Teaching Guide

U.S. Department of the Interior
U.S. Geological Survey

Introduction

Land and People: Finding a Balance is an environmental study project that engages high school students in studying earth science resource issues. The project focuses on the interaction between people and the environment in three regions of the United States: Cape Cod, Los Angeles, and the Everglades. Each section of this project is devoted to one of the three regions.

Contents of This Packet

- Teaching Guide
- Poster
- Cape Cod section
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- Los Angeles section

How to Use This Packet

The Teaching Guide provides an overview of the project as well as a list of references for teachers, by region. The references cited in this list were used as background information for the sections of the Packet.

The poster presents a variety of visual images from each region with explanatory text about each one. Use the poster to begin a general discussion about human impact on the environment as well as to discuss the specific consequences of human actions in each region.

Each section contains a set of student materials and a set of teacher materials for either Cape Cod, the Everglades, or Los Angeles. Each section is divided into two parts: “For the Student” and “For the Teacher.” The student materials present students with a Focus Question to answer and also provide them with several types of information they should use to answer the question. Student materials include some or all of the following:

- a reading about the region
- a description of the “Interested Parties” so students can role-play as they answer the Focus Question
- maps
- population data
- geologic information
- water use data
- photographs

The teacher materials include a brief explanation of what students will learn as they work on answering the Focus Question and a description of what form their answer might take. The teacher materials also present three Activities that will help students answer the Focus Question. Each Activity clearly describes what students will need to complete the Activity, explains the procedure, and in some cases, suggests extension activities. Any maps or other information students will use to complete the Activities are included in the teacher materials.

The sections can be studied in any order. A class could complete all three sections or just one. The sections can be used in whole or in part. Students might read the entire set of student materials for a region then complete all the Activities in the teacher materials, or just complete selected Activities.

Each student will need a copy of the student materials. These materials are designed to be photocopied clearly and easily. Students will also need copies of the maps and other data that accompany the Activities in the teacher materials.

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Land and people : Finding a Balance

Cape Cod

U.S. Department of the Interior
U.S. Geological Survey

Finding a Balance **is an environmental study project that allows you and a group of your classmates to consider real environmental dilemmas concerning water use and to provide solutions to these dilemmas. The student packet gives you most of the information you'll need to answer the Focus Question, information like maps, data, background, a reading about the region, and a description of the "Interested Parties," or the various interest groups that have a stake in the outcome of the Focus Question. While you are working on this project, each member of your group will take a role or become one of the interested parties. Your teacher will guide you through a series of discussions, activities, calculations, and labs. At the end of this project, your group will be asked to present and justify a solution to the environmental dilemma.**

The following excerpt from a book published by the Association for the Preservation of Cape Cod, an environmental group, explains the problem from the viewpoint of the people who live and work around the contaminated area.

Reading

From *The Enemy Within: The Struggle to Clean Up Cape Cod's Military Superfund Site* by Seth Rolbein. *Chapter 1: A Watershed Place, A Watershed Moment, 1995.*

"July 7, 1994. The dignitaries were seated under a blazing sun, the flat, broad landscape of the Massachusetts Military Reservation [MMR] broken by a small building behind them. Inside that building was the only respite from the heat, because huge tanks holding underground water stood in the shade, acting as air conditioners.

That wasn't why they were there, of course, to serve as multi-million-dollar air conditioners. Their purpose was something else entirely:

The water is being pumped out of the ground and held in these tanks so it can be treated. This water bears telltale remnants of pollution dumped decades ago. This water must now be filtered to remove poisons left from the past.

It was a fitting place to hold this ceremony, between hot sun and cool groundwater, beside the first small treatment plant on the giant base. The chairs and tables where politicians and military brass sat side by side, where community activists, newspaper reporters and television cameramen focused their attention, were all directly above one of many so-called "plumes" buried deep underground, a spreading pool of contamination no longer ignored or denied, one of many invisible catastrophes which have caused so much concern for thousands of people who live and work around Camp Edwards and Otis Air National Guard Base. This was the appropriate place because after more than a decade of study, argument, delay and frustration, Cape Cod was about to hear a promise: the federal government will spend hundreds of millions of dollars to try to stop these plumes from reaching even farther into the neighborhoods of Falmouth, Bourne, Mashpee, and Sandwich...

...Some of the people who have dedicated years to this effort, spent countless hours in meetings, labored over thousands of pages of documents, done everything from digging wells to lobbying officials to getting arrested, were sitting in the hot sun that July day... many of them seem to have vivid memories of their first steps down this long road, when they first realized that something was wrong at Cape Cod's military base:

Dr. Joel Feigenbaum, a mathematics professor at Cape Cod Community College, says that moment came in the early 1980s as he watched smoke and debris from a huge fire blowing over Sandwich, a fire caused by artillery shells exploding on a dry, windy day. He stood with a hose in his hand, protecting his house from sparks. He wondered why this was happening, and what else was going on inside the borders of the base...

For Bob Kreykenbohm, manager of the Sandwich Water District, the moment came later, in 1990. Water pumped from deep underground, below what looked like a pristine forest, foamed as it came to the surface. There was enough fuel coming out of the pipe to make a lit match flame. It didn't take long for him to suspect that the only thing that could have caused something so big, so disastrous, was the old pipeline that carried fuel through his town, from Cape Cod Canal to the base...

...For Ralph Marks, who now runs the Bourne Water District, the moment came as he pulled the plug and stopped Falmouth's public supply well from pumping water in the late 1970s. Even back then, he figured he knew where the contamination was coming from. It was coming from the same place where he had been serving his National Guard duty...

...For Denis LeBlanc [a hydrologist with the U.S. Geological Survey], who studies geology and underground water movement, the moment came more than 15 years ago, when he sank a test well into the sandy soil on the southern side of the base. As it turned out, he had put his first dart into the bulls eye: thousands of test wells and samples later, the Ashumet Valley plume would become studied, analyzed, and charted with more detail than virtually any other plume in the country...

...And so Cape Cod finds itself in the vanguard of what will be one of the most important environmental issues to face this country as we move into the next century..."

Focus Question

Cape Cod has a serious problem with its ground water. During the past six decades, activities of the Massachusetts Military Reservation (MMR) — formerly known as Camp Edwards, then Otis Air Force Base — on the Upper Cape have resulted in contamination of billions of gallons of underground water. (The Upper Cape is the western part of Cape Cod, including the following towns: Bourne, Sandwich, Barnstable, Mashpee, and Falmouth.)

You and your group are members of a blue-ribbon panel that has been formed to present a plan for providing safe, drinkable water to the Upper Cape for the next 10 years. You know of the contamination problem of the underground water supply. You also know how many Cape Cod residents will require water; your panel has been given data that describe the predicted increase in the region's population. Now, you and the members of your panel must figure out how the Upper Cape will meet its need for safe ground water in spite of the vulnerability of its water supply to contamination.

The Interested Parties

Many groups and individuals are affected by water-quality issues on Cape Cod and are interested in the answer to the Focus Question. As your group works to answer the Focus Question, each person will take one of the following roles:

The Military

Military officials, including the Air Force, Army, and National Guard, are responsible for the cleanup of ground water contaminated by activities at the base and for prevention of additional ground-water pollution. The U.S. Environmental Protection Agency classified the MMR as a Superfund site in 1989. When a military site is classified as a Superfund site, the Department of Defense MUST carry out the cleanup under the oversight of the U.S. Environmental Protection Agency. However, ground-water cleanup is expensive and difficult. The Department of Defense must remedy the problem, but responsibility for the cleanup is complicated because the base has changed hands and functions several times in the last generation.

Regulatory Agencies

Regulatory officials from the U.S. Environmental Agency and the Massachusetts Department of Environmental Protection who oversee the cleanup want to restore and protect water quality in the aquifer. As "public servants," they must balance the difficult task of cleanup and associated costs with the public demand for action. They are working closely with the Department of Defense to find a solution that is quick, effective, and affordable.

Municipal Water Managers

Officials responsible for providing town residents with a clean, safe supply of water want to do all they can to protect the Cape Cod aquifer. And if a town's water supply becomes contaminated by ground-water plumes, water supply officials want action to restore the lost supply. In fact, when underground contamination closed supply wells in Mashpee and Falmouth, the military base paid most of the costs of building new public water systems.

Cancer Victims' Rights Group

As a member of the Cape Cod chapter of the Massachusetts Breast Cancer Coalition, you are concerned about how contaminated ground water might be affecting cancer rates on the Upper Cape. Between 1982 and 1988 the incidence of cancer was 22 percent greater in the five towns that make up the Upper Cape than in the rest of the state. You want to know — is polluted ground water causing cancer?

Environmentalists

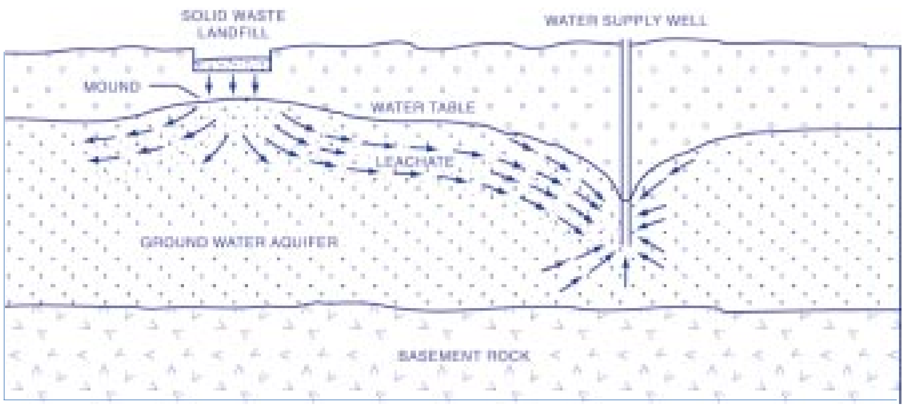
Environmentalists celebrate Cape Cod's unique geology, protected seashores, native plants, and crystal ponds. Generations of naturalists, including Henry David Thoreau, have celebrated Cape Cod's beauty. People have protected the Cape's dunes, grasses, and coastline for many years. Now they need to turn their attention to protecting an important unseen player in the environmental balance — the Cape Cod aquifer.

Homeowners

Residents on the Upper Cape are afraid. They worry that the water they drink and bathe in is unsafe. They worry about getting cancer. They worry that the value of their property will plummet if the ground-water problems are not fixed. If the contaminated ground-water plumes aren't stopped, will the tourists stop coming? How would Cape Cod survive without tourist dollars?

Cape Cod's Unique, "Absorbent" Geology

Cape Cod, a sandy peninsula formed mostly during the Ice Age, sticks out into the Atlantic, looking from above like a bodybuilder's flexed arm. Cape Cod is particularly interesting, geologically speaking, because it was formed by glaciers very recently in terms of geologic time. The geologic history of Cape Cod mostly involves the last advance and retreat of glacial ice in southern New England and the rise in sea level that followed the melting of the ice. These events occurred within the



How leachate from a solid waste disposal site contaminates a well. From the *Environmental Impact of Ground Water Use on Cape Cod.* (Strahler, 1972).

last 25,000 years. Sometime between 18,000 and 23,000 years ago, the Wisconsin ice sheet (large glacier that completely covers the terrain) that had been moving southeast across all of New England reached its maximum advance. About 18,000 years ago, the glacial ice started to recede rapidly northward by melting; within about 4,000 years, the ice sheet front had retreated to just north of Boston.

As it retreated, the glacier deposited rock debris, called drift. On Cape Cod, drift overlies a surface of much older rock. This older rock is buried by drift 200-600 feet thick. Most of the drift on Cape Cod has been fashioned into either moraines or outwash plains. Both features mark the various positions of the front of the glacier as it moved. Moraines are ridges of rock debris formed by moving ice. In a moraine, rock fragments carried by the ice are piled up along the ice front. Moraines may also form when the ice front advances and bulldozes the sand and gravel of an outwash plain into a ridge. The moraines on Cape Cod were formed by a combination of these processes. Outwash plains make up most of the landscape of Cape Cod. They were built by meltwater streams flowing from the glacier margin that deposited sand and gravel to form a broad, flat, porous plain.

Cape Cod's landscape is defined by the glacier's deposition of loose material. These porous, sandy soils are highly absorbent. Such soils have a profound effect on the quality of underground water. Sandy soils make the underground water supply vulnerable to contamination — toxic substances on the surface can travel through the soil quickly and can move great distances underground.

Where Do Cape Codders Get Their Water?

Cape Cod has what is called a sole-source aquifer. An aquifer is an underground rock or sand body that permits water to move through with ease. This ground water is the only source of drinking water for residents of western Cape Cod. Aquifers are classified as confined or unconfined. Confined aquifers are overlain by materials that have low permeability and receive little or no direct recharge from rainfall. The movement of water into and out of confined aquifers is slow. Unconfined aquifers are exposed to the atmosphere and are continually recharged by the percolation of rainfall, snowmelt, or water from streams or rivers. Recharge rates vary with the seasons and from year to year. Under natural conditions, discharge, or water flowing out of the aquifer, is balanced by recharge.

The unconfined Cape Cod aquifer is segmented into six sections called lenses. The upper limit of the lenses, or the water table, has about the same shape as the land above. The largest lens is on the Upper Cape. The highest point of this lens is right under the MMR. Ground water flows perpendicular to the contours of the water table, much like rainwater would flow down hillsides above ground. It moves at the rate of about a foot a day until it reaches the sea.

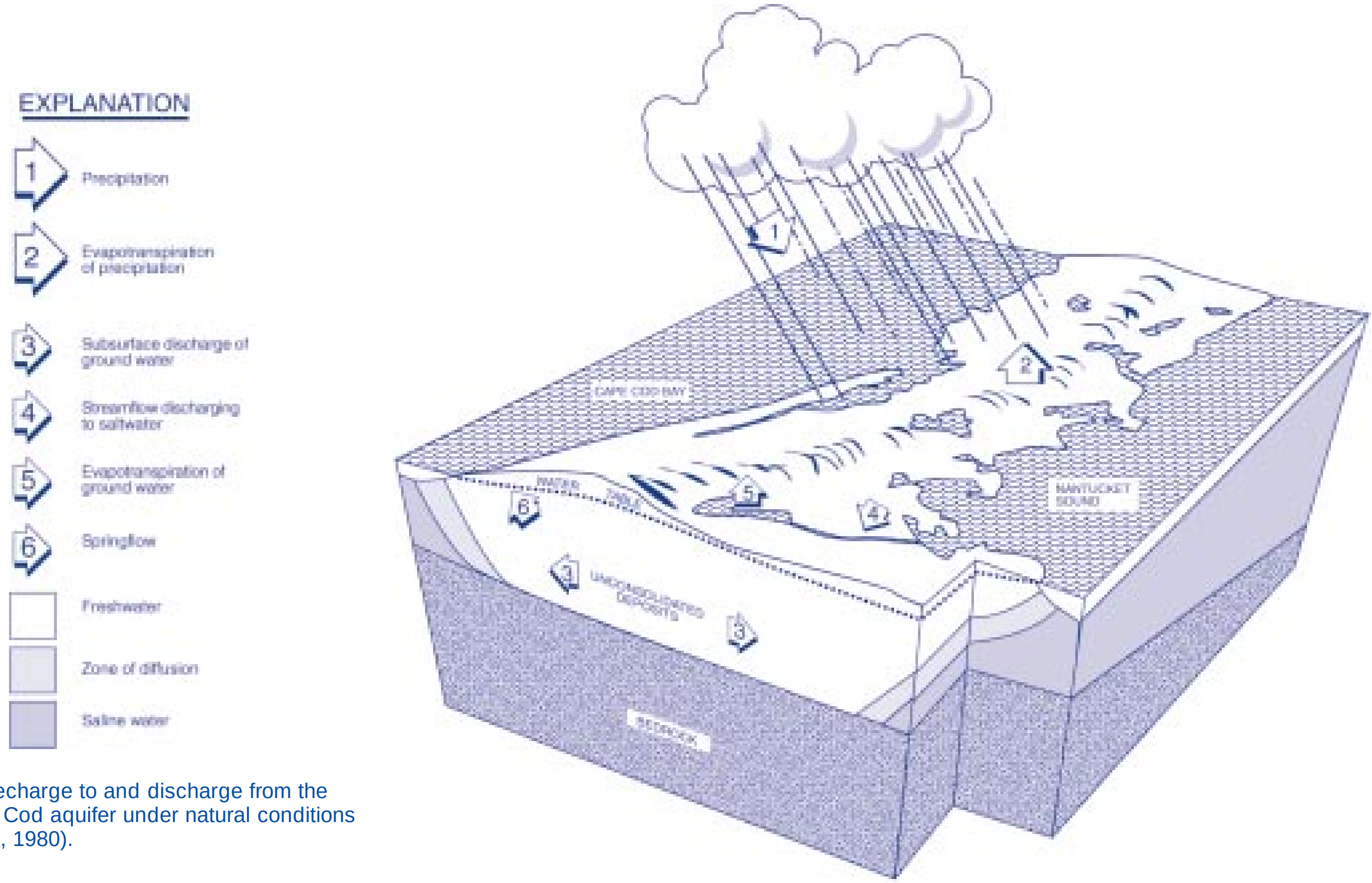
Cape Codders get their drinking water from the aquifer. Public water supply systems bring drinking water to about 70 percent of the population of the MMR and the towns of Bourne, Sandwich, Mashpee, and Falmouth. The other 30 percent of the population use domestic wells to supply their drinking water. The total average daily water demand on western Cape Cod is about 6.4 million gallons per day. This figure was calculated on an average of the amounts of water used during the vacation season and during the off season. During the summer season, water demand rises to 10.1 million gallons per day; during the off season, demand is at 5.2 million gallons per day.

Here's a paradox — ground water is the primary drinking supply for the Cape, but it is also the primary disposal area for wastewater generated by the population of the Cape.

Porosity, Permeability, and Ground Water

To discuss water-supply issues, you must understand how ground water moves through or is contained by rock underground. Ground water is stored in small cracks and voids in soil and bedrock. Porosity is the proportion of a volume of rock or soil that consists of open spaces. Igneous and metamorphic rocks, such as granite and schist, have low porosities unless they are fractured. However, many sedimentary rocks can be quite porous. Loose sediments, such as Cape Cod's glacial deposits, can be highly porous: 40 percent in sand, and even 90 percent in clay.

Porosity tells us how much water rock or soil can retain. Permeability is a measure of how easily water can travel through porous soil or bedrock. Soil and loose sediments, such as sand



The recharge to and discharge from the Cape Cod aquifer under natural conditions (Ryan, 1980).

and gravel, are porous and permeable. They can hold a lot of water, and it flows easily through them. Although clay and shale are porous and can hold a lot of water, the pores in these fine-grained materials are so small that water flows very slowly through them. Clay has a low permeability.

Remember these water-holding and water-moving characteristics when you do Activity 1 — A Model Aquifer.

The Massachusetts Military Reservation – An Environmental Dilemma

The story of the Cape Cod aquifer in the 20th century is the story of a plot of land now identified as the Massachusetts Military Reservation (MMR). The MMR on western Cape Cod covers an area of about 34 square miles. It includes parts of the towns of Bourne, Sandwich, Mashpee, and Falmouth. The present MMR area has been in existence since 1912. Over the years, it has been occupied by many tenants and been called by many names. In the 1940's, it was Camp Edwards. From 1948 until 1973, it was Otis Air Force Base. Since 1973, the MMR has been used primarily by the Massachusetts National Guard and the U.S. Coast Guard.

During the late 1970's and early 1980's, Upper Cape residents began to discover how the long history of the MMR had affected the land it occupied and the area around it. They discovered that activities at the MMR have contaminated the ground water. Over the years, those using the MMR have dumped or disposed of many toxic substances, including jet fuel, solvents, and industrial chemicals. Most of these substances were disposed of during the last 50 years and have been percolating down through the Cape's sandy soil ever since. These chemicals dissolved into and moved with the ground water; contaminant plumes formed, much like the plumes coming from smokestacks.

