Educational Product	
Educators	Grades 9–12

The Potential Consequences of Climate Variability and Change

COASTAL AREAS

Coral Reefs In Hot Water

2001 APPROVED by NASA Earth Science Enterprise

AN ACTIVITY RESOURCE FOR TEACHERS

Responding to National Education Standards in:

- ***English Language Arts***
- ***Geography***
- ***Mathematics***
- ***Science***
- ***Social Studies***

This learning activity was developed to examine the potential impacts of climate variability and change. Each activity is part of an overall series entitled ***The Potential Consequences of Climate Variability and Change,*** which includes 1–12 teacher resources. Twelve modules (10 printed and 2 online resources) comprise the set and are presented below:

OVERVIEW

- Too Many Blankets (Grades 1–4)
- Global Balance (Grades 5–12)

AGRICULTURE

- El Niño (Grades 5–8)
  This activity is provided in an online format only and is available at *http://ois.unomaha.edu/casde/casde/lessons/Nino/teacherp.htm.*
- The Great American Desert? (Grades 9–12)
  This activity is provided in an online format only and is available at *http://ois.unomaha.edu/casde/casde/lessons/grass/teacherp.htm.*

COASTAL AREAS

- What Could a Hurricane Do to My Home? (Grades 5–8)
- What Is El Niño? (Grades 5–8, 9–12)
- Coral Reefs in Hot Water (Grades 9–12)

FORESTS

- A Sticky Situation (Grades 5–8)
- Planet Watch (Grades 9–12)

HUMAN HEALTH

- Beyond the Bite: Mosquitoes and Malaria (Grades 5–8, 9–12)
- Climate and Disease: A Critical Connection (Grades 9–12)

WATER

- Here, There, Everywhere (Grades 7–8, 9–12)

The development of the activities was sponsored by the National Aeronautics and Space Administration and the Environmental Protection Agency, in support of the US Global Change Research Program. The Institute for Global Environmental Strategies implemented the effort. For more information, see *http://www.strategies.org.* For additional resources, please visit *http://teach earth.com*—Resources for Teaching and Learning about Earth System Science.

Climate Variability & Change
COASTAL AREAS

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ACTIVITY
Coral Reefs In Hot Water

CONTENTS

Coral Reefs In Hot Water

This activity explores the potential impact of climate variability and change on one of nature's most wondrous, yet fragile, creations—coral reefs. Designed to tap specific skills and knowledge through scientific inquiry, the activity more generally seeks to stimulate thought about the long-term impacts of a warmer planet.

GRADE LEVELS

Grades 9–12

TIME REQUIRED

Eight to ten 45-minute class periods

OBJECTIVES

Through their participation in the activity that follows, students will:

- Describe characteristics of coral and coral reef ecosystems;
- Evaluate the importance of and threats to coral reefs;
- Describe the symbiotic nature of coral reef organisms;
- Determine the impact of environmental change on coral reef partnerships;
- Use Internet resources to examine data on the causes of coral bleaching events; and
- Analyze the impact of humans and other environmental effects on coral reef ecosystems.

DISCIPLINES ENCOMPASSED

- Biology
- Chemistry
- Earth Science
- Ecology
- Environmental Science
- Geography
- Language Arts
- Mathematics
- Social Studies
- Technology

