What's up with Earth's water resources?

Module Overview

This module addresses issues that are of fundamental importance to life. Four case studies of a coastal bay, an inland sea, a river, and mountain snow pack investigate water resources important to millions of people in North America, Asia, and Africa. Each investigation focuses on the physical nature of the resource, how humans depend upon the resource, and how human use affects the resource creating both problems and opportunities.

***Investigation 1:* Chesapeake Bay: Resource use or abuse?**
Students play roles of concerned citizens, public officials, and scientists while learning about the Chesapeake Bay and its environs. They use data and satellite images to examine how human actions can degrade, improve, or maintain the quality of the bay in order to make policy recommendations for improving this resource for future use.

***Investigation 2:* What is happening to the Aral Sea?**
Students work as teams of NASA geographers using satellite images to measure the diminishing size of the Aral Sea. Then they analyze and interpret graphic and tabular data about the causes of the shrinking sea and its effects on habitat, resources, and people in order to make recommendations for improving this resource for future use.

***Investigation 3:* The Nile: A sustainable resource?**
Students analyze data and make graphs to explore the relationship between population, water resources, water stress, and sustainable economic development. A simulation of a meeting of the Nile River Basin Initiative provides students with an opportunity to consider the perspectives of nations within the Nile River Basin.

***Investigation 4:* Why is snow important in the southwestern United States?**
Students role-play U.S. senators from seven western states seeking to find solutions to important problems in the Southwest: recurrent drought, which reduces vital snowpack resources; and rapid population growth, which increases demand on those resources. Information from satellite images, in tandem with ground-based perspectives, assist students in playing their roles as senators seeking to make recommendations on these problems.

Geography Standards

World in Spatial Terms
- **Standard 1:** How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective

Places and Regions
- **Standard 4:** The physical and human characteristics of places

Physical Systems
- **Standard 7:** The physical processes that shape the patterns of Earth's surface
- **Standard 8:** Characteristics and distribution of ecosystems

Environment and Society
- **Standard 14:** How humans modify the physical environment
- **Standard 15:** How physical systems affect human systems

The Uses of Geography
- **Standard 18:** How to apply geography to interpret the present and plan for the future

Science Standards

Unifying Concepts and Processes
- Systems, order, and organization
- Evidence, models, and explanation
- Evolution and equilibrium

Science as Inquiry
- Abilities necessary to do scientific inquiry

Life Science
- Structure and function in living systems
- Populations and ecosystems

Earth and Space Science
- Structure of the Earth system

Science and Technology
- Understandings about science and technology

Science in Personal and Social Perspectives
- Risks and benefits
- Science and technology in society

History and Nature of Science
- Science as a human endeavor

Connection to the Curriculum

"What's up with Earth's water resources?" provides an instructional unit—about a month in length—that can be integrated, either in whole or in part, into high school courses in world geography, environmental geography, regional geography (of North America, of Africa, and of Asia), earth science, and global studies. The materials support instruction about aquatic and terrestrial habitats and ecosystems, as well as the dynamic interactions between physical and human environmental changes at both local and regional scales. Connections to mathematics skills are easily made because the materials require students to work with a large amount of quantitative data in graphic and tabular form.

Time

Investigation 1: Four to five 45-minute sessions
Investigation 2: Five to eight 45-minute sessions
Investigation 3: One to two 45-minute sessions
Investigation 4: Five to nine 45-minute sessions

Mathematics Standards

Number and Operation

- Compute fluently and make reasonable estimates

Algebra

- Understand patterns, relations, and functions
- Analyze change in various contexts

Measurement

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements

Data Analysis and Probability

- Formulate questions that can be addressed with data, and collect, organize, and display relevant data to answer them
- Develop and evaluate inferences and predictions that are based on data

Communication

- Communicate mathematical thinking coherently and clearly to peers, teachers, and others
- Analyze and evaluate the mathematical thinking and strategies of others

Connections

- Recognize and apply mathematics in contexts outside of mathematics

Representation

- Create and use representations to organize, record, and communicate mathematical ideas
- Use representations to model and interpret physical, social, and mathematical phenomena

Technological Literacy Standards

Nature of Technology

- **Standard 3:** Relationships among technologies and the connection between technology and other fields

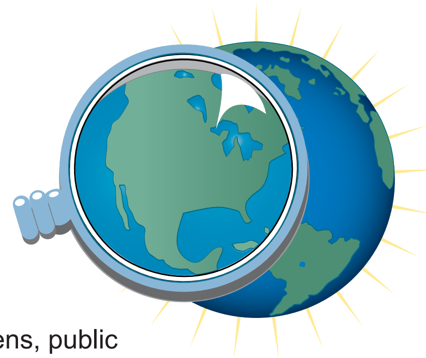
Technology and Society

- **Standard 4:** The cultural, social, economic, and political effects of technology

Abilities for a Technological World

- **Standard 13:** Assess the impact of products and systems

Chesapeake Bay: Resource use or abuse?



Investigation Overview

Students play roles of concerned citizens, public officials, regional planners, and scientists to explore the Chesapeake Bay and its environs. They use data and satellite images to examine how human actions can degrade, improve, or maintain the quality of this water resource in order to make policy recommendations for improving the resource for future use.

Time required: Four to five 45-minute sessions

Materials/Resources

Briefing (one copy per student)
Handout 1: Roles (one role card for each of 10 students)
Handout 2: Testimony Points (one copy for three-four investigators)
Handout 3: Regional Planner Instructions (one copy for each student in class)
Computer station(s) with Internet access (optional)

Content Preview

Human action in the sensitive, highly interdependent Chesapeake Bay ecosystem has led to environmental degradation during the past century. Land use changes related to deforestation, agricultural use of fertilizers, and urbanization have led to increases in sediments and pollutants flowing into the bay. Natural climate cycles, periods of drought for example, exaggerate the effects of human action on the bay.

Classroom Procedures

Beginning the Investigation

1. Conduct a discussion on water as a resource. Ask these questions:
   - How do we use it? *(Drinking, transportation, recreation, industry.)*
   - What are some ways that water quality is affected by natural processes? *(Drought affects flow of fresh water; storms affect amount of sediment and water flow.)*
   - What are some ways water quality is affected by human actions and processes? *(Pollution from industry, run off, and sewage, diversion/reduction of feeder streams/rivers, sedimentation, destruction/development of wetlands.)*

   Relate these issues to water resources in your region.

Geography Standards

Standard 1: The World in Spatial Terms

How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective

- Produce and interpret maps and other graphic representations to solve geographic problems.

Standard 8: Physical Systems

Characteristics and distribution of ecosystems

- Apply the concept of ecosystems to understand and solve problems regarding environmental issues.

Standard 14: Environment and Society

How humans modify the physical environment

- Develop possible solutions to scenarios of environmental change induced by human modification of the physical environment.

Geography Skills

Skill Set 5: Answering Geographic Questions

- Formulate valid generalizations from the results of various kinds of geographic inquiry.

2. Explain that water is such a key resource that citizens and scientists often join forces to ensure the quality and supply of water. This investigation focuses on how this has occurred in Chesapeake Bay.

3. Have students locate Chesapeake Bay and the watersheds that drain into the bay. Ask them to note the major cities in the Chesapeake Bay River Basin. Resources for students to use to situate Chesapeake Bay are listed in the **Briefing**.

Developing the Investigation

4. Distribute the Briefing. Ask students to read the entire Briefing but assign a few specific paragraphs to groups of three or four. Ask each group of students to generate several questions, summarize their assigned reading, and take turns asking and answering questions.

5. Explain the premise of the role playing:
   - A public forum will be broadcast on public television moderated by the League of Women Voters under the auspices of the federal government.
   - The purpose of the forum is to give citizens and scientists the opportunity to voice their opinions on key issues related to Chesapeake Bay, to collect information, and to begin to develop a sustainable policy to preserve and maintain the integrity of this national resource.
   - Students play a role representing individuals involved in exploring the uses and abuses of Chesapeake Bay, one of the United States' most significant water resources.

6. Briefly explain the format for the role playing.
   - Ten *individuals* (concerned citizens, public officials, scientists) testify before the hearing. They are questioned by a team of three or four invited *investigators*. All students are *regional planners*. They may ask questions of witnesses and will write a draft statement recommending future policies based on the testimony they hear.
   - Role summaries for each *individual* are provided (Handout 1). These are in the form of questions that may be asked of each role player during the testimony. Students learn their role and develop answers to the questions by reading and discussing the **Handout**.
   - The *investigators* (three or four students) receive the list of questions each role player is prepared to answer (Handout 1) and the points that they should have each testifier make (Handout 2). They must sequence the presenters and questions to ensure the points are made effectively and logically.
   - The *regional planners* (all students when not role playing) keep a summary of points made and draft the policy statement and justification for it after hearing the testimony.

7. Seek volunteers for each role and distribute the role cards (Handout 1). Each student must find the answers to the questions from the **Briefing** and assume the character. Require presenters to prepare a visual (for example, a map, diagram, overhead of images appearing in the **Briefing**, graphs made from additional data obtained by researching the suggested resources) to support their testimony. For example:
   - Susan Elliott: a diagram to show the local, state, and federal agencies that have cooperated to study the bay
   - Fred Kyle: a system diagram showing changes in sea grass, fin fish, oysters, and crabs over the past 100 years
   - Pam Gibbons: LANDSAT images and maps to show population growth in the region
   - Chris Sprinski: a graphic to illustrate the role of excess nutrients in water and air causing degradation of the bay
   - Georgina Giovingo: pictures of her husband fishing on the bay
   - Phil Klein: a graphic describing how sediments flow into the bay
   - Kristin Hyche: a graphic illustrating the role climate plays in the bay ecosystem
   - LeVar Jenks: a graphic showing the relationships among agriculture, industrialization, and urbanization and bay health and productivity
   - Evalia Tweedle: see role card
   - Steve Sui: copies of the AVIRIS, SeaWIFS, and LANDSAT images

   You may wish to have two-person teams for each individual role to facilitate the preparation of the graphic.

8. Distribute the list of roles and questions (Handouts 1 and 2) to the investigators. Allow them to divide the questions among themselves and to coordinate a strategy to ensure they are efficient and logical in their questioning.

9. Distribute directions to the regional planners (Handout 3). Explain that all students will contribute to the preparation of the policy recommendations. While some students prepare for and present the testimony, others will need to listen carefully, take notes, and synthesize and evaluate the testimony to form policy recommendations later. All students may ask questions. Decide on a format for the policy recommendations.

10. Have participants make name tags for themselves. Check that students are comfortable with their roles. Arrange the room in a town forum setting.

Developing the Investigation

11. Begin the role play. You may wish to act as moderator Susan Elliott or ask a student to play the role. Susan Elliott calls the forum to order, explains its purpose, and introduces the team of investigators. The investigators proceed by calling the concerned citizens and scientists to testify in any order they wish. Continue through the testimony. At close, request that the regional planners (all students) draft a policy statement.

Concluding the Investigation

12. Debrief the town forum.
    - Review the points presented by the individuals, the major concerns, and key issues.
    - Give students time to meet as regional planners and draft a policy to preserve and maintain the integrity of Chesapeake Bay. When they are finished, ask for a summary.
    - Discuss it. How well does the policy reflect a new understanding of the natural and human processes that affect water quality and use? What would be the long-term impact of such a policy? Who would be most affected? Least affected? Would it work? Ask students to make generalizations about water resources in densely populated regions of the world as well as in your region of the United States.

Susan Elliott

You are the president of the League of Women Voters. Because of its impartiality, your organization has been asked to sponsor a town forum on Chesapeake Bay. You are moderating the forum.

As moderator you should

- state the purpose of the town forum and provide some background (see the Questions listed below);
- introduce the investigators, citizens, and scientists;
- ensure that order is maintained and that everyone is polite and has an opportunity to speak; and
- remind all participants that they will, as regional planners, develop a policy to preserve and maintain the health of Chesapeake Bay.

Questions You May Be Asked

- Why is water important?
- How is water used?
- Why have many local, state, and federal agencies cooperated to study the bay?
- How successful have such partnerships of citizens and scientists been in setting environmental policies?

Fred Kyle

You are 44 years old and a concerned citizen employed by a high technology company outside of Washington, D.C. You and your family have lived near Chesapeake Bay in Virginia for generations and love it for its beauty and recreation opportunities. You enjoy taking your children on the water and someday hope to take your grandchildren but are worried about the degradation of the bay's water you have observed.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- How has Chesapeake Bay changed in the past 100 years in terms of sea grasses, fin fish, oysters, and crabs?
- When did you first become concerned with the health and quality of the bay?

Pam Gibbons

You are 28 years old and have just completed a master's degree in geography at the University of Maryland. Your first job is working for the state of Maryland doing long-range land use planning. Your research focuses on land use change in the Chesapeake, and you are considered an expert on the topic.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- What river basins flow into the Chesapeake?
- What are some ways that the Chesapeake has changed over the last few decades?
- What factors have caused these changes?
- What are the likely population trends in this area in the next 20 years?
- How will population affect land use?
- What role does sedimentation play in affecting the health of the bay?
- From your studies, what are the effects of land use and population change on the bay?
- What tools/images can you use to help in planning?

Chris Sprinski

You are in your mid-30s and a lifelong environmentalist. You have worked for several nonprofit organizations devoted to preserving the environment. In college you majored in biology with an emphasis in marine sciences but took environmental science courses as well. Currently you serve as a consultant to the Friends of Chesapeake Bay, a nongovernmental organization funded by private donations.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- What is the current model for bay ecosystem management?
- From your studies, what are the effects of land use and population change on the bay?
- What is the role that excess nutrients in water and air play in causing degradation in the bay? Please explain what happens step by step, beginning with algal blooms.

Georgina Giovingo

You are in your late 50s and have been a widow for a year. You and your husband made your living fishing the Chesapeake. Most of your limited income was made harvesting blue crabs. Your late husband, Dave, died of a mysterious infection possibly related to contamination from the waters of the bay. You are clearly upset about the degradation of the bay, the decline in fish, oysters, and crabs, and the loss of recreational value of the bay. You cannot contribute scientific information, but you show the forum that many people care passionately about the bay and rely upon it for their livelihood.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- How important is fishing to the economic well being of people in the Chesapeake region and the nation?
- From your experiences of fishing the bay for 30 years, how has the bay changed?
- Why do you think it is important to develop a policy to preserve and maintain the bay?

Phil Klein

You are a legislative aide assigned to the governor of the state of Maryland. You have three young children and live close to your office in Annapolis, the capital. You are an expert in the development of environmental policy and environmental law and act as the governor's liaison on Chesapeake issues, which includes attending meetings of the Chesapeake Bay Program. The governor has asked you to make sure that the state of Maryland is not responsible for causing damage to one of its key resources, Chesapeake Bay.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- What is the mission of the Chesapeake Bay Program?
- What actions have been taken or programs put in place related to the Chesapeake's health and well-being?
- How much sediment enters the bay from Maryland?
- What action has the state taken to affect the amount of sedimentation?

Professor Kristin Hyche

You are a professor at the University of Delaware specializing in climatology and hydrology in the Department of Geography. You study bay ecosystems from a geographic perspective, looking at the interactions between human and natural processes. You live in Newark, Delaware.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- How does the Chesapeake Bay ecosystem function?
- What role does climate play in the ecosystem? What are some of the effects of climate change on the health of the bay?
- How have policies to preserve the bay been helpful? For example, have subaquatic grasses returned in some bay tributaries?
- What are the causes of the changes observed in the bay in discharge, sea grasses, and blue crabs?
- Which of these are caused by natural processes and which by human actions? Explain.

LeVar Jenks

You are a research scientist with the USGS assigned to the Chesapeake Ecosystem Response Project. You grew up in innercity Baltimore and, as a young boy, loved to fish the bay with your grandfather and cousins. That inspired you to study the environment and to pursue a geology degree in college. You specialize in the geochemical analysis of sediments and worked hard to be assigned to the project. You are in your early 40s and live in a Maryland suburb of Washington, D.C. You are also a history buff interested in the way of life of your ancestors, enslaved persons in Virginia and Maryland.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- What is the Chesapeake Ecosystem Response Project? What is the project investigating?
- What methods are being used?
- Why is the project investigating the impacts of agriculture, industrialization, and urbanization at different periods of time? What role do they play in bay conditions?
- Do you have any research results to report yet?
- In your professional opinion, which do you think is having a greater impact on the bay, human processes or natural processes? Why?

Evalia Tweedle

Your training as a classroom educator prepared you well for your current administrative position with the Public Affairs Office of the EPA in Washington, D.C., where you also live, sharing a house with five other recent college graduates. You primarily work to heighten public awareness and understanding of key scientific and environmental issues. Since you were an educator and work with the public a great deal, you come to the forum prepared with teaching tools to present what you feel are key ideas that will contribute to the forum's success.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- What is the difference between point and nonpoint source pollution?
- What are some of the key sources of pollution?
- What are some strategies the EPA suggests home owners adopt to lessen their impact on the environment in general?
- How important is this kind of recommendation for people who live in the Chesapeake Bay watershed?
- What tools and resources can help EPA understand and control sources of pollution?

Steve Sui

You are employed as a research scientist specializing in remote sensing at NASA's Ames Research Center located near San Jose, California. You live close to San Francisco Bay and thus became interested in the Chesapeake Bay Project. You have worked closely with Phil Klein in the past; he invited you to participate in the forum. Your expertise is in using AVIRIS to remotely sense Earth, particularly its oceans. You are also expert in SeaWIFS, a sensing system to observe the world's oceans and monitor ecosystem change. You think you may be asked to explain two images produced by these sensors and plan to come prepared.

Questions You May Be Asked

- What is your name, where do you live, and what is your occupation?
- How did you become involved with the Chesapeake Bay Project?
- What is AVIRIS?
- How was it used to monitor Chesapeake Bay? What was the end result?
- Can you draw any conclusions about the health of the bay from the map that was produced?
- What is SeaWIFS? What is it being used for?
- What is LANDSAT? What is it being used for and by whom?
- What do the colors on the image of Chesapeake Bay indicate?
- Discuss the usefulness of remote sensing for tracking changes on Earth?

Handout 2: Investigator's Points That Each Witness Should Make

Susan Elliott

- Water is important to human health and all its endeavors. It is equally important to other living creatures in the ecosystem upon which humans depend. It has a variety of uses, including transportation, irrigation, recreation, industry, and fishing.
- Chesapeake Bay is the nation's largest and one of the world's most productive estuaries.
- Chesapeake Bay is an important resource to many people in six states who live in urban, suburban, and rural areas. A watershed is a complex system. It requires the cooperation of many agencies at different scales to address watershed-wide issues because the boundaries of governmental jurisdictions do not match the boundaries of watersheds.

Pam Gibbons

- Nine river systems flow into the bay. They are the Susquehanna, the Potomac, the Patuxent, the Choptank, the Rappahannock, the Mattaponi, the Pamunkey, the James, and the Appomattox.
- Human activities play a role in the degradation of the bay. Changes in how people use the land (land use change) are the major culprits, including deforestation, urban development, and expansion of agricultural land. As population grows, forests are cut and land cleared to build houses, malls, and businesses. Agriculture expands into new areas to feed the growing population. More people produce more sewage and pollution. When it rains, exposed dirt (sediments) disrupted by human activity washes into the bay.
- The population will continue to grow in this already densely populated region of the nation, and land use changes will continue. There are about 18 million people living in the area now.
- Sediments cloud the bay water so much that subaquatic vegetation like sea grasses cannot survive.
- Land cover maps and images like the one from LANDSAT 7 are used to estimate polluted water runoff. Remote sensing is an important tool.

LeVar Jenks

- The U.S. Geological Survey (USGS) Chesapeake Ecosystem Response Project is designed to improve understanding of large-scale environmental changes that influence water quality and living resources in the Chesapeake Bay. In particular, project workers investigate the links among changes in climate, precipitation, discharge, salinity, and dissolved oxygen over different time periods.
- The human factors that most affect these natural factors are industrialization, agricultural practices, and urban development.
- USGS scientists and other researchers are collaborating to study the bay's sediments, which capture the history of its water, plants, and animals during the period before monitoring began in the 1980s. Using ecosystem "indicators" (microfossils), geochemical data preserved in the bay's sediment, and historical and reconstructed discharge data, we have reconstructed trends and responses in the bay since 1950 to determine the natural conditions in the bay over the last few millennia, including periods prior to 17th-18th century colonial agriculture and 19th-20th century industrialization and urbanization. The emphasis has been on separating natural versus human causes of and responses to extreme events.

Evalia Tweedle

- Point pollution is pollution coming from a known, identifiable source, such as a pipeline spewing waste. Nonpoint source pollution is pollution that enters surface, ground water, and the oceans from widespread and distant activities, that is, from no one, single point.
- The key sources of nonpoint source pollution are agriculture and livestock, urban runoff, automobiles, land clearing, sewage, factories producing air pollution, and industrial waste.
- The EPA suggests homeowners manage hazardous waste carefully. Householders need to be aware that they have an impact on the environment when they dump chemicals down the drain.
- This advice is especially important for the millions of people that live in the Chesapeake watershed. Something placed onto the ground anywhere in the region ultimately affects the health of the bay.
- Remote sensing is helping us to better pinpoint the sources of polluted runoff.

Chris Sprinski

- The model is the system. All elements of the various systems present in the bay are linked, connected, and affect the other elements. Everything is interrelated; managing just one system element will not necessarily cause positive changes throughout the system.
- Land use and population changes increase the amount of agricultural fertilizers and urban sewage treatment plants, which cause increased phosphorus and nitrogen loading in surface and ground water.
- Excess nutrients from water and air can lead to an increase in algal blooms, reduced dissolved oxygen levels on the bottom, habitat degradation, and depleted living resources.
- Algal blooms can reduce the clarity of the water, which prevents sunlight from penetrating to the bottom and thus inhibiting the growth of sea grasses or subaquatic vegetation (SAV). SAV is important because it helps absorb nutrients, adds oxygen to the water, and provides a sheltered habitat for organisms, especially juvenile blue crabs. It is also a food source for water birds living in the bay.

Georgina Giovingo

- The bay provides 50 percent of the nation's blue crab harvest, worth about $130 million per year. There are many people who make their living by fishing and many more who make their living serving the needs of recreational boaters, birders, and beach goers in the region.
- The bay is not as clean as it once was. There are fewer fish and shell fish. Sometimes there are algal blooms that make people sick. The water is not as clear as it was. More people live around the bay now. There are fewer birds because there are fewer fish.
- People's livelihoods depend on the health of the bay.

Professor Kristin Hyche

- Ecosystem function is very complex, and there are gaps in our understanding of the relationships among river discharge into the bay, the amount of oxygen dissolved in the water, and aquatic grasses.
- We have better tools now, like the data and images obtained through remote sensing, to measure nutrients in the bay.
- The amount of rainfall affects the freshwater discharge entering the bay. In recent years, fluctuating climate patterns have made this relationship especially evident. The amount of fresh water changes the nutrients entering the bay and the salinity of the water. These factors in turn influence how bay phytoplankton use the nutrients and thus, oxygen levels in the water.
- Historical trends, for example comparing the drought years of the 1950s and 1960s to later decades, indicate the importance of climate to bay health.
- Aquatic grasses have returned in some areas and not others. We do not yet know precisely what works and what does not work to repair environmental damage. The factors of habitat change, overharvesting, natural mortality, and climate change all play varying roles.
- The bay ecosystem is very complex, and little is known about the relations among species and their environment and climate change. It is also difficult to separate human and natural effects.

Phil Klein

- The Chesapeake Bay Program (CBP) was formed in 1983 as a regional cooperative effort between the U.S. Environmental Protection Agency and various state and local governments of the bay watershed including the states of Maryland, Pennsylvania, and Virginia, the District of Columbia, and the Chesapeake Bay Commission.
- Its primary mission is restoration of living resources, including fish, shellfish, bay grasses, and other aquatic wildlife of the nation's largest and one of the world's most productive estuaries.
- The Chesapeake Bay Program monitors water quality and biotic resources in order to assess the bay's ecological health on a regular basis and to produce computer models to predict watershed quality and ecosystem response to nutrient loading.
- The CBP routinely conducts an ongoing ship-based monitoring program to collect *in situ* measurements of physical, chemical, and biological indicators of the bay's health. The CBP is evaluating the use of remote sensing as an adjunct to the monitoring program, with the idea that highly accurate point measurements may be used in conjunction with appropriately processed imagery to generate a spatial dataset of water quality.
- About 155 million metric tons of sediment have entered the bay in the last 100 years from the state of Maryland alone. That is a serious problem.
- Biological resource management plans have been developed to restore and preserve key species for commercial and recreational use.

