SPLASH: The Student-centered Program for Learning about Semi-arid Hydrology

Module 2: The History of Water Quantity in Southern Arizona, a Case Study

Student Guide

Produced by SAHRA: The NSF Science and Technology Center for Sustainability of semi-Arid Hydrology and Riparian Areas

This material is supported by SAHRA under the STC program of the National Science Foundation, agreement no. EAR-9876800; the University of Arizona under the Water, Economic Development, and Sustainability program of the Proposition 301 Technology and Research Initiative Fund; the Arizona Board of Regents under the Eisenhower Professional Development Program, grant no. 992001-02; and the Collaboration to Advance Teaching Technology and Science under the GK-12 program of the National Science Foundation, agreement no. GRD-9979670.

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Imagine…

Traveling south from Phoenix in a helicopter a few hundred feet above Interstate 10 in late spring and approaching the northwestward sprawl of Tucson. You begin to observe a desert landscape more obviously in full retreat with fresh rectangular areas scraped to receive the advancing brick and stucco structures. Continental Ranch is right below you now, hugging the freeway boundary and creeping up into the foothills of the Tucson Mountains. Then you catch a passing glimpse of a small stream within a wider channel. You have not seen much surface water since leaving Phoenix, none flowing in a river, so this startles you. What you see is the Santa Cruz River, and here north of the Ina Road Treatment Plant, water trickles along slowly. Which way? Embarrassingly, you realize that you're not sure. Aren't rivers supposed to go south? But now as you reach the outer boundary of Tucson's official city limits the scarred and gouged banks of the river bed holds no water at all. What happened? Suddenly you have an awareness never experienced before. Why can so many people live here on a land that is so dry?

What if the river was flowing from bank to bank? Could this only occur after recent storms, like the ones you remember during last year's monsoon season? Or, stretching your imagination further, what if moisture was frequent, and the river flowed as rivers are supposed to flow? Then it might fulfill the needs of all who lived here. You might see people boating or fishing instead of dry sand. But, where does the water come from that flows out of your faucets at home?

Now your mind is full of questions in search of answers. You are aware that just as previous inquiries have begun, one answer leads to more questions and your curiosity grows. How much water do people in the Tucson Basin use each day? How big would the Santa Cruz River have to be to supply that amount of water just daily for drinking and for bathing? This is hard to imagine because you know that the climate here is semiarid and this is now the driest time of the year.

That is the reality, yet you don't want that restraint just yet. You decide to question more and let your imagination stretch and probe the possibilities. You begin to wonder about what might be, or what would have to be if the roughly 900,000 people who presently call the valley home were to have all the water that they currently consume and still enjoy a flowing river. The river would have to be pretty big, but how big is that? And what if the river were larger still, would others seize the opportunity to get more water for other uses? Who would decide? More people keep coming, how much larger would the river have to be in order to provide for future population growth? You think about pumping ground water instead of river water, but does this also tend to reduce the surface water that would otherwise flow in the river? And you think you have heard that too much pumping causes the land to cave in, sink holes you seem to remember. Don't they have those in Florida, and there it is wet? Does it happen here, too? You recall getting a passing glimpse a long concrete ditch as you flew down from Phoenix. Isn't that what they call
CAP? You remember that a lot of people in Tucson didn't want CAP water? Is it water we really need? Look how far it has to travel!

Other thoughts pour in. Tucson thrives on tourists. How many more gallons should be added in calculating the present rate of consumption? All of the hotels and resorts have big swimming pools and thousands of private pools are part of many people's "Tucson lifestyle." Where does that water come from?

That pulls your thoughts back to the Santa Cruz River. What about the people who live upstream? Which direction was that again? They take water from the river so it would have to flow in even a larger volume before entering Tucson, or it would it? Where does the river start and where does it get its water? Or, if it has few sources, is that why it is so dry? How much of a factor is evaporation in drying up the river? The hot sun of southern Arizona must suck up a lot of water, so maybe that is why it is so dry. Yet, the river channel tells you that water must have formed it as it flowed through. So probably the river just doesn't dry up and disappear, but you remain uncertain. Even so, another fact enters your mind and you wonder more. You remember learning about a people called the Hohokam that once lived in southern Arizona and as far north as Phoenix. As you recall, they are best known today for building irrigation ditches. Was there more water flowing in the river then? There must have been, or maybe they just used less of it. Or maybe they found ways of storing it.

So far you have only thought in terms of human use. Many plants and animals live here as well. How much rain would have to fall to produce the kind of river that you imagine to include their survival needs? Imagine if it was not semi-arid and several inches fell pretty regularly every month! But where would all that moisture have to end up in the river? This means that you definitely will have to identify the area that comprises the drainage basin upstream into the Tucson Basin. What about runoff? You know that mountains lie to the south so rain water would tend rush into local washes that must eventually empty into the Santa Cruz. This is another reason why, you remind yourself, the river would never flow at a constant rate even if the area was more humid as you now are imagining it to be. Would a three foot deep stream of water in a channel 90 feet wide be the targeted minimum? That doesn't seem like a lot of water, but it is a huge amount compared to now. How much river water does this area's wildlife require? If a larger river existed more (and even different) kinds of plants and animals would compete for its water. Finally you realize that if this river were to be as large as you imagine, southern Arizona would no longer be a desert. But, then was it always a desert? How did the river form and what are the natural forces that still affect it? How much has the river and the valley changed over time? How can anyone find out?

Just as you suspected, this is going to take some time to build a good understanding. However, you do not care about that now. This is exciting! Water, you realize, is something almost everyone takes for granted and otherwise thinks little about. Your new found interest has created a thirst to learn much more. You decide to pool your thoughts. "Thirst," "pool"; this water thing is really starting to get to you! First you must organize your inquiry, decide to reform and rephrase basic questions. Where is the best place to start? At the beginning, of course! Here we go!

1] When and how did the Santa Cruz River form?
2] What area encompasses the Santa Cruz River Basin?
3] How have the various cultures through the centuries affected water resources in the Santa Cruz River Basin?
4] Who determines who gets water and how much they can use?
5] How will CAP impact this area's water resources?
6] Is it possible to achieve a sustainable water supply in southern Arizona?

NOTE: Each of the questions above organizes a study unit that ends with Inquiry Six for this module. They provide information plus designed activities that will help you highly literate about water quantity issues that continue to challenge life in southern Arizona. The first five inquiries will explore the topic of water supply in some depth. Based on these studies, the last inquiry will ask you to apply what you have learned in order to realize lasting understanding about the last question above. That question, as hopefully you will soon realize, is vital to personally and to all of those who choose to make their home in southern Arizona now and in the coming years.

STUDENT INSTRUCTIONS FOR SUCCESSFUL COMPLETION OF EACH INQUIRY
After reading the Opening Story and thinking about the significance of inquiring about the water quantity history of southern Arizona, students are asked to follow the path of inquiry laid out in the six connected inquiries as directed by your teacher. At any point you may take notes and write down questions to be answered by yourself, other classmates, or your teacher. Students are to read and then do the tasks as indicated under what is labeled, "IV. Basic Inquiry." Students may also choose or be directed to do expanded activities designed to broaden their study. Students will be expected to be thorough and thoughtful in pursuit of the information in order to build a sound knowledge base for advanced water literacy. Continue to think of questions that probe more deeply in order to create enduring understandings. The following Rubric will help you should assess your own efforts before being evaluated by your teacher.

INQUIRY ACTIVITY RUBRIC
5 = Demonstrates a thorough understanding of all the required tasks using and applying the basic term/concepts. Much evidence present to demonstrate an effort to thoroughly complete the tasks with thoughtful detail provided, including highly accurate interpretation of data and documents plus many appropriate examples in support of answers made. The compliance percentage range for a score of 5 indicates a performance range of 90 to 100% for measures of quality and accuracy. At this stage of assessment this results indicates the potential for levels of competency much above stated standards.

4 = Demonstrates a good understanding of the required tasks using and applying the basic term/concepts. Evidence present to demonstrate an effort to complete the tasks with good detail provided, including interpretation of data and documents with few significant errors plus examples in support of answers made. The compliance percentage range for a score of 4 indicates a performance range of 80 to 89% for measures of quality and accuracy. At this stage of assessment this result indicates the potential for levels of competency above stated standards.

3 = Demonstrates an adequate understanding of the required tasks using and applying the basic term/concepts. Evidence present to demonstrate an effort to complete the tasks with good detail provided, including interpretation of data and documents that have only a few errors plus examples that largely support answers made. The compliance percentage range for a score of 3 indicates a performance range of 70 to 79% for measures of quality and accuracy. At this stage of assessment this result indicates the potential for levels of competency that meet stated standards.
2 = Demonstrates a fair understanding of the required tasks using and applying some of the basic term/concepts. Evidence present to demonstrate an effort to complete many of the tasks with some detail provided, including some interpretation of data and documents but with some significant errors plus a few examples that support answers made. The compliance percentage range for a score of 2 indicates a performance range of 60 to 69% for measures of quality and accuracy. At this stage of assessment this result indicates the potential for levels of competency that likely fall below stated standards.

1 = Demonstrates a poor understanding of the required tasks with limited use and application of the basic term/concepts. Little evidence present to demonstrate an effort to complete the tasks with little or no detail provided. Interpretation of data and documents is limited with many significant errors or not present at all. Little to no effort has been made to provide examples in support of answers attempted. The compliance percentage range for a score of 1 indicates a performance range of 59% or lower for measures of quality and accuracy. At this stage of assessment this result indicates the potential for levels of competency that likely fall far below stated standards.
Santa Cruz Water History Inquiry One

When and how did the Santa Cruz River form?

Student Activity Guide

Resources:

*Water in the Tucson Area: Seeking Sustainability* at:

and

AZPEPP at
http://www.geo.arizona.edu/geoed/spinet/ (BAD LINK)

and

NSP Instructor Web at
http://www.patrol.org/instructor/avalan/advava/img28.htm

or,

alternative from Weather.com at
http://www.weather.com/glossary/?from=tabset

and,


I. Introductory Statement

The present Santa Cruz River Valley was shaped out of a long past that began thousands of years before humans lived in southern Arizona. History is a human invention that explains events with a human bias that is difficult to see and to understand in terms of the patterns developed over millions or even thousands of years. The Industrial Revolution began during the latter 18th century and initiated rapid, man-made environmental global changes. The capacity for man-made catastrophes continues to grow. However awesome man’s power has become the power of natural forces remains much greater, and to truly understand an ecosystem such as the Santa Cruz watershed we must look at the long-term patterns and those perpetual forces that shape and alter it. Any attempt to evaluate the history of the Santa Cruz River Valley therefore must also include this broader perspective. In fact, it is the interaction of human societies with their natural environment that shapes the world in which we live. As you read the information in Chapter One from *Water in the Tucson Area*, Chapter One, “The Setting” pp. 1-4, it is important to keep that understanding in mind.

II. Targeted Standards:

*Science Standard*

Strand 1: Inquiry Process: thinking critically and logically about relationships between evidence and explanations, and communicating results.

*Reading Standard*

Strand 3: Concept 2 – Functional Text- Identify, analyze, and apply knowledge of the purpose, structures, clarity and relevancy of functional text.

III. Basic Inquiry Concepts to be learned and applied

A. Basin and Range Topography

B. Earth-time
C. Aquifer
D. Plate Tectonics
E. Orographic Lifting

IV. Basic Inquiry Questions
(from Water…)
1. How does southern Arizona's climate compare to what it was like 10,000 years ago?
2. How did the various mountains that lie along the Santa Cruz River Valley in the Tucson Basin contribute to the formation of the aquifer?
3. What does the aquifer in the Tucson Basin store and what was its original source?

(from AZPEPP…) (BAD LINK)
1. What is the basic geologic descriptor for southern Arizona?
2. When did it form?
3. What geologic process has shaped the Tucson Basin?
4. What geologic force creates mountains in southern Arizona?
5. What term is used to identify where basins form detached from the mountains, and what happens when these shift?
6. Where in the immediate Tucson area could you find evidence of that action?
7. What is the approximate height and depth of Tucson Basin in meters? In feet?

Enlarging the context: At least part of the Basin and Range topography of southern Arizona is part of the Sonoran Basin and Range Ecoregion as defined and studied by the USGS. Click here (BAD LINK) to identify this on the USGS map.
1. Why should we know this?
2. Why is the map incomplete?

Questions for understanding (NSP Instructor Web)
1. What is the term that identifies the interaction between advancing air and the area's mountains?
2. What is the potential benefit of that interaction (see question #1) in creating and re-supplying surface water?
3. How old is the water at the deepest portions of the aquifer in the Tucson Basin?
4. How would know more about the climate in the Tucson Basin over many thousands of years help explain ground water quantities available for human into the present?
5. How would the topography of southern Arizona contribute to possibility of flooding?
6. Why would the depth of the basin have important implications affecting water quantity?

V. Expanded Inquiry Activity: Creating the Big Picture of Time
A. Instructions: Read the information immediately below and then answer the questions that follow.
B. Reading:
Change affects our lives each day. It serves as a concept that embraces our own emergence as an infant, our maturation as we pass from childhood, adolescence to an adult as we continue on to old age. This cycle of birth, life and death applies to all living things and scientists believe even to the earth itself. If
change is placed within the context of time, we can begin to make quantitative comparisons and relate them. For instance, if a human's life expectancy is 75 years and a dog's is 12 years, the rate of change for a dog is relatively faster (over six times) than for a human. When viewed in this way, time applied to a dog’s life seems to run at fast forward compared to us. Many organisms live much longer than humans. The oldest living trees have been around for over 2,000 years.

Scientists estimate the age of the earth to be at least 4.5 billion years. If we were able to go back to the moment that the earth was "born" it would appear much different than it is today. Certain features of the earth's surface were formed hundreds of millions of years ago and others much more recently. Volcanic eruptions such as the big blow up at Mount St. Helens in 1980 created instantaneous change. The opening of the web page for the Mount Saint Helens National Monument can help us grasp this: "At 8:32 Sunday morning, May 18, 1980, Mount St. Helens erupted. Shaken by an earthquake measuring 5.1 on the Richter scale, the north face of this tall symmetrical mountain collapsed in a massive rock debris avalanche. Nearly 230 square miles of forest was blown over or left dead and standing. At the same time a mushroom-shaped column of ash rose thousands of feet skyward and drifted downwind, turning day into night as dark, gray ash fell over eastern Washington and beyond. The eruption lasted 9 hours, but Mount St. Helens and the surrounding landscape were dramatically changed within moments." This illustrates that change may be dramatic but that change does not stop and features subtly appear to alter the landscape that only a longer perspective of time can perceive and measure. The Grand Canyon is estimated to be over a billion years old. The Colorado River has etched into the plateau cutting it to a depth of over a mile. This process has been relatively slow, something like making a mark across a sheet of paper with a pen year after year after year until after millions of years a giant chasm has formed.

The landscape of southern Arizona is relatively young, and of course, continues to change. About 75 million years ago southern Arizona was under water. Since then geological forces have shaped the present contours, and for the past ten thousand years the climate has been similar to that of the present. Over the past 150 years or so, man has increasingly interacted with the natural forces causing physical change to occur. As you move through these inquiries you should be able to grasp the significance of these changes. In the process, remember to keep the big picture of geologic time in mind. This will help you gain the perspective that will bring deeper understandings.

C. Questions to Answer:

1. Create a ratio that condenses the earth's geologic age into one hour, i.e., each second in that hour is equivalent to ___ years of the earth's age; each second will thus be ___ years of "earth time."
2. Compute the average age of southern Arizona's Range and Basin into earth time, i.e., AZ's period of time = ___ seconds.
3. Assuming that humans have regularly lived in southern Arizona for 10,000 years, what would be its equivalent measured in earth time?
4. If Arizona has been known to Europeans since around 1539, what % of the answer you got in 2 above would that represent?
5. Assuming the average human today lives for 75 years, what % of an "earth time" second does this represent?