PREREQUISITE KNOWLEDGE: TEACHER

- Living things depend on one another and on non-living aspects of the environment.
- Relatively short-term changes in the environment can have a serious impact on a species' survival.
- Coral reefs are home to an estimated 25 percent of all the ocean's species, including about 5,000 species of fishes and 1,000 species of reef-building corals. No place else on Earth, except possibly the rain forest, can match the coral reefs for their variety of creatures.
- Coral reefs are the creation of two principal architects: the coral polyp and zooxanthellae. The coral polyp is a small vase-shaped creature that takes calcium carbonate out of the sea water to build itself a stony, limestone house. Each polyp is connected to the surrounding polyps by a thin layer of living tissue. Long after the polyps die, their stone skeletons remain attached to the reef, and succeeding generations of corals grow on top of their "bones."
- The coral polyps couldn't build a reef without the help of their algae companions, the zooxanthellae. Zooxanthellae are single-celled plants (dinoflagellates) that live inside the thin layer of tissue connecting the coral polyps. Like all plants, zooxanthellae use the energy from the sun to grow. The food and oxygen produced by the plants during photosynthesis are used by the polyp to help it grow. (Scientists have found that coral polyps sometimes get more food from the zooxanthellae than from capturing plankton!) The zooxanthellae use the wastes of the polyp—carbon dioxide, phosphorus, and nitrogen—to help them grow. The zooxanthellae also help the coral remove calcium carbonate from the seawater to build its limestone skeleton.
- These algae also give the corals their distinctive colors; coral polyps don't have any color

of their own. The algae can make them appear pink, yellow, orange, purple, red, blue, or brown. If the algae left, you'd be able to see right through the coral's tissues to the white limestone skeleton underneath.

- Coral reefs grow best in warm, relatively shallow water, so they are found only in a wide band on either side of the Equator. However, if the water gets too warm, it can be a disaster for them. Divers have watched in dismay as whole reefs turned ghostly white in a matter of days. Scientists call this coral bleaching, a natural occurrence in which some or all of zooxanthellae leave. If ocean conditions return to normal, the zooxanthellae that stayed behind begin to grow again and the coral will recover. If not, the corals die.
- Although localized cases of coral bleaching had occurred before, beginning about 1980, scientists began to observe cases of "mass bleaching," where huge areas of coral reefs—sometimes thousands of miles across—suffered. Some of these areas were far from land, people, and obvious causes.
- Why does coral bleaching take place? That is the mystery that Thomas Goreau of the Global Coral Reef Alliance has been investigating for over 20 years. In many places, he has found that almost all of the corals are affected. Says Goreau, "When the coral loses the algae, it's not only lost its color and most of its food supply, it completely stops growing and reproducing. If the stress continues or gets worse, bleaching is just the first step toward dying."
- Why is this happening? To find out, Goreau matched field observations from scientists and sports divers with satellite data. He used infrared images (which measure the amount of heat emitted by the surface) taken by orbiting satellites that showed the heat radiating from the ocean's surface. Goreau could tell from these images where coral bleaching was taking place, because warmer water shows up darker on the satellite images.
- Goreau and fellow researchers have mapped bleaching events and climatic patterns around the world since 1983. As a result of this research, they have come up with a startling deduction: "Every mass bleaching follows a period of time when the temperature of the sea water increased as little as 1° C (≃2–3° F) above the average temperature for the warmest month of the year. If it gets to be warmer than what corals are used to for a month or longer, the corals bleach. If it gets to be 2° to 3° C (≃4–6° F) above normal, they die." Using this guideline and satellite information, Goreau has predicted every single bleaching event since 1990. "We're able to tell where it's happening, as it's happening, without even going to the field."
- Goreau strongly believes that coral bleaching is caused by worldwide climate changes. "The 1980s and 1990s have been the hottest decades on record since temperature measurements began 150 years ago. When we get just one degree Celsius above normal for one month, most of the corals will recover. If it is one and a half degrees, maybe half will die. When it's two to three degrees, they almost all die. We are seeing a number of species disappearing in some areas."
- At a meeting of 50 scientists in 1991, researchers agreed that coral bleaching was on the increase, but most blamed environmental stress, not global warming. However, they warned that a 3° to 4° C (≃5–8° F) rise in ocean temperature could seriously damage coral reefs.
- Coral reefs actually temper the greenhouse effect. As corals construct their calcium carbonate houses, they remove a significant amount of carbon dioxide from the water and, indirectly, from the atmosphere. By destroying living coral reefs, we may actually speed up the rate of climate change.
- Living coral reefs are found in shallow, sunlit water in a band about 3,000 miles wide around the Equator. Corals do best in warm, salty water rich in calcium carbonate, with sea surface temperatures ranging between about 25° to 29° C (75–85° F).