Fred Kyle

- The bay has degraded seriously in the last 100 years. Sea grass acreage has declined. There are fewer fish and shell fish, particularly blue crab for which the bay is famous. The amount of dissolved oxygen has decreased, and more soil is washing into the bay.
- The changes really became noticeable in the 1970s when the commercial fishermen started to notice declines in fish, and recreational users became aware of reduced water quality.

Steve Sui

- A NASA experiment showed the utility of remote sensing in monitoring the Chesapeake Bay watershed. A sensing device known as AVIRIS was flown over the southern part of the bay to measure the amount of chlorophyll and sediments in the waters.
- AVIRIS is an acronym for the Airborne Visible InfraRed Imaging Spectrometer. It is a remote-sensing instrument that flies aboard a NASA ER-2 airplane approximately 20 kilometers above sea level. It is used to identify, measure, and monitor constituents of Earth's surface and atmosphere. Research with AVIRIS is directed towards understanding processes related to the global environment and climate change.
- SeaWiFS is a sensor mounted on a satellite that observes Earth from a noontime sun-synchronous orbit, which means that the sensor is always viewing Earth around local noon at an altitude of 705 kilometers. This orbit provides data to detect concentrations of microscopic green plants, called phytoplankton, which live just beneath the ocean surface. These green plants absorb sunlight during photosynthesis, the most basic and essential chemical process necessary for life on Earth.
- The red colors show high concentrations of chlorophyll in the water, the yellows/greens indicate intermediate concentrations of chlorophyll, and the blues/purples show low concentrations of chlorophyll.
- In the image of Chesapeake Bay, ocean patterns are clearly evident, such as plumes of material discharging out of eastern Long Island Sound. Red and yellow areas in Chesapeake Bay indicate turbid waters while the blue hues offshore represent clear oceanic water.
- LANDSAT is a satellite that picks up information particularly related to land cover such as pasture, crop lands, different types of forest and wetlands, and types of residential land uses. It is very useful for local and regional planning agencies.

Instructions to Regional Planners

You are a planner on the Chesapeake Bay regional planning council. Prior to the town forum, summarize the situation in the Chesapeake in the space provided.

The Situation

The Town Forum

The purpose of the town forum is to collect information about the bay from different points of view. Everyone at this meeting is in favor of taking action to "save the bay." Your job will be to make recommendations to develop a sustainable policy to preserve and maintain the health of the bay.

During the forum, investigators will call a series of concerned citizens, local and state government officials, and scientists to give testimony about the bay. You will listen to the testimony and take notes summarizing the points each individual makes. As you listen, synthesize and evaluate the testimony. You will need the information to decide policy later. You may ask questions to clarify a point, but in general you should leave that to the investigators.

Writing the Policy

Your work really begins with the end of the forum when you develop the recommendations. Summarize your findings based on the testimony, and then make at least three specific recommendations to preserve and restore the bay.

Module 1, Investigation 1: Briefing
Chesapeake Bay: Resource use or abuse?

How do natural processes and human actions affect the Chesapeake Bay as a water resource?

Background

Water is essential to life on Earth. Three-quarters of Earth's surface is covered by water. Because it is almost everywhere, we sometimes take it for granted, but we do things that affect its quality and quantity. This briefing shows how human actions have combined with natural processes to affect Chesapeake Bay, one of the United States' most significant water resources.

Because Chesapeake Bay is such an important resource, many citizens and government agencies are concerned about its present and future status. Several federal, state, and local organizations and agencies have combined their efforts to study the bay in order to provide ideas and programs to ensure its future health.

NASA, USGS, EPA, and NOAA are federal agencies doing this research. Three NASA missions have contributed data to bay studies: SeaWiFS (Sea-Viewing Wide Field-of-view Sensor), AVIRIS (Airborne Visible InfraRed Imaging Spectrometer), and LANDSAT 7. The data gathered from SeaWiFS and AVIRIS have contributed to a better understanding of the ability of the bay to support plant and animal life. The data produced by LANDSAT 7 allow smarter land use planning and better estimates of polluted water runoff across the 110,000 square kilometer Chesapeake Bay watershed.

Chesapeake Bay is located in the northeastern United States in the most densely populated region of the nation. Figure 1 indicates its location and the river systems that flow into the bay. Turn to Figure 6 to see the land use in this highly industrialized, highly urbanized region.

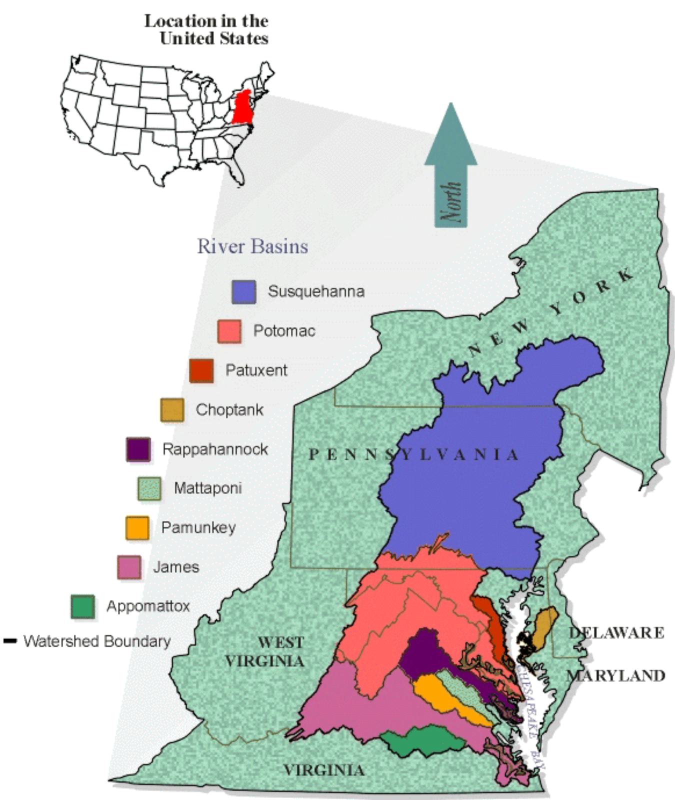


Figure 1: Location of Chesapeake Bay and the river systems that flow into it

Source: http://mapping.usgs.gov/mac/chesbay/overview_cbep_fig1.html

Ecosystem Trends and Response: Chesapeake Bay

The Nation's Largest Estuary

Chesapeake Bay, the nation's largest estuary, has had serious environmental degradation during the past century. The evidence of damage includes declines in sea grass acreage, reduction of fin fish and shellfish (oysters and crab), seasonal depletions of dissolved oxygen, and increases in sedimentation.

These changes raised serious concern in the 1970s because they threatened major commercial and recreational activities. Most scientists attribute these changes, at least indirectly, to human activities. Land use changes in the bay watershed (deforestation, agriculture, and urbanization) brought added pollution and sewage. Future stress on bay ecosystems is likely to worsen, as the Chesapeake Bay Commission predicts that the population in the bay watershed will swell to over 18 million by the year 2020.

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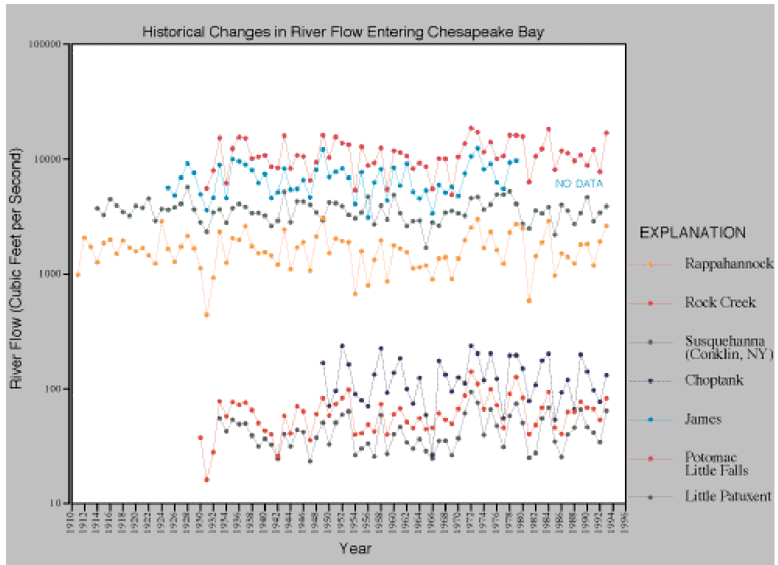
Chesapeake Bay: Resource use or abuse?

Critical Issues for Ecosystem Management and Restoration

Chesapeake Bay is a complex natural ecosystem with many interrelated human and natural subsystems. Changes in each subsystem ripple through others, causing various effects. Ecosystems recycle chemicals needed by living things, redistribute wastes, control pests that cause disease in both humans and plants and animals, and offer a huge pool of resources for humans and other living creatures. Ecosystems are affected by natural events such as droughts. But ecosystems are more drastically changed by human activities.



Interannual and decadal variations in river flow are obtained from seven tributary monitoring stations, unimpeded by dams and other structures. River flow strongly influences nutrient input and dissovled oxygen in Chesapeake Bay. Climatic factors in turn, control to a great extent interannual and decadal flow variations.

Figure 2

Source: http://geochange.er.usgs.gov/pub/info/facts/chesapeake/graph.gif

The model used for bay ecosystem management is a system which shows links among land, sea, and living creatures that result in changes in the watershed affecting the bay. For example:

- Land use and population changes increase the amount of agricultural fertilizers and urban sewage treatment plants, which cause increased phosphorus and nitrogen loading in surface and ground water.
- Excess nutrients from water and air can lead to an increase in algal blooms, reduced dissolved oxygen levels on the bottom, habitat degradation, and depleted living resources.
- Algal blooms can reduce the clarity of the water, which prevents sunlight from penetrating to the bottom and can inhibit the growth of sea grasses or subaquatic vegetation (SAV).
- Subaquatic vegetation helps absorb nutrients, adds oxygen to the water, and provides a sheltered habitat for organisms, especially juvenile blue crabs. It is also a food source for water birds living in the bay.
- Sedimentation is another critical problem. Over the last 100 years, 155 million metric tons of sediment were deposited in the Maryland portion of the bay. Sedimentation rates have increased since colonial times because of land use changes. Sediment can cloud the water so much that SAV cannot survive.

Causes of Recent Trends in Dissolved Oxygen and SAV

Fluctuations in the amount of freshwater entering the bay from its tributary rivers (termed discharge) result from changing precipitation patterns over the last few decades (Figure 2). Recently, these fluctuations have become extreme. Trend data show the influence of discharge on the total nutrients entering the bay and on bay salinity. These influence phytoplankton growth and oxygen levels. Climatic factors play a role in controlling water quality. For example, the drought years of the 1950s and 1960s caused low tributary discharge into the bay.

Bay restoration efforts began in the early 1980s. Surveys have indicated that sea grasses have begun to grow again in several tributaries of the bay. In theory, this reflects a response to improved water quality. But there were areas where subaquatic vegetation (SAV) did not return despite improved water quality. This continued absence of SAV concerns scientists and resource managers, in part because SAV provides habitat for young blue crabs. The bay provides 50 percent of the nation's total blue crab harvest. The bay crab harvest was worth $126.6 million in 1993. Chesapeake Bay is a significant source of fish and shellfish.

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A Complex System

What do recent trends in discharge, anoxia (too little oxygen in the water), sea grasses, and blue crabs mean? Are they caused by habitat change, overharvesting, or natural mortality related to long-term climatic factors? These questions remind us of how complex the bay ecosystem is and of how little we know about the relations among individual species, their environment, and climate. They also illustrate how difficult it is for scientists to separate natural versus human effects on critical species and their habitats based solely on monitoring. Detection of a trend can be easy, but assigning cause is much more difficult.

Cross-country Sources
Side Effects Spread from Land to Sea

Identifying a water polluter is easy when the source of the pollution is a single point, such as a single pipeline spewing wastes. But it's not so simple when you consider *nonpoint source pollution*, which comes from nearly everything we do on land that contributes to polluted runoff that enters surface and ground water, as well as oceans. It can lead to beach and shellfish-bed closings and spoiled habitats for fish and other aquatic life. Below are some of the sources of pollution entering the bay.

Agriculture and Livestock
Runoff from barnyards, feedlots, and cropland contributes nutrients from manure and fertilizers, as well as pesticides and eroded soil.

Urban Runoff
Urban runoff from buildings and paved surfaces carries sediment, nutrients, bacteria, oil, trace metals, chemicals, road salt, pet droppings, and litter.

Automobiles
Leaking oil and motor fluids run off roadways and into waterways. Emissions send nitrogen and other contaminants into the atmosphere that eventually settle into coastal waters.

Land Clearing
Construction, clearing land, and logging often lead to soil erosion, putting more sediment in rivers and coastal waters. Filling in wetlands takes away vast natural water filters that can break down many common pollutants before they reach other water bodies.

Sewage
Sewage, leached from faulty septic systems, or dumped directly overboard instead of emptied at boat pump-out stations, contributes nutrients and disease-causing organisms.

Air Pollution
Airborne pollutants, chiefly from factories and automobiles, are responsible for almost a third of all contaminants and nutrients entering marine waters.

Industrial Waste
Industrial runoff brings heavy metals and other compounds into marine waters, from industrial-waste landfills, from mining, and from storm water draining off of industrial sites.

Warning Signs

Too Many Nutrients Lead to Too Little Oxygen
Too much nitrogen (from fertilizers, sewage, feedlot runoff, or air pollution), or too much phosphorus (from the same sources, as well as detergents or water-treatment chemicals), can set off explosive growth of algae and aquatic plants. As the over-populated plants and algae die off, bacteria can deplete oxygen from the water as they decompose the dead plants. Lack of oxygen kills fish and other animals.

Managing Hazardous Waste Hits Home
Many products for home and garden can burn, explode, corrode, or poison. Dumped down the drain, onto the ground, or into the trash, they can pollute water, pose health risks, and damage water-treatment systems. Since 1980, thousands of community programs have begun to collect household hazardous waste.

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Get a Handle on Household Hazards
To cut your "pollution contribution," use fewer hazardous or unsafe products if you can. If you can't, use only as much as you need; share leftovers with neighbors, businesses, or charities; and dispose of leftovers safely.

Chesapeake Bay's Health Depends on the Kindness of Many Strangers

The bay's watershed covers six states and the District of Columbia. It drains 150 rivers and streams—an enormous catchall for urban, suburban, and agricultural pollution. Environmental problems often occur over large areas that fall into the control of more than one governmental unit. For this reason, a landmark 1983 agreement formed the Chesapeake Bay Program (CBP).

The Chesapeake Bay Program is a partnership between the U.S. Environmental Protection Agency, Maryland, Pennsylvania, Virginia, the District of Columbia, the Chesapeake Bay Commission, and local governments of the bay watershed. The program has helped reduce nutrient pollution from farming and livestock, banned phosphate detergents and tributyl-tin boat paints, and protected ecologically sensitive shorelines.

The Chesapeake Bay Program
- aims to restore living resources, including fish, shellfish, bay grasses, and other aquatic wildlife;
- monitors water quality and biotic resources;
- produces computer models to predict watershed quality and ecosystem response to nutrient loading;
- used modeling studies to establish a goal of a 40 percent reduction from 1985 levels of nutrient input into the bay by 2000;
- developed biotic management plans to restore and preserve key species for commercial use and recreation; and
- conducts ship-based monitoring to collect measurements of physical, chemical, and biological indicators.

Taking Action: Research, Response, and Management

The U.S. Geological Survey's (USGS) Chesapeake Ecosystem Response Project is another effort to understand large environmental changes influencing the water quality and living resources in the bay. In particular, the project scientists
- investigate links among changes in climate, discharge, salinity, and dissolved oxygen over different time periods and geographical scales;
- study the effects of past events recorded in the layers of sediment deposited on the floor of the bay over time;
- collaborate with researchers from the University of Maryland, the Maryland Geological Survey, and the Virginia Institute of Marine Science to study the bay's sediments;
- reconstructed trends and responses in the bay since 1950 to determine the natural conditions in the bay over the last few millennia, including periods prior to 17th-18th century colonial agriculture and 19th-20th century industrialization and urbanization;
- found a linkage between climate and land quality and habitat loss in the bay;
- continue to study trends in oxygen, nitrogen, and phosphorus levels, phytoplankton, benthic invertebrates, sedimentation, and biodiversity with emphasis on separating natural versus human causes of and responses to extreme events.

Using Remote Sensing as a Research Tool: Three Examples from NASA

Using the unique perspective from space, NASA observes, monitors, and assesses large-scale environmental processes, such as the oceans' productivity.

AVIRIS Analysis of Chesapeake Bay
During 1997-1998, NASA's Ames Research Center performed a remote-sensing demonstration project in collaboration with the Chesapeake Bay Program (CBP). The CBP wanted to evaluate the use of remote sensing in its monitoring program, hoping that point measurements could be used with satellite imagery to develop water quality data.

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Previously, University of Maryland scientists had explored the use of airborne remote sensing to map chlorophyll concentration in the bay.

NASA's AVIRIS (Airborne Visible InfraRed Imaging Spectrometer) was chosen for the demonstration. The objective of AVIRIS is to identify, measure, and monitor Earth's surface and atmosphere. Research with AVIRIS seeks to understand global environmental processes such as climate change. The instrument flies aboard a NASA ER-2 airplane at an altitude of about 20 kilometers.

It flew over the bay on August 17, 1997, and July 3, 1998. The data it collected allowed scientists to estimate chlorophyll and suspended sediment concentrations. These data were compared with CBP shipboard measurements.

The 1998 flight identified submerged aquatic vegetation (SAV). Scientists compared the satellite images with aerial photography and found that imagery analysis was useful in determining sea grass distribution.

SeaWiFS

Figures 3, 4, and 5 show views of Chesapeake Bay from the SeaWiFS (Sea-Viewing Wide Field-of-View Sensor). Figure 3 shows data taken on September 16, 1997, and Figures 4 and 5 record data from September 19, 1997. SeaWiFS data allow assessment of global vegetation patterns, both land and ocean, needed to understand ecosystems and global change. The SeaWiFS instrument observes the oceans from space to measure "ocean color." SeaWiFS is essential to NASA's efforts to study how the global environment is changing.

SeaWiFS observes Earth from a noontime sun-synchronous orbit, which means that the sensor always views Earth around local noon at an altitude of 705 kilometers. This orbit provides data at the maximum solar illumination, the most desirable for detecting concentrations of phytoplankton, which live just beneath the ocean surface. These green plants absorb sunlight during photosynthesis.

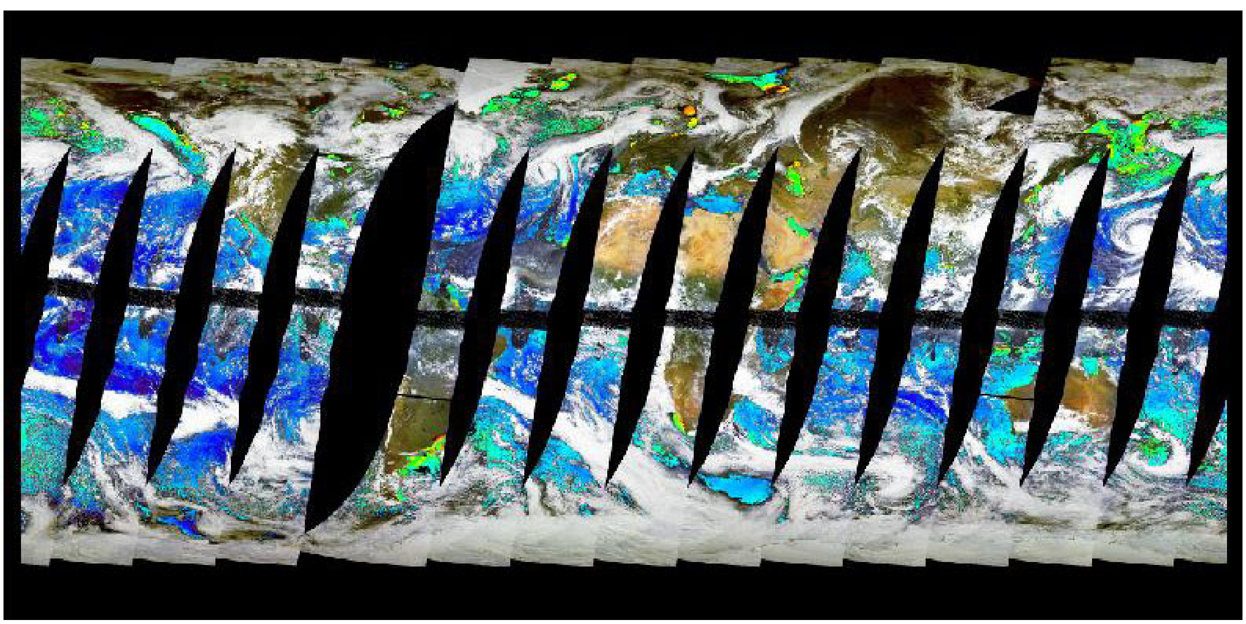

Figure 3: SeaWiFS data from September 16, 1997

Source: http://seawifs.gsfc.nasa.gov/SEAWIFS/IMAGES/SEAWIFS/revised_ocean_color_and_land_4096x1024.jpg

In Figure 3, the red colors show high concentrations of chlorophyll in the water, the yellows/greens indicate intermediate concentrations of chlorophyll, and the blues/purples show low concentrations of chlorophyll. The black swaths indicate no data because of gaps between the orbits. On Earth, coverage is every two days.

The two images of Chesapeake Bay offer SeaWiFS high-resolution data obtained over the mid-Atlantic on September 19, 1997. Figure 4 highlights vegetation associated with the coastal plain and mountain ridges and valleys. White areas are clouds and dense aerosols. Note that ocean features are not noticeable.

In Figure 5, ocean patterns are evident, such as plumes of material discharging out of Delaware Bay. Red and yellow areas in Chesapeake Bay indicate turbid (sediment filled) waters, while the blue hues offshore represent clear oceanic water. Black areas, such as in the right bottom corner, are locations where the processing could not be completed.

Figure 4: SeaWiFS, September 19, 1997, New York—Chesapeake Bay, true color

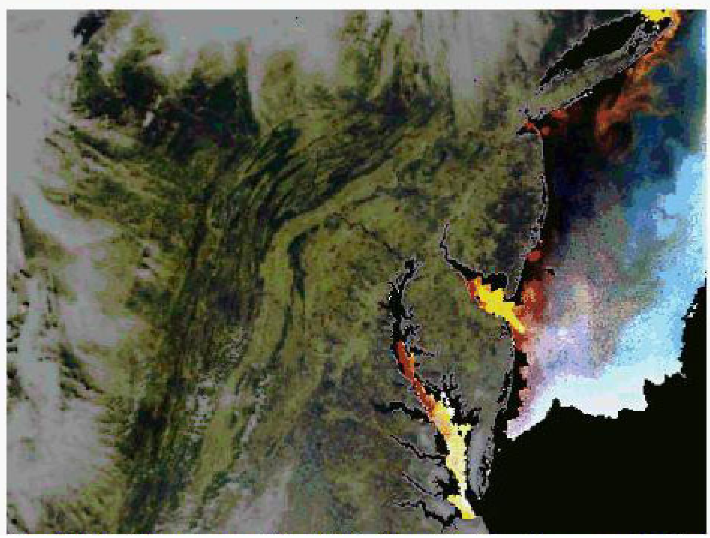

Figure 5: SeaWiFS, September 19, 1997, New York—Chesapeake Bay showing ocean radiance

http://seawifs.gsfc.nasa.gov/SEAWIFS/IMAGES/SEAWIFS/ches_combined.jpg
http://seawifs.gsfc.nasa.gov/~grey/slides/october97.html

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LANDSAT

LANDSAT (Land Remote Sensing Satellite) is designed to gather data on Earth's resources in a regular and systematic manner. It collects information related to land use, geological and mineralogical exploration, crop and forestry assessment, and cartography. The image in Figure 6 was produced by LANDSAT 7 to assess the amount of different land cover types in the bay region, including residential development, wetlands, forests, and crop lands.

The maps produced from LANDSAT will help make estimates of polluted river runoff flowing into the bay by identifying pasture land and different types of crops. The amount of nutrient pollution entering the bay can be measured by knowing the area of a type of land cover and estimating the average water quality of runoff from that type of land. Heavily fertilized agricultural fields, for example, produce higher levels of nutrients in runoff than the same acreage of pasture land.

