Radioactivity in the Environment—A Case Study of the Puerco and Little Colorado River Basins, Arizona and New Mexico

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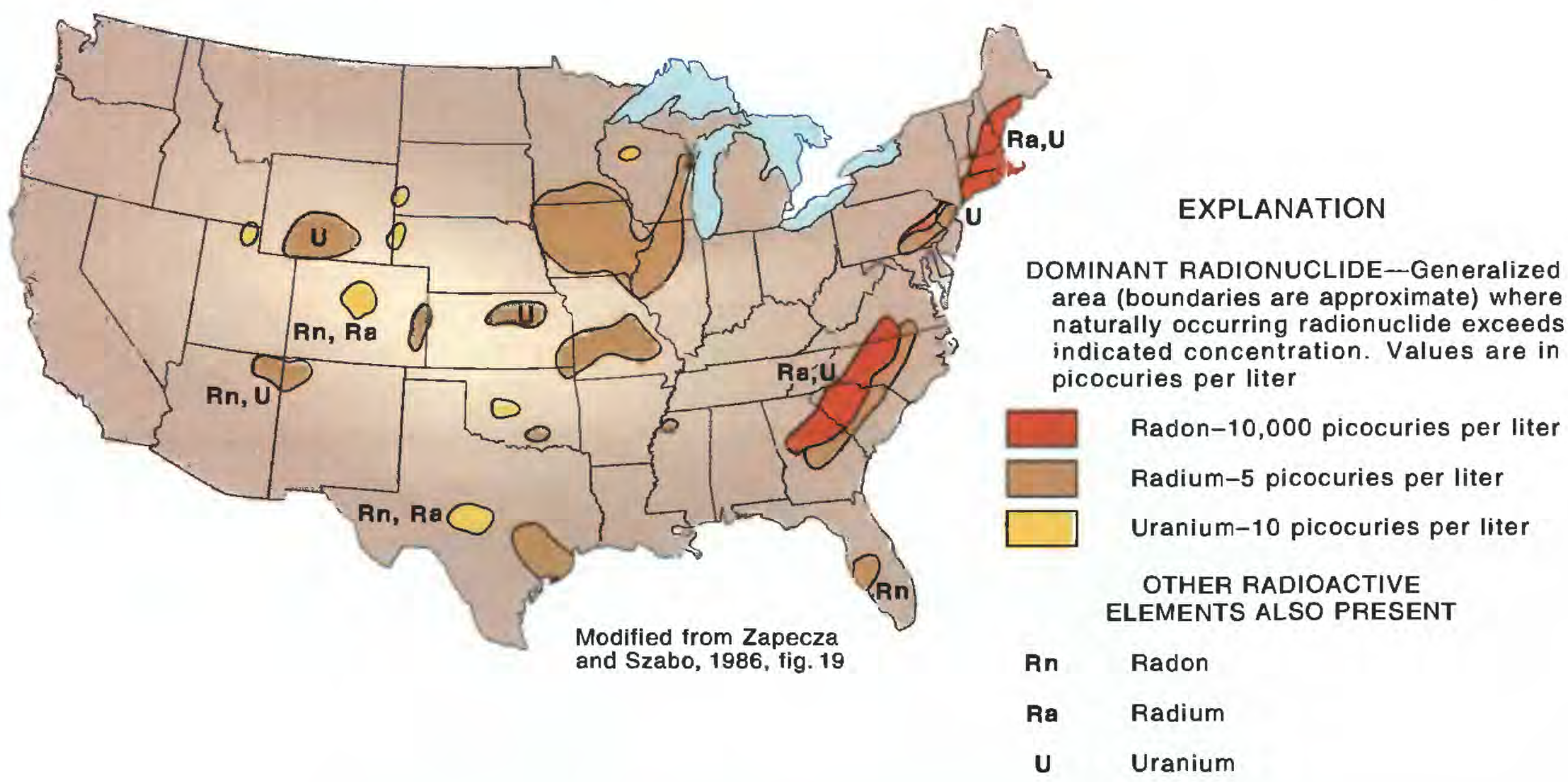
CONTENTS

TABLES

RADIOACTIVITY IN THE ENVIRONMENT—A NATIONAL AND LOCAL CONCERN

Many areas throughout the United States are known to have high amounts of natural radioactivity in rock, in streams and the sediment in streams, and ground water. The Colorado Plateau of Arizona and New Mexico has higher than average levels of radioactivity from natural sources, and this region contains more than half of all uranium mineral reserves in the Nation. The presence of radioactivity in our environment is a continuing concern of citizens, regulatory agencies, resource managers, and policy makers in the region, as well as in other areas throughout the United States. Why? Because radioactive substances, which are invisible, odorless, tasteless, and thus undetected by our senses, are toxic and have cancer-causing potential that can affect human health. Radioactive elements such as uranium, radium, and radon are normally present in low levels in all drinking water. The concentration and the composition of these elements in water may vary from place to place, depending principally on the type of soil and rock through which the water passes. In addition, levels of radioactivity may be increasing throughout the environment as a consequence of human activities, including mining and processing of uranium ore.

More than two decades of uranium mining and the failure of a mine tailings dam have released radioactive water and sediment into the Puerco River, leading to public concern that water used by residents and their livestock along the river (in New Mexico and Arizona) was contaminated. To address this concern, in June 1988 the U.S. Geological Survey (USGS) began a detailed study of radioactive elements in water and sediments in the Puerco and Little Colorado River basins. The study was done in cooperation with the Office of Navajo and Hopi Indian Relocation, the U.S. Bureau of Indian Affairs, the Navajo Nation, the Arizona Department of Water Resources, the Arizona Department of Environmental Quality, and the New Mexico Environment Department. This



High levels of radioactivity from radon, radium, and uranium are found throughout the United States.

report summarizes the results of the 4-year study.

The main purpose of the study was to find which radioactive elements are present, how these elements are distributed between water and sediment in the environment, how concentrations of radioactive elements vary naturally within the basins, and how levels of radioactivity have changed since the end of uranium mining. Scientists of the USGS studied the relation between streams and ground water to understand the processes that affect the transport of radioactive elements and evaluated the quality of ground water near the Puerco River in areas thought to be vulnerable to the effects of past uranium mining. The study area included the entire Puerco River basin in New Mexico and Arizona and reaches of the Little Colorado River, including major tributaries (such as Black Creek and the Zuni River) where no mining has occurred. These latter areas provide baseline information for determining whether the radioactivity of the water and sediment is a natural phenomenon or if it has been caused by and enhanced by human activities.