PREREQUISITE KNOWLEDGE: STUDENTS

Students must have the following skills and knowledge to complete this activity:

- Ability to read and interpret written data, maps, and data tables.
- Ability to organize information obtained in research.
- Ability to employ written data, graphs, tables, and maps in making arguments, drawing conclusions, and making predictions.
- Ability to use Internet browsers to do research for problem-solving.
- Ability to work collaboratively in groups.
- An understanding of photosynthesis.
- What coral reefs are and what their importance is in their environment.
- An understanding of what climate variability and change is, and its effects on the environment.

KEY TERMS AND CONCEPTS

The following terms and concepts will be presented in the following text and activities:

Calcareous
Coral bleaching
Coral reefs
Climate variability and change
Ecosystem
Exoskeleton
Greenhouse effect
Infrared
Photosynthesis
Plankton
Polyp
Symbiotic
Zooxanthellae

SUGGESTED READING/RESOURCES

■ *WEB PAGES*

General Information on Reefs and Their Threats

NOAA's Office of Public and Constituent Affairs
http://www.publicaffairs.noaa.gov/

Coral Reef Alliance
http://www.coral.org/Home.html

Reef Relief
http://www.reefrelief.org

Remote Sensing of Coral Reefs
http://seawifs.gsfc.nasa.gov/reefs/

The Canadian Institute of Oceanography
http://www.yrbe.edu.on.ca/~mdhs/compsci/dpt3ar/oceanog/tcoral.htm

Letsfindout.com
http://www.letsfindout.com/

National Aquarium in Baltimore
http://www.aqua.org/

University of the Virgin Islands
http://www.uvi.edu/pub-relations/uvi.htm

Coral Bleaching Information

1 Global Coral Reef Alliance
http://www.fas.harvard.edu/~goreau

NOAA Coral Reef Hot Spots
http://manati.wwb.noaa.gov/orad/sub/noaarsrc.html

NOAA Coral Health and Monitoring Program
http://www.coral.noaa.gov

Current 'Daily' SST Anomaly Charts
http://psbsgi1.nesdis.noaa.gov: 8080
Click on PSB, then EPS, then SEA SURFACE TEMPERATURE, and finally CURRENT SST ANOMALY and CORAL BLEACHING HOTSPOT CHARTS.

Global Climate Change Background Information

US Global Change Research Information Office
http://www.gcrio.org/index.html

Earthview
http://earthview.sdsu.edu/

Global Climate Change
http://www.climatechange.gc.ca/

Earth System Science Online
http://www.usra.edu/esse/essonline/

■ *PUBLICATIONS*

Bunkley-Williams, L. and E.H. Williams. "Global Assault on Coral Reefs," ***Natural History.*** April, 1990.

Wells, Sue and Nick Hanna. ***The Greenpeace Book of Coral Reefs.*** Sterling Publishing. New York, NY. 1985.

ACTIVITY

Coral Reefs In Hot Water

This activity will answer the questions: What is coral bleaching, what causes it, and how does it affect different environments?

MATERIALS

- 2 world maps
- Push pins
- Computers with Internet access
- Student activity sheets
- Different color highlighters
- Infrared satellite image of the Earth obtained from the CURRENT 'DAILY' SST ANOMALY CHARTS web page.

PROCEDURE

Step 1
Group students into teams of 2 or 3. Using the Internet, teams independently research information on coral reefs and answer Questions 1–7 on ***Student Activity Sheet 1: Coral Reefs.*** The list of sites given in the Resource section may be used as a guide, or students can conduct independent searches.