The image and maps also distinguish low- and high-density residential development from wetlands and different types of forest. These images will allow smarter land use planning and better estimates of polluted water runoff across the watershed.

References

Information on the AVIRIS mission
http://geo.arc.nasa.gov/sge/johnson/epa/chesbay.html
Information on the SeaWiFS mission
http://seawifs.gsfc.nasa.gov/~grey/slides/october97.html
Oblique view of Chesapeake Bay watershed and surrounding region
http://svs.gsfc.nasa.gov/imagewall/SeaWiFS/zoom_chesapeake.jpg
QuickTime movie locating the Chesapeake Bay
http://svs.gsfc.nasa.gov/imagewall/SeaWiFS/zoom_chesapeake.mov
USGS Chesapeake Bay web site
http://earth.jsc.nasa.gov/
Shuttle images of Earth
http://mapping.usgs.gov/mac/chesbay/index.html
Poster image of the Chesapeake Bay watershed
http://mapping.usgs.gov/mac/chesbay/poster.html
Site for Chesapeake Bay ecosystem background information
http://geochange.er.usgs.gov/pub/info/facts/chesapeake/
Resource site developed by the Chesapeake Bay Program
http://www.chesapeakebay.net/
Look up your community's watershed at this site
http://www.epa.gov/surf2/locate/
Site for population data
http://www.chesapeakebay.net/pop.htm
Site for human use background information
http://www.chesapeakebay.net/landscape.htm
USGS FactSheet FS-116-00. September 2000. "Effects of Climate Variability and Human Activity on Chesapeake Bay and the Implications for Ecosystem Restoration."

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Chesapeake Bay: Resource use or abuse?

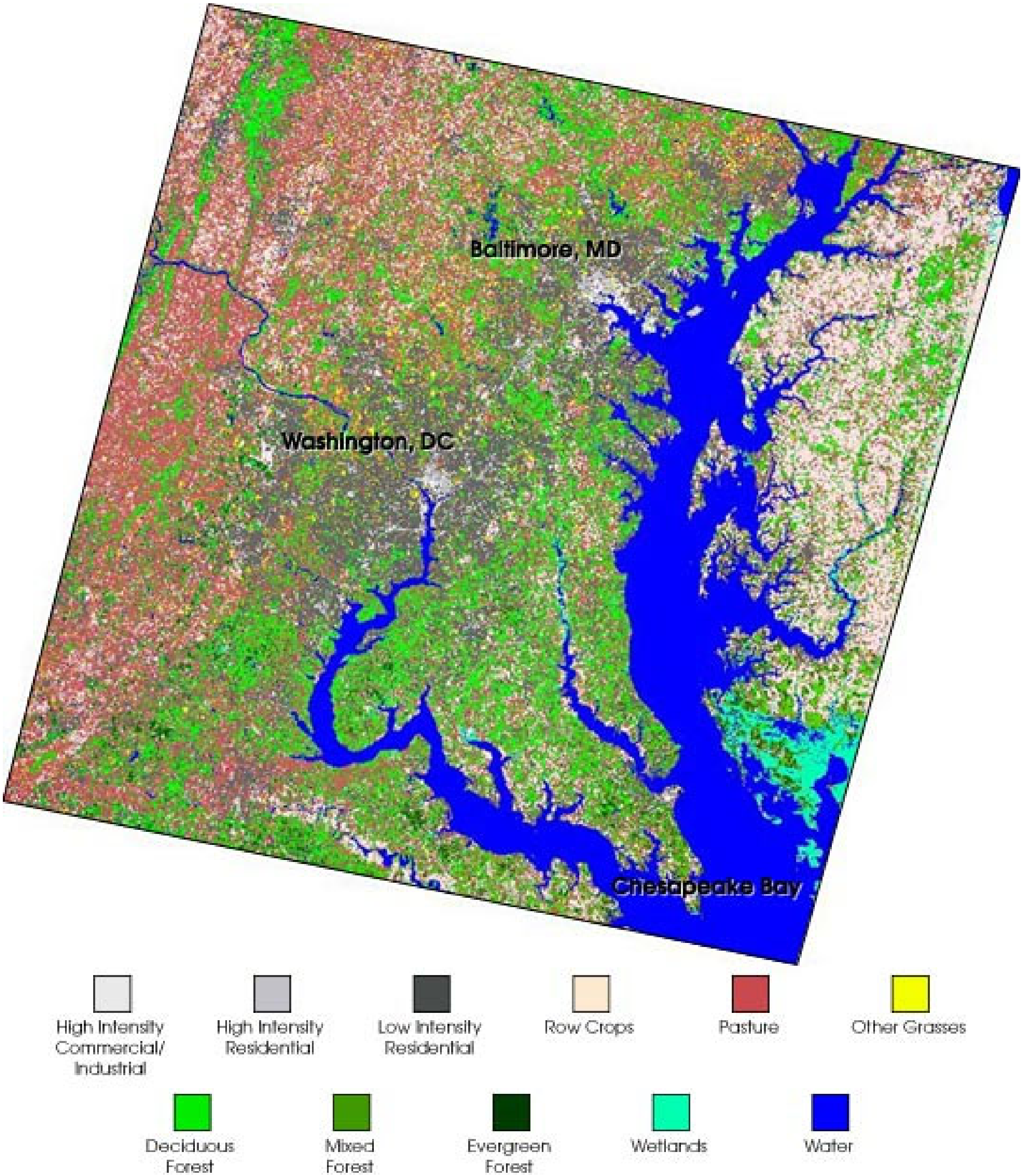
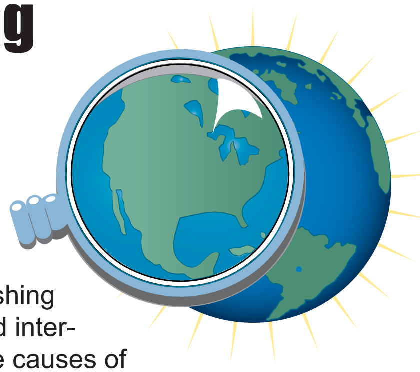


Figure 6: LANDSAT 7 image showing land cover types in Chesapeake Bay area including residential development, wetlands, forests, and croplands

What is happening to the Aral Sea?



Investigation Overview

In Investigation 2, students work as teams of NASA geographers using satellite images to measure the diminishing size of the Aral Sea. They analyze and interpret graphic and tabular data about the causes of the shrinking sea and its effects on habitat, resources, and people in order to report their recommendations for improving this resource for future use.

Time required: Five to eight 45-minute sessions (as follows):
Introduction and Part 1: Two or three sessions
Part 2: One session
Parts 3 and 4: One or two sessions
Conclusion and debriefing: One or two sessions

Materials

Briefing and Log, one copy for each student
Transparency of Figure 5 in Briefing
Graph paper
Computer with CD-ROM drive. The Mission Geography CD-ROM contains color graphics needed for this activity.
Access to the Internet, which offers opportunities for extending this activity

Content Preview

The Aral Sea, which lies in an interior basin, has shrunk because the rivers that flow into it have been diverted for irrigation. This has caused both positive and negative physical and human consequences.

Classroom Procedures

Beginning the Investigation

1. Introduce this as a puzzle. Show a transparency or slide of abandoned Aral Sea fishing boats (**Figure 5** in **Briefing**, *without the caption*), and ask students to solve the puzzle. Ask students what they think happened here. Keep the discussion open ended and entertain numerous ideas, but don't provide answers. Simply tell students that they will be investigating this puzzle, which is about a huge lake—about the size of Lake Huron—in Central Asia, called the Aral Sea.

Developing the Investigation

2. Hand out copies of the **Briefing** and **Log** to each student or to small groups of students. Students can work individually, but small groups of two to four are recommended.

Geography Standards

Standard 4: Places and Regions

The physical and human characteristics of places

- Describe and interpret physical processes that shape places.
- Explain how social, cultural, and economic processes shape the features of places.
- Evaluate how humans interact with physical environments to form places.

Standard 7: Physical Systems

The physical processes that shape the patterns of Earth's surface

- Explain Earth's physical processes, patterns, and cycles using concepts of physical geography.

Standard 14: Environment and Society

How human actions modify the physical environment

- Evaluate the ways in which technology has expanded the human capacity to modify the physical environment.
- Develop possible solutions to scenarios of environmental change induced by human modification of the physical environment.

Standard 15: Environment and Society

How physical systems affect human systems

- Analyze examples of changes in the physical environment that have reduced the capacity of the environment to support human activity.

Geography Skills

Skill Set 3: Organizing Geographic Information

- Select and design appropriate forms of graphs, diagrams, tables, and charts to organize geographic information.

Skill Set 4: Analyzing Geographic Information

- Make inferences and draw conclusions from maps and other geographic representations.

3. Leaf through the materials with students and point out the underlined questions, which are to be answered on the **Log** at the end of the materials. Give students a schedule for completing the several questions.

4. Have students read the first two sections: **Background** and **Objectives**. Take questions and ask questions to be sure students understand the reading. For example, draw out examples in support of the ideas in the Background. Have students explain the difference between, and give examples of, fresh and salt water lakes. Begin a discussion of lakes as resources. Are lakes resources? How do people use lakes? What can happen to lakes that affect their use as resources? How can people change lakes for better and for worse?

5. Form teams of two to four students to be NASA geographers studying recent changes in the Aral Sea. Emphasize that they will be required to make recommendations to improve the Aral Sea as a resource, so it is important that they carefully work through all the material. Have the teams begin with **Part 1: How can you measure changes in the size of the Aral Sea?** and help them as needed as they work through the procedures, putting their answers in the Log.

6. Students may need some guidance in using the grid (**Figure 4**) on the satellite images to measure the size of the sea surface. Students can lay the images over the grid on a window or light table. Alternatively, you may wish to provide transparencies of the grid. In any case, remind students that this method of measurement (a "count GIS") will only give an estimate.

7. As you move from team to team answering questions and monitoring progress, you may find that some students will need assistance computing the percentage change to the Aral Sea. Since the estimates of size may vary considerably, the percentage changes will also vary.

8. **Part 2: Why has the Aral Sea been shrinking?** is the second major question in the investigation. Students are asked to *hypothesize* about the causes and to list their hypotheses on the Log at Questions 8 and 9. (The word hypothesis is used here to simply mean "explanation.") You may need to discuss the difference between *physical* processes (natural) and *human* processes (caused by humans). Encourage teams to discuss the meaning and plausibility of their hypotheses. Also, have them suggest the information they would need in order to test their hypotheses. These questions have no single, correct answers but should encourage critical thinking along new lines of thought. Remind them to put their answers to the questions on the **Log**. Emphasize to students that they should test their hypotheses with data in this part and in **Part 3: How has the region's landscape changed?** The **Background** below will give you the most commonly held scientific interpretation of what happened.

9. Students may need help interpreting Tables 1 and 2. Be sure they can explain the terms: *surface elevation, precipitation, evaporation, annual river inflow, and volume*. Students can convert some of the figures in the tables to English system equivalents if you want them to practice that skill. If you wish, you can also have them practice the skill of computing percentage changes over time for one or more of the categories in Tables 1 and 2. In any case, they need to study Table 1 to answer Question 10.

10. You may wish to hold a general discussion to help students answer Question 11, "What physical processes might explain the changes in precipitation and evaporation shown in Table 1?" To direct this discussion, see the answer to Question 11 in the Log Key. Students should understand the relationships among the data provided in the tables and figures. For example, in Table 1, evaporation from the sea decreased because the size of the sea was decreasing—there was less surface area from which to evaporate. In Table 2, as population increases, both irrigated area and water withdrawals increase; and the increasing salinity shown in Table 5 corresponds to the decreasing volume shown in Table 1.

11. You may wish to provide graph paper for the exercise for Question 12. A basic framework is given in the answers to the Log. You may wish to give that framework to students so they can simply plot the data for the three variables (year, population, irrigated area). Or, you may wish to challenge students to design their own graphs. In any case, they should add (and justify) their projections for 2000 and 2010.

12. **Part 3: How has the region's landscape changed?** and **Part 4: What are the human consequences of the shrinking Aral Sea?** provide information about physical and human consequences.

Concluding the Investigation

13. Teams should write their final reports to NASA, using the guidelines given in Question 15.

14. You may wish to debrief the investigation by discussing the Log, especially emphasizing the recommendations students have made in their final reports. Alternatively, use the Objectives listed at the beginning of the **Briefing** to organize the debriefing. You could also draw the investigation to an end by asking students to weigh the economic benefits against the consequences of this regional development scheme.

Background

The Amu Darya and Syr Darya Rivers empty into the Aral Sea, which lies in an interior basin. The development by the Soviet Union of irrigation projects in the region, especially to grow cotton beginning in the 1950s, captured the river waters so that little fresh water reached the Aral Sea. Withdrawal of water from the Amu Darya and Syr Darya, primarily for irrigation, is the most important factor reducing water flows into the Aral Sea. This caused the Aral Sea to shrink in size.

The shrinking Aral Sea has had both positive and negative physical and human consequences. Agricultural production and population in the region increased dramatically, thus improving the economy of the region, which was clearly the main goal of the Soviet government planners. On the other hand, contaminated soil and water resulted from the use of chemical pesticides, herbicides, and fertilizers. And soils became saltier (salinization) and less suitable for agriculture. In addition, as the waters of the sea retreated, salty soil remained on the exposed lake bed. Dust storms blow away up to 75,000 tons of this soil annually, dispersing its salt particles and chemical residues into the air. This air pollution has caused widespread nutritional and respiratory ailments. This is not necessarily an example of unintended consequences. Perhaps some of these negative ecological consequences were unintended, but there is no clear evidence of this. It is just as likely that the goal of economic development in the short run took precedence over the long-term goal of environmental stability and protection.

Evaluation

Log

1. What is the latitude and longitude at the center of the Aral Sea?
   45 degrees North and 60 degrees East

2. What countries surround the Aral Sea?
   Kazakhstan and Uzbekistan

3. What is the surface area in square kilometers of the Aral Sea in 1964?
   51,609.6 square kilometers, but estimates may vary from about 48,500 to 53,700 square kilometers.

4. What was the surface area in square kilometers of the Aral Sea in 1997?
   26,542 square kilometers, but estimates may vary from about 23,000 to 28,000 square kilometers.

5. What was the percentage change in the surface area of the Aral Sea from 1964 to 1997?
   The Aral Sea decreased in size about 50 percent, but calculations may vary from about 40 to 60 percent.

6. How did the satellite imagery help you to draw conclusions about changes in the Aral Sea?
   Satellite imagery is helpful in determining changes to the Aral Sea because you can examine the entire water body in a single image and compare it with images taken at earlier times.

7. Name the two major rivers that flow into the Aral Sea.
   Amu Darya and Syr Darya

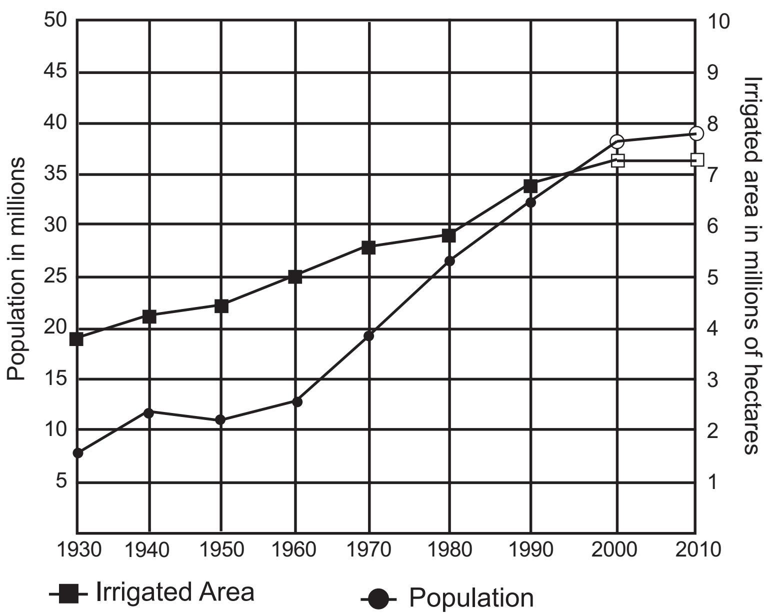
8. List your hypotheses about physical processes that have caused the Aral Sea to shrink.
   Rising regional temperatures resulted in higher rates of evaporation.
   Regional drought reduced snowfall in the mountains, the source areas of the major rivers that flow into the Aral.

9. List your hypotheses about human processes that have caused the Aral Sea to shrink.
   Human use of the water source for large-scale irrigation agriculture reduced the inflow to the Aral.
   In-migration caused a rapid rate of increase of the human population in the region, which increased the demand for domestic water.

10. Fill in the blanks below (with the words *increasing* or *decreasing*) to indicate what has been happening to the Aral Sea.
   The data in Table 1 show that the Aral Sea has been <u>decreasing</u> in surface elevation, precipitation has been <u>decreasing</u>, evaporation has been <u>decreasing</u>, annual river flow has been <u>decreasing</u>, and the volume of the sea has been <u>decreasing</u>.

11. What physical processes might explain the changes in precipitation and evaporation shown in Table 1?
As the inflow is reduced, the volume of water in the sea is reduced, which results in a reduction of the surface area. A smaller surface area means less evaporation from the sea surface. Less evaporation puts less water vapor into the air and thus less that is available for precipitation.

12. Graph the data in Table 2 to illustrate the relationship between irrigation in the Aral Sea region and human population growth. Include projections for 2000 and 2010 on your graph. Write a description of the relationship(s) below your graph.
Over time, irrigated area increased as population increased, but both are likely to slow because of environmental problems and increasingly scarce agricultural resources.



13. How has the shrinking of the Aral Sea affected the human populations in the region?
   - *The traditional fishing industry, which supported thousands of people in the region, was destroyed, thus destroying the livelihoods of these people.*
   - *Large areas, formerly under water, became exposed to wind erosion; salt-dust storms caused air pollution, which led to respiratory diseases.*

14. What types of human activity can you detect from the Space Shuttle image in Figure 7?
Numerous rectangular shapes are agricultural fields. Very large areas are covered with these shapes, which indicate a large amount of agriculture.

15. Final team report. Briefly describe what has happened to the Aral Sea. Indicate how human consequences have been related to the decline in the size of the sea. You should also make predictions about what will happen in the future. Finally, make recommendations for government planners on how to reduce the environmental problems of the region and how to manage the region's water resource and stabilize the Aral Sea.

The Aral Sea has significantly decreased in size over the last 40 years as a result of human demand for water; in particular, water has been diverted from the sea to irrigate cotton and rice. The Aral Sea is landlocked and has no outlet. The development of irrigation projects has reduced the amount of fresh water reaching the Aral Sea from the Amu Darya and the Syr Darya Rivers, drastically increasing the salinity of the sea. Residues of chemical pesticides, herbicides, and fertilizers have contributed to water pollution; air pollution from salt dust storms has contributed to nutritional and respiratory ailments.

Students should be credited for all reasonably practical recommendations. As a guide, the following four steps were recommended by a conference of 200 scientists in 1990:
   - *Strictly limit water use by countries in the region and introduce water-saving technology in all areas of the economy.*
   - *Prohibit expansion of irrigated land to free river flow for preserving the Aral Sea.*
   - *Limit rice and cotton agriculture and remove unproductive land from irrigation. Develop instead orchards, vineyards, and other crops that use less water.*
   - *Remove systems that drain polluted agricultural runoff from irrigated land to the Aral Sea.*

Module 1, Investigation 2: Briefing
What is happening to the Aral Sea?

Background
Lakes become salty when they form in interior basins in arid areas. Water contains salts, and when water evaporates, the salts remain to accumulate. Without a continuing inflow of fresh water, these lakes become smaller and saltier. The Great Salt Lake in Utah and the Salton Sea and Mono Lake in California are examples of lakes that have no outlets and have become salty. These salt water lakes are more prone to pollution problems than are fresh water lakes. This is especially true when the amount of water flowing into them is severely reduced. The Aral Sea, in arid central Asia, is the world's leading example of a shrinking salt lake that is suffering from pollution problems. In 1973, it was the fourth largest lake in the world, but by the 1990s it was only the sixth largest lake. In this investigation, you will be a geographer on a NASA team finding out what is happening to the Aral Sea, and why the changes threaten entire ways of life for millions of people.

Objectives
In this investigation you will
- locate the Aral Sea and describe its physical characteristics,
- use satellite imagery to identify and measure recent changes in the Aral Sea,
- explain how human activities have changed the physical characteristics of the Aral Sea and its surroundings,
- discuss the consequences of human actions on the Aral Sea and how the resulting changes are affecting human populations, and
- recommend actions to reduce further damage to the Aral Sea and the human populations that use its resources.

Part 1: How can you measure changes in the size of the Aral Sea?
Imagine that you are a member of a team of geographers working for NASA to survey Earth's water resources. Your team is investigating changes to the Aral Sea over the last 40 years in order to assess the current and future condition of the Aral Sea as a resource. First, locate the Aral Sea in Figure 1, which is a map of the region made by the U.S. Geological Survey. Estimate the latitude and longitude of the sea and note the countries that surround it.

<u>Answer questions 1 and 2 on the Log following the Briefing.</u>

Your team will use a *time-series* of satellite images of the Aral Sea taken from 1964 to 1997 (Figures 2 and 3) to estimate the change in the size of the Aral Sea over time. The squares labeled 38.4 kilometers on a side in the lower left-hand corner of the images represent 1474.56 square kilometers (38.4 X 38.4 = 1474.56).

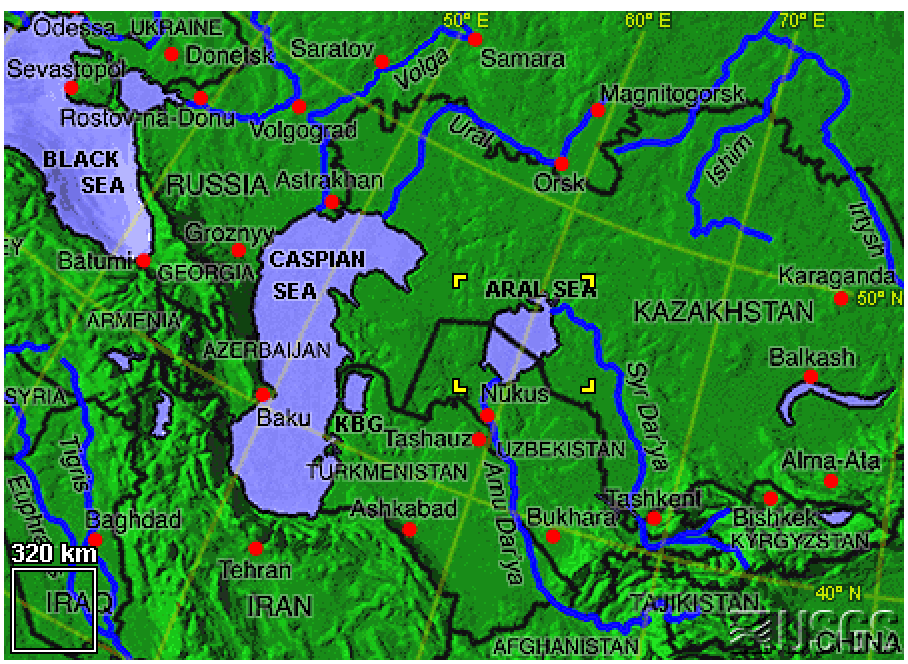


Figure 1: Map of Central Asia
Source: http://edcwww.cr.usgs.gov/earthshots/slow/Aral/Aral

Module 1, Investigation 2: Briefing
What is happening to the Aral Sea?

To estimate how the Aral Sea has changed in size, you will use a procedure that is part of a geographic information system (GIS). GIS is a way to store, analyze, and display many kinds of data. Most GIS procedures start by dividing an area into smaller units, much like the squares in the bottom of each image of the Aral Sea (Figures 2 and 3). A count (or inventory) GIS procedure is designed to answer questions about an entire area, such as "How large is the Aral Sea?"

Using the GIS count grid provided in Figure 4 (or a transparency), lay it on or under Figure 2 (the 1964 satellite image). Line up the bottom left square from the GIS count grid with the square on the image and then count the number of times the points in each square lie on the sea surface. If part of the point lies on the Aral Sea, count it for your estimate. Then estimate the surface area by multiplying the total number of points by the grid measure (1474.56 square kilometers).
Surface area in square kilometers = number of points in grid squares X 1474.56 square kilometers

Answer question 3 on the Log.