Sign warns visitors outside a closed uranium-processing mill in the headwaters of the Puerco River basin.

What is radioactivity? Why is alpha radiation a concern?

How much is too much?

How do radioactive elements occur in the environment?
In river water?
In river sediment?
In ground water?

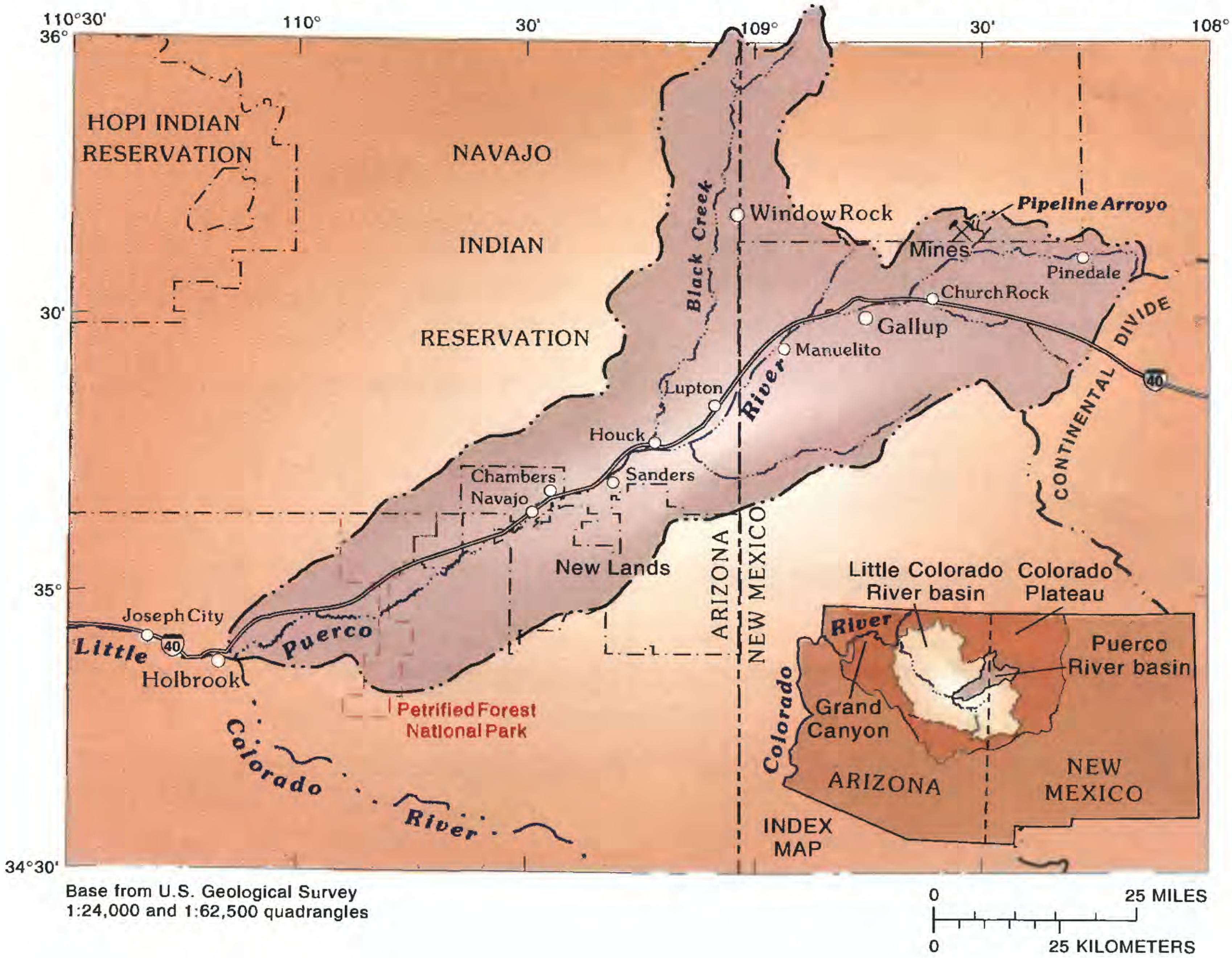
What is the source of radioactivity in the Puerco River?

What are the long-term effects of past uranium mining?

What is the potential risk to residents who live near areas where ground water is affected by mining?

THE PUERCO RIVER AND LITTLE COLORADO RIVER BASINS

The Puerco River and Little Colorado River basins are part of the Colorado Plateau in northwestern New Mexico and northeastern Arizona. It is a land of colorful rock, wide open spaces, and sky where one can see for miles. Both the Little Colorado and the Puerco Rivers are dry most of the year. The Little Colorado River begins in the White Mountains of east-central Arizona and flows approximately 350 miles to the Colorado River above the boundary of Grand Canyon National Park. From the sandstone cliffs of the Continental Divide, east of Gallup, New Mexico, the Puerco River flows about 130 miles westward to the Little Colorado River through the Painted Desert near Holbrook, Arizona. The Puerco River and the Little Colorado River downstream from the mouth of the Puerco River meander across a windy desert plateau, which is surrounded by gently sloping terraces and low mountains. Annual rainfall in this desert climate is between 9 and 13 inches. These two river valleys are a principal east-west route of travel and are traversed by Interstate 40 and by the Atchison, Topeka, and Santa Fe Railway. Thousands of visitors pass through this area each year to visit natural attractions on the Navajo Indian Reservation and the Petrified Forest and Grand Canyon National Parks. Most of the land is part of the Navajo Indian Reservation, although large



The Puerco River is a major tributary of the Little Colorado River. Recent population growth and changing lifestyles have created an increased demand for water in the basin.

sections are managed by private ranchers and landowners, the States of Arizona and New Mexico, and Federal agencies.

The Puerco River basin has been inhabited by native people for thousands of years. In the past, the population was in balance with the limited resources of a desert climate. Before this century, the principal inhabitants were Navajo Indian families depending on sheep and cattle for food and livelihood and living far apart from one another. River water was available only during seasonal runoff periods. Small springs, catch basins, and shallow hand-dug wells offered more dependable water supplies. In this century, wells were drilled and equipped with windmills capable of pumping water to the surface. Many of these wells are drilled in shallow rock and alluvium along the Puerco River. In the past few decades, the population has grown and shifted in density with more people living in towns and cities requiring larger water supplies. Indian and non-Indian residents no longer depend solely on agriculture. Although uranium mining was once important to the economy of the Puerco River basin, most residents presently are employed by government, commerce, construction, and other service occupations.