One of the earliest casualties of the contaminant plume from the reservation was a public water-supply well in Falmouth.This large well was pumped strongly enough to draw a plume of treated sewage from the base into its intake pipe, while individual household wells continued to tap the clean water above the plume.The town of Falmouth lost 25 percent of its water supply when the sell was shut down in 1975.

After much alarm and much civic action, a report on the extent of the contamination on the MMR was published in 1986. The report listed many areas with many problems and used abbreviations to describe them:

- SD sites were storm drainage ditches that caught the contaminated runoff, which then seeped into the ground water.
- LF stood for landfills that had been used for disposing of everything from household waste to explosives to entire trucks.
- CS meant chemical spill — including fuels, battery acid, and unburned gunpowder.
- FS sites were fuel spills, such as the runways where planes tested their fuel-dump valves.

- FTA's were fire training areas, which are large, squared-off patches of ground where fuels and other chemicals were spilled and then burned to give firefighters practice in extinguishing fires.

Each of the kinds of sites listed above has contributed to the spread of plumes of underground contamination. Almost a decade of study has led to the documentation of 11 major contaminant plumes that move off the base. These plumes threaten ponds, beaches, individual wells, and town water supplies alike. The plumes are large and have traveled far because the sandy soil allows the ground water to move quickly. Although parts of the plumes are very dilute, with small "hot spots" that contain high levels of contaminants, large volumes of water can be rendered unfit for drinking and sensitive ecosystems can be harmed by contact with small amounts of the industrial solvents and other organic chemicals contained in the plumes. The plumes are now well documented, but many problems remain to be resolved: demand for water continues to increase, and plumes move more than a foot a day and contaminate additional acres of aquifer each day. Other unknown contamination sites may exist, waiting to be discovered. New methods are needed to clean up the plumes in accordance with stringent water-quality standards.

In 1996, the U.S. Air Force Center for Environmental Excellence (AFCEE) assumed responsibility for cleanup of ground water at the MMR. By late 1996, dozens of pumping wells were being drilled to stop the advance of the plumes, the base landfill had been capped to stop leachate from reaching the ground water, and contaminated soils at several sources had been treated to remove solvents and fuels. A long-term plan is being developed by AFCEE, the U.S. Environmental Protection Agency, and the Massachusetts Department of Environmental Protection to clean up the plumes and to provide safe drinking water to the base and surrounding communities. Additional information about the plan can be obtained from the Installation Restoration Program (IRP).

The Facts About Septic Tanks, and Other Threats to the Cape's Ground–Water Quality

Another cause of ground-water contamination on the Upper Cape is effluent, or outflow, from septic tanks and cesspools. A majority of the homes on the Cape have septic systems.

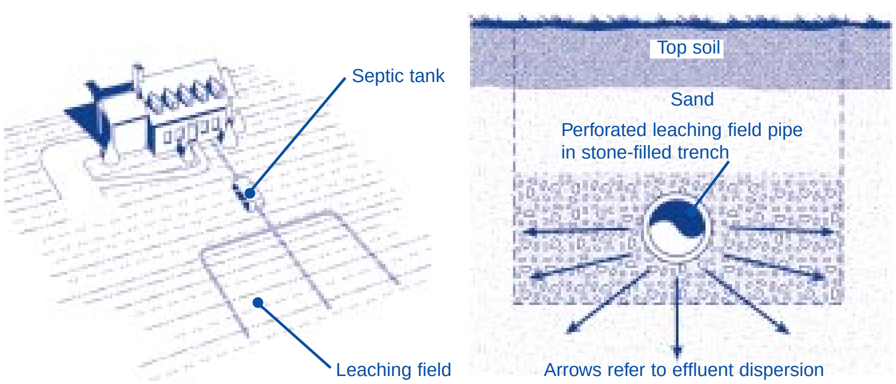
During the operation of a septic system, domestic sewage is flushed into a large underground tank. The solids settle to the bottom of the tank and accumulated septage is pumped out every 2 years or so. The effluent flows out of the tank and into a series of underground trenches filled with gravel. The effluent trickles through the gravel into the soil where the organic matter decomposes.

For purification to work, however, effluent must move slowly through aerated soil or rock. That way, organisms can feed on the sewage and make it harmless before it moves very far. If the polluted water moves through the soil or rock too quickly, the organisms cannot decompose it, and the polluted water can contaminate the aquifer underneath. Geologic conditions on the Cape — the sandy, permeable soil and unconfined aquifer — make the ground water highly susceptible to septic-tank effluent contamination. The Cape's sand filters bacterial contamination well, but it allows other household toxins, such as paint thinner, to move straight through to the aquifer from which the drinking water supply is drawn.

In addition to septic tank systems, other sources of ground-water contamination in Cape Cod include wastewater treatment facilities; landfills; underground tank storage of fuel oil and home-heating oil in addition to gasoline; pesticide, herbicide, and fertilizer application in agricultural areas as well as salt application in residential areas; deicing salt-storage areas and salt application on highways; waste from industrial parks, leaking sewer lines, and so forth. Information on additional sources of ground-water contamination in Cape Cod is described by Frimpton and Horsley (1993).

Ground-Water Cleanup – No Easy Task

Restoring ground water is not easy, it's not cheap, and it's not always effective. The two most common approaches are containment and extraction. Containment keeps the polluted water away from the rest of the aquifer. If the residents of the Upper Cape want to contain their polluted water, they could have under-



A septic tank holds solid waste and releases wastewater into a leaching field that contains stone-filled trenches. On Cape Cod, septic tank wastewater frequently percolates to the aquifer below.

ground retaining walls built or have the water's natural flow direction altered by pumps. The downside of containment? It doesn't do anything to purify the water — it just keeps the contaminated water from moving into the rest of the aquifer. Extraction involves getting the water out of the ground, cleaning it by aeration and filtration, and then returning it to the aquifer. The downside of extraction — it requires a long time, even decades. A final option is to do nothing — just let the contamination flow into the ocean. The downside? You decide.

The USGS's Toxic Substances Hydrology Program, or "How We Learned About the Ashumet Valley Sewage Plume"

Government and university scientists are using the sewage plume created by the MMR sewage treatment plant on Cape Cod as a field laboratory. They are studying how toxic chemicals move in ground water. For 50 years, treated sewage disposed on the reservation has leached into the sand and gravel aquifer below. To figure out how and where this sewage affects the quality of the ground water, scientists have drilled a "well field" or set of narrow wells. These wells enable them to pump ground-water samples for examination.

To study the Ashumet Valley plume, the USGS scientists have dug more than 300 sampling wells. They began the study after State and Federal officials became concerned that sewage disposal was contaminating shallow aquifers. At one of their first test wells, dug in 1979, 10,000 feet away from the sewage treatment plant, water foamed when it came out of the ground. The USGS scientists knew they had discovered a problem.

To decide where to place the sampling wells, they had to hypothesize about what chemicals in the treated sewage would move in the aquifer and where the contaminated ground water would move. Then, using topographic and water table contour maps to guide them, they dug wells downgradient — along the downward slope of the water table — below the suspected source of contamination. To gather information about the shape, content, and movement of the plume, they kept digging groups of

Tying theory to reality: the USGS uses experimental wells in the area of the Ashumet Valley sewage plume, (Photo by D. LeBlanc, USGS, 1985).

Source of water samples taken in 1979	Chemical Concentration: Chloride (milligrams/liter)	Boron (micrograms/liter)	Nitrogen (milligrams/liter)
Treated sewage released at the MMR	33	510	19
Contaminated ground water 3,000 feet from the sewage disposal site	28	280	16
Uncontaminated ground water in the area	8	7	0.4

This table shows the levels of ground-water contamination caused by sewage. Soils may be able to trap some contaminants, but they cannot turn sewage into pristine ground water.

Year-Round Population, 1980-2010, by Community*

	Federal Census Year-Round Population		Projected Population		
Community	**1980**	**1990**	**1994 (est.)**	**2000**	**2010**
Barnstable	30,698	40,949	42,579	46,417	51,684
Bourne	13,874	16,064	16,646	17,891	19,061
Falmouth	23,640	27,960	28,949	30,157	31,701
Mashpee	3,700	7,884	9,540	10,945	14,088
Sandwich	8,727	15,489	17,755	19,587	23,720
TOTAL	80,639	108,346	115,469	124,997	140,254

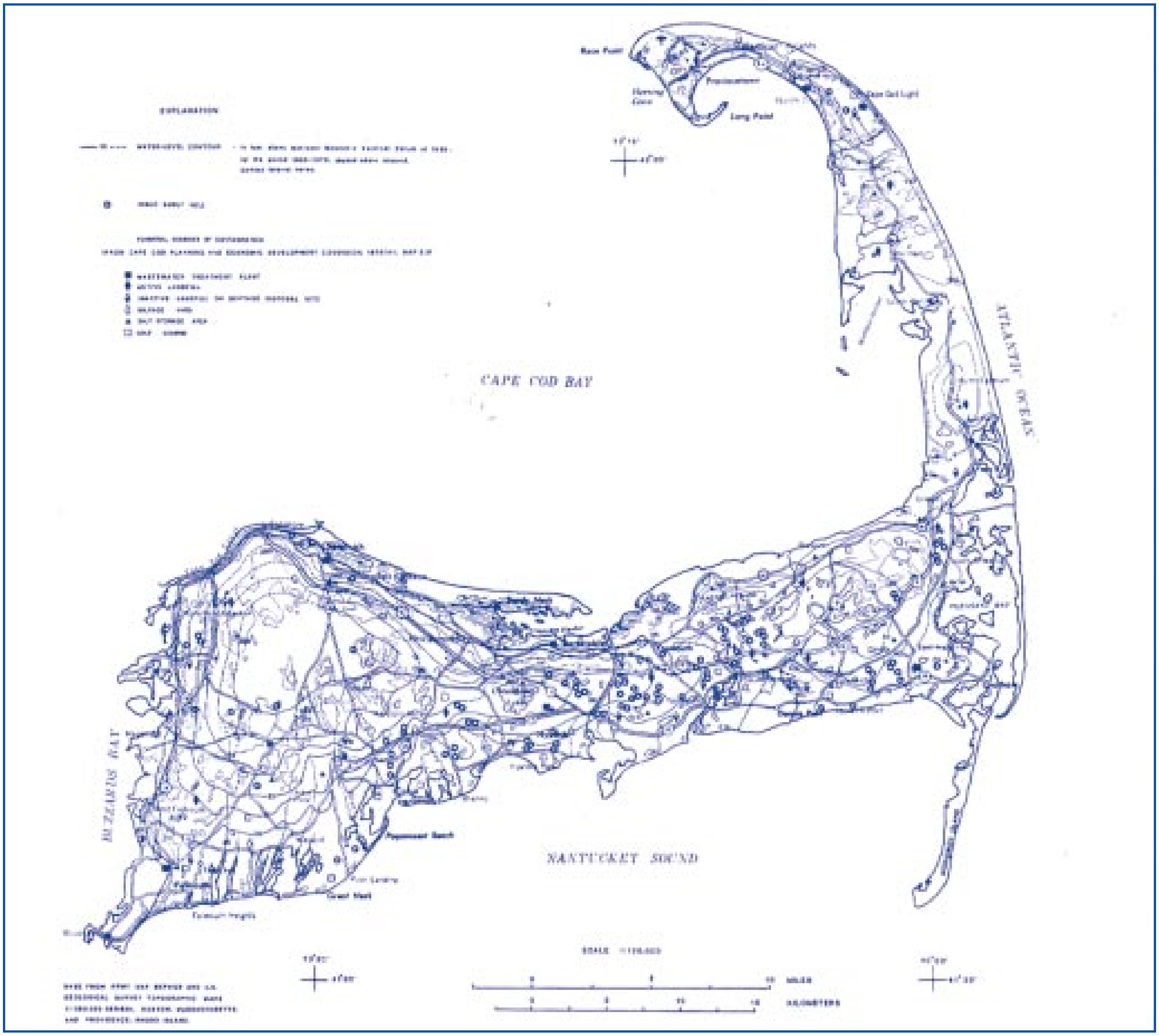
* From Cape Cod Commission, Barnstable County Population 1980-2010.

Use these data to help you answer the Focus Question. By what percentage is the total population of the Upper Cape likely to increase during the next decade? Where will the population jumps be the largest? How are the areas with the fastest growing demand for clean water affected by the ground-water contaminant plumes?

Community	1990 Federal Census Year-Round Population*	Projected Peak Summer Population*
Barnstable	40,949	81,800
Bourne	16,064	37,900
Falmouth	27,960	69,300
Mashpee	7,884	25,800
Sandwich	15,489	29,200
TOTAL	108,346	244,000

*From Cape Cod Commission (Cape Trends, 3rd edition, 1996).

By what percentage does the Upper Cape's population increase during the summer? How many ways does the increase in population affect the water supply? How does the increase in population change the quantity or the effects of contamination in the ground water?



Use this map as a decisionmaking tool as your group identifies potential ground-water contamination sources (Ryan, 1980).

sampling wells until they found clean, uncontaminated water.

By sampling ground water in the area for several years, scientists have been able to describe accurately the sewage plume. The Ashumet Valley plume is more than 2 miles long. However, the plume is only 75 feet thick. It is overlain by as much as 40 feet of uncontaminated ground water. The plume moves 0.9 to 1.5 feet per day southward toward Nantucket Sound. The plume contains high concentrations of boron (found in household cleaners), chloride, nitrogen (a byproduct of decomposing organic material), and detergents, which cause the water to foam. Approximately 2.6 billion cubic feet of the Cape Cod sole-source aquifer have been contaminated by the treated sewage from the MMR.

Can the Ashumet Valley plume story have a happy ending? Perhaps. In late 1996, proposals were being prepared to contain the Ashumet Valley plume and other plumes on the MMR with extraction wells.

The Harwich Solar Aquatic Septage Treatment Plant — the Neighbors May Have One Answer

About 20 miles from the MMR, the community of Harwich is treating its septage in a greenhouse. The facility treats 5,000 gallons of septage per day and returns sewage-free water to the aquifer. To begin the process, trucks bring the septage from homes and businesses to the greenhouse, situated near the Harwich town dump. The septage moves through large, transparent tanks that are full of bacteria, algae, water hyacinths, and trees that put down roots in the sludge. All these help break down the sludge; roots absorb some of the toxins while bacteria consume others.

The effluent from these tanks then goes on through an artificial marsh that contains gravel, grasses, and small flowers. The filtering process continues with more tanks and more marshes until at last the water is clean enough to be returned to the aquifer.

The greenhouse is a warm, pleasant, leafy place to enjoy a picnic lunch, which many people do. There's no bad smell, and Harwich residents enjoy the greenhouse's mix of lush plant life and environmental responsibility.

Glossary

Use these definitions of important terms as you answer the Focus Question.

AQUIFER- A geologic formation that contains sufficient saturated permeable material to yield economically significant quantities of water to wells and springs.

EFFLUENT- Something that flows out, such as the discharge of a pollutant from an industrial plant or a septic tank into surface or ground water.

LEACHATE- The soluble product obtained from the action of percolating liquid on the soil or landfill waste.

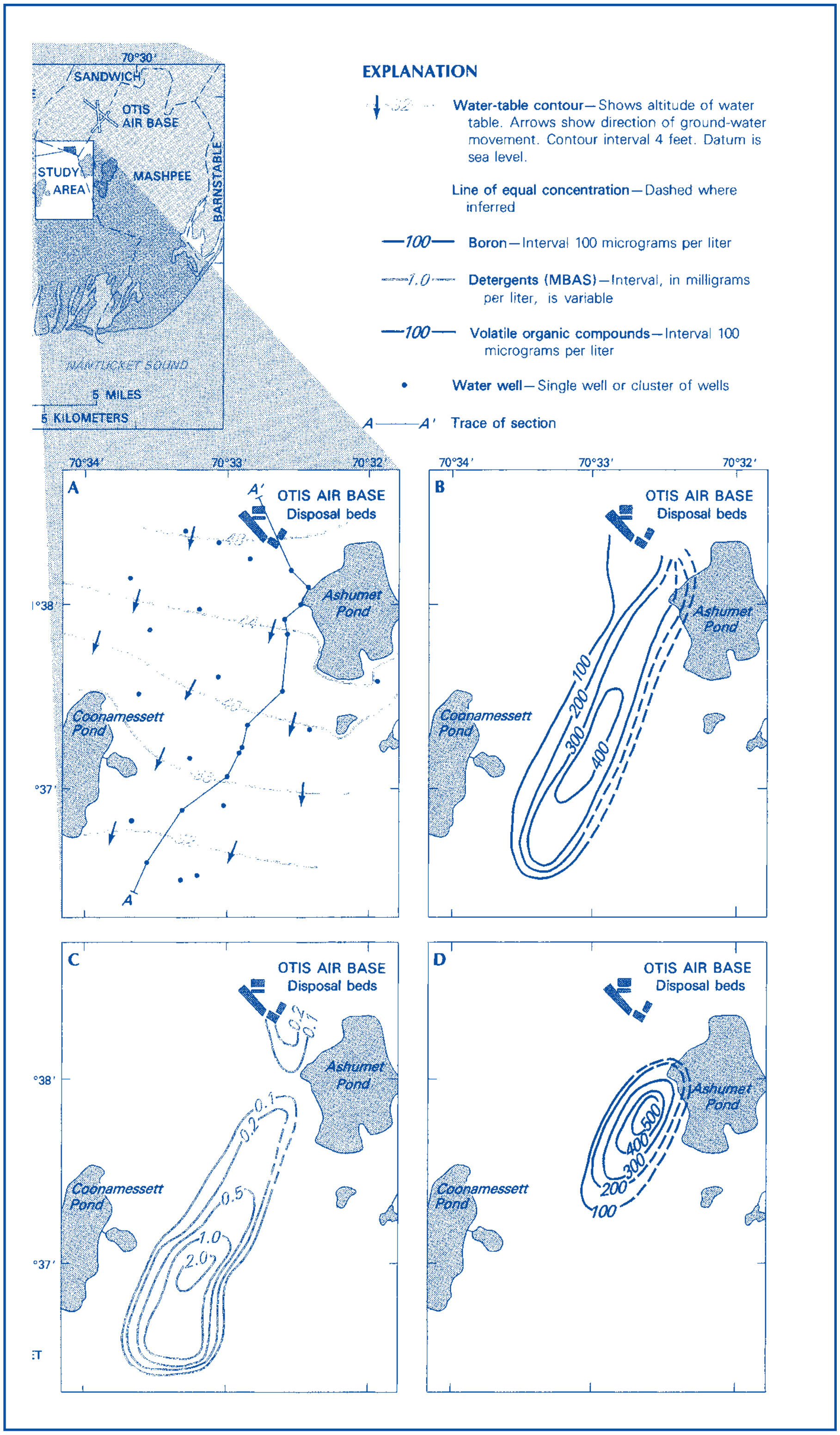
PERMEABILITY- The measure of the ability of porous material to transmit fluid.

PLUME- A zone of ground water that is contaminated by various chemicals and that often has an elongated shape, much like a smokestack plume.

POROSITY- The proportion of the volume of a material that consists of open spaces.

SEPTAGE- Effluent from septic tanks.

SOLUBILITY- The amount of a substance that can be dissolved in a liquid at a given pressure and temperature.



Sewage plume in ground water downgradient from Otis Air Force Base in 1983. **A** shows the water-table contours and the location of sampling wells. **B** shows the distribution of boron, in micrograms per liter. **C** shows the distribution of detergents, in milligrams per liter. **D** shows the distribution of volatile organic compounds, in micrograms per liter (Hess, 1986).

Why did different contaminants have different concentrations in the plume? Consider such factors as the solubility of the contaminants and when they were released. For example, in 1964 new biodegradable detergents replaced the nonbiodegradable detergents being used at the time.