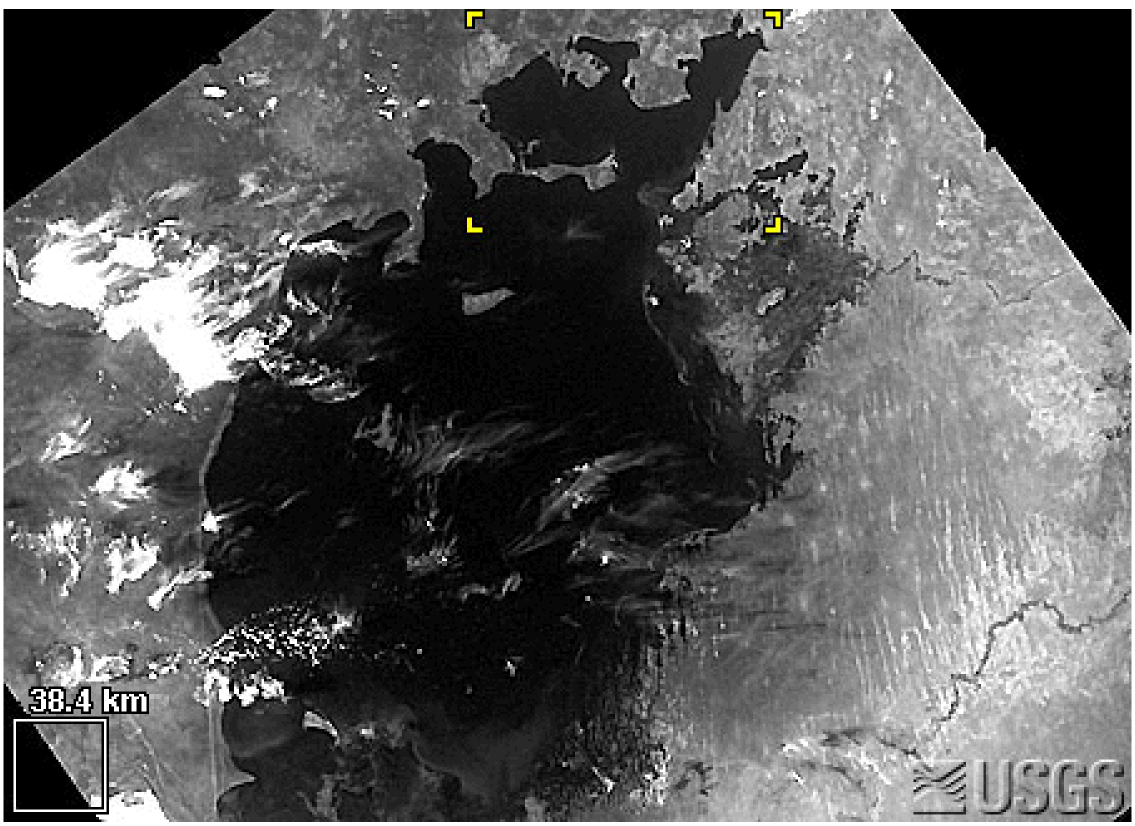


Figure 2: The Aral Sea on August 21, 1964; Argon satellite photo

Module 1, Investigation 2: Briefing
What is happening to the Aral Sea?

Now that you have determined the size of the Aral Sea for 1964, measure the size of the Aral Sea in 1997 (Figure 3).

Answer question 4 on the Log.

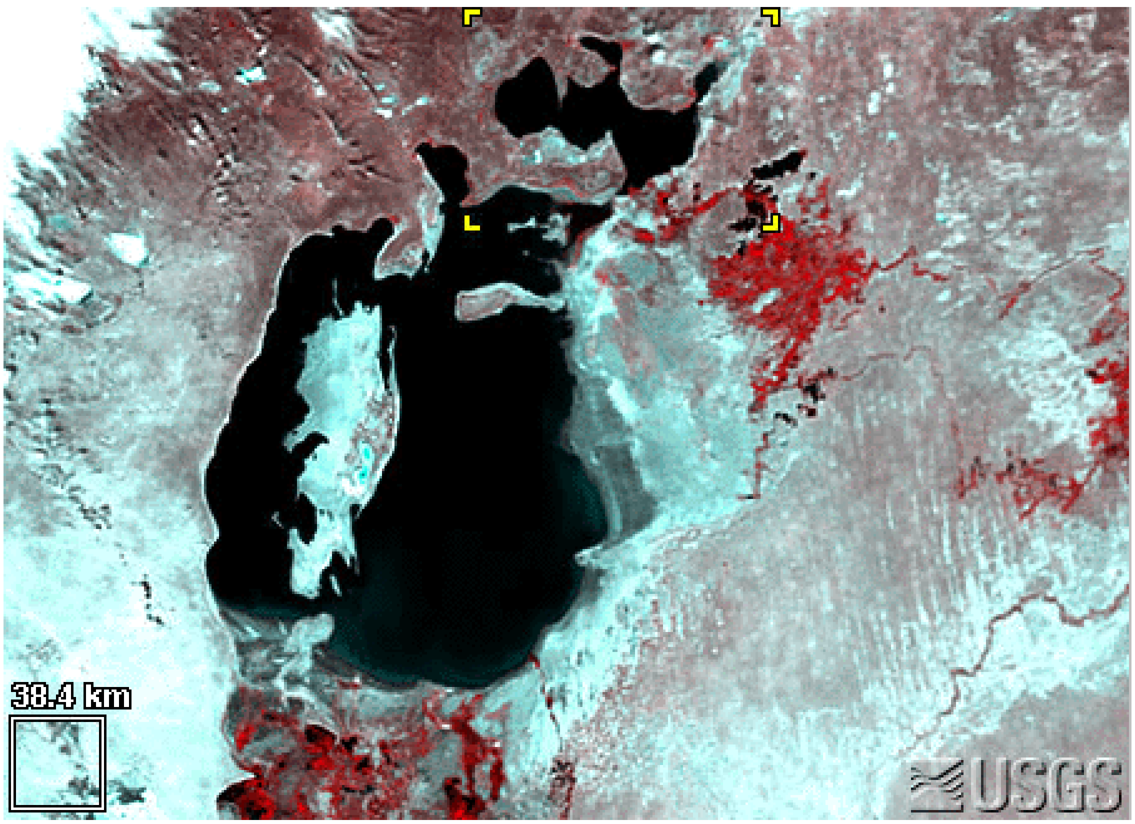


Figure 3: The Aral Sea on July 11, 1997; NOAA 14 AVHRR bands 2 1 1

Module 1, Investigation 2: Briefing
What is happening to the Aral Sea?

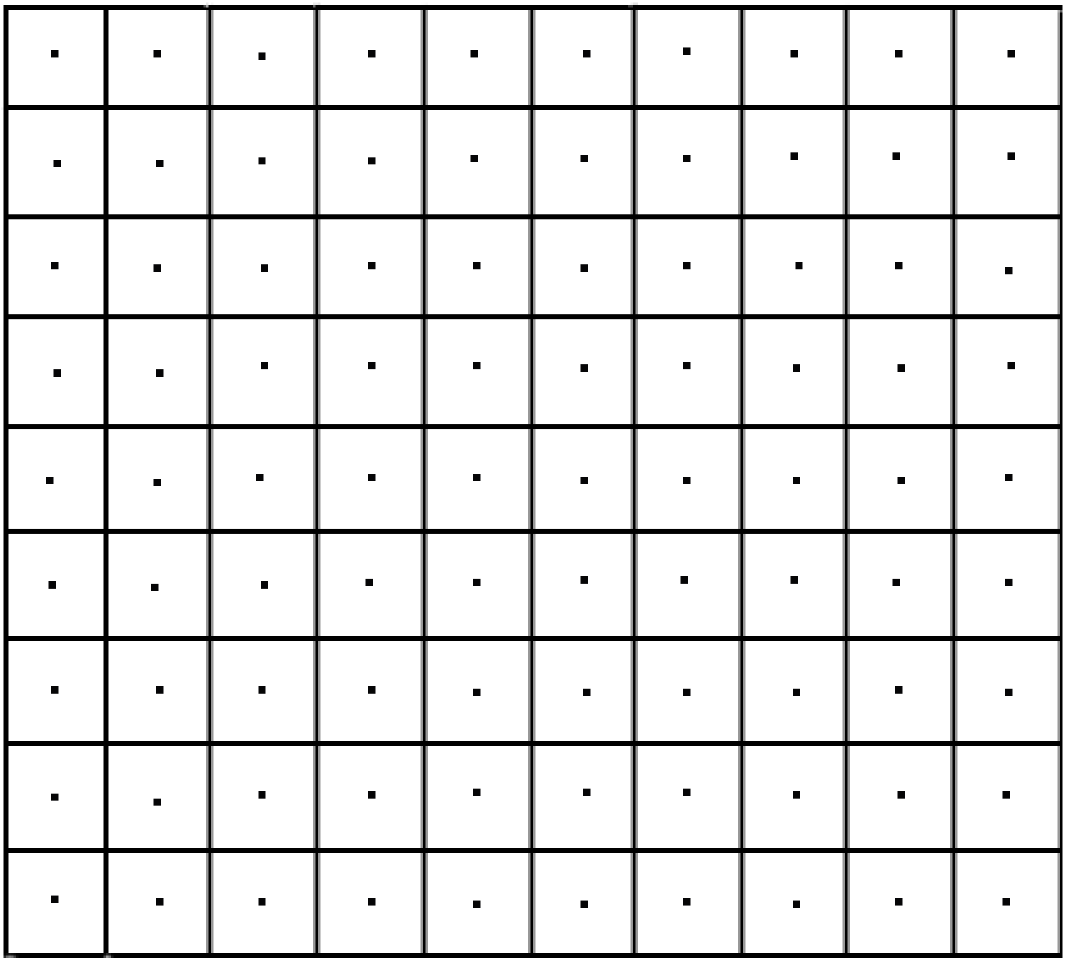


Figure 4: GIS count grid for Aral Sea

Module 1, Investigation 2: Briefing
What is happening to the Aral Sea?

Next, compute the *percentage change* in the size of the surface area of the Aral Sea from 1964 to 1997. To do this, use the following mathematical procedure:

$$\text{Percentage change} = \frac{\text{square km in 1964 - square km in 1997}}{\text{square km in 1964}} \times 100$$

For example, if your 1964 estimate is 20,000 square miles and your 1997 estimate is 10,000 square miles, subtract 10,000 from 20,000 and divide by 20,000 to get 0.5. Multiply that by 100 to get the percentage, or 50 percent.

Answer question 5 on the Log.

Now that you have your estimates for the change in the size of Aral Sea over time, consider how satellite imagery helped you to draw conclusions about changes in the Aral Sea. What does satellite imagery allow you as a geographer working for NASA to accomplish?

Answer question 6 on the Log.

Part 2: Why has the Aral Sea been shrinking?

Government agencies are interested in reducing the loss of the Aral Sea and need to know the major causes of its decline. Use Table 1 to determine the sources of the Aral Sea's water supply.

Answer question 7 on the Log.

Consider the possible causes of the shrinking of the Aral Sea. A key step in scientific research is to *hypothesize*—to suggest explanations for the things you observe. Your team should make two lists of hypotheses to explain the shrinking of the Aral Sea. On the first list, identify causes that are physical processes. For example, the sea might be shrinking because the rate of evaporation has increased (but what would cause this?). Label the second list human processes. For example, in-migration has caused a rapid rate of population increase in the region, which has made increasing demands on the water supply that flows into the sea.

Answer questions 8 and 9 on the Log.

Your team should now begin to test its hypotheses about the causes of the Aral Sea's decline. Use the information in Table 1 and Table 2 to help you do this.

Answer questions 10, 11, and 12 on the Log.

Table 1: Aral Sea surface elevation, precipitation, evaporation, river inflow, and volume, 1950-1990.

	Surface elevation above sea level (meters)	Precipitation (cubic kilometers)	Evaporation (cubic kilometers)	Annual river inflow (cubic kilometers)	Volume (cubic kilometers)
1950	52	9	66	63	1,083
1960	53	9	66	56	951
1970	51	8	65	43	628
1980	45	6	55	17	329
1990	38	5	39	4	282

Sources: P. Micklin and W. Williams, *The Aral Sea Basin*, NATO, 1996

Module 1, Investigation 2: Briefing
What is happening to the Aral Sea?

Table 2: Population, irrigated area, and water use, Aral Sea region, 1930-1990.

	Population (millions of people)	Irrigated area (millions of hectares)	Water withdrawals for irrigation (cubic kilometers)
1930	7.3	3.8	NA
1940	10.9	4.2	46.3
1950	10.6	4.3	39.1
1960	13.8	5.0	51.5
1970	19.9	5.5	83.5
1980	26.1	5.8	110.5
1990	33.0	6.8	110.0

Sources: D. Glasgow in W.S. Ellis and D.C. Turnley. "A Soviet Sea Lies Dying" in *National Geographic*, February 1990, and P. Micklin and W. Williams, *The Aral Sea Basin*, NATO, 1996.

Part 3: How has the region's landscape changed?

The Amu Darya and Syr Darya Rivers empty into the Aral Sea, which lies in an interior basin. The development of irrigation projects in the region, especially to grow cotton beginning in the 1950s, captured the river waters so that little fresh water reached the Aral Sea. Withdrawal of water from the Amu Darya and Syr Darya, primarily for irrigation, is the most important factor reducing water flows into the Aral Sea. This has caused the Aral Sea to shrink in size. How do you think the irrigation projects and the shrinking Aral Sea have affected the human populations that depended on it? Figure 5 offers some clues.

Figure 5: Abandoned Aral Sea fishing boats

Source: http://kidsat.jpl.nasa.gov/kidsat/photogallery/aral_ships.gif

<u>Answer question 13 on the Log.</u>

Increases in population, coupled with a demand for agricultural products, have resulted in a specific type of landscape (the entire set of human and physical features on Earth's surface that characterize a particular area or region) surrounding the Aral Sea. Figure 6 is a map of the Aral Sea. The rectangle to the east of the sea locates the image found in Figure 7. This image, a recent photograph taken from NASA's Space Shuttle, depicts land use surrounding the Syr Darya River. How does Figure 7 help you assess how human populations have affected the Aral Sea region?

<u>Answer question 14 on the Log.</u>

Module 1, Investigation 2: Briefing
What is happening to the Aral Sea?

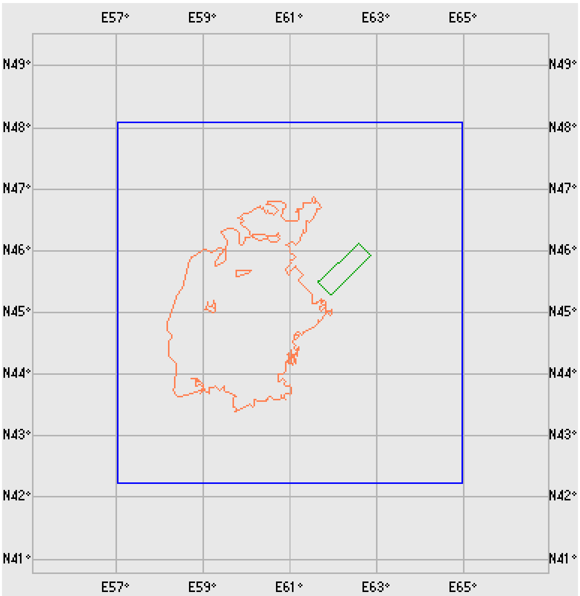


Figure 6: Aral Sea on geographic grid

Source: USGS—http://edcww.cr.usgs.gov/landaac…02086/lrlon=66.636154/result=13042

Figure 7: Land use east of the Aral Sea

Source: USGS—http://edcww.cr.usgs.gov/landaac…02086/lrlon=66.636154/result=13042

Part 4: What are the human consequences of the shrinking Aral Sea?

The shrinking Aral Sea has had both positive and negative human consequences. Agricultural production and irrigation increased, which improved the economy of the region. On the other hand, contaminated soil and water resulted from the use of chemical pesticides, herbicides, and fertilizers. Also, soils became saltier (salinization) and less suitable for agriculture. In addition, as the waters of the sea retreated, salty soil remained on the exposed lake bed. Dust storms blow away up to 75,000 tons of this soil annually, dispersing its salt particles and chemical residues into the air. This air pollution has caused widespread nutritional and respiratory ailments.

Government planners concerned with the human consequences of the shrinking Aral Sea have collected data for your team to analyze. Information on the fishing industry, health, and salinization have all been submitted for your consideration. In addition, predictions about the future size of the sea were submitted. Your team has been asked to make recommendations on how to address these problems and reduce the negative effects on populations in the region. You should make recommendations to regional governments for each type of effect listed below. Your recommendations should be based upon your hypotheses about why the sea has been shrinking.

Destruction of the Fishing Industry

As the Aral Sea has receded and the quality of the water reaching the sea has declined, there has been a sharp reduction in fisheries production (Table 3).

Table 3: Aral Sea Fish Catch, 1960-1990

Year	Metric Tons of Fish
1960	43,430
1965	31,040
1970	17,460
1975	2,940
1980	0
1985	0
1990	0

Source: M. Glantz, ed., *Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin*, 1999, Cambridge University Press.

Table 4: Major Health Problems and Causes, Aral Sea Region

Disease/Affliction	Major Cause
Respiratory problems	Blowing salt and dust
Viral hepatitis	Contaminated water
Typhoid fever	Contaminated water
Cancer	Blowing salt and dust, toxic contaminants
Intestinal disorders and infections	Contaminated water, blowing salt and dust
Birth abnormalities	Toxic contaminants
Plague	Explosion of rodent population on dry sea bottom

Source: P. Micklin and W. Williams, *The Aral Sea Basin*, NATO, 1996

Today, no fish are caught commercially in the sea. Former ports to the south (Muynak) and the north (Aralsk) of the sea are stranded many miles from the receding shoreline. The loss of the Aral Sea's fisheries sparked the collapse of the entire industry, causing unemployment and the decline of economies of former coastal towns.

Health Problems

The dependence of countries surrounding the Aral Sea on cotton production and irrigation using the waters bound for the Aral Sea has had a major impact on human health. Large-scale pesticide and fertilizer use has resulted in groundwater contamination, and many fertilizer and pesticide residues have been blown from the exposed lake bed across the landscape. The widespread regional health effects include dramatic increases in many types of health problems (Table 4).

Salinity Increases

The shrinking size of the Aral Sea has also increased the *salinity* (salt content) of the waters of the sea (Table 5). In the 1960s, the water was drinkable and supported a wide variety of fresh water animals and plants used by humans. Today, the sea water is undrinkable: it is saltier than the open ocean.

Table 5: Salinity of the Aral Sea, 1960-1995.

Year	Average Salinity (grams per liter of water)
1960	10
1970	11
1980	22
1990	37
1995	50

Source: P. Micklin and W. Williams, *The Aral Sea Basin*, NATO, 1996

Size of the Aral Sea

Figure 8 gives a chronology of the size of the Aral Sea from 1960 to 2010.

Your team should conclude its investigation by summarizing what it has learned about the Aral Sea and by making recommendations in a final report to NASA on the Log.

Answer question 15 on the Log.

Module 1, Investigation 2: Briefing
What is happening to the Aral Sea?

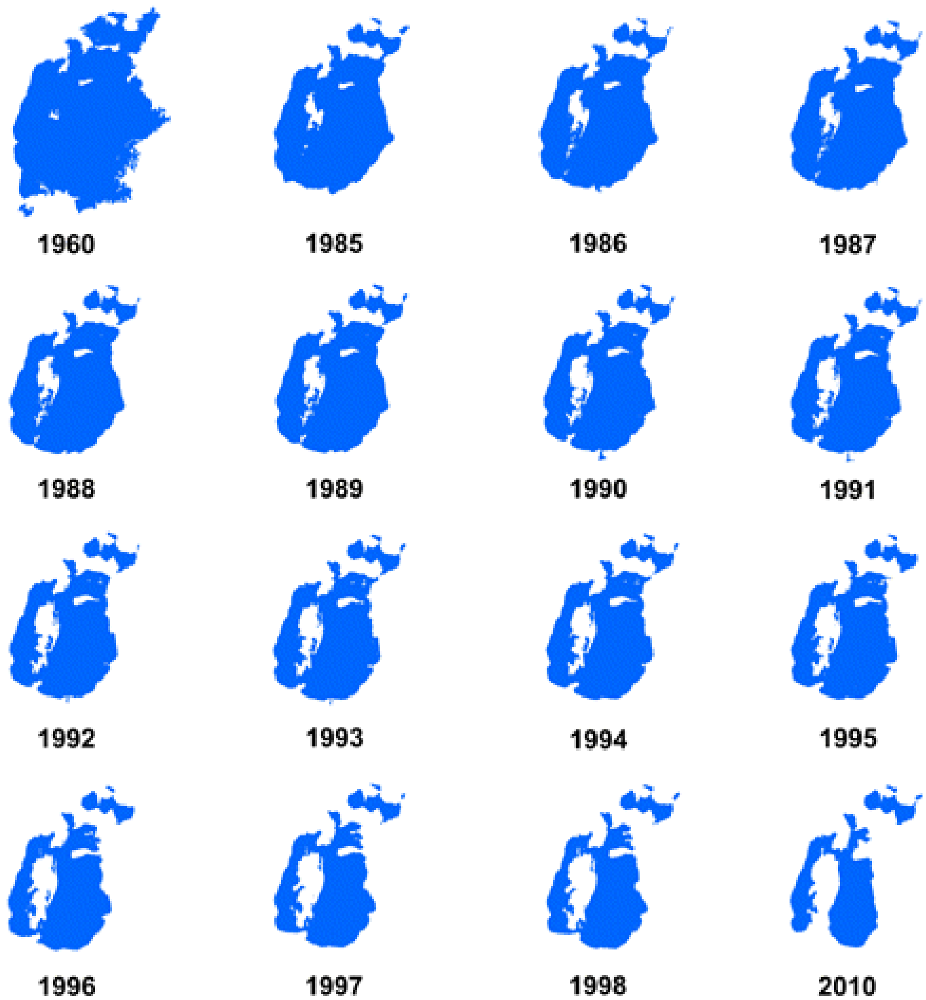


Figure 8: Chronology of the size of the Aral Sea

Source: German Department of Defense (http://www.dfd.dlr.de/app/land/aralsee/chronology.html)

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USGS SIR-C browse, coverage map, and scene metadata http://edcwww.cr.usgs.gov/landaac…02086/lrlon=66.636154/result=13042

Module 1, Investigation 2: Log
What is happening to the Aral Sea?

1. What is the latitude and longitude at the center of the Aral Sea? ____________________

2. What countries surround the Aral Sea? ____________________
____

3. What was the surface area in square kilometers of the Aral Sea in 1964?
____

4. What was the surface area in square kilometers of the Aral Sea in 1997?
____

5. What was the percentage change in the surface area of the Aral Sea from 1964 to 1997? __________

6. How did the satellite imagery help you to draw conclusions about changes in the Aral Sea?
____
____

7. Name the two major rivers that flow into the Aral Sea.
____

8. List your hypotheses about physical processes that have caused the Aral Sea to shrink.
____
____
____

9. List your hypotheses about human processes that have caused the Aral Sea to shrink.
____
____
____

10. Fill in the blanks below (with the words *increasing* or *decreasing*) to indicate what has been happening to the Aral Sea.

    The data in Table 1 show that the Aral Sea has been ____________ in surface elevation, precipitation has been ____________, evaporation has been ____________, annual river flow has been ____________, and the volume of the sea has been ____________ .

11. What physical processes might explain the changes in precipitation and evaporation shown in Table 1? ____________________
____
____
____
____
____

What is happening to the Aral Sea?

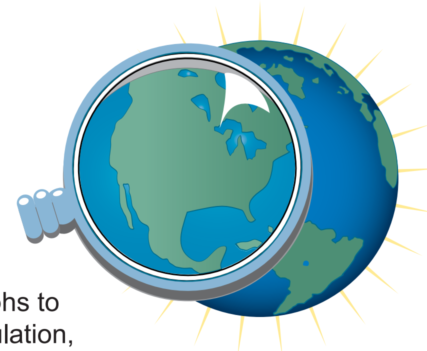
12. In the space below, graph the data in Table 2 to illustrate the relationship between irrigation in the Aral Sea region and population growth. Include in your graph your projections for the years 2000 and 2010. Write a brief description of the relationship(s) below your graph.

