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

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

Instructor’s Guide

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

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Opening Story for Module Two

Imagine…

INSTRUCTOR'S GUIDE, AN INTRODUCTION

The "Opening Story" has been designed to perk student interest about water and to establish a detailed unit of study that focuses on the history of water supply in southern Arizona. Despite the "ancient" rhyme, water is not found everywhere in southern Arizona and yet we continue to have "drops" to drink. The Opening Story has been designed to get students to think about how we are able to meet our water needs in such a dry land. In the process of study students will think more critically about water use and supply. Water is omnipresent in our lives but how often do we notice? Consider these facts. It requires this much water to produce one serving of:

- Tomato (medium) = 8 gallons
- Lettuce (1 cup) = 3 gallons
- Orange (small) = 14 gallons
- Pasta (2 oz) = 36 gallons
- White bread (1 slice) = 11 gallons
- Cheese (1 oz) = 56 gallons
- Plain yogurt (1 cup) = 88 gallons
- Butter (.36 oz) = 46 gallons
- Egg (1) = 63 gallons
- Chicken (8 oz) = 330 gallons
- Hamburger (4 oz) = 616 gallons
- Steak (8 oz) = 1,232 gallons

The average American consumes 1,500 pounds of food each year, requiring 1,000 gallons of water per pound, or 1.5 million gallons of water for each person's diet. U.S. Industries use 7 trillion gallons of water per year to produce the products that we buy and use. Examples include:

- 50,000 gallons to produce rayon for an average-sized living room carpet,
- 40,000 gallons just to produce the steel for one automobile and another 2072 gallons for the tires not counting the spare.
- It also requires 24 gallons per pound of plastic and 55 gallons to make a pound of synthetic rubber. *(Source: Cadillac Desert)*

A small portion of these foods and products are produced in southern Arizona, but most are not. Nevertheless this example invites expanded thinking about what is mostly taken for granted as we pursue our daily lives.

**Brief Overview:** Module Two provides a meaningful opportunity for students to gain mastery of the Arizona Academic Standards through the study of the history of water quantity in southern Arizona. The Instructor's Guide is intended to help provide direction for lesson design, allowing the teacher the flexibility to adapt the material to their own classroom needs. Each of the six inquiries offers learning activities requiring student response and ending assessments to help evaluate student understanding. What follows is a more detailed explanation of the structure of this module.
Module Two is part of a larger curriculum designed to increase water literacy among high school students in southern Arizona. In all, six modules and a core to introduce them will comprise this course of study. It will quickly be realized that each are interdependent, yet can be explored separately.

Module Two will establish a solid sense of historical continuity to develop the necessary perspective for considering the on-going issue of water quantity. Southern Arizona is defined as roughly the area south of the Gila River extending south into the Mexican border region. Both of the two main watersheds, the Santa Cruz and the San Pedro, extend into northern Sonora and must be seen as part of the whole. As designed, the module will provide both an overview of the area defined with the option of focusing more on either the Santa Cruz or the San Pedro. Even so, the Santa Cruz portion narrows still further with its emphasis on the Tucson Basin. As developed, the focus on this middle basin of the Santa Cruz will require approximately six to eight weeks to complete depending on how much depth the teacher determines is needed. Needless to say, this study of the history of water quantity in southern Arizona must still be regarded as an introduction to a more complex inquiry.

This module is organized into six inquiries, each with an organizing question. They have been developed with both a student portion and an accompanying "Instructor's Guide." The Opening Story and this introduction have been created to help set-up the unit of study. Hopefully the operating structure provides enough depth and flexibility to be used according to what the instructor decides best fits their curricular needs. It is interdisciplinary in approach, yet portions may be excluded to fit within traditional course boundaries. All six modules have been developed to work within an expansive scheme of a multitude of disciplines because students will gain the most useful understanding and thus become more highly water literate. Thus, it is highly recommended that Module Two be studied in its multi-disciplinary format.

These modules, which were written to create higher water literacy in arid and semi-arid environments, generally follow the logic of a unit plan called "Understanding by Design" created by Grant Wiggins and Jay McTighe. In this module units should be constructed looking backward with the end always in mind. Essentially, the designer should continually ask, what is it that I want students to learn?; how am I going to get them there?; and how will I know that they have learned the things I want them to know? Ultimately, besides successfully demonstrating targeted competencies for tested standards, we must consider what the student will always remember as a result that will enrich their lives. In other words we must ask ourselves, what are the "enduring understandings" of this unit of study? A list of these enduring understandings for this module appears at the end of this introductory guide.

As much as possible, an attempt has been made to provide consistency throughout. Inquiry Six is organized differently, but as the capstone, easily flows within the larger schematic. In the five inquiries that precede it, the student study guide begins by identifying the main resources that will be used for that portion. These are almost entirely online, and because almost all are public information websites, desired parts should be easily converted to print form. Following the section for Resources Used, an introduction appears that opens up the organizing question. This is followed by a listing of "Targeted Arizona State Standards." The instructor can decide which of these in particular apply to given segments. Next, a list of the operative concepts for that inquiry is given. The Instructor's Guide provides definitions that can be provided to the students if desired. The premise for listing these concepts can be explained in this way. That in order to be able to function with deeper levels of thought, guiding ideas (concepts) should be introduced and explained in order to open up more specific inquiries. These concepts operate as
both points of entry and receipt so that information can be more readily processed and evaluated to create a systematic analysis.

Following the listing of "Basic Inquiry Concepts," the "Basic Inquiry" appears. This discussion provides information and sets up questions to be answered. Whenever possible existing information sources are used to provide study material, but in some cases a narrative has been constructed to convey the necessary understandings. Next is either a section for an Expanded Inquiry or "Basic Inquiry Activities." The questions raised have suggested ways for aiding assessment in the Instructor's Guide for that inquiry. The "Assessments" and the "Enduring Understandings" are only found in the Instructor's Guide. The rubric for the Inquiry Activities may also help in assessing the quality of each student's effort. Additional information is provided below.

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**TARGETED STATE STANDARDS FOR MODULE TWO**

**Language Arts,**

**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;

**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;

**Mathematics,**
Strand 5-Concept 1: The concept of using reasoning to solve mathematical problems in contextual situations;
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**
Science Strand 1-Concept 1: Formulate predictions, questions, or hypotheses based on observations. Evaluate appropriate resources;
Strand 1-Concept 2: Design and conduct controlled investigations;
Strand 1-Concept 3: Evaluate experimental design, analyze data to explain results and to propose further investigations. Design models;
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 3-Concept 1: Describe the interactions between human populations, natural hazards, and the environment.
Strand 3-Concept 2: Develop viable solutions to a need or problem;
Strand 4-Concept 3: Analyze the relationships among various organisms and their environment;
Strand 4-Concept 4: Understand the scientific principles and processes involved in biological evolution.

**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.

**KNOWLEDGE AND SKILLS THAT THE STUDENT WILL APPLY IN MODULE TWO**

1. Students will use and become more proficient in using multiple resources to gather information.
2. Students will be able to read maps, tables, charts and graphs to process and apply information for understanding.

3. Students will apply quantitative and logical thought processes in calculating measures that include determining specific quantities of water, water flow rates, and per capita consumption.

4. Students will be able to read and analyze scientific evidence and reports.

5. Students will be able to read and analyze historical documents of various kinds.

6. Students will understand, use and apply basic terms/concepts that include DENDROCHRONOLOGY, ACRE FOOT, TOPOGRAPHY, BASIN AND RANGE, CFS, WATERSHED, HISTORICAL EPOCH, RIPARIAN, PRIOR APPROPRIATION, FEDERALISM, WINTERS DOCTRINE, CAPPAERT RULE, 100 YEAR FLOOD, "AMERICAN NILE," THE LAW OF THE RIVER, GWMA, AMA, SUSTAINABILITY, SAFE YIELD, CAP, AQUIFER, GROUNDWATER, SURFACE WATER, HOHOKAM, ACEQUIA, HYDRAULIC SOCIETY, COLORADO RIVER COMPACT

7. Students will use specific web-sites to learn more about water quantity issues affecting southern Arizona.

8. Students will be able to form a literate opinion about vital issues affecting water use and conservation in southern Arizona.

9. Students will be able to process, analyze and evaluate information to produce a real-life proposal that tackles the problem of building a sustainable water supply in southern Arizona.

**Primary Enduring Understandings for Module Two**

1. By embracing a multi-disciplinary inquiry approach, students will become highly literate about the history of water quantity in southern Arizona. (Throughout all six inquiries)

2. Students will understand and be able to explain how geologic and hydrologic forces established the quantity and quality of water resources that have sustained human life in southern Arizona for thousands of years. (Inquiry One)

3. Students will better understand how semi-arid and arid environments affect water supplies through the unending cycles of wet and dry. (Inquiry One)

4. Students will acquire a better conceptual understanding and use large measures of water quantities, such as acre foot, so that they can better appreciate the "big picture" of water quantity issues in southern Arizona and beyond. (Inquiry Two)

5. Students will appreciate the limits and the possibilities of living in semiarid and arid environments. (Inquiry Three)

6. Students will recognize how humans over the millennia have shaped and altered the Santa Cruz River watershed. (Inquiry 3)

7. Students will understand how the globalizing ethos of industrial capitalism has determined the future course of the West and southern Arizona since 1865, a process of incorporation that increasingly appropriated greater amounts of surface and ground water. (Inquiry 3)

8. Students will understand the interdependent relationship between ground and surface water and how present laws still fail to adequately take this into account. (Inquiry 4)

9. Students will understand how competing private and public interests continue to affect water quantity issues. (Inquiry 4 & Inquiry 5)

10. Students will recognize and be able to explain why present state and federal laws may not effectively ensure appropriate water conservation. (Inquiry 5)
11. Students will understand and more greatly appreciate the essential importance of water as a primary source of life and energy. (Inquiry 5)
12. Students will understand the meaning and importance of the phrase "the American Nile," as it applies to the Colorado River. (Inquiry 5)
13. Unless more efficient and effective water conservation practices are implemented to sustain life, water supplies at some time in the future may become inadequate. (Inquiry 5 & 6)
14. Students will be able to construct a research activity that examines the possibilities of attaining a sustainable water supply in southern Arizona. (Inquiry 6)
15. As a result of completing this module students will be able to intelligently develop useful measures to practice better water conservation in their own lives. (Inquiry 5)
16. Students will become more familiar with and thus better able to share the multitude of water-related resources, particularly online, to be used towards building and sustaining higher levels of water literacy for themselves, their families and their community. (All Six inquiries).

**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.

**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.
Santa Cruz Water History Inquiry, Question One

When and how did the Santa Cruz River form?

Instructor's Guide

PRIMARY LEARNING OBJECTIVE: Students will understand how the geologic history of southern Arizona has affected how water flows and is stored within the context of change with a scale of time extending tens of millions of years.

III. Basic Inquiry Concepts to be learned and applied (online reference sites provided for easy access):
http://ga.water.usgs.gov/edu/dictionary.html#
and,
http://www.patrol.org/instructor/avalan/advava/img28.htm

A. Basin and Range Topography: A surface landscape with physical features comprised of higher areas that drain and erode into lower ones
B. Earth-time: Used in a relative sense as a measure extending for 4 to 5 billion years
C. Aquifer: A geologic formation that stores and releases (ground) water
D. Plate Tectonics: A theory in which the earth's crust extending into its mantle is divided into mobile, rather rigid slabs that at certain points create enough pressure to cause earthquakes and lifting of the crust, forming mountains and creating rifts
E. Orographic Lifting: Air moving against mountains is forced to rise, and as it cools, (an average of 3 degrees per thousand foot rise) clouds form and precipitation can occur (because cooler air lacks the capacity to hold as much moisture as warmer air)

IV. Basic Inquiry Questions
(from Water…)
1. How does southern Arizona’s climate compare to what it was like 10,000 years ago? It was cooler and wetter
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? Runoff either at the surface or from springs
3. What does the aquifer in the Tucson Basin store and what was its original source? water from prehistoric precipitation accumulating for thousands of years
(from AZPEPP…) (BAD LINK)
1. What is the basic geologic descriptor for southern Arizona? Basin and Range
2. When did it form? 12 to 25 million years ago
3. What geologic process has shaped the Tucson Basin? *Tectonics and then erosion of earth and rock that slides down from the range down into the basin*

4. What geologic force creates mountains in southern Arizona? *Heat underneath the earth's crust puts pressure along plates to create an upward force called plate tectonics*

5. What term is used to identify where basins form detached from the mountains, and what happens when these shift? *Faults*

6. Where in the immediate Tucson area could you find evidence of that action? *Pirate Fault on private land north of Tucson*

7. What is the approximate height and depth of Tucson Basin in meters? In feet? 7000 meters, or 22,970 feet (Note: Module 6 examines water quality issues and its history. Should the student express interest in exploring this further at this point in reference to groundwater formation, have them explore this online resource at: [http://capp.water.usgs.gov/GIP/gw_gip/quality.html](http://capp.water.usgs.gov/GIP/gw_gip/quality.html)

**Enlarging the context.**

1. Why should we know this? *It enlarges the context to help identify the inter-relationships across a larger area*

2. Why is this shown incompletely? *Because the area east of the Santa Cruz is shown in white is not currently under study, but this does not mean that this portion would not be part of this large ecoregion.*

**Questions for understanding (NSP Instructor Web)**

1. What is the term that identifies the interaction between advancing air and the area's mountains? *Orographic lifting*

2. What is the potential benefit of that interaction (see question #1) in creating and re-supplying surface water? *It tends to wring out moisture from the air thus increasing water quantities over time.*

3. How old is the water at the deepest portions of the aquifer in the Tucson Basin? *At least ten thousand years old.*

4. How would knowing more about the climate in the Tucson Basin over many thousands of years help explain ground water quantities available for human into the present? *Over the period a drying trend set in. However, the depth of the underlying basin formed a deep aquifer capable of storing groundwater. Given the span of time, even if only 3 inches per year percolated into the aquifer, this would amount to a 2500 foot pool of groundwater. A wetter climate at an earlier time increases the potential for greater groundwater depths.*

5. How would the topography of southern Arizona contribute to possibility of flooding? *Orographic lifting combined with rapid descent from the many higher areas into the basin would cause the main collection source, the Santa Cruz River, to rise rapidly. Of course, the various washes, streams and smaller rivers in whole or in part would do the same, creating flash flooding.*
6. Why would the depth of the basin have important implications affecting water quantity? With depths over 4,000 meters accumulating over the millennia has created a deep storage area (called an aquifer).