Land and people : Finding a Balance

Cape Cod

U.S. Department of the Interior
U.S. Geological Survey

The Cape Cod project in this curriculum packet asks students to consider the following Focus Question: Cape Cod has a serious problem with its ground water. During more than six decades, the activities at the Massachusetts Military Reservation (MMR) — formerly known as Camp Edwards, then Otis Air Force Base — on the Upper Cape have resulted in contamination of billions of gallons of underground water. (The Upper Cape is the western part of Cape Cod, including the following towns: Bourne, Sandwich, Barnstable, Mashpee, and Falmouth.)

You and your group are members of a blue-ribbon panel that has been formed to present a plan for providing safe, drinkable water to the Upper Cape for the next 10 years. You know of the contamination problem with the underground water supply. You also know how many Cape Cod residents will require water; your panel has been given data that describe the predicted increase in the region's population. Now, you and the members of your panel must figure out how the Upper Cape will meet its need for safe ground water in spite of the vulnerability of its water supply to contamination.

To develop an answer to this complex question, students will:

- learn about how Cape Cod's unique geology makes the ground-water supply vulnerable to contamination,
- create a working model of an aquifer, and
- discover how hydrogeologists gather data to describe the composition and movement of contaminated ground-water plumes.

At the end of this project, students should produce a presentation or paper to share with the class. Their presentation will discuss what they believe will be western Cape Cod's ground-water needs for the next decade, how well the existing water supply will meet those needs, and what other sources of uncontaminated ground water exist. Students will use what they have learned about how geology, water use, and wastewater disposal interact to develop a water-use plan. They will support their plan for supplying the area with safe, drinkable water with the information they received in the Student Packet, their understanding of the availability of ground water and human responsibility for maintaining its quality, and the lessons they learned as they completed the three activities in this packet.

An excerpt from Seth Rolbein's book, "The Enemy Within: The Struggle to Clean Up Cape Cod's Military Superfund Site," is included to demonstrate to your students that these environmental problems involve real people and real concerns. It is reprinted here with the permission of the Association for the Preservation of Cape Cod, a local environmental organization, and does not imply an endorsement of Rolbein's book by the U.S. Geological Survey.

Activity 1
A Model Aquifer

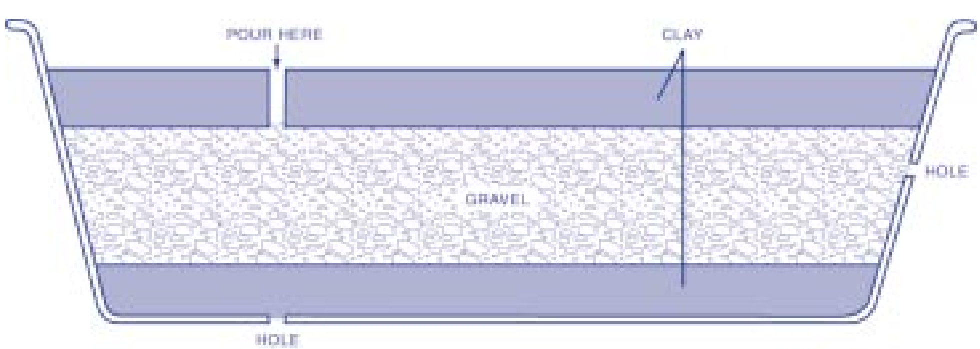
PURPOSE

This activity will help students understand how Cape Cod's ground-water system is unique and how contamination spreads easily underground. To do so, students will build a model of an aquifer. They will "recharge" the aquifer by pouring water into designated areas in the model and collecting water from holes they have made in the box holding the model. By doing this activity, students will determine how water moves through the aquifer and which materials make the "best" aquifer.

MATERIALS

Each group of students will need:

- a clear rectangular 3-gallon-sized, plastic box or tub. Use the longest box you can find,
- potter's clay or natural clay soil,
- sand,
- gravel,



Model aquifer (Activity 1)

- measuring scoop made of a plastic gallon milk jug with the top cut off,
- graduated cylinder,
- two pie plates or petri dishes for catching water that flows out of the aquifer,
- a ten-penny nail for making holes in boxes,
- water, and
- a copy of the illustration of the model aquifer.

PROCEDURE

1. Introduce students to the diagram of the aquifer. Tell students that they will be working in groups to build model aquifers. Explain that different groups will be using different mixes of materials in their aquifers. Some will be using all sand; some will be using all gravel; some will be using a mix of sand and gravel.

2. Instruct students to punch holes in the plastic tub. Holes should be no smaller than 1 mm and no larger than 2 mm.

3. Have students measure out the different aquifer materials using the measuring scoop. Make sure each group uses the same volume of material — sand, gravel, or half and half — for the aquifer. Have the students who are using the half-sand half-gravel mixture prepare the mixture before measuring it or packing the mixture into the aquifer.

4. Students should then pack the tubs with the "aquifer" materials. The bottom layer of clay should be very thin — 2 mm — and well packed. Students should then add the aquifer material — 2-3 scoops, depending on the size of the tub. The upper layer of clay — 1-2 cm thick — should also be well packed.

5. The next step is to elevate the tub or place it on the corner of a table so the holes where water will emerge are accessible. The tub could be elevated with coffee cans or blocks, or placed diagonally on a table corner. Students should position the two pie plates or petri dishes to catch the water that comes out of each hole.

6. To observe how the aquifer model works, students should pour water in the hole in the clay at the top, 10 mL at a time, until drops appear at the holes. After drops appear, students should pour in one final graduated cylinder full of water. Students should record the amount of water that is poured into the model. In the pie plates or petri dishes, they will collect the water that comes out of each hole, then measure the amount of water in an empty graduated cylinder.

7. When students have finished pouring water into their aquifer models, gather the class together. Have the students in different groups compare the water-holding capabilities of different materials.

8. Refer students to the section of the Student Packet that explains porosity and permeability. Review these concepts. Then hold a general discussion of what students expected to discover and what actually happened. Students are likely to be surprised to find that even a thin layer of impermeable material will not allow water through.

EXTENSION

1. Describe how a town built on top of this model could access and use the water in the aquifer for its water supply.

2. Invite a local well driller to class to discuss information related to local aquifers, drilling depth, and costs.

Activity 2
Cleaning Up A Contaminated Aquifer

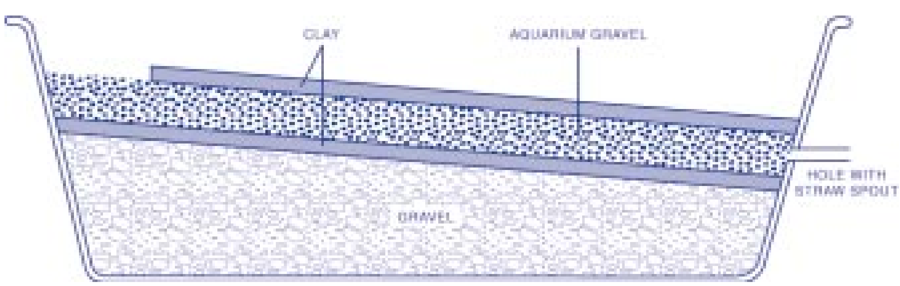
PURPOSE

Students will discover that once an aquifer is contaminated, cleaning it up is a long and difficult process.

MATERIALS

Each group of students will need:

- modeling or potter's clay,
- white aquarium gravel,
- gravel,
- food coloring,
- graduated cylinder,
- 2-3-inch-long eyedropper,
- a clear rectangular gallon-sized plastic box or tub. Use the longest box you can find,
- small drinking straw,
- spray pump from a household cleaner bottle,
- water, and
- a copy of the illustration of the "contaminated" aquifer.



Contaminated aquifer (Activity 2).

PROCEDURE

1. Before beginning this activity, ask students the following questions:

- How does an aquifer get recharged? Where does the water come from?
- How does an aquifer become contaminated?
- How might an aquifer get cleaned up once it has been contaminated?

Record their answers to these questions and refer to their answers after the activity is completed.

2. Students will build a model of an aquifer as illustrated in the diagram. (Students will notice that this aquifer looks different than the one they built in Activity 1. Explain that this model's slope simulates how ground water moves through the Cape Cod aquifer and shows the water-table slopes toward the sea.) They will "contaminate" this aquifer model with food coloring and then try to clean up the spill.

3. Have students fill the plastic box with clay and two kinds of gravel. Both clay layers should be well sealed against the sides of the plastic box.

4. Use an eyedropper pushed into the aquarium gravel to place 10 drops of food coloring deep into the aquifer to simulate underground leakage.

5. Have students slowly pour 50 mL of water on the gravel recharge area and collect it as it runs out of the straw. Repeat this process until all food coloring is washed out and the water is clear. (Note — be sure to use white gravel. If the gravel is colored, then students might think the color is coming from the gravel.) Collecting the liquid in white paper cups makes it easier for students to see faint coloration. Students may wish to transfer a portion of the liquid to a series of test tubes; looking down the length of the tubes will help students to see faint colors easily.

6. Have students record the number of flushings required for the water to run clear.

7. After the aquifer model has been flushed clean, have students use a clay plug to block the hole that had the straw spout in it. They should then recontaminate the model in two places: at the surface and at the same depth as they did before. Again, have them contaminate the aquifer using ten drops of food coloring. This time, however, have them use two different colors so they may track the effects of contamination at different levels.

8. Students should observe how the contamination spreads in the aquifer from the two different sources. Ask them to think about what might be the sources of contamination at the surface and at depth. Refer them to the sources of contamination at the MMR and at other places on Cape Cod.

9. Ask students "Could this contamination be cleaned out of the aquifer by drilling a well and pumping it out?" Have them discuss why they believe pumping will or will not draw the contamination out of the aquifer.

10. Students will try to pump the contamination out of the aquifer. They should begin by poking a hole in the clay in the center of the aquifer. Insert a straw 1-2 inches into the aquarium gravel to simulate a well. Place a spray pump (from a household cleaner bottle) into the straw and then pump the contamination from the aquifer. Students should record how well (and whether) pumping is able to clean up contamination. How many times did they have to pump to clean up the well?

11. Have students discuss which clean up method worked best, flushing or pumping. What would they do to improve the effectiveness of each method? Which method do they think works best on surface contamination? Which works best on contamination at depth?

Activity 3
Predicting the Path of Ground-Water Contamination

PURPOSE

In this activity, students will use different kinds of geologic information to predict the path of ground-water contamination from several toxic waste sources on the MMR. Once they have drawn possible plume paths, students will receive the actual contaminant plume traces for comparison.

MATERIALS

Each group of students will need:

- map of MMR and water table configuration on March 23-25, 1993,
- map of surficial geology of area with location of hydrogeologic sections and explanation,
- figure showing hydrogeologic sections with explanations,
- map showing contaminant plumes at MMR,
- tracing paper, and
- colored pencils.

PROCEDURE

1. Begin by defining the water table for the students. Explain that about half of the water that falls on the Cape Cod landscape — in the form of rain — or snow — percolates into the ground. It gathers in the saturated zone, where all the pores and crevices of the rock and soil are filled with water. The top of this zone is the water table. If one were to dig a well that just penetrates the top of the saturated zone, the water table would be the level at which water stands in the well.

2. Provide students with copies of the water-table map. As a class, have them identify the highest elevation of the water table and the lowest elevation.

Explain that the contours on the map indicate the surface of the aquifer, or the water table.

3. Ask students what direction(s) they think water is moving in the aquifer. (Water moves down the water-table slope in the aquifer. The MMR sits atop a round hill at the highest point of the water table.) To answer this question, ask them to remember how water moved in their model aquifers in Activities 1 and 2.

4. Now have students look at the hydrogeologic map and the sections. Explain that the sections are vertical slices that represent the distribution of rocks and sediments underlying the surface. These sections were constructed using materials brought to the surface during well drilling.

5. When you are confident students understand the information provided by the geologic map and sections, ask them to predict what kind of materials make up the aquifer in this region. To make this prediction, students can refer to the sections.

6. Have students locate the four major contamination sites on the water-table map. Then, ask them to use the water-table contour map and the geologic information to predict the path of contamination movement. Remind the students to think about the kinds of sediments and rocks that are likely to be permeable and that are likely to be impermeable.

7. Have students place the tracing paper on top of the water-table contour map. Then have them sketch the paths they predict the contamination will take on the tracing paper.

8. When students have finished drawing what they believe will be the path of contamination movement on the tracing paper, have them show each other what they drew. Ask students to explain why they believe the contamination will follow the path they drew.

9. Distribute the map that shows the plumes. Have students compare the contamination paths they drew to the actual plumes. Point out that these maps were developed by geologists who sank a large number of test wells into the aquifer to measure the contamination levels in the ground water. Lead students in a discussion of how their predictions could have been used by geologists trying to decide where to put their initial test wells.

Extension

Since 1973, the MMR has been used primarily by the Massachusetts National Guard and the U.S. Coast Guard. In 1986, the National Guard Bureau's Installation Restoration Program (IRP) began investigating the contaminant plumes related to hazardous materials at the MMR. Since 1994, the IRP has published fact sheets that describe the history, size, and risks caused by each plume and what the IRP proposes to do about it. Call the IRP office at (508) 968-4678 to request copies of the 11 fact sheets published in 1994 and any others published since that time. Distribute copies of the IRP's Plume Response Fact Sheets to students as they answer these extension questions.

1. Are any of the local ponds in danger of contamination?

2. Are any of the town water supplies in danger of contamination?

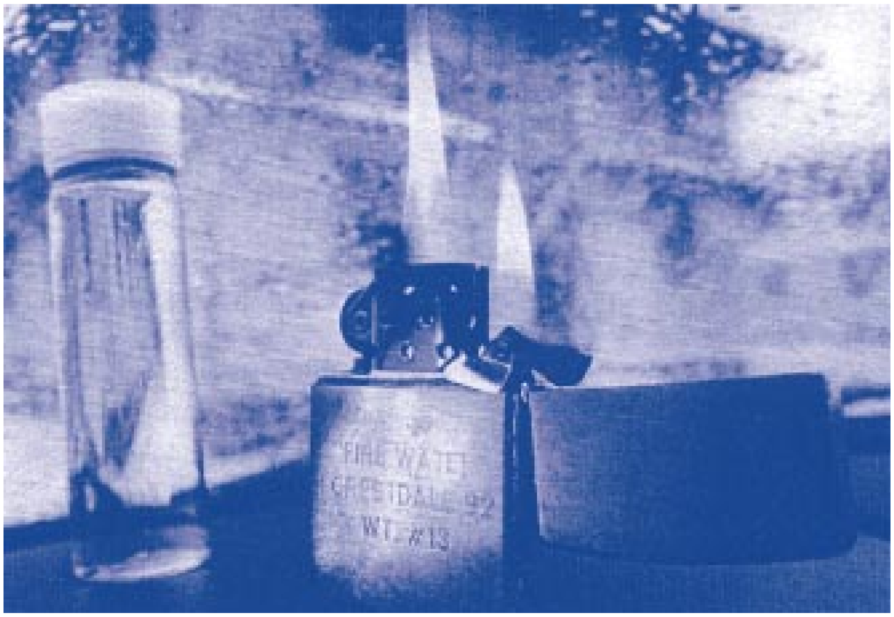
3. How can the movement of the contaminant plumes be slowed?

4. Where would students put in wells to remove contamination?

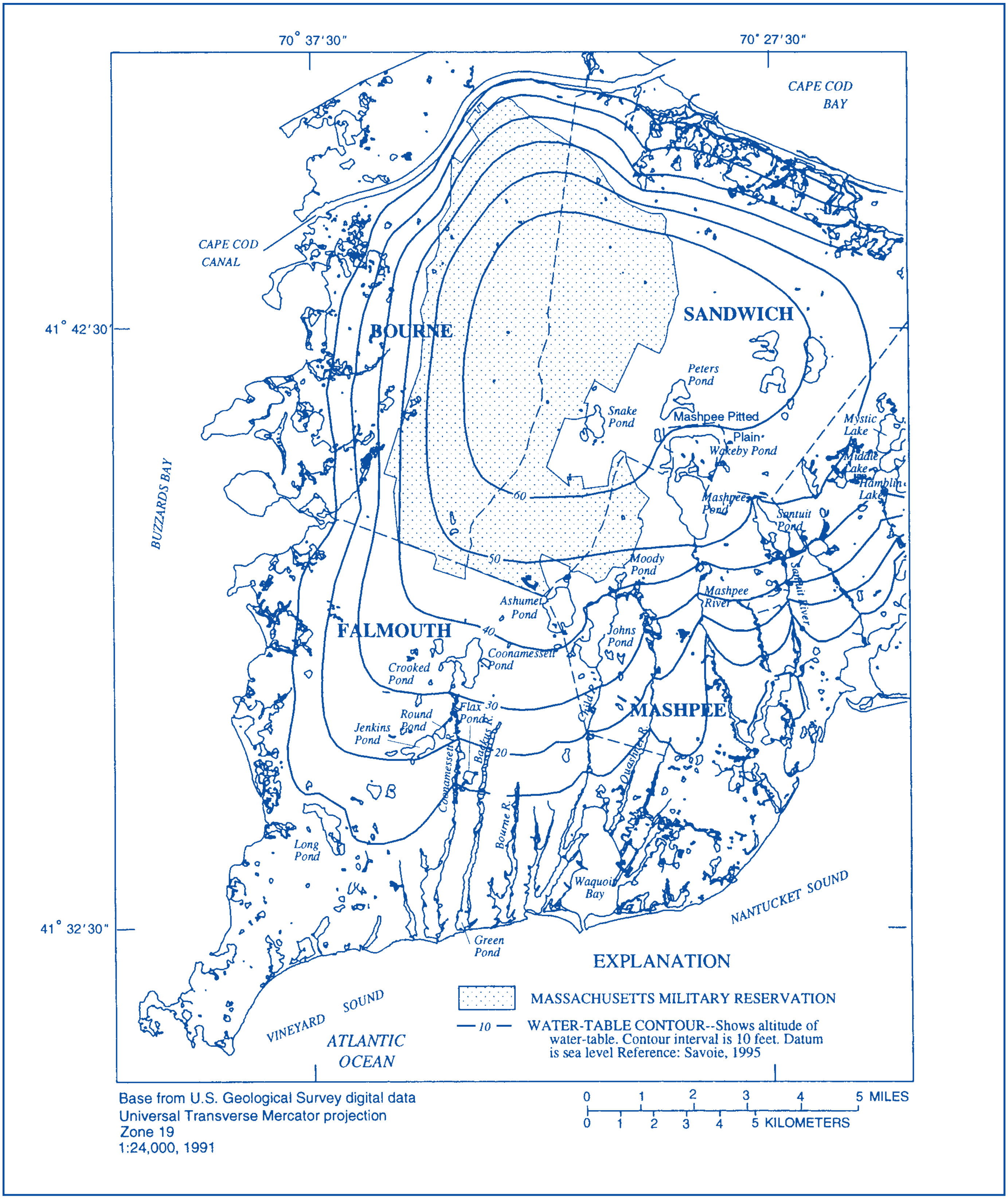
5. How else could the contaminated ground water be cleaned up?