6. Write a paragraph supporting or rejecting this statement. "To properly understand the interaction between human and non-human forces against the long span of time, humans act as flash floods, leaving definite and lasting imprints on the land."

NOTE: For the activities above other measures of earth time equivalencies can be used. The hour was used to represent close to an average class period. The essential (and "enduring" understanding) that each student should learn is the relevancy of time. This can be applied to understanding the creation of the aquifer in many ways. For example, if the tap water coming from ground water is 10,000 years old, and a person drank an 8 oz. glass of that water in a minute's time that can be viewed as "speeding up time as if passing at the rate of almost 167 years per second, still a "drop in the bucket" in earth time.

7. Evaluation: After having completed this inquiry, write a brief discussion that expresses your deeper understanding of the introduction (I) above.
Santa Cruz Water History Inquiry, Question Two

What area encompasses the Santa Cruz River Basin?

Student Activity Guide

Resources:
and,
Santa Cruz Watershed Map (See Appendix item1)
  [http://ag.arizona.edu/watershed/](http://ag.arizona.edu/watershed/)
  or,
  [Detailed map below](http://ag.arizona.edu/watershed/)
and
A glossary of water terms from the US Geological Service (USGS) at
  and,
The science of dendrochronology at
  [http://www.sonic.net/bristlecone/dendro.html](http://www.sonic.net/bristlecone/dendro.html)

I. Introduction:

Watersheds are delineated by USGS using a nationwide system based on surface hydrologic features. This system divides the country into 21 regions, and 222 sub regions. Thus the Santa Cruz River Watershed lies within one of the 21 regions, the Colorado River Basin, and is one of 222 sub regions. However, even though the Santa Cruz sub region is comparatively large in surface area, it produces much lower than average water flow. As we learned in the first inquiry, were it not for the Range and Basin topography, even less water would be available. Since water is essential for life, it would be fair to say that a watershed such as the Santa Cruz is literally the life-force for all dwelling within. Thus, it is important to appreciate the interconnectedness of this drainage area. Since water flows by force of gravity down hill, one might think it would be possible for humans living near the source of a river to deprive those downstream of some, most, or even all of the water. Let's examine this further and see how interconnected people might be to one another in the Santa Cruz Basin. This interconnection also extends to how humans have interacted with nature to affect water quantity in the past.

II. Targeted Standards:

Reading
Strand 3: Comprehending Informational Text: Comprehending Informational Text delineates specific and unique skills that are required to understand the wide array of informational text that is a part of our day-to-day experiences;

Math
Strand 5 – Concept 1: Algorithms and Algorithmic Thinking The concept of using reasoning to solve mathematical problems in contextual situations;
Strand 5- Concept 2: Logic, Reasoning, Arguments, and Mathematical Proof, The concept of evaluating situations, selecting problem-solving strategies, drawing logical
conclusions, developing and describing solutions and recognizing their applications;

**Science**

Strand 1-Concept 1: Formulate predictions, questions, or hypotheses based on observations. Evaluate appropriate resources.

Science Strand 4- Concept 3- Interdependence of Organisms: Analyze the relationships among various organisms and their environment.

**Social Studies**

1SS-P1 Apply chronological and spatial thinking to understand ... historical and current events;

3SS-P1: Acquire, process, and analyze geographic information about people, places and environments by constructing, interpreting, and using geographic tools;

3SS-P2: Analyze natural and human characteristics of places in the world studied to define regions, their relationships, and their pattern of change

**III. Basic Inquiry Concepts to be learned and applied:**

A. Watershed:

B. Dendrochronology:

C. Flash Flood:

D. Flood Plain:

E. CFS:

F. Archaeology:

G. Alluvium:

H. Acre-foot:

**IV. Basic Inquiry:**

Look at the Santa Cruz Watershed maps (the general one online, and/ or the detailed one below). Before using it you must be aware of this essential fact about the Santa Cruz River. While its channel can be mapped as is true for any other river, unlike many other such bodies of water, the Santa Cruz did not regularly flow above ground principally because it drains a semiarid area. The channel marks its above ground path when water volumes have been sufficient to remain above ground from source to mouth. (1) Where does the Santa Cruz River begin? This would be its source. (2) What is the approximate elevation at its source? Follow its path. (3) As the river flows downward (in terms of elevation) what natural process would occur? That process cuts into the land creating river and stream "banks." Depending on the quantity of water flowing, a stream or river may or not extend from bank to bank. When the river rises above its banks it is called a flood. (4) What is the term used for the level area beyond river banks? In a way, recognizing this feature is a way of "reading" a river's history. However, this would be an imprecise reading because we would not be able to determine when the river flooded unless it had very recently occurred. (5) Read about the science of dendrochronology and briefly explain how this method of inquiry might help provide a more detailed reading of river history. We will build more on this later, but first we need to follow the Santa Cruz River to where it merges into a larger river. (6) What is this point of merger called?

Follow the path of the river as it descends from the San Raphael Valley. As it moves south-southwest it does something no other US river does. (7) What do you think that is? (8) The river leaves the U.S. near Kino Springs, and eventually reenters the country near what city? From this point it flows primarily north towards Green Valley and eventually moves from the Upper
Santa Cruz Basin into the Middle **(Tucson)** Basin, roughly at the point that it enters Pima County. (9) What is the name of the largest city in the Middle Basin? The Santa Cruz River has turned north-northwest well before it entered the Lower Basin in Pinal County. (10) Eventually it reaches what river as it completes its northward journey?

We have traced the general path of the Santa Cruz River, but now we need to get back to some still open questions. (11) First, if people near its mouth in the San Raphael Valley were to construct a dam to capture all of the river's water, would this mean that people downstream in Nogales and Tucson would be unable to get any water from the river? If you look carefully at the detailed map you can answer this question correctly and also gain a fuller grasp of what is meant by the term *watershed*. (12) Briefly define the meaning of this term.

Now we should return to the idea of reading the river's history. (13) What are two ways that we have already found to get some understanding of the Santa Cruz's past flow history? Unfortunately both of these methods only give a very general picture. Here are some ways that we can get greater precision. When the river overflows its banks it extends into its *flood plain*. Flooding can be a gradual process or it can occur rapidly. (14) What is one characteristic of Range and Basin topography that can lead to rapid ("flash") floods? Let us examine this more closely.

(15) What physical evidence might you find that indicates previous flash flooding? As the river cuts its way across a landscape the force of the water erodes rock and soil. If it has done this rapidly it gouges and cuts into the bank. This scarring is evident in many places along the Santa Cruz River. This is also true of many of its feeder streams that are normally dry called *washes*. In the West, deeply scarred cut banks are called *arroyos*, a word that comes from the early Spanish explorers and settlers. The force of the river is determined by the combination of its weight and rate of movement. Measuring the flow rate of a river is done in units called cubic feet per second, *cfs*. One "cfs" = 7.48 gallons of water flowing per second. (16) What is the larger unit of measure used to identify thousands of gallons of water? As an expanded inquiry you can do some pretty basic math and calculate the number of gallons of water that would move per second to equal an acre-foot of water. Click [here](bad link) for reference as needed in order to answer the questions in the Expanded Activities (V.) section below:

(17) Generally, what would the tendency for erosion and bank cutting be if the cfs is high? (18) What would determine a high cfs rate? The answer to this is relative to the size of the river within the given capacity of parts or all of part of its watershed. In another inquiry session we will explore this history for the Santa Cruz River in more detail.

In addition to the approaches described already, additional methods using two different types of scientific inquiry can help to fill in more detail of the Santa Cruz River's past. Since humans have lived in southern Arizona for many millennia, it is possible to find some evidence in the area along the river and the adjacent flood plain. The science that is used to find this kind of evidence is called *archaeology*. (19) We can predict that humans lived along the Santa Cruz because it and the floodplain provided at least two kinds of benefits. Name them. For one of these two answers, click [here](bad link) for a definition of the word *alluvium*. Archaeology provides more of a long distance look. Geology can provide an even longer vantage point because of the rock layers (strata) themselves and the fossil remains that might lie hidden within.
Review the time perspective that we gained in the first inquiry, comparing human time to earth time. Other than a few stories that come from the stories (oral tradition) handed down by the native inhabitants of southern Arizona, more recent sources can be found. One of these is to find and examine the reports made by early European, Mexican and American visitors and residents. These texts, along with photos that begin to record the area's history during the latter 19th century, can provide important information about the history of the Santa Cruz River. (20) What would be several limitations to these sources that would cause us to have to be cautious in using them to draw conclusions?

While we have not exhausted all the possible tools to uncover the river's hidden past, we have found many of the most important ones.

V. Expanded Inquiry Activities
A. Examining a topographical map (this, if I remember correctly, refers to the watershed map that Dan and Kyle were developing.)
   a. What is the approximate elevation of the headwaters of the Santa Cruz?
   b. What is the approximate elevation of the Santa Cruz at Kino Springs?
   c. What is the elevation at the point that the Rillito enters the Santa Cruz?
   d. What is the elevation at the point that the Santa Cruz enters the Gila?
   e. Find an average rate of descent for the Santa Cruz from source to mouth, i.e., ___ feet (or meters) per mile (kilometer).
   f. Assess the potential for flash flooding due to sudden rains in the surrounding higher terrain of the Santa Cruz watershed.
   g. In another inquiry you will be asked to assess the probability of flash flooding due to the actions of humans and how this interaction with natural conditions has affected the potential off rapid flooding of the Santa Cruz

B. Calculating quantifies and rate of flow
   1. Click here (BAD LINK) and write down answers to the following
      a. How many gallons of water in an acre-foot?
      b. How many gallons of water equal the volume of 1 cfs?
      c. What other factors affect the volume of water to equal a rate of one acre-foot per second?
   2. Examine this data in The Lessening Stream by Michael Logan, p. 221:
      Peak flow recorded in the Tucson area for four dates:
      1884: one acre-foot in 43 minutes (this was measured as a more "normal" flow)
      1915: one acre-foot in 2.9 seconds
      1977: one acre-foot in 1.85 seconds
      1983: one acre-foot in 0.83 seconds
      a. Convert each into cfs.
      b. The volume of water is cubed, i.e., the same number multiplied by itself 3 times. 1 acre-foot of water moving at the rate of 1 cfs equals approximately 52.6 feet to the third power. 52+ feet of water is roughly the height of a five-story building. The Santa Cruz River is not that deep, so if that is the case what must happen? In answering this consider what is meant by force).
      c. ___ borders a river and is composed of deposits from flood events..
      d. Hydrologists and geologists calculate the rate of occurrence of flooding
stated in terms of the probability of massive flooding as defined here. (BAD LINK) A 100
year flood can be thought of in terms of either having a 1 in 100 chance of occurring in any given year or having a 1% chance of occurring. Examine the data from Logan again. How might the three episodes of high cfs have affected their calculations of the probability of future "100 year floods?"
What might explain this trend?

C. Using and applying written reports and photo documents to help "read" the more recent history of Santa Cruz water flow. Be prepared to answer the questions that follow.

1. Examining Historical Documents:

   a. Document # 1: (Source: Henry F. Dobyns. Spanish Colonial Tucson: A
      Demographic History (Arizona: 1976)

      There is enough arable land for said town’s people and the Sobaipiris. As for water, all these years the neophytes have said that their grain fields dry up for lack of water, and now that they have conceived that they desire to change, they say that there is surplus water. I can only say that before the Sobaipiris came they used to complain about the scantiness of water . . . and the Governor of Tucson asked that I free him from the obligation of cultivating a maize field for the church so that there might be that much more water.42

   b. Document # 2

      To Captain Pedro de Allande y Saavedra,
      In obedience to your order of November 20, 1777, I Manuel Barragua, together with two other leading settlers of Tubac, Francisco Castro and Antonio Romero, appear in your presence to give the information you request concerning), the Tubac area: watering places, land for cornfields, pastures for horses and cattle, and minerals of the region, as well as routes taken by the Apaches for their attacks and escapes and the places where they camp.

      The Tubac settlement is situated between two mountains, some fifteen miles apart, forming a valley with abundant and fertile fields for the growing of corn. We have enough water for the cultivation of wheat, but not enough to grow the corn we need. If Tubac shares Tumacacori water, damned up by the mission at that place, there is enough water for all. Captain Juan Bautista de Anza set up a schedule whereby Tubac used the Tumacacori water for a week, then the Tumacacori Pimas used it for a week, and so on. We were overjoyed to hear recently that you have approved the continuance of this arrangement.

      Tubac has abundant pasture for cattle and horses in the valley and on the hillsides. There are cottonwoods and willows in the valley and there is easy access to excellent pine forests some fifteen miles away in the Santa Rita Mountains. The Tubac settlers are raising over 600 bushels of wheat and corn annually, and we are farming only two-thirds of our land…. 
Since they [i.e., the Apaches] have already done away with all of our possessions and show no signs of leaving, all they can be waiting for is to take the only thing they have not taken, the lives of ourselves and our families. Our only hope is the restoration of our presidio to its original location and the positioning of troops along the routes of Apache attack and escape. We have great confidence in the fame and name of Allande y Saavedra. Only you can save us!

In the name of all the settlers at Tubac,
Manuel Barragua
Francisco Castro
Antonio Romero

c. Document # 3: This letter by Usarraga 3 de Mayo describes an Apache attack on Tucson in 1782.

My Dear Sir:
In compliance with Your Honor's order of the second of this month, and in accordance with the questionnaire that accompanied it, I expound the following under my word of honor:
The first day of the present month when the enemies fell on this presidio, I found myself in the Pueblo of Tucson on my own affairs and with Your Honor's permission, accompanied by the distinguished Don Juan Phelipe Beldarrain. At that time, despite the distance of the shots and disturbance, I attempted to return to the presidio. I did not reach it, however, because when I arrived at the Bridge with the distinguished person mentioned, the enemy was already in possession of that site in great numbers. They tried forcefully enough to advance over the Island to the Pueblo, but seeing that those who had come there were many, and that, moreover, if I won through them I should find it necessary to enter another multitude who were covering the lake and ditch, I decided it would be well to make a stand with the distinguished person mentioned, firing on said Bridge as much to impede their advance on the Island and Pueblo as to succor some women and children who found themselves in the ditch. From there we saw the presidio surrounded and notwithstanding that there were very many on all sides, the major resistance from the presidio was directed to the north of it, which made me decide that the greater part of the enemies were there.
When they had abandoned their intention of entering the Pueblo, I returned to it and asked Father Friar Juan Baptista Beldarrain for some Indians whom he gave me immediately. With them and the distinguished person I was able to enter the presidio after the battle ended, although the enemies were still gathered not far distant.
As for their number, I am unable to say definitely (inasmuch as I was not present) what it might have been. Yet I can assure you under the faith of my word that I have not seen such a body in the battles in which I have engaged, nor have I heard said that they have made such an attempt to enter any other presidio.
The troops who were in the presidio that day (including the captain, cadet, and sergeant, who was sick) were eighteen men and two citizens. The enemy losses
[were as follows]: ... From the Bridge I saw one fall in the Ojito (spring) and the Apaches picked him up and carried him. Another among those whom the distinguished one and I were firing on at the Bridge fell and the Pimas continued shooting arrows at him and and (sic) yelled to us, 'We are going to get him.'