V. Expanded Inquiry Activity: Creating the Big Picture of Time
A. Instructions:
B. Reading:
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." 75,000,000: Each second represents the passing of 75 million 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. 247 seconds of earth time; In other words, the time that it took to form Arizona's Range and Basin topography in southern Arizona took approximately a quarter of a second of the hour of earth time we measured, where one hour equals 4.5 billion earth years (time).
3. Assuming that humans have regularly lived in southern Arizona for 10,000 years, what would be its equivalent measured in earth time? .00013 second of earth time. This is beyond a person's ability to recognize. For example, a major league baseball batter facing a pitcher throwing a ball at 90 mph has less than a tenth of a second to respond (i.e., think about it). Therefore, 10,000 years of human history is almost nothing against the longer span of time.
4. If Arizona has been known to Europeans since around 1539, what % of the answer you got in 2 above would that represent? 4.6% of that time, significantly less of second of earth time than calculated in 3 above.
5. Assuming the average human today lives for 75 years, what % of an "earth time" second does this represent? 75/75,000,000 or .00001%
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." The idea that the student should demonstrate in their response is that the average human's time on earth is comparatively brief, and even that of different cultural epochs. From a human perspective, environmental change can appear to be abrupt and have significant consequences. While one can debate whether the flash flood analogy is a good one, the point to be made is that the geological and physiological forces continue to shape and reshape the earth. For example, over the past century human interaction in the Santa Cruz watershed has significantly altered the water picture and changed the landscape. If humans were to disappear totally from this area, the effects they caused would slowly ebb and the on-going patterns caused by natural forces would continue, only without a human presence they would become more apparent (that is if one
could see it since in this scenario humans are gone). At the same time this should not be a dismissal of the significance of the human impact in the Santa Cruz Basin.

**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 above. Assessment: The student should show that he or she appreciates the relevancy of time that affects how we perceive and thus judge our surroundings.

**VI. Assessment Alternatives:**

A. Multiple Choice

1. The Basin and Range topography of the Tucson Basin can be described as
   - A. the reason why so little water exists in southern Arizona.
   - B. creating an uneven landscape that strongly affects drainage patterns.
   - C. very recent in development, mostly over the last few thousand years.
   - D. unique in the Southwest.
   - E. all of the above.

**ANSWER:** B

2. If cut from the side, the resulting profile of the Tucson Basin would
   - A. show a limited depth, only a few thousand feet.
   - B. display a very shallow, but broad aquifer.
   - C. extend for a total depth of about 23,000 feet.
   - D. show that the Santa Cruz River lies exactly in the center.
   - E. both B and C are correct.

**ANSWER:** C

3. What is the relationship between the topography of the Tucson Basin and a process called orographic lifting?
   - A. The range areas force passing air to rise, which in turn encourages greater precipitation.
   - B. The Tucson Basin collects and stores all the precipitation that enters the surface and subsurface flow.
   - C. Because of the mountains, the climate became semiarid.
   - D. Because the ranges are highest in the west, they force the air to rise and dry out.
   - E. Orographic lifting is a process unique to this region.

**ANSWER:** A
4. What is the name of the place in the Tucson Basin's geography where groundwater accumulates?
   A. Aquifer.
   B. Reservoir.
   C. Tank.
   D. Cienega
   E. Lake
   \textbf{ANSWER: A}

5. What explanation is given to explain why ranges formed in southern Arizona?
   A. The Third Law of Thermodynamics.
   B. Newton's Law.
   C. The Orographic Lift Theory.
   D. The Continental Drift Theory
   E. Plate Tectonics.
   \textbf{ANSWER: E}

6. Earth time
   A. is comparatively short for southern Arizona.
   B. is calculated according to the rotation of the earth on its axis.
   C. defines a span of time approximately one million years old.
   D. or geologic time, makes a human life appear as a mere moment in time.
   E. provides little sense of the geologic and hydrologic forces applicable to understanding the history of water supply in southern Arizona.
   \textbf{ANSWER: D}

7. At levels about 500 hundred feet below the surface, how long ago might the oldest water be in the Tucson Basin since it fell as precipitation?
   A. 50 years.
   B. several hundred years.
   C. 800 years.
   D. one thousand years.
   E. several thousand years or more.
   \textbf{ANSWER: E}

\section*{B. Presentation}
Small groups of students will make a graphic representation that uses and applies the main concepts and ideas learned relative to the targeted standards and share this with the class: Geologic or "earth time"; Basin and Range topography; Aquifer; (Plate) Tectonics. \textit{Assessment here can benefit from the Inquiries Activity Rubric. However, criteria might be developed to reward how successfully the student(s) can creatively portray these concepts.}

\section*{VII. Enduring Understandings:}
A. The Basin and Range topography has shaped the Santa Cruz River and the
underlying aquifer.
B. The earth’s processes create complex patterns of change that extend for many thousands of years beyond a human life or even a cultural epoch.
C. Humans interact with their natural environment adding to the complex patterns of natural change.
D. When measured against "earth-time" human beings occupy this earth for a short period.

**VIII. Expanded Option**

Check this site for information about the 1887 earthquake that was the largest in southern Arizona’s recent history:
http://www.geo.arizona.edu/K-12/azpepp/education/history/pitay.html
(BAD LINK)
For more information about plate tectonics, this site may prove useful:
http://dax.geo.arizona.edu/saso/Education/Plates/
(BAD LINK)
Santa Cruz Water History Inquiry, Question Two

What area encompasses the Santa Cruz River Basin?

INSTRUCTOR'S GUIDE

PRIMARY LEARNING OBJECTIVE: Students will understand the concept of watershed and apply it to the landscape of southern Arizona in order to explain how weather and climate interact in affecting the varying flow rates of the Santa Cruz River.

III. Basic Inquiry Concepts to be learned and applied (online reference sites):

http://ga.water.usgs.gov/edu/dictionary.html
and,
http://www.sonic.net/bristlecone/dendro.html

A. Watershed: The area that drains into the main river bordered by the highest elevated land areas that surround it

B. Dendrochronology: The study of tree rings based on the theory that precipitation increases plant growth, which produce wider rings, which are then "mapped" to create a longer chronology of past climatic events

C. Flash Flood: A rapid rise in water drainage that causes overflow into adjacent areas often causing significant erosion

D. Flood Plain: a strip of relatively flat and normally dry land alongside a stream, river, or lake that is covered by water during periods of bank overflow (flooding).

E. CFS: Water flow at the rate of one cubic foot per second, which equals 7.48 gallons

F. Archaeology: The study of past human cultures based on the careful digging through layers of soil to gather artifacts and other data that are then analyzed and interpreted

G. Alluvium: deposits of clay, silt, sand, gravel, etc. that have been left by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain

H. Acre Foot: the volume of water per 1 acre of land (43,560 square feet) at a depth of 1 foot, which equals 325,851 gallons or 1,233 cubic meters

V. Basic Inquiry Activities:

(1) Where does the Santa Cruz River begin? The source of the river is in the higher terrain above the San Raphael Valley near the Arizona-Mexico border.

(2) What is the approximate elevation at its source? 9,200 to 5,000 feet (need to check)

(3) As the river flows downward (in terms of elevation) what natural process would occur? Erosion
(4) What is the term used for the level area beyond river banks? Flood Plain

(5) Read about the science of [dendrochronology](https://en.wikipedia.org/wiki/Dendrochronology) and briefly explain how this method of inquiry might help provide a more detailed reading of river history. This is the study of tree rings based on the theory that the rate of growth of plants is strongly determined by the quantity of water that is available for any given year. These have been catalogued by year and provide a record of wet and dry cycles for over the past one thousand years.

(6) What is this point of merger called? Mouth

(7) What do you think that is? it leaves the US and enters Mexico. No other US river leaves from and then reenters a bordering nation.

(8) The river leaves the US near Kino Springs, and eventually reenters the country near what city? Nogales, AZ (Nogales, Sonora, MX)

(9) What is the name of the largest city in the Middle Basin? Tucson

(10) Eventually it reaches what river as it completes its northward journey? Gila River

(11) First, if people near its mouth in the San Rafael Valley were to construct a dam to capture all of the river's water, would this mean that people downstream in Nogales and Tucson be unable to get any water from the river? No, because the watershed extends downstream with other sources of water becoming part of the Santa Cruz. However, it would lower the stream flow. In addition, in more localized portions, upstream users could suppress water from those immediately downstream.

(12) Briefly define the meaning of this term. A watershed comprises the total land area where water supplies a river, stream or lake

(13) What are two ways that we have already found to get some understanding of the Santa Cruz's past flow history? Evidence of bank erosion and the extent of its flood plain. Dendrochronology can also be used, but mainly to infer the possibility of higher or lower flows based on precipitation patterns.

(14) What is one characteristic of Range and Basin topography that can lead to rapid ("flash") floods? Steep terrain, particularly mountains tends to increase precipitation through a process called orographic lifting. Runoff occurs and can quickly descend through washes and feeder streams into the river valley. If the quantity and rate of rainfall is comparatively high, the river can receive much more water than its capacity to hold, which leads to flooding.

(15) What physical evidence might you find that indicates previous flash flooding? Gouged and severely cut out banks that leave a scarred look. Huge boulders or the remains of whole trees can also be indicators.

(16) What is the larger unit of measure used to identify thousands of gallons of water? An Acre Foot, which equals 325,851 gallons.
(17) Generally, what would the tendency for erosion and bank cutting be if the cfs is high? More erosion and scarring along the bank and increased flooding upon or even beyond the flood plain.

(18) What would determine a high cfs rate? This is relative to the carrying capacity of the river and the amount of water that was flowing in it before this episode occurred.

(19) We can predict that humans lived along the Santa Cruz because it and the floodplain provided at least what two kinds of benefits? Water in reasonably dependable quantities and proximity, plus fertile soil due to silting.

(20) What would be several limitations to these sources that would cause us to have to be cautious in using them to draw conclusions? These, especially the written documents, can be impressionistic and based on prior assumptions. For example, after a long, thirsty march running water can look huge, or if one is used to larger rivers such as those found from the Mississippi River east, the Santa Cruz could appear very disappointing. In addition, if the document is a report by some official, it may contain an agenda, using positive or negative statements, each distorted and biased, to get some favorable action. Unless they record a longer span of time they can at best be used as pieces to create small glimpses of a longer, more involved history. Finally, they are best used if integrated with the other methods to read the past identified above.

VI. Expanded Inquiry Activities

A. Examining a topographical map
   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. Very rugged terrain with peaks that lie five to six thousand feet above the river valley help to create the conditions that lead to flash flooding. Generally, at any point in time, the quantity of water in the Santa Cruz is greater than it would be if the area was relatively level.
   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? 325,851
      b. How many gallons of water equal the volume of 1 cfs? 7.48 gallons
      c. What other factors affect the volume of water to equal a rate of one acre foot per second? the width and depth of the river
   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.
   \[ 1884 = 16.88 \text{ cfs} \ (325,851 \text{ divided by } 43, \text{ divided by } 60 \text{ seconds, divided by } 7.48) \]
   \[ 1915 = 15,022 \text{ cfs} \ (325,851 \text{ divided by } 2.9 \text{ seconds divided by } 7.48) \]
   \[ 1977 = 23,548 \text{ cfs} \ (325,851 \text{ divided by } 1.85 \text{ seconds divided by } 7.48) \]
   \[ 1983 = 52,486 \text{ cfs} \ (325,851 \text{ divided by } .83 \text{ divided by } 7.48) \]

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?
   The river must dig deeper and push outward with much force, demonstrating the tremendous power (energy) required to do this. Water weighs approximately 8 34 pounds per gallon. (Note: An advanced math activity would be to have students calculate the force of moving water under different scenarios.)

c. Arroyo (Spanish name) + Flood plain indicates the historic flow pattern at its greatest extreme, a situation called a flood, with the first indicated by rapid or flash flooding and the second either by more gradual flooding (such as with continual, heavy rain) or (including possibly and) the above-bank consequences of flash flooding.

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 in estimating the probability of a future "100 year flood?" What might explain this trend? Since the trend has been upward and has enlarged the bank area, the carrying capacity of the river has been increasing. Higher cfs rates have therefore increased the likelihood of floods that might formally have happened only once in one hundred years. These higher rates are largely due to the actions of human populations in the Santa Cruz basin that accentuate those forces of nature. Examples of man-made causes include putting concrete along sides of major streams or washes to minimize erosion, straightening washes for more lineal housing developments, increased pavement and other structures that allow for faster run off, and defoliating land areas by overgrazing, preparing a field for crops or developing commercial and housing areas.

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:

   There is enough arable land for said town's people and the Sobaipuris. 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 Sobaipuris 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

   San Agustin del Tucson, November 24, 1777,

   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
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 its 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? Corn

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. “We have enough water for the cultivation of wheat, but not enough to grow the corn we need.”