In the past decade, population in the Puerco River basin has grown dramatically as many Navajos have moved to an area along the river in Arizona, known as the New Lands area, as part of the Office of Navajo and Hopi Indian Relocation program. In the existing towns and newly developed areas, it is no longer possible for residents to rely solely on near-surface sources of ground water. The New Lands has constructed a public water system that relies on larger and deeper wells to satisfy the increased demand for water. In rural areas, however, many residents do not have public water supplies. All residents, however, share a common concern about the quality of their environment and their drinking water.

Archaeological evidence suggests that in the past the human population was in balance with the limited resources of a desert climate.

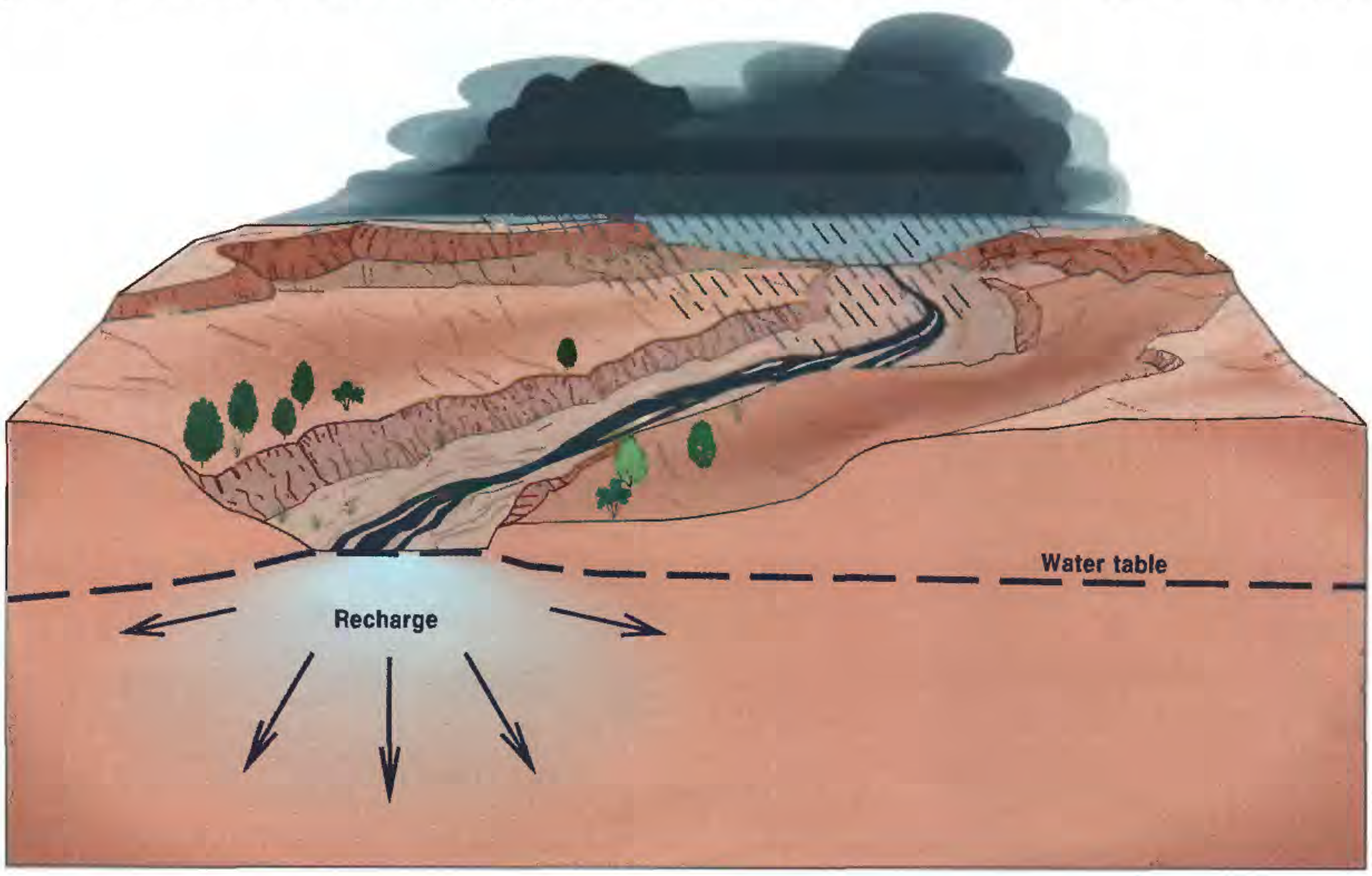
The Puerco River meanders across a high desert plain. The seasonally dry stream is sometimes used to water livestock.

Rainfall in this desert climate is between 9 and 13 inches in a typical year.

WATER IN THE PUERCO RIVER— A PRECIOUS RESOURCE

Water is a precious resource in this arid land of little rain. The Puerco River was once called *Tó Nízhóní* or "beautiful water" by local Navajos. Today, however, there is uncertainty whether the river is safe for use by either animals or people. Local residents worry that the water contains radioactive elements from past uranium-mining activities. Because there are few other convenient sources of water for livestock for miles around, many Navajo families say they have no choice but to allow their horses, sheep, and cattle to drink from the Puerco River when it flows. In addition, residents are concerned that radioactive contaminants from the river may have flowed beneath the stream channel to the underlying ground water. Because the Puerco River is often dry, ground water is the primary source of water supply. Although water from public water systems in the New Lands and in the larger communities of Sanders, Lupton, and Gallup is regularly tested and must meet all drinking-water criteria, most private wells are not tested. Many rural residents do not have their own water supply and travel many miles to transport water from shallow wells along the Puerco River that could contain radioactive contaminants. They are concerned that possible effects of radiation on their health will not be apparent for many years.

