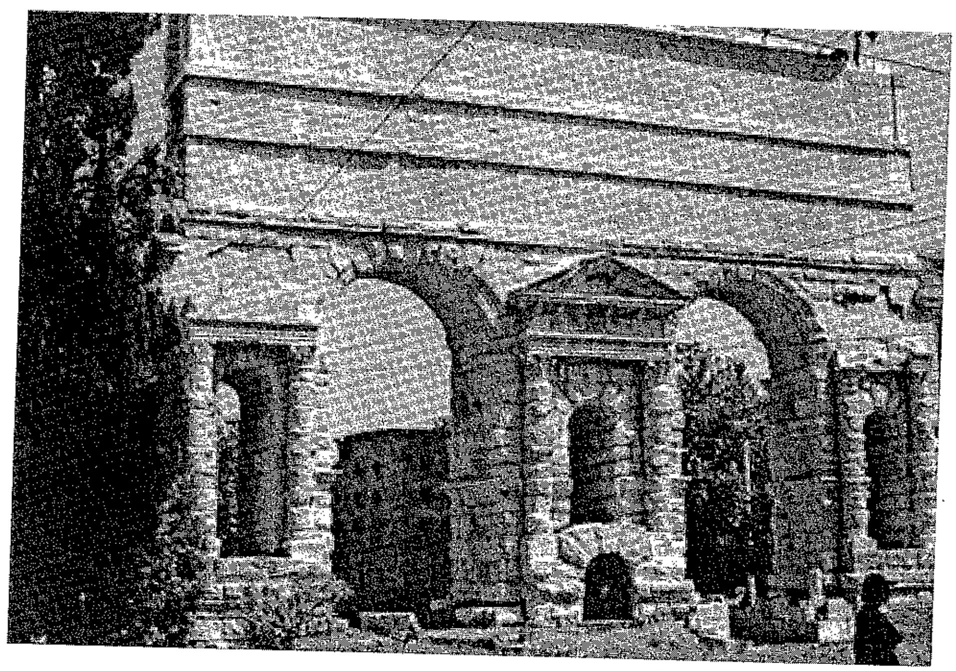

Figure 2.3 (b) View of Porta Maggiore (double-arched gate) on the Aurelian wall where all the eastern aqueducts entered Rome (*Photo copyright by L. W. Mays*)

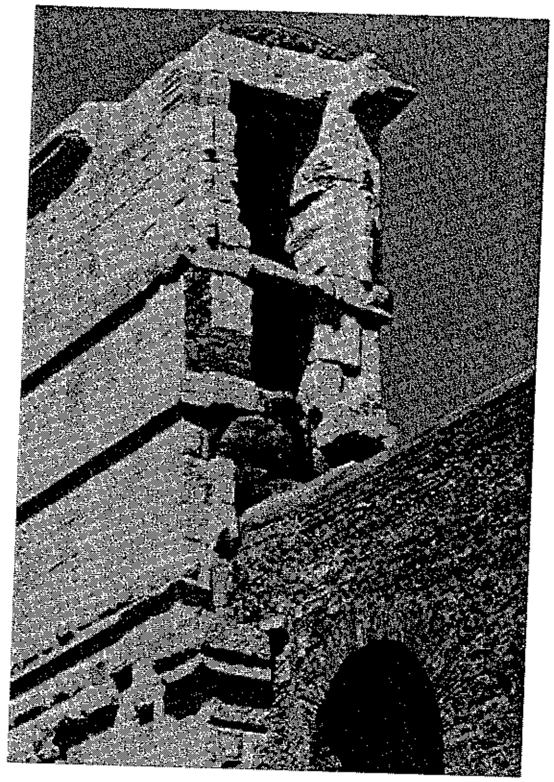

Figure 2.3 (c)
Aqueducts Claudia (top) and the Anio Novus (bottom) above the Porta Maggiore. (*Photo copyright by L. W. Mays*)

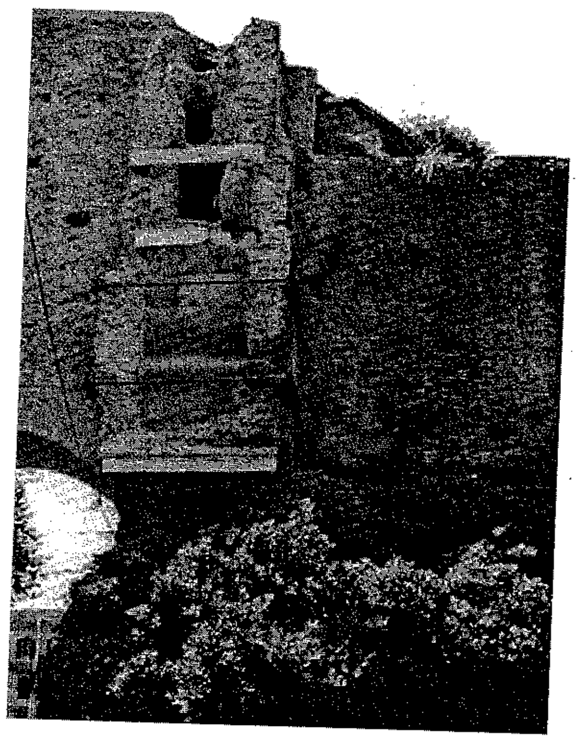

Figure 2.3 (d)
Three aqueducts Julia (top), Tepula (center), and Marcia (lower). (*Photo copyright by L. W. Mays*)