Inasmuch as we did not foresake the Bridge, we left him, and I am sure that this Apache is the one whose head the Pimas cut off which Your Honor placed on the gate of the stockade because he had a ball in the chest and two arrow wounds in the side according to what those who went to see the body say.

d. Document # 4

1884 Report by City Engineer J. P. Culver

The water supply afforded by the Santa Cruz river I have for several years observed and can state with accuracy the amount visible at the dryest [sic] seasons of the year for the past three years, which is a crucial test to its value. The visible waters of the valley, of greatest quantity and value, in this locality, commences about nine miles southerly of Tucson, at the Punta del Agua near San Xavier, on the Papago reservation, where a gauging shows in the neighborhood of 700 miner's inches of live water, which, with moderate development, could likely be largely increased. Following down the valley this water all disappears by sepage [sic], only a moderate, or a partial use being made of it for the cultivation of small tracts of land and some minor domestic uses. Six miles south of town the Tucson water company have [sic] developed about 170 acres of miner's inches of sweet and pure water.... About a mile below this point live water again makes it[s] appearance and gauging made in 1881-2-3 resulted in showing about 23 miner's inches. The next point below and following the line of water all the way is Lee's mill [Silver Lake] where gauging made in 1881 and 1882-3 [sic] showed from 500 to 700 miner's inches passing through the waste flume. An examination at Warner's millrace, the next point below, was found to carry about the same volume of water as at Lee's mill.

The final point, and the last place examined in the valley below Tucson, where live water is diverted from the valley, is the lower settlement about four miles from Tucson, where the irrigation ditch carries about ten miner's inches. In the aggregate it is safe to assume of the total 1,403 miner's inches of water that there can be placed implicit reliance upon at least 1000 miner's inches of visible flowing water during the dryest [sic] of seasons.... The live water as enumerated, so far as a careful study of the physical features of the valley are concerned looks to the conclusion that it is only a very small part, compared to the underlying water measures passing downstream through the coarse gravel, invisible to the eye but by digging it is soon reached, rarely being but a few feet below the surface. When reached, it is found in great in quantity and over a large area in width....that there is an immense invisible subterranean water course in the water channel of this river; that in the aggregate would be astonishing if properly collected and developed. [Quoted from Logan, The Lessening Stream, pp. 155-156 from a report]
originally published in the *Arizona Daily Star*, 12 February 1884, p. 4; a miner's inch equals about 1.5 cu. ft. per minute.]

c. **Refer now to the documents to answer the following questions:**

1. **Document # 1** indicates that water was a scarce resource in early Tucson, a combination of the local climate and the burden placed upon the converted Indians ("neophytes") to support the mission. What crop in particular required a large amount of water?

2. Corn was originally a tropical plant requiring much more water than wheat, which naturally grows in more temperate climates. Find and write the statement in **Document # 2** that indicates that comparatively high water requirements affected how much corn could be raised in the Tubac area.

3. What is the statement in **Document # 2** that indicates the irrigation was used to raise crops around Tubac?

4. *(Refer to question # 3.)* What was the likely source of that water?

5. What was the primary purpose of Barragua, et al. for writing this letter (**Document # 2**)?

6. **Refer to Document # 3.** What important clue is given about the size of the Santa Cruz River near downtown Tucson almost two and one half centuries ago?

7. What indication is given that irrigated farming was supporting the presidio of Tucson at this time?

8. The bridge was the focal point of the battle with the Apache raiders. What fact is given that indicates the likely recent weather pattern that was affecting the volume of the river's flow?

9. **Refer now to Document # 4.** At what location was the flow of the Santa Cruz the highest?

10. If this were the “driest” time of the year, in what month would Culver have made his survey? *(Examine the NOAA data immediately below these question to answer this question.)*

11. What was the likely source of Silver Lake?

12. What does Culver mean by “live” water?

13. Culver’s term, “subterranean” water, refers to ___.

14. "Reading the river" through historical documents: What general statement can you make by using these documents that would describe the Santa Cruz River and its nearby banks over roughly a century from 1780 to the early 1880s?

**TABLE:**

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<th>TUCSON PRECIPITATION RECORDS FOR THE PAST THIRTY YEARS FROM NOAA</th>
<th>(This data can be regarded as representative of a longer pattern for this area over the past several centuries at least and thus can be applied to question # 10 above.)</th>
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16
### Monthly rainfall normals (1971-2000) across Southeast Arizona

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D. Exploring the science of dendrochronology through this online source:
http://www.sonic.net/bristlecone/dendro.html

E. Physics might be applied to determine the force of moving water at given cfs rates.
Santa Cruz Water History Inquiry, Question Three

How have the various cultures through the centuries affected water resources in the Santa Cruz River Basin?

Student Activity Guide

Resources:

Paleoclimateology and Drought, by the NOAA Paleoclimateology Program at
http://www.ngdc.noaa.gov/paleo/drought/drgh_t.paleo.html
and

Discover Southeast Arizona at
http://discoverseaz.com/History/PaleoInd.html

Hohokam Indians of the Tucson Basin by Linda M. Gregonis & Karl J. Reinhard
at
http://www.uapress.arizona.edu/onlinebks/hohokam/tithoho.htm
and

Historical Background Information of the Coronado Expedition at
http://www.psi.edu/coronado/historicbackground.html
and

The Coronado Expedition at
http://www.psi.edu/coronado/
and

American Water Works Association, "Zanjeros ride again" at
http://www.awwa.org/communications/mainstream/archives/2000/August/ms0800zanjeros.cfm
and

Martha Summerhayes, Vanished Arizona, Chapter 25
and

Managing the Interconnecting Waters: The Groundwater-Surface Water Dilemma
by Joe Gelt at
http://ag.arizona.edu/AZWATER/arroyo/081con.html
and

Water Watch Basics at
http://www.waterwatch.org/waterlaw.html (BAD LINK)
and

Water in the Tucson Area, Seeking Sustainability at
http://ag.arizona.edu/azwater/sustainability/
+
http://ag.arizona.edu/AZWATER/publications/sustainability/pdf/Chapter_2.pdf
and

John Wesley Powell's Watershed Commonwealths at
http://www.tnews.com/text/powell_story.html (BAD LINK)
and (optional)

Tucson Weekly, 27 June 2002, "Convento or 'Invento'?"
I. Introduction:

Even though it may have been wetter thousands of years ago, the long-term trend established southern Arizona’s climate as semi-arid. Recurring cycles of drought and wet have occurred over thousands of years of southern Arizona’s past. (If you would like to explore the science of paleoclimatology to examine how this story can be told, click here.) This means that all forms of life, native or "immigrant," must be able to adequately respond to this pattern of wet and dry in order to survive. Drought creates stress that threatens survival. Relatively speaking, too much precipitation can also be harmful as well. The region in which we live is classified as semi-arid, and that means southern Arizona averages inadequate precipitation for the kinds of plants (and many animal species) that live in areas that receive more than 20 inches annually. All regions, "wet" or "dry" can experience below average or above average precipitation, either of which can put significant stress on plants, animals and even humans. Drought in a humid area may produce less rain over a period of time than the average, but the total amount can still be more than in semi-arid or arid locations. A sudden downpour in Tucson that produces several inches of rain in an hour creates flooding because this is highly unusual while in a humid area such as southern Louisiana, flooding may not occur at all in a similar event. Thus, drought and flood are relative terms, applied in a comparative way to specific areas measured against their "normal" (average) patterns. Wherever they occur, in humid or arid regions, drought or too much rain create stress that plants and animals must endure in order to survive.

The first humans arriving in southern Arizona are called Paleo-Indians. As with the use of the prefix for climate, paleo comes from the ancient Greek word for old, and when used in this way the adverb "very" is implied. These people were hunter-gatherers and have been named Clovis People because archaeologists first found evidence of their existence near Clovis, New Mexico in the 1920s. At the time that they lived in southern Arizona, it was cooler and wetter, and these hunters are identified with killing huge animals that were able to live here then. Some sites have been found near the San Pedro River, but since these early inhabitants lived in small bands and existed over a territory of thousands of square miles, they no doubt moved through and even lived for only short periods in the Santa Cruz Valley. These were courageous hunters who engaged in organized group kills of large animals. The largest of these was the Woolly Mammoth, which stood about 13 feet high at the shoulder with a powerful trunk and tusks up to ten feet long. A combination of climate change to warmer and drier and over-hunting led to the extinction of these large beasts. Clovis hunters were followed by another culture-group named for another New Mexico archaeological site, Folsom. In time, several thousands of years at least, new peoples would arrive and the shift to a more sedentary life began. We will examine this story in greater detail below. For more information about the Paleo-Indians of southern Arizona, click here.

II. Targeted Standards:
Reading
Strand 3-Concept 2: Identify, analyze, and apply knowledge of the purpose, structures, clarity and relevancy of functional text.

Writing
Concept 6: Research- Research writing is a process in which the writer identifies a topic or question to be answered. The writer locates and evaluates information about the topic or question, and then organizes, summarizes, and synthesizes the information into a finished product;
Math
Concept 2- PO5- Identify a valid conjecture using inductive reasoning;
Science
Strand 1-Concept 1: Formulate predictions, questions, or hypotheses based on observations.
Evaluate appropriate resources.
Science
Strand 1-Concept 3: Evaluate experimental design, analyze data to explain results and to propose further investigations. Design models;
Science Strand 2-Concept 1: Identify individual, cultural, and technological contributions to scientific knowledge. Science
Strand 2-Concept 2: Understand how scientists evaluate and extend scientific knowledge;
Social Studies
1SS-P1 Apply chronological and spatial thinking to understand ... historical and current events;
1SS-P2: Demonstrate knowledge of resource sources ...;
1SS-P3: Develop historical interpretations ...;
1SS-P11: Understand the transformation of the American economy and the changing social and political conditions in response to the Industrial Revolution;
1SS-P112: Analyze the development of the American West and specifically Arizona
1SS-P18: Apply the skills of historical analysis to current social, political, geographical and economic issues facing the United States;
3SS-P1: Acquire, process, and analyze geographic information about people, places and environments by constructing, interpreting, & using geographic tools;
3SS-P2: Analyze natural & human characteristics of places in the world studied to define regions, their relationships, and their pattern of change;
3SS-P4: the interactions between human activities and the natural world in different regions, including changes in the meaning, use, distribution, and importance of natural resources,
3SS-P5: Apply geographic knowledge of people, places, and environments to understand the past and present and plan for the future;
4SS-P1. Analyze the implications of the economic problem of scarcity.
III. Basic Inquiry Concepts to be learned and applied:
A. Epoch:
B. Hohokam:
C. Pimeria Alta:
D. Hispanic:
E. Cienega:
F. Acequia:
G. Riparian Right:
H. Prior Appropriation:
I. Beneficial Use:
J. Winters Doctrine:
K. Hydraulic Society:
L. Industrial ethos:
K. Reclamation:
IV. Basic Inquiry:
The human story of southern Arizona can be divided into several periods of time or epochs. We have already briefly examined the earliest one, the Paleo-Indian Period. Archaeologists have identified a second epoch beginning about 9000 years ago, or 7000 B.C.E. Technology helps identify the character and level of development of a culture group, and archaeological sites found from this second epoch contain stone grinding slabs. This period is called the Desert Archaic Tradition, and it lasted until about 300 C.E. (approximately 1700 years ago). Here in the Tucson Basin, small groups, bands, of people lived a mobile lifestyle built around gathering plants. Even so, they did build temporary shelters. "Summer found them in the foothills, collecting foods such as cactus fruits and mesquite beans. Acorns, pine nuts, and other foods from the higher mountains were gathered in the fall. Although hunting took place the year-round it was especially important in the winter and spring months when plant foods were scarce. The Archaic people established camps at each collection point, to which they returned year after year" (Gregonis & Reinhard).

Since these people had selected the Tucson Basin as their home, the attraction must have included the availability of surface water, primarily in the Santa Cruz River. At approximately 2000 B.C.E this area physically and climatologically was much like it is today. The Santa Cruz then flowed above ground from near where the San Xavier Mission is located, then went underground northward. At the base of A Mountain, a spring emptied into the river bed. From this point until near Avra Valley Road and Interstate 10, the river flowed above ground before again descending underground, which was its normal pattern until reaching the Gila River. That portion is generally referred to as the Lower Basin. Given their sparse numbers and mobile lifestyle it is likely that Archaic people had no restriction regarding who in their group could use this water or how much. Use of the surface water would have become more complicated when corn entered southern Arizona from Mexico sometime after 2,000 B.C.E. Whether this technology by-passed the Tucson Basin and was first developed in the Phoenix area is still a matter of debate, but recent archaeological findings due to Tucson's Rio Nuevo project have pushed back the time when corn was grown here, lending more support to those who believe that corn-based agriculture moved northward and eastward from Mexico. Thus it is possible that the Tucson Basin saw fields of corn earlier than did the Salt-Verde Basin around Phoenix.

Corn (commonly referred to as maize) proved revolutionary, although against the perspective of time the changes it brought took many generations to become profound. Food provides us with energy, the capacity to work and accomplish. Corn provides rich source of energy with comparatively higher yields than native plants, corn-based agriculture supported higher populations with people living together in larger villages. This significantly impacted social organization and relationships and most likely altered understandings about water and land use. Irrigated agriculture appeared by around 1,200 B.C.E. and farming communities in the Tucson Basin grew in number and size. Digging ditches for directing water to fields and maintaining them require stronger social organization. Since yields depended on the kindness of nature thought had to be given to how surplus produce could be stored. Attitudes about the powers of nature also influenced religious views. Eventually a more advanced culture emerged known to us as the Hohokam. In the Tucson area they developed a network of farming hamlets and villages with densities that border on what we would call urban today. The Phoenix area supported a larger urban population. The Hohokam learned to weave beautiful baskets and make both functional and decorative pottery.

Given the relative aridity of the climate and the fact that corn requires significantly more water than native plants, those who raised it became highly dependent on surface water. Why
could more people live here during the Hohokam Epoch? How might this have affected attitudes about the river and the structure of society?

Click here (BAD LINK) and read about the Hohokam in "12,000 Years of Tucson History," pp. 7 and 8, from Downtown Underground: Archaeological Clues to Tucson's Past, The Rio Nuevo Project by Kyle Lyn McCoy. The Hohokam was culture group commonly used to label an epoch that lasted from approximately 300 C.E. until around 1450. After reading these two pages and the information above that preceded it be prepared to answer questions for understanding (V. Basic Inquiry Questions). You may also find this additional site useful in conceptualizing Hohokam settlement patterns that were based on irrigation and water harvesting strategies.

http://carbon.cudenver.edu/stc-link/hohokam/Hohokam.htm

The Hohokam culture crumbled towards the eve of the last major epoch of southern Arizona's history. A brief interlude occurred that we will call the Pima period. Lasting for about a century it was a time of uneasy transition. With the arrival of the first Spanish explorers the Pima were caught into the undertow of global change initiated by the expansion of Western Europe. In fact, the Pima were named by the Spanish, an act of "conquering." The Pima today have taken back their identity and in southern Arizona call themselves the Tohono O'Odham. With the arrival of the Spanish in the mid 16th century the first written records appear and thus this final span of time is called the Historic Epoch. For convenience of study it can be subdivided as follows: A. Spanish Exploratory (circa 1539 to 1690); B. Spanish Colonial (circa 1690 to 1821); C. Mexican Rule (1821 to 1856); D. American Territorial (1856 to 1912); E. Modern Statehood (1912 to the present). Each will be briefly explained, and as you read, continue to think about how the human element eventually became a major component in the dynamics of the region's hydrology. If the student wishes to supplement his or her understanding of this period with a deeper understanding about Tucson's history, click here (BAD LINK) to continue reading about "12,000 Years of Tucson's History," pp. 8-15 in Downtown Tucson.

A. The Spanish Exploratory Period (circa 1539 to 1690)

The lure of gold rather than the desire to find an area with lush agricultural potential brought the Spanish to Arizona. To gain more background information about Coronado's Expedition, click here. To obtain more detail about his expedition, click here.