3. What is the statement in Document # 2 that indicates the irrigation was used to raise crops around Tubac? “If Tubac shares Tumacacori water, damned up by the mission at that place, there is enough water for all.”

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

5. What was the primary purpose of Barragua, et al. for writing this letter (Document # 2)? To get more military protection

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? The river flow was deep enough that a bridge was needed [or the island in the middle]

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

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? May is normally one of the driest months of the year

9. Refer now to Document # 4. At what location was the flow of the Santa Cruz the highest? Near San Xavier Mission

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 questions to answer this.) June (May and June are both low so either answer will work.)

11. What was the likely source of Silver Lake? Santa Cruz River

12. What does Culver mean by “live” water? Surface flow [the river]

13. Culver’s term, “subterranean” water, refers to ___. Groundwater in the aquifer
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? Answers will, of course, vary but it should be clear that it was much wetter along the banks and that the river did flow year-round. Perceptive students might add that even though water did run above the surface throughout the year that the volume would have varied. Students might also describe more tall grass and other forms of greenery that would have been present where farmers had been planting crops.

TABLE: TUCSON PRECIPITATION RECORDS FOR THE PAST THIRTY YEARS FROM NOAA (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.)


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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.

VII. Assessments

A. Multiple Choice
1. Which of the following does not correctly describe the Santa Cruz watershed?
   A. International.
   B. Large differences in elevation.
   C. Generally drains to the south-southwest.
   D. It lies within a semi-arid region.
   E. Basin and Range topography.
   ANSWER: C (general flow is north-northwest)

2. Which of the following natural processes helps to increase the tendency for episodes of flash flooding in the Santa Cruz watershed?
   A. Dendrochronology.
   B. Orographic lifting.
   C. Topography.
   D. All of these.
   E. B and C.
   ANSWER: E (Topography and Orographic forces tend to increase rainfall with rapid runoff downstream)

3. Long-range measures of this region's climatic history can be gained primarily from
   A. Dendrochronology.
   B. Documents.
   C. Archaeology.
   D. Meteorology.
   E. Alluvium.
   ANSWER: A

4. Flood plains
   A. exist only in areas that are more humid than the Southwest.
   B. indicate that abnormal rates of water flow have occurred and their extent.
   C. are areas that farmers avoid because of large amounts of debris and rocks are found here.
   D. are not considered part of a watershed.
   E. none of these are correct.
   ANSWER: B

5. Which of following is indicative of erosion?
   A. Aquifer.
   B. CFS.
   C. Arroyo.
   D. Alluvium.
   E. Both C and D.
   ANSWER: E
6. Reading the history of the Santa Cruz River and its watershed back a thousand years or more would not include which of the following disciplines?
   A. Dendrochronology.
   B. Geology.
   C. Archaeology.
   D. Historical documents.
   **ANSWER:** D (These provide at best a record only three centuries old.

7. In regards to explaining extreme (abnormal) events in the water history of southern Arizona, the increased trend over the past century for catastrophic flooding is due to
   A. changes in climate due to global warming, which increases precipitation.
   B. human interaction in the watershed with natural processes.
   C. more frequent orographic lifting has occurred.
   D. increased levels of agriculture.
   E. redefining what is meant by "100 year flood."
   **ANSWER:** B (more 100 year floods have occurred because of statement B, but 100 year floods have been redefined to account for the capacity of the river to withhold higher cfs rates because of bank widening, and has thus been adjusted for a 1 in 100 probability)

8. If each in a family of four used 180 gallons of water per day, how long would it take to equal an acre foot?
   A. One week.
   B. One month.
   C. 367 days.
   D. 453 days.
   E. 2.5 years.
   **ANSWER:** D (180 x 4 divided into 325,861 gallons, which = 452.57 days)

9. According to the USGS, the Santa Cruz lies within which of 21 watershed regions?
   A. Colorado River Basin.
   B. Gila River Basin.
   C. Sonora River Basin.
   D. Great Basin.
   E. Arizona Basin.
   **ANSWER:** A

10. Historically, the Santa Cruz River
    A. is geologically the oldest one in the Southwest.
    B. is the only U.S. river to flow northward instead of southward.
    C. almost never flowed above ground.
    D. had areas of above-ground flow and places where it descended below ground.
    E. was unimportant to people living here because it offered very little water.
    **ANSWER:** D (Statement E is quite opposite of the truth that the student should grasp by now: this river has been vital to people living here.)

B. Alternative assessments may be devised as deemed appropriate by the instructor

II. Enduring Understandings
   A. The Santa Cruz River is unique because it is the only US river to leave this country
and then reenter, flowing southwest in extreme southern Arizona into Sonora before turning north-northwest to eventually enter the Gila River to the southwest of Phoenix.

B. The topography of southern Arizona produces a watershed prone to flash flooding.

C. In the past century, human interactions with natural processes have tended to increase the number and extent of severe flooding (100 year floods).

D. Moving water as cfs rates increase has tremendous power.

E. "Reading" the history of the Santa Cruz River is a complex process involving many disciplines of inquiry.

F. The Santa Cruz River has been influenced by recurring cycles of wet and dry.

G. Except during very wet periods, historically the Santa Cruz River semiarid environment, along with the area's geology/hydrology has not allowed it to flow above ground from source to mouth.
Santa Cruz Water History Inquiry, Question Three

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

INSTRUCTOR'S GUIDE

PRIMARY LEARNING OBJECTIVE: Students will understand how different cultures over the past ten millennia have adapted to life in the Santa Cruz watershed.

III. Basic Inquiry Concepts to be learned and applied:
A. Epoch: A period of the past identified by distinctive characteristics
B. Hohokam: A Pre-Columbian culture group that effectively exploited and manipulated surface water resources in the Salt, Verde, Gila and Santa Cruz basin to build and support relatively dense population clusters
C. Pimeria Alta: The Spanish Colonial name for southern Arizona that created a socio-political identity around the various bands of "Pima" Indians whom they sought to incorporate into the Spanish imperial system
D. Hispanic: An identity that indicates a mixed Spanish and American Indian heritage
E. Acequia: The Hispanic communal system of shared water use for farming and personal use
F. Cienaga: In the Southwest, a non-forested area, often grassland, that may be seasonably dry
G. Riparian Right: A legal principle that recognizes the right of an individual landowner to use their proportionate share of adjacent surface water
H. Prior Appropriation: A legal principle that became common in the West including Arizona whereby whomever was first to use surface water was entitled to the continued right irregardless of other people's desires downstream
I. Beneficial Use: Under Western water law, including Arizona, a prior user has the right to appropriate water to be used productively either for personal needs or economic ones
J. Winters Doctrine: Based upon the U.S. Supreme Court decision Winters vs. United States (1908) upon which Indian rights to water are supposedly guaranteed
K. Hydraulic Society: Used to describe the dependency on pumping and transporting water to where individuals and groups want to use it
L. Industrial Ethos: The set of behaviors that are based upon the belief that resources should be developed and processed to improve the material basis of human life
M. **Reclamation:** A value incorporated into water law that encourages irrigation in dry lands and hydro-electric power to support the energy needs of an industrialized society

IV. **Basic Inquiry** (found in the students’ copy)

V. **Basic Inquiry Questions**

A. **Hohokam Reading**

1. Raising corn in southern Arizona began about how many years ago? ~4,000 years ago

2. What region provides the immediate source of corn agriculture in southern Arizona? **Mexico**

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 preceded the Phoenix area’s development of corn agriculture? The "north-first" view (as the countering view) might be supported by archaeological evidence reinforced by dating techniques such as Carbon 14 or from dendrochronology. Water was more abundant in the Salt/Gila complex because it drains a much larger surface area with higher average precipitation totals because of higher elevations relative to the drier deserts below. Today dams provide water to this area, but until the last century they had had a perennial flow at least down to about where Interstate 10 is today. It might also be possible that water resources along the Santa Cruz were viewed as presenting greater difficulty because of the river system’s more erratic flow. The Hohokam in the Tucson Basin practiced flood-plain agriculture, indicating that they needed the runoff from the spring snow melt in the mountains to provide water in expanded areas, but still smaller in total area than found along the Salt-Gila. However, recent archaeology in preparation for Tucson’s rio Nuevo project has pushed the clock backwards considerably for corn agriculture here. Until more archaeological work is done in the Salt-Verde valleys (where this might even be possible today) the "southern" view has gained more support.

4. Summarize the inter-relationship between the river, corn-based farming, and cultural development for the Hohokam towards and beyond 1000 C.E. This is direct and somewhat complex. Irrigating the river increased the amount of food resources, which in turn greatly increased caloric energy available for larger human populations. Because they lived in Rancherias they could benefit from pottery (that might otherwise break if carried from place to place), which could store food better than could baskets.

5. How might attitudes about the river and the rules about the use of water been affected by the development of intense farm irrigation? Water would have been regarded as more important than ever and social customs would have been more complexly organized around the need for cooperation in building and maintaining the irrigation works and how water was used.

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? The Santa Cruz through much of the west portion of Tucson plus parts of the Rillito, Pantano and CDO, especially near their confluence with one another, must have had a fairly dependable flow during the period of cultivation.
7. Why might too much water, i.e. flooding, have possibly presented problems for the Hohokam? Located near the river bank and on the flood plain, their fields were vulnerable to periods of heavy runoff and so, too, their irrigation works.

8. What role did water possibly play in causing the disappearance of the Hohokam culture? It has been argued that drought led to population dispersal and decline. (Tree ring data lends support to this explanation)

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? Dating human settlement here back to 4000 years ago, which makes a claim for Tucson being the oldest continuously inhabited site in the US, shows the central importance of Santa Cruz water. Bill Doelle of Desert Archaeology is quoted as saying, "It was not a city. But even if they went away (periodically) people kept coming back, because of the water and because A Mountain presented a high point to look from-for attackers or to look at the sky." In a settlement that derives from 1500 years later, a canal was its central feature. According to Gregoris and Reinhard, irrigated agriculture made a geographical leap frog north to the Salt River Valley before moving south. These findings place that view in doubt. In addition, since the Hohokam appear over 1000 years later, they may well have acquired their irrigation technology from these earlier Santa Cruz residents.

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? Since the Spanish were interested in mineral wealth and not building a sustainable agricultural base to expand colonization northward, it would be likely that descriptions of the Santa Cruz valley would be limited and vague. Some evidence might be found in documents relative to the issues of movement and of available water. Also, since results were disappointing, it can be assumed that few expeditions were made here during this time.

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? The desire to convert Indians to Christianity gave a purpose for permanent Spanish settlement in southern Arizona. Since missions would have to be sustainable, largely self-sufficient, water for humans, crops and livestock would have been crucial. Any surviving written document in the form of reports, journals and letters might provide a glimpse at least of the water history from that point.

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? Cattle ranching. Most likely, as herds spread northward, movement towards the Santa Cruz, which loops into Sonora before re-
crossing the border would have been made because of water and because generally river valleys serve as natural land routes.

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? Although a missionary Kino was a born explorer. Combined with his training as a cartographer he is an important source of geographical information. He should provide us with some clues at least.

3. What important clue about Santa Cruz water history is provided by the name of Tucson? An Indian village near the base of A Mountain existed when Kino arrived. They had located there because of a spring that emerged to the surface and evidently fed the river, which is where Tucson gets its name.

D. The Period of 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? The end of relative peace led to increasing Apache raids on isolated ranches, farms and settlement in southern Arizona and northern Sonora. This lowered the demand for water and probably helped to rebuild the aquifer and allowed for more river flow.

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? West of Albuquerque at Acoma
   b. What system was applied from their previous in Europe experience by the Spanish? The acequia (canal) system introduced by the Moors during Europe’s Middle Ages
   c. Why did the demands of building and maintaining an irrigation require a community effort? Building and maintaining a diversion dam and headgate, lateral ditches to the farms, and a channel that returned surplus water to the source benefited each farmer and required shared labor.
   d. How, then, did climate influence the socio-political order during the Hispanic presence in the Southwest? Since the quantity of water was determined by organizing effective control of available surface water a communal sense of being was created.
   e. What were the two different titles of those who were in charge of the acequia? Mayordomo in New Mexico or zanjero in Arizona and California.
   f. Describe the structure and system of the acequia and determine to what extent it was democratic. Since the mayordomo and zanjero were appointed by commissioners who were elected by water rights owners this was a democratic system. However, since this “ditch boss” was the chief person in charge of the acequia, its structure was hierarchical.
   g. What is the legacy of the zanjero? In hundreds of communities in New Mexico this system has continued for four centuries and must be effective. More recently, Tucson Water implemented this authority to lower water use.
   h. In an individualistic, market-based society what is the lesson that the concept of zanjero can teach us, especially for the Southwest? The key issue here that the concept of zanjero highlights is whether or not water should be
considered a private or public resource. This is especially important when applied to a semi-arid or arid region. Thus the question for debate is: in a largely semi-arid region should water be viewed as a community resource, used by individuals who are aware that their actions affect the wellbeing of all of those who live here or remain within the context of a market system?. However, economic incentives must also be applied in a market oriented society as illustrated in the example of Tucson Water.

i. (This question applies AWWA information with the reading from Martha Summerhayes): What can we observe from what Martha Summerhayes tells us? In this setting water made life bearable in the hot desert. Based on the needs of the military and its dependents, the acequia functioned very well, and given the hierarchy of military command, the post commander, or whomever he appointed could function in the capacity of the zanjero. It is possible that a person with the experience of being a zanjero was so used, although we cannot determine that from what Martha Summerhayes tells us.