Step 2
Each group will research specific locations of coral reefs around the world. These regions can be assigned or chosen by the groups. When finished, they will take turns to mark, with a push pin, points on the world map where coral reefs are found. (Examples can be found at *http://www.reefrelief.org/library.html,* under the section ALL ABOUT CORAL REEFS, and at *http://www.cgiar.org/iclarm/reefbase/frameg/,* the REEF BASE HOME PAGE.)

Step 3
Discuss with the class some of the threats they found to coral reefs in their research. Pose the question "What is coral bleaching?" Give each group 10 minutes to come up with a possible definition and answer Question 8 on ***Student Activity Sheet 1: Coral Reefs.*** Discuss their answers, and then have them research coral bleaching on the Internet. Answer the rest of the questions on ***Student Activity Sheet 1: Coral Reefs.***

Step 4
Present the infrared satellite image of the Earth to illustrate where warmer waters occur. Ask students to verbally theorize what could cause changes in the ocean's water temperatures. (Their responses may include, for example, El Niño, climate variability and change, local weather patterns, rain or lack of rain, and runoff from wastewater treatment plants or nuclear power plants.)

Step 5
Discuss the work of Thomas Goreau and others on coral bleaching. Have groups look up information on specific regions and prepare presentations on how coral bleaching has or is affecting these regions. Use ***Student Activity Sheet 2: Coral Bleaching Presentation*** to guide them in their research. Use the map at the following site to help determine assigned locations: *http://www.reefrelief.org/library.html.*

Step 6
Each group will conduct a 5–10 minute presentation on their findings. They should prepare a 1 page review of their research, to hand out to the class.

Step 7
Have groups combine their findings to make a composite map of coral bleaching occurrences, using the second world map. Each group will use a highlighter to mark the areas they studied. Compare the two world maps and discuss the similarities and differences.

CONCLUSION

- Discuss with the students the importance of coral reefs.
- Ask the students to describe coral bleaching and what they think is the most predominant threat to coral reefs.
- Discuss climate variability and change and have the students describe its potential effects on coral reefs.

EXTENSIONS

1. **Side Effects of Warming Water.** Scientists fear that once corals are weakened, they are less able to resist natural threats from predators, storms, and disease. Ailing coral reefs show symptoms such as white blotches, black stripes, and yellow spots as they succumb to new strains of diseases with names of White Pox, Black Band, and White Plague. Says Goreau; "Diseases are becoming a major source of (coral reef) mortality in many places. We are not seeing them early enough to see where they come from or how they spread…We don't understand their causes nearly as well as we do other stresses."
   - Have students research other ecosystems or species that may suffer the secondary effect of disease as a result of environmental stresses (humans included).
2. **Coral Reefs and Carbon Dioxide.** At a recent scientific symposium on coral reefs and global change, scientists expressed concern that the calcification rates of corals (i.e., reef building) would be impacted by a decrease of carbon dioxide in the oceans due to climate variability and change. Carbon dioxide is used by corals, as well as by shell-building mollusks, in constructing their exoskeletons of calcium carbonate.
   - Have students research and discuss how water temperature, coral bleaching, and removal of carbon dioxide by reef-building organisms all impact the "steady state" of the ocean.
   - Have students research this problem by starting at the Web site summary of the 1998 workshop, CORAL REEFS AND GLOBAL CHANGE: ADAPTATION, ACCLIMATION OR EXTINCTION, *http://coral.aoml.noaa.gov/themes/coral_cg.html*. This Web site includes a list of symposium participants that students might use to further research this issue.
3. **Coral Reefs During the Ice Age.** During the Ice Age, coral reefs shrunk. This is in part due to cooler ocean temperatures, even in the tropics, but also because sea level was about 200 feet lower than it is today.
   - Have students research the distribution of coral reefs during the Ice Age and develop a presentation about how cooler and warmer climates may impact coral reef ecosystems.
4. **What Can You Do to Save Coral Reefs?** Some people are taking a proactive approach to restoring coral reefs. In the Maldives in the Indian Ocean, where pollution has inhibited reef formation, Goreau and his colleagues are working on a new technology to restore coral reefs. "We've developed a method called 'mineral accretion' that allows us to use electricity to speed up the growth of coral. We use small electric currents to precipitate minerals out of sea water," Goreau reports. Utilizing electricity generated by solar panels or turbines run by tidal currents, they are attempting to grow limestone rock structures on which young corals can settle and grow.