Power shifted gradually with the arrival of the Spanish in the Americas following the first voyage of Christopher Columbus. With the conquest of the Aztecs the Spanish were able to benefit from a significant power base from which to expand northward. First probes were made by a group of explorers and entrepreneurs called conquistadores. Their primary motivation was to repeat the success of Cortez by finding and seizing large amounts of gold and other minerals. They were largely disappointed and found little interest in colonizing southern Arizona. Missionaries, however, saw more souls to save, but it took over a century for them to carry out their work in southern Arizona.

B. Spanish Colonial Period (circa 1690 to 1821)

Late in the 17th century a Jesuit priest named Eusebio Kino decided to extend his efforts to convert Indians north of his missionary base of Dolores, Mexico, which initiated the second historical epoch. Although not as intensive as the colonial thrust into northern New Mexico beginning in 1598, this period can be distinguished from the first by its more comprehensive impact on the local Indian peoples. The transition to colonization probably began with the
northward thrust of cattle ranching from Sonora into extreme southern Arizona during the early 1680s. Available water and suitable grazing lands would have enabled this expansion. Here Spanish ranchers and missionaries encountered natives of northern Sonora whom they called Pimas and the area in which they lived was designated *Pimeria Alta*.

Already in his middle forties in 1691, Kino set out to expand Christianity to the Pima peoples in southern Arizona. He made three dozen journeys into the greater Southwest during the next two decades. Kino was an explorer at heart. He apparently traveled through much of Arizona as well as parts of New Mexico and southern California. He was the first to provide proof that Lower California (Baja) was a peninsula, and his skill as a cartographer provided a map the Southwest that most would rely upon for the next century.

Father Kino established missions along the Santa Cruz River at Guevavi and Tumacacori, as well as San Xavier del Bac and San Agustin, the last of these in Tucson at a Pima village (the Spanish called this Pima group the Papago) near the base of A Mountain. These people provided Tucson's name, transcribed into Spanish as *Chuk Shon* (variously translated, but usually referring to the spring at the base of a black --"A"--mountain). Thus, the very name of Tucson identifies the importance of water and provides a clue about the physical characteristics of the Santa Cruz River Valley several centuries ago. Spanish crops were introduced, the most important being wheat. This would enable Indians to raise a winter crop and thus they would have depended even more on the waters of the Santa Cruz.

Spain was only able to build a thin thread of power in *Pimeria Alta* eastward into New Mexico. Spanish imperial authority in southern Arizona clearly depended on the Santa Cruz River. This is where the Indian population was the largest and most willing to conform to the Spanish lifeway. Protection for the missions against Indians (mostly Apaches) who resisted Spanish authority was provided by small military forts called *presidios*. Two were established and both were near the banks of the Santa Cruz. The first was Tubac, built in 1752 and the second was Tucson, dedicated in August, 1775. Tucson would become the primary base of military power in southern Arizona, but weakly staffed with less than 100 soldiers with meager supplies.

The Spanish were able to attract a few non-Indian settlers into the valley to farm and to raise cattle. Some colonists from Mexico and Spain moved into southern Arizona, but limited opportunities and the danger of Apache raids kept these numbers low. When Spain recognized Mexico's independence in 1821, the transfer of power received little noticed in the remote northern province of *Pimeria Alta*. However, the next two decades would signal the beginning of significant change that would extend across the greater Southwest and beyond.

### C. The Period of Mexican Rule (1821 to 1856)

The third epoch was the shortest, in many ways a continuation of the previous one, only distinguished by its politics. Instead of royal rule via a viceroy from distant Spain, political authority emanated from a comparatively closer but still distant one, Mexico City. In many ways, however, this change in political status proved to be a liability. The unstable Mexican government and the lack of available resources to maintain power in *Pimeria Alta*, ended the peace with the Apaches. Their raids mounted against the isolated farmers and ranchers across much of southern Arizona. The lucky ones fled, many of their neighbors killed. The area returned closer to the natural cycle of wet and dry, affecting the quantity of water to a much greater degree.
One aspect of the two epochs that constitute the Hispanic period of southern Arizona needs to be examined to provide a better focus on the story of water here. Click here and read about Spanish water law and custom as it was applied in the greater Southwest. Be prepared to answer questions in the Basic Inquiry (IV) below. During the Spanish and Mexican periods agriculture (with the exception of cattle ranching) increased but not enough to significantly alter the surface water flow beyond the natural cycle of wet and dry. The acequia system was probably similar to the native Pima communal understanding of water use. This illustrates the meaning of the term Hispanic when applied to the greater Southwest.

After reading about the zanjero examine this excerpt from Martha Summerhayes, Vanished Arizona, Chapter 25.

In front of our quarters was a ramada, supported by rude poles of the cottonwood tree. Then came the sidewalk, and the acequia (ditch), then a row of young cottonwood trees, then the parade ground. Through the acequia ran the clear water that supplied the post, and under the shade of the ramadas, hung the large ollas from which we dipped the drinking water, for as yet, of course, ice was not even dreamed of in the far plains of MacDowell. (note: Fort MacDowell was located in the valley north and east of Phoenix.) The heat became intense, as the summer approached. To sleep inside the house was impossible, and we soon followed the example of the cavalry, who had their beds out on the parade ground.

Clearly the benefits of the acequia remained during the early years of the American period. During this period, the area had high surface water levels cienagas sprinkled across the landscape. As a result, in the summertime especially, malaria, troubled many area residents because mosquitoes found numerous wetlands from which to breed. However, as we will see in a more detailed look of the next epoch, a major shift in thinking would begin to impact Arizona, which would have far-reaching effects on water quantity issues into the present day.

D. American Territorial Period (1856 to 1912)

With the Treaty of Guadalupe Hidalgo in 1848 most of Arizona came under US authority, but incorporating this vast region into the American national system took much longer. Arizona south of the Gila River waited another six years for official annexation another three years before the US flag officially flew in its main settlement, Tucson. This was the heyday of manifest destiny with Arizona serving largely as a means to an end, securing the prize of California. Anglo-Americans had begun arriving in the 1820s on a fairly regular basis mostly to hunt and trap fur-bearing animals or to collect bounties on Apaches scalps. The 1849 California Gold Rush brought many more opportunistic adventurers who took the southern land route through southern Arizona but almost everyone perceived the landscape as too parched and desolate to remain. Southern Arizona might remain part of Mexico today were it not for the desire of Congress to build a transcontinental railroad. As it turned out the best route lay south of the Gila River and after a survey was completed in the early 1850s Congress offered to buy the needed land and Mexico accepted. Until the railroad was completed in the early 1880s, this half of the
territorial epoch remained one of transition. Even so, a decided trend was established that would completely reorder the perception and use of the Santa Cruz watershed.

The most significant index of change came from the increasing development of mining in the territory. Mining in Arizona Territory was strongly influenced by the American experience in other places in the West, especially California. To understand this relationship and its importance several inter-related facts need to be understood. First, these Anglo miners brought with them the bias of a humid climate that failed to comprehend the fundamental aridity of the far western territories. Second, they were opportunists, "expectant capitalists," who believed that a little hard work and some luck would pay off and make them rich. Third, their aggressive pursuit of riches provided a pragmatic justification that the ends justified the means, so that even harming or destroying other potential resources in pursuit of quick profits was justified. Fourth, placer (surface deposits) tended to be quickly exhausted. Panning for gold and silver required a various techniques in which water was used as a separating agent to extract the metal. Once surface deposits were largely exhausted the search intensified to find minerals lying beneath the ground. In a relatively short amount of time, digging for these deposits required more machinery than muscle could efficiently provide. Fifth, the need for machinery accelerated the growing demands for capital brought in from outside investment that reduced local miners from capitalists to employees. Sixth, minerals, along with land and labor, were commodified, i.e., judged and evaluated on the basis of their economic (market) value. Concern for the well-being of workers and the long-term benefits to the local environment were shoved aside in the name of profit. Seventh, growing capitalistic environment demanded managed control to minimize risk and to lower costs in order to maximize profits. What emerged in the western mining regions was a doctrine of water law that reflected as it reinforced this new industrial order. Eighth, this new industrial order incessantly incorporated the region into the globalizing forces of market capitalism that redefined values and local man-land relationships.

In the humid eastern half of the United States, water flowing in rivers in streams was a common feature. English law and thus early American law ruled that owning land included the use of a fair share of the water that ran through or adjacent to their parcel. This "riparian" right had developed as the customary and lawful use of water in the pre-industrial era (largely one of subsistence rather than commercial agriculture) in a humid and originally forested region. This water right derived from property rights arising from owning land along a river, lake or stream. Riparian law includes implicit rights of ownership but with some restrictions. First, the property owner must make "reasonable" use of the water, limited by the rights of other property owners along that same body of water. Second, if the waterway is considered navigable, use is subject to the maintenance of that right of movement along it. In other words, the first landowner arriving along a river enjoyed riparian rights because that was considered part of their parcel, but could not legally dam the river or divert the flow of that river in way that would deprive the rights of other property owners or the public to use that water or move upon it.

Where precipitation is rather frequent it is likely that many people will live nearby surface water and can expect to be able to use sufficient amounts without preventing others from doing the same. However, in the West where precipitation was more infrequent and less abundant a custom evolved, which happened to complement ethos of industrial capitalism. It reflected this new, more expansive form of power where control was essential. This water law was called "prior appropriation," and means, "first in time, then first in right." It should be emphasized that under this doctrine that to be "first in time," water must be appropriated for "beneficial use," which establishes the water right. Essentially that right is one of use, not actual "ownership." The
action taken by an individual or group (e.g. a company or corporation) to appropriate water for beneficial use is called "diversion," which means removing water from its natural path of flow, or controlling its movement in some manner. This can be done by digging an irrigation ditch, providing drinking water for personal or community use, watering livestock, or for industry and any other "productive" application. As rationalized by law, the terms productive and beneficial exist in an economic context. Thus legally this water right begins when water is taken (appropriated) for productive use ("non-wasteful" meaning for profit) thus understood to be beneficial. It should be obvious that the benefit does not need to be for everyone, which aggravates the inherent tension between "privatization" and "the law of the commons."

This system of water rights was resisted by small-scale miners and others who sought to make a living upon a land where water was scarce. Nevertheless the trend in Western law and policy was against them, favoring the big users who were enjoying significant profits from rights based on prior appropriation. As we will see, the democratic rhetoric of public land policy was largely hijacked in the West by these new realities. The many federal water projects that began in the early 20th century were supposedly designed to aid the small land owner. Instead the big water users were the big winners. (Arizona Water Resource Center has more in-depth information about water law in this state at [http://ag.arizona.edu/AZWATER/arroyo/081con.html].

During the Civil War more adventurers came in search of Arizona's mineral wealth, clearing a path for a new order built upon industrial capitalism. In 1864, the first Territorial legislature created the Arizona's first water legislation. Known as the Howell Code, its provisions formally established prior appropriation as the basis of surface water law in Arizona. The Arizona Territorial Supreme Court upheld the doctrine of prior appropriation in 1888. In Clough v. Wing the Court employed rather curious language to decide that, based on historic evidence, the right to appropriate and use water for irrigation had been recognized "longer than history, and since earlier than tradition." Prior appropriation got another boost in the Territory when it was aggressively applied to reduce Indian water rights. In the 1908, the U.S. Supreme Court Decision, Winters v. US, had supported the fundamental right of Indians to sufficient quantities of water for their present and future needs on their reservations. Nevertheless, two years later Territorial Judge Kent ruled differently in a dispute that had raged through the courts for five years. Despite Winters, the "Kent Decree" applied prior appropriation rights in favor of Non-Indian irrigation interests and against the water rights of Indians on the Fort McDowell reservation. States have often challenged the federal government by acting to protect their interests. Since American Indians are under federal guardianship, this has fostered legal battles over water rights between Indians and non-Indians that represent important implications for the Western states who are gaining increasingly larger populations who will put increasing pressure on already scarce water resources.

Throughout the West prior appropriation reflected a new order based on greater expectations but unfortunately rested upon a poor hydrological understanding. This aggressive approach to water use has had enormous consequences. Prior appropriation does not encourage people to conserve water use even with the restriction of being beneficial. Worse still are the decisions made under this doctrine that have failed to recognize the interconnection between surface and ground water. This potentially fatal lack of hydrologic "literacy" would increasingly affect the Tucson Basin and the Santa Cruz River following the Civil War.

One way of recognizing and appreciating what was beginning to happen in southern Arizona after 1865 is to step back and reassemble the pieces that form the big historical picture.
Up until the late 19th century the previous ten millennia of human history in this region was almost entirely the story of relatively small subsistence oriented populations. In other words, people sought to produce what they needed to survive with little thought of surplus beyond storing excess amounts when they could for drier, less productive years. Except for the Hohokam little large-scale systematic use of surface water had been practiced. Archaeology demonstrates that the Hohokam were primarily farmers. Trade added a certain level of material luxury, but was itself dependent on the ability to produce sufficient local material resources. Yet the number of people living in the Tucson Basin during the first third of the second millennium (through about 1300 CE) was larger than it would almost 600 years later, i.e., until after 1880. The crucial point of difference is one of scale. The "modern" period would inaugurate a lifestyle that was decidedly non-agricultural, i.e.," urban," unlike the Hohokam whose culture was essentially "rural," dependent on cultivated crops produced locally. Modern life depends upon distant, interconnected tentacles of external supply. Local inhabitants have the capacity to withdraw ("purchase") from that system. Little of what they produce is intended to be consumed locally. However, when examined more closely this becomes illusory, more like a desert mirage. The international market system may have extended the limits of prosperity and comfort for hundreds of thousands of people in southern Arizona, but much like an overdrawn bank account. The aggressive consumption of fossil water, stored in the Santa Cruz Basin, is the substance of this lifestyle, and the imbalance between demand and supply threatens future. This has become extremely more complicated because our way of life is based on an interdependency extending well beyond our local area. The over-pumping of groundwater is a growing problem within the United States and around the world. As global food production expands to meet the demands of many more billions of people towards the year 2025 and beyond, securing sufficient amounts of water adds to the burden of survival for more than a billion people each and every day, and that number is growing. Therefore, maintaining and expanding our current level of prosperity can only occur if we act locally, nationally and internationally to enact appropriate water conservation measures.

Rising immigration into the US combined with the long-established pattern of westernization made rapid settlement of territories in the Far West such as Arizona possible. Economic opportunities, including mining, ranching, farming and lumbering, provided the motivation to re-locate and the expanding infrastructure the means. The coming of the transcontinental railroad in the early 1880s with trunk lines extending to the mining towns more efficiently connected East and West while improving travel within the Territory. Also, with the infusion of Eastern and European capital Arizona functioned as a colony to supply a variety of raw materials for the host market. Unlike subsistence economies, production for the market is built around specialization in which the surplus is sold not stored locally for future use. In this way what is produced is commodified and this significantly changes relationships with the land including water.

During the 1870s, people's daily routine might have included drawing water from a well near the Santa Cruz River or from the South Main community well. Vendors also sold water house to house for a penny a gallon drawn from bags carried on the backs of burros. In 1881, the Tucson Water Company was the first provider to supply water through a pipeline, which had been connected to a well it had dug south of town. Yet as more people arrived urban water consumption moved unremittingly towards dominance. Supplying water for a "modern," expanding urban population became a matter for public discussion, which in turn made it a political issue. The city council began to think in municipal terms in the 1870s when they issued
a contract to Thomas Jeffords to build an artesian water system. He failed due to the basin's hydrology. The supply problem was intensified because of the corresponding need to extend distribution. As the University of Arizona was being built on the desert to the east of downtown Tucson, housing developments began to close the vacant space in between during the 1890s. Finally, in 1900 the city purchased Tucson Water Company, for $110,000. At this time, through water mains extending almost 47,000 feet, the company was supplying 2 million gallons per day. The city then had 7,500 residents, which means that per capita use was at least 266 gallons per day, since not everyone was a customer. Even though per capita consumption fell by about 90 gallons per day, expanded urban water consumption placed greater demands on ground water. As the water table lowered, the city moved from one water "crisis" to another, leading directly to campaigns such as "Beat the Peak," and to the controversy the use of CAP water. In the meantime large-scale agriculture thirstily thrust more deeply to draw water from beneath the Tucson Basin. (A great resource for this period of Tucson's water history is Michael Logan, The Lessening Stream: An Environmental History of the Santa Cruz. Arizona: 2002, especially Chapters 8 and 9. See also Tellman online at http://ag.arizona.edu/AZWATER/publications/conservation/conserve.pdf.)