E. American Territorial Period (1856 to 1912)

1. What economic activity strongly influenced how Arizonans would view water rights? Mining

2. Ironically, what feature of western water led to the understanding of rights based on prior appropriation? The relative scarcity of water

3. Prior appropriation contrasts with the Hispanic acequia system most in what way? It emphasizes an individualistic approach to use rather than a communal, or shared use

4. How did prior appropriation fit well with what was termed the "industrial ethos"? The industrial mind-set commodifies resources (i.e. gives them an economic value) and seeks to create surplus for sale in the market. Prior appropriation supports those who are first eager and aggressive to control water in the production process such as mining and farming

5. Why is control (such as of water) so important in the capitalistic system? Control is the means to minimize risks to investment and to lower production costs so that profit goals can be met or exceeded

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? This is a term applied directly to the properties of water itself. In particular, it expresses the idea of engineering. As irrigation efforts expanded and as pumping groundwater went deeper, increasing quantities of water were being harnessed for expanding commercial use and to meet the needs of larger populations. In other words, hydraulic applies directly to the conscious action of bringing huge quantities of water from their source(s) to where people wanted this water to be.

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? Without legal support large-scale development of the land would have been discouraged.
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? Prior appropriation allowed Hughes "to get there first," i.e., to literally tap into the river upstream in order to expand his crop irrigation.

9. What was the environmental consequence of Hughes's ditch? It undermined the river while creating a channel for flood waters that came through in 1890, which significantly widened the river, enabling faster stream flow.

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? 1940, the last year of recorded surface flow between Martinez Hill and Sentinel Peak.

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? 40 acres (which is 492 sq. miles)

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. It would be lower because of the various dams north of here that hold back water into various lakes and reservoirs.

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? Surface figures are without depth, which would allow for calculating volume (gallons). In addition, it does not include groundwater in aquifers. What it does indicate, especially when we examine an Arizona map, is why southern Arizona has been so dependent on groundwater.

4. What hydrologic concept did John Wesley Powell fail to get Congress to recognize in his 1890 report? Watersheds, where political authority was more logically organized by divisions based on watersheds so that irrigation could more efficiently and effectively be developed in this arid region.

5. What is the significance of the National Reclamation Act for Arizona and the West? This began the era of aggressive dam building for expanding irrigation and hydroelectric power that has supported ever larger human populations (the first project under this 1902 law was the Salt River Project, which has allowed the city of Phoenix to become one of the ten largest in the United States).

6. What is the distant connection between the Hohokam and the "hydraulic society?" Epochs of higher than average populations (over the past ten thousand plus years) in the Santa Cruz Basin since both cultures utilized a sophisticated system of water use.

7. What is the root word of reclamation and what does its meaning tell us about how "industrial" man perceives water in his world? The root word is "reclaim," which means to take back. Reclamation suggests a vision and a belief that wet land is natural rather than dry land since water sustains life. Thus, industrial man has engineered ways towards "squeezing" every last drop out of rivers before they reach the sea and of pumping groundwater from prehistoric storms. Another way to view this term is to recognize that in a world systems based society the demand exists to create the
infrastructure to move resources (including water) to the desired points of consumption.

8. What is the logical connection between the National Reclamation Act and CAP? Engineering part of the Colorado River to flow into southern Arizona to augment surface water and reduce groundwater so that people can continue to live where water normally is not in sufficient quantities.

9. Answer these questions from the reading Seeking Sustainability, Chapter 2, "Looking to the Past to Understand the Present," from "EARLY 20TH CENTURY EXPANSION to "CENTRAL ARIZONA PROJECT", pp. 7-10. 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? Urban sprawl and the rising cost of expanding the water system. Water shortages were experienced and restrictions on water use were imposed.

b. What happened that should have caused observant people to see first hand the relationship between surface and groundwater? As wells pumped to ever lower layers, they robbed the river of its surface water so that after the early 1940s the Santa Cruz no longer had a sustained surface flow through the Tucson area.

c. What caused an extensive mesquite bosque south of San Xavier Mission to die in the 1950s? Expansion of the well field and deeper pumping. (Mesquite can tap down to about 80 feet, so this is an indicator of the lowering level of the aquifer.)

d. In what area near Tucson did city leaders actively seek to secure additional groundwater to meet its growing thirst? The Avra Valley

e. What was the chief cause for significant water problems in Tucson by the mid 1970s? Rapid population growth

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? A flat rate no matter where you lived meant that urban sprawl could continue without concern for cost of delivering water through an expanded system, which might 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? Yes, per capita use was among the lowest in the state, partly due to the demands of the 1980 Groundwater Management Act

VI. Expanded Inquiry Activities/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. This question encourages the student to examine how technology has allowed the deferment of problems of scarcity that tend to enhance dependence on the resource exploited and the
technology that provides it. A good example of this is the deep pumping of the Ogallala Aquifer in the former Dust Bowl and the same in the Santa Cruz Basin where well depths dropped considerably after WWII, and in some cases, such as near Eloy, caused significant subsidence. If the technology allows demand to exceed what ultimately is a finite supply, then it only defers the problem, which is what the GMA was supposed to begin reversing.

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.):

http://www.ci.phoenix.az.us/PUEBLO/dfdisapp.html

One essential lesson of history is that all great civilizations have had a rise and a fall. Does any reason exist to argue that ours will break that pattern? While a student might argue otherwise, the Hohokam example is apt because these people stretched the semiarid landscape to the limits of their technology. We do not know why they disappeared (and disappearance seems to be the best way of describing what happened based on the archaeological record). However, climatic extremes and salinization problems probably played a role. War and disease, also both tend to intensify as populations become denser and compete for resources. It would be dangerous to allow our students to think that we alone can stand outside history. At the very least, thinking about this with the Hohokam as context should increase their awareness of the problems of survival that are too often masked by modern life.

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? This question invites interesting and contrasting views that are becoming more evident in the public debate. In an economically driven society it has been demonstrated many times that the profit motive (production side) and the cost (producer) price (consumer) concerns of "environmentally friendly" performs better than idealism in changing behaviors. This is true, for example, with recycling. If water rates rise, price sensitive users do try and restrict use. However, dangers exist if water is defined primarily in terms of economic value rather than more mystical, spiritual, intrinsic life-giving or aesthetic values. Critics argue that water bought and sold to the highest bidder would be harmful to the poorest groups., and cite evidence that that this already happens, especially in Third World countries. Others argue that many poor countries do not have sufficient capital to develop adequate water systems and that this can only be done by providing incentives to private companies to build such an infrastructure. Students might be asked to debate this issue and to find ways of building a compromise position.

4. Should Americans, and Arizonans in particular, shift to viewing water communally? The reading about the zanjero (click here to refresh if necessary) will help add perspective. Essentially, if everyone needs water to survive should water be controlled by private individuals and groups or be allocated more fairly to ensure that all have enough? This may be easy to
support until one probes more deeply and realizes how water has flowed into the mainstream of capitalistic society. An example of this fact is the question of big users (e.g. agribusiness) versus individual consumers. Restricting water rights for big irrigation farmers so that no one goes thirsty places higher demand on farm products (and therefore higher costs). What is a fair proportion? In addition, whose thirst should be considered, just humans or wildlife as well? What about competing demands: irrigation water vs. recreation, fishing or navigation interests? These kinds of issues get back to question number 3.

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. Assessment of student response to this inquiry should seek to measure how well students understand the competing that economic interests apply, which usually has large, receptive (and thus politically powerful) audience and concerns about health, safety and water quantity and quality issues. Finding the balance is difficult, an important understanding that the student should express.

VII. Assessments
A. Multiple Choice
1. The earliest known human culture to take up residence within the Santa Cruz River Basin were
A. the Hohokam.
B. the Spanish.
C. Pimeria Alta.
D. Clovis hunter-gatherers
E. None of these.

**ANSWER:** D

2. Which of the following are the first known people to use surface water in the Santa Cruz Basin for crop irrigation?
   A. the Hohokam.
   B. the Spanish.
   C. Pimeria Alta.
   D. Clovis hunter-gatherers
   E. None of these.

**ANSWER:** A (Note: If students have read the article about recent archaeological findings due to the Rio Nuevo Project, then they would know that strong evidence exists to extend this back to about 2000 years earlier.)

3. For the early Spanish explorers, the Santa Cruz and San Pedro rivers would have been valued most for their
   A. water to irrigate crops.
   B. water to extend cattle ranching.
   C. drinking water and a natural route of travel.
   D. large deposits of gold and silver.
   E. both A and B.

**ANSWER:** D (Note: this answer requires the student to infer as a part of creating a category of distinction to identify this epoch.)

4. What would be the best statement to help place Father Kino's story within our larger context of water history?
   A. Father Kino depended on the river water to make his explorations.
   B. The Spanish leaders sent Kino north specifically to locate water sources.
   C. Kino's missionary efforts would have had their largest potential among more densely populated Pima Indians, who would have lived near easily accessible water.
   D. Kino brought laborers to build wells as a part of building mission structures.
   E. Father Kino cannot be placed within the context of water history.

**ANSWER:** C (Note: this requires students to make connections with the information provided.)

5. What modern day place name has a hidden history that identifies the importance of water to life in southern Arizona?
   A. Tubac.
   B. Tucson.
   C. Pima.
   D. Nogales.
   E. Eloy.

**ANSWER:** B

6. Martha Summerhayes comments about the acequia suggest that
A. water was more plentiful in southern Arizona because many more wells were dug.
B. it was a system considered too primitive by the U.S. military.
C. without demands for intensive use, this system easily served the communal needs for each of the water users then.
D. since it was so democratic, the military hierarchy found it a difficult system to use.
E. it was being rapidly replaced as too primitive.

**ANSWER**: C

7. The legal doctrine of prior appropriation fit quite well with
A. communal values.
B. the Anglo-American emphasis on individualism.
C. Indian rights to water.
D. agri-business, but not with mining.
E. the concept of riparian rights.

**ANSWER**: B

8. The industrial ethos that began to affect the Santa Cruz Basin’s water resources
A. placed a higher value on ground water than surface water, which allowed the Santa Cruz River to continue flowing well into the 20th century.
B. sought to maximize resource use to expand the profit potential, which led to a growing tendency for water demand to exceed supply.
C. led to much manufacturing in southern Arizona as an extension of the kind of industrialization taking place in the east.
D. began to recognize riparian rights over prior appropriation.
E. placed a higher value on conservation because those efforts lowered production costs and thus increased profits.

**ANSWER**: B

9. John Wesley Powell thought that given the reality of the physical geography the Far West
A. that building dams should be discourage because the topography presented a definite danger of destructive flash flooding, which would cause many dams to break under the pressure.
B. it was necessary to divide the West in a linear pattern to form roughly equal sizes for future states so that each would have approximately the same amount of water.
C. that populations would also be sparse except in areas closest to rivers.
D. it was more logical and practical to create political divisions built around watersheds where irrigation projects would green the land.
E. None of the above.

**ANSWER**: D

10. Prior appropriation and the *Winters* decision
A. are consistent with one another.
B. both tend to benefit the water rights of Indian tribes.
C. both hurt Indian rights to water on their reservations.
D. encourage a "fair use" doctrine.
E. tend to contradict each other when defining the primacy of water rights.

**ANSWER:** E (Note: what the student should recognize is that if *Winters* overrides prior appropriation, then the water rights of non-Indians are restricted even if the water use occurred before the Indians determined a need for it. The courts have not been consistent in part because the language of the 1908 decision lacked precision and was vague about future needs on reservation. In addition, because so much is at stake and politics is tied to litigation, that Indian rights have and will likely continue to be at risk when so much is at stake.)

11. Using the concept of hydraulic society we can see how the Newlands Act
A. helped open up undesirable areas such as Arizona by pumping federal money for massive highway and railroad construction.
B. inaugurated an era of massive irrigation projects across the West that transported water and its energy to support economic and social growth.
C. provided money to those who wanted to establish farm homesteads on desert lands.
D. provided federal money to clear and level areas for housing development, thus making new land out of old unusable land.
E. established strict federal laws for the pumping of underground water for commercial use.

**ANSWER:** B

12. One of the chief problems with water rights law has been
A. that it has given a preference to small landowners because it grew out of a democratic, common law era.
B. that it has mainly dealt with groundwater rather than surface water use.
C. that it has been based on riparian rights, which are more effective in humid areas rather than in drier areas.
D. it has given preference to Indian rights to water as "prior users."
E. that it has treated surface and ground water as separate from one another.

**ANSWER:** E

13. In 1908, the city of Tucson experienced its first water crisis because of what action that continues to affect the city?
A. a shift from planting wheat to more cotton in the surrounding area.
B. residential expansion.
C. sustained drought.
D. three central wells became contaminated with arsenic.
E. water rates were raised too quickly, angering citizens.
ANSWER: B

14. What more than any other factor increased the cost of water to businesses and consumers in Tucson during the 20th century?
   A. more water treatment to ensure quality.
   B. reduction of federal subsidies that had helped to keep costs down.
   C. expansion of the water system due to expanding population.
   D. as the city expanded people lived farther from the main water supply, the Santa Cruz River.
   E. water costs actually went up only a few per cent.

ANSWER: C

15. For the thousands of years of human history in the Santa Cruz Basin,
   A. the Santa Cruz River was a major artery of transportation until it finally ran dry during the 1940s.
   B. drought has rarely occurred and usually only for no more than a year.
   C. the Santa Cruz River was mostly dry.
   D. water has been the key to sustaining life.
   E. no technological advances occurred until after the American Civil War.