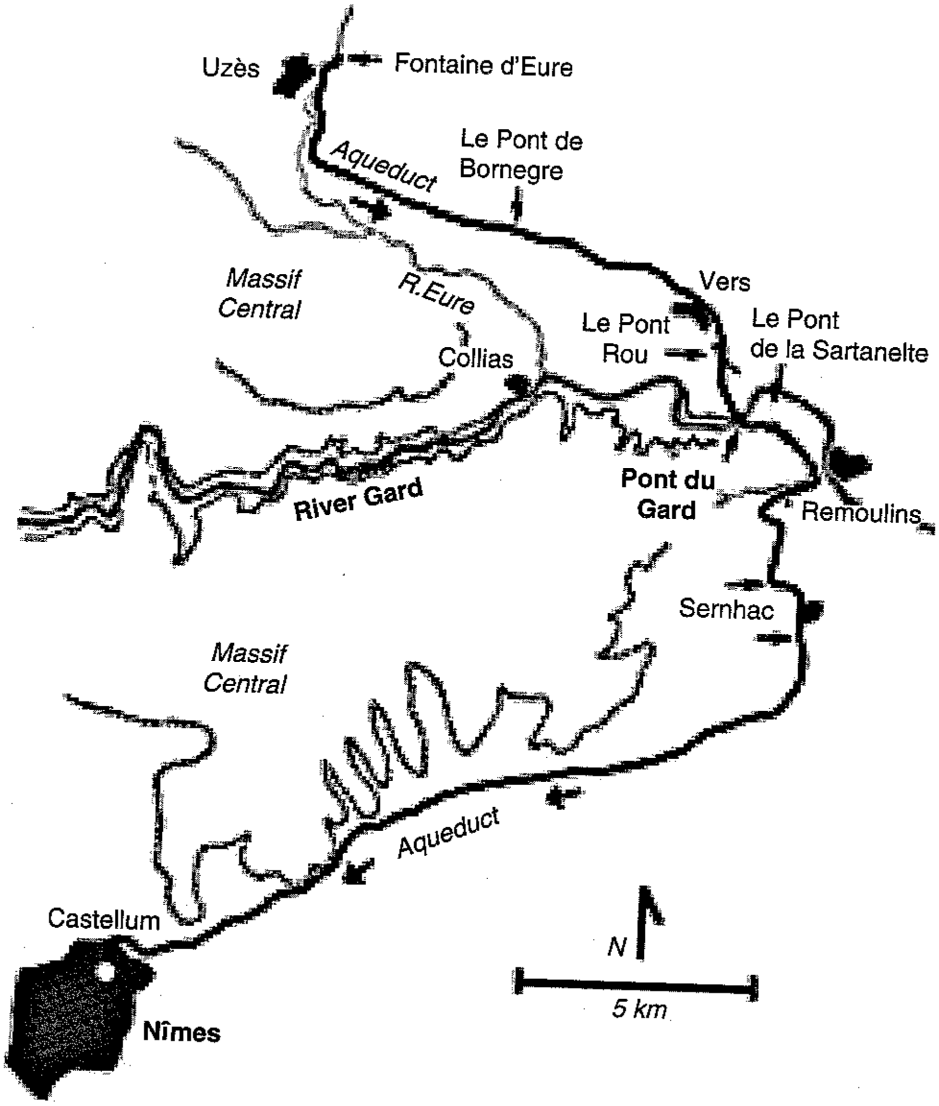

Figure 2.4 (a) Route of the aqueduct of Nimes, France. (*From Hauck, 1988*)

As the urban area expanded in size, there was an increased socioeconomic diversity, and an expanding political influence. At its height, around 600 AD, Teotihuacan was fully urban with a population of approximately 85,000 people and covering an area of 19 km^2 (Haviland, 1970). Others have estimated that the maximum population was approximately 125,000 during the Xolalpan phase (Millon, 1993). Teotihuacan was the largest urban center of the time in Mesoamerica.

Around 300 BC, the use of canals for irrigation rapidly spread throughout the central highland basin, the location of Teotihuacan (Doolittle, 1990). South of Teotihuacan