Large-scale agriculture is termed agribusiness and such enterprises invaded the Santa Cruz watershed during the last quarter of the 19th century. Huge demands were placed on the river, which in addition to the natural pattern of wet and dry climatic swings, began to show the effects of overuse. As demand increasingly outstripped supply, for the first time more extensive use of groundwater was demanded. Digging shallow wells to supply water away from the river was not new. Tapping a hundred feet or more to pump groundwater was, and became possible only with new technology. Historians have created a concept to encapsulate what was happening to communities such as Tucson. They call it a hydraulic society, language indicative of an industrial ethos built upon machines and increasingly sophisticated technology. While it would take many years into the twentieth century, the hydraulic pumping of groundwater at depths of hundreds of feet below the surface would eventually force the courts to reconsider the relationship between surface and groundwater as surface flows fell to a trickle or disappeared entirely. Given its complexity and the powerful interest groups potentially affected, it should not be surprising that as of yet no new doctrine has clearly emerged.

The transition to agribusiness significantly changed the surface flow of the Santa Cruz River. Not only did the river gradually dry up, but its banks were widened and gouged by more rapid runoff when heavy rains did fall. In the process the Hispanic communal understanding of shared water use was undermined, but not without resistance. In 1884, one such dispute affecting fields near St. Mary's Road led to litigation. After hearing both sides of the argument the judge made his decision using the doctrine of prior appropriation, which happen to favor the defendants. Meanwhile efforts to draw more water from the river continued as ditches were dug to tap into the aquifer immediately below. By interrupting the flow beneath it the river was effectively undermined. Similar actions were also taken along the Rillito, a major tributary of the Santa Cruz. One especially aggressive farmer upstream near St. Mary's Road during the late 1880s, Sam Hughes, cut a twenty-foot wide ditch adjacent to the river channel to access water for his fifteen hundred acres of crops. When heavy monsoon rains came in the summer of 1890 the flooding scarred its once gently sloping grassy banks, gouging and widening the river bank. By the early 20th century the river looked a lot different, wider from bank to bank with significant bank erosion and a more irregular flow. As more wells were drilled to pump...
groundwater at depths of forty feet or more, the river and its aquifer were being summoned to satisfy a growing, seemingly insatiable thirst.

As the Territorial Epoch drew to a close in 1912 a crucial question needs to be asked. Had demand already exceeded supply to the point that the river had been permanently transformed into a ditch? This is a matter of debate but is of great importance when the issue of sustainability is applied. We will briefly examine this issue before surveying the last historic epoch because of the interconnection between both periods of the Santa Cruz's history.

In its 1997 report, *Water in the Tucson Area, Seeking Sustainability*, the Water Resources Research Center, College of Agriculture, at the University of Arizona took the position that the balance between supply and demand was lost at the beginning of the 1940s. This is based upon both written and photographic evidence of water in the Santa Cruz River as it passed west of downtown Tucson between Martinez Hill and Sentinel Peak. If it is true that the balance was lost then it has crucial implications for the question of sustainability. Balance between supply and demand is "sustainability." If it was first lost on the eve of World War II it would mean that the rapid development of agribusiness along the Santa Cruz sixty years before had not destroyed that balance. World War II is an important marker because of the rapid expansion of agriculture during wartime and the surge of population into the valley that followed. The huge increase in the quantity of water consumed, first mostly by agriculture and then by sharply rising urban demand definitely lowered ground water tables and caused the river to cease to flow except after heavy rains. Essentially by wiping out almost sixty years of previous history before that balance was lost, sustainability by 2025 would be easier to achieve. This is the date targeted by the Arizona Groundwater Act of 1980. Is 1940 the point to which we should look? The question of sustainability will be probed more deeply in Inquiry 6.

E. Modern Statehood (1912 to the present)

The Far West including Arizona was rapidly incorporated into the American national system by a combination of distant capital (from the Eastern U.S. and Western Europe) and the policies and actions of the federal government. Statehood served to magnify that integration. To those in power back east maximizing the economic potential of Western states was vital. In particular, this vast region was fundamentally arid and policies were designed, with suitable encouragement of various regional power brokers, to minimize that perceived liability. With .4% of its land area composed of surface water, Arizona (47th among the 48 contiguous states) certainly stood to benefit from these efforts. While these actions would benefit the Phoenix area more, its impact still rippled deep into southern Arizona.

The operative term used to envision a new western landscape was "reclamation." Slowly the hard realities of life beyond the 100th Meridian chipped away at assumptions made from a long tradition of life in the humid forest and prairie. The optimism based on an agrarian dream that "rain followed the plow" did not work here, although many were reluctant to admit defeat. One of the most important sources of new information about the West's aridity came from the explorations of John Wesley Powell. His Report on the Lands of the Arid Region, published in 1878 was the result of geologic surveys of the Colorado Plateau made over the previous decade. This amazing one-armed man emphasized the aridity of this vast region and the need to reform land policy and its expectations dating back the land ordinances of the 1780s. A persistent crusader for land reform, he presented his detailed proposal before the Senate Select Committee on Irrigation and Reclamation, a more rational vision of creating states divided by watersheds. In
In his view, this would allow for more effective and efficient "reclamation" of arid lands for agricultural use. Powell's plan cut strongly against the deeply entrenched American cultural assumptions and institutional development. Thus his proposals were ignored but in time federal reclamation programs would transcend state borders in regionally planning patterns designed to green-up the brown landscape. If you would like to learn more about Powell's vision click [here](#).

An important early step towards watering dry lands was the Desert Land Act of 1877. This law directed the Land Office Commissioner to convey 640 acres of public land to anyone who would provide a down payment of 25 cents an acre and bring water to that acreage within three years. That individual could then purchase that section of land for an additional $640. While this law was poorly conceived and easily led to the widespread corruption of its terms, it did indicate that Congress was beginning to recognize that more land than the traditional 160 acres was needed for successful farming in the arid West and that manipulating water was the key. Promoters in Washington and especially those who stood to gain or expand great fortunes in the Far West pushed for more substantial efforts. They succeeded and the federal government became the means for many projects that would bring water to where the people wanted it to be.

The most path-breaking legislation proved to be the National Reclamation Act of 1902, often referred to as the Newlands Act in honor of its chief architect. Francis Newlands, a congressman from Nevada, introduced the bill early in 1901. It empowered the Department of Interior to use the proceeds of public land sales to finance irrigation projects. The law's intent was to help those who wished to establish and develop small farmsteads, but it largely served to benefit large landowners and developers. The National Reclamation Act inaugurated the era of hydroelectric dam building -- the full embodiment of the hydraulic society -- that would unfold over the next seven decades. While the Phoenix metropolitan area would be the primary beneficiary of reclamation projects in this state, a pathway was also established for the approval of the Central Arizona Project.

For southern Arizona the increasingly aggressive use of natural resources that had begun early during the Territorial period continued and expanded. As surface sources diminished users tapped into the underground supply, and as the river was being increasingly relieved of its water, pumps drove deeper into the aquifer. By the last quarter of the 19th century increasing urban growth, extensive mining and sprawling agribusiness accelerated the demand for groundwater. As a result civic boosters believed that Tucson's future depended on an external water source. In other words, in order to sustain a future based on growing prosperity for an expanding population depended on securing an adequate water supply. However, some wondered if the quest for sustainability was much like a desert mirage.

V. Basic Inquiry Questions

A. Hohokam Reading

1. Raising corn in the Tucson Basin began about how many years ago?
2. What region provides the immediate source of corn agriculture in southern Arizona?
3. What might support the view that corn came into the Tucson Basin from the north even though it first came to Arizona from Mexico? How might water have played a role in this? What is the case for believing that the Tucson Basin exceeded the Phoenix area's development of corn agriculture?
4. Summarize the inter-relationship between the river, corn-based farming, and cultural development for the Hohokam towards and beyond 1000 C.E.
5. How might attitudes about the river and the rules about the use of water...
been affected by the development of intense farm irrigation?

6. Be sure to click on the high resolution map option to answer this question. What does this map suggest about the quantity of surface water during the Hohokam period?

7. Why might too much water, i.e. flooding, have possibly presented problems for the Hohokam?

8. What role did water possibly play in causing the disappearance of the Hohokam culture?

9. **Optional Expanded Activity**: Compare the view of Linda M. Gregonis & Karl J. Reinhard with more recent archaeological finding due to the Rio Neuvo Project by clicking [here](#). Why are these important clues about Tucson's distant past and that relationship to water?

B. Spanish Exploratory (circa 1539 to 1690)

1. Based the Spanish exploratory objective and the history that followed what can you hypothesize about the potential for documents that would help us write a thorough Santa Cruz water history for this period?

2. What would be the source of Spanish interest in southern Arizona and how might this affect what we know about the water history here once that objective was pursued?

C. Spanish Colonial (circa 1690 to 1821)

1. What activity may have preceded the missionary advance of Father Kino, and why might this be important to know within the context of water history?

2. Besides converting the Pima peoples why would the work of Father Kino be important to us as we seek to build a useful water history for southern Arizona?

3. What important clue about Santa Cruz water history is provided by the name of Tucson?

D. Mexican Rule (1821 to 1856)

1. What undesirable political and military development after 1821 was beneficial from the standpoint of water quantity in the Santa Cruz River Basin?

2. Questions concerning Hispanic Water Law (from AWWA), click [here](#) if you need to refer back
   a. Where did the Spanish observe irrigation farming in the Southwest?
   b. What system was applied from their previous in Europe experience by the Spanish?
   c. Why did the demands of building and maintaining an irrigation require a community effort?
   d. How, then, did climate influence the socio-political order during the Hispanic presence in the Southwest?
   e. What were the two different titles of those who were in charge of the **acequia**?
   f. Describe the structure and system of the **acequia** and determine to what extent it was democratic.
   g. What is the legacy of the zanjero?
h. In an individualistic, market-based society what is the lesson that the concept of *zanjero* can teach us, especially for the Southwest?

i. (This question applies AWWA information with the reading from Martha Summerhayes): What can we learn about water use practices in Arizona during the 1870s from what Martha Summerhayes tells us?

E. American Territorial (1856 to 1912)

1. What economic activity strongly influenced how Arizonans would view water rights?
2. Ironically, what feature of western water led to the understanding of rights based on prior appropriation?
3. Prior appropriation contrasts with the Hispanic *acequia* system most in what way?
4. How did prior appropriation fit well with what was termed the "industrial ethos?"
5. Why is control (such as of water) so important in the capitalistic system?
6. How does the concept of hydraulic society help identify how water resources were increasingly used and expanded in the West including in southern Arizona?
7. Why is it important that Arizona Territorial water law became consistent with the values of the increasing number of "Anglos" who sought opportunity in Arizona?
8. What cause and effect relationship exists between the 1884 Pima County Court decision and the ditch built by Sam Hughes a few years later?
9. What was the environmental consequence of Hughes’s ditch?
10. What year is "officially" used to determine when the balance between supply and demand was lost, threatening future "sustainability," and what fact is this based on?

F. Modern Statehood (1912 to the Present)

1. In Arizona, on average how many acres of land is there for every acre of surface water?
2. Look at an Arizona map and estimate whether southern Arizona (i.e., the area south of the Gila River) would be higher or lower than this average.
3. Why is the amount of surface water in Arizona stated in question 1 only a partial indicator of water quantity in Arizona, and especially southern Arizona?
4. What hydrologic concept did John Wesley Powell fail to get Congress to recognize in his 1890 report?
5. What is the significance of the National Reclamation Act for Arizona and the West?
6. What is the distant connection between the Hohokam and the "hydraulic society?"
7. What is the root word of reclamation and what does its meaning tell us about how "industrial" man perceives water in his world?
8. What is the logical connection between the National Reclamation Act and CAP?
9. Answer these questions from the reading Seeking Sustainability, PDF file, pp. 8-10+. Click here for easy reference.
   a. Generally, why did the city of Tucson during the first quarter of the 20th century began to face water problems?
   b. What happened that should have caused observant people to see first hand the relationship between surface and groundwater?
   c. What caused an extensive mesquite bosque south of San Xavier Mission to die in the 1950s?
   d. In what area near Tucson did city leaders actively seek to secure additional groundwater to meet its growing thirst?
   e. What was the chief cause for significant water problems in Tucson by the mid 1970s?
   f. What issue divided people in the city of Tucson during 1975-76? Accepting CAP water
   g. Why were city leaders extra sensitive to taxpayer pressures concerning water costs? The threat of being recalled
   h. What "democratic" feature is incorporated in Tucson Water's rate structure and how might this be unfair?
   i. Was there any measure to indicate the city of Tucson had become more successful in water conservation efforts on the eve of receiving CAP water?

VI. Expanded Inquiry Questions

1. To what extent is industrial man dependent on technology to solve self-induced problems? Apply this in particular to water use in southern Arizona over the past century and one half.

2. What lessons of overuse might "modern man" still learn from the experience of the Hohokam? (Use this link to read more about theories that explain the relatively rapid disappearance of this cultural epoch):

3. Given the growing scarcity of water, would it be in the best interests of all concerned for water to be viewed and valued primarily as a commodity?

4. Should Americans, and Arizonans in particular, shift understandings of use from individualistic to communal need?

5. Mining proved to be a major factor in populating the West. While silver and gold mining has received more notoriety in popular culture, significant copper mining activities in Arizona represented a multi-billion dollar industry. Water is important in the mining process. In placer mining where mineral deposits lie in stream beds, water is used to sift out sediment leaving flakes of gold or silver in the bottom of a pan or sluice box. Aggressive pursuit of minerals led to hydraulic mining, where water under intense pressure literally washed away hillsides to access minerals. The Mining Act of 1872, (for more information click here:) which encouraged mineral exploration and development on public lands did not address environmental consequences, which meant that many mines were opened and then abandoned once they were no longer considered profitable. In Arizona, over 100,000 mines are abandoned. Many of these are in remote areas, but some lie beneath or near towns and cities. In particular, Tombstone's mining...
history provides interesting insights in water history. Because of the availability of surface water from the San Pedro River, stamping mills were located near its banks to process silver. However, water underground became a problem because as the shafts went deeper they cut into the veins of water that began to enter the mine. Eventually, the difficulty and cost of pumping out this water led to the closure of the mine. Water continues to flow into and through these shafts, which at times has added to problems of underground stability of Tombstone. As water concerns have grown in Arizona, mining activities have come under closer scrutiny. Read [here](#) about mining and water in the Tucson AMA. Apply this information with the information gathered above about mining, and explain the relationship between groundwater management and the economic value of mining. Is water for life a more precious resource than what this multi-million dollar industry seeks to produce? Explain.
Santa Cruz Water History Inquiry, Question Four

Who determines who gets water and how much they can use?