ANSWER: D

16. If one looked at a map of southern Arizona and observed areas called cienagas, which of the following statements would best show good historically-based water literacy?
   A. This indicates a period of time, generally before the 20th century, when the water table was close to ground level in many areas, and water from precipitation could collect in low spots and remain except through longer periods of dry weather.
   B. This indicates where the U.S. military built their forts because the cienagas were natural holding tanks where irrigated water could be stored for drinking water and for recreation.
   C. These are areas mostly along river and streambeds that functioned as "sinks" where water was the deepest and of the best quality for drinking.
   D. A cienaga is a Spanish word meaning an irrigation storage ditch and one could look at this map and pinpoint the location of villages built by the Spanish, often the same places that the Pima Indians lived and farmed.
   E. Cienagas mean "sink holes" in English, i.e., areas of subsidence that are caused by excessive groundwater pumping that endanger the stability of structures that lie above and which permanently close off areas of seepage into the aquifer.

ANSWER: A

17. In tracing the history of Arizona water law, which legal decision or legislative act supports a person's right to water on the basis of the principle of "first in time, first in right."
   A. Clough vs. Wing.
B. Kent Decree.
C. Groundwater Management Act
D. Winters vs. United States.
E. A, B and C above.

ANSWER: E (Note: Both A and B clearly articulated the principle of prior appropriation. In some ways, one might argue that the Groundwater Management Act of 1980 (C above) reversed prior appropriation as it attempted to put the brakes on groundwater overdraft. However, with its grandfather provisions and allowance to sell excess water, this law still recognized the rights of prior claimants who had used large quantities of water. Winters, (D above) threatened prior appropriation rights by creating language that suggested (because it lacked the necessary legal precision) that Indian reservations, whenever created, had an implied right to water to meet the needs of people living on that reservation. In fact, it originated in a lawsuit by Henry Winters and his neighbors who were irrigating along the Milk River upstream from the Fort Belknap Reservation in Montana. The lawyers for Winters argued on the basis of prior appropriation law and lost. Nevertheless, it must be viewed as contradicting the doctrine of prior appropriation. See, http://www.crcwater.org/issues6/19981129waterrights.html.)

18. Under prior appropriation water law, which of the following would not normally be considered beneficial use?
A. Mining silver.
B. A water supply business.
C. Canning vegetables.
D. Paper pulp mill.
E. All of the above represent beneficial use as normally defined by that law.

ANSWER: E

B. Short Answer Essay
1. Using the concept of hydraulic society describe the relationship of the coming of the transcontinental railroad and the increased use of groundwater in southern Arizona. The railroad represents a modern component of an improved technological infrastructure. The railroad tied the local economy to the national and international market system. Agribusiness and mining used water in the production process, and as the desire to profit from this growing market connection, more demands were placed on water.

2. Draw a chart or construct a graphic that illustrates the long connection between human life in southern Arizona and the role of water. Students should indicate major historical epochs and their primary characteristics and illustrate the interaction of these groups with water resources and the consequences. Assessment should include how well students convey a sense of chronology and understand what happened to water resources as a result of the actions taken to support the social group.

VIII. Enduring Understandings
A. Water, readily available near and along the Santa Cruz River, has been the basis of human occupation in the Santa Cruz Basin.

B. Most of the human part of the water history of the Santa Cruz Basin has been based upon a communal sense of sharing surface water.

C. The Hohokam were the first to develop a system to extend the possibilities of human life in southern Arizona by building elaborate irrigation and water harvesting systems.

D. With the coming of the railroad in 1880, an aggressive "industrial ethos" rationalized the aggressive use of water extending to groundwater.

E. When the balance between supply and demand was lost is strongly debated, but as fact this excessive use threatens future human life in southern Arizona.

F. The doctrine of prior appropriation still functions as the main legal definition determining water rights in Arizona.

G. The Arizona Groundwater Act of 1980 was an important first step in a long process in trying to create a balance between use and sustained supply.
Santa Cruz Water History Inquiry, Question Four

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

INSTRUCTOR'S GUIDE

PRIMARY LEARNING OBJECTIVE: Students will understand how political and legal decisions have significantly impacted water supplies and water delivery systems in southern Arizona and the greater Southwest.

III. Basic Inquiry Concepts to be learned and applied:
A. Cappaert Rule: Based on the U.S. Supreme Court decision in 1952, the federal government has a protected right to water irregardless of state water use law.
B. Tucson AMA: As required by the 1980 Groundwater Management Act, this 3,866 square mile section of the middle Santa Cruz River Basin monitors and sets goals to achieve "safe yield" by 2025.
C. Santa Cruz AMA: As required by the 1980 Groundwater Management Act, this 716 square mile sub-section of the upper Santa Cruz River Basin extending to the Arizona-Mexico border monitors and sets goals to maintain "safe yield" through 2025.
D. Surface/Ground Water: The basic hydrologic understanding that water flowing above ground and underground are interdependent.
E. Recharge Water: Used to identify water that rebuilds the watershed, a process that can be achieved by practices that allow water to filter into the aquifer.
F. Renewable Water Supply: The rate of water, stated by volume, that potentially or theoretically can be indefinitely available for use in a designated area.
G. Water Budgeting: Applied to managing and monitoring water inflow and outflow by user categories stated in measurable units, such as acre feet or cubic yards/meters, creating "paper water" for accounting purposes.
H. Safe Yield: As defined by the Arizona Groundwater Act of 1980, achieving an approximate balance between the use and supply of groundwater.
I. Banking Water: A method of accounting for retained rights to equivalent measured quantities of unused water, which lawfully could be used or be transferred to another at some future date.
J. Effluent: Waste water that has been treated and potentially available for reuse.

V. Basic Inquiry
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? Water rights traditional have applied to ownership of the land, the kind of individualism supported by laws democratically conceived and written. It also reflects the "taking for granted" attitude about the abundance of water. Even though water serves an ultimate public need the individuals, groups and agencies do not usually want to limit their rights to water and because so many exists, it becomes more difficult to effectively monitor use.
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? This question offers an opportunity to voice an opinion. It really is intended as a check to see if the student is aware of traditional attitudes about water and how they have affected water rights. In particular, it is commonly said that water is free like the air we breathe, and it is only the cost to deliver it for which we pay. Water is less abundant than air so one can argue how free it really is. As for delivery costs, students could be engaged to explore how many users do not pay the true delivery costs due to government subsidies of various kinds. Support for an answer/opinion should be with facts that identify the role of interest groups in the democratic process along with basic cultural assumptions and beliefs. An answer might include the lack of water literacy to create the kind of public pressure to rethink about water from an individualist to a communal supply perspective.

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? First, we have a federal system, with two levels of jurisdiction, state, and "national ("federal"). Second, water rights have been largely left to the states to determine. Third, Indian Law complicates the picture with supporting legal right to a guaranteed water supply (Winters, 1908). Fourth, acting to protect Indian water rights at times as well as federal facilities and lands within state boundaries, the federal government has sought to supercede state law (such as in Cappaert v. United States, 1952). Fifth, water either above or under ground, does not recognize man-made political boundaries. Thus in state to state issues and international ones, especially with Mexico, one state such as Arizona cannot decide on water use alone since other entities are affected.

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? Because of a more local constituency, states are more responsive to localized interest group demands. Drawing from a national political base, the federal government is in a political position of having a much lower risk in taking such actions.

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? If the question of who is one that people decide. If it means who can use, then this also includes wildlife. For the interested student, a more in-depth look at wetlands in the U.S. and their evolution as an issue can be found at this website: [http://water.usgs.gov/nwsum/WSP2425/history.html](http://water.usgs.gov/nwsum/WSP2425/history.html)

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? [http://ag.arizona.edu/AZWATER/publications/sustainability/report_html/groundwater](http://ag.arizona.edu/AZWATER/publications/sustainability/report_html/groundwater) (BAD LINK)
The Commerce Clause, Article One, Section 8, Clause 3); Gibbons vs. Ogden, 1824. Note: If desired, the student can explore the Rivers and Harbors Appropriations Act of 1899. While this has little application for Arizona, it does further emphasize the power of the national government to supercede state laws. See <http://www4.law.cornell.edu/uscode/33/401.html>.

7. The Arizona Groundwater Management Act, click here 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? Groundwater Management Act, which suggests that the state of Arizona was seeking to coordinate how groundwater was used across the state.

b. What are AMAs and INAs and why were they created? These are Active Management Areas, identified as those sub-regions of the state with severe overdraft of groundwater, and Irrigation Nonexpansion Areas, where new pumping for agriculture is limited, but other pumping is not.

c. What does the GMA require each AMA to do? Each must develop a series of five plans, the first four being ten years in length and the last five years, towards reaching sustainability, i.e. a balance between supply and demand.

d. What term expresses the understanding of "sustainability," and how is it defined? "Safe yield," which involves working towards and maintaining a long-term balance between the annual amount of groundwater withdrawn and the annual amount of natural and artificial recharge within an AMA.

e. Is the goal, then, of the GMA to realize true balance between groundwater supply and the demand for it? No, safe yield means to significantly slow the rate of groundwater use, implicitly to extend the sustainability of life in Arizona further into the future than the then (1980) use rate would have allowed.

f. How is the rate of groundwater overdraft expected to fall over the 45 year planning period? From recharge of CAP water or other surface water.

g. How might the quantity of surface water be increased for recharge other than by CAP? By building reservoirs and more efficient use of effluent.

h. How is demography used in creating the projections in the AMA plans? Population growth is projected with an assumed per capita use times that number.

i. What other factors are used in projecting the groundwater budget? Use by agricultural and industrial producers and Indians.

j. What do the terms "paper water" and "wet water" mean, and what essential fact about water budgeting under the GMA does this indicate? Paper water is the figure calculated - assumed -- to be available for recharge, while wet water is the actual quantity of water that is recharged and available for use. What this suggests is the budgeting process is open for optimistic projections so that an AMA would look like it is coming closer to a safe yield that it really is.

k. Regarding new subdivisions, what does GMA now mean by the phrase, "assured water supply?" Sufficient quantities of water for the next 100 years consistent with quality and conservation criteria.

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? Their customers are under no direct legal obligation to limit personal water use.
m. What is one way that these water suppliers (question 1 above) can encourage their customers to practice water conservation? By increasing water rates. However, this involves a process of public hearings.

n. What factors impact the effectiveness of GMA conservation measures for agricultural water use? It would seem that since the water duty was based upon a figure from a high period of irrigation with the permitted flexibility to bank water against the future water duty, that this law does not effectively promote conservation. Since agriculture still accounts for over 70% of water use in Arizona, this is significant.

p. What are some suggestions that you would make to encourage each person to conserve water? Install low water shower heads, low-flow toilets, check for and repair leaks, collect rain water, and xeriscape are among the ways that people could conserve personal water use, and thus reduce groundwater depletion.

For other ways click on this link: > http://water.az.gov/Water_Use_it_Wisely.htm (BAD LINK)

Link to xeriscape: http://www.xeriscape.org/xeriscape.html

VI. Optional focused Inquiry based on reading Tucson and/or Santa Cruz AMA

1. Describe each AMA in terms of size (square miles), major geographic boundaries, and major municipalities. TAMA: 3,866 sq. miles bounded by northern Santa Cruz county on the south and southern Pinal County on the north composed of two basins, the Santa Cruz and Avra Valley. By far, the largest city is Tucson with at least 3/4 million people. Smaller cities include Marana, Oro Valley, and Green Valley (unincorporated, but with a population approaching 20,000). Also included is the San Xavier Tohono O’odham reservation. The SAMA is 716 sq. miles extending through the Santa Cruz Valley (Upper Basin) from the international border on the south to northern Santa Cruz County, south of Green Valley. Nogales is the largest city here with just under 19,000 people in 1995.

2. In regards to safe yield, what distinguishes TAMA from SAMA? TAMA has not achieved safe yield unlike 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 this exercise is to help you realize how much of an overdraft of groundwater each user currently consumes.) Per capita use would have to drop to 119.6 GPCD. (This is calculated as follows: 98,667 AF, which is the current deficit times 47.3%, which was the 1994 use percentage. That result is 46,669 AF. Total consumption in the municipal sector for 1994 was 142,202 AF. The later figured divided by the former -- 46,669/142,202
is 32.8%. This means that the GPCD would have to be cut by 58.4 GPDC or by subtracting 58.4 from 178, a GPCD of 119.6.

4. What accounts for SAMA’S present safe yield designation and what might danger that status in the future?

Comparatively low population since the three largest water companies serve around 35,000 people, which should account for over 80% of the total population. Also, while agriculture uses about 60% of the total water, that figure is only 11,873 AF. In addition, with lower average temperatures and higher precipitation totals, crops require less water use than in the TAMA. Dangers to safe yield will come from increased population, including that of Nogales, Sonora where increased water use threatens to reduce surface water flow of the Santa Cruz and groundwater underflow, although the latter is a relatively small amount.

VII. Assessments

A. Multiple Choice

1. In Arizona hundreds of groups, many of them companies, have ownership rights to water, which

A. currently are not regulated in any way by state or federal authorities.
B. complicates the problem of managing any water conservation program.
C. illustrates that water is still seen in natural, non-economic terms.
D. are scheduled to revert to public ownership by 2025 according to the Arizona Groundwater Management Act of 1980.
E. Both B and C are correct.

ANSWER: B

2. Currently in the state of Arizona, water resources are

A. managed by a central department, the ADWR (Arizona Department of Water Resources.
B. taken for granted as inexhaustible, which explains by no state-wide hydrological survey has been done.
C. being used wisely, with strong conservation policies and methods in place.
D. not monitored by a single agency, but instead uncoordinated by several that include the ACC and ADEQ.
E. effectively defined by law to include the inter-relationship between surface and groundwater.

ANSWER: D

3. Under American federalism,

A. generally water use rights are a matter of state law.
B. the federal government has the sole power to determine where and how water is used and by whom.
C. Indians have primary water use rights, the federal government second, and the states last in line.
D. only when it comes to navigation issues does the federal government have a primary right under constitutional law.
E. A and D are correct.