Surface water and ground water are commonly considered to be separate resources; in reality, they generally are closely interconnected. Ground water originates as rainfall that moves through the soil. Annual rainfall on the Puerco River basin averages about 10 inches. Much of this water flows over the land as runoff in washes and stream channels or is used by plants. In arid lands, a large part of rainfall is lost by evaporation before it can enter the ground. Only a fraction of the water moves through the soil below the root zone to become ground water. Contrary to popular belief, ground water seldom forms underground

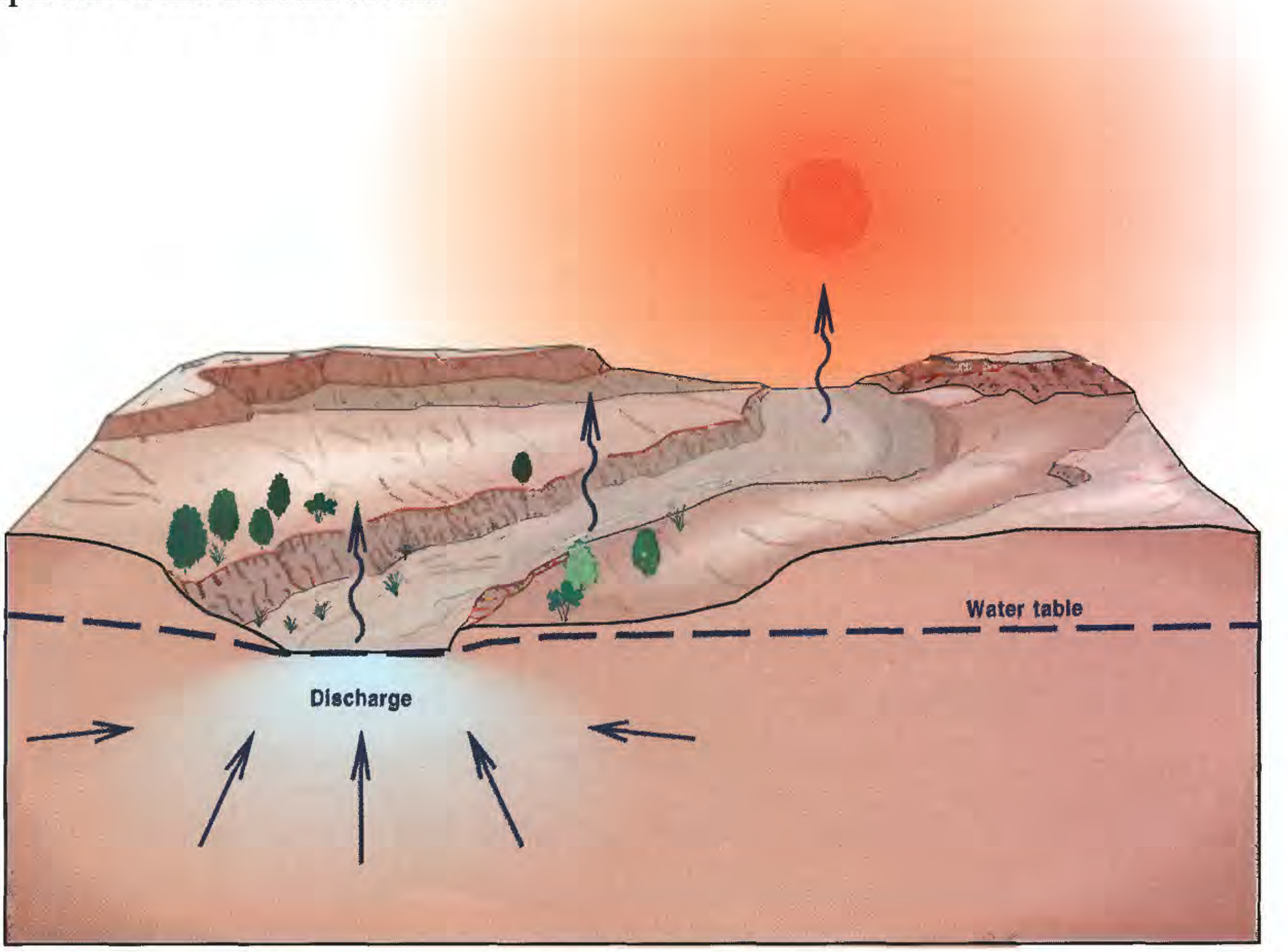


When the river flows, water moves downward as recharge to the aquifer.

"lakes" and "rivers." Instead, it fills the tiny spaces between sediment grains and travels very slowly. In fine-grained sediments, water may move at rates as slow as 1 inch per year, but in coarse sands and gravel it may travel tens of feet per day. A body of rock or sediment supplying usable quantities of water to wells and springs is known as an aquifer.

In the Puerco River basin, the shallow alluvial aquifer is a saturated layer of river-deposited alluvium that overlies sedimentary bedrock. The alluvium consists of fine sand interfingered with layers of silty clay. Ground water in the alluvium moves at a rate that ranges from about 0.10 inch to 3 feet per day. Water may remain in the alluvial aquifer from several decades to as long as several centuries. Shallow, near-stream water tends to be younger, and the oldest water tends to be deeper and farther from the stream.

The place where water first enters the ground is referred to by hydrologists as a "**recharge**" area. The water then moves through the aquifer to "**discharge**" areas. The river channel is a zone of both recharge and discharge where water is either gained or lost by the aquifer. When the river is flowing, water moves by gravity downward through the sediments to recharge the aquifer. When the river is dry, ground water is drawn toward the surface and lost through the plants and sediments by evaporation. In a few areas where rock is shallow, ground water may be forced to the surface as small springs. Because the water level in the alluvial aquifer generally is less than 2 feet below the streambed, the ground water is vulnerable to contaminants in streamflow.