Student Activity Guide

Resources:
and
Map of Federal Land Management and Ownership in Arizona (See Appendix Item 2) [http://www.propertyrightsresearch.org/articles5/federal_lands_in_arizona.htm](http://www.propertyrightsresearch.org/articles5/federal_lands_in_arizona.htm)
and
Know Your Watershed at (See Appendix item 3) [http://ag.arizona.edu/OALS/watershed/management.html](http://ag.arizona.edu/OALS/watershed/management.html)
and
and
The Tucson AMA at [http://www.adwr.state.az.us/AZWaterInfo/InsideAMAs/amatucson.html](http://www.adwr.state.az.us/AZWaterInfo/InsideAMAs/amatucson.html) (BAD LINK)
and
The Santa Cruz AMA at [http://www.adwr.state.az.us/AZWaterInfo/InsideAMAs/amasanta.html](http://www.adwr.state.az.us/AZWaterInfo/InsideAMAs/amasanta.html) (BAD LINK)
and
Arizona Water Bank Authority at [http://www.awba.state.az.us/](http://www.awba.state.az.us/)

I. Introduction:
Determining who decides who gets water and how much they have a right to use forms a human-based decision-making process. Initially this may seem to be easy to explain and understand. Unfortunately it quickly becomes, involving the recognition of the various, often competing, interest groups involved and their relative political and economic power. Adding the state, federal and Indian legal perspective adds to the complexity. Thus, probing the history that creates the context of laws determining water rights leads to complicated and contested meanings. While laws directly reflect the history of the society that make them, in many cases the past serves as a brake on the present, holding back new values, understandings, beliefs needs and concerns that are interwoven into the water-related issues debated publicly and privately.

The Anglo (American) system of law has an imperial basis that derives from the political expansion of Western European societies in general and of Great Britain in particular. Inquiry 3 explored how Arizona was transformed through the process of being incorporated into the American political and economic system. Even though measured against the long span of Arizona’s past that “modernization” occurred comparatively quite rapidly, the understanding and
application of the body of laws that determine water rights illustrates how little water hydrology and geology are understood. In addition, as we shall see, the inherent tension within the American federal system of government made potential more explosive when Indian law is added into the mix, continues to make it difficult for decision-makers to make the best decisions on water use in the best ways possible for all concerned. Before continuing below, you might want to look online at this summary of Tucson's long history with water as part of the perspective. <http://www.wwm.co.pima.az.us/hist/part1.htm>

II. Targeted Arizona State Standards:

Reading
Strand 3-Concept 2: Identify, analyze, and apply knowledge of the purpose, structures, clarity and relevancy of functional text;

Math
Strand 5-Concept 2: PO 7. Create inductive and deductive arguments concerning geometric ideas and relationships, such as congruence, similarity, and the Pythagorean relationship; Science

Science
Strand 1-Concept1: Formulate predictions, questions, or hypotheses based on observations. Evaluate appropriate resources;
Strand 1-Concept 3: Evaluate experimental design, analyze data to explain results and to propose further investigations. Design models.
Strand 2-Concept 2: Understand how scientists evaluate and extend scientific knowledge; Strand 4-Concept 3: Analyze the relationships among various organisms and their environment;

Social Studies
1SS-P1 Apply chronological and spatial thinking to understand ... historical and current events;
1SS-P2: Demonstrate knowledge of resource sources ...;
1SS-P3: Develop historical interpretations ...;
1SS-P18: Apply the skills of historical analysis to current social, political, geographical and economic issues facing the United States;
3SS-P2: Analyze natural and human characteristics of places in the world studied to define regions, their relationships, and their pattern of change;
3SS-P4: Analyze the interactions between human activities and the natural world in different regions, including changes in the meaning, use, distribution, and importance of natural resources, 3SS-P5: Apply geographic knowledge of people, places, and environments to understand the past and present and plan for the future;
4SS-P1. Analyze the implications of the economic problem of scarcity.

III. Basic Concepts to be learned and applied:

A. Cappaert Rule:
B. Tucson AMA:
C. Santa Cruz AMA:
D. Surface/Ground Water:
E. Recharged Water:
F. Renewable Water Supply:
G. Water Budgeting:
H. Safe Yield:
I. Banking Water:
J. Effluent:
IV. Basic Inquiry:

One of most curious things about who decides about water use is how much water rights are held by private groups and individuals who can act independently of the public interest. Water is a precious, and especially in southern Arizona, scarce (and becoming more so) resource with a body of law that tends to mediate conflicts between competing users rather than all who might be affected. Over than 30 water companies operate well systems (in some cases with hundreds of individual wells) in the Tucson area alone, and almost 22,000 individuals and businesses own and operate wells. Examine how many private and public water providers exist in southern Arizona. Click [here](#) to find the names of the dozens of water systems providing drinking water in Pima and Santa Cruz counties. Once you get to the opening page, choose the county that you want from the list as you scroll down, and then click SEARCH. You will find them divided as 'Community Water Systems,' defined as Water Systems that serve the same people year-round (e.g. in homes or businesses), and "Non-Transient Non-Community Water Systems," or those Water Systems that serve the same people, but not year-round (e.g. schools that have their own water system, and finally, "Transient Non-Community Water Systems," which are Water Systems that do not consistently serve the same people (e.g. rest stops, campgrounds, gas stations. This list includes only those "public" providers of drinking water that must report water quality readings to the Environmental Protection Agency, and does not include "private" wells that serve one or several families. Presently 1,687 companies supply drinking water to the public across the state, while thousands of private wells exist across the state. All have rights to water and to this we must add the dozens of irrigation companies that also have water rights. It would appear reasonable to assume that a state agency has been established to monitor water use in Arizona. Unfortunately this is not the case. Instead the Arizona Department of Water Resources (ADWR), the Arizona Corporation Commission (ACC), the Arizona Department of Environmental Quality (ADEQ), the Central Arizona Water Conservation District all monitor water use issues, but not in a coordinated manner.

Obviously the question of who decides and how much becomes quite complicated when so many parties ("interests") have rights to water. It can generally be said that water rights are the primary domain of the fifty states. In other words, in the American federal system of government the power to determine who and how much water has been retained by the states. Yet, as we have seen with Indian rights to water, the federal government can contest state usage laws in the courts. In addition, across the arid West the federal government is a major land holder. In Arizona, 69% of its 72.9 million acres is under the control of the federal government either as reservations, military installations or as part of the public domain. Click [here](#) for more information. In addition, state interaction and agreement on water rights has been necessary, the most important in the Southwest being use of the Colorado River. Finally, international issues regarding water rights also affect state water laws. State-to-state and nation-to-nation matters often involve the federal government extending from the roles of mediator to negotiator.

The federal government has used its power to protect its holdings from groundwater depletion. Crucial support was provided in the 1952 decision by the U.S. Supreme Court, *Cappaert v. United States*. In this case resulting from the Presidential Proclamation of a national monument in Nevada, the court stated that this land had a protected right to water against the "subsequent diversion, whether the diversion is of surface or groundwater," irregardless of state law. In the future, the federal government might take action based on this case to even prevent individual well owners from depleting ground water if a state like Arizona
will not. Apart from protecting federal holdings, the issue of groundwater depletion and the interests of the federal government to protect and extend riparian areas (such as the Lower San Pedro), might also create a legal battle between state and federal interests. It should be remembered that in a democracy political force runs the fault line of powerful constituencies (interest groups), and a state such as Arizona will tend to act to protect local users of water unless forced to do otherwise by the federal government. With rising populations and increasing demands for water in Arizona and elsewhere in the arid West, future water wars fought in court are likely.

Recall from Inquiry 3 the doctrine that has driven Arizona water law. You should also remember that legal understandings that evolved from mid 19th century law did not understand the relationship between surface water and groundwater, which complicated the application of prior appropriation rights. Nationally, approximately 40% of surface water depends on groundwater (Source: "Know Your Watershed," coordinated by Purdue University <http://www.ctic.purdue.edu/KYW/Brochures/GroundSurface.html>). This dependency is even stronger in southern Arizona because the Santa Cruz River naturally had both a sub-surface and surface flow as it descended to the north.

Apart from surface water issues, water law has been based upon the assumption that rights to water go with the land, which stems from riparian rights from a "humid lands experience." This legal construction was modified by prior appropriation, but a landowner still had the right to "mine," i.e. to use, groundwater by digging a well. The city of Tucson and town of Marana engaged in "water wars" from the 1960s, buying land in the Avra Valley in order to control the aquifer. However, since groundwater moves within aquifers that extend across the boundaries of titled land, pumping ground water is not as simple as taking and using one's own water immediately underneath. As Arizona's population growth mushroomed following World War II municipal interests (users) began to compete with agricultural interests. Even though urban dwellers used considerably less water per capita than did farmers and farm land was converted into subdivisions, the assault on groundwater created frightening levels of groundwater depletion. The Arizona state legislature finally felt compelled to act. This action was taken in no small part, because this state desperately wanted the Central Arizona Project and had to show "good faith" to keep Congressional support for funding. The CAP has its own story and will be explored more fully in Inquiry Five. For now, we will examine the question of who and how much by surveying the Arizona Groundwater Management Act of 1980.

Click here to read about the 1980 law. When you are finished you might select to read more about either the Tucson AMA (BAD LINK) or the Santa Cruz AMA. (BAD LINK) As you continue your inquiry evaluate how effective this law is in limiting water use towards realizing "sustainability. The question of who determines who and how much becomes more involved as it is probed and because of the increasing demands placed upon water against supply in this state and in the southern Arizona region. Tougher laws can be written if that is the expressed public desire, but as with other laws enforcement is the key. Creating a single state agency that effectively interacts with a regional and federal authority may be one important step in doing that, but ultimately wise use of water remains the task of each individual. Finally, the question of who determines who and how much involves other areas to examine. One is the inter-relationship between quality and quantity. Quality issues can be pursued in Module Six. Other quantity areas to explore include the use of effluent and the issue of banking water. For more information about using effluent check this site:
V. Basic Inquiry Questions

1. What explanation might be given for why so many water companies/systems exist in southern Arizona and how does this situation complicate the question of who and how much?

2. Why is it surprising that given the obvious scarcity of water in Arizona that no single agency presently exists to enforce current water use laws?

3. Since water use becomes ultimately a question of political decision making, what specific features of the American political system complicate matters as they interact with the natural conditions that also affect water supply?

4. Relating to question 3, what important fact about the political process explains why the federal government might take action to limit water use of those who have state recognized water rights?

5. It is stated that the federal government can take action to limit water consumption at the state and local level to protect designated riparian habitats. What other dimension does this add to the question of who and how much?

6. Could the federal government at least in theory, use its power to reduce water consumption from the Colorado River in order to increase levels to enable navigation along it, and if so, what is the source of that power and its earliest Supreme Court support?

7. The Arizona Groundwater Management Act, click here (BAD LINK) to refer back as needed:
   a. What do the initials GMA represent and what does this name suggest about the fundamental purpose of the law?
   b. What are AMAs and INAs and why were they created?
   c. What does the GMA require each AMA to do?
   d. What term expresses the understanding of "sustainability," and how is it defined?
   e. Is the goal, then, of the GMA to realize true balance between groundwater supply and the demand for it?
   f. How is the rate of groundwater overdraft expected to fall over the 45 year planning period?
   g. How might the quantity of surface water be increased for recharge other than by CAP?
   h. How is demography used in creating the projections in the AMA plans?
   i. What other factors are used in projecting the groundwater budget?
   j. What do the terms "paper water" and "wet water" mean, and what essential fact about water budgeting under the GMA does this indicate?
   k. Regarding new subdivisions, what does GMA now mean by the phrase, "assured water supply?"
   l. What is a serious obstacle created by GMA that has been imposed on water suppliers as they seek to meet the targeted goal of safe yield?
   m. What is one way that these water suppliers (question l above) can encourage their customers to practice water conservation?
n. What factors impact the effectiveness of GMA conservation measures for agricultural water use?
p. What are some suggestions that you would make to encourage each person to conserve water?

VI. Optional focused Inquiry based on reading Tucson and/or Santa Cruz AMA
Use these links to answer the questions below:
http://water.az.gov/AZWaterInfo/InsideAMAs/amatucson.html (BAD LINK)
http://www.adwr.state.az.us/AZWaterInfo/InsideAMAs/amasanta.html (BAD LINK)

1. Describe each AMA in terms of size (square miles), major geographic boundaries, and major municipalities.
2. In regards to safe yield, what distinguishes TAMA from SAMA?
3. Based on the information provided on the TAMA site for 1994, if nothing else changes to reduce groundwater depletion to achieve safe yield, what would the total GPCD rate for municipal users have to be to achieve safe yield if all other sectors reduced their consumption proportionately? In order to answer this you must first go here to get the use and proportions found on the Home Page section of the ADWR > http://water.az.gov/AZWaterInfo/statewide/amas.html (BAD LINK)
Return to the TAMA page to finish your calculations:
http://water.az.gov/AZWaterInfo/InsideAMAs/amatucson.html (BAD LINK)
(Note: 1994 is the year for which the information matches and so you will have to ignore the increase use for 1995. The purpose of these exercise is to help you realize how much of an overdraft of groundwater each user currently consumes.)
4. What accounts for SAMA'S present safe yield designation and what might danger that status in the future?
Santa Cruz Water History Inquiry, Question Five

How will CAP impact the area's water resources?

Student Activity Guide

Resources:

Homepage of the Central Arizona Project at
http://www.cap-az.com/
and

The Colorado River Compact at
http://ag.arizona.edu/AZWATER/arroyo/101comm.html
and

Carl T. Hayden Biography Capsule from the Arizona Republic at
and

The Law of the River: Colorado River Compact at
http://www.crwua.org/colorado_river/lor.htm
and

Congressman Mo Udall's 1963 Report for Proposed CAP at
http://www.library.arizona.edu/branches/spc/udall/congrept/88th/630521.html
and

Tucson Weekly's Position on CAP and the debate in Tucson in the mid 1990s at
http://www.tucsonweekly.com/tw/06-25-98/feat.htm
and

An Outline of the Issues Affecting CAP use in Tucson at
http://www.hwr.arizona.edu/hwr203/notes/whoswho.html
and

CAP Issue Historically in Tucson at
http://ag.arizona.edu/swes/tucwater1/LeighEricFinalPaper.htm
and

4/21/02 Article from North Country Times about California's overuse of Colorado River Water

Water warning comes from farmers by Gig Conaughton at
http://www.nctimes.com/articles/2002/04/21/export7767.txt
and

USGS Water Use in the US in 1995 at
and

Arizona Water Issue Summary from U of A Water Resources Center at
http://ag.arizona.edu/AZWATER/azmap/azmap.html
and

Colorado River Use Issues at
http://www.udel.edu/inst/problems/colorado/
and

Colorado River Water Quality Dispute with Mexico at
http://www.american.edu/ted/COLORADO.HTM
I. Introduction:

Since WWII millions have decided to make Arizona their home. Most of them have selected to relocate on the lower deserts, the majority in the Phoenix area, but hundreds of thousands of others have selected southern Arizona. The growth, particularly in Phoenix and Tucson is astounding. This would astound many of those Americans who came here during the 19th century because they did not see much to like. One of the most outspoken critics of Arizona was General Tecumseh Sherman, Union hero of the Civil War. After a very brief military tour through southern Arizona, he used language indicating that he believed that hell and Arizona were much the same, except perhaps Arizona is hotter. He also quipped that the U.S. ought to fight another war to get Mexico to take the Territory back! Arizona was the last of the forty eight contiguous states to enter the Union, and though not the most important reason behind this delay, its hot climate added to its undesirable reputation. One of the most intriguing questions to be answered is, why did the popular perception of Arizona become so favorable?

On most any summer day in southern Arizona by noon it is very hot. If you are outside, you will feel a refreshing coolness if you go inside an air cooled building. If you have the option, a cold glass of lemonade or a swim in a nearby pool will add to your feeling of contentment. Thus, cooled off you can observe your surroundings, and if you are close to the desert even marvel about how beautiful it looks.