ANSWER: A
4. That only about three of every ten acres of land in Arizona are not owned by the federal government is important because
   A. only around 30% of the state's water can be regulated by state authorities.
   B. that means most of the rest is undesirable desert with little to no water.
   C. the federal government, which claims ownership to the other almost 70%, has potential power to determine the use of significant quantities of water in state.
   D. water law states that land ownership includes rights to water underneath, a principle of riparian rights that came west early during Arizona's Territorial period.
   E. none of the above are correct.
   **ANSWER: C**

5. The *Cappaert Rule*
   A. potentially has little importance in Arizona water law.
   B. is a legal rule of thumb that determines the ratio of groundwater to surface water to which an individual user is entitled.
   C. states that the original intent of the framers of the U.S. Constitution was to leave decisions about water to the states, closest to the people who stood to be hurt or benefit by how it was used.
   D. is the basis of the formula used to determine the allowable quantity that can be placed into an AMA's budget under the category of recharged water.
   E. has huge potential in Western states including Arizona because it establishes a strong precedent for federal needs to override state water use laws.
   **ANSWER: E**

6. "Nationally 40% of surface water depends on groundwater." Which concept best identifies that interdependency?
   A. Surface/Ground Water.
   B. Recharged Water.
   C. Renewable Water Supply.
   D. Effluent.
   E. Safe yield.
   **ANSWER: A**

7. The goal of the four AMAs that were originally created with the 1980 Arizona Groundwater Act was to work towards balancing groundwater use and supply by the year 2025. Which of the following concepts was used to state that goal?
   A. Water banking.
   B. Safe yield.
   C. Perpetuity.
   D. Water harvesting.
   E. Hydrological equilibrium.
   **ANSWER: B**

8. Concerning effluent in the Tucson AMA, what is not true according the information explained in the study called, "Seeking Sustainability?"
   A. Effluent is defined as a renewable supply because it enlarges the supply of stored groundwater.
   B. Over half of the treated wastewater was being used (purchased) by golf courses, which is the main reason why so many could be built after 1990.
C. As the population grows so does the quantity of effluent.
D. the largest portion of waste water treated and distributed was east of the Santa Cruz River.
E. Effluent is a major source of surface water north of the Roger Road and Interstate 10 Sewage Treatment Plant.

ANSWER: B

9. Concerning groundwater in the Tucson AMA,
   A. generally the flow is to the south/southwest.
   B. movement is surprising quick, roughly one half mile per day.
   C. more leaves the area than enters it from the south.
   D. very little, about 3,000 acre feet per year, is naturally recharged because of the presence of a ten to thirty foot "hardpan" layer, commonly called caliche.
   E. because of rapid depletion during the middle third of the 20th century, very little (about 10%) remains fit for human consumption without expensive treatment.

ANSWER: C

10. What term indicates that the process of reporting and planning for water use quantities is at best an estimate rather than a precise measure?
   A. Effluent.
   B. INA.
   C. GMA.
   D. Paper water.
   E. Consumptive use.

ANSWER: D

11. As defined under GMA "assured water supply" refers to
   A. the quantity of water that all human beings and wildlife are entitled to use.
   B. the guarantee any water service provider has to make when adding new customers.
   C. a sufficient quantity of water continuously available to satisfy the water demands of a housing development for 100 years.
   D. the amount of water to which the federal government is entitled under the Federal Water Management and Consumptive Use Act of 1988.
   E. what is meant by safe yield to meet the needs of commercial producers in an AMA.

ANSWER: C

B. Essay & Activity

1. To what extent is the goal of achieving safe yield by 2025 in each of the AMAs politically rather than scientifically based and why is this important for southern Arizona's future? This question asks the student to assess the premise of safe yield and evaluate it against the goals set in the ten year plans. They might address the politics tied to the goal of receiving continued CAP funding that led to the passage of the GAMA. In addition, they might consider how this might be wishful thinking given the on-going pattern of use exceeding sustainable supply. They could also include the concept of "paper water" used in the budgeting process. In addition, since use-rates were grandfathered in, and for INAs with figures that represented peak use, the law in effect discourages conservation and instead encourages people to use what they have a right to use. That this is an important question about Arizona's future is obvious. If groundwater
continues to be depleted, many problems --subsidence, quality, pumping costs, etc--enter the picture. To sustain the level of prosperity currently experienced and to continue the path towards its improvement depends on water, and if deficiencies some time in the future reach the level of true crisis, that lifestyle cannot be sustained.

2. Use the Tucson AMA report online and create a graphic display that underscores what is at issue in reference to realizing "safe yield." This allows for students to be creatively expressive, so this might be done in various ways. The key understanding is to illustrate the concept of safe yield and the ways that renewable supplies can be increased and more efficiently utilized.

VII. **Enduring Understandings**
A. Many competing interests exist for rights to use water.
B. Since the federal government owns approximately 70% of Arizona land, it possesses the potential power to significantly influence future water supplies in this state.
C. CAP is only one way in which renewable water sources can reduce the groundwater overdraft in the Tucson Basin.
D. The Arizona Groundwater Act of 1980 (GMA) established five AMA’s where excessive pumping of groundwater threatened the future sustainability of resident populations.
E. The GMA requires that the five AMAs work to achieve or maintain a "safe yield" by the year 2025 in order to balance groundwater supply and use.
Santa Cruz Water History Inquiry, Question Five

How will CAP impact the area's water resources?

INSTRUCTOR'S GUIDE

III. Basic Concepts to be learned and applied:
A. "American Nile": The Nile River has been the lifeblood of Egypt for millennia and during the last two centuries, the Colorado River as another desert river has become the same for people in the Southwest, especially Arizona, California and Nevada

B. CAP: Central Arizona Project, which delivers Arizona's largest quantity of renewable water over a canal extending 336 miles from Lake Havasu to 14 miles south of Tucson, raised in elevation over 2400 feet in the process

C. Colorado River Compact: 1922 agreement among the seven states within the Colorado River Basin that apportioned the river to 7.5 million af per year for each of the Upper and Lower Basins

D. Hydro-electric Power: Energy regarded as "clean" supplied by the power of moving water in specially constructed areas of dams for that purpose

E. Quantity vs. Quality: The idea that water available for use (supply) is directly contingent upon its determined quality for that use

F. Arizona vs. California: This Supreme Court decision decided in Arizona's favor in 1963 is part of a long battle between these two states especially regarding how the water of the Colorado River is to be used

G. Mined Water: The quantity of groundwater withdrawn without being replaced ("renewed")

V. Basic Inquiry Activity Questions
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? Phoenix grew by around 14 times and Tucson by over 10 times. This is much faster than the rate of growth for the whole state, thus from a statistical standpoint, Arizona rapidly urbanized during this period.

2. Among other factors, how does water help explain why Phoenix, and especially including its metropolitan area, is so much larger than Tucson? Phoenix, because of the reclamation projects begun after 1902, has much more surface water, and thus can support more people.
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? Just under 200 acre feet more for that day, or almost 72,849 more acre feet for the year. (325,851 people X 176, that total divided by 325,851 gallons for one acre foot; 199.586 day, 72,848.94 year)

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? 1,457 feet tall (actual total is 1,456.98, which is slightly smaller than the largest structures in the world, the twin Petronas Towers, which are 1,483 feet tall.)

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 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 "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? The essential point for the student to grasp here, is that the amount of electricity use per capita has risen even more than the quantities of water actually used in some way to sustain life. Air conditioning, rare in private homes in 1940, is (along with evaporative coolers) an essential appliance that few people would abandon and still live in the desert. Add television, dishwashers and computers to this energy load, and one might assume an exponential growth rate for energy consumed. Palo Verde Nuclear Plant is an important supplier of energy as well, and along with coal burned to generate power instead of moving water, these methods would have to be significantly increased without hydro-electric power.

B. Colorado River Basin Map
1. What two states serve as the source of the Colorado River and what are these rivers called? Wyoming (Green River) and Colorado (Colorado River).

2. In addition to the two source states, two others are considered Upper Basin states. What are their names? Utah and New Mexico.

3. Name the three Lower Basin states: Nevada, California and Arizona.

4. Which state contributes the largest drainage area for the Colorado River? Arizona.
5. What other political entity lies within the Colorado Basin? Mexico

C. Examining "The Law of the River"
(Online at http://crwua.mwd.dst.ca.us/lor/crwua_lor.htm) (BAD LINK)
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 the largest allocation? It has the largest area of drainage and the longest stretch of the Colorado River's course is also through Arizona.

2. What advantage did California have over the other six states when the CRC was being made? It had already begun to take water from the Colorado into the Imperial Valley, and it had a much larger population than the other six states.

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? The Salton Sea. In part this is natural because this once was where the river flowed into the Salton Sea. Today, Colorado River water is used to re-supply this inland, salty sea, which is valued by recreation interests, still another competing special interest for Colorado River water. If the student would like to research this further, have them check out this website at http://www.sci.sdsu.edu/salton/SaltonBasinHomePage.html

4. What were the two main arguments made before the construction of Hoover Dam for making "better use" of the Colorado River? Flood control and irrigation

5. Where is the point of division in the CRC between Upper and Lower Basins, and what does that mean for Arizona? The two basins were divided at Lee's Ferry, leaving parts of Arizona in both basins.

6. Which state refused to sign the CRC in 1922 and why? When did it agree to the CRC? Arizona did not believe that it was getting its fair share of Colorado River water, and would finally sign on in 1944.

7. What was a major miscalculation from which the river was apportioned? Its flow was calculated based on a wet year (18 million acre feet, when 14 million would be more accurate for a drier year), and thus was over allocated.

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? Mexico used the Rio Grande as a bargaining chip (this affected the potential water available for Texas in the lower portion), and the US needed a close allegiance from its neighbor. No stipulation for water quality was added to define water quantity for Mexico's allocation. Damming the river has led to increased levels of salt as it reaches the mouth. Eventually the US agreed to build a desalting plant in Yuma. For a summary of the 1944 Treaty online, see http://www.american.edu/ted/COLORADO.HTM

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? Arizona and California, with Arizona bring suit to the Supreme Court in 1952 (Arizona vs. California). Beginning about 1945, the two states differed on how they interpreted the 1922 CRC, the Boulder Canyon Project Act of 1929, and the issue of surplus water. Even though Arizona won
in 1953, California retained enough power to support the vote for the CAP if Arizona guaranteed its primary right to 4.4 million acre feet before a drop would enter the CAP (Julie Ferguson, Colorado River Dispute, TED Case Studies, September 1992).

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? Water and the Grand Canyon

12. What are two chief issues affecting the future of the CRC today that are most important to you and why? This allows for the student to consider and balance the competing demands placed on the river. The following copies this section from the web site for sake of convenience. The challenges of the '90s for users of Colorado River water are many and varied. What about Native American water rights? How much should they have? How should it be used? Should there be provisions for transfers, leasing, selling? Endangered species - there's an issue of concern to all. How far should it go? At what cost or tradeoffs? Has it already gone too far? The factors are many and the opinions wide-ranging. The uses to which the water is put is becoming a topic of concern along the length of the river. Should agricultural water be less subsidized? Should there be new options for satisfying the needs of rapidly growing urban areas? What are the true costs of water? Should marketing and transfer negotiations be put on fast track? Drought management is another area where decisions have to be made. Is there sufficient water in the reservoir system to meet current needs of more than 7.5 million acre-feet in the lower basin? And then there's water quality - salinity control has long been an ongoing problem. What must be done to reduce the salt load flowing into the Colorado River system? Will selenium concentration in river water pose a threat in the future? And what about the river's mother-and-apple-pie capability - clean, non-polluting generation of hydro-electric power? What could be better than that? Unfortunately, serious issues surround this source of energy as well. Repayment, environmental impacts from operations, replacement power from other sources - none of these issues has easy answers. And even recreation on the river poses problems. How much water should be devoted to meeting expectations? At what times? Where? How? At what cost? Who benefits? And for what trade-offs?

CAP: Refer to 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? Four in all, three in Pima County

2. Most of the 336 miles are along an aqueduct, which means what happens as the water moves towards Phoenix and Tucson? That this water passes through above ground and is allowed to evaporate along the way. It also grows proportionately harder due to mineral deposits that are left after this evaporation occurs.
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?  
\[ 52,500 \text{ af} \times (3.5\% \times 1.5 \text{ million af}) \]

4. How many cubic feet of water can the aqueduct carry at its source point if entirely filled?  
\[ 31,680 \text{ cu ft} \times (80 \times 24 \times 16.5) \]

5. In what year did CAP first deliver one million acre feet of water, and what percentage of its capacity goal does this represent?  
1996, which is \( \frac{2}{3} \) of its capacity of 1.5 million af. (Its rated capacity is 2.2 million af)

6. Including CAP, how many people are estimated to be using Colorado River Water for drinking?  
20 million people in five states plus Mexico.

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?  
$33 \text{ million}, $5.50 \text{ per capita per year}$

8. What is the af cost for the Tucson AMA for 2001-2002?  
$88 \text{ per af}$

9. Applying your understanding about watersheds, what fact must be considered regarding the delivery of Colorado River water to Tucson?  
Since the Colorado River is the primary drainage basin for southern Arizona, this means that CAP is accessed (Lake Havasu) at a lower elevation than Tucson, which means that it must be pumped along the way. (In fact, 14 pumping stations lie along the way, pumping water approximately 2400 feet up along the way--some sources state that it is 2900 feet.)

10. Using the information from question 9 above, what would be the direct consequence for the consumers of CAP water?  
It would account for much of the cost of delivery, i.e., it costs money to pump water, which weighs 8 1/3 pounds per gallon.