6. Where would it be safe to drill wells for drinking water?

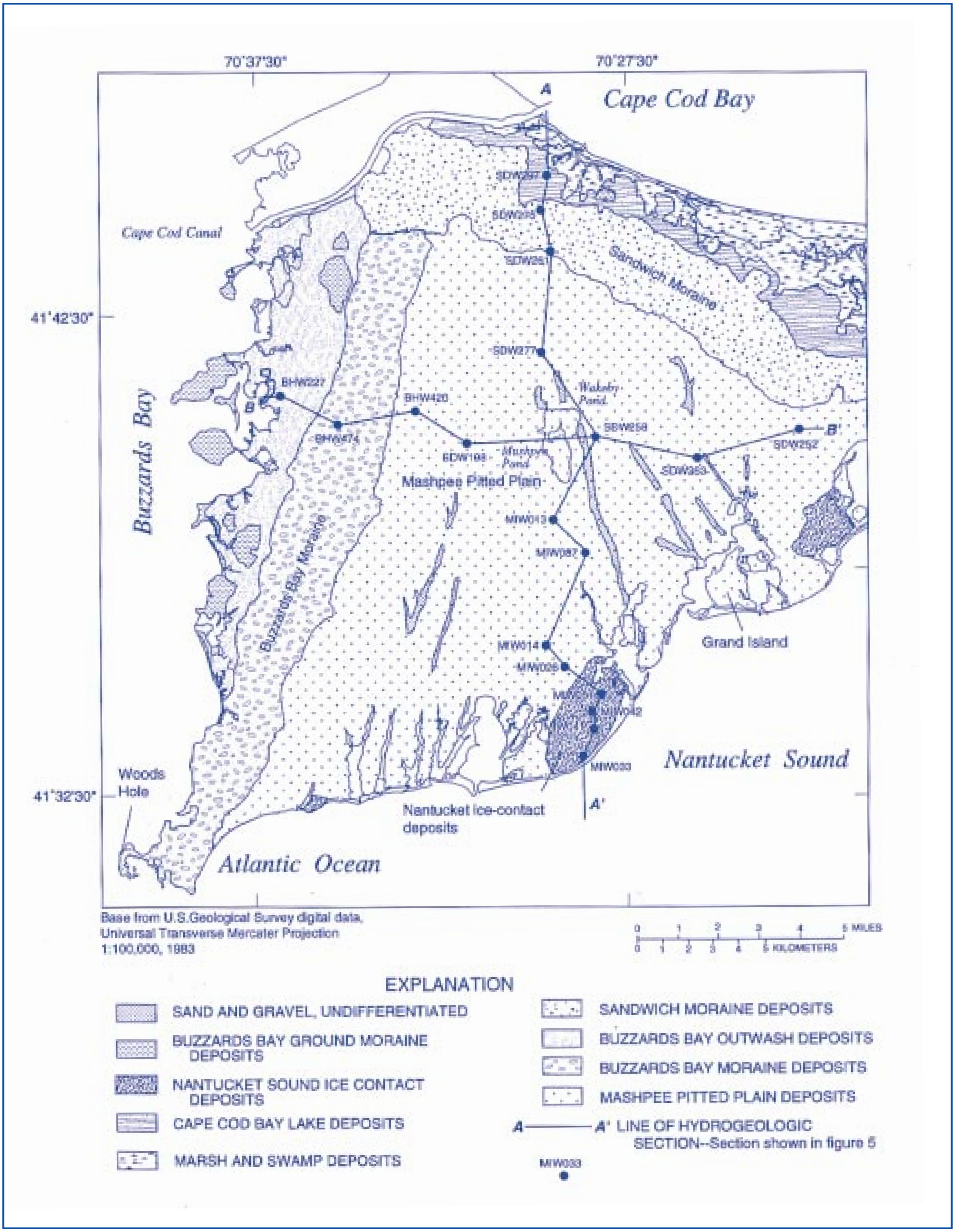
Note: In 1996, the U.S. Air Force's Center for Environmental Excellence assumed responsibility for containment, cleanup, and remediation of contaminated ground water within and emanating beyond the boundaries of the MMR.



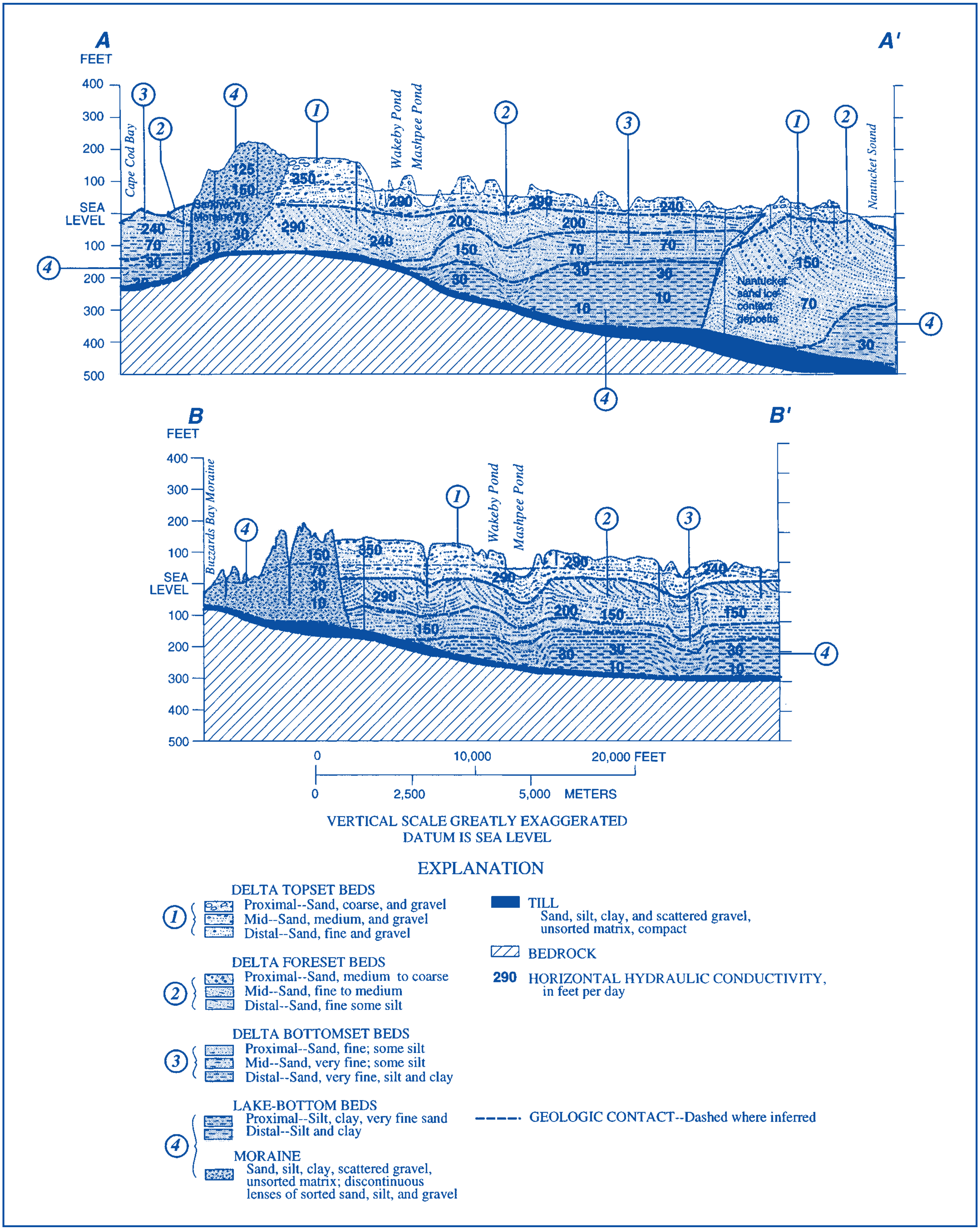
Firewater: a ground-water sample from one site on the MMR contained enough jet fuel to burn.



Location of Massachusetts Military Reservation and water-table configuration on March 23-25, 1993 (Masterson and others, 1996).



Surficial geology and lines of hydrogeologic sections, western Cape Cod, Massachusetts (Masterson and others, 1996).



Hydrogeologic sections A-A' and B-B' showing glacial drift of western Cape Cod, Massachusetts (Masterson and others, 1996).

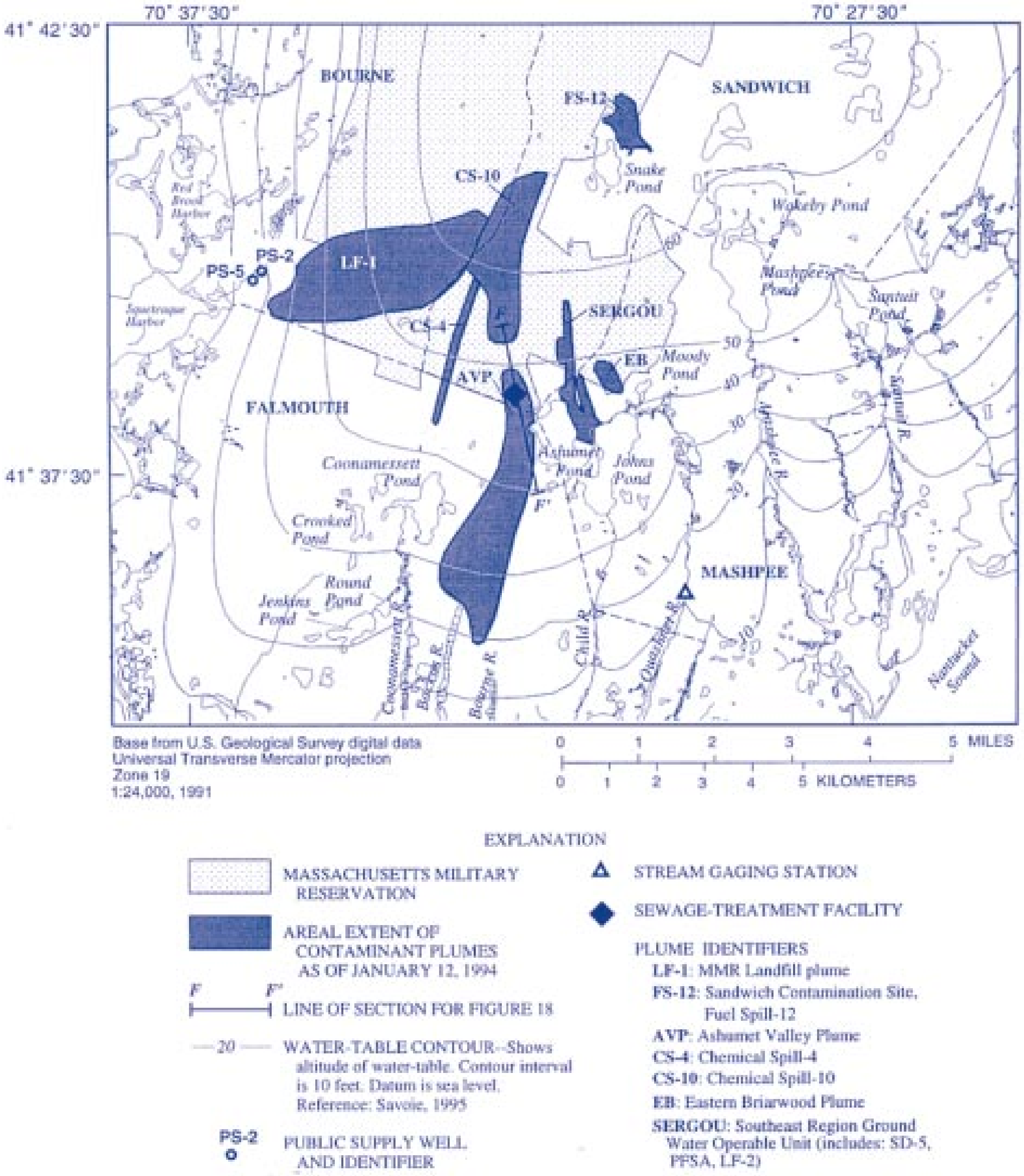


Figure 2. Location of contaminant plumes at Massachusetts Military Reservation, western Cape Cod, Massachusetts.

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Land and people : Finding a Balance

Everglades

U.S. Department of the Interior
U.S. Geological Survey

Finding a Balance **is an environmental study project that allows you and a group of your classmates to consider real environmental dilemmas concerning water use and to provide solutions to these dilemmas. The student packet gives you most of the information you'll need to answer the Focus Question, information like maps, data, background, a reading about the region, and a description of the "Interested Parties," or the various interest groups that have a stake in the outcome of the Focus Question. While you are working on this project, each member of your group will take a role, or become one of the interested parties. Your teacher will guide you through a series of discussions, activities, calculations, and labs. At the end of this project, your group will be asked to present and justify a solution to the environmental dilemma.**

Reading

From *The Everglades: River of Grass* by Marjory Stoneman Douglas (1947).

"There are no other Everglades in the world. They are, they have always been, one of the unique regions of the earth, remote, never wholly known. Nothing anywhere else is like them: their vast glittering openness, wider than the enormous visible round of the horizon, the racing free saltness and sweetness of their massive winds, under the dazzling blue heights of space. They are unique also in the simplicity, the diversity, the related harmony of the forms of life they enclose. The miracle of the light pours over the green and brown expanse of saw grass and of water, shining and slow-moving below, the grass and water that is the meaning and central fact of the Everglades of Florida. It is a river of grass...Where do you begin? Because, when you think of it, history, the recorded time of the earth and of man, is in itself something like a river. To try to present it whole is to find oneself lost in the sense of continuing change. The source can be only the beginning in time and space, and the end is the future and the unknown... So it is with the Everglades, which have that quality of long existence in their own nature. They were changeless. They are changed."

Florida author and conservationist Marjory Stoneman Douglas was born in 1890. Her best-selling book, *The Everglades: River of Grass* was published in 1947, the same year the 1.4 million acre Everglades National Park, opened. A noted author, editor and environmentalist, she received the Presidential Medal of Freedom in 1993, which she donated to her alumnus, Wellesley College. At the age of 104, Douglas published a novel, *Freedom River.*

Focus question

The year is 2010. The National Weather Service has studied the last decade's rainfall rates and the storm patterns over the Atlantic Ocean and has produced an alarming forecast: over the next 5 years, the Everglades-region will experience a 30-percent-decrease in the amount of rainfall it receives. But lack of rainfall is not the only challenge the Everglades faces. During the last century, the Everglades has been profoundly changed by increasing urban and agricultural activity. Humans have drained the wetland and created a complex canal and levee

system, thus causing drastic changes in the ecosystem: shrinking populations of wading birds and the collapse of alligators' nesting activities.

How will your group respond to this serious decrease in rainfall? Create an action plan that will reduce the damage the long period of dry weather will cause to human and ecological interests.

The Interested Parties

Here is an overview of the competing interests that affect the Everglades region. As your group works to answer the Focus Question, each person will take a role as an environmentalist, farmer, or developer.

ENVIRONMENTALISTS

Environmentalists want to stop the destruction of the Everglades, an ecosystem which is quickly dying. Only one fifth of the water that reached the ecosystem at the turn of the century is getting to the Everglades today. Only 5 percent of the wading birds that used to nest there are still doing so. Agricultural runoff has severely altered vegetation, replacing saw grass with cattails, which crowd out algae, an important food source.

AGRIBUSINESS

South Florida farmers are some of the most productive in the Nation, producing everything from sugarcane, to lettuce, to tomatoes. To produce these crops, south Florida farmers use a large portion of the region's water. Irrigation of sugarcane and citrus dominates water use in the six counties that comprise the Everglades Agricultural Area and the Indian River Citrus Area in Florida. About 1 million acres are irrigated with more than 2 billion gallons of water per day.

Population Growth

COUNTY	1980	1990	NET CHANGE IN NUMBER	NET CHANGE IN PERCENT
BROWARD	1,018,257	1,255,488	+237,231	+23.3
DADE	1,625,509	1,937,094	+311,585	+19.2
PALM BEACH	576,758	863,518	+286,760	+49.7

Which county gained the most people between 1980 and 1990? Which county gained the largest percentage of growth during that period?

■

Projected Range of Public Supply Water Use Per Day (in millions of gallons)

COUNTY	2000	2010	2020
BROWARD	257.4	285.4	316.2
DADE	395.8	425.5	471.4
PALM BEACH	253.1	305.0	338.0

Which county has the slowest rate of projected use of public water?
(To answer this question, subtract the figure for 2000 from the figure for 2020.)

■

Total Freshwater Withdrawn Per Day (in millions of gallons)

COUNTY	1965	1970	1980	1990
BROWARD	173.13	184.35	235.58	266.53
DADE	287.80	276.47	440.45	490.55
PALM BEACH	414.50	504.38	752.71	996.84

Palm Beach County's use of freshwater more than doubled between 1965 and 1990. Did Palm Beach County's population grow at about the same rate?

Everglades farmers make a lot of money and employ a lot of people. Palm Beach County has the fifth largest farm income in the Nation. Twenty thousand people work in the Everglades Agricultural Area on 450,000 acres of land. Farmers plant the rich peat soil that is exposed when surface water is drained. (The Everglades sustains the Nation's largest sugarcane crop and second largest vegetable crop.) But, exposed to air, this soil decomposes, rapidly drying up and blowing away. Because the soil is exposed to this and, thus, is drier than it would normally be, peat is lost at the rate of between one-quarter and three-fourth inch per year.

In addition to transforming the flow of water, farming introduces runoff that contains phosphorus and nitrogen into the Everglades. This runoff has choked the Everglades' saw-grass prairies with cattails. In 1994, a sugar cane company, which produces nearly one-third of Florida's sugar, was required to reduce phosphorus pollution in the water that drains from its lands in the Everglades Agricultural Area. The company also agreed to help build large artificial marshes to filter pollution that flows toward the Everglades National Park.

Urban developers

Developers want the human population to continue to expand in numbers and in the amount of space people take up. The population of Broward county alone has doubled in the last 20 years. (South Florida has one of the fastest growing populations in the U.S.) They also want to offer residents a high standard of living, which in Florida includes high domestic water consumption. The demand for water drains the aquifers below ground, while more and more pavement inhibits the land's ability to absorb water.

Developers also build to accommodate vacationers and retirees. In 1989 alone, 39 million people vacationed in south Florida. Twelve million arrive during the winter, the driest months of the year in south Florida.