13. How has the shrinking of the Aral Sea affected the human populations in the region?

14. What types of human activity can you detect from the Space Shuttle image in Figure 7?

15. Final Team Report. Briefly describe what has happened to the Aral Sea. Indicate how human consequences have been related to the decline in the size of the sea. You should also make predictions about what will happen in the future. Finally, make recommendations for government planners on how to reduce the environmental problems of the region and how to manage the region's water resource and stabilize the Aral Sea.

The Nile: A sustainable resource?



Investigation Overview

Students analyze data and make graphs to explore the relationship between population, water resources, water stress, and sustainable economic development. Students consider the perspectives of 10 countries within the Nile River Basin in a simulated meeting of the Nile River Basin Initiative.

Time required: One to two 45-minute sessions

Materials

Representative discussion points (one copy for each student per group per nation)
Data cards (as needed for a class of 25)
Script/briefing points
Computer with display device (optional)
Log 1: Outline map (one copy for each student)
Log 2: Water stress (one copy for each student)
Log 3: Discussion points data organizer (one copy for each student)
Figures 1-4 (overhead transparency of each)
Small paper cups
Optional: water

Content Preview

Water is a scarce commodity in northeastern Africa. Water is used for irrigated agriculture, industry, and human consumption. The Nile River is the main source of water for the nations through which it flows. The Nile does not provide sufficient quantities to meet current needs, let alone future needs as populations rise, industrial growth takes place, and more land is irrigated. When nations find themselves with less than 2000 cubic meters of renewable water supplies per person, they are water stressed. Water resources in the region have been affected by past human actions; natural factors such as evaporation present problems too. The interaction of population growth, water scarcity, and international conflict is apparent in this region. Governments in the region, particularly in Egypt, are building new irrigation projects to expand arable land. Monitoring river basins from space provides a useful and efficient way to demonstrate changes over a large area.

Geography Standards

Standard 1: The World in Spatial Terms

How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective

- Produce and interpret maps and other graphic representations to solve geographic problems.

Standard 14: Environment and Society

How human actions modify the physical environment

- Evaluate the ways in which technology has expanded the human capability to modify the physical environment.
- Develop possible solutions to scenarios of environmental change induced by human modification of the physical environment.

Standard 15: Environment and Society

How physical systems affect human systems

- Analyze examples of changes in the physical environment that have reduced the capacity of the environment to support human activity.

Geography Skills

Skill Set 3: Organize Geographic Information

- Select and design appropriate forms of graphs, diagrams, tables, and charts to organize geographic information.

Skill Set 4: Analyze Geographic Information

- Make inferences and draw conclusions from maps and other geographic representations.

Classroom Procedures

Beginning the Investigation

1. Distribute **Log 1** and ask students to follow the path of the Nile River from its origins in the highlands of Ethiopia and Burundi to its mouth in Egypt. Have them draw a boundary around the Nile River Basin. This watershed makes a functional region. Next, have students identify the 10 countries with territory in the Nile River Basin. (*Burundi, Rwanda, Tanzania, Kenya, Congo [Zaire], Uganda, Ethiopia, Eritrea, Sudan, Egypt.*) Point out to students that 40 percent of Africa's population lives in these 10 countries, which constitute only 10 percent of its landmass.

2. Divide the class into groups roughly proportional to the size of the population of each nation in the Nile River Basin. The proportions for a class of 25 are listed at right.

Country	Population	% of Total Population	# of Students
Burundi	6,064,000	2	1
Rwanda	5,184,000	2	1
Tanzania	30,026,000	11	2
Kenya	27,154,000	10	2
Congo	45,453,000	16	4
Uganda	19,689,000	7	2
Ethiopia	56,404,000	20	5
Eritrea	3,171,000	1	1
Sudan	26,707,000	9	2
Egypt	62,096,000	22	5
Total	281,948,000	100	25

   Distribute **Log 2** and the data cards for each country. Explain that students will play the role of representatives from each of the Nile River Basin nations. First, they must do some research on their nation, its water resources, and population prospects. Students use the data for their nation to graph population growth against water resource availability and determine water stress in the past, present, and future.

   Students can draw the graph by hand or use a computer-based graphing program. The left-hand scale represents population shown as bars; the right-hand scale represents the per capita water available in cubic meters shown as a line graph. Data for Burundi are graphed below as an example.

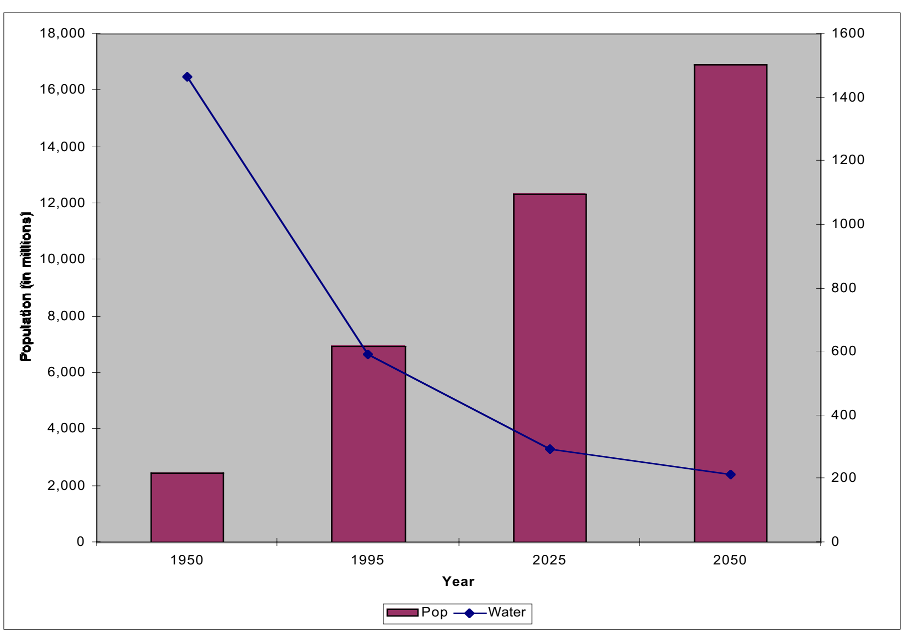
   Have students analyze their graphs and answer questions 2-4 on **Log 2**.

3. When students have completed **Log 2**, check to make sure they understand the relationship among population growth, water resource availability, and the water stress index.

Developing the Investigation

4. Group the students by nation or group of nations: Other Nile Basin Countries (Rwanda, Burundi, Tanzania, Kenya, Congo, and Uganda form one block)—6 students, Ethiopia and Eritrea—6 students, Sudan—2 students, Egypt—5 students.

Water stress in Burundi



Distribute the appropriate **Representative Discussion Points** (Educator's Guide handout) to each group. Ask students to use the Data Cards from **Log 2** to fill in the blanks in the Representative Discussion Points. Next they should create three-dimensional histograms representing the per capita water availability of their nation(s) at different periods of time with paper cups. Allow students to work out a proportion of water per cup. Identify students to play the role of representative from each nation or group of nations. Students may share the responsibility, or one student may play the position. The Representative Discussion Points contains the information they need to share. Distribute **Log 3** to all students.

5. Call a meeting of the Nile River Basin Initiative. Establish that the purpose of the meeting is to make plans to manage existing and proposed water development projects in the Basin, specifically to seek international funding to monitor the basin's water resources using remote sensing. As was clear in the previous activity, water is in short supply in the region. Following the Script/Briefing Points in this Educator's Guide, introduce the past and current situation in the region. Illustrate the presentation using **Figures 1-4**. Next, ask each representative to present the water status of each nation (or group of nations), point of view on management issues, and water resource objectives or goals. Representatives should use the histogram and graph from Log 2 to illustrate their status. Students complete **Log 3** using the information presented during the meeting.

Concluding the Investigation

6. In conclusion, ask students working alone or in groups to evaluate the geographic reasoning of each presentation and to prepare a summary to support funding to continue to monitor basin changes from space. Students should include evidence obtained in the meeting of the Nile River Basin to substantiate their request for funding, e.g., specific water stress data, current and past water projects in each country, each country's perspective on water management.

Background

The Nile is formed by three tributaries, the Blue Nile, the White Nile, and the Atbara. The White Nile begins in Burundi and flows through Lake Victoria into southern Sudan. Near the capital of Sudan, Khartoum, it meets the Blue Nile which begins in the highlands of Ethiopia. North of Khartoum the Atbara joins the river. The Nile flows north through Lake Nasser, the second largest human-made lake in the world, and the Aswan Dam, then splits into two distributaries north of Cairo, the Rosetta in the west and the Darneita to the east. The Nile has created a large delta into the Mediterranean Sea.

Additional information is included in Educator's Guide Script/Briefing Points.

Evaluation/Key

Log 2

1. Graphs will vary depending on the country.
2. Answers vary.
3. Answers vary.
4. Answers vary.

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http://earth.jsc.nasa.gov/

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Ethiopia and Eritrea

Our combined population is 59,578,171 people. We have just emerged from a long period of civil war and famine. Although Eritrea is now independent, we work closely on water resource issues. The economies of both nations are growing and developing rapidly in this period of peace. Our population is growing as well, at a rate of 3.3 percent per year. In 2025 our population is expected to be 142,792,000, and 25 years later it will be 221,540,000. In order to grow more food to feed our growing population, we must develop a large portion of land. This will take more water for irrigation.

Eighty-six percent of the Nile's water originates in our nations, yet we have not taken full advantage of our key resource and are water stressed. Ethiopia is worse off than Eritrea. In 2000 Ethiopia had ____cubic meters of water per person. In 2025 Ethiopia expects to have _____ and in 2050_______. We are in the process of constructing more than 200 small dams to use Nile water to irrigate needed cropland. But we are afraid this will anger Egypt, the most powerful nation in the region. We seek ways to peacefully share our common resource and to enhance our environment.

Egypt

Our population is 62,096,000 people and we occupy only 4 percent of Egypt's land—that strip along the Nile. For thousands of years Egyptians have relied on the Nile for almost all of our fresh water. We never worried about the supply of water. But now the nations upstream from us are using more and more Nile water. We are concerned—very concerned. This is a threat to our national security. Our population is growing at a rate of 2 percent per year. In 2025 our population is expected to be ________ , and 25 years later it will be ________ .

In 2000 we had ____cubic meters of water per person. In 2025 we expect to have _____ and in 2050_______. We are developing new water projects to accommodate our population growth. We are especially proud of a project, the New Valley Project, to pipe 5 billion cubic meters of Nile water from Lake Nasser through the Western Desert to the New Valley. Seven million people will be persuaded to move away from the Nile to live in this new agricultural area. This project is very expensive, and the Nile may not provide enough water. Although in the past Egypt's official policy was to maintain a monopoly on Nile water, today we wish to cooperate to equitably distribute the river resources to bring stability to the region and to promote economic development. We also need help in monitoring the effects of our water development projects on the environment.

Sudan

Our population is 26,707,000 people. Our nation is suffering a civil war in the south, and we are struggling economically and politically. Our population is growing at a rate of 2.2 percent per year. In 2025 our population is expected to be ________, and 25 years later it will be ________. We need to use more of our Nile water to produce food for our growing population but know that this will anger the Egyptians. In 2000 we had ____cubic meters of water per person. In 2025 we expect to have _____ and in 2050_______. We have ambitious plans for the Nile; it is our chief resource. We started a canal with money from the World Bank to increase supplies of Nile water in the 1970s; construction was halted in 1983 because of rebel action. This was a loss. We are building a dam north of our capital, Khartoum, where the Blue Nile and White Nile converge. We plan to work closely with Egypt and Ethiopia to develop the Nile in a way to help generations of peoples.

Other Nile Basin Countries

The other Nile Basin countries are Rwanda, Burundi, Tanzania, Kenya, Congo, and Uganda. Currently we use only a small proportion of the river's water. However, together our current combined population of ________ is expected to grow to ___________ in 2025 and ___________ in 2050.

- In 2000 in Rwanda we had ____cubic meters of water per person. In 2025 we expect to have _____ and in 2050_______. Our population growth rate is 2.3 percent per year.
- In 2000 in Burundi we had ____cubic meters of water per person. In 2025 we expect to have _____ and in 2050_______. Our population growth rate is 2.5 percent per year.
- In 2000 in Tanzania we had ____cubic meters of water per person. In 2025 we expect to have _____ and in 2050_______. Our population growth rate is 2.9 percent per year.
- In 2000 in Kenya we had ____cubic meters of water per person. In 2025 we expect to have _____ and in 2050_______. Our population growth rate is 2.1 percent per year.
- In 2000 in Congo we had ____cubic meters of water per person. In 2025 we expect to have _____ and in 2050_______. Our population growth rate is 3.2 percent per year.
- In 2000 in Uganda we had ____cubic meters of water per person. In 2025 we expect to have _____ and in 2050_______. Our population growth rate is 2.9 percent per year.

With this growth, it is inevitable that we will start to claim a larger share of the Nile's flow to meet our growing irrigation and development needs. We understand that this will not please the countries down river from us, particularly Sudan and Egypt. We are forming a joint program to develop our shared resource. But we need help to monitor our resource in all Nile Basin nations.

Burundi

1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
2,456,000	1,466	6,964,000	594	12,341,000	292	16,937,000	213

Rwanda

1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
2,120,000	2,972	5,184,000	1,215	12,981,000	485	16,937,000	372

Tanzania

1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
7,886,000	11,286	30,026,000	2,964	62,436,000	1,425	88,963,000	1,000

Kenya

1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
6,265,000	4,820	27,150,000	1,112	50,202,000	602	66,054,000	457

Congo (Zaire)

1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
12,184,000	83,684	45,453,000	22,419	105,925,000	9620	164,635,000	6,189

Uganda							
1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
4,762,000	13,860	19,689,000	3,352	44,983,000	1,467	66,305,000	995

Ethiopia							
1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
18,434,000	5,967	56,404,000	1,950	136,288,000	807	212,732,000	517

Eritrea							
1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
1,140,000	7,719	3,171,000	2,775	6,504,000	1,353	8,808,000	999

Sudan							
1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
9,190,000	16,757	26,707,000	5,766	46,850,000	3,287	59,947,000	2,569

Egypt							
1950		2000		2025		2050	
Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)	Population	Per Capita Water Availability (cubic meters)
21,834,000	2,661	62,096,000	936	95,766,000	607	115,480,000	503

These are the points you should make at the opening of the meeting of the Nile Basin Initiative:

- The Nile is the longest river in the world at 6601 kilometers and is the main source of water for the nations that make up the Nile watershed.

- Currently, the water provided by the system barely meets the demands of the region. In the near future it is expected that many of the nations that share the Nile's water will experience water stress.

- Access to the Nile's waters has already been defined as a vital national priority by countries in the region. As more of the countries in the region develop their economies, the need for water will increase. Although the demand for resources increases, the supply is likely to remain unchanged, increasing the chances for conflict over a scarce resource.

- Development projects that are aimed at increasing the flow of the Nile remain endangered by tension and instability in the region as well as environmental and financial concerns.

- **Figure 1.** As you can see from these figures, the Nile is in an arid region. Figure 1, a handheld Space Shuttle photograph, shows clearly the contrast in land use along the Nile. River water is used for irrigation in a narrow strip on either side of the river. Beyond is the desert. *(This bend of the river is the home of many historical points of interest—Valley of the Kings, Valley of the Queens, Temple of Luxor, the Tomb of Tutankhamen, and the Necropolis of Thebes)*.

- **Figure 2.** Figure 2 is a radar image of an area west of Cairo, Egypt, approximately 20 by 30 kilometers in size. The Nile is the dark band along the right side of the image. It flows almost due north from the lower edge of the image to the right. The boundary between dense urbanization and the desert is seen between the bright and dark areas. This boundary is the extent of the yearly Nile flooding which played an important part in determining where people lived in ancient Egypt. The pattern persists today. As the population of Egypt grows, the irrigated land along the river becomes more and more densely settled. Egypt is eager to disperse its population to newly irrigated areas.

- **Figure 3.** Figure 3 is the delta of the Nile, which contains 60 percent of Egypt's cultivated land. This figure shows again the stark contrast between desert and irrigated land along the river. Cairo is at the center of the image. The Mediterranean is to the north.

- **Figure 4.** Figure 4 shows the Nile River, the Aswan Dam, and the lake created by the dam, Lake Nasser, located in southern Egypt on the border with Sudan. Changing a significant resource in a vulnerable, dry environment can have serious consequences. The Aswan Dam, completed in 1971, provides examples of the array of potential and actual problems.
    - One major problem is that silt from the river which for thousands of years fertilized Egypt's cropland no longer flows down the river. Chemical fertilizers are needed to enrich the soil.
    - There is more erosion along the banks of the Nile which previously were replenished by the silt being carried down river.
    - Much of the delta shown in Figure 3 is being swept into the Mediterranean. If barriers near the Nile's outlet erode any more, low-lying delta land could find itself in the sea, causing a devastating loss of cultivated land.
    - The Nile is also bringing more salt to the fields of Egypt. Increased evaporation in Lake Nasser makes irrigation water more saline. The evaporation also presents a severe problem in terms of water loss.

- The Nile belongs to no one country or people. It is a shared resource.
- It is also an interconnected system—what affects one part of the system affects all parts of the system.
- It is difficult to monitor watershed changes over a large area and to communicate information to stakeholder groups, such as governments and scientists. However, remote sensing is a very effective and efficient means to accomplish this goal.
- Organizations like the Nile River Basin Initiative meet regularly to coordinate water policies, especially in relation to development needs. But there is a need for good reliable information about the entire water basin. This is especially true today as countries balance climate change, population growth, and development issues.

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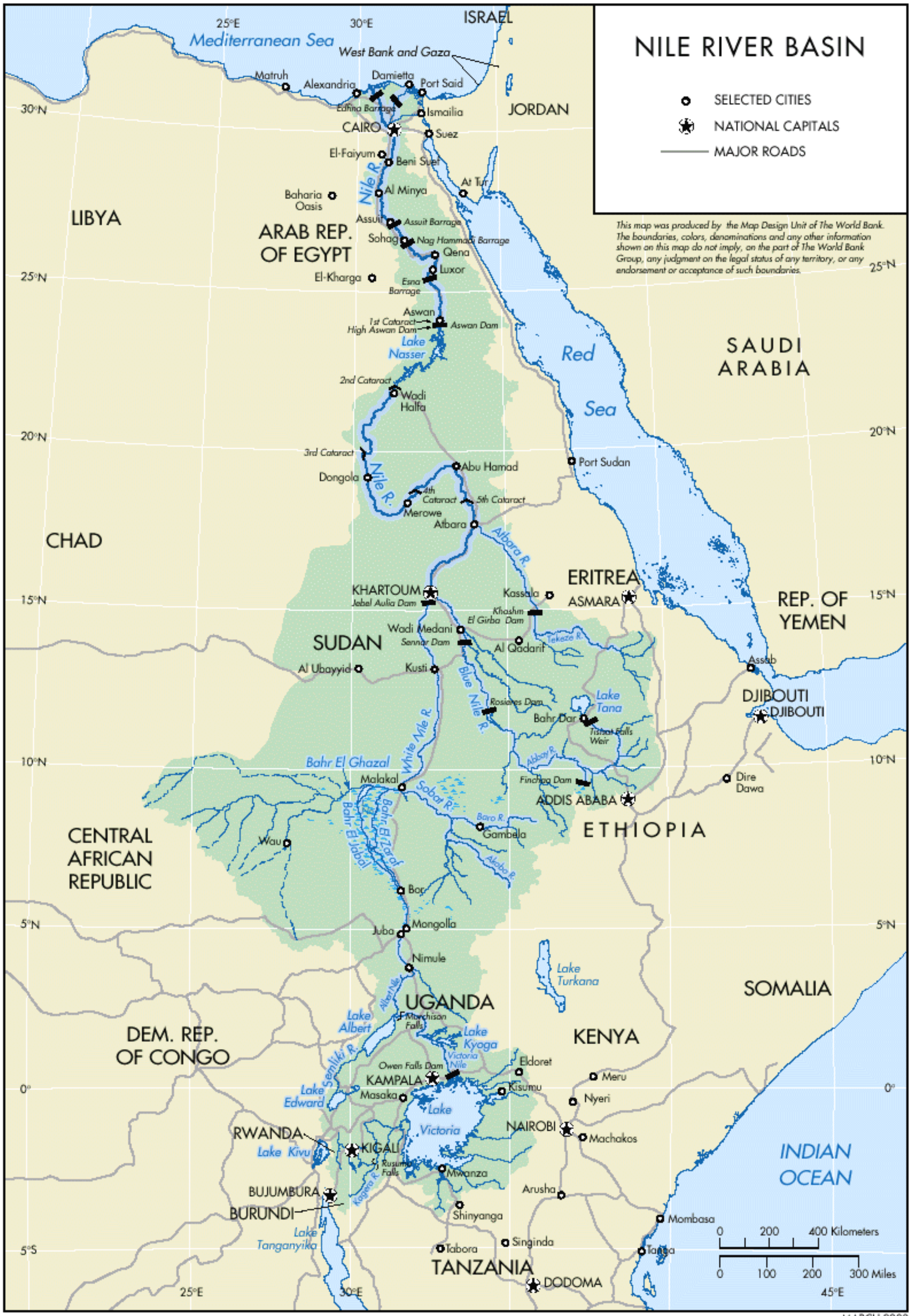
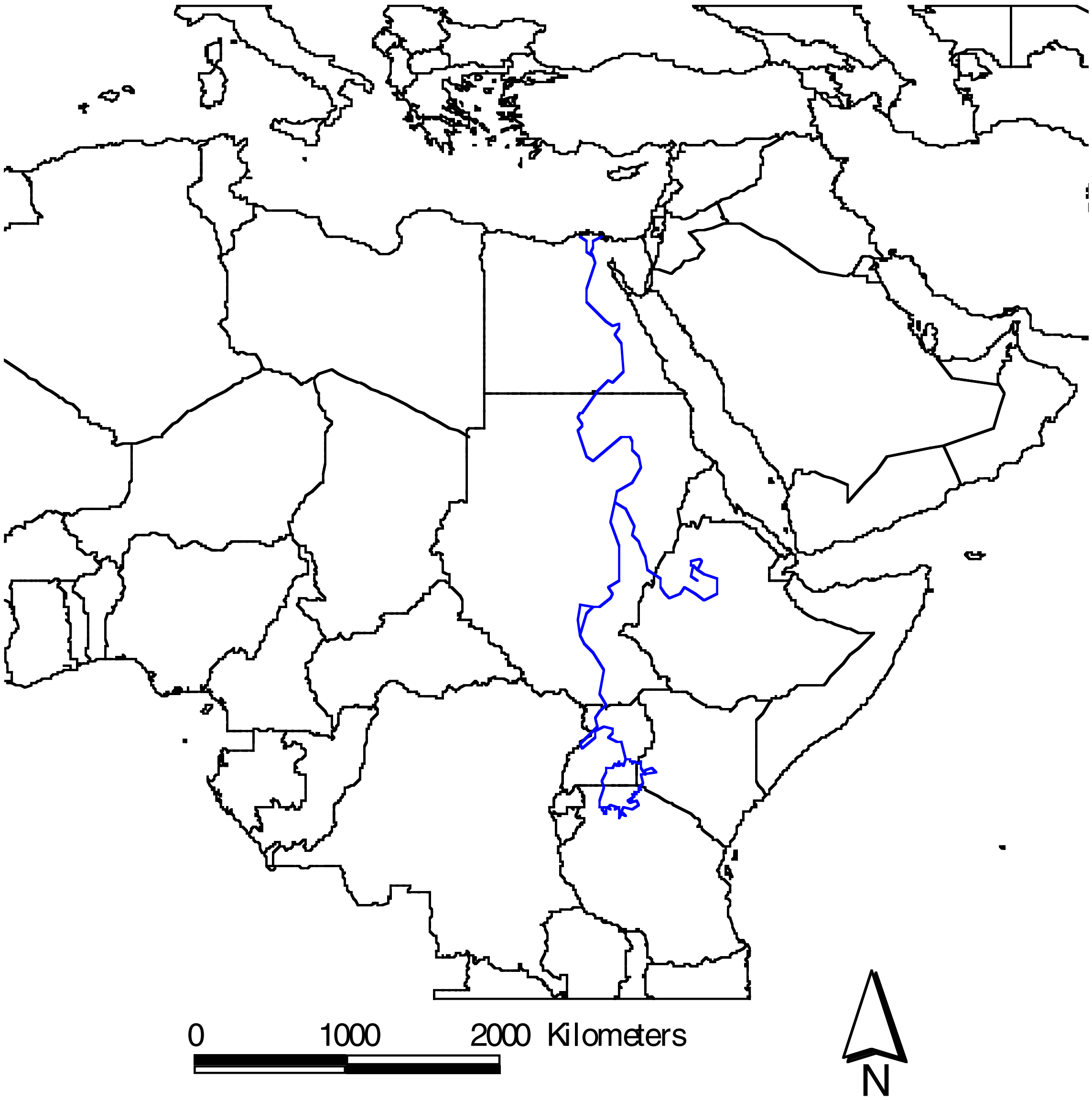

NILE RIVER BASIN
SELECTED CITIES
NATIONAL CAPITALS
MAJOR ROADS
This map was produced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.
Mediterranean Sea
Red Sea
INDIAN OCEAN
LIBYA
ARAB REP. OF EGYPT
ISRAEL
West Bank and Gaza
JORDAN
SAUDI ARABIA
CHAD
SUDAN
ERITREA
REP. OF YEMEN
DJIBOUTI
ETHIOPIA
CENTRAL AFRICAN REPUBLIC
DEM. REP. OF CONGO
UGANDA
KENYA
SOMALIA
RWANDA
BURUNDI
TANZANIA
CAIRO
KHARTOUM
ASMARA
ADDIS ABABA
KAMPALA
NAIROBI
KIGALI
BUJUMBURA
DODOMA
Nile R.
Blue Nile R.
White Nile R.
Atbara R.
Lake Nasser
Lake Tana
Lake Victoria
Lake Albert
Lake Kyoga
Lake Edward
Lake Kivu
Lake Tanganyika
Lake Turkana
Bahr El Ghazal
0 200 400 Kilometers
0 100 200 300 Miles
MARCH 2000

Module 1, Investigation 3: Log 1



Module 1, Investigation 3: Log 2
Water stress

Sustaining Water
Water is a scarce resource, particularly in arid regions of the world. Water is used for irrigated agriculture, industry, and human consumption. As population grows, demands on water resources grow. It is estimated that the minimum level of water needed per person for drinking, bathing, and cooking is 100 liters per day. It takes from five to 20 times this amount to meet the demands of agriculture, industry, and energy production.