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?  
Slightly more than 2072 cfs. (1.5 million af divided by 365 days, then divided by 86,400 seconds in a day = .0476 af \times 325,851 \text{ gallons per af} = 2072.06 \text{ gallons})

E. The CAP and Tucson.

   [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? 1999 or 2000 (It could even be more recent still.)

   b. Given Tucson's demographic history for the previous half century, what interest group is identified as favoring the use of CAP water? It's named "Growth Lobby" (The fight between proponents of growth and those favoring slow or no growth is a long one. The controversy over CAP seems to have triggered the anti-growth reflex, because in 2000 the Arizona voters decisively rejected Proposition 202, the controlled growth initiative, in which water concerns regarding that growth at best far in the background. Of primary concern was the strongly held belief in private
property rights that real estate interests successfully lobbied to gain public sentiment support in voting against it.)

c. What can you infer was the basis for the adversarial relationship between the "Establishment" and the Opposition? Lack of trust (Note: the 60s term borrowed from the New Left that was based on that same sentiment.)

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

e. Who were the two main components of the Establishment? The Tucson City Council (with Mayor George Miller) and Tucson Water Company

f. Use the information supplied in the timeline and state a thesis that expresses what the opposition was most about regarding CAP water. Quality of that water, which led to the enactment of the Water Consumer Protection Act (Prop. 200). (Note: the student may or not be aware of the fact that when Tucson Water began to supply CAP water to customers in parts of the city, significant problems arose that varied from rusty water, poor tasting, to significant pipe damage. The city of Tucson and Tucson Water Co. were still in the process of settling the damage lawsuits in 2003. In addition, portions of the city waterlines had to be replaced, part of the reason for the problems that consumers endured. In short, the city and Tucson Water had miscalculated regarding how much different CAP water was from the groundwater that formerly had been the sole supply. For additional information and background about Proposition 200 see http://ag.arizona.edu/AZWATER/awr/jul99/news.html

g. What is the term used on this site that identifies the role of CAP in accomplishing safe yield? Sustainability (next to AWS)


a. What should be known and kept in mind about the authors of this article in Tucson Weekly? Molly McCasson, who served on the Tucson City Council from 1989 to 1997, and Dave Devin both supported Proposition 200, therefore they would be expected to have a bias in that regard.

b. What is the date of this article and why is that important to know? 6/25/98, which is before Prop 200 was amended by the voters in 1999 to allow blended ground and processed CAP water to be used as part of Tucson Water Co.'s delivery to its customers. Recharging CAP was being continued as required by that same proposition.

c. Essentially what do they allege and what do they believe explains why the city is doing this? The city is not following the law, and it is by design because city leaders are determine to use CAP for drinking water.

d. Why does CAP water have to be treated? This water is less pure with 750 TDS (total dissolved solids) compared to 300 TDS in groundwater. (Note: It should be pointed out that Phoenix has not had this controversy over quality in large part because surface water has been used there for years unlike the naturally filtered groundwater upon which Tucson had been totally dependent.)

e. How is this issue related to growth concerns and how does that impact attitudes about conservation in their opinion? CAP water means more
water to support growth. Here they use strong language that sets up the classic rich vs. poor dialectic with words such as "suburbs" and "swimming pools." (This attitude against growth and the expensive infrastructure that it requires, was explained as a major factor in the May 2002 Tucson voters' decisive rejection of a multi-million dollar transportation plan). This affects programs such as "Beat the Peak" because they allege that it is a "sham," designed to favor interests outside the city.

f. What is their strongest, perhaps real concern about CAP in Tucson? Cost; they say, ”Those indirect, or "hidden," costs of CAP can range from a few dollars to several thousand per household. As the 1993 experience showed, the impact of the water is impossible to predict."

3. Analysis:

a. Explain how the question of water quantity is interconnected with water quality as illustrated by the controversy over CAP in Tucson. The student should see that especially when it comes to drinking water, the public is very sensitive regarding taste, which is understood to mean quality.

b. What might be an important source of external pressure that city leaders felt that the vast majority of Tucson residents did not? Primary pressure would come from GMA, because the water budget of the Tucson AMA depends on CAP to help it reach the 2025 goal of safe yield. Some might have felt the legacy of Arizona's long battle to benefit more strongly from Colorado River water.

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? Given Arizona's long fight with California over the Colorado River, the people of Tucson should at least realize how others might see CAP. In addition, whether they had supported it or not, they are part of a state legacy with a long history of lobbying Congress to build this project, of which more than half of the cost of construction has become the burden of tax payers throughout the U.S. Beyond this, each student is entitled to their own opinion, but their point of view should be assessed upon how well they understand the complexities of the water quantity issue (also relative to the judgment of quality) in southern Arizona and beyond.

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." The student should note that with CAP water in Tucson,
the intricate connection between quantity and quality can be strong. It is obvious that groundwater is being depleted because demand exceeds supply, and thus ways of reducing its use and finding renewable supplies are crucial. At best, however, current estimates are that CAP can only supply about 10% of Tucson's water.

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? Yes, several are listed at the CUWRA site.

2. Does southern California have a strong dependency on the Colorado River? Yes, over 55% of the water used.

3. How does southern California's average precipitation compare to that of Arizona's? Much the same, ranging from about 2.5 to 14 inches per year.

4. According to the North Country Times, southern California currently experiences a struggle for water between what two large interest groups or users? Municipal users in San Diego County and farmers in the Imperial Valley compete for Colorado River water. This has not been as heated an issue in Arizona, where municipal interests began to benefit immediately from the National Reclamation Act. While agricultural interests have been strong in Arizona, with over 75% of the water consumed largely owned by private irrigation companies, a large portion of this agriculture is close to large metropolitan areas (Phoenix and Tucson) where agricultural land has either been retired for water rights, or converted into residential areas. California, on the other hand, led the way in agribusiness and massive irrigated networks to sustain it. Many such areas, such as the Imperial Valley in the south and the San Joaquin in the north, remain productive and account for a significant amount of produce in the United States, for which water needs have continued. But overall in the Far West, the past fifty years have seen a significant shift to municipal use due to large population growth. As with the millions of acres of public lands, these urban interests are pushing hard to change how rural folks use that land, which often is not environmentally sound because by placing a recreational use on the land and water they become "overused" in another way.

5. Why is southern California labeled a "water hog?" It currently overuses its Colorado River allocation of 4.4 million af by 800,000 af.

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? The CRC entitled it to 50% of the surplus, with a much larger population than its neighbors, it easily swallowed the extra water upon which it is now dependent.

7. How does California plan to end using this surplus and how risky is this strategy? It would allow Imperial Valley farmers to sell (transfer) water currently used to San Diego County and with the money it can invest in conservation practices. The series of agreements that need to be approved are
interdependent and all must be made or California could be sued and forced to give up the surplus.

8. What would be the potential environmental consequences for the Imperial Valley in making these transfers? The Salton Sea would slowly disappear by evaporation, which would harm wildlife adapted to the present habitat. Indeed as the sea dries, this is already happening.

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 1). On what grounds does the federal government justify its power to act in settling disputes regarding the Colorado River? Essentially it could justify its position on several positions including the right to regulate interstate commerce, its vested rights according to Cappaert, the fact that the Colorado River is an international waterway and involves the treaty making authority that only the federal government has, and because in disputes between states, the federal courts in particular, and federal government in general is the forum to try and resolve them. While this is decided at least in part politically, and California has the highest population, the other Western states have become stronger politically as well, which could serve to balance California's political power. Politics indeed is more complicated than that, it would be hard to predict how a major dispute would be resolved because of many other variables including the time and the context in which it was viewed and judged.

VI. Assessments

A. Multiple Choice:

1. Concerning water suppliers in the Tucson metropolitan area, what is least correct?
   A. Tucson Water Company is the sole provider for those who live within the city limits of Tucson.
   B. Dozens of companies supply water in Pima County, many in the Tucson metropolitan area.
   C. Those defined as public providers must submit water quality reports to EPA.
   D. They are within an area called the Tucson AMA.
   E. Thousands of individuals supply their own water from wells on or near their property.

   **ANSWER:** A

2. The Arizona Groundwater Management Act of 1980
   A. was declared unconstitutional by the Supreme Court in 1985.
   B. essentially removed prior appropriation as water right law, replacing it with riparian rights.
   C. provided the funding for CAP.
   D. was designed to redress the imbalance between groundwater supply and use.
   E. ended "grandfathered" rights to groundwater for all INAs by 2025.
3. What is the best statement regarding the relationship between ground and surface water?
   A. As a general rule, if no surface flow exists then the aquifer is dry to the Cambrian layer.
   B. It is an interdependent relationship so that for example, we can expect that as surface flows increase the water table tends to rise.
   C. It is an inverse relationship.
   D. No relationship of importance exists because ground water is fed by springs, not by seepage from the base of the streambed.
   E. Generally the groundwater flow moves in an opposite direction to that of the surface flow.

   **ANSWER: B**

4. As Tucson's and southern Arizona's population increased rapidly after WWII
   A. leaders responded with a creative and imaginative water conservation program.
   B. per capita consumption rates rose by 30% because more swimming pools were built.
   C. state leaders devised a plan to build a canal from the Colorado River to Phoenix and Tucson.
   D. water tables fell more rapidly and total water consumption rose.
   E. the climate coincidentally turned drier and hotter.

   **ANSWER: D**

5. For AMA budgeting purposes, water delivered from the Central Arizona Project is classified as
   A. Effluent.
   B. Renewable supply.
   C. Paper water.
   D. Hard water.
   E. Banked water.

   **ANSWER: B**

6. The term "safe yield" is applied to
   A. water harvesting.
   B. containing surface runoff by building reservoirs.
   C. growing more predictable, drought resistant crops.
   D. the mixture of riparian and prior appropriation rights according to the 1980 GMA.
   E. achieving a rough balance between ground water supply and demand.

   **ANSWER: E**

7. In regards to state authority to adopt and implement water laws and policies, an important source of federal power to restrict these actions derives from
   A. recent legislation in Congress.
   B. NAFTA.
   C. *Cappaert v. U.S.*
   D. *Arizona v. California*.
   E. all of the above.
8. Regarding the Tucson AMA during its third ten year plan
   A. some progress had been made in reversing the groundwater overdraft.
   B. safe yield was expected to be achieved by the end of this ten year period.
   C. the rate of groundwater depletion remains higher in the Avra Valley due to
      large-scale irrigated agriculture.
   D. CAP water was reported as still having no impact.
   E. the area had been enlarged to include the Upper Santa Cruz.

**ANSWER:** A

9. Which of the following best expresses the context of the CAP relative to the
   "law of the river?"
   A. The Colorado River Compact of 1922 allocated 4.4 million acre feet of
      river water to California, a right that its Congressional representatives
      used to support the legislation authorizing CAP.
   B. The law of the river is built upon federal power to enforce navigation
      rights under the commerce clause, and thus reduces the amount of water
      that can be diverted from the Colorado River.
   C. The law of the river since the early 1920s has become more complicated,
      with fishing and recreational interests gaining powerful support in
      Congress so that appropriations from the Colorado have been reduce,
      threatening CAP.
   D. The law of the river applies to Mexico's right to receive surface flow
      "sufficient to its needs," which is an open-end agreement that has allowed
      the expansion of irrigation there, using over 3 million af of the Colorado.
   E. The law of the river divided the Colorado into two basins, and since
      Arizona is in both, it receives the most water, which raises the potential to
      deliver CAP water to it maximum carrying capacity.

**ANSWER:** A

10. Based on current use of water in the Tucson AMA the possibility of achieving
    safe yield by the target date of 2025 without CAP water
    A. is possible.
    B. very likely.
    C. would be very unlikely.
    D. cannot be predicted.
    E. the Tucson AMA has already achieved safe yield.

**ANSWER:** C

11. The chief controversy concerning the use of CAP water in Tucson during the
    middle and late 1990s concerned
    A. outrage from angry customers, forced to pay the $100 annual surcharge to
       the federal government on their year-end water bills.
    B. its quality.
    C. its unfair method of distribution, since the wealthier sections of the city
       were the first to receive it.
    D. how much of its allocation Tucson Water Company had to deliver to local
       mines.

**ANSWER:** C
E. frustration because the EPA ruled that all of it had to be recharged before being pumped through the water system.

ANSWER: B

12. Currently the largest use sector within the Tucson AMA is
A. industry.
B. agriculture.
C. recreation.
D. mining.
E. municipal.

ANSWER: E

13. The Tucson AMA currently mines water,
A. which has increased with the addition of CAP water.
B. because Arizona supplies 60% of the copper produced in the U.S.
C. because that is part of the plan-design to achieve safe yield.
D. which is a violation of the 1980 GMA, for which water customers have been apportioned an approximate $2 per month fine.
E. meaning that it uses more ground water than is being replaced (renewed).

ANSWER: E

14. Which of the following best opens up our understanding of the hidden role of water to expand comfort in our daily lives?
A. Effluent.
B. Recharge.
C. Affluent.
D. Hydro-electric.
E. TAMA.