Largest Population Growth 1980-1992

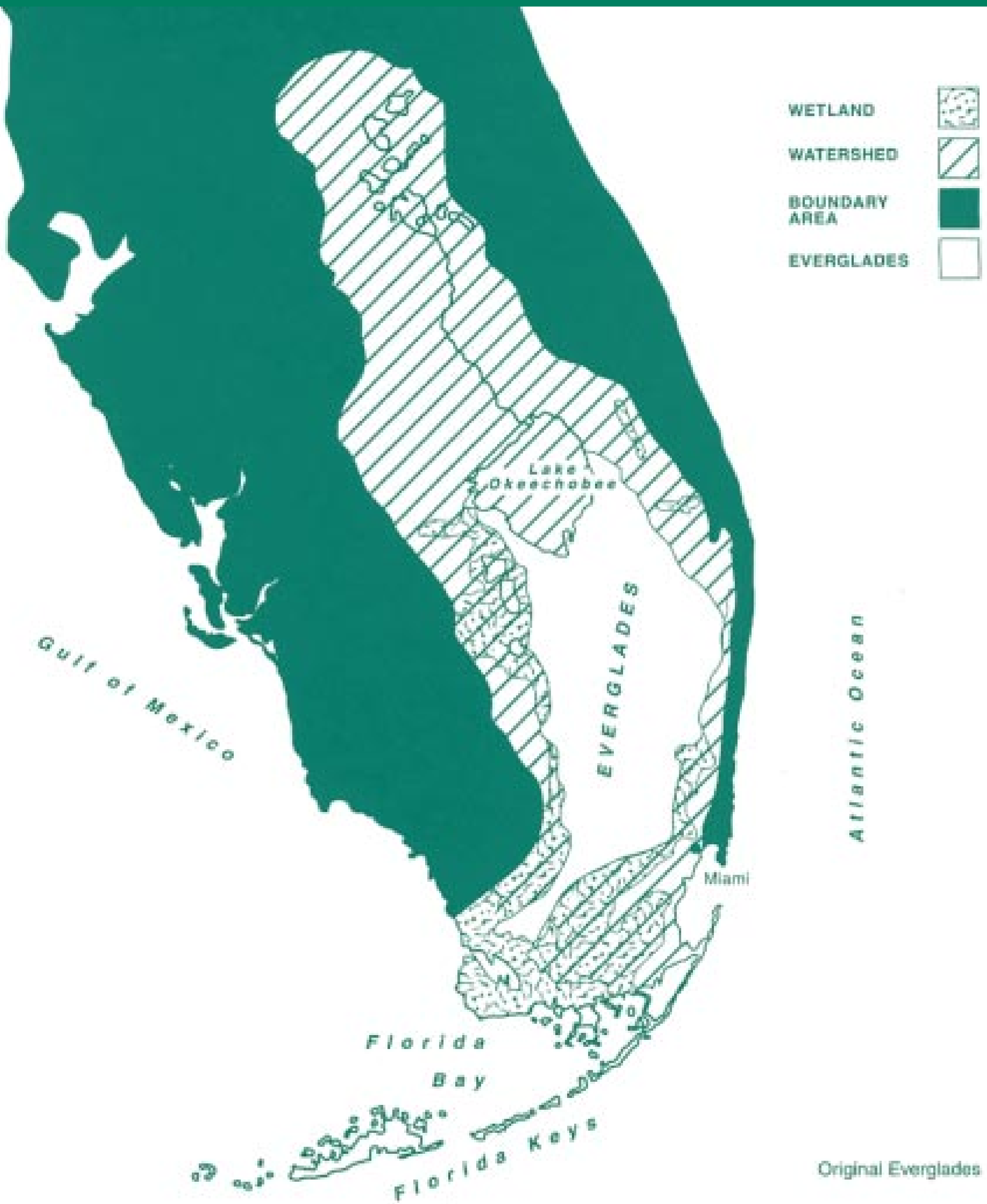
COUNTY	NUMBER
Los Angeles, CA	1,576,407
San Diego, CA	739,209
Maricopa, AZ	700,392
San Bernardino, CA	639,327
Riverside, CA	625,236
Harris, TX	562,208
Orange, CA	551,868
Clark, NV	382,546
Dade, FL	382,463
Tarrant, TX	359,239
Dallas, TX	356,976
Palm Beach, FL	323,897
Sacramento, CA	309,856
King, WA	287,639
Broward, FL	283,017
Fairfax, VA	261,266
Bexar, TX	244,125
Orange, FL	243,714
Santa Clara, CA	233,456
Gwinnett, GA	224,947
Hillsborough, FL	211,613
Alameda, CA	202,193
Montgomery, MD	201,969
Travis, TX	193,586
Fresno, CA	190,992
United States	28,535,337

How many Florida counties are among the 25 fastest-growing counties in the U.S.? Which of these Florida counties are in the Everglades?

Largest Number of New Private Housing Units Authorized by Building Permits 1990-1992

COUNTY	NUMBER
Los Angeles, CA	53,004
Clark, NV	51,996
Maricopa, AZ	48,210
Harris, TX	35,356
Riverside, CA	32,865
King, WA	32,437
San Diego, CA	29,694
San Bernardino, CA	27,310
Dade, FL	26,692
Broward, FL	26,011
Dallas, TX	25,851
Palm Beach, FL	25,665
Orange, FL	25,521
Orange, CA	24,359
Cook, IL	23,540
Sacramento, CA	21,003
Franklin, OH	19,486
Oakland, MI	16,352
Mecklenburg, NC	15,488
Duval, FL	15,194
Pierce, WA	15,126
Tarrant, TX	14,993
Fresno, CA	14,711
Hillsborough, FL	14,682
Wake, NC	14,533
United States	3,154,493

Dade, Broward, and Palm Beach Counties are permitting many new homes to be built in the Everglades region. What conclusion about people's impact on the environment can you draw from this fact?



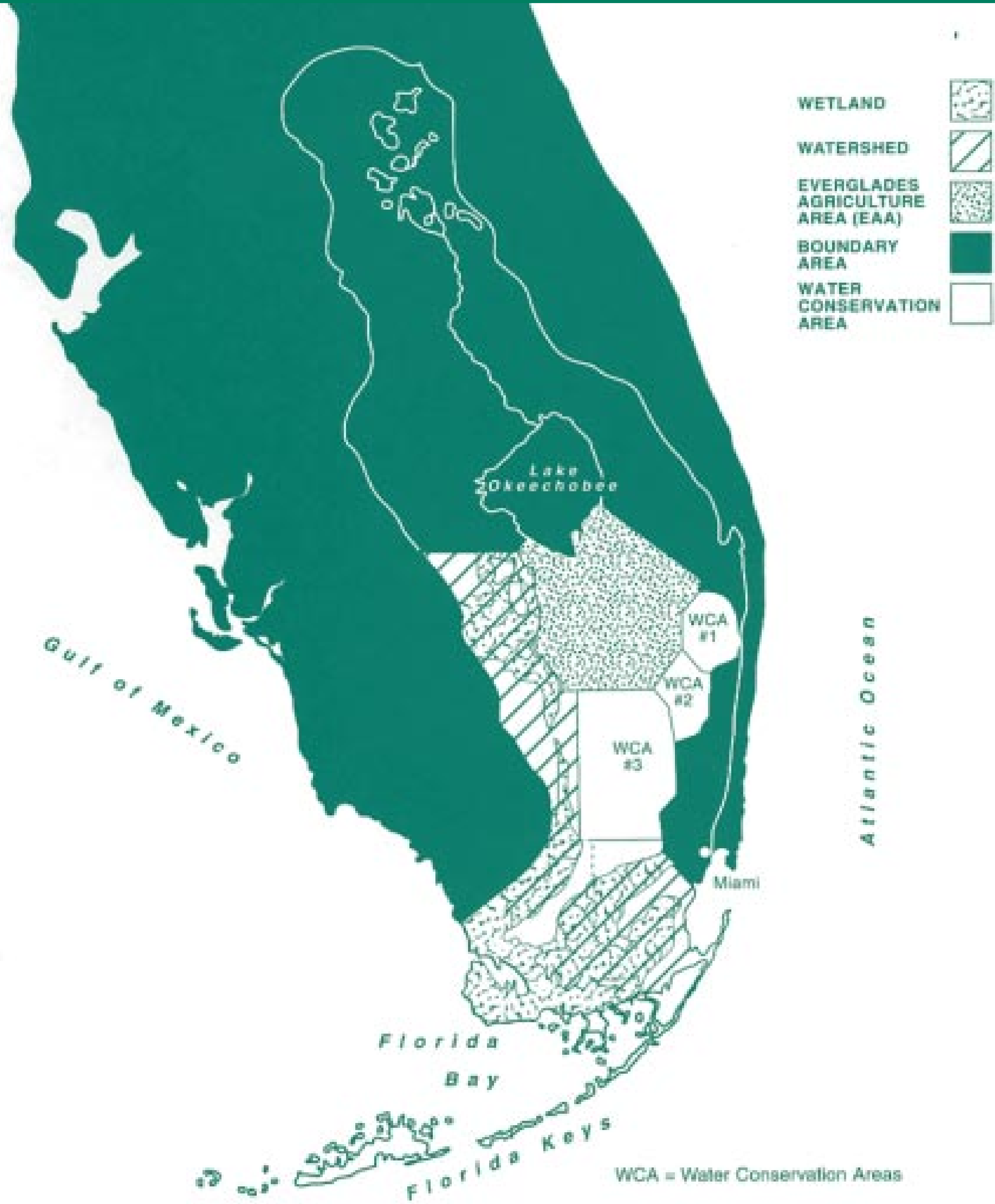
Original Everglades

The Everglades – What You Need To Know

To understand what the Everglades is today, you need to know what it once was. The pristine Everglades was a wetland that spanned the state of Florida south of Lake Okeechobee, about 2.9 million acres of mostly peatland covered by tall saw-grass growing in shallow water. When the lake was full, water overflowed into the northern Everglades and moved slowly to the south in a 50-mile-wide sheet, a foot deep. In the 1880's people began to drain the Kissimmee River-Lake Okeechobee-Everglades watershed. Drainage exposed the organic muck soil, which produced extraordinary crop yields.

The last 100 years have seen tremendous change in the Everglades. Water is controlled by a complex management system that includes canals, levees, and pumps. The region is divided into the Everglades Agricultural Area (the world's largest zoned farming area), three Water Conservation Areas, and Everglades National Park. The Everglades has been called "…the biggest artificial plumbing system in the world."

Today more than 50 percent of the historic Everglades has been eliminated. Widespread population growth and land-use modification in Florida affect the quantity and quality of drinking water, alter natural wetlands, and increase human exposure to hydrologic



Today's Everglades

WCA = Water Conservation Areas

hazards, such as floods. More than 1,400 miles of drainage canals and levees have altered the Everglades wetlands in Florida for flood control. These agricultural, industrial, and urban areas affect water quality in southern Florida. Farming involves the use of numerous chemicals, including fertilizers, insecticides, herbicides, and fungicides, that leak into the ground water or nearby surface waters. Stormwater runoff from urban areas commonly transports heavy metals and nutrients into canals and the Biscayne aquifer.

Restoring the Everglades — Add Water and Mix?

The south Florida ecosystem is one of the most threatened ecosystems in the Nation. The greatest impacts on the ecosystems may have resulted from the construction of a complex canal and levee system to control flooding and supply freshwater. This system has drained over half of the Everglades and altered the flow of freshwater into Florida Bay. Without enough standing water, the ecosystem supports half as much aquatic life, thus the Everglades can no longer feed the storks, alligators, and other animals that once flourished. Many people believe the lack of water and the change in how and when it flows are the causes for a declining population of wading birds and a collapse of nesting activities, and major changes in plant communities as “weedy” species, such as cattails, invade the wetlands.

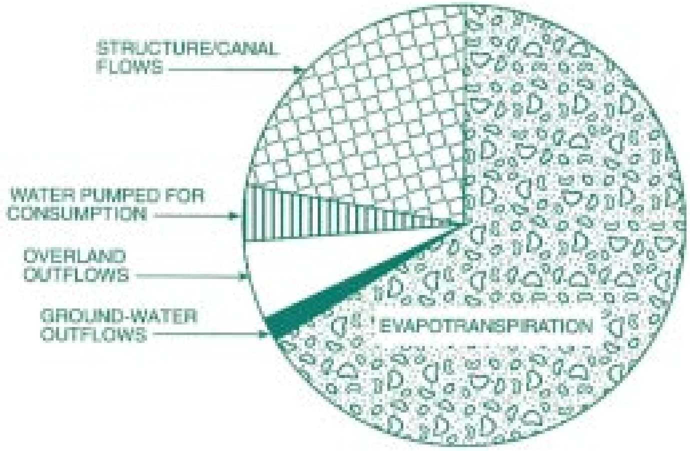
Restoring the Everglades begins with returning its water. Plans are being developed to reestablish the natural hydrology of the south Florida ecosystem so that water patterns in parts of the historic Everglades more closely resemble those that existed about 150 years ago, before significant human intervention.

A second major restoration effort involves removing nutrients from agricultural waste water. In 1994, the State legislature mandated a project that would construct artificial marshes around the agricultural area to filter phosphorus from the water. The third restoration effort is removal of non-native plants that crowd out indigenous species and reduce wildlife habitat.

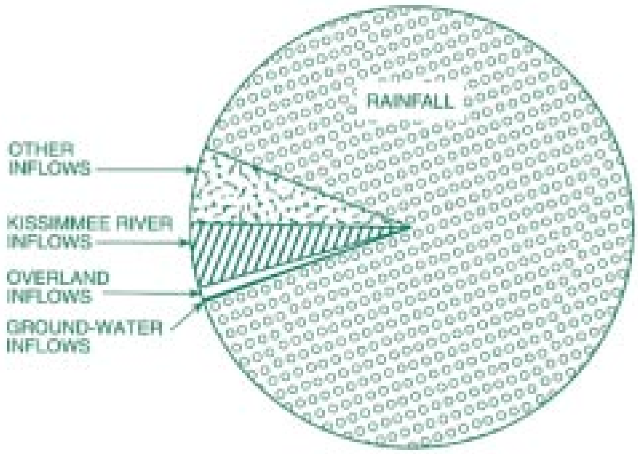
No one knows how well the restoration efforts will work.

Geologic Background — Flat and Wet

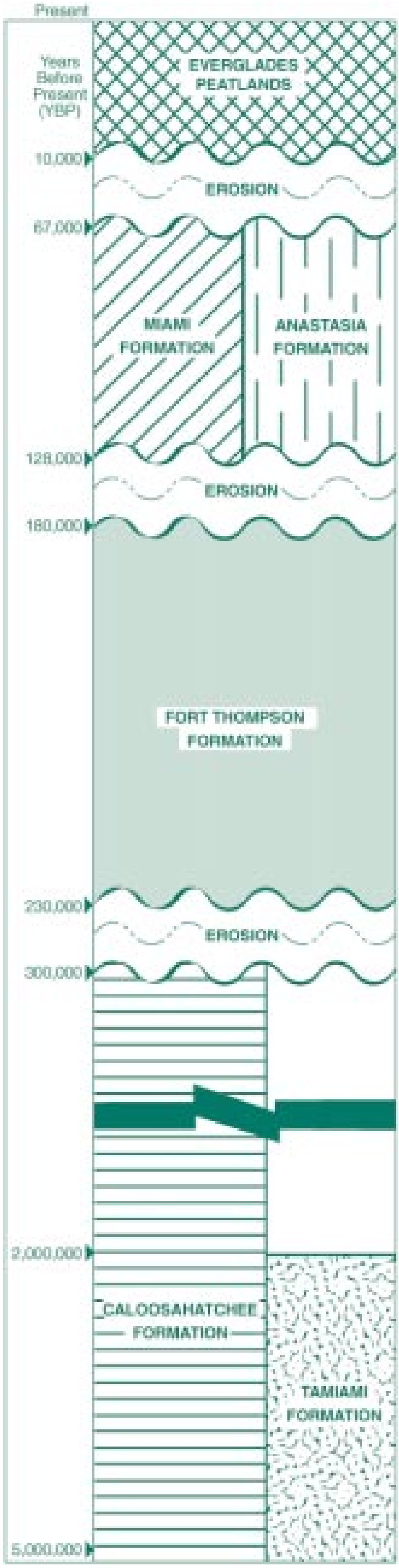
For most of its geologic history, Florida was under water. The shells of millions of sea animal form the layers of limestone that blanket the State. The peninsula rose above sea level about 20 million years ago. Even then, the southern portion remained largely submerged, until the buildup of coral and



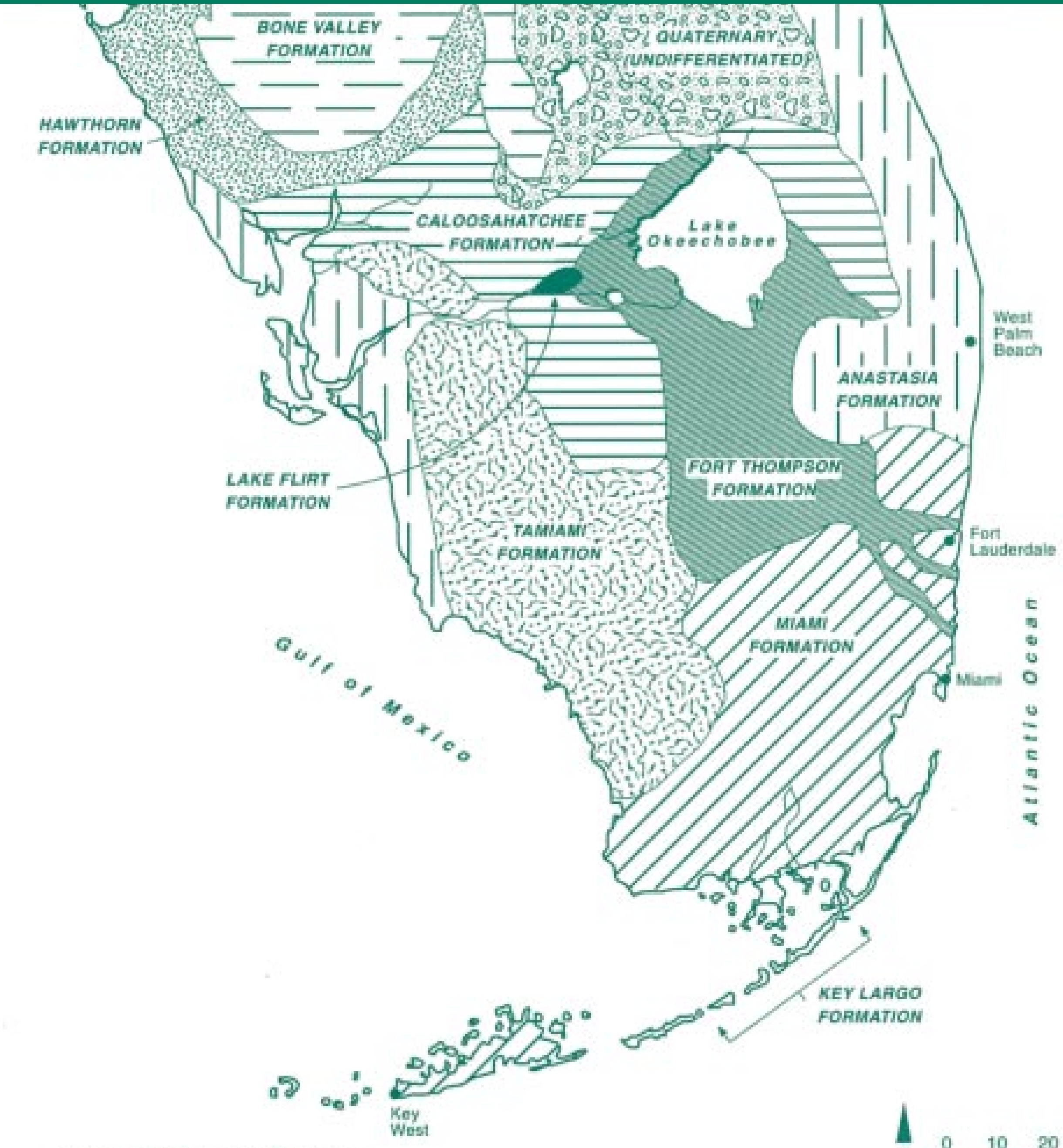
How water is drawn from the Everglades water budget



How water flows into the Everglades water budget



Geologic Chronology of the Everglades Bedrock Basin



Geologic Map of Southern Florida

sand around its rim blocked out the sea, leaving dense marine vegetation to decay and form the peaty soil of the present-day Everglades.

Dependent on rain for freshwater, the subtropical stretch of the peninsula receives 40 to 65 inches a year. But this flat, porous limestone land has little surface storage capacity, and after evaporation, transpiration, and runoff, only a fifth of the rainwater remains to recharge underlying aquifers and shallow lakes.

Climate — What Does It Mean to be Subtropical?

South Florida's climate is rainy, hot and humid. The average annual temperature is about 75 degrees Fahrenheit. Freezing temperatures are rare. Annual rainfall averages about 53 inches — more than half of which occurs from June through September.

Glossary

Use these definitions of important terms as you answer the Everglades Focus Questions.

AQUIFER- A geologic formation that contains sufficient saturated permeable material to yield economically significant quantities of water to wells and springs.

ECOSYSTEM- The interacting system that encompasses a living community and its non-living physical environment.

EVAPOTRANSPIRATION- The conversion of water from a liquid to a vapor including the evaporation of water vapor from plants.

HYDROLOGIC CYCLE- The water cycle, which includes evaporation, precipitation, and flow of water to the seas. The hydrologic cycle supplies terrestrial organisms with a continual supply of freshwater.

LEVEE- A natural or artificial bank that constrains the flow of water to a channel.

PEAT- A spongy organic substance made of decayed plant fibers.

WATER BUDGET- The freshwater available for plant, animal, and human use plus the water necessary to maintain streamflow.

WATERSHED- All of the land that drains into a particular body of water.

WETLAND- Land that is transitional between aquatic and terrestrial ecosystems and is covered with water for at least part of the year.