Water Stress Index
Scientists have developed ways to measure the balance between population and water supply and the onset of water stress and scarcity.

- **Adequate:** More than 1700 cubic meters of renewable fresh water per person per year. Countries with this amount of water will experience only minor water shortages.
- **Water stress:** 1000-1700 cubic meters of renewable fresh water per person per year. Countries at this level experience water stress—chronic and widespread water supply problems.
- **Severe water stress:** Below 1000 cubic meters of renewable fresh water per person per year. Water scarcity is the rule in these countries, causing economic development problems and serious environmental degradation.

Nile River Basin
Water is a scarce resource in the generally dry northeastern Africa. The Nile River is a significant source of water for this area. Some nations such as Rwanda, Uganda, Sudan, and Egypt depend on the Nile River as their primary source of water. Other countries in the Nile River Basin, such as the Congo, have additional water resources.

The region is experiencing rapid population growth. More irrigated land is needed to grow food for the growing population. In addition, the standard of living is improving among many of the people who live in the Nile Basin, placing greater demand on water resources.

Task

1. Prepare a graph presenting the data on the card for your nation. Construct and then use the left-hand scale to draw a bar graph showing population in your nation at four dates, 1950, 2000, 2025, and 2050. Construct and then use the right hand scale, to plot per capita water availability as a line graph.

Population

Per Capita Water Availability
(cubic meters)

Module 1, Investigation 3: Log 2

Water stress

2. **Analyze the graph**.

   Does there appear to be a relationship between population growth and per capita water availability in your nation? What is the relationship?

   What was the water stress index in your country in 1950? ________________

   What was the water stress index in your country in 2000? ________________

   What is the expected water stress index in your country in 2025? ________________

   What is the expected water stress index in your country in 2050? ________________

3. Do you think the citizens of your country should be concerned about water resources? Why or why not?

4. Based on the amount of water available, is economic development and population growth sustainable in your country? Why or why not?

Module 1, Investigation 3: Log 3

Discussion points data organizer

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Module 1, Investigation 3: Log 3
Discussion points data organizer

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Module 1, Investigation 3: Log 3

Discussion points data organizer

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Module 1, Investigation 3: Log 3

Discussion points data organizer

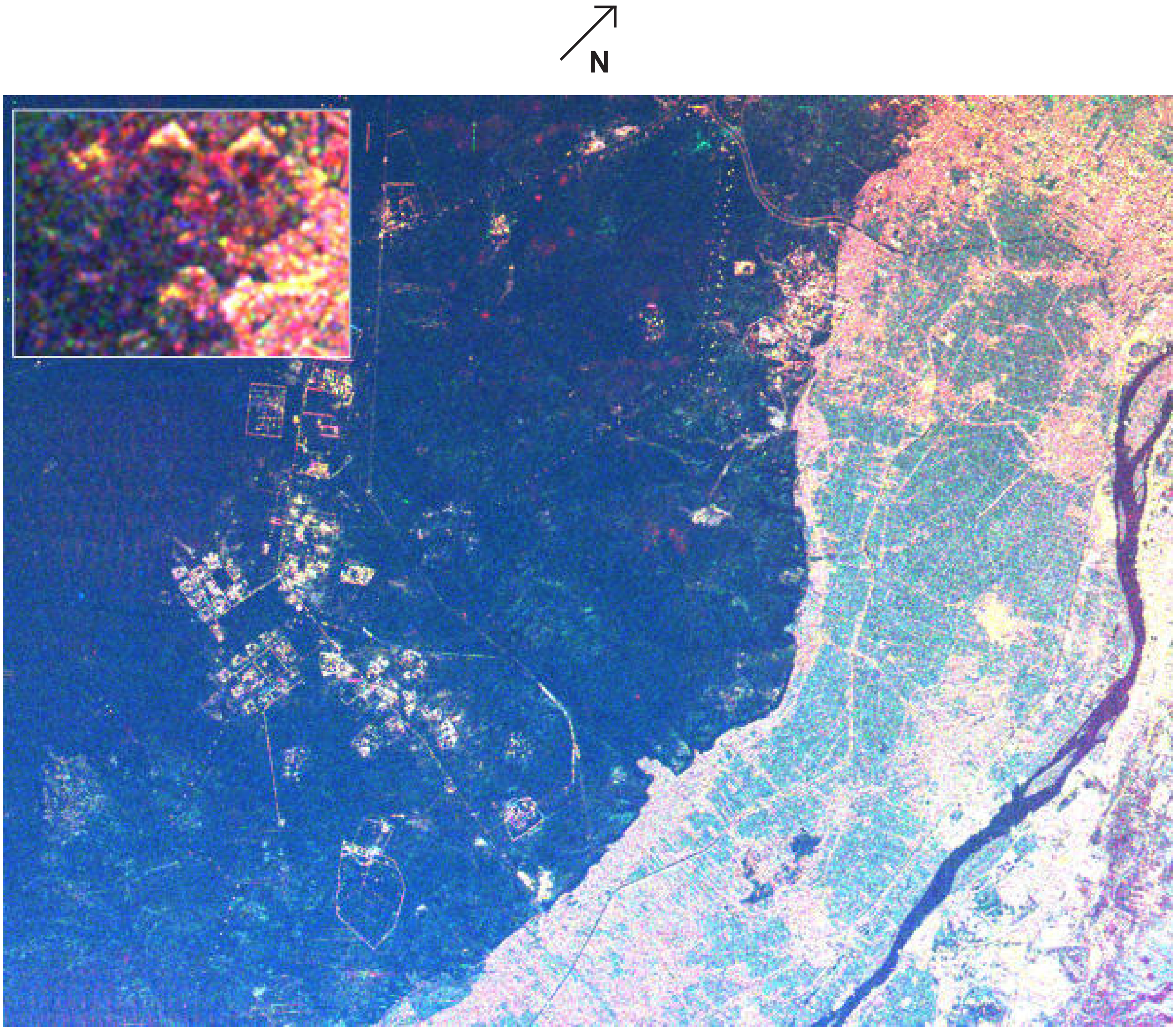
Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Nation	Population 1950	Population 2000	Population 2025	Population 2050	Water Stress 1950?	Water Stress 2000?	Water Stress 2025?	Water Stress 2050?
Key Management Issues								

Module 1, Investigation 3: Figure 1

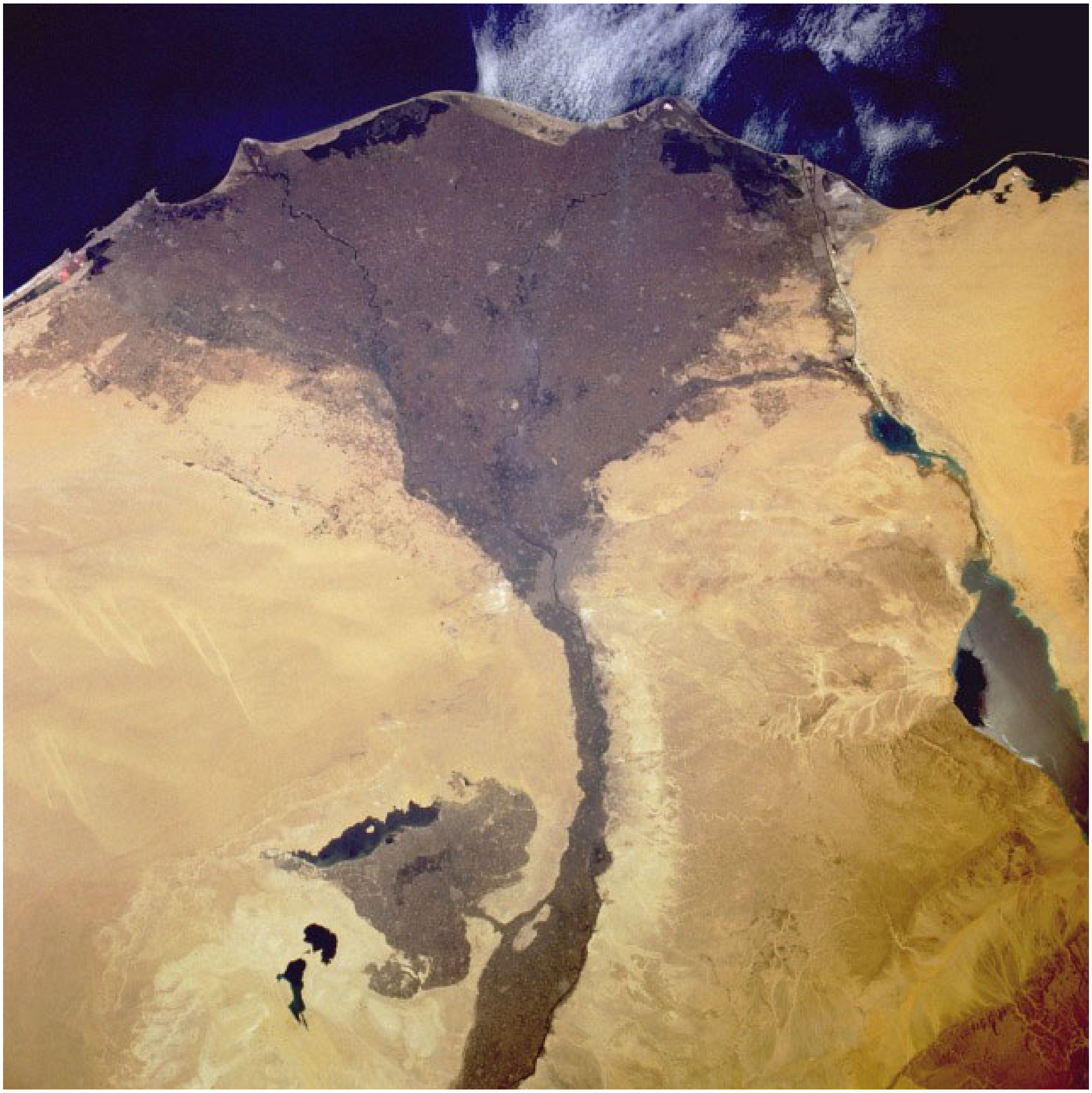
STS026-041-058 Valley of the Kings, southern Egypt, October 1988

Module 1, Investigation 3: Figure 2



SIR-C/X-SAR image, April 1994

Module 1, Investigation 3: Figure 3



STS077-710-091 Nile River Delta, Suez Canal, Egypt, May 1996

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Module 1, Investigation 3: Figure 4

STS046-075-018 Nile River and Aswan Dam, Egypt, August 1992

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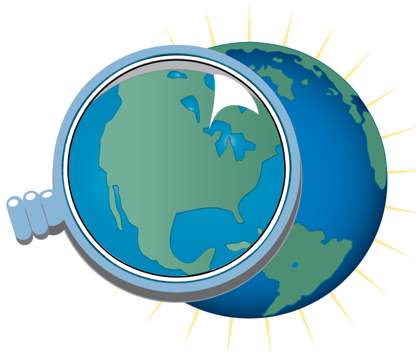
Why is snow important in the southwestern United States?



Investigation Overview

In Investigation 4, students role-play U.S. senators from seven western states seeking to find solutions to important water problems in the Southwest: recurrent drought, which reduces vital snowpack resources, in the face of rapid population growth and therefore increasing demand on those resources. Information from satellite images, in tandem with ground-based perspectives, assist students in playing their roles as senators. Because the investigation uses a case study in the United States, all statistics will be in English units. This conscious exception to the standard use of metric units reflects the real-world practice of American water resource managers.

Time required: Five to nine 45-minute sessions (as follows):
Introduction and Parts 1 and 2: One or two 45-minute sessions
Part 3: One 45-minute session
Parts 4 and 5: One or two 45-minute sessions
Parts 6 and 7: One or two 45-minute sessions
Part 8 and Debriefing: One or two 45-minute sessions

Materials/Resources

Briefing (one per student)
Log (one per student)
Computer with CD-ROM drive. The Mission Geography CD contains color graphics that contain data needed for the investigation.
Access to an atlas with an index to show location of cities in the western United States
Optional: Access to the Internet, which offers opportunities for extending this investigation

Content Preview

The southwestern United States faces critical water shortages. The Southwest is the driest quarter of the United States and yet its population is growing faster than that of any other region. Most of the population depends upon mountain snowmelt for its water supply, but the amount of snow varies, and the climate is subject to recurrent droughts. The allocation of water among both competing uses and areas is a huge political and management problem.

Geography Standards

Standard 7: Physical Systems

The physical processes that shape the patterns of Earth's surface

- Describe how physical processes affect different regions of the United States and the world.

Standard 15: Environment and Society

How physical systems affect human systems

- Analyze examples of changes in the physical environment that have reduced the capacity of the environment to support human activity.
- Apply the concept of "limits to growth" to suggest ways to adapt to or overcome the limits imposed on human systems by physical systems.

Standard 18: The Uses of Geography

How to apply geography to interpret the present and plan for the future

- Develop policies that are designed to guide the use and management of Earth's resources and that reflect multiple points of view.
- Analyze a variety of contemporary issues in terms of Earth's physical and human systems.

Geography Skills

Skill Set 4: Analyzing Geographic Information

- Make inferences and draw conclusions from maps and other geographic representations.

Skill Set 5: Answering Geographic Questions

- Evaluate the answers to geographic questions.

Classroom Procedures

Beginning the Investigation

1. Tell students that in this investigation they will play the roles of senators from seven western states on the Senate Subcommittee on Future Water Policy in the Southwest. Generate initial discussion by asking questions such as:
   - Why might there be a need for changing water policies in this region?
   - What kinds of issues might you expect to face in doing this?

2. Organize for cooperative learning by forming students into seven small groups:
   - Form a small group for Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.
   - Give students some choice of group, randomly assign, or count off by seven.
   - All groups do not need to be the same size: assign larger groups to the more populous states (California is by far the largest, followed by Arizona and Colorado; Wyoming has the smallest population).
   - Students help each other in their small group learn to play the role of their state's senator.

   (Cooperative learning will be completed in Part 8 when students from each group come together in groups of seven to formulate recommendations.)

3. Hand out copies of the **Briefing** and **Log** to each student. (Alternative: If you don't want each student to complete a Log, hand out only one copy per group.)

4. Have students look over the **Briefing** and **Log** and emphasize
   - the importance of studying the images (called figures) that support the written material;
   - the questions and the need to write out answers on the Log (answers are provided at the end of this Educator's Guide); and
   - the schedule for handing in answers on the Log, either all together at the conclusion, or one or two at a time as they complete individual parts of the investigation.

5. In their small groups,
   - have students read **Background**, **Objectives**, and **Scenario**;
   - take any questions they may have; and
   - tell them they should begin working through the Briefing in their small groups—reading, studying the figures, discussing, and answering the Log questions.

6. For students who do not live in the Southwest, ask: Why would you care about this region's water problems? Student responses might include
   - the Southwest provides fresh fruits and vegetables to the rest of the country;
   - the economic burdens caused by regional problems, such as drought or flooding, are often borne by the rest of the country through federal assistance; or
   - you should care about the problems of people in other places.

Developing the Investigation

7. Beginning with **Part 1: Why is this investigation important?**, small groups can work through the material on their own.
   - If you want to keep the groups progressing at about the same pace, you might conduct whole class discussions on interesting and difficult points and/or of the Log questions.
   - From Part 1, for example, you might check for understanding of the concept of reservoir storage and hydropower by asking: "How is snow used to make electricity?" and "What is meant by the phrase water-stressed areas?"
   - The first **Log** question comes at the end of Part 2. Remind students that in answering the Log questions carefully, they are preparing to play their roles as members of the Senate Subcommittee on Future Water Policy in the Southwest.

8. At the beginning of **Part 3: How much do cities in the Southwest depend on snow?**, Question 2 directs students to complete the table in the **Log**. The table is designed to help students organize the information in Part 3 as they cover it.
   - Students should find all the locations referred to, either on Figure 4 or in an atlas.
   - Ask students to match features on the images (figures) with features in their atlases. For example, they should try to find Lake Powell in the atlas (or on Figure 4) and compare the map view with the image in Figure 2.
   - Another check could occur with Figure 5. Have them find the Sierra Nevada Mountains, California Central Valley, and San Francisco Bay area on a map. Then, have them identify these features on the oblique NASA image in Figure 5.
   - Have students orient their atlases to try to reproduce the angles of the oblique photos in Figures 5, 7, and 9. Be sure directions also correspond.

9. Encourage brainstorming to answer Question 3 at the end of Part 4.

10. **Part 5. Who's in charge of the water?** discusses the importance of the Colorado River to the region, the Colorado River Compact of 1922, the competition for Colorado River water among states and users, and water rights, including legal challenges to rights and uses.

11. At the end of Part 6 students are asked to find information on the Internet on the status of snow and water resources both for their local areas and for the states they are representing as U.S. senators. Several URLs are given to help them in their searches.

12. To save time, you may choose to skip **Part 7: Is water rationing in your future?** and Question 7.
    - This portion of the investigation acquaints students with water rationing and personal water use. It challenges students to decide how they would use water when faced with strict rationing (Question 7).
    - If you include this, have students create their own categories for personal water use (as suggested in the **Briefing**). Alternatively, have them fill out the **Personal Water Use Survey** below.
    - Remind students that personal water use is only a small part of total water use. For example, of total water use in California, approximately 11 percent is now used in urban areas by residences, industries, governments, and commercial enterprises; 42 percent is used for agriculture; 45 percent of the runoff is used for the environment. About 2 percent of developed water supplies is used for other reasons, such as recreation and energy production. <http://wwwdwr.water.ca.gov/dir-CA_Water_Resource/CA_Wtr_Supply-Needs.html>

Personal Water Use Survey

Investigation	Normal Use	Conservation Use	25 Gallons/Day Limit
Flushing	5-7 gallons	With displacement bottles in tank, 4 gallons	
Showering	25 gallons water running	4 gallons, wet down, soap up, wash down	
Bathing	40 gallons, tub full	10 gallons, minimum level	
Brushing teeth	5 gallons, tap running	<1 gallon, wet brush, turn water off, rinse	
Washing hands or face	2 gallons, tap running	1 gallon, plug and fill basin	
Drinking	1 gallon, run water to cool	8 ounces, keep water cool in refrigerator	
Cleaning vegetables	3 gallons, tap running	<1 gallon, fill pan with water to clean	
Dishwasher	16 gallons, full cycle	7 gallons, short cycle	
Dishes by hand	30 gallons, tap running	5 gallons, wash and rinse in dishpan or sink	
Washing clothes	60 gallons, full cycle, top water level	27 gallons, short cycle, minimal water level	25 gallons
TOTALS	117-148 gallons	59 gallons	

Source: National Resources Conservation Service (http://pelican.gmpo.gov/edresources/water_5.html)

Concluding the Investigation

13. Part 8 concludes the investigation with the Hearings of the Senate Subcommittee.
    - Form cooperative learning groups of seven so that each group has a representative—a senator—from each of the seven states: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.
    - Using the table in question 8 of the Log, each group should propose the allocation of Colorado River water among different uses and among each of the seven southwestern states.

Evaluation

- Collect and evaluate students' **Logs** using the Key.

Log

1. Give three reasons why snow is important in the Southwest?
    - *Possible answers include: Snow meltwater is the major source of water in the Southwest. It provides water for hydroelectric power or electricity, irrigation of crops, residential or domestic uses, industries, businesses, and recreation.*

2. Complete the following table:

Water Supplies for Selected Southwestern Cities

City	Types and Locations of Water Sources
Las Vegas, Nevada	Groundwater has been main source, but that is now inadequate so are beginning to rely on importing Colorado River water.
Los Angeles, California	Snowmelt from the Sierra Nevada Mountains and Colorado River originating in the Rocky Mountains
Phoenix, Arizona	Snowmelt from the Mogollon Rim via Salt River Project provides 2/3rds of supply; local groundwater supplies 3%, about 1/3rd comes via Central Arizona Project, which taps Colorado River water.
Salt Lake City, Utah	Snowmelt from the Wasatch Mountains
San Francisco, California	Snowmelt from the Sierra Nevada Mountains stored behind Hetch Hetchy dam
Tucson, Arizona	Groundwater has been "mined" and is no longer adequate, so are using more and more of Colorado River water brought in by Central Arizona Project.

3. How do droughts in the Southwest affect people and the physical environment? What do you think would happen if the Southwest experienced a drought lasting several decades?
    - *In dry years (called droughts), there is less snowmelt. Reservoirs dry up. Water is sometimes rationed. There are also more fires.*
    - *The student should extrapolate with more of the first part, with a healthy opportunity for creativity, e.g., impact on virtually all aspects of economic life.*

4. Name the seven states through which Colorado River water flows?

   - *Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. Students should note that waters tributary to the Colorado should be included, e.g., the Green River flowing out of Wyoming is a tributary to the Colorado River.*

5. Who are the major water users of the Colorado River? Who do you think *will* win the most in the fight for its water? Who do you think *should* win the most in the fight for its water? Why?

   - *The major water users are California, Nevada, Arizona, and Colorado. As to who **will** win the snowmelt water, there's no clear answer, but students should discuss the issue. If political and economic power are the main criteria for winning, then California would likely be the biggest winner. As to who **should** win the snowmelt water, see if students can determine if there is a geographic bias in answers.*

6. Briefly summarize the current status of snowpack or other water resources in your home state *and* in the state that you represent as a U.S. senator, and give your sources of information.

   - *The answer will depend upon your location.*

   - *The students may simply repeat the web site listed in the student guide.*

   - *If you live in an area that does not have this information on the Internet, you can ask students where they might find information about water supplies in a nearby large river basin.*

7. Assume that you normally use the average amount of water used per person in the United States. And assume that a severe drought forces you to ration your personal water use to only 25 gallons per day. If that were all the water you had, how would you use it? List below your personal daily uses and amounts totalling 25 gallons.

   *Answers will vary, even if students use the **Personal Water Use Survey.***

8. Meeting as the Senate Subcommittee on Future Water Policy in the Southwestern United States, complete the table below and be prepared to defend your allocations.

   Answers will vary.