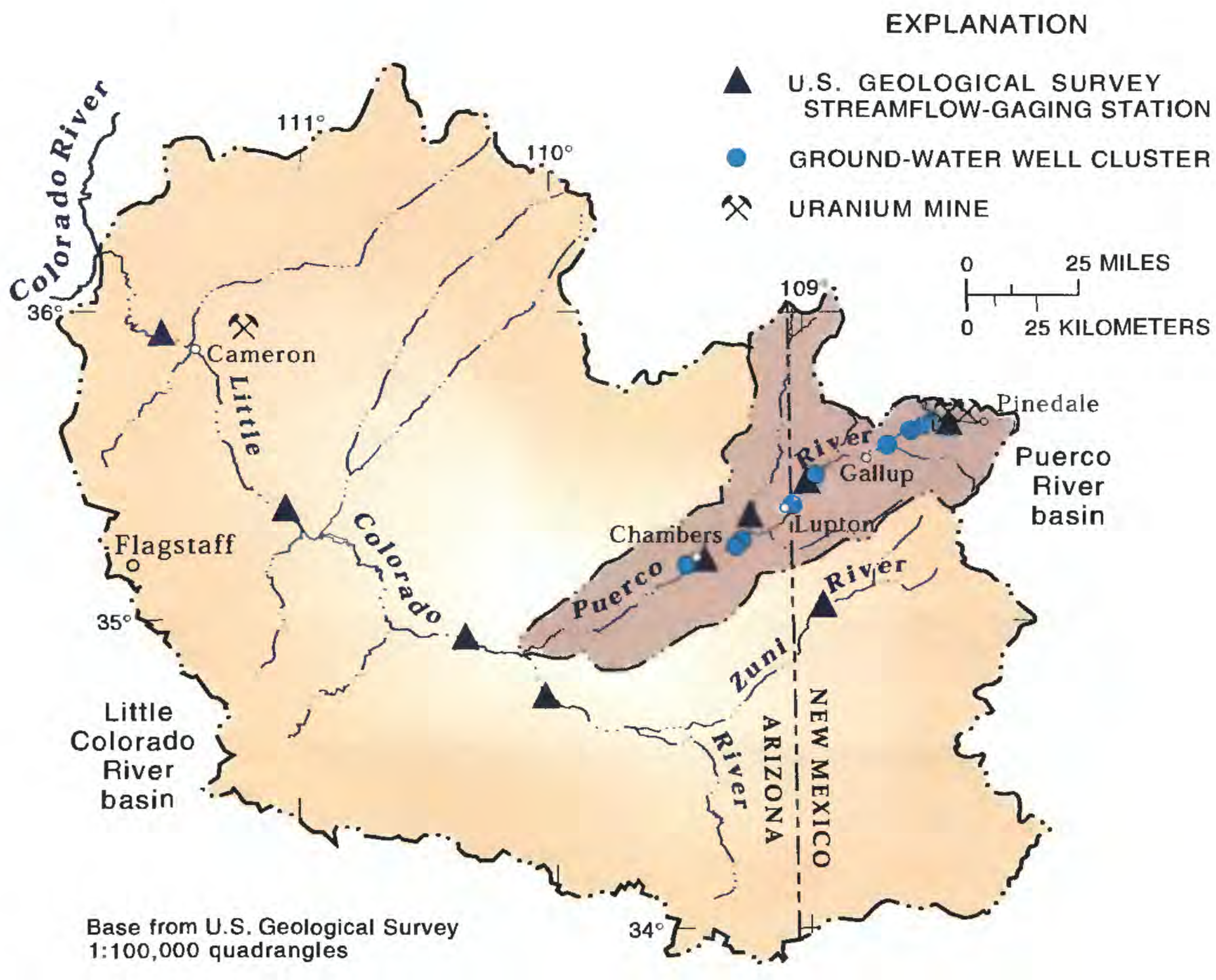
When the river is dry, ground water moves upward and is lost by evaporation through plants and sediments.

SAMPLING STRATEGY IN THE PUERCO RIVER AND LITTLE COLORADO RIVER BASINS

To determine the distribution of radioactive elements in the Puerco River basin, U.S. Geological Survey hydrologists collected samples of river water and sediment from a network of streamflow-gaging stations throughout the Little Colorado River basin and samples of near-stream ground water from a network of wells in the Puerco River basin.

SURFACE-WATER SAMPLES

The surface-water network included nine streamflow-gaging stations in the Little Colorado River basin. Six of the stations were downstream from the former uranium mining area—three stations on the Puerco River and three stations on the Little Colorado River downstream from the mouth of the Puerco River. In order to determine the quality of uncontaminated streamflow, the three remaining stations were selected at tributaries that were not affected by mining—at Black Creek, Zuni River, and the Little Colorado River at Woodruff. All gages were designed to automatically collect water and sediment during sudden and infrequent flash floods typical of the arid Southwest. Samples were filtered so that both water and sediment from the rivers could be analyzed separately for gross-alpha and gross-beta radiation; radioactive elements of uranium, radium, and



Surface-water samples were collected from a network of streamflow-gaging stations throughout the Little Colorado River basin. Ground-water samples were collected from a network of well clusters in the Puerco River basin.

thorium; and other dissolved and suspended trace elements that affect water quality.

GROUND-WATER SAMPLES

The ground-water sampling strategy was based on the assumption that the river was a linear source of contamination. Most of the 69 ground-water sampling points were selected in areas near the Puerco River where contamination from mining was thought most likely to occur. Some wells also were selected upstream from mining or on tributaries where no mining occurred. Many of the wells were drilled in groups referred to as well clusters. Thirty-eight wells were sampled from 10 well clusters from Pinedale, New Mexico, to Chambers, Arizona. Each well cluster con-

Streamflow-gaging stations were designed to collect water and sediment samples automatically during sudden flash floods.

sisted of three to nine wells drilled in a pattern of different depths and distances from the river channel. Temporary shallow wells were used to sample beneath the stream channel near each well cluster. This three-dimensional sampling strategy enabled hydrologists to determine both horizontal and vertical extent, as well as concentration, of radioactive contamination near the river. Wells sampled were less than 700 feet from the Puerco River and ranged in depth from a few feet to more than 150 feet below the land surface. To determine whether the shallow aquifer was connected with deeper water supplies, about 10 percent of ground-water samples from the underlying bedrock aquifer were analyzed. Ground-water samples were analyzed for radioactive constituents, such as uranium, radium, radon, and other dissolved trace elements that affect water quality. Selected wells were sampled repeatedly from 1989 to 1991 to measure changes in water quality with time.

Ground-water samples were collected from wells that ranged in depth from a few feet to more than 150 feet and were less than 700 feet from the Puerco River.