   Scientists are trying to set up a volunteer network of divers to relay information via the Internet about coral bleaching events. More and more scientists are depending on trained volunteers to collect data on ecosystems. Even people who live far from reefs can do things to help preserve them.
   - Have students check out the NOAA Coral Reef Web Page, 25 THINGS YOU CAN DO TO SAVE CORAL REEFS, *http://www.yoto98.noaa.gov/books/reefs/reef1.html*.
   - Discuss in class how this list can be expanded.

Student Activity Sheet 1: CORAL REEFS

Names

Answer the following questions in complete sentences, using your own words:

1. What is coral?

2. What are coral reefs?

3. How do coral reefs form? What are they formed from?

4. What type of environments are coral reefs found in?

5. Give at least 10 organisms that live in coral reefs.

6. Why are coral reefs important?

7. What are some threats to coral reefs?

8. What does your group think coral bleaching is?

9. What is coral bleaching? Be sure to include possible causes.

10. Was your definition correct? Why or why not?

11. Where does it occur?

Student Activity Sheet 2: CORAL BLEACHING PRESENTATION

Names

Location

Use the following as a guide for your presentation research. Be sure to include a list of ***all Web addresses used:***

- What caused coral bleaching in this area?
- When was coral bleaching first observed in this area?
- What is the frequency of coral bleaching events?
- Is the situation becoming more or less severe and what is the evidence?
- How would the infrared satellite image help researchers studying coral bleaching in this area?
- What can be done to prevent or lessen the effects of coral bleaching in this area?
- What are effects of climate variability and change on marine life?

Use these Web sites as a ***beginning:***

- *http://psbsgil.nesdis.noaa.gov.8080/PSB/EPS/SSt/climohot.html*
- *http://manati.wwb.noaa.gov/orad/al/hot_anual82_97.html*
- *http://www.fas.harvard.edu/~goreau/bleaching.html*

Appendix A
Bibliography

Cerullo, Mary. 1999. Ocean Detectives: ***Scientists Solving the Mysteries of the Sea.*** Turnstone Publishing. Boston, MA.

Goreau, Thomas. 1998. Global Coral Reef Alliance. Personal communication.

"Toward Sustainable Development," in ***World Resources: A Guide to the Global Environment.*** 1992–93. The World Resources Institute. P. 177–178.

http://www.reefrelief.org/library.html

http://www.letsfindout.com/subjects/undersea/reefmove.html

http://www.uvi.edu/coral.reefer/

Appendix B

Assessment Rubric & Answer Key

Student Activity Sheets: CORAL REEFS IN HOT WATER

Assessment Rubric

SKILL	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Demonstrates ability to access relevant information at appropriate Internet sites.	Able to access relevant information from appropriate Internet sites.	Accesses some relevant information from appropriate Internet sites.	Accesses very little relevant information at a few appropriate Internet sites.	Is not able to access relevant information at appropriate Internet sites.
Collects and organizes data.	Able to collect a lot of data that is well organized.	Able to collect some data with good organization.	Able to collect some data with poor organization.	Not able to collect and organize data.
Provides logical answers to questions.	All answers are logical.	Provides many answers, most are logical.	Provides few or illogical answers.	Not able to provide answers
Participates in class discussions/ presentations.	Frequently participates.	Participates sometimes.	Participates only with encouragement.	Does not participate.
Findings are presented and clearly represented during presentation.	Findings are presented and clearly represented.	Few findings are represented or are not clearly presented.	Few findings are represented and are not clearly presented.	Findings are not presented.
Infers links between coral bleaching and climate variability and change.	Able to infer many links.	Able to infer some links.	Able to infer links with guidance.	Not able to infer any links.