During the fifty years after 1940, Arizona's population increased by over six times, from 499,261 to 3,665,339. The estimated population for 2002 is close to 5.5 million with over 80% living in Arizona's deserts (over 3 out 4 people live in either the Tucson or Phoenix metropolitan areas), due in no small part to air conditioning. (See the chart below.) However, this air of comfort depends more directly on water. The earlier inquiries have examined the role of water in sustaining human life in southern Arizona. Inquiry 5 will add to the level of your literacy about water supply and use by relating past to future.

Phoenix Population Data (last row in blue is metropolitan area)

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<td><strong>2,238,480</strong></td>
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Tucson Population Data (last row in blue is metropolitan area)

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<td>35,752</td>
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<td><strong>666,880</strong></td>
<td><strong>843,746</strong></td>
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Source: U.S. Bureau of Census figures

II. Targeted Standards:

Reading

Strand 3-Concept 2: Identify, analyze, and apply knowledge of the purpose, structures, clarity and relevancy of functional text;
Math
Strand 5-Concept 2: PO 7. Create inductive and deductive arguments concerning geometric ideas and relationships, such as congruence, similarity, and the Pythagorean relationship;

Science
Strand 1-Concept 1: Formulate predictions, questions, or hypotheses based on observations. Evaluate appropriate resources;
Strand 1-Concept 3: Evaluate experimental design, analyze data to explain results and to propose further investigations. Design models;
Strand 2-Concept 2: Understand how scientists evaluate and extend scientific knowledge;
Strand 4-Concept 3: Analyze the relationships among various organisms and their environment;

Social Studies
1SS-P1 Apply chronological and spatial thinking to understand ... historical and current events;
1SS-P2: Demonstrate knowledge of resource sources ...;
1SS-P3: Develop historical interpretations ...;
1SS-P18: Apply the skills of historical analysis to current social, political, geographical and economic issues facing the United States;
3SS-P2: Analyze natural and human characteristics of places in the world studied to define regions, their relationships, and their pattern of change;
3SS-P4: Analyze the interactions between human activities and the natural world in different regions, including changes in the meaning, use, distribution, and importance of natural resources, 3SS-P5: Apply geographic knowledge of people, places, and environments to understand the past and present and plan for the future;
4SS-P1. Analyze the implications of the economic problem of scarcity.

III. Basic Concepts to be learned and applied:
A. "American Nile":
B. CAP:
C. Colorado River Compact:
D. Hydro-electric Power:
E. Quantity vs. Quality:
F. Arizona vs. California:
G. Mined Water:

IV. Basic Inquiry:
In inquiries 3 and 4 you have had the opportunity to relate the history of water quantity and use in southern Arizona to include the story of the huge migration to sunbelt states such as Arizona. The development of a largely arid landscape, roughly the western half of the 48 contiguous states, benefited from the sponsorship and support of major public works programs. Beginning with the National Reclamation Act of 1902, massive projects were begun that would shape this vast region into its present form, complete with the tens of millions of people who came here in their wake.

In many ways the story of bring water to the desert focuses on the Colorado River, which Marc Reisner in his book Cadillac Desert called "The American Nile." To begin to understand what he meant and how this river connects to the story of Arizona's population surge, you will need to examine the map immediately below:
The Colorado River is the lifeblood of the last three states that lie along its long journey to the sea, Arizona, Nevada, and California. Their largest cities thrive in large part from due to the Colorado River. This is an impressive river because it is asked to do so much with so little. It drains a comparatively large area, 242,000 square miles and its 1,360 miles length, places it fifth among United States rivers. However, the drainage area is mostly a dry land and the river’s rate of water discharge places it only within the top 25 in this country. Moreover, it carries proportionately much more silt than the mighty Mississippi (without dredging, Hoover Dam would eventually become a giant man-made waterfall). Its descent of almost 13,000 feet from the Wyoming and Colorado Rockies to the Gulf of California is greater than most rivers anywhere in the world, most in the United States. Before being “tamed” during the 20th century,
it was a "wild" river, expressing the temperament of a vicious monsoon thunderstorm. Flood waters could rage with tremendous force plowing through narrow rock canyons and then bursting out into the flat land. To a large extent, one of the wonders of the modern age is that it has been made to bow to man's command. Today its waters almost always flow obediently through and even beyond its natural drainage basin; so many drops are squeezed out of it that this once mighty waterway rarely completes its final eighty mile journey into Mexico and the sea.

To understand how this came to be, and how in recent years the Central Arizona Project added to its burden, it is necessary to look back over eighty years ago and beyond.

The people who moved to Arizona after 1865 carried with them a distinctive American brand of great expectations. While some like General Sherman saw endless heat and dust, many of this later generation of "pioneers" saw promise. While a common misconception during this period was that "rain follows the plow," only but the most naïve who were making some corner of Arizona Territory their home believed that more was necessary. Indeed the first large group to farm, bands of Mormon families, located near rivers and streams and dug irrigation ditches to expand crop land. More was needed, especially if the urban communities that began to appear could be sustained and grow.

This was accomplished by the teamed effort of local and regional interest groups to policy makers in Washington D.C. As we have seen, it led to the National Reclamation Act in 1902. By that time some people in Arizona Territory began to realize the potential of harnessing the Colorado River. This is a long and involved story, one that will only be summarized here. Essentially we can focus briefly on the work of two men, both from families of "pioneer" stock.

The first and perhaps the more important of these was Carl T. Hayden, whose family operated a ferry along the Salt River in Tempe. After serving in public office previously, Carl entered Congress in 1912, the year of statehood, and remarkably would represent Arizona's interests there for the next fifty-seven years. He brought with him a mega-Hohokam vision, to channel water from Colorado River into the lower deserts. To many this was a pipe dream, an expensive one at that, and the battle to get Congress to allocate the massive sums to required build it was long and drawn out. Hayden's tenacity and longevity, which brought with it the power of seniority, played a key role in winning Congressional approval in 1968. The battle was not over because opposition continued for the next decade and beyond both in and out of Washington. For more information about Carl Hayden's life, examine this online source: http://www.azcentral.com/news/specials/azhistory/02081hayden0210.html (BAD LINK)

Morris Udall, descended from Mormon pioneers, entered Congress in 1961 and would serve for the next thirty years. He, too, would play an important role in guiding CAP and the need for continuing funding along its tortuous path. In 1946, the Central Arizona Project Association was organized to rally support in Arizona for CAP. Educating the public remained an important task and so carrying on this effort. Congressman Udall's Congressional Report, 21 May 1963, was one such effort to sustain this. This report appears online at http://www.library.arizona.edu/branches/spc/udall/congrept/88th/630521.html. To learn more about Mo Udall's life see http://www.library.arizona.edu/branches/spc/udall/homepage.html.

Construction for CAP began at Lake Havasu in 1973 and was completed twenty years later south of Tucson. The entire project cost over $4 billion to construct. However, more must be added to this story both before and after 1993. This will be accomplished in a guided activity below, (as part of V. Inquiry Activity). In closing this discussion a couple of points do need to be made now, however. First, as should be clear from the inquiry activity that you do
below, the Colorado River is a major supplier of energy to meet the on-going expansion of our power needs, including air conditioning. CAP is intricately linked to how the Colorado had previously been apportioned and used. Secondly, in answer to the question raised with Inquiry 5 of this module, it should be obvious that CAP will have a huge impact on southern Arizona's water needs and use. By the time that you include this Inquiry section you should have a better way of assessing that importance. In the finally inquiry of this module, Inquiry 6, you will be asked to use the perspective that you have gained along the way, as you try and determine both the possibilities and the limits of "sustainability."

V. Basic Inquiry Activities:

A. Introductory section (I.)
   1. What was the rate of growth for Phoenix and Tucson between 1940 and 1990, and how does that compare to the demographics for the entire state?
   2. Among other factors, how does water help explain why Phoenix, and especially including its metropolitan area, is so much larger than Tucson.
   3. Assuming an average per capita use of 176 gallons per day, how many more acre-feet of water would have had to be supplied to meet Tucson's population in 1990 on the day that it reached the state population than on the corresponding statistical day in 1940? What would its yearly total then be if the population did not change along with per capita water use?
   4. Just to get an idea of how much water that increase represents, assume that the yearly total was to be stored in a tank whose circumference was the size of a high school campus of 50 acres. How tall would that tank have to be to hold that water?
   5. The previous three questions have emphasized water in some way, and this one does less directly. Hydro-electric power is the most important source of generating electricity in Arizona. The following information is quoted from the Glen Canyon Dam information site, Page, Arizona, online at: [http://www.canyon-country.com/lakepowell/gcdam.htm](http://www.canyon-country.com/lakepowell/gcdam.htm) "The plant generates more than 1.3 million kilowatts of electricity with each of the 40-ton steel shafts turning at 150 rpm, generating nearly 200,000 horsepower. With all eight generators operating at full output, over 15 million gallons of water will pass through the power plant's penstocks each minute. The electricity is upgraded on a transformer deck from 13,800 volts to 230,000 and 345,000 volts for transmission to distant markets" (Printed with permission from Canyon Country Online, LLC). Hoover dam claims to generate more than 4 billion kilowatt-hours a year - enough to serve 1.3 million people. Question: As Arizona's population mushroomed, how would water have to "work harder" to keep up with their energy needs?

B. Colorado River Basin Map
   1. What two states serve as the source of the Colorado River and what are these rivers called?
   2. In addition to the two source states, two others are considered Upper Basin states. What are their names?
   3. Name the three Lower Basin states:
   4. Which state contributes the largest drainage area for the Colorado River?
5. What other political entity lies within the Colorado Basin?

C. Examining "The Law of the River"

(Online at http://www.crwua.org/colorado_river/lor.htm)

1. Remember the Colorado River Basin map. If the Colorado River Compact (CRC) would be open to revision today, what case would you make for Arizona receiving at the largest allocation?
2. What advantage did California have over the other six states when the CRC was being made?
3. Well before Hoover (Boulder) Dam was built in the 1930s, less sophisticated appropriation of the Colorado River created what "natural" feature in southern California?
4. What were the two main arguments made before the construction of Hoover Dam for making "better use" of the Colorado River?
5. Where is the point of division in the CRC between Upper and Lower Basins, and what does that mean for Arizona?
6. Which state refused to sign the CRC in 1922 and why? When did it agree to the CRC?
7. What was a major miscalculation from which the river was apportioned?
8. What advantages did Mexico have when it negotiated rights to 1.5 million acre-feet of the Colorado during WWII, and what significant flaw did that agreement have for Mexico?
9. About the time that the treaty with Mexico was being approved, what two states fought a long legal battle over Colorado River Water and how was that dispute related to the CAP?
10. Why was it necessary to develop storage areas for Colorado River water and how was this accomplished? This was intended to store up to four years of water to account for dry years and was accomplished by building more dams along the Colorado.
11. What are the two "precious resources" that came into direct conflict especially after 1960?
12. What are two chief issues affecting the future of the CRC today that are most important to you and why?

D. CAP: Refer to the CAP home page and navigate as necessary to answer these questions. http://www.cap-az.com/

1. According to the map, how many recharge stations are part of the system and how many are located in Pima County?
2. Most of the 336 miles are along an aqueduct, which means what happens along the way?
3. Using the average evaporation rate that is estimated at its designed capacity of 1.5 million af, how many acre-feet of water is lost annually?
4. How many cubic feet of water can the aqueduct carry at its source point if entirely filled?
5. In what year did CAP first deliver one million acre-feet of water, and what percentage of its capacity goal does this represent?
6. Including CAP, how many people are estimated to be using Colorado River Water for drinking?
7. Without interest calculated in, what would be the annual cost to Arizona taxpayers to pay the debt owed to the federal government over the fifty years allowed? Assuming an average state population of 6 million people over that time, what would be the annual per capita debt?

8. What is the af cost for the Tucson AMA for 2001-2002?

9. Applying your understanding about watersheds, what fact must be considered regarding the delivery of Colorado River water to Tucson?

10. Using the information from question 9 above, what would be the direct consequence for the consumers of CAP water?

11. Challenge question option: Assuming that CAP delivers the targeted 1.5 million af in a calendar year, what would the rate of flow (cfs) be in order for that to happen?

E. The CAP and Tucson.

Examine "Who's Who in the Tucson Water Debate."
[http://www.hwr.arizona.edu/hwr203/notes/whoswho.html](http://www.hwr.arizona.edu/hwr203/notes/whoswho.html)

a. What year do you think this summary was made?

b. Given Tucson's demographic history for the previous half century, what interest group is identified as favoring the use of CAP water?

c. What can you infer was the basis for the adversarial relationship between the "Establishment" and the Opposition?

d. In addition to the issue identified above, what other concern was voiced prominently about the consequences of using CAP water?

e. Who were the two main components of the Establishment?

f. Use the information supplied in the timeline and state a thesis that expresses what the opposition was most about regarding CAP water.

g. What is the term used on this site that identifies the role of CAP in accomplishing safe yield?


a. What should be known and kept in mind about the authors of this article in Tucson Weekly?

b. What is the date of this article and why is that important to know?

c. Essentially what do they alleged and what do they believe explains why the city is doing this?

d. Why does CAP water have to be treated?

e. How is this issue related to growth concerns and how does that impact attitudes about conservation in their opinion?.

f. What is their strongest, perhaps real concern about CAP in Tucson?

3. Analysis:

a. Explain how the question of water quantity is interconnected with water quality as illustrated by the controversy over CAP in Tucson.

b. What might be an important source of external pressure that city leaders felt that the vast majority of Tucson residents did not?

c. Read this quote: "It took 20 years and billions of dollars to bring Colorado River water across the desert to Tucson. It only took three years, a funny taste, and some burst pipes for voters to say, 'no, thank you,' and
permanently restrict its use.” (LA Times, October 31, 199, p. A14) How sensitive should the people of Tucson be in response?

d. Respond to this statement made regarding the vote in 1999 to amend CAP use provisions in Tucson. Your comments are to be made to illustrate your understanding of the complexities of water supply and demand in southern Arizona. "Already, Tucson's water table has declined anywhere from 50 to more than 200 feet over the past 50 years. If 55 years of serious groundwater overdraft has dewatered only about 10 percent of the aquifer, what is the concern? Even with continued population growth, it might seem we have enough extractable groundwater to last for many decades, if not centuries."

F. California and Colorado River Water

Use these two online sources:
http://www.nctimes.com/articles/2002/04/21/export7767.txt
and
http://crwua.mwd.dst.ca.us/ca/crwua_ca.htm (BAD LINK)

1. Do equivalents for the CAP exist for California?
2. Does southern California have a strong dependency on the Colorado River?
3. How does southern California's average precipitation compare to that of Arizona's?
4. According to the North Country Times, southern California currently experiences a struggle for water between what two large interest groups or users?
5. Why is southern California labeled a "water hog?"
6. Why has southern California been able to draw more water than 4.4 million af and how dependent has this region become on this surplus?
7. How does California plan to end using this surplus and how risky is this strategy?
8. What would be the potential environmental consequences for the Imperial Valley in making these transfers?
9. What are the potential implications for CAP? California's right to take surpluses would likely be contested, and this tangled legal battle can only add to the cost of water and create some bitter losers.
10. Optional Question: Refer to:  http://www.udel.edu/inst/problems/colorado/ (See Appendix item 4) On what grounds does the federal government justify its power to act in settling disputes regarding the Colorado River?
Santa Cruz Water History Inquiry Question Six

Is it possible to achieve a sustainable water supply in southern Arizona?

Student Activity Guide

Resources: It is suggested that the student work from resources identified in the other inquiries and use appropriate links when or as necessary.

I. Introduction:
It is assumed that at this point the student has completed most or all of the five inquiries that following the opening story. Inquiry Six will be different than the other five as explained below, intended to complete the foundation for water literacy in the area of the history of water quantity in southern Arizona.