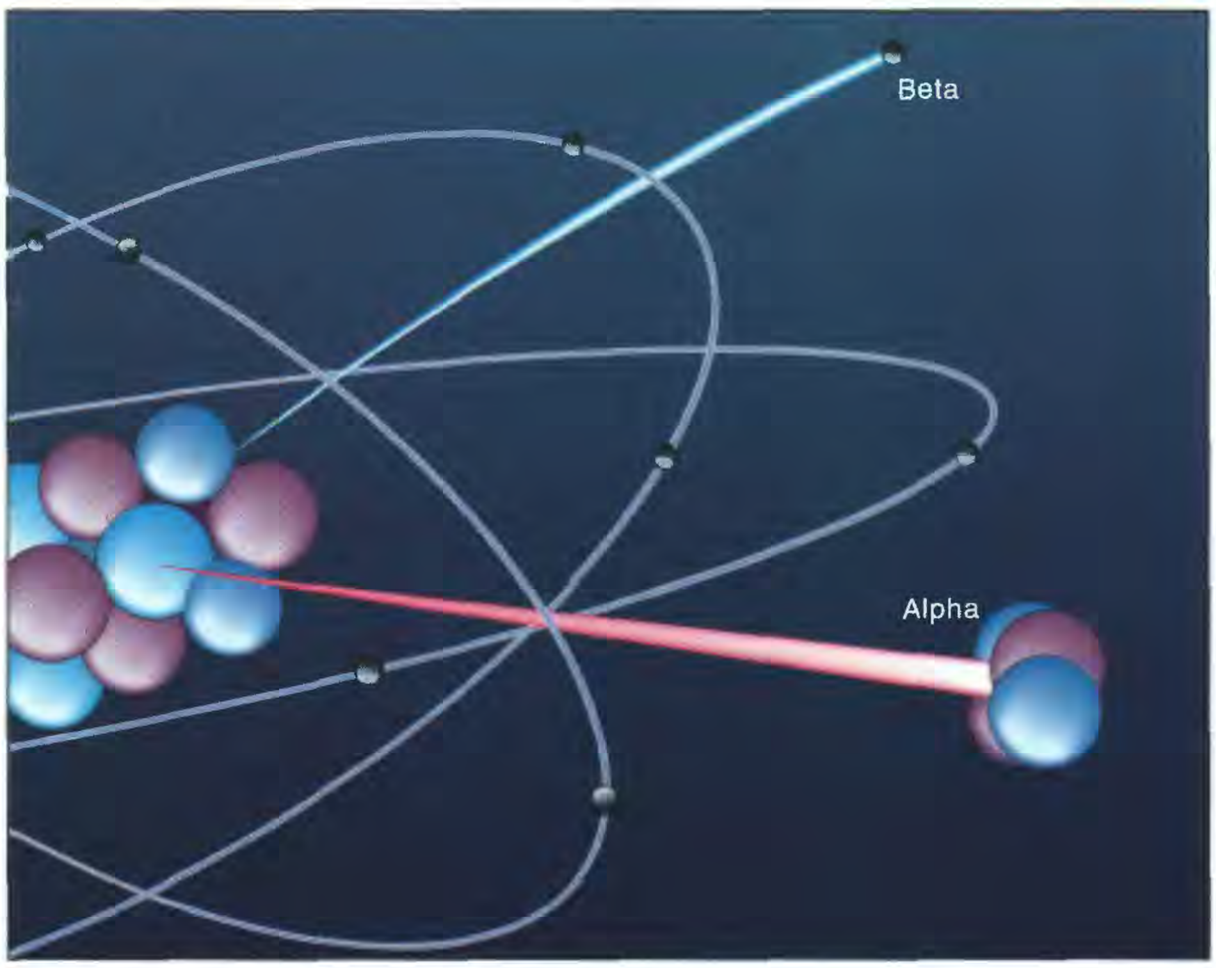
Petroglyph near the Puerco River, Petrified Forest National Park.

FACTS ABOUT RADIOACTIVITY

WHAT IS RADIOACTIVITY?

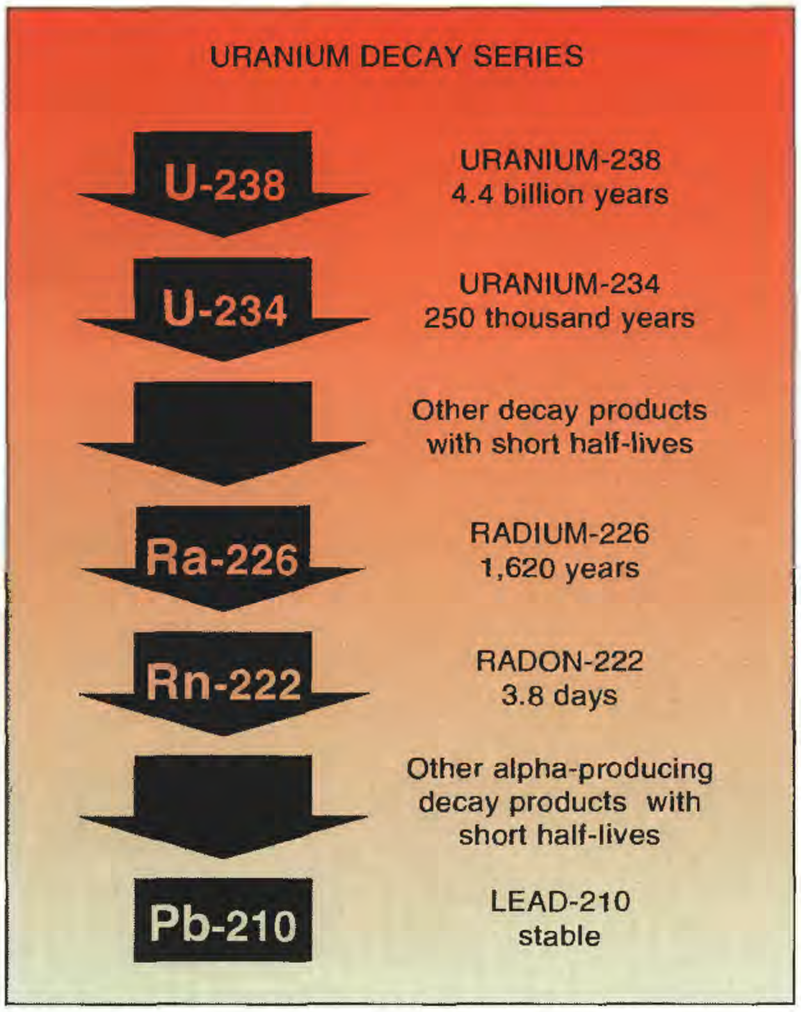
Radioactivity is the property of certain elements, such as uranium, to spontaneously break apart, releasing energy and mass. Atoms are the building blocks that form individual elements and are too small to be seen, even with the highest powered microscope. The nucleus or core of the atom, which is surrounded by tiny randomly moving particles called electrons, is composed of somewhat larger particles known as protons and neutrons. The quantity of protons and neutrons in the nucleus determines the physical bulk, or mass of the atom. The mass number identifies the type of atom or nuclide. For example, uranium-238 has a total of 238 protons and neutrons. All the atoms of a particular nuclide have the same mass; different nuclides have different masses. Most atoms are stable but certain atoms, known as radionuclides, are physically unstable because they change their structure by releasing radiation in the form of particles—protons, neutrons, and electrons—and (or) energy. This process is known as radioactive decay.