■

These tables allow you to compare crops by the amount of water used to raise them. For example, which crop requires more irrigation — miscellaneous vegetables or sweet corn? Which crops require a lot of water? Which ones need very little? Which crops did farmers plant more of in 1990 than in 1985? Are these crops ones that use a lot of water?

Irrigation Acreage and Water Use by Crop Type in Florida

BROWARD COUNTY	1985		1990	
CROP TYPE	ACRES FARMED AND IRRIGATED	WATER USE FOR IRRIGATION PER DAY (IN MILLIONS OF GALLONS)	ACRES FARMED AND IRRIGATED	WATER USE FOR IRRIGATION PER DAY (IN MILLIONS OF GALLONS)
TURF GRASS (GOLF COURSES AND OTHER USES)	10,000	16.82	18,000	26.80
SWEET CORN	6,100	5.57	3,072	3.45

Irrigation Acreage and Water Use by Crop Type in Florida

PALM BEACH COUNTY	1985		1990	
CROP TYPE	ACRES FARMED AND IRRIGATED	WATER USE FOR IRRIGATION PER DAY (IN MILLIONS OF GALLONS)	ACRES FARMED AND IRRIGATED	WATER USE FOR IRRIGATION PER DAY (IN MILLIONS OF GALLONS)
SWEET CORN	29,500	32.04	28,475	31.04
MISCELLANEOUS VEGETABLES	30,100	11.17	44,300	48.28
SUGAR CANE	320,000	381.97	323,433	505.33
TURF GRASS (GOLF COURSES AND OTHER USES)	15,000	31.36	30,000	59.80

Irrigation Acreage and Water Use by Crop Type in Florida

DADE COUNTY	1985		1990	
CROP TYPE	ACRES FARMED AND IRRIGATED	WATER USE FOR IRRIGATION PER DAY (IN MILLIONS OF GALLONS)	ACRES FARMED AND IRRIGATED	WATER USE FOR IRRIGATION PER DAY (IN MILLIONS OF GALLONS)
MISCELLANEOUS FRUIT	21,300	49.23	14,530	22.95
MISCELLANEOUS VEGETABLES	33,630	3.90	28,815	33.64
TURF GRASS (GOLF COURSES AND OTHER USES)	7,750	18.00	47,000	17.39

Land and people : Finding a Balance

Everglades

U.S. Department of the Interior
U.S. Geological Survey

Introduction

The Everglades project in this curriculum packet ask students to consider the following focus question: The year is 2010. The National Weather Service has studied the last decade's rainfall rates and the storm patterns over the Atlantic Ocean and has produced an alarming forecast: over the next 5 years, the Everglades region will experience a 30-percent decrease in the amount of rainfall it receives. How will your group respond to this serious decrease in rainfall? Create an action plan that will minimize the damage the long period of dry weather will cause to human and ecological interests.

To develop an answer to these complex questions, students will need to:

- understand the concept of a water budget,
- predict characteristics of the Everglades region in the future, including the size of the watershed, the population, the amount of rainfall,
- learn how soils reveal chemical changes in an environment over time, and
- explore the unique geology of the Everglades.

At the end of this project, students should produce a plan for meeting the region's water needs in light of the upcoming drought. Their plan should address how they think the drought will affect the environment, residents, and agribusiness. They should also provide justification for their plan, based upon the data they received in the Student Packet, their understanding of the water budget, and the lessons they learned through calculation and experimentation.

Opening Session

Help students look through the Student Packet. Ask them to read through the tables of data and, in small groups, write generalizations about the Everglades region on the basis of the data. (In this packet, the Everglades region is defined as Broward, Dade, and Palm Beach Counties.) Post these generalizations and discuss them as a class.

Return to these generalizations as students complete the three activities in the Teacher Packet.

Activity 1
The Everglades Spending Plan — Water Budgets and the Hydrologic Cycle

Purpose

This activity will acquaint students with the hydrologic cycle and introduce watersheds and water budgets. Students will realize that water is a limited resource and that they will have to consider competing interests as they allocate this resources.

Materials

- 1/2-gallon clear plastic beverage bottle,
- roll of masking tape,
- marker,
- water, and
- graduated cylinder or beaker.

Procedure

1. Before beginning the activity, discuss the hydrologic cycle with students. (This information may be for review.) Ask students to make a sketch that explains the hydrologic cycle, then use the illustrations to review the components of the hydrologic cycle. Explain that water circulates continually in its three states — liquid, solid, or vapor — through the geosphere, atmosphere, hydrosphere, cryospohere, lithosphere, and the biosphere.

2. In small groups, have students discuss the meaning(s) of the term, "watershed." Provide dictionaries, encyclopedias, and textbooks. How many definitions can they find? Direct the discussion to the following definition of watershed: all of the land that drains into a particular body of water.

3. Have students brainstorm about the possible sources of water and various methods of drainage, such as rivers, streams, rainfall runoff, storm drains, gutters, and so forth. Have students

generate a list of ways that humans affect the watershed system. Revisit this topic as you introduce Activity 2, "How Big is the Watershed?"

4. Working in pairs, have students calibrate a clear plastic bottle in 50 mL graduations by placing a strip of masking tape along its length and marking the gradations. Have them pour 50 mL of water into the bottle and mark the water level, continuing this process until the bottle is full.

5. Tell students that the water in the bottle represents the amount of water in a model watershed, and that they are in charge of allocating water for a growing town of 1,000 households. Before the students begin allocating, have them make a list of uses for the water in the model watershed. (Use the following table as a guide.) Point out that there is a minimum volume of water required to sustain streamflow and that streamflow must be maintained. You may wish to assign mL of water use per household for each water use, or you may use the sample provided below.

6. Once the amount of water used for each purpose has been assigned, have the groups pour water from their 1/2-gallon bottles to represent each use for the 1,000 households in the town. Students should record the amount of water left after each withdrawal.

7. Have students devise a method to determine the maximum number of households the model watershed can support.

8. Once the activity is complete, lead students into a discussion of water budgets. (Use the information below as background for the discussion.) Ask them to revisit the Focus Question for the Everglades. How will the drought affect the water budget in general? What effects might the drought have on each of the interested parties?

Discussion of water budgets

When discussing the concept of a water budget (the freshwater available for plant, animal, and human use plus the water necessary to maintain stream flow), you many want to begin by discussing the distribution of water in the hydrosphere:

97.30% in the ocean (saltwater),
2.14% frozen into glaciers,
0.54% ground water,
0.02% in streams, rivers, freshwater and saltwater lakes, and soil moisture.

To determine a region's water budget, hydrologists consider "deposits" to be water from precipitation, and "withdrawals" to include water lost to the atmosphere through evaporation and transpiration, water which runs off to rivers, streams, and lakes, and water that seeps underground. Humans also make withdrawals from the water account. Although much of this water is recycled back into the system, only a small portion of water used in agriculture is returned to the account. When the account is overdrawn, humans rely on water supplies stored in aquifers.

For the continental U.S., about 3.8 trillion gallons of water are credited to the water account annually through precipitation. Sixty-six percent is returned to the atmosphere through evapotranspiration, 31percent runs off and 3 percent enters the ground-water supply. South Florida's water budget differs from the national water budget. To highlight south Florida's unique water budget, refer students to the inflow and outflow pie charts in their Student Packets.

Adapted from "Watershed Wisdom." Ellen Pletcher Metzger, *Journal of Geological Education,* 1993, v.41, p. 508.

Activity 2
Disappearing Drainage — the Incredible Shrinking Everglades Watershed

Purpose

This activity will introduce students to the drastic changes in the Everglades watershed. They will use their understanding of the historic changes in the watershed to help them predict what the Everglades watershed will be like in 2010. This activity will also introduce them to changes in land use in the Everglades watershed area.

Sample Table of Water Use in the Model Town and Amount Needed

USE	WATER NEEDED
minimum streamflow	550 mL
household use	50 mL/1,000 households
industrial use	25 mL/1,000 households
agricultural use	50 mL/1,000 households
hydroelectric use	25 mL1,000 households

Materials

- original and present Everglades watershed maps (see Student Packet),
- string,
- rulers,
- graph paper,
- tag board or cardboard for mounting,
- cutouts of historic and present day Everglades watershed, and
- balance.

Procedure

1. Ask students to examine the two watershed maps provided in the Student Packet. Ask them to compare the maps, then list changes in the Everglades watershed from the original to the present day. Changes include the decline in watershed area, the addition of agriculture, the loss of wetlands, and the introduction of Water Conservation Areas.

2. Open a discussion of the changes in the watershed configuration and how these changes might be results of the impact of human settlement on the Everglades. Have the students brainstorm reasons why the watershed configuration has been changed.

Note: Hold this discussion before students read the Student Packet text about the history of the Everglades.

3. Tell students that their next task will be to determine the change in area of the Everglades watershed. Have students brainstorm about ways they can calculate the difference in the areas of the original and present watershed. Once they have generated a list of methods for calculating the areas, have students work in pairs or small groups to determine the change in watershed area. Have each group try a different technique from the list.

Possible methods for determining the change in the area of the watershed include the following:

- Use string to create shapes within the watershed that students will be able to calculate the area for.
- Put the graph paper on top of the watershed map. Trace the outlines of the current and historic watersheds. Count the squares within the traced outlines. Compare the numbers of squares.
- Cut out each of the historic and current day maps. Mount each of these on cardboard. Weigh the two pieces of cardboard. Compare the weights.
- By using two copies of the map, overlay the present watershed on the original watershed. Find the area of the difference in the two watersheds, then weigh the difference (as suggested above) or use graph paper to count the squares within the difference.

4. Once the students have completed their measurements, have each group report their results. (The difference is less than 25 percent) Have the students suggest why different techniques might yield different results. Ask students which techniques they believe yield the best results.

Extension

In addition to changes in the watershed caused by the extensive water-management system, other land-use changes have affected the movement of water in south Florida. Draining and filling in wetlands for agricultural use and paving for extensive urbanization have increased runoff and the risk of flood.

In the past, wetland areas were like sponges, storing great quantities of water and serving as a flood control. How does replacing the wetland with agricultural land or cities increase flood hazards? Students can model the three, land-use wetlands — foam rubber, sponge, or a premium paper towel; farmland — mix of sand and potting soil; urban area — smooth hard surface like a clipboard or coated cardboard (cereal box). Have students design experiments where they can investigate the characteristics of surface water on wetlands, farmlands and urban areas by simulating runoff over models of each surface.

Activity 3
The Everglades — A Geology All Its Own

Purpose

This exercise will acquaint students with the physiographic and geologic characteristics of the south Florida region. They will also speculate on how the geology of the region influences topography and land use.

Materials

- geologic map of south Florida (in Student Packet),
- geologic column of rock units in south Florida (in Student Packet),
- rock samples (optional),
- fossiliferous limestone (marine),
- freshwater limestone,
- peat,
- sandstone, and
- marl.

Background

Much of south Florida is underlain by limestone. The surface topography reflects the underlying geology. Low areas associated with limestone erosion allow for water to pond, thus supporting the wetlands environments necessary for peat deposition. The sequence of freshwater and marine limestones provide a record of sea-level rise and fall over the geologic history of the Everglades. Also, the Everglades themselves lie in a basin that was most likely an ancient atoll-like structure that formed a lagoon. The higher regions that allowed for the development of the

Everglades wetlands are fossil reefs.

The process of limestone deposition in the area began about 5 million years ago. During the last 5 million years, the sequence of marine and freshwater limestones preserved the record of seawater inundation of south Florida. About 5,000 years ago, post-glacial rise in sea level slowed enough to allow the build-up of coastal structures, which impounded freshwater in the lowlands that are not the Everglades. The Everglades have evolved since then as a result of the deposition of peats and marls (mixture of 35-65 percent clay and 65-35 percent calcium carbonate formed under marine or freshwater conditions known as calcitic muds.)

Just as geologists use limestone to determine past conditions in the south Florida region, they also use peat cores to reconstruct the more recent history of the region. Peat is a chemical filter that holds a number of cations and anions. Scientists have used these peat cores to document the build-up of pollutants in the Everglades over the past 100 years.

Procedure

1. Refer each group to the geologic map of south Florida in the Student Packet and provide a copy of the geologic column. If students are unfamiliar with geologic maps, explain that geologic maps show the surface distribution of rock formations in the area. Have students use the geologic column to identify the oldest and youngest formations in the area. Ask them to identify which geologic formations border the Everglades and which formations underlie the Everglades.

2. Ask what kinds of rocks and unconsolidated deposits are represented on the geologic maps. (Show samples of these rocks if you have them.) Do they have any experience with these rock types? Have them speculate on what the difference is between marine and freshwater limestones. How did these rocks, which form underwater, end up on dry land? How did marine limestones, which are deposited in seawater, end up associated with the freshwater Everglades?

Use these discussions to introduce the concept of sea-level rise and fall related to the retreat and advance of continental ice sheets.

3. Have students use the geologic map and column to reconstruct the history of the Everglades region by relating marine and freshwater limestones to sea-level rise and fall. Ask them if they can determine the last time the region was under seawater? What has happened to the region since then?

Now would be a good time to discuss the use of peat cores in determining the environmental health of the Everglades. See the Discussion of Peat Cores below.

4. Have the students compare the land uses on the watershed map to the geologic units which occur in the area. What conclusions can they draw about distribution of rock types and present day land use?

Discussion of Peat Cores

USGS scientists are using peat cores to study peat accumulation rates and the change in peat chemistry from 1961 to the present. They have sampled two sites in Water Conservation Area 2. The first area shows a shift from saw-grass to cattail vegetation due to the increased nutrient input it receives from canal water. Peat accumulation near the canal has nearly doubled in this area. The second area, with near-pristine, low-nutrient conditions, shows slower rates of peat accumulation. The differences in these areas are recorded in peat cores as differences in preserved plant material and differences in peat chemistry.

Since 1961, peat chemistry shows increases in phosphorous, sulfur, copper, and zinc that probably originated from agricultural activities where they have been applied as fertilizer.

Land and people : Finding a Balance

Los Angeles

U.S. Department of the Interior
U.S. Geological Survey

Finding a Balance **is an environmental study project that allows you and a group of your classmates to consider real environmental dilemmas concerning geologic and hydrologic hazards and to provide solutions to these dilemmas. The student packet gives you most of the information you'll need to answer the Focus Question, information like maps, data, background, a reading about the region, and a description of the "Interested Parties," or the various interest groups that have a stake in the outcome of the Focus Question. While you are working on this project, each member of your group will take a role, or become one of the interested parties. Your teacher will guide you through a series of discussions, activities, calculations, and labs. At the end of this project, your group will be asked to present and justify a solution to the environmental dilemma.**

Reading

From *The Control of Nature* by John McPhee.

"In Los Angeles versus the San Gabriel Mountains, it is not always clear which side is losing. For example, the Genofiles, Bob and Jackie, can claim to have lost and won. They live on an acre of ground so high that they look across their pool and past the trunks of big pines at an aerial view over Glendale and across Los Angeles to the Pacific bays. The setting, in cool dry air, is serene and Mediterranean. It has not been everlastingly serene.

On a February night some years ago, the Genofiles were awakened by a crash of thunder — lightning striking the mountain front. Ordinarily, in their quiet neighborhood, only the creek beside them was likely to make much sound, dropping steeply out of Shields Canyon on its way to the Los Angeles River. The creek, like every component of all the river systems across the city from mountains to ocean, had not been left to nature. Its banks were concrete. Its bed was concrete. When boulders were running there, they sounded like a rolling freight. On a night like this, the boulders should have been running. The creek should have been a torrent. Its unnatural sound was unnaturally absent. There was, and had been, a lot of rain.

The Genofiles had two teen-age children, whose rooms were on the uphill side of the one-story house. The window in Scott's room looked straight up Pine Cone Road, a cul-de-sac, which, with hundreds like it, defined the northern limit of the city, the confrontation of the urban and the wild. Los Angeles is overmatched on one side by the Pacific Ocean and on the other by very high mountains. With respect to these principal boundaries, Los Angeles is done sprawling. The San Gabriels, in their state of tectonic youth, are rising as rapidly as any range on Earth. Their loose inimical slopes flout the tolerance of the angle of repose. Rising straight up out of the megalopolis, they stand ten thousand feet above the nearby sea, and they are not kidding with this city. Shedding, spalling, self-destructing, they are disintegrating at a rate that is also among the fastest in the world. The phalanxed communities of Los Angeles have pushed themselves hard against these mountains, an aggression that requires a deep defense budget to contend with the results. Kimberlee Genofile called to her mother, who joined her in Scott's room as they looked up the street. From its high turnaround, Pine Cone Road plunges downhill like a ski run, bending left and then right and then left and then right in steep christiania turns for half a mile above a three-hundred-foot straight-away that aims directly at the Genofiles' house. Not far below the turnaround, Shields Creek passes under the street, and there a kink in its concrete profile had been plugged by a six-foot boulder. Hence the silence of the creek. The water was not spreading over the street. It descended in heavy sheets. As the young Genofiles and their mother glimpsed it in the all but total darkness, the scene was suddenly illuminated by a blue electrical flash. In the blue light they saw a massive blackness, moving. It was not a landslide, not a mudslide, not a rock avalanche; nor by any means was it the front of a conventional flood. In Jackie's words, "It was just one big black thing coming at us, rolling, rolling with a lot of water in front of it, pushing the water, this big black thing. It was just one big black hill coming toward us."

In geology, it would be known as a debris flow. Debris flows amass in stream valleys and more or less resemble fresh concrete. They consist of water mixed with a good deal of solid material, most of which is above sand size. Some of it is Chevrolet size. Boulders bigger than cars ride long distances in debris flows. Boulders grouped like fish eggs pour downhill in debris flows. The dark material coming toward the Genofiles was not only full of boulders; it was so full of automobiles it was like bread dough mixed with raisins. On its way down Pine Cone Road, it plucked up cars from driveways and the street. When it crashed into the Genofiles' house, the shattering of safety glass made terrific explosive sounds. A door burst open. Mud and boulders poured into the hall. We're going to go, Jackie thought. Oh, my God, what a hell of a way for the four of us to die together.

The parents' bedroom was on the far side of the house. Bob Genofile was in there kicking through white satin draperies at the paneled glass, smashing it to provide an outlet for water, when the three others ran in to join him. The walls of the house neither moved nor shook. As a general contractor, Bob had built dams, department stores, hospitals, six schools, seven churches, and this house. It was made of concrete block with steel reinforcement, 16 inches on center. His wife had said it was stronger than any dam in California. His crew had called it "the fort." In those days, 20 years before, the Genofiles' acre was close by the edge of the mountain brush, but a developer had come along since then and knocked down thousands of trees and put Pine Cone Road up the slope. Now Bob Genofile was thinking, I hope the roof holds. I hope the roof is strong enough to hold. Debris was flowing over it. He told Scott to shut the bedroom door. No sooner was the door closed that it was battered down and fell into the room. Mud, rock, water poured in. It pushed everybody against the far wall. "Jump on the bed," Bob said. The bed began to rise. Kneeling on it — on a gold velvet spread — they could soon press their palms against the ceiling. The bed also moved toward the glass wall. The two teen-agers got off, to try to control the motion, and were pinned between the bed's brass railing and the wall. Boulders went up against the railing, pressed it into their legs, and held them fast. Bob dived into the muck to try to move the boulders, but he failed. The debris flow, entering through windows as well as doors, continued to rise. Escape was still possible for the parents but not for the children. The parents looked at each other and did not stir. Each reached for and held one of the children. Their mother felt suddenly resigned, sure that her son and daughter would die and she and her husband would quickly follow. The house became buried to the eaves. Boulders sat on the roof. Thirteen automobiles were packed around the building, including five in the pool. A din of rocks kept banging against them. The stuck horn of a buried car was blaring. The family in the darkness in their fixed tableau watched one another by the light of a directional signal, endlessly blinking. The house had filled up in six minutes, and the mud stopped rising near the children's chins."