II. Targeted Standards:

Reading
Strand 3-Concept 2: Identify, analyze, and apply knowledge of the purpose, structures, clarity and relevancy of functional text.

Writing
Concept 6: Research- Research writing is a process in which the writer identifies a topic or question to be answered. The writer locates and evaluates information about the topic or question, and then organizes, summarizes, and synthesizes the information into a finished product.

Math
Strand 1- Concept 1: The concept of understanding and applying numbers, ways of representing numbers, the relationships among numbers and different number systems;
Strand 5-Concept 2- PO5: Identify a valid conjecture using inductive reasoning;
Strand 5-Concept 2: The concept of evaluating situations, selecting problem-solving strategies, drawing logical conclusions, developing and describing solutions and recognizing their applications;
Strand 5-Concept 2: PO 7. Create inductive and deductive arguments concerning geometric ideas and relationships, such as congruence, similarity, and the Pythagorean relationship;

Science
Strand 3-Concept 2: Develop viable solutions to a need or problem;
Science Strand 1-Concept1: Formulate predictions, questions, or hypotheses based on observations. Evaluate appropriate resources;
Strand 1-Concept 3: Evaluate experimental design, analyze data to explain results and to propose further investigations. Design models;
Strand 1-Concept 2: Design and conduct controlled investigations;
Strand 2-Concept 1: Identify individual, cultural, and technological contributions to scientific knowledge;
Strand 2-Concept 2: Understand how scientists evaluate and extend scientific knowledge;
Strand 4-Concept 3: Analyze the relationships among various organisms and their environment;
Social Studies, History:
1SS-P1 Apply chronological and spatial thinking to understand ... historical and current events;
1SS-P2: Demonstrate knowledge of resource sources ...;
1SS-P3: Develop historical interpretations ...;
1SS-P11: Understand the transformation of the American economy and the changing social and
political conditions in response to the Industrial Revolution;
1SS-P112: Analyze the development of the American West and specifically Arizona
1SS-P18: Apply the skills of historical analysis to current social, political, geographical and
economic issues facing the United States;

Geography
3SS-P1: Acquire, process, and analyze geographic information about people, places and
environments by constructing, interpreting, and using geographic tools;
3SS-P2: Analyze natural and human characteristics of places in the world studied to define
regions, their relationships, and their pattern of change;
3SS-P4: Analyze the interactions between human activities and the natural world in different
regions, including changes in the meaning, use, distribution, and importance of natural resources,
3SS-P5: Apply geographic knowledge of people, places, and environments to understand the past
and present and plan for the future; Economics –
4SS-P1. Analyze the implications of the economic problem of scarcity.

The Arts, Visual Arts - 2AV-P4: Identify and evaluate the role of the visual arts and artists in
business, industry, technology and the community.

Workplace Skills Standards: The design of this unit, and its interdisciplinary qualities correlate
directly to the Workplace Skills Rationale of the Arizona State Standards.

III. Basic Inquiry:

A. Performance Tasks:

After having completed the five previous inquiries you should be prepared to provide a
thoughtful answer to the question for this inquiry. To do this you need to make a detailed
analysis of relevant information. Therefore establish the criteria that you will use to examine and
evaluate the essential data, documents, etc. You may prepare charts, graphs, tables and pictures.
Sources for your evidence need to be appropriately cited.

B. Student Activity Description:

PURPOSE: The question for Inquiry 6 is intended to be the capstone for Module 5. It has been
designed to engage the student in a thoughtful, research oriented process that examines the vital
issue of sustainability of southern Arizona's water supply. As a result, it will allow both the
student and the teacher to assess the level of understanding achieved from completing this
module. How well people understand the elusive problem of achieving a sustainable water
supply in this semi-arid environment is more than an academic exercise. Indeed, it is about life
itself.

APPROACH: The research activity will ask the student to play the role of a consultant hired by
a select group of civic leaders who want you to investigate the question as to whether or not
sustainability can be realized. In considering the evidence, you must make recommendations about what needs to be done to move towards balancing groundwater demand with its supply. By its nature your investigation is interdisciplinary, demonstrating how the interplay of science, history and politics and the skilled use of language to communicate ideas in a logical, persuasive way based on solid evidence.

**DESIGN:** The following components must be included and developed for this research activity:

1. Introduce and clearly state your understanding of the problem under investigation.
2. Briefly describe the process that you used to gain a deeper understanding to include identifying the following: chief causes, any attempted solutions and their consequences, and present remedial actions or policies and how successful they have been or are likely to be.
3. Describe the additional actions that you believe must be taken and the extent to which they will likely lead to achieving sustainability.
4. Prioritize the steps that need to be taken and how they should be implemented.
5. Identify the various stakeholders and specifically what each must do in support of your plan of action.
6. Summarize the evidence that supports these recommendations.
7. Clearly state the long-term benefits that can be realized and the importance of making a prompt commitment to realize them.
8. Identify three enduring understandings as a result of completing this inquiry.

**GUIDELINES:** The following are offered as suggestions on how best to accomplish this task

**Task One (Set-up):** In stating the on-going problem of groundwater overdraft be sure to define key term/concepts that open your inquiry and others' understanding of it.

**Task Two (Inquiry):** This should express a good understanding of historical continuity that includes recognizing key players and policies into the present.

**Task Three (Thesis):** Your studied opinion about how likely sustainability is for the people of Pima County and your justification for taking this position.

**Task Four (Plan Idea):** This step and number five are interdependent because policies can be recommended and even enacted but enforcement depends directly upon the degree of support from the various stakeholders. Thus, your plan of action must thoughtfully and creatively consider how best to motivate the entire community.

**Task Five (Plan Involvement):** Energizing the important stakeholders involves selecting appropriate language that builds support while building confidence that you thoroughly studied and understand the situation and/or problem.

**Task Six (Summary):** A good summary should not be redundant, but instead include a few carefully key phrases and concepts crisply imbedded in language that gains both a deeper understanding of your ideas and greater acceptance.

**Task Seven (Closure):** A terse final spark to ignite action in your favor.

**Task Eight (Personal Legacy):** What are several meanings gained that will always be with you?
RUBRIC: The following evaluative tool is to be used by the student in preparing their action plan and by the teacher to determine the level of understanding demonstrated. Each value and descriptor below applies separately to each of the eight tasks. The teacher can apply different weights of importance if wished in advance of asking students to do this assignment. The descriptive assessment categories will be found above the rubric that appears on the next page.
**Understanding the assigned task including applicable key terms & concepts; Historical continuity with the relevant politics & social values; Identification & understanding of key data and other evidence; Logical sequencing & development to create a thoughtful & realistic plan of action; Communication of language to clearly present facts & to thoughtfully persuade.** Words underlined identify the assessment category on the chart. \( V \) = the base point amount applied to the total grade as indicated by the instructor.

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<td>The task is thoroughly completed so that the student demonstrates conceptual and contextual understandings that greatly exceeds the targeted performance standards.</td>
<td>The task is completed with the student demonstrating a generally clear conceptual and contextual understandings. Targeted performance standards are achieved and to some extent exceeded.</td>
<td>The task is almost completed. The student demonstrates little confusion of conceptual and contextual meanings. Targeted performance standards are achieved.</td>
<td>The task is almost completed. The student demonstrates a conceptual and contextual understanding that is vague or confused at times. Targeted performance standards are not achieved.</td>
<td>The task is incomplete. Understanding is lacking with many misunderstandings or inconsistencies evident. The quality of work is below to greatly below the targeted performance standards.</td>
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<td>Excellent &amp; thorough analysis. Exceptional understanding of the examples used that shows great thought and unusual maturity. Mastery of this task is much above targeted performance standards.</td>
<td>Good analysis with examples that show few inaccuracies. An effort to think through and find the deeper meanings is evident at times. The quality of work is at &amp; at times above targeted performance standards.</td>
<td>Generally good understanding of the task. Attempts are made to provide detail, and although some errors are made meanings are adequately understood. The completed task meets targeted performance standards.</td>
<td>Fair understanding of the task. Attempts were made to provide detail, but too many errors are made, with definite confusion about meaning and importance. The task as done falls below targeted performance standards.</td>
<td>Poor understanding of this task. Many errors of fact exist and the narrative is vague and too general lacking substance. Well below target performance standards.</td>
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<td>Exceptional inquiry and analysis to build a very solid data base that was used to identify the scope of the problem and possible solutions. Effort well above targeted performance standards.</td>
<td>Good inquiry and analysis that developed a good data base that was used to identify the scope of the problem and possible solutions. At and at times above targeted performance standards.</td>
<td>Inquiry and analysis adequate in developing a data base that was used to identify the scope of the problem and possible solutions. Effort meets targeted performance standards.</td>
<td>Inquiry and analytical skills shown were insufficient to develop a data base to be used to identify the scope of the problem and possible solutions. Effort below targeted performance standards.</td>
<td>Poor inquiry and analytical skills led to little supporting evidence towards understanding the problem's causes with little data to support possible solutions. Effort well below targeted performance standards.</td>
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<td>Mature &amp; insightful understanding of cause &amp; effect for thesis support. Excellent analysis &amp; logical sequencing apparent throughout. Effort greatly exceeds targeted performance standards.</td>
<td>Good understanding of cause &amp; effect in support of the thesis. Analysis &amp; logical sequencing show a few minor faults. Effort meets, at times exceeds, targeted performance standards.</td>
<td>Thesis supported with adequate understanding of cause &amp; effect. Analysis &amp; logical sequencing show some faults but none are significant. Meets targeted performance standards.</td>
<td>Some factual basis but illogically analyzed with little sequencing; Limited understanding of relationships with inconsistent thesis support. Effort falls below targeted performance standards.</td>
<td>Poor factual foundation. Evidence is lacking or inaccurately applied. Poor use of logic with a limited sense of sequence. Thesis either ignored or unproven. Well below targeted performance standards.</td>
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<td>An exceptional effort to present an action plan. The language used demonstrates command of the pertinent facts, conveyed with words &amp; phrases that quickly build understanding. Effort greatly exceeds targeted performance standards.</td>
<td>A very good action plan. The language used demonstrates a basic understanding of the pertinent facts, conveyed with words &amp; phrases that are easily understood. Effort at or at times exceeds targeted performance standards.</td>
<td>A good action plan. The language used conveys adequate understanding of the facts and relevant concepts that are, in general, clearly expressed. Effort meets targeted performance standards.</td>
<td>A fair action plan. The language used does show some misunderstanding of the pertinent facts, with word choice that is too often vague or misleading. Effort is near, but below targeted performance standards.</td>
<td>A poorly conceived &amp; executed action plan that shows limited effort. Language used is confusing in part due to lack of understanding and thus fails to persuade. Effort is below to greatly below targeted performance standards.</td>
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Appendix

Item 1: Santa Cruz Watershed Map
(Used with permission from Kevin Fitzsimmons University of Arizona college of Agriculture and Life Sciences, December 2004)
Item 2: Map of Federal Lands throughout Arizona
(Used with permission from University Libraries, Arizona State University, December 2004)
Public Land Management and Land Ownership in Arizona

- There are 72.9 million acres of land in Arizona. The USDA Cooperative Extension System, through the University of Arizona, provides educational programs throughout the state in land management.
- Approximately 12.9 million acres, or 18%, in Arizona are privately owned. The USDA Natural Resource Conservation Service is responsible for assisting private landowners.
- Approximately 9.6 million acres in Arizona, or 13%, are managed by the State of Arizona. The Arizona State Land Department is responsible for the management of the state trust land.
- Approximately 20.1 million acres in Arizona, or 27%, are held in trust by the United State Government for native Americans. The Tribal governments and the USDI Bureau of Indian Affairs are responsible for the management of rangelands on reservations.
- Approximately 30.3 million acres in Arizona, or 42%, are owned by the citizens of the United States. These public lands are managed by the USDA Forest Service, the National Park Service, military organizations, and USDI Bureau of Land Management.
On December 18, 1997, U.S. Interior Secretary Bruce Babbitt announced first-ever rules to permit interstate transfers of Colorado River water from agricultural users to urban users. He also strongly cautioned that much still needs to be done before California is in a position to live within its allocation of Colorado River water. "I believe the time has come for me as River Master to play a more active role," Babbitt said.

This action by Secretary Babbitt followed a warning he issued to California in 1996 that it can no longer rely on receiving more than its yearly entitlement because of growing demand in Arizona and Nevada.

The Colorado River supplies water to seven states (Arizona, Colorado, California, New Mexico, Utah, Wyoming, and Nevada) in addition to Mexico. Since the early 1900's, water distribution rights have been in contention. And starting in 1922, the distribution and management of Colorado River water has been governed by a complex body of laws, court decrees, compacts and an international treaty.

- Why is water from the Colorado so important to the Southwest?
- Who are the various stakeholders that have an interest in the distribution of water?
• What issues need to be considered in designing a fair plan for water distribution?

As the Southwest was being developed, the big question was, "Will there be enough water?"
Today people ask, "How good will the water be?"
At the headwaters of the Colorado, the salinity is 50 parts per million (ppm). Where the river crossed the border into Mexico in the early 1900's, it was about 400 ppm, but rose to 1200 ppm in the 1960's. Original agreements with Mexico dealt with the quantity of water in the Colorado that the US agreed to deliver. But later with the decrease in quality of water, Mexico pursued renegotiations that would ensure a maximum level of salinity in water reaching Mexico from Arizona.
In 1905, an irrigation canal diverting Colorado River water to California farmland broke and flooded an ancient basin for two years. The basin now contains a 35 mile long, 15 mile wide lake, named the Salton Sea. As California's largest in-land body of water, it was a recreational mecca, attracting boaters, water skiers, birders, sports fishermen, and vacationers. Over the years, the Salton Sea has become 25 percent saltier than the Pacific Ocean and polluted. Recently fish and birds have been dying in droves. The late Representative Sonny Bono made the rehabilitation of the Salton Sea a priority. On December 19, 1997 Secretary Babbitt called it a national treasure and he promised to work toward a solution to its problems. Some Salton Sea advocates are calling for an infusion of fresh water from the Colorado.

Aerial views of the Salton Sea

• Why have the salinity levels risen in the Colorado and Salton Sea? Why is this a problem?

Choose a stakeholder position for which you will be an advocate. In your new group, discuss the following:

• Why is water from the Colorado River important to you?
• How does the quantity and quality of the water affect you?
• What questions do you have to answer in order to be an effective advocate?
• Where do you think you can find information?

On September 28, 1999 the Congressional Salton Sea Task Force was briefed about some restoration options for the Salton Sea. The most feasible is to drain some of the Sea's waters and replace them with water from the Colorado. This meets the objectives of the Salton Sea advocates who want to preserve the Sea, for recreation and wildlife, and reduce the salinity levels to 40 ppt. Other interest groups disagree, stating that the Salton Sea is a lost cause.

March 12, 2000
Bruce Babbitt the Rivermaster declared today that after reviewing options for restoring the Salton Sea, he recommends as a first step diverting one million acre-feet of the Colorado River water to the Salton Sea, after drain the Sea and reclaiming the salts and minerals by using evaporation towers.
Which stakeholder group do you recommend receive less water?
How should priorities be set on the use of the Colorado's water, given the needs of the cities, agriculture, the environment, recreation, business, and Mexico?
Some Relevant Online Colorado River Resources

- Water Resources Research Center at the Univ. of Arizona
- The Colorado River from Grand Canyon Explorer
- Metropolitan Water District of California
- Accounting for Consumptive Use of Lower Colorado River Water in Arizona, California, Nevada, and Utah Assessment Program---Central Arizona Basins from Arizona Water Resources, U.S. Geologic Survey
- News Room of the Bureau of Reclamation, U.S. Department of the Interior