Answer Key Student Activity Sheet 1: CORAL REEFS

Students' answers should be in their own words and in complete sentences.

1. Corals are colonies of tiny animals, or polyps, that grow slowly upward and outward as a thin layer of living tissue. Coral skeletons are the framework of coral reefs.
2. Coral reefs are underwater mounds composed of fragments of coral, coral sands, and solid limestone that are found slightly below sea level. They are known to have diverse communities of marine plants and animals. Organisms, such as coralline algae, bind the components together, and can make up as much as half the coral reef.
3. Coral reefs form as thin layers of calcium carbonate skeletons, produced by coral polyps, are cemented together over thousands of years. Coralline algae cement the corals together with a calcium compound. Added to this are hard parts of other organisms, such as tubeworms and mollusks. Living polyps grow on top of the limestone remains of former colonies to create reefs. Only the surface layer of a coral reef is made up of living coral organisms.
4. Many coral reef organisms are very sensitive to change and therefore can tolerate only a narrow range of environmental conditions. Warm, clear tropical water, with an optimum temperature of 24° C (75° F) is their ideal environment. Due to ocean currents, necessary water temperatures are found along eastern continental coastlines. Warm equatorial currents travel along eastern coastlines, while cold polar waters are carried along the western coastlines of continents. Coral reefs require clear water in shallow environments so enough sunlight can penetrate to allow algal photosynthesis, which provides coral with necessary nutrients and oxygen. Because of these, they are not able to grow where there are too many suspended particles in the water or at a depth below 230 feet.
5. Coral reefs are home to one of the most diverse ecosystems in the world, containing more than a quarter of all known fish species. Answers could include, but should not be limited to: algae (red, brown and green), anemones, arthropods, basses, basslets, butterflyfish, cardinalfish, coal polyps, crabs, damselfish, dolphins, hard coral, lobsters, mollusks, pearlfish, rays, reef shark, shrimp, snails, soft coral, soldierfish, sponges, squirrelfish, sweepers, starfish, turtles, zooxanthellae.
6. Coral reefs are important for many reasons. Because of their natural beauty, coral reefs bring revenue to the local communities in the form of tourism, fishing, and recreation. Also, they provide food and shelter for many organisms. Barrier coral reefs act to protect shorelines against erosional and storm damage. Medically, coral reefs, and the organisms that live in them, provide compounds that are being used or studied for medicinal value.
7. Because many coral reef organisms can tolerate only a narrow range of environmental conditions, reefs are sensitive to damage from environmental changes. Corals are susceptible to diseases and bleaching. Also, dramatic natural events such as hurricanes can damage coral reefs. In addition, many problems to reefs are caused by humans, including overfishing, coastal development, pollution (polluted water discharge, garbage), anchor damage, accidental boat groundings, diver/snorkeler touching, standing and dragging equipment, boat propellers, siltation (coastal development and beach renourishment), overdevelopment, poor infrastructure, coral harvesting, destructive fishing/harvesting techniques, overharvesting, mining coral as a mineral supplement, poor land management, dumping of sewage, poaching, coral collecting, dredging for boat access, mill discharges, agricultural runoff.

8. Answers will vary.

9. Coral bleaching occurs when symbiotic algae are expelled from coral due to environmental stresses. This algae provides the coral with color, food, and most of their ability to grow skeletons. Scientists have found many possible causes of coral bleaching, such as changes in temperature, salt concentrations, light intensity and amount of suspended sediments. However, the primary cause is suspected to be elevations in sea surface temperature. Changes as little as 1° C have been determined to cause coral bleaching. If the stresses worsen, the corals can die, but if they lessen, most corals can recover.

10. Answers will vary.

11. Before the 1980s, coral bleaching was a small scale phenomenon. Since the 1980s it has become a large scale problem that effects all coral reef regions.