ANSWER: D

B. Essay/Project

1. How much will CAP water in the Tucson Basin help to reduce the rate of groundwater overdraft? Assessing the student’s response should include observing how they dealt with the vague phrase “reduce the rate.” So the student needs to quantify because logically even one drop of CAP water reduces the rate if it exceeds the current demand or the rate of its increase. The student should demonstrate that he or she understands and connects several key ideas. First, CAP is a finite amount, with a total of 215,333 allocated to the AMA, which exceeds the current rate of "mined groundwater" which the Tucson AMA reports is 50% of total use or about 157,000 af. However, continued growth increases the rate of groundwater use. (Thus, it is possible to project the time at which that figure would exceed the allocation, although the student is not being asked to do this.) Second, CAP allocations may not be fully realized due to a variety of possibilities, plus a certain amount estimated around 6 to 7% is "lost." Third, with a high dependency on "mined" groundwater, more than CAP water is needed to create renewable supplies to reduce the rate of mining. These include raising the quantity of effluent and a variety of conservation methods such as how water might be reused within the same residence or business. The latter requires education along with economic incentives. Fourth, it can be argued that even with the risk of politicizing the
process the various stakeholders need to be more involved in the planning process. Currently the AMA is invisible to much of the area's population. Criticisms of the limits of the GMA aside, ways to extend awareness to increase commitment across the community towards safe yield could be suggested in this essay as well. So while the student is not being asked to calculate the rate of reduction, they must clarify what they mean by it and demonstrate that they understand the complexity of this problem and of finding ways of tackling it.

2. Express in some manner the concept of watershed as it applies to the Santa Cruz River and the Colorado River. Assessment here should focus on how well the student understands the interrelationship of subregions within a watershed. If the instructor desires, a more "scientifically" based essay could be required, one that would ask for greater quantification. Or the student might be asked to express their understanding more abstractly. For example, the concept of recycling might be employed to show how part of the Santa Cruz returns to southern Arizona through the CAP.

3. Make a poster that could be used for a public education campaign by the Tucson AMA that would help residents of this area better understand the planning process towards achieving safe yield. Include the following in this poster: showing the physical area of the CAP and Tucson AMA, connecting the GMA to the Tucson AMA, CAP water to the concept of renewability, plus groundwater depletion to renewable water (the student can decide how much graphic emphasis should be given CAP). As much as possible this should be done graphically, with a minimum use of words so that the main ideas can be quickly communicated. Assessing this project should be based on how well the student grasps the concepts and interrelationships of safe yield and CAP. In addition, the instructor might give the students latitude to indicate the purpose of the poster. For example, it might be done to "sell" CAP, or to deal with a potential problem such as subsidence.

4. Design a poster that illustrates the role of Colorado River water in the daily lives of the people of southern Arizona. Assess the student's comprehension of how much we depend on the river's power to generate our expanding energy needs as well as how the delivery of a portion of its surface flow to southern Arizona impacts groundwater supplies.

VII. Enduring Understandings
A. Mining groundwater endangers future populations and their right to live in southern Arizona.
B. CAP represents the largest renewable source of water in the Tucson Basin but has created controversy over if, how and where it should be used.
C. The people of southern Arizona have been increasing dependent on "the American Nile" to sustain their lifestyle.
Santa Cruz Water History Inquiry, Question Six

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

INSTRUCTOR'S GUIDE

PRIMARY LEARNING OBJECTIVE: Inquiry Six is intended to be the capstone; a problem solving activity that is intended to have students apply what they have learned as a result of doing the previous five inquiries in this module. It asks students to explore the vital question of sustainability and suggests a practical, "hands on" project in which to do so.

I. Introduction:

This, like the inquiry that it supports is organized and developed differently from the other five. As it states in the student section, this is intended to be the capstone for Module 5 to help assess the extent of water literacy relative to the history of water quantity in southern Arizona's past, present and future. However, if desired, and depending on time, this inquiry could be done without doing all or any of the previous ones. If this course is chosen, it is suggested that the opening story be used to help hook student interest and to help provide a better perspective as to the importance and scope of the on-going issue of sustaining water supplies in an area that is semi-arid but rapidly growing in human populations. Furthermore, the students will probably need additional guidance as to what materials and resources are available in this module.

In earlier inquiries in this module the question of sustainability was introduced and left open. The "official" report completed by the Water Resource Center and the College of Agriculture at the University of Arizona in 1997, Water in the Tucson Area, Seeking Sustainability, concluded that the balance between supply and demand--i.e., sustainability--was lost in the early 1940s when the Santa Cruz River failed to regularly flow above ground in that portion where it had historically done so. When sustainability was indeed lost has great importance in long range planning, particularly as mandated by the Groundwater Management Act of 1980. Quite simply, the farther back it is moved, the more difficult realizing "safe yield" (sustainability as termed by the 1980 GMA). Because of rapidly increasing groundwater use surrounding the decade immediately before and after the 1940s, the loss of balance was probably more exponential than geometrical to mirror use and population growth. A dissenting voice that might be helpful to reintroduce is that of Michael Logan. Logan has completed a detailed historical study of the Santa Cruz River, and since this Module has tried to develop a strong historical sense of continuity towards demand and supply, his dissenting view is worth consideration. Should you as the instructor decide to add this information for the student inquiry, you might also ask them to consider validity when measured between disparate disciplines. In other words, how much of the same evidence was analyzed and interpreted to draw different conclusions.

Consider, then, if you will, Michael Logan's argument about sustainability summarized below.

Michael Logan, The Lessening Stream, An Environmental History of the Santa Cruz River (Arizona: 2002). The author argues for a much earlier date than the early 1940s. "The perennial flow of the river ceased to provide sufficient water for all Tucsonans by at least 1884 when
farmers north of St. Mary's Road ran out of water" (155). He supports this view by citing the 1884 report by City Engineer, J. P. Culver. (Culver's observations are used as part of the activities in Inquiry 2.) 1884 is roughly three years after Tucson Water Company began to supply drinking water to residents of the city of Tucson. This immediately complicated the water problems for farmers downstream and it points to the future where urban demands would greatly outstrip agricultural use of water, as rows of grain were replaced by rows of homes. If Michael Logan's assessment is correct, achieving sustainability may well lie far beyond 2025. Either way, in the several decades before Arizona was admitted as the 48th state, the internal and external forces were transforming the landscape and its water resource, gathering momentum for the WWII era surge

III. Inquiry Understandings:

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: Additional information above in this guide

APPROACH: The instructor is invited to alter this assignment to fit the needs of the class. Module 5 has been developed for interdisciplinary audiences. However, this research oriented activity might be applied more singularly for a specific class.

DESIGN: If the instructor wishes to modify the approach, then most likely the same will have to be done for the design. A scientific study normally has a different format than an English or history research paper. As written, the design tries to adopt an interdisciplinary blend. The most important thing to consider is how "real world" the instructor wants this project to be. A study produced for a scientific audience will look and sound different than one produced for the public at large. Water literacy is about education. The lack of water awareness easily generates overuse. Economic, i.e. cost for water including delivery, definitely can produce conservation, but without literacy, it also breeds resentment and hostility. If southern Arizona has a chance to bring its water use into a balance or at least a closer one with groundwater supply, education is the key, one of the primary reasons that these modules (One through Six) have been developed. Thinking about the politics of water and the history of water use has significant scientific consequences.

GUIDELINES: The suggestions apply to the instructor's acceptance of the research activity was suggested, but certainly can still be modified accordingly. A few additional comments in *italics* are intended to clarify the student tasks.
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. In terms of writing a research paper this step would normally be the introduction. Also, it would be set up differently if students were asked to present this orally to their peers.

Task Two (Inquiry): This should express a good understanding of historical continuity that includes recognizing key players and policies into the present. The intent is not to get "lost" in the past, but to assess how well the student understands how the past affects the present and suggests a path for the future.

Task Three (Thesis): Your studied opinion about how likely sustainability is for the people of Pima County and your justification for taking this position. This is not only the crux of the assignment but it is hoped that all see it as a vital question that has significant importance on the future of this area.

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. This does not have to be overdone, but it is important that students understand that while most everyone will agree that water conservation is important, it is often fine for someone else but not for them. In other words, most might agree that southern Arizona needs better transportation but will oppose a freeway if it is right next to their house.

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. Part of what is meant by language here is choosing carefully words that provide the kind of incentive necessary to cause smaller group and individual actions to move towards a larger end.

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. The idea here is that anyone can repeat their argument in a rather mechanical way, but if that is all that it does, it tends to 'talk down" to an audience, or at least cause them to feel like, "yes, I know that already!"

Task Seven (Closure): A terse final spark to ignite action in your favor. This can be powerful; finding a few good words to evoke the big picture and an individual's position in it.

Task Eight (Personal Legacy): What are several meanings gained that will always be with you? Finding deeper meanings should be of prime importance in the learning process. The students may assess to "mastery" but if it is then quickly forgotten, what is the real value?

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 desired 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: As with the other comments above, certainly this can be modified. Finding precise and clear language for assessment is very difficult and despite the best efforts remains subjective. However, it does provide a more consistent basis of evaluating student performance while giving a guide to help to produce a better product.

**Understanding** of the assigned task including applicable key terms & concepts. *It is strongly believed by the developer of this module that in order to engage students to think larger and more deeply, they have to think and work conceptually. Concepts are understood to mean the opening from which we begin to think and learn and the place where the mind begins to gather and sort in order to learn. In addition, this performance criterion asks the student to present a vision of where he or she intends to take whoever will be their audience. As an evaluator, it should be readily apparent how well the student has mastered the information to complete the assignment. A 5 indicates that the student thinks and expresses conceptually to see the larger picture i.e. that in the case of water, when demand succeeds supply, more than increased cost is at stake. Certainly sustainability or safe yield are key concepts, but so is interdependency as it applies to ground/surface water and life and death. These are essential understandings and they should be apparent from the very beginning.*

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**Historical** continuity with the relevant politics & social values. *Seeing, appreciating and understanding historical connections are essential in studying societal problems and issues and seeking solutions. One understanding that should be present is the connection between human and natural systems. For example, extensive water use by the Hohokam and then post Civil War American settlers and developers involved developing and using systems to acquire large amounts of water. These human systems directly impacted on the natural hydrological ones, the watershed, especially for the later of these systems. Students should see connections between industrial capitalism and prior appropriation. Additional links should be made between reclamation projects and the eventual building of CAP. They should appreciate local, regional and national special interests and how these affect water quantity use and issues. They should appreciate the connection between GMA and the Tucson AMA, and politics of water and goals such as sustainability. Finally, they need to understand how past trends in all their complexities help one project potential future outcomes that can either be encouraged or minimized according to plan.*
Excellent & 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.

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 & at times above targeted performance standards.

Generally good understanding of the task. Attempts are made to provide detail, and although some errors are made means are adequately understood. The completed task meets targeted performance standards.

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.

Identification & understanding of key data and other evidence; This performance criterion is predominately quantitative. However, analysis demands a sense of qualitative understanding, part of weighing and evaluating how useful that information is to completing the task at hand. In addition, some of the data is historical photo and written documents, which offer elements of subjectivity. To earn a 5 for DATA, the student should cite and use facts that he or she has shown to be pertinent to the thesis (plan proposal). Data is often best summarized in the text, pointing out what the audience might miss or not may not initially understand, before being shown in detail at the bottom of the page, on a poster, or in an appendix. Creative or insightful ways of assembling data without distortion should be considered above average or even exceptional.

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<td><strong>DATA</strong></td>
<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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**Logical** sequencing & development to create a thoughtful & realistic plan of action. This criterion assess the level and quality of thinking accomplished by the student. Direct relevance to the thesis (action plan) should be readily evident. In particular, the plan of action should show considerable understanding of interrelating complexities without distracting and thus confusing the audience about what should be done by whom and how. Suggesting more stringent water conservation measures should take into account developing paths of least resistance. Balancing benefits between potentially competing groups (riparian development and ranching plus local, state, federal or even international interest groups) should be taken into account.

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<td><strong>LOGICAL</strong></td>
<td>Mature &amp; insightful understanding of cause &amp; effect for thesis support. Excellent analysis &amp;</td>
<td>Good understanding of cause &amp; effect in support of the thesis. Analysis &amp; logical sequencing show a</td>
<td>Thesis supported with adequate understanding of cause &amp; effect. Analysis &amp; logical</td>
<td>Some factual basis but illogically analyzed with little sequencing; Limited understanding of</td>
<td>Poor factual foundation. Evidence is lacking or inaccurately applied. Poor use of logic with</td>
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### Communication

Communication of language that clearly presents facts & in order thoughtfully persuade. *Six Traits criteria may be adapted to this or used in replacement. The student must ultimately be convincing. To do so language should express certainty that this action plan is the right and best thing to do without ignoring the difficulties involved. The vocabulary used should show variety and build upon larger understanding without being overly academic, technical or pedantic. From reading or listening to the student's plan of action, the audience should feel compelled to act.*

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<td>An exceptional effort to present an 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 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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### IV. Concluding Remarks:

The information above and that which appears on the student portion is presented as a guide. It was decided to present this inquiry in an ambitious manner because it is easier to scale down than to expand. It is sincerely hoped that it provides a useful course of action, one which students will gain immensely.

### V. Enduring Understandings:

Since this is the capstone, it is hoped that by completing this inquiry the student will reinforce understandings previously learned. In addition, the statements below reflect additional long-term understandings and meaning so that a lifelong water literacy concerning water supply in southern Arizona is attained.

1. Water conservation is important to the wellbeing of all us because water makes our lives happen.

2. Developing a comprehensive water plan to realize a sustainable water supply in arid and semi-arid environments begins with each individual.
Appendix

Item 1: Colorado River Problem
(Used with permission from Barbara Duch, December 2004)

The Colorado River
Whose water is it anyway?

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](http://univ.arizona.edu) at the [Univ. of Arizona](http://univ.arizona.edu)
- [The Colorado River](http://grandcanyonexplorer.com) from [Grand Canyon Explorer](http://grandcanyonexplorer.com)
- [Metropolitan Water District of California](http://www.mwdc.org)
- [Accounting for Consumptive Use of Lower Colorado River Water in Arizona, California, Nevada, and Utah Assessment Program---Central Arizona Basins](http://arizona-water-resources.com) from [Arizona Water Resources](http://arizona-water-resources.com), U.S. Geologic Survey