When a radioactive element decays, it is transformed according to a series of reactions known as a radioactive decay series. During a decay-series reaction, the parent atom gives off tiny particles of mass and bits of energy to become a new atom, known as a daughter product. This daughter product will eventually decay to form a different daughter product. In time, less of the parent element remains, although different radioactive nuclides within the series may coexist at the same time. The average length of time for each reaction to occur is called a half-life. For example, uranium-238 has a half-life of 4.4 billion years, so a 4.4-billion-year-old rock has only half of the uranium-238 with which it started. Different radioactive elements have half-lives ranging from fractions of a second to millions of years. The shorter the half-life, the greater the radioactivity and the greater the hazard to health. Hence, radon-222, with a half-life of 3.8 days, is more hazardous than radium-226, with a half-life of 1,622 years, because radon-222 and its immediate daughters have very short half-lives. In turn radium-226 is far more hazardous than the long-lived uranium-238.

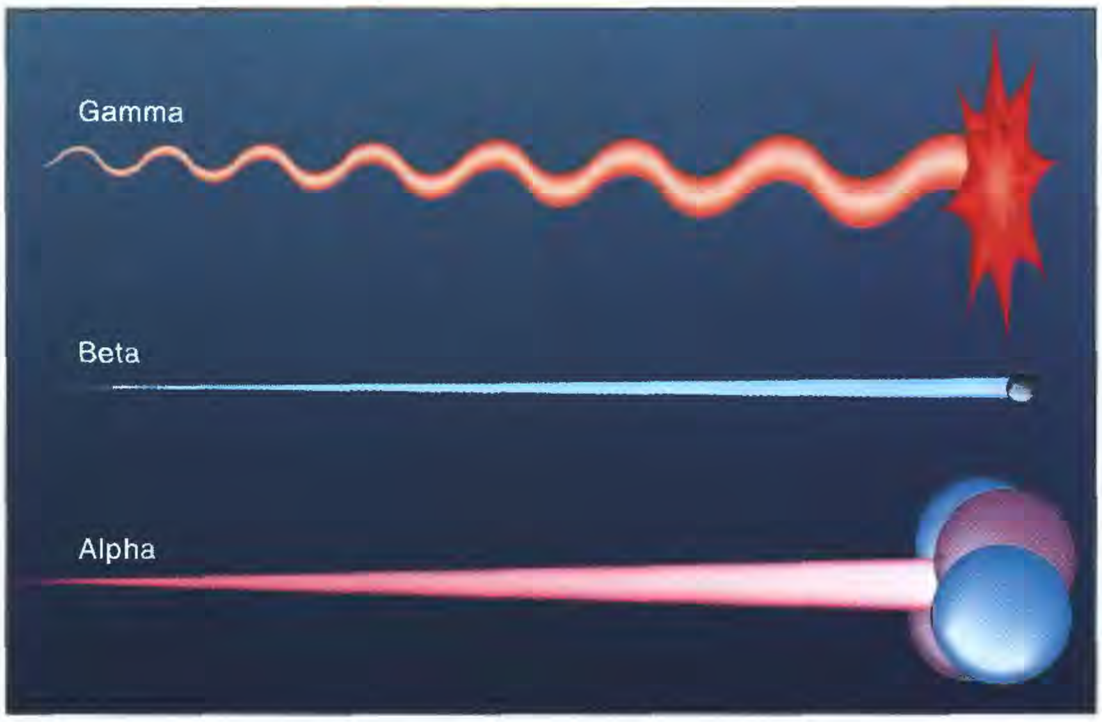


Atomic structures too small to be seen are known as nuclides. The nuclide in the diagram is a radionuclide because it is undergoing radioactive decay by releasing energy and mass.

The three main types of radiation are gamma, beta, and alpha.



Radionuclides become different elements according to a sequence of time reactions known as a decay series. The average length of time for each reaction to occur is called the half-life. The shorter the half-life, the more hazardous the element is to human health.



The three main types of radiation are gamma, beta, and alpha. Most damaging radiation in natural environments is caused by alpha radiation. Beta and gamma radiation generally are not a concern.

Gamma radiation travels as an electromagnetic wave similar to X-rays. Nuclear explosions and nuclear powerplants produce gamma radiation. Because of their penetration ability, high-energy gamma rays are a severe external health hazard. Fortunately, most gamma radiation is man-made and is not a problem in most environments, including the Puerco River basin. Beta radiation releases both energy and tiny electrons and also is produced in manmade as well as natural environments, but it is generally not a health concern. Beta radiation can pass through a sheet of paper but would be stopped by a book or by skin. Most of the damaging natural radiation from water, rock, and soil is caused by elements that primarily release alpha radiation, such as radium, uranium, thorium, and radon. Alpha decay releases a large particle composed of two protons and two neutrons. Although alpha radiation is easily stopped by a sheet of paper, there is a health risk if alpha particles are inhaled or ingested.

WHY IS ALPHA RADIATION A CONCERN?

Alpha radiation is a concern because overexposure can cause sickness. Alpha radiation is far more dangerous when exposure is internal than external. Breathing or ingesting alpha-emitting elements, such as radium, uranium, and radon, significantly increases the life-long risk of cancer. Radium poses a high risk because it substitutes for calcium in bone and stays in the body, releasing high-energy particles that damage body tissues. Uranium is far less toxic than radium because it has a longer half-life and a shorter residence time in the body. Prolonged ingestion of uranium can, however, cause kidney damage and increase the risk of cancer. Radon gas is thought to be the Nation's second leading cause of lung cancer (smoking is number one) and is estimated to cause as many as 8,000 to 40,000 deaths annually (U.S. Environmental Protection Agency, 1991d). Thorium, another common radioactive element, poses a low threat to health because it has a long half-life and dissolves poorly in water and therefore is unlikely to be present in drinking water.

TERMINOLOGY: Instead of separately measuring each element, scientists sometimes measure just the ***"gross"*** alpha or ***"gross"*** beta activity as a screening tool for the presence of alpha- and beta-emitting elements. ***"Dissolved"*** gross alpha means that the water sample was filtered to remove small sediment particles, whereas the term ***"total"*** gross alpha indicates that the sample was not filtered.

For gross alpha, gross beta, radium-226, radium-228, thorium-230, and radon, radioactivity or simply ***"activity,"*** is expressed in units known as ***picocuries***. The picocurie is named for the French physicist Marie Curie, a pioneer in the research of radioactive elements and their decay. One picocurie per liter is equivalent to 37 radioactive disintegrations each 100 seconds in a liter of water. One curie of radioactivity is equal to 1 trillion picocuries.

The terms ***milligram per liter*** and ***microgram per liter*** are units used to measure concentrations of elements dissolved in water. A milligram is equal to one-thousandth of a gram and is approximately equal to the weight of six grains of common table salt. A microgram is 1,000 times smaller than a milligram. Analytical results reporting uranium and gross alpha as natural uranium are commonly reported in micrograms per liter.