Additional Resources

Site at JPL devoted to the study of snow, ice, and glaciers with radar.
http://www.jpl.nasa.gov/radar/sircxsar/snowice.html

NASA's Goddard Space Flight Center Laboratory for Hydrospheric Processes is responsible for programs that include theory and experiments on snow and ice. One of the goals of the remote sensing of snow is to describe the spatial and temporal variability of snow cover.
http://hydro4.gsfc.nasa.gov/research_areas/snow.html

This site represents some of the best work of visualization specialists and NASA scientists. One of the best visualizations about glaciers and climate change, related to glacier bay. This page also indicates how you can order the excellent NASA video: Glacier Bay, Alaska, from the Ground, Air and Space.
http://sdcd.gsfc.nasa.gov/GLACIER.BAY/glacierbay.story.html

On this web site you'll find text, visualizations, pictures, and links relating an exciting research project studying Antarctica. The images and QuickTime movies are very well done.
http://svs.gsfc.nasa.gov/imagewall/antarctica.html

This site has links to NASA's MODIS Snow and Ice Global Mapping Project, as well as links to NASA Climate News, NSF's National Science and Technology Week: Polar Connections, The National Snow and Ice Data Center, Ice and Snow site, Scott Polar Research Institute, Ice Core Dating, Glaciers, Snow, Ice and Permafrost Research Projects, Nansen Environmental and Remote Sensing Center (NERSC), Snowtastic Snow, Cyberspace Avalance Center, and Antarctic Warming—Early Signs of Global Climate Change
http://snowmelt.gsfc.nasa.gov/MODIS_Snow/snowice.web.addr.html

This site, supported by NASA, is a gold mine of information on general snow information links, avalanche awareness, glaciers, snow removal efforts in the United States, the blizzards of 1996, ice shelves and icebergs, and an introduction to the method NSIDC uses to store satellite sensing data in "grids"
http://www-nsidc.colorado.edu/NSIDC/EDUCATION/

Information on the geography of the wildfires in the West
http://wildfire.usgs.gov/html/geomacpublichome.html

Search the status of the water supplies in your area
http://www.wcc.nrcs.usda.gov/water/quantity/westwide.html

Water supply outlook for the western United States, including mountain snowpack maps and reservoir storage graphics. State basin reports for the current water year.
http://www.wcc.nrcs.usda.gov/water/quantity/st_report.html

Adolescent-oriented news about life and ice and snow
http://www.southpole.com/

Good information on water and water conservation
http://pelican.gmpo.gov/edresources/water_5.html

The National Drought Mitigation Center helps people and institutions develop and implement measures to reduce societal vulnerability to drought. The NDMC stresses preparation and risk management rather than crisis management. You can review the drought histories of different states. You can create graphs of the historic droughts experienced by different states, for example, California.
http://enso.unl.edu/ndmc/
http://enso.unl.edu/ndmc/climate/palmer/calif.gif

If you live in California or southern California, these sites will be interesting:
http://rubicon.water.ca.gov/b160index.html (California Department of Water Resources, Bulletin 160-98: California Water Plan, 1998 update. This has lots of information for students living in California.)
http://www.mwd.dst.ca.us/index.htm (The metropolitan water district of southern California site. This would be of use for educators in southern California.)

Reisner, Marc. *Cadillac Desert.*
http://www.pgs.org/kteh/cadillacdesert/home.html

Postel, Sandra. *Last Oasis.* Norton/Worldwatch Books. 1998.

Conniff, R. November 1993. California: Desert in disguise in water. The power, promise and turmoil of North America's fresh water. November 1993. *National Geographic* Special Edition, p. 38-53.

Jim Carrier, June 1991, The Colorado. A river drained dry. *National Geographic*, v. 179 (6) 4-35.

Module 1, Investigation 4: Briefing

Why is snow important in the southwest United States?

Background

There is little chance that you would experience snowfall in one of the big cities of the southwestern United States. Los Angeles, San Francisco, Las Vegas, and Phoenix are too low in elevation to get snow; it is just not cold enough. And yet these cities depend upon snow for their water supplies. Mountains get the snow, the snowmelt is stored in reservoirs, and the water is then moved in streams and aqueducts to supply farms, cities, and industries, which in some cases are hundreds of miles away from the mountain snows (Figure 1).

This may seem like an ideal situation, except for two potential problems of water supply and water demand: drought and population growth. In the generally arid Southwest, a prolonged drought can mean that there is too little snowfall in the mountains to resupply the reservoirs. The other potential problem is that the Southwest has the fastest growing population of any region in the United States, and this population is making unprecedented demands on the water supply. Underlying these potential regional problems is the fact that *each* of the southwestern states seeks to increase its *own* water supply.

Figure 1: Snow and snowmelt in the mountains of the western United States

Source of top image: http://snowmelt.gsfc.nasa.gov/MODIS_Snow/snow.html
Source of bottom image: ftp://ftp.wcc.nrcs.usda.gov/images/snomlt01.jpg

Objectives

In this investigation, you will

- use satellite imagery and other sources to find and organize information about the water supplies of major cities in the southwestern United States,
- consider the ways in which droughts in the Southwest affect people and the physical environment,
- learn about water management policy and water law in the Southwest,
- find out how ground crews and remote sensing measure mountain snowpacks to aid the planning of water managers,
- use Internet sites to find the status of snowpack or other water resources in one or more states,
- project personal water use under severe water rationing, and
- apply your knowledge to role-play a member of a U.S. senate subcommittee making recommendations on water policy issues in the Southwest.

Scenario

You are to play the role of a U.S. senator from one of the following states: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. You are to represent your state on the Senate Subcommittee on Future Water Policy in the Southwest. Specifically, the subcommittee is charged with proposing the allocation of Colorado River water (1) among different uses and (2) among the southwestern states. This investigation will help you prepare for your role as a member of this subcommittee, which will meet to do its business near the end of this investigation.

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Part 1. Why is this investigation important?

Springtime melting of mountain snows helped ancient civilizations flourish. For example, Mesopotamia depended on water from snowmelt in the Tigris and Euphrates Rivers to irrigate crops, and Hohokam peoples from the Phoenix Valley, Arizona, dug many canals to move the snowmelt water from the Salt River to their crops. And new canals along similar routes now supply snowmelt to millions of inhabitants of the Phoenix area.

Today, snowmelt is stored in reservoirs behind dams so it can provide water and energy. For example, Lake Powell stores the water behind Glen Canyon Dam (Figure 2). The water released by dams drives turbines that generate hydroelectric power. The hydroelectric power from Glen Canyon Dam supplies cities in the Southwest such as Las Vegas, Phoenix, and Los Angeles.

When the Colorado River reaches the Gulf of California, the once-mighty river is a mere trickle after upstream users have dammed it and siphoned off its water (Carrier 1991). Little is left of the Colorado below the Glen Canyon Dam in Arizona to sustain natural ecosystems and their aquatic life, a fate that other rivers around the world share. Each year, the supply of clean fresh water becomes more scarce, as more and more people are living in dry, “water-stressed” areas, according to research reported by Dr. Kenneth Strzepek at the American Geophysical Union meeting in San Francisco in 1999 (Denver Post 1999). Computer models show that one-third of the world’s people live in areas classified as “water-stressed,” meaning the demand for clean fresh water exceeds the supply. In addition to the Colorado River basin, other water-stressed areas include the regions near China’s Yellow River, Africa’s Zambeze River, and the Syr Darya and Amu Darya Rivers that flow into the Aral Sea in central Asia.

Part 2. What is NASA’s role in this issue?

NASA uses satellites to monitor the amount of snow and ice on Earth (Figure 3). Instruments aboard satellites sense a type of microwave radiation that is emitted and scattered by snow. Different snow conditions are associated with different microwave signals, which are received by satellite instruments.

Figure 2: Ground and space views of the Colorado River and Lake Powell, Arizona and Utah, taken along the river and also by astronauts aboard Space Shuttle *Columbia*.

The water of the Colorado River starts as snowmelt in the Rocky Mountains to the east (right of picture). The water then moves through the dry Southwest, as shown in this photograph, but dams help store the water. The blue color to the left of the Space Shuttle’s tail is the valley of the Colorado River flooded by snowmelt.

Source of Space Shuttle imagery: http://images.jsc.nasa.gov/images/pao/STS-73/73727045.JPG

Module 1, Investigation 4: Briefing

Why is snow important in the southwest United States?

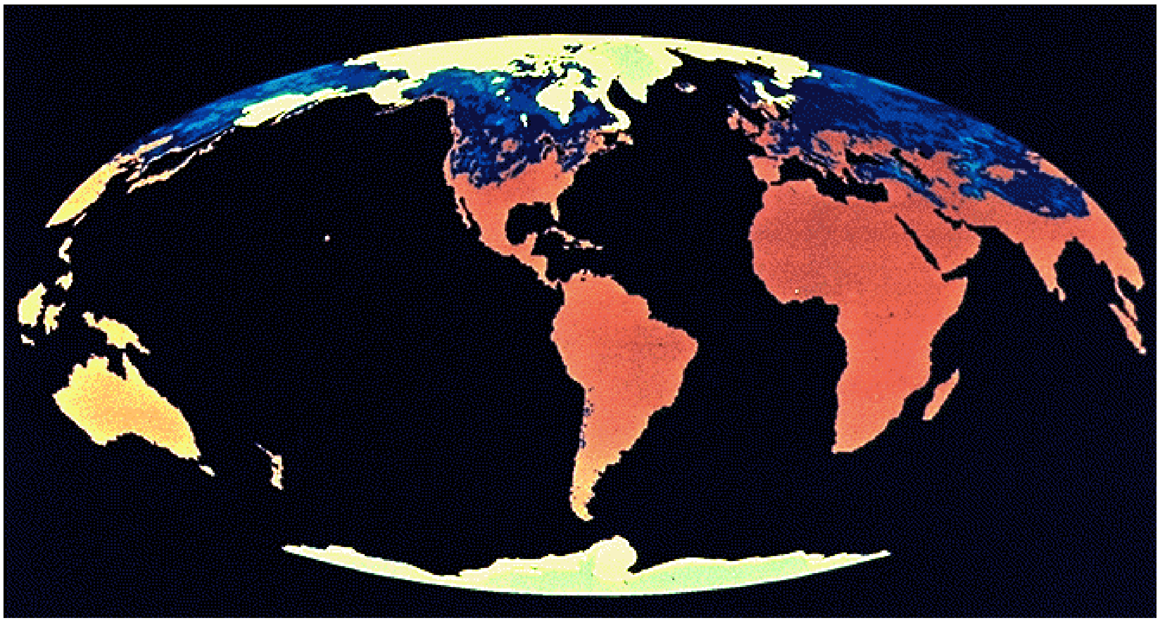

Figure 3: This image comes from NASA's Nimbus-7 satellite. It shows global snow and ice coverage in the Northern Hemisphere winter. In this image, blues from light to dark indicate snow depths ranging from deep to thin. Sea ice is white. Areas not covered by snow are red to brown.

Source: http://eospso.gsfc.nasa.gov/eos_edu.pack/p26.html

NASA monitors and maps snow cover for many reasons. Snow cover is important in developing military strategies and even national foreign policy. Snow cover affects the climate of continents and Earth as a whole. Thus, by gaining more accurate information about properties and effects of snow cover, scientists hope to develop a better understanding of Earth's climate. And the monitoring of mountain snowpack is crucial to the economic life of peoples in many parts of the world, including, as you will see, the southwestern United States.

Throughout this investigation you will find a number of underlined questions. Write your answers to these questions on the Investigation Log at the end of the Briefing. Your answers will prepare you to play your role as a member of the Senate Subcommittee on Future Water Policy in the Southwest.

Answer Question 1 in the Log.

Part 3. How much do cities in the Southwest depend on snow?

Part 3 gives information about the water supplies of selected cities in the Southwest. As you work through Part 3, organize this information by completing the table at Question 2 in the Log.

Look at the mountains and rivers of the Southwest (Figure 4 or an atlas). Each river system catches water over an area called a *watershed*. In a watershed, the tributaries (smaller streams) feed all their water to the main stream. Then, the river system uses gravity to move the water to the ocean or a lake. More than 75 percent of the water in the large river systems on Figure 4 start in mountains as snowfall. It typically takes 25.4 centimeters of snow to melt down to 2.54 centimeters of water.

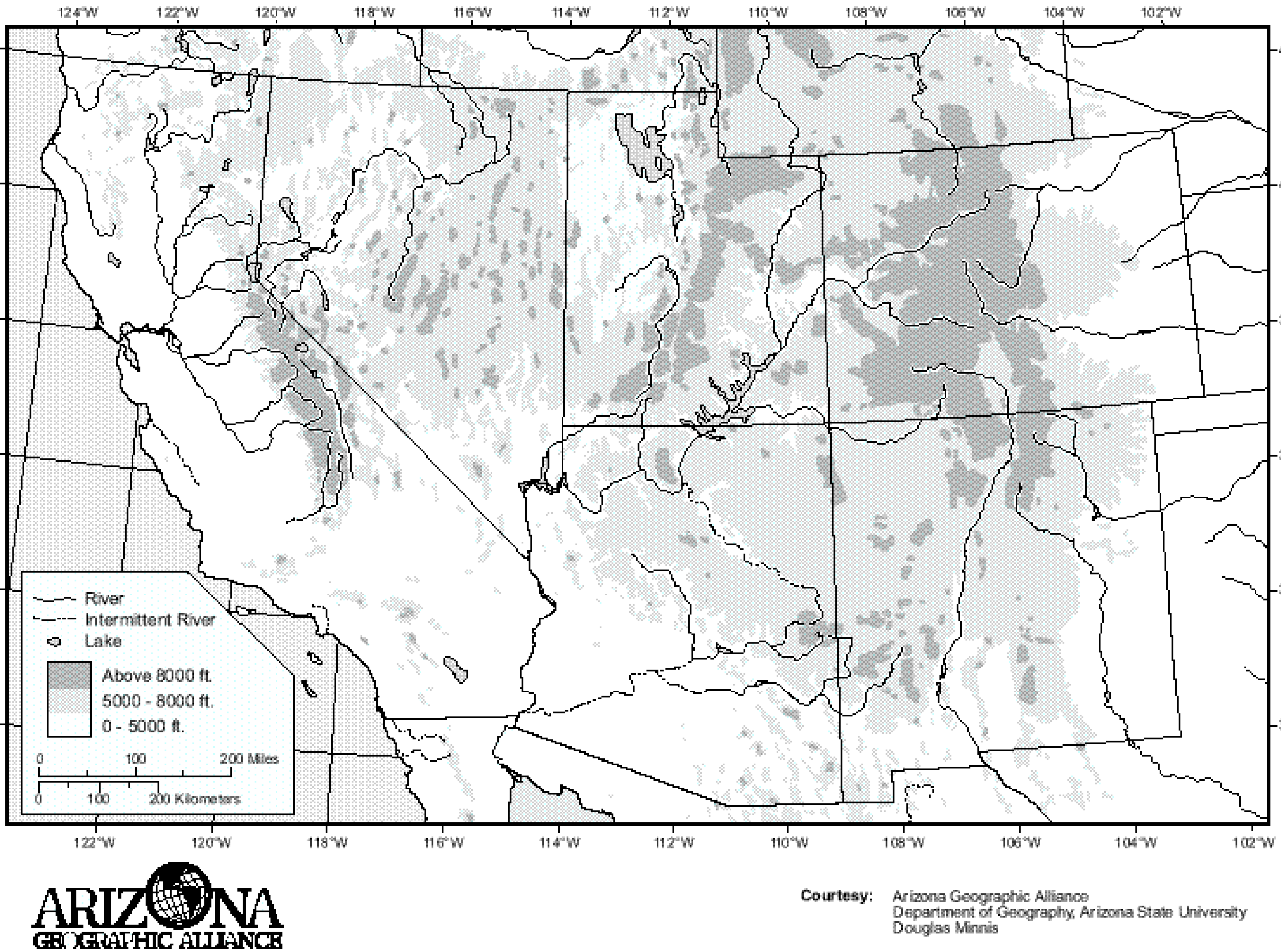

Figure 4: Map of the topography and rivers in the southwestern United States

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Locate **San Francisco** on Figure 4 using an atlas. Now look to the east of San Francisco at the high land (dark shading) called the Sierra Nevada Mountains. At the start of the 1900s, the city of San Francisco had a population and industry that needed more water than local watersheds could provide. So San Francisco built a dam in Hetch Hetchy Valley in the Sierra Nevada Mountains to trap snowmelt for its citizens and industry.

Now examine a NASA satellite view of San Francisco (Figure 5). Most of NASA's imagery is from directly overhead or in **planimetric view**. Figure 5 presents a different type of view—a view from the side, or **oblique view**.

Now locate **Phoenix** on Figure 4 using an atlas. Also, on Figure 4, look north and east of Phoenix at the high land (dark shading)—called the Mogollon

Figure 5: NASA's SeaWiFS satellite view of the San Francisco Bay area, California's Central Valley, and the snow-capped Sierra Nevada mountains

The brown around San Francisco Bay is the color of the cities. The green shows vegetation with dark green being trees. The two large lakes in the middle of the white snow are Lake Tahoe (upper left) and Mono Lake (upper right). The snowmelt flows to the west (to the bottom of the image) and makes its way through the Sacramento and San Joaquin Rivers. Diversion structures route some of the snowmelt water to San Francisco, some through aqueducts to thirsty southern California, and some flows naturally through the rivers and delta. This natural flow is to preserve endangered fish: winter-run Chinook salmon; the tiny Delta smelt; and the Delta splittail.

Source: http://svs.gsfc.nasa.gov/imagewall/SeaWiFS/zoom_sanfran.html

Figure 6: Snow at the Grand Canyon, Arizona, as seen from the Space Shuttle on February 9, 1994

Although Arizona is mostly desert, this shows that snow covers Arizona's high country. The zone of dark color running parallel to the snow line is the pine forest. Pine forest and snow cover the Mogollon Rim of Arizona in most winters.

Source: http://images.jsc.nasa.gov/ images/pao/STS60/20120924.jpg

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Rim. The Mogollon Rim is high country (not really mountains) with pine trees and winter snow (Figure 6).

At the start of the 1900s, Phoenix was only a small city. But Phoenix was located near rivers with very large watersheds up in the Mogollon Rim. Most of the people living in the Phoenix area were farmers, and they started the Salt River Project to manage these watersheds for irrigation.

Phoenix lies in a desert with an average of only 18 centimeters of rainfall a year. But unlike San Francisco, Phoenix does not have to bring water from a great distance. It comes directly to them from its watersheds to the north and east.

Throughout the first half of the 20th century, the Salt River Project built dams to hold water coming down the Verde River from the north and Salt River from the east (Figure 7). About two-thirds of the Phoenix area's water supply comes from the Salt River Project. Most of the water in these reservoirs comes from snowmelt, which is stored behind dams (such as Roosevelt Dam) and distributed by canals to farms, cities, and industries. Local groundwater contributes about 3 percent of the Phoenix supply, and almost one-third of the supply comes from the Central Arizona Project, which taps the Colorado River at Lake Havasu some 536 kilometers away.

Locate **Salt Lake City** and the Great Salt Lake on Figure 4 using an atlas. Find the highlands to the

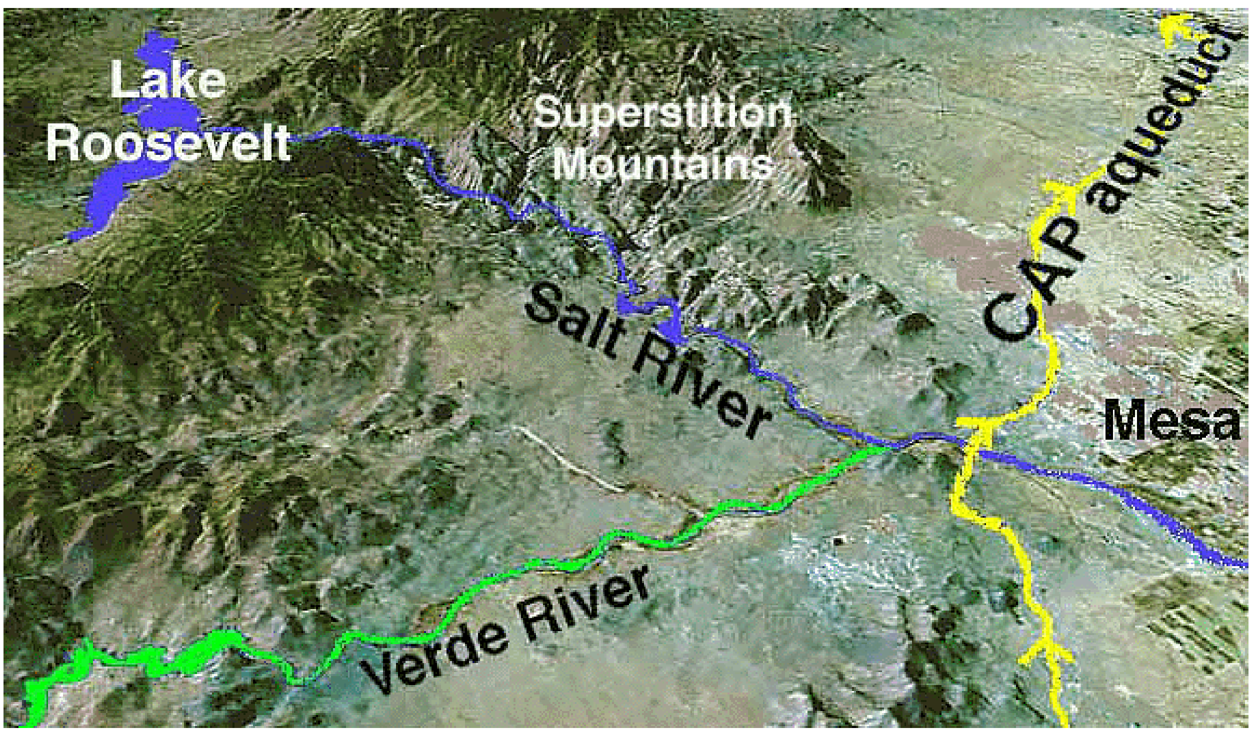

Figure 7: Satellite view of the water sources feeding the Phoenix metropolitan area, where the water is managed by the Salt River Project. The view is looking to the southeast. Mesa is on the eastern side of the Phoenix area. The CAP is the Central Arizona Project.

Source: LANDSAT 1993 Thematic Mapper image combined with digital elevation data available from the U.S. Geological Survey. The 1993 year was very wet, fostering a lot of vegetation growth (green color in this image) in the normally dry desert.

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Figure 8: Salt Lake City depends on snow from the Wasatch Range, seen as white on this Space Shuttle photograph

The importance of snowmelt can even be seen in the color of the Great Salt Lake, Utah. The lake appears as two separate bodies of water with a narrow divider in the middle. At the turn of the century, a railroad bridge without culverts was built across the lake, and ever since, the water and salinity levels have been unequal. The lower right side gets more snowmelt and has more freshwater. When there is too much snowmelt from the nearby Wasatch Mountains, the lake can flood local lowlands.

Source: http://images.jsc.nasa.gov/images/pao/STS36/10063852.htm

east (the dark shading on Figure 4) called the Wasatch Mountains. Salt Lake City lies at the foot of the Wasatch Mountains. The snow from the Wasatch provides water for the cities, agriculture, and industry of the Salt Lake City area. The importance of snowmelt is also seen visually from outer space in Figure 8.

Locate **Los Angeles** on Figure 4 using an atlas. Los Angeles does have some mountains nearby, but the metropolitan area is so large that there isn't enough snow in these mountains to meet the needs of the region.

As early as 1913, the Los Angeles Department of Water started to bring water to the city from great distances. Cities in the Los Angeles metropolitan area now get water from the snow of two mountain areas far away. One major source of water is the Sierra Nevada Mountains (Figure 9). The other major source of water comes from the Rocky Mountains through the Colorado River and the

Colorado River Aqueduct (Figure 2). Some southwestern cities rely mainly on local groundwater rather than snowmelt. Las Vegas, Nevada, and Tucson, Arizona, (locate them on Figure 4) are two large cities that have been pumping much of their water from wells. But both of these cities faced major water crises at the start of the 21st century. Both cities have been “mining” their groundwater. This means that they have been taking water from wells faster than rainfall can resupply the groundwater. They have mined groundwater because populations have grown too fast and too large for the water supply.

So what are Las Vegas and Tucson doing? They are importing water from somewhere else. Both of these cities are trying to get more and more water from the Colorado River, which has its origin in the snow of the Rocky Mountains (Figure 2).