Over the last 30 years, writer John McPhee has written 22 books on the world around us. His latest, *Assembling California,* is about the geologic and human history of California.

Focus Question

You and your classmates are members of a La Crescenta civic group that has been formed to evaluate the safety of your community's school children in the event of the following geologic and hydrologic hazards: earthquakes and landslides (including mud and debris flows). Using the maps, tables, and other information in this packet, your job is to present the study of the geologic and hydrologic hazards to children that attend the following schools: Monte Vista School, Valley View School, and Rosemont Junior High School. Once your group has discovered what the hazards are, you will decide whether school children are safe attending the three schools in their present locations, or new sites for the schools must be found. Your group will make a presentation at a La Crescenta "community meeting" in which you will describe your analysis about how the community can guarantee children's safety during school.

Note: The information in this packet focuses on the community of La Crescenta, about 15 miles north of Los Angeles. The environmental and geological issues raised in this discussion of La Crescenta are the same ones facing most southern Californians.

The Interested Parties

Many groups and individuals have a stake in the La Crescenta area in southern California and in the answer to the Focus Question. As your group works to answer the Focus Question, each person will play one of the following roles:

Parent

Parents want assurances that their children are safe when they attend school. They hold local officials legally responsible for their children's safety in this geologically dynamic area; however, parents are also unwilling to send their children to far-away schools.

Geologist

Geologists realize that unwise land-use choices increase safety risks. This member of the civic group will explain what the geologic and hydrologic hazards are and how they might affect the safety of children at school.

Developers

Developers want to continue developing the land at the foot of the San

Gabriel Mountains. They hope residents will be assured that children are safe at school and that the area is, or can be made, geologically stable enough to live in.

SUPERINTENDENT OF SCHOOLS

The school superintendent wants to assure parents that children are safe and wants State and Federal support to make children safe. This person will try to protect the school board's funds from being used for school rebuilding or remodeling.

The Los Angeles Area — What You Need to Know

Los Angeles County is a beautiful, crowded, complicated place to live, and lots of people want to live there. Southern California has grown tremendously over the last century and in recent years. From 1980 to 1992, Los Angeles County had the largest population growth in the nation. Los Angeles County may be attractive, but it is not a peaceful place to live, in geologic terms. Many population centers are in areas of natural hazards, including earthquakes, floods, landslides, and mudflows.

The effects of urban growth are heightened in a region with such dynamic geology. Increased population puts great pressure on the environment. For example, increased recreation in the mountains increases the number of fires. Fires lead to erosion and erosion can lead to landslides.

The San Gabriel Mountains have always experienced fires, floods, and landslides. But, because more people live in the foothills of the San Gabriel Mountains, in communities like La Crescenta and Montrose, normal geological processes have become hazards. To build these communities, people have altered hillsides and drainage systems, have replaced absorbent top soils with runoff-causing asphalt. As the area has become more crowded, it has become necessary and desirable to build homes into the hillsides. To build safely on steep slopes, people have had to alter the slopes, thus decreasing the slopes' stability.

Climate — Warm, Dry Summers and Cool, Wet Winters

The topography of Los Angeles is diverse. The landscape ranges from beach to mountain, from desert to woodland. The Los Angeles area divides distinctly into the Los Angeles basin, which includes most of the city, the surrounding San Gabriel and San Fernando valleys, and the backdrop of high mountain ranges.

Los Angeles' weather is greatly affected by topography. The climate within the city varies widely. Summer temperatures can range from a cool 68 degrees Fahrenheit on the coast to 80 degrees or 90 degrees Fahrenheit only 20 miles inland. During the winter, heavy rains are common and a single storm may drop as much as 3 inches of rain in an hour.

The San Gabriel Mountains in the Los Angeles area cause special weather conditions. Here, moist air masses move inland from the Pacific and are cooled as they meet and rise over the mountains. This cooling produces heavy rainfalls on the windward slopes. This is called the orographic effect. The eastward mountain slopes are in a rain shadow, hence rainfall is much less.

The Geologic Hazards of La Crescenta

A HISTORY OF FLOODS

Floods are among the most frequent and costly natural disasters in terms of human hardship and economic loss. Much of the damage related to natural disasters (excluding droughts) is caused by floods and associated mud and debris flows.

Los Angeles Civic Center

	NORMAL MONTHLY PRECIPITATION (IN INCHES)	AVERAGE DAYS OF PRECIPITATION (.01 INCHES OR MORE)
January	2.92	6
February	3.07	6
March	2.61	4
April	1.03	1
May	0.19	1
June	0.03	≤1
July	0.01	1
August	0.14	5
September	0.45	1
October	0.31	2
November	1.98	3
December	2.03	5

Which county gained the most people between 1980 and 1990? Which county gained the largest percentage of growth during that period?

About how much rainfall does each storm bring? Answer this question by dividing the monthly precipitation amount by the number of days per month with measurable rain. Which month has the heaviest storms?

Floods can be categorized by what caused them. Dam failure can cause catastrophic flooding. If a dam fails as a result of neglect, poor design, or structural damage caused by an event such as an earthquake, a gigantic quantity of water is let loose downstream, destroying anything in its path. Intense or prolonged storms that drop large amounts of rain within a brief period can cause flash floods. Flash floods occur with little or no warning and can reach full peak in a few minutes.

Southern California's climate makes floods more likely. The area has a distinct wet season. Floods are more frequent during this season. When a very wet winter follows several dry ones severe flooding can occur.

In *The Control of Nature,* John McPhee writes about the dramatic floods of 1978. But dramatic floods occur regularly in the San Gabriel foothills. La Crescenta, Shields Canyon, La Canada, and Pickens Canyon have experienced several profound and damaging floods during the 20th century.

The year 1934 came in with a bang in Los Angeles County. The "New Year's Day Flood" in the La Canada Valley killed more than 40 people, destroyed about 400 houses, and damaged streets, bridges, and highways. A deadly debris flow killed 12 people who had gone to seek shelter in the Montrose Legion Hall. The debris simply crashed through the middle of the building, leaving holes in the uphill and downhill walls.

Why was the 1934 debris flow so damaging? Two reasons — fire and lack of heavy rainstorms in the years before the flood. First, fire increases the likelihood of landslides after a heavy storm. Fire destroys the vegetation that anchors top soil, and makes it more likely that the soil will slide when saturated. A report on the 1934 storm notes, "About 7.5 square miles of mountain area tributary to La Canada Valley was burned over by a fire in November, 1933, and from this burned-over area came practically all of the run-off that produced the debris movement in the La Crescenta-Montrose district." Second, the 1934 storms produced the heaviest rainfall in years. Sediments of all sizes — including boulders weighing tons — had been building up in the canyons for a long time. The heavy rains and the burned hills caused the debris to flow, and destroy all in its path.

Living in Earthquake Country

Southern California is home to more than 20 million people and is vital to the Nation's economy. Unfortunately, the region is also laced with many active faults that can produce strong earthquakes. The San Andreas Fault is the best known. It runs almost the entire length of California and generates shocks as large as magnitude 8. In Southern California the last magnitude 8 earthquake was in 1857. But smaller temblors, like the 1971 San Fernando and 1994 Northridge earthquakes, occur more frequently. Both of these magnitude 6.7 quakes were very damaging.

An earthquake is a sudden, rapid shaking of the Earth caused by the breaking and shifting of rock beneath the Earth's surface. This shaking can cause buildings and bridges to collapse; disrupt gas, electric, and phone service; and sometimes trigger landslides, avalanches, flash floods, fires, and huge, destructive ocean waves (tsunamis).

More Earthquakes to Come

Southern California has a problem with earthquakes — it hasn't been having enough of them. After the 1994 magnitude 6.7 earthquake in Northridge (northwest of La Crescenta), scientists used new techniques to study seismic activity. They have discovered that Southern California has not had enough large earthquakes to release all the pressure building up underground.

When the tectonic plates under the Earth's crust grind against each other, energy builds. In Southern California, the stresses are distributed along the San Andreas Fault and other smaller faults. When too much stress builds up along a fault, the earth's crust cracks and earthquakes occur. Quakes must occur to relieve the pressure along the faults.

But a look back at the earthquake history of the last two centuries suggests that Southern California should have had seven times as many Northridge-sized earthquakes as it has had. The scientists' conclusion: in Southern California, the probability of a magnitude 7 or greater earthquake by the year 2024 is as high as 80 to 90 percent.

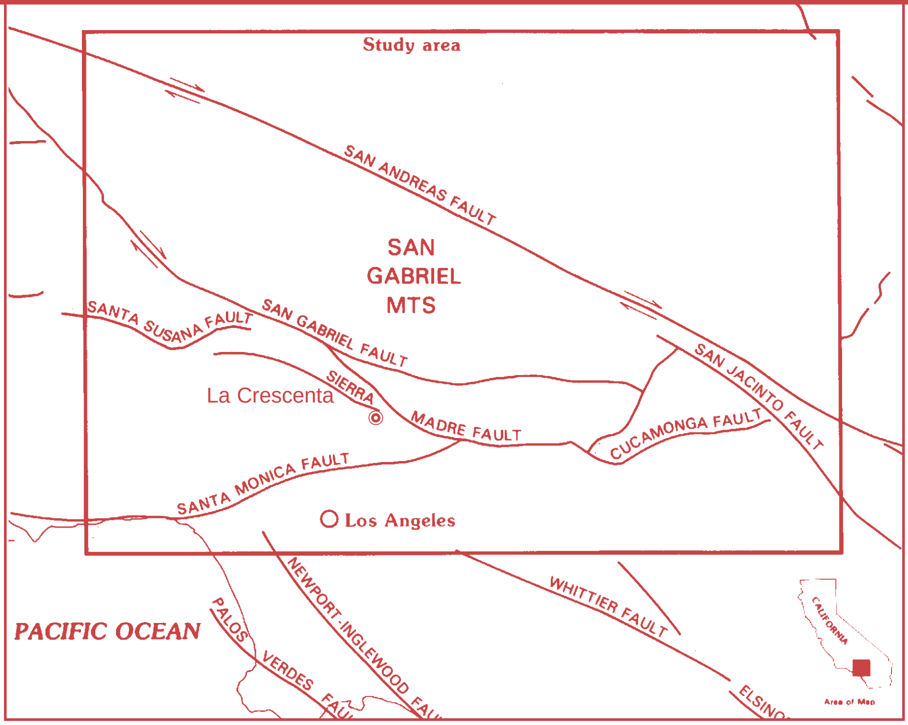
Landslides Too?

Landslides occur when masses of rock, earth, or debris move down a slope. Landslides may be small or large and can move at slow to high speeds. They are activated by storms and fires and by human modification of the land. New landslides occur as a result of rainstorms, earthquakes, volcanic eruptions, and various human activities.

Mudflows (or debris flows) are rivers of rock, earth, and other debris saturated with water. They develop when water rapidly accumulates in the ground, such as during heavy rainfall. Mud and debris flows can move rapidly down slopes or through channels and can strike with little or no warning at avalanche speeds. These flows can travel several miles from their source, growing in size as they pick up trees, cars, and other materials along the way.

Landslides are classified in several ways. One way to describe a landslide is by sediment size. Debris flows contain a wide assortment of sediments — boulders, sand, and mud — but generally less than 10 percent silt and clay. Earthflows contain few boulders and contain mostly fine sand, silt, and clay. Debris flows move faster, farther, but earthflows can move over lower slopes. In the mountains, debris flows and mudflows fill up channels and reservoirs. Landslides are also classified by material type and how it moves. Geologists also describe landslides by the percentage of saturation (with water) and the slope inclination necessary for the slide to occur. (See the table "Geologic environments likely to produce earthquake-induced landslides in the Los Angeles region.")

Landslides and mudflows are common events in Los Angeles County because of active mountain-building processes, rock characteristics, intense storms, and earthquakes. In fact, the 1994 Northridge



This figure shows that faults run under the Earth's crust in southern California like veins run under your skin. Remember that an earthquake is a release of stored energy that causes the sudden movement of rock on opposite sides of a fault.

earthquake triggered more than 10,000 landslides. Many landslides have been occurring over the same terrain since prehistoric times. Although they may be stable right now, these landslides can be activated by storms, fires, or inappropriate human modification of the land.

Debris Basins — Catch It If We Can

Since the 1930's, debris basins have been used to catch sediments that otherwise could damage land downstream. The huge basins are designed to catch large amounts of sediment. When they become about 25 percent full, debris basins are cleaned out. Removing the debris is expensive. Each basin holds about 78,480 cubic yards of debris! One reason debris removal is so expensive is that Southern California is running out of places to put the debris. The sediments have to be taken further away for disposal, increasing the cost. Another problem is that some basins have filled up during storms. Generally, however, when debris basins are in the right place, they do a good job of protecting developments downstream from debris flows.

NEWSFLASH!

The Population's Growing Just Ask the Mountain Lions

To learn more about what's happening in the Los Angeles area, read the following newspaper articles.
"Big Southland Population Jump Expected"
by Jesus Sanchez
Los Angeles Times July 13, 1995.

"Bolstered by an anticipated economic revival, the Los Angeles area will grow by 2.3 million residents over the next decade, the largest numerical gain of any metropolitan area in the Nation, according to the study scheduled to be released today by the Palo Alto-based Center for Continuing Study of the California Economy....

In the Los Angeles area, the center's estimated regional population growth rate will exceed the pace of the past five years, when the area was hit by severe economic slump. The study's authors said the newcomers will be drawn to the area by the job growth in such industries as high-technology manufacturing, foreign trade, tourism, and entertainment....

The report had good news for the Los Angeles area's long-suffering residential real estate market, which will benefit from the anticipated addition of between 750,000 and a million new households by 2005.

Among the study's other major findings and projections for the region:

- The size of the school-age population — ages 5 to 17 — will rise by a million in the next 10 years...
- The share of households with incomes above $75,000 will grow from 22.5 percent this year to nearly 32 percent by 2005."

"Officials Hunt for Menacing Mountain Lion"
by Nicholas Riccardi
Los Angeles Times, March 14, 1995.

"Sheriff's deputies and state officials hunted big game in the foothills near La Crescenta on Monday — a mountain lion that they say has killed two dogs and come within 10 feet of humans over the past week.

The most recent encounter was at 1 a.m. Monday, when Chul Yoon was awakened by the barking of his Akita dog....When Yoon looked out his window, he saw a mountain lion clamp its jaws around the 80-pound dog's neck and drag it over the 4-foot stone wall that separates Yoon's back yard from the surrounding woods....

Several residents have also reported seeing a big cat in the La Crescenta Valley over the last week, officials said.

Sightings are not that unusual anymore, said Patrick Moore, a Fish and Game spokesman. But the incidents indicate that there is a mountain lion up there that's found an easy way to find a meal. It's easier to snatch a dog than spend all that time fighting over deer.

In the last few years, numerous residents have seen mountain lions in the foothills, as the cats overrun their habitat and suburban developments encroach...

...It's just coming too close to human beings for comfort, [Moore] said. The fear is that it's only a matter of time before a human being is involved."

For Your Information: We Have a Plan

Unlike earthquakes, debris flows can be predicted and avoided to some extent. Earthquakes occur without warning and create most of their destruction within minutes. But rainfall-induced debris flows develop over several hours, leaving some time for forecasting, warning, and emergency response. The USGS and the National Weather Service operated a real-time warning system for rainfall-induced debris flows in the San Francisco Bay region for a decade (1986-1995), and were usually able to provide a general advisory (a watch) early in the storm. When necessary, they provided a warning at the beginning of significant debris flow activity.

Even if a school is in the path of a potential debris flow, there should be time for an orderly evacuation, that is **if** an advisory is issued, and **if** an evacuation plan exists. The plan must include enough school buses, drivers, and a system for deciding who goes in which bus. Most important, the plan must include a safe place to take kids until the storm passes and their parents can pick them up.

Glossary

Use these definitions of important terms as you answer the Focus Question.

CLINOMETER- An instrument used to measure angles.

DEBRIS FLOW- A moving mass of water-saturated near-surface materials.

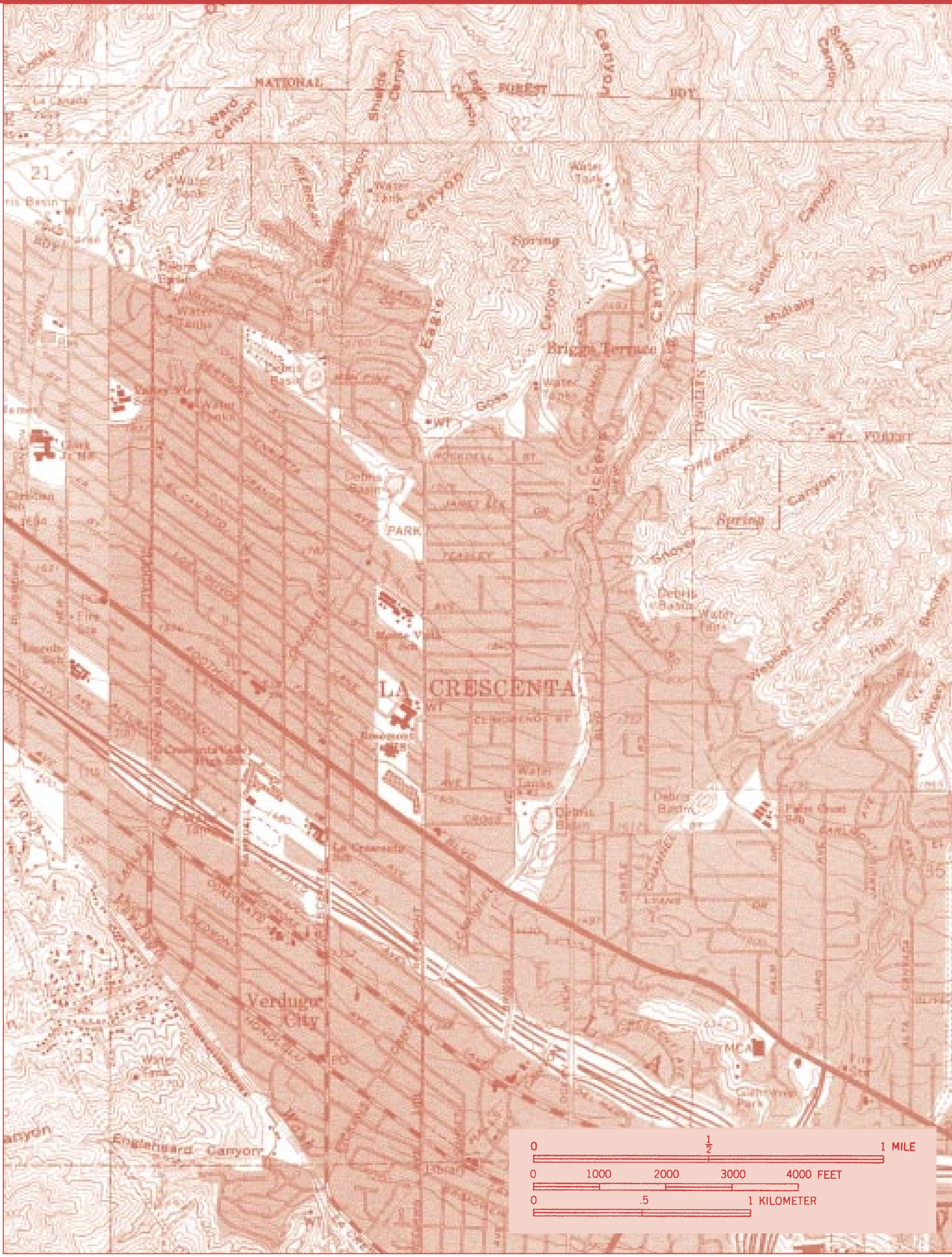
EARTHFLOW- A flowing mass of fine-grained soil particles mixed with water.

SEDIMENT- Solid rock or mineral fragments transported and deposited by wind, water, gravity, or ice. Sediment accumulates loosely in layers.