Answer Key Student Activity Sheet 2: CORAL BLEACHING PRESENTATION

Location _____

(Determined by the teacher)

Use listed Web addresses to check accuracy of information.

Appendix C

National Education Standards

This activity responds to the following National Education Standards:

STANDARDS FOR THE ENGLISH LANGUAGE ARTS

Standard 3: Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and of other texts, their word identification strategies, and their understanding of textual features (e.g., sound- letter correspondence, sentence structure, context, graphics).

Standard 4: Students adjust their use of spoken, written, and visual language (e.g., conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

Standard 5: Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences for a variety of purposes.

Standard 6: Students apply knowledge of language structure, language conventions (e.g., spelling and punctuation), media techniques, figurative language, and genre to create, critique, and discuss different print and nonprint texts.

Standard 7: Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and nonprint texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.

Standard 8: Students use a variety of technological and informational resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge.

Standard 12: Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

National Council of Teachers of English and International Reading Association. 1996. ***Standards for the English Language Arts*** *p. 24–46. Urbana, Illinois and Newark, Delaware: National Council of Teachers of English and International Reading Association.*

NATIONAL GEOGRAPHY STANDARDS GEOGRAPHY FOR LIFE (9–12)

Geography 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.

Geography Standard 7: *Physical Systems.* The physical processes that shape the patterns of Earth's surface.

Geography Standard 8: *Physical Systems.* The characteristics and spatial distribution of ecosystems on Earth's surface.

Geography Standard 15: *Environment and Society.* How physical systems affect human systems.

American Geographical Society, Association of American Geographers, National Council for Geographic Education, and National Geographic Society. 1994. ***Geography for Life: National Geography Standards*** *p. 183–222. Washington, DC: National Geographic Research and Exploration.*

CURRICULUM AND EVALUATION STANDARDS FOR SCHOOL MATHEMATICS (9–12)

Standard 1: Mathematics as problem solving.

Standard 3: Mathematics as reasoning.

Standard 4: Mathematical connections.

National Council of Teachers of Mathematics. 1989. ***Curriculum and Evaluation Standards for School Mathematics*** *p. 123–186. Reston, VA: The National Council of Teachers of Mathematics, Inc.*

NATIONAL SCIENCE EDUCATION STANDARDS (9–12)

CONTENT STANDARD: K–12

Unifying Concepts and Processes

Standard: As a result of activities in grades K–12, all students should develop understanding and abilities aligned with the following concepts and processes:

- Systems, orders, and organization
- Evidence, models, and explanation
- Constancy, change, and measurement

National Research Council. 1996. ***National Science Education Standards*** *p. 115–119. Washington, DC: National Academy Press.*

CONTENT STANDARDS: 9–12

Science as Inquiry

Content Standard A: As a result of activities in grades 9–12, all students should develop:

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Life Science

Content Standard C: As a result of activities in grades 9–12, all students should develop an understanding of:

- Interdependence of organisms
- Behavior of organisms

Science and Technology

Content Standard E: As a result of activities in grades 9–12, all students should develop:

- Understandings about science and technology

Science in Personal and Social Perspectives

Content Standard F: As a result of activities in grades 9–12, all students should develop an understanding of:

- Natural resources
- Environmental quality

National Research Council. 1996. ***National Science Education Standards*** *p. 173–204. Washington, DC: National Academy Press.*

CURRICULUM STANDARDS FOR SOCIAL STUDIES

Strand 3: *People, Places, & Environments.* Social studies programs should include experiences that provide for the study of people, places, and environments.

Strand 8: *Science, Technology, & Society.* Social studies programs should include experiences that provide for the study of relationships among science, technology, and society.

Strand 9: *Global Connections.* Social studies programs should include experiences that provide for the study of global connections and interdependence.

National Council for the Social Studies. 1994. ***Expectations of Excellence: Curriculum Standards for the Social Studies*** *p. 21–30. Washington, DC: National Council for the Social Studies.*

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STRATEGIES

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