An aqueduct called the Central Arizona Project (CAP) brings water hundreds of miles from the Colorado River to Tucson (Figures 7 and 10). And although the CAP water tastes worse than groundwater and rots pipes of older homes, Tucson has no choice. There just isn’t enough local groundwater to support Tucson’s growing population.

Contaminated ground water is an increasing threat to human health in some regions. If alternative sources of water are available, such as from snow, these regions are fortunate. For example, in December 1999, Fort Morgan, a small city northeast of Denver on Colorado’s Eastern Plains, joined many other northern Colorado cities that get municipal water from snow in the Colorado River Basin (Coleman 2000). The water, which originates in and around Rocky Mountain National Park northwest of Denver, is delivered to the Front Range region east of the Rockies by the Colorado River-Big Thompson River Project. This system of reservoirs, pipelines, pumping stations, and canals takes water from the Colorado River on the western side of the Rockies and moves it to the Big Thompson watershed on the eastern side. Fort Morgan’s switch to mountain snowmelt meant that its population no longer had to use groundwater

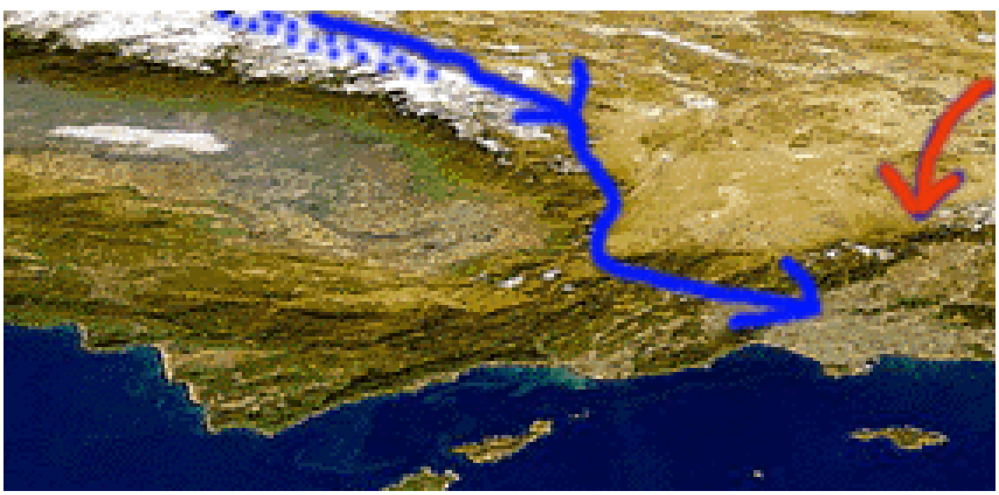

Figure 9: The Los Angeles metropolitan area is in the lower right corner of this SeaWiFS image from NASA

The blue dots represent the watershed of the eastern Sierra Nevada Mountains whose water rights were purchased by the Los Angeles Department of Water (LADWP). LADWP built two aqueducts—one in 1913 and the other in 1970—to bring water to the city of Los Angeles. The blue and red lines show the pathway of water that comes from the Sierra Nevada (blue) and Colorado River (red).

Source: http://svs.gsfc.nasa.gov/imagewall/SeaWiFS/zoom_losangeles.html

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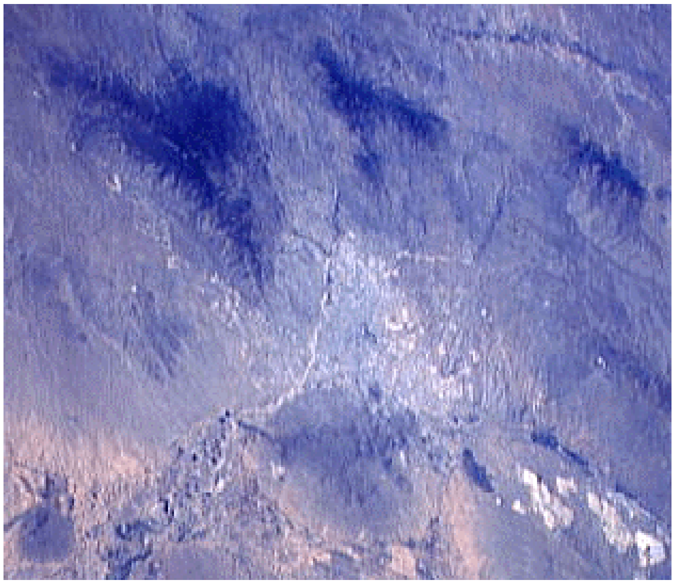

Figure 10: The desert city of Tucson, Arizona, as seen by the Space Shuttle in 1994

The light-colored area in the middle of the photograph is Tucson. The dark areas to the east (up) are mountains that surround Tucson. Most of the lowlands in the image look light brown because vegetation is scarce in this arid area.

Source: http://images.jsc.nasa.gov/iams/images/earth/STS039/lowres/10020684.jpg

that had become increasingly polluted by nitrates from agricultural fertilizers.

The Fort Morgan example raises another issue. There is rapid urban growth in Colorado's Front Range communities (Long 1996). The Denver metro area is the center of this rapidly urbanizing region stretching from Fort Collins in the north to Pueblo in the south. This area is another major competitor for Colorado River water.

Part 4. How dependable are the snows?

Are you getting the impression that millions of people in the southwestern United States depend on snowmelt? You are absolutely right! And if you are thinking that snowfall might not be dependable, you are right again. Some winters have almost no snow in the mountains. The climate record in the Southwest shows great variability—big swings in precipitation from year to year. Generally, the drier the climate, the greater the variability. So, in the Southwest, the driest quarter of the United States, you can expect the greatest variability.

The table below illustrates this variability.

1987-1992 Drought
- In California, reservoirs holding water declined; some dried up.
- Water was rationed in California.
- People in cities began conserving water.
- New California laws tied real estate development to water supplies.

1993-1998 Snowy Years
- Water surplus

1999-2000 Drought
- Ski resorts in California and Colorado experienced poor skiing conditions and loss of business.
- In December 1999, the snowpack in the Central Rockies was only half of normal.
- The winter of 1999-2000 was the driest in Arizona since records were kept.
- In summer 2000, Roosevelt Reservoir, which supplies Phoenix, was only 17% of normal and was projected to go down to 10%.

Unfortunately, the drought of 1987-1993 was not the greatest one on record. The Southwest experienced much longer droughts around 1000 A.D. and 1300 A.D. There is evidence of a very long drought centered around 1300 A.D. that lasted about 160 years. It was so dry that the high alpine lakes of the Sierra Nevada Mountains stopped overflowing. Even in the worst *recent* droughts, these same lakes have *always* overflowed.

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Droughts do more than ruin a ski season, make reservoir levels drop, and force water rationing. Plants on hillsides dry out and burn easily in wildfires. Major fires occur during droughts. In the United States, over 5 million acres were burned in the summer of 2000, which had the largest number of wildfires in many decades. NASA has a team of fire specialists that study fires with remote sensing while the fires are burning. For example, see <http://asapdata.arc.nasa.gov/YellowstoneFire.jpg>.

<u>Answer Question 3 in the Log.</u>

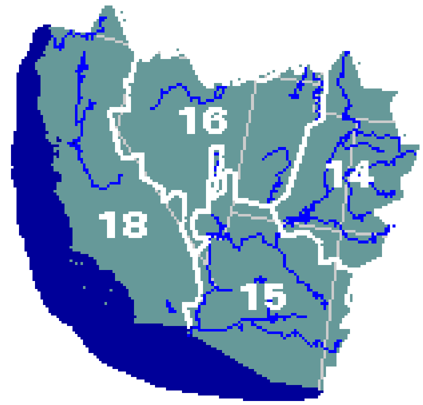

Figure 11: Water resources regions of the southwestern United States, as defined and used by the U.S. Geological Survey.

14 is the Upper Colorado River Basin.
15 is the Lower Colorado River Basin.
16 is the Great Basin.
18 is California.

Source: http://water.usgs.gov/images/regions.gif

Part 5. Who's in charge of the water?

If you are thinking that the answer depends on the place, you are a natural geographer. Geographers tend to answer questions like this at different scales. This means that if you kept zooming in from outer space you would get different answers. If you zoomed way up close and looked at a city, the usual answer is that the city is in charge of the water. If you zoomed out, there are often planning regions for different parts of a state. For example, the Salt River Project distributes water to many cities in the Phoenix area. If you zoomed out even more, states have some control of water. But for the Southwest as a whole, there is an out-and-out fight for control of the major water source—the Colorado River (Carrier 1991).

Sometimes called the "jugular vein" of the Southwest, Colorado River water flows through seven states, and eventually into Mexico (Figures 2 and 11). About 85 percent of Colorado River water is used by agriculture.

<u>Answer Question 4 in the Log.</u>

The amount of Colorado River water each state gets was first determined by the Colorado River Compact of 1922. This agreement divided these seven states into upper and lower basins (Figure 11) and allocated 7.5 million **acre-feet** (maf) per year to each basin. At the time, the total flow was thought to be 17 maf per year (For comparison, the average annual flows of the Mississippi and Columbia rivers are 400 and 192 maf, respectively.) But since 1930, the Colorado's flow has averaged only 14 maf. A 1944 treaty guaranteed Mexico 1.5 maf. Today, evaporation from reservoirs removes about 2 maf.

Of the seven states, three take most of the water—California, Nevada, and Arizona. Mexico only gets water in wet years when there is a surplus. According to the Compact of 1922, California is

How much is an acre-foot?

An acre-foot is the amount of water spread over an acre a foot deep. An acre-foot is 325,850 gallons.

How can you visualize a million gallons?

The usual bathtub holds 40 gallons, so a million gallons would be 25,000 baths. A pool that would hold a million gallons would be as long as a football field, 10 feet deep, and 50 feet across.

permitted to use 4.4 maf each year, but for most years, California has used far more than its allotment. Now, Arizona and Nevada are demanding some of the water that California has been taking. At the start of the 21st century, U.S. Secretary of the Interior Bruce Babbitt tried to force California to reduce its use to the agreed-upon amount, but in the year 2000, California was still taking more than its allotment.

Finally, California agreed to meet with Arizona and Nevada to sort things out. Arizona and Nevada hoped to force California to keep to its agreement. Californians wanted the Colorado River's water distributed according to population (of course, California has the largest population by far). At the turn of the 21st century, Nevada and Arizona ranked #1 and #2 among the states in the rate of population growth. And in Colorado, the state that is the source of the Colorado River, the rate of population growth is also among the highest in the nation. Also, Mexican agriculture (which produces a large share of its products for the U.S. market) has water needs as well.

Nobody knows for sure whether the states will keep to the old agreement, whether there will be a new agreement, what a new agreement will look like, or what will happen to the Colorado River water.

Answer Question 5 in the Log.

Another way to answer the question **Who's in charge of the water?** is to understand which user legally owns the right to water. The primary law controlling water rights in the West is "first in time, first in right." In other words, water is the property of those who used it first, which is called "prior appropriation." This law usually applies at the level of the individual water user.

The major users of water are agriculture, towns and cities, industries, and the physical environment (ecosystems require water to sustain them).

But legal rights to water can be challenged. For example, environmentalists won a major fight in court against the City of Los Angeles, which was importing water from the sources that feed Mono Lake. Five decades of this caused the surface of Mono Lake to drop 40 feet, which threatened that unique ecosystem. Environmentalists won a 15-year court battle, and Los Angeles was forced to reduce flow diversions to allow Mono Lake to rise to healthy levels.

It is even possible for Native American farmers to win water battles in court. Take the example of the Akimel O'odham (Pima Indians), who resided along the Gila River for centuries (Figure 4 at about 32˚N, 111˚W). In 1859, the Gila River Reservation was established, the first in Arizona. Anglo-American farmers settling in areas up river from the Akimel

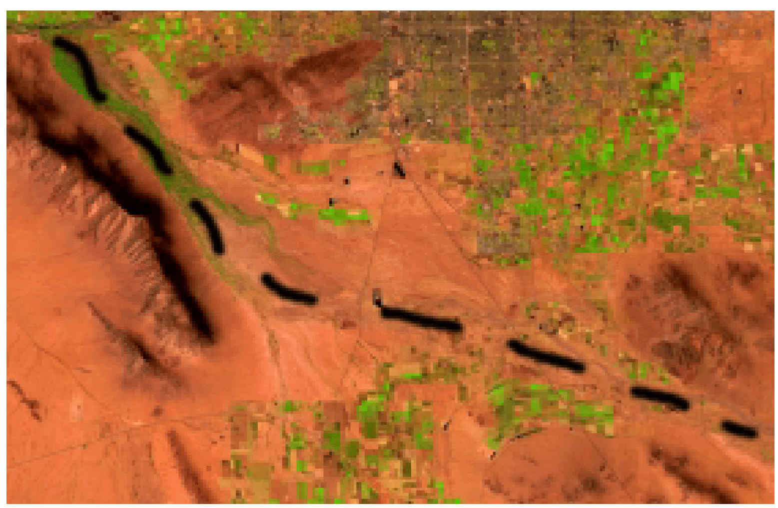

Figure 12: Before Coolidge Dam, the Gila River flowed all year round. Now, this NASA LANDSAT image shows the Gila to be dry (position shown by black dashed line).

Now that the Akimel O'odham will be getting water returned to the Gila, NASA imagery can be used to monitor changes. The green shows vegetation in irrigated farms, and the growing south edge of the Phoenix metropolitan area is at the top of the image.

Source: http://svs.gsfc.nasa.gov/imagewall/LandSat/

O'odham built water-diversion structures and then Coolidge Dam (Schroeder 1973). Figure 12 shows the effects of this diversion of snowmelt: a dry river most of the year in place of a formerly year-round (perennial) flowing stream—a dry condition that is once again set to change. The Akimel O'odham recently won a battle in court to have some of the Gila River's water returned. Future NASA imagery can be used to document the changes to the Akimel O'odham and their lands.

Part 6. How can you tell if there is enough snow?

Water managers need to know how much water is in the snow. They do this in different ways. Snow surveyors go into the mountains and measure the depth and water content of the snow (Figure 13). There are also automated stations to measure snow. But under the current system, people must visit sites, and there are hazards to travel in the backcountry (Figure 14). Thus, NASA scientists are also exploring ways to measure the amount of water in the snow with satellite sensors.

Snow hydrologists are using Spaceborne Imaging Radar-C and X-Synthetic Aperture Radar (SIR-C/X-SAR) data to determine water held in seasonal snowpacks. SIR-C/X-SAR is a powerful tool because it can measure most snow pack conditions (Figure 15).

Using satellites to measure snow is not yet as reliable as field measurements. But because field

Figure 13: Snow surveyor weighing snow to determine water content

Source: ftp://ftp.wcc.nrcs.usda.gov/images/survey02.jpg

Figure 14: Helicopter crashing—the downside of doing snow surveys in person, and a good reason to investigate safe remote-sensing alternatives

Source: ftp://ftp.wcc.nrcs.usda.gov/images/helicrsh.jpg

Module 1, Investigation 4: Briefing

Why is snow important in the southwest United States?

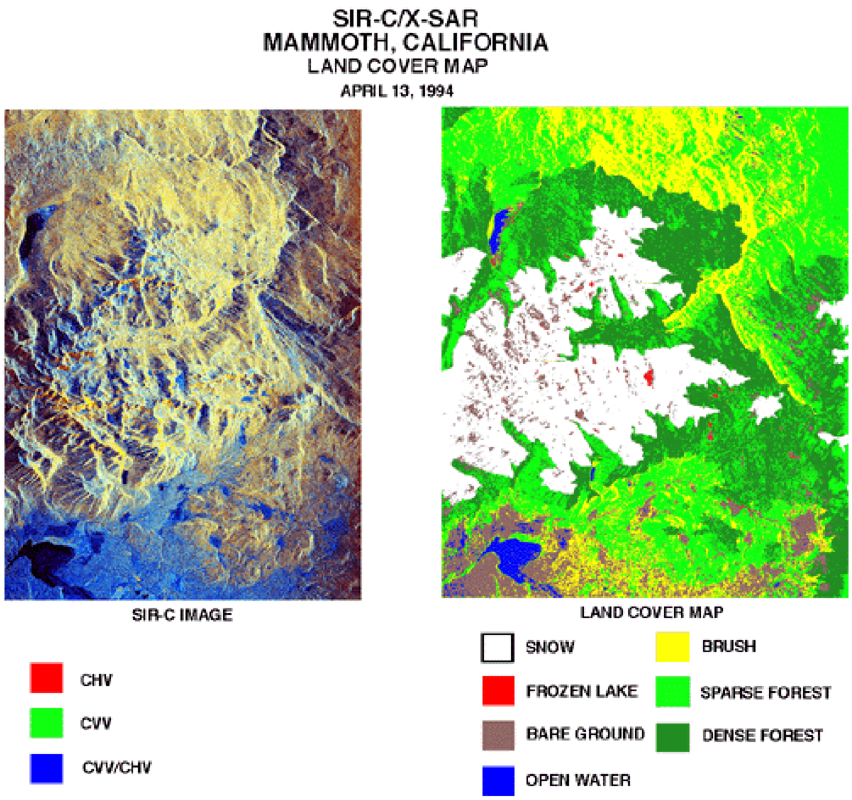

Figure 15: Radar is being used to study snow. The image on the left and the map on the right are of the Mammoth Mountain area in the Sierra Nevada Mountains, California.

The image is centered at 37.6˚ N 119.0˚ W. The 11.5 kilometers by 78.3 kilometers area is a part of the watershed of the city of Los Angeles. On the radar image, blue areas are lakes or slopes facing away from the radar illumination. Yellow represents areas of dry, old snow as well as slopes facing directly the radar illumination. The radar image on the left was acquired by the SIR-C/X-SAR aboard Space Shuttle *Endeavour* on its 40th orbit, April 11, 1994. The time of the overflight was towards the end of the snow season. Total snow depth was about 1 to 1.5 meters, only about 40 percent of the average.

Source: http://www.jpl.nasa.gov/radar/sircxsar/mammoth-land.html

work is dangerous and time consuming, the hope is that satellites will someday provide an accurate picture of water resources in snow—and not just in the United States.

Many developing countries depend on snowmelt for water and hydroelectric power; remote sensing of the snowpack would be a great help to planning. Water managers put their information on Internet sites. Thus, you can also learn if your local area is having a wet year or a dry year. Keep in mind that Internet sites change. Here are sites where you can find the depth of your snowpack or the amount of water in the reservoirs that water your city or town.

- Water supply outlook for the western United States, including mountain snowpack maps and reservoir storage graphics
  http://www.wcc.nrcs.usda.gov/water/quantity/westwide.html
- State basin reports for the current water year
  http://www.wcc.nrcs.usda.gov/water/quantity/st_report.html

For example, somebody living in Phoenix, Arizona, can find water storage along the Salt River at <http://www.wcc.nrcs.usda.gov/water/quantity/st_report.html>. In April 1999, a person in the Phoenix metropolitan area would have learned at that site that storage was below average conditions (Figure 16)—even before the major drought of the winter of 1999-2000.

You can also obtain an outlook for the water supply throughout the western United States at <http://uinta.cbrfc.noaa.gov/product/westwide/>.

Another important source to check out is the Colorado Basin River Forecast Center: <http://www.cbrfc.gov/> where you can obtain forecasts throughout this large watershed.

Answer Question 6 in the Log.

Module 1, Investigation 4: Briefing
Why is snow important in the southwest United States?

Part 7. Is water rationing in your future?

The average person in the United States uses 168 gallons of water a day. In future droughts, the chances are good that water will be rationed. Consider conditions in the state of California. By the year 2020, California's population is estimated to reach 48 million (http://rubicon.water.ca.gov/b16098/estxt/esch4.html) with 41 million living in cities (http://www.ruralhealth.cahwnet.gov/demographics/graphs.htm). If California experiences the type of drought that it did in 1987-1993 (when it received only three-fourths of its average amount of water), people living in cities might be forced to cut back to as little as 25 gallons per day per person. This is an extreme scenario, but it could happen under conditions of extreme drought. One thing is sure: The first indications of the need for rationing in the future will come from satellite monitoring devices. The quicker we are able to remotely sense the need for action, the better we can plan.

<u>Answer Question 7 in the Log.</u>

Part 8. Hearings of the Senate Subcommittee on Future Water Policy in the Southwestern United States

The seven members of the subcommittee should propose principles to guide allocation of water (1) among different uses and (2) among the southwestern states. They should also vote to determine proposed allocation of Colorado River water. <u>Your subcommittee's allocation proposal should be recorded on the table in the Log at Question 8.</u>

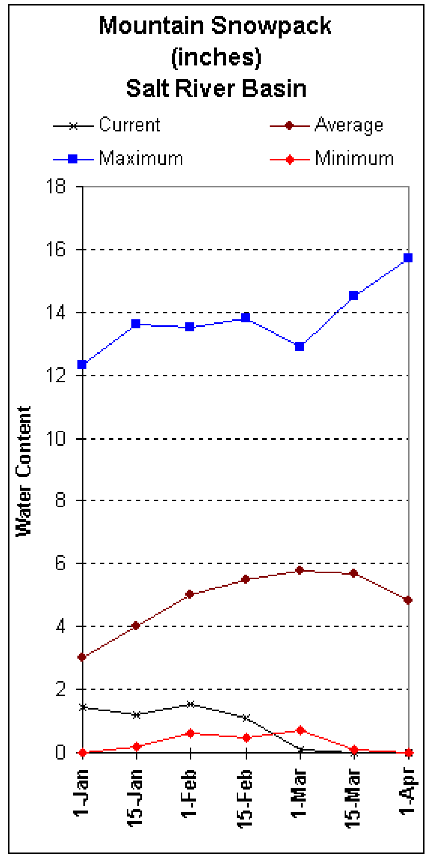

Figure 16: Salt River, Arizona, water levels as of April 1, 1999

Source: http://www.az.nrcs.usda.gov/snowsurv/wy99/apr1/az4s20.htm

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Module 1, Investigation 4: Log

Why is snow important in the southwest United States?

1. Give three reasons why snowmelt is important in the Southwest?

2. Complete the following table:

Water Supplies for Selected Southwestern Cities

City	Types and Locations of Water Sources
Las Vegas, Nevada	
Los Angeles, California	
Phoenix, Arizona	Snowmelt from the Mogollon Rim via Salt River Project provides 2/3 of supply; local groundwater supplies 3%; about 1/3 comes via Central Arizona Project, which taps Colorado River water.
Salt Lake City, Utah	Snowmelt from the Wasatch Mountains
San Francisco, California	
Tucson, Arizona	

3. How do droughts in the Southwest affect people and the physical environment? What do you think would happen if the Southwest experienced a drought lasting several decades?

Module 1, Investigation 4: Log

Why is snow important in the southwest United States?

4. Name the seven states through which Colorado River water flows. ____________________

5. Who are the major users of the Colorado River? Which states do you think *will* win the most in the fight for its water? Why? Which states do you think *should* win the most? Why?

6. Briefly summarize the current status of snowpack or other water resources in your home state *and* in the state that you represent as a U.S. senator and give your sources of information. You should use this information as a member of the Senate Subcommittee on Future Water Policy in the Southwestern United States.

7. Assume that you normally use the average amount of water used per person in the United States. And assume that a severe drought forces you to ration your personal water use to only 25 gallons per day. If that were all the water you had, how would you use it? List below your personal daily uses and amounts totalling 25 gallons.

Module 1, Investigation 4: Log
Why is snow important in the southwest United States?

8. Meeting as the Senate Subcommittee on Future Water Policy in the Southwestern United States, complete the table below and be prepared to defend your allocations.

Proposed Allocation of Colorado River Water, by States and Uses, in Million Acre-Feet (maf)

State	Urban		Agriculture		Environment		Other		TOTAL	
	maf	%	maf	%	maf	%	maf	%	maf	%
Arizona										100
California	.05	11	1.9	42	2.0	45	0.1	2	4.5	100
Colorado										100
Nevada										100
New Mexico										100
Utah										100
Wyoming										100
Mexico										100
TOTAL		—		—		—		—	10.0	100

Notes
- Urban uses include residences, industries, governments, and businesses.
- Environment is the runoff needed to maintain ecological systems.
- Other uses include recreation and energy production.
- Currently, 85 percent of all Colorado River water use is for agriculture.
- The total amount of water to be allocated in the table is 10.0 maf.
- Percentages total to 100 across, but not down.
- Amounts for California approximate current use and are shown as an example. If you wish to propose different allocations for California, write them in the same boxes below the current figures.
- Currently, Mexico receives no Colorado River water.