EROSION- The removal of weathered rocks by the action of water, wind, ice, or gravity.

LANDSLIDE TYPE	TYPE OF MATERIAL	MINIMUM SLOPE INCLINATION	REMARKS
Rock falls	Rocks weakly cemented, intensely fractured or weakened	40	Common near ridge crests and on spurs, ledges, artificially cut slopes, and slopes undercut by active erosion
Rock avalanches	Rocks intensely fractured and exhibiting significant weathering, planes of weakness dipping out of slope, weak cementation, or evidence of previous landsliding	25	Restricted to slopes of >153 yards relief that are undercut by active erosion
Rock slumps	Intensely fractured rocks, preexisting rock slump deposits, shale and other rocks containing layers of weakly cemented or intensely weathered material	15	
Disrupted soil slides	Loose, unsaturated sands	15	
Soil slumps	Loose, partly to completely saturated sand or silt; poorly compacted manmade fill composed of sand, silt, or clay; preexisting soil slump deposits	10	Common on embankments built on soft, saturated foundation materials, in hillside cut-and-fill areas, and on river and coastal flood plains
Soil block slides	Loose, partly to completely saturated sand or silt; poorly compacted manmade fill composed of sand or silt	5	Common in areas of preexisting landslides along river and coastal flood plains, and on embankments built on soft, saturated foundation materials
Soil earth flows	Stiff, partly to completely saturated clay and preexisting earth-flow deposits	10	
Soil lateral spreads	Loose, partly or completely saturated silt or sand; slightly compacted manmade fill composed of sand	0.3	Common on river and coastal flood plains, embankments built on soft, saturated foundation materials, delta margins, sand dunes, sand spits, alluvial fans, lake shores, and beaches
Rapid soil flows	Saturated, slightly compacted manmade fill composed of sand or sandy silt; loose, saturated granular soils	2.3	
Subaqueous landslides	Loose, saturated granular soils	0.5	Common on delta margins (subaqueous part)

Table: Geologic environment likely to produce earthquake-induced landslides in the Los Angeles region.



Topographic map (Activity 3). Study this topographic map of the La Crescenta area. Find the schools mentioned in the focus question, the debris basins, and the foothills of the San Gabriel Mountains. Note every feature, natural or manmade, that would affect childrens' safety in the event of a geologic hazard.

Geologic map of the Sierra Madre Fault Zone (Activity 3). This geologic map provides important information: the age, type, and distribution of sediments in the Sierra Madre Fault Zone. Use this map to consider the effects of earthquake-induced landslide in the La Crescenta area.

Description of Map Units

af — ARTIFICIAL FILL includes housing development, flood-control dams, flood-debris storage, and road fill.

Qc — COLLUVIUM (Holocene) talus and slopewash, generally brown to red-dish-brown poorly sorted heterogeneous deposits of locally derived debris. These deposits are more abundant than indicated on the map but are generally too small to show.

Qal — ALLUVIUM (Holocene and Pleistocene).

Qal_1 — UNIT 1 (Holocene) white to light-gray unconsolidated fine to coarse sand and gravel containing abundant cobbles and boulders; includes deposits of present stream channels, flood plains, and alluvial fans (now mostly controlled by flood-control channels and dams). Qal_1f, alluvial-fan surface.

Qal_2 — UNIT 2 (Holocene) gray to pale-brown unconsolidated fine to coarse sand and gravel containing abundant cobbles and boulders; includes deposits of stream terraces, recently abandoned flood plains, and alluvial fans with incipient soil. Qal_2f, alluvial-fan surface.

Qal_3 — UNIT 3 (Pleistocene) yellow to yellowish-pale-brown unconsolidated fine to medium sand and gravel containing abundant cobbles and boulders and highly weathered diorite clasts; includes stream terraces and moderately dissected alluvial fans with poorly to moderately developed soils. Qal_3f, alluvial-fan surface.

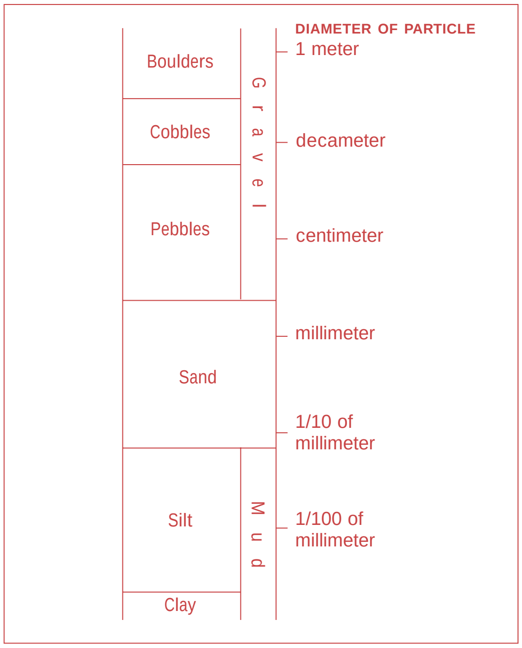


Table: Standard size classes of sediments. What's the difference between silt and sand? Size. This table shows how geologists classify sediments by size.

Land and people : Finding a Balance

Los Angeles

U.S. Department of the Interior
U.S. Geological Survey

Introduction

The La Crescenta project in this curriculum packet asks students to consider the following Focus Question: You and your classmates are members of a La Crescenta civic group that has been formed to evaluate the safety of your community's school children in the event of the following geologic and hydrologic hazards: earthquakes, and landslides (including mud and debris flows). Using the maps, tables, and other information in this packet, your job is to present the study of geologic hazards to children that attend the following schools: Monte Vista School, Valley View School, and Rosemont Junior High School. Once your group has discovered what the hazards are, you will decide whether school children are safe attending the three schools in their present locations, or new sites for the schools must be found. Your group will make a presentation at a La Crescenta "community meeting" in which you will describe your analysis about how the community can guarantee children's safety during school.

To develop an answer to this complex question, students will:

- explore the unique geology of the Los Angeles area,
- study the area's natural hazards and explore how human impact on the environment increases the effects of these hazards, and
- learn how to use a variety of maps (geologic, topographic) to answer questions about safety risks.

At the end of this project, students should produce a presentation or paper that they will share with the class. Their presentation will discuss what they believe are the most serious geologic and hydrologic hazards in the La Crescenta area, how those hazards affect school children, and whether the schools should be left where they are, closed, or relocated. They will provide justification for their analysis, based upon the information they received in the Student Packet, their understanding of geologic and hydrologic hazards, and the lessons they learned as they completed the three activities in this packet.

Activity 1
Sand Castles

Purpose

The 'sand castles' activity will help students understand slope stability and how adding water to earth materials affects slope stability.

Materials

Each group of students will need:

- One 1/2-gallon plastic bottle filled with dry sand,
- One plastic gallon-size tub,
- One foam cup with holes punched in the bottom (use a paper clip as a hole-punch),
- One graduated cylinder or measuring cup (something to measure the volume of water used during the activity),
- One ruler or yardstick, and
- One protractor with a piece of string and a small weight (or contact goniometer if available — used to measure the angle between mineral crystal faces).

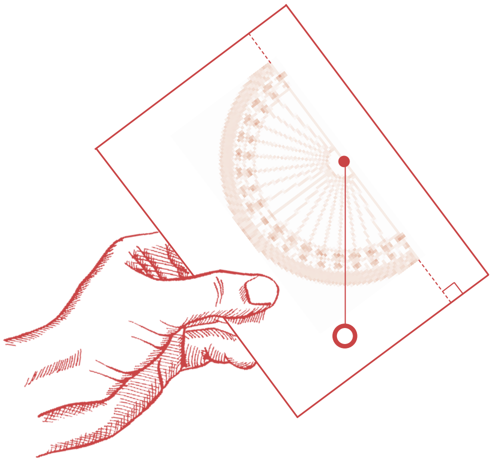
Procedure

1. Ask each group of students to build a sand castle in the plastic tub by using all the sand in the bottle. How tall can they make their castles? Encourage them to try different options with the dry sand, such as building the castle in the middle or against the side of the tub. Have them discuss the problems they encounter trying to build the tallest castle possible.

2. Once they have experimented for several minutes, have the students measure the height of their castles with the ruler. Make sure students measure from the base of the castle to its tallest point, not the length of its slope. Have students report their measurements to the class.

3. Have students brainstorm about how they might measure the slope angle. To measure the slope angle, students can construct a simple clinometer by using a protractor, a piece of string and some small weight, such as a nut or small bolt. Thread a weighted string (the string should be at least the same length as the straight edge of the protractor) through the pencil hole in the protractor. Glue the protractor to a piece of cardboard as shown in the illustration. Place the straight edge of the cardboard on the slope to be measured and read the angle of slope on the protractor scale. Have students record the slope angle.

4. Challenge students to suggest ways they can make their castles higher. Invite them to think of any means possible, even using materials other than sand. Students may suggest such methods



Make your own clinometer by gluing a protractor to a piece of cardboard, then threading a weighted string through the center. Your clinometer will help you measure slope angles as you build sand castles and models in these activities.

as building walls, bracing the sand, adding water to the sand, and adding other materials to the sand. Record these suggestions on chart paper so students can refer to them later.

5. Have the students add water to the sand and, again, try to build a sand castle. Let them experiment until they are satisfied they have the highest possible castle. Collect height measurements from each group. Discuss the results of this second attempt to build the castle, then compare the wet sand castle heights to the dry sand castle heights. Have students calculate the average height of the dry sand castles and the average height of the wet sand castles.

6. Ask, "Why do you think the wet sand castles are higher?" Students will realize that wet substances have different properties than dry ones. Ask students to think of other instances in which adding moisture changed the property of a dry substance, such as adding milk to flour when baking.

7. Ask students what they think will happen if they add more water to their sand castles. Suggest that the groups 'rain' on their castles by filling the perforated Styrofoam cups with water and then letting the water rain on the castle. They should fill the perforated cups with 100 mL of water at a time so they can easily record the amount of water that caused the castle to slump.

8. Have the groups observe how their castle changes as it becomes wetter. Students should describe these changes in their lab notebooks, as well as the amount of water they rained on the castle.

9. Initially, the changes in the sand castles will be subtle. At some point the sand castle will slump, causing a landslide. When all of the sand castles have slumped, gather the class together to discuss their observations. Ask students how much water they had poured on the castle when it began to look like a liquid instead of a solid. Ask them where the castle failed first—the top, bottom, or middle?

Discussion

This activity is an excellent way to introduce concepts, such as erosion, geologic and hydrologic hazards, mass movements of earth materials (landslides) and water-earth interactions. Gravity provides the energy for landslides, but water also plays a number of roles. Small amounts of water added to the sand increase the cohesion of the sand grains — surface tension — as the water begins to fill pore spaces between the sand grains. As more water is added to the sand castle during the student-generated rain storm, the pore spaces fill with water and the force of the water actually pushes the sand grains apart, causing a landslide. Dry materials, such as sand, have a threshold of slope stability related to gravity and the cohesion of the material. Known as the angle of repose, this threshold limits the height of the castle for a given volume of sand.

Extension

- Discuss how the sand castles could be designed to prevent them from slumping. Ask students what methods they have observed of preventing walls from slumping. They might recall seeing retaining walls or terraces along rivers, streams, or highways.
- Build castles using other earth materials, then compare the height of these castles to the sand castles. Students can bring samples of soil from home.
- Explore how the rate of water flow affects erosion.

Activity 2
Creating a Topographic Model

Purpose

Students often have difficulty visualizing topography from two dimensional contour maps. In this activity, students will build a topographic model of Shields Canyon and the area south into La Crescenta. They will be able to see and feel the steep slopes in the area and the sharp change in topography from the San Gabriel Mountains to the nearly flat valley where the population is concentrated.

Materials

Each group will need:

- Topographic map of model area (Teacher Packet page 4),
- Thick cardboard boxes,
- Scissors,
- Tracing paper, and
- Glue.

Procedure

1. Begin by deciding what kinds of models the students will create. They could work in groups to construct models by using different vertical exaggerations (2:1, 4:1, 1:1) or, you may want to divide the map into smaller areas and have each group construct a model

of an area. After constructing the individual models, students would then assemble the models and create a model of the entire area.

You may want to invite your students to devise their own method of making a three-dimensional representation of the area. They may want to use modeling clay, Styrofoam, or sheets of acrylic. The model-making activity explained below uses heavy cardboard.

2. After deciding what area students will create a model of, explain the model-building process to the students. They will begin by tracing the outlines created by individual contour lines, starting with the lowest elevation. Using the traced shape as a template, students will then cut out cardboard to match the shape. Students will trace each subsequent (and higher) contour, reproduce the shape in cardboard, and stack it on top of the last cardboard shape. Students should glue each piece in place. They will need to refer to the topographical map to see how to place each layer of cardboard.

3. Once they have built the models, have the students compare the topographic map to their model. Comparing the model to the map will help students see that when the topography is steep, the contour lines are close together. When the topography is relatively flat, the contour lines are far apart. Ask students if the model surprises them in any way. Ask students to focus on the Shields Canyon area. Can they now see why in Shield's Canyon the contour lines make upside down v's.

4. Ask students a variety of questions that will help them interact with the model. Have them place markers on the map to represent the schools in the focus question. Ask them to indicate the necessary path of a debris flow.

5. Have students locate the debris retention basins on their models. Ask students to consider the following questions:

- Why were the basins placed where they are?
- What areas do the basins protect?
- What developed areas are not protected by a debris-retention basin?

6. Have students measure the slopes in their model area by using the clinometer they constructed in Activity 1 or a contact goniometer. How do the slopes in the model compare with the slopes of their sand castles? If the slopes in the model are steeper than the ones in the sand castle, ask students to explain why.

7. Display the models prominently during this unit. Have students refer to the models as they answer the Focus Question.

Extension

- Students could construct a series of topographic profiles, which are perpendicular, then connect the profiles.
- Students could pick new sites for debris retention basins that would protect development upstream, from existing basins.

Activity 3
Determining Earthquake-Induced Landslide Potential

Purpose

In this activity, students will use a geologic map of the La Crescenta area and slope inclination data, which are derived from the topographic map and their topographic model, to determine the possibility of earthquake-induced landslides in the region.

Materials

Each group of students will need:

- Geologic map of the Sierra Madre Fault Zone (Student Packet page 8),
- Topographic map (Student Packet page 7) and student-made topographic model,
- Table: Geologic environments likely to produce earthquake-induced landslides in the Los Angeles region (Student Packet page 6) (adapted from USGS Professional Paper 1360), and
- Table: Standard size classes of sediment.

Procedure

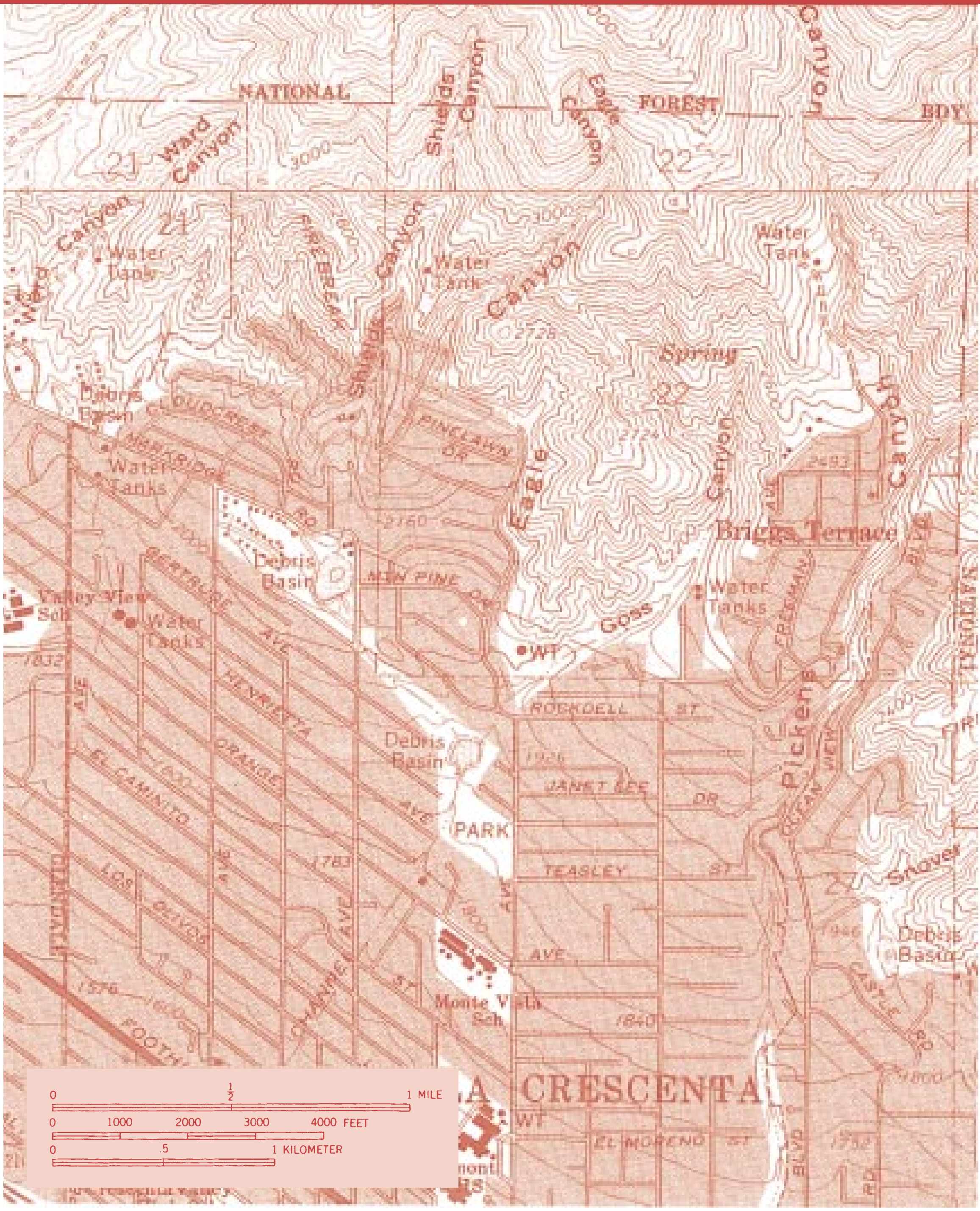
1. Provide students with copies of the materials listed above. Briefly explain to students what kind of information each of the materials (tables, model, maps) contains. For example, explain to students that a geologic map shows what materials are exposed at the surface.

2. Have students study the geologic map and the two tables. Ask students to locate the geologic environments listed in the table on the map.

3. Discuss the sediment-size table with the class. Explain that the table shows how geologists classify large and small sediments. Consider bringing in samples of the smallest sediments and creating mock pebbles, cobbles, and boulders out of wadded newspaper or paper-filled trash bags.

4. Have students use the tables, geologic map, and topographical model to answer the following questions about slope, geologic materials, and the risk of earthquake-induced landslide: Where is the landslide hazard the lowest? Where is the hazard the highest? What kinds of landslides are likely to occur in this region?

5. Have students mark the topographic map "Highest Landslide Risk," etc., as they answer these questions in Step 4.



Topographic map of model area (Activity 2). Create your own landslide hazard map. Use this topographic map to mark locations where you believe landslide risk is high or low.

6. Present students with the following scenario: It's February 1998. There's been an earthquake along the Sierra Madre Fault, magnitude 7.0 on the Richter scale. Have students find the Sierra Madre Fault on the geologic map. Then ask them to identify the locations where earthquake-induced landslides are likely to occur.

7. To connect this extended map interpretation activity to the Focus Question, ask students, "Based on the information in the geologic environments table, what can you predict about the potential for earthquake-induced landslides in the La Crescenta area?"

Extension

Students could predict what would happen in the La Crescenta region if an earthquake occurred right after a heavy rain.

Students could develop a susceptibility map and use it to answer the Focus Question in their final presentations.