HOW MUCH IS TOO MUCH?

Table 1. Maximum contaminant levels for commonly occurring radioactive elements in drinking water set by the U.S. Environmental Protection Agency

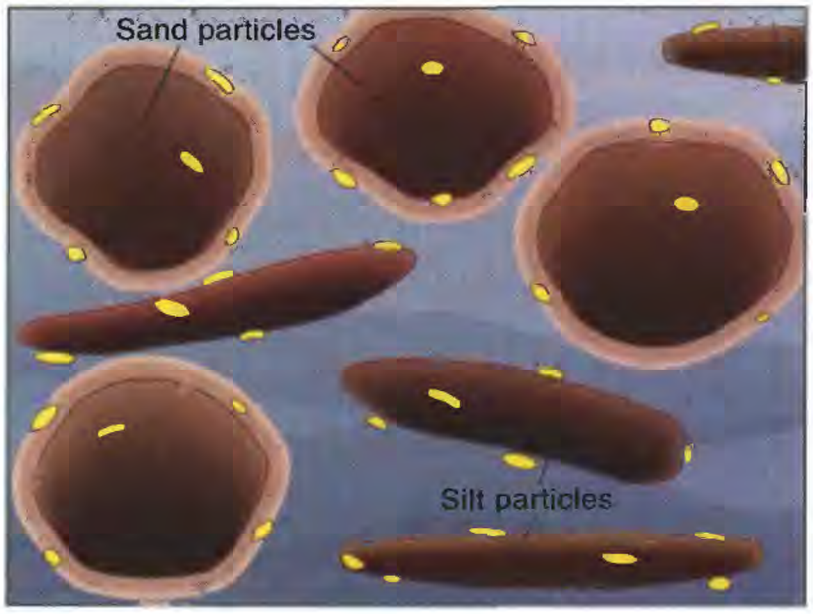
[Maximum contaminant levels in whole water samples are in picocuries per liter, unless otherwise noted; dashes indicate no established maximum contaminant level. Water-quality standards for specific surface-water uses defined by the State of Arizona—such as domestic water source, aquatic and wildlife, irrigation, and livestock—may be less restrictive than drinking-water standards]

Constituent	Maximum Contaminant Level		
	Primary	Proposed	Recommended
Radium-226	5	20	--
Radium-228	5	20	--
Radium-226 plus radium-228	5	20	--
Radon	---	300	--
Gross alpha, excluding uranium and radon	15	----	--
Uranium, total (micrograms per liter)	---	20	35

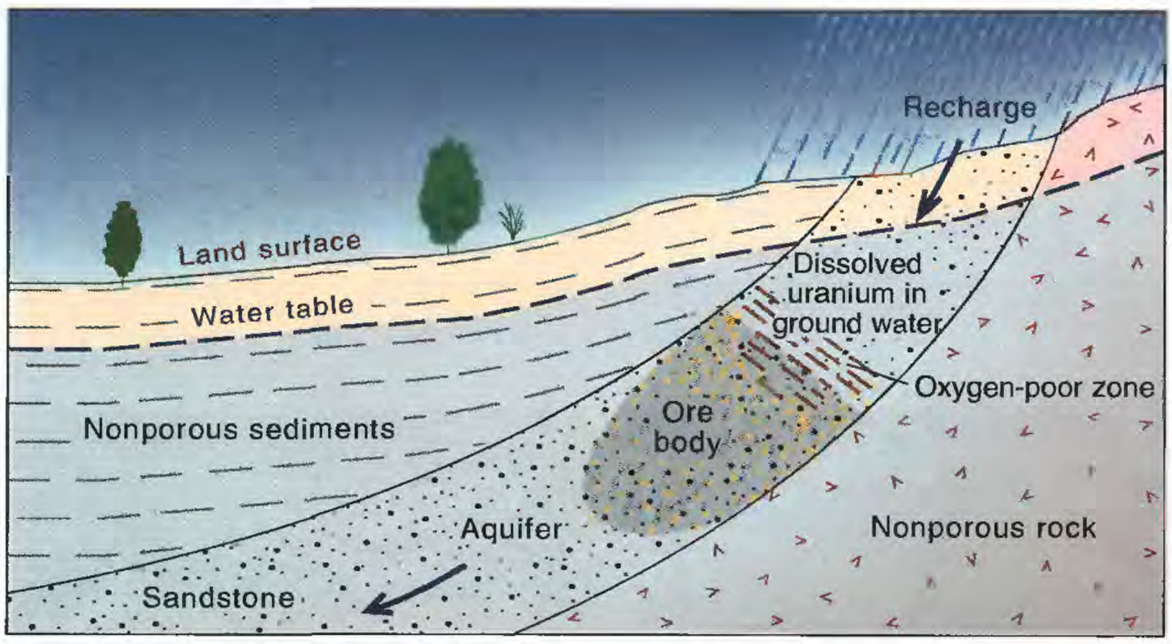
HOW DO RADIOACTIVE ELEMENTS OCCUR IN THE ENVIRONMENT?

Radioactive elements occur naturally in the rock, soil, and water around us. The most common radioactive elements present in water are uranium, radium, and radon. Other radioactive elements, such as thorium, are common in rock and soil but do not dissolve readily and generally are not present in water. Radioactive elements near the Earth's surface can be transported by water and wind. In the right environmental setting, natural processes will concentrate radioactive minerals in underground zones. If enough minerals are deposited, it is economically feasible to mine these zones, which are then referred to as ore bodies. The presence of radioactive elements in water is determined by the type of rock and sediment in contact with the water.

Uranium, radium, and radon each behave differently in water. Uranium generally is quite soluble in the presence of oxygen. Because uranium is carried by water in solution—like dissolved salt or sugar—it is easily transported far from its original source. Uranium also can be present as a solid—attached to clays and mineral coatings on sand and silt. Sand and silt particles carrying uranium can be suspended in moving water and transported during floods. Radium, like thorium, generally is less soluble than uranium and is found as a solid on clays and in mineral coatings. Radium will also travel on sediment during floods. Unlike radium and uranium, radon occurs as tiny bubbles of gas in ground water and will readily escape to the air like fizz from a can of soda. Consequently, radon in river water is quickly lost to the atmosphere. In homes where ground water from wells is used as the source of water supply, radon can escape from the water to the indoor air as people take showers, wash clothes and dishes, or otherwise use water. Radon can build up inside buildings that have poor ventilation, causing a hazard to health.



Uranium, thorium, and radium (shown in yellow) may be transported on sand and silt particles suspended in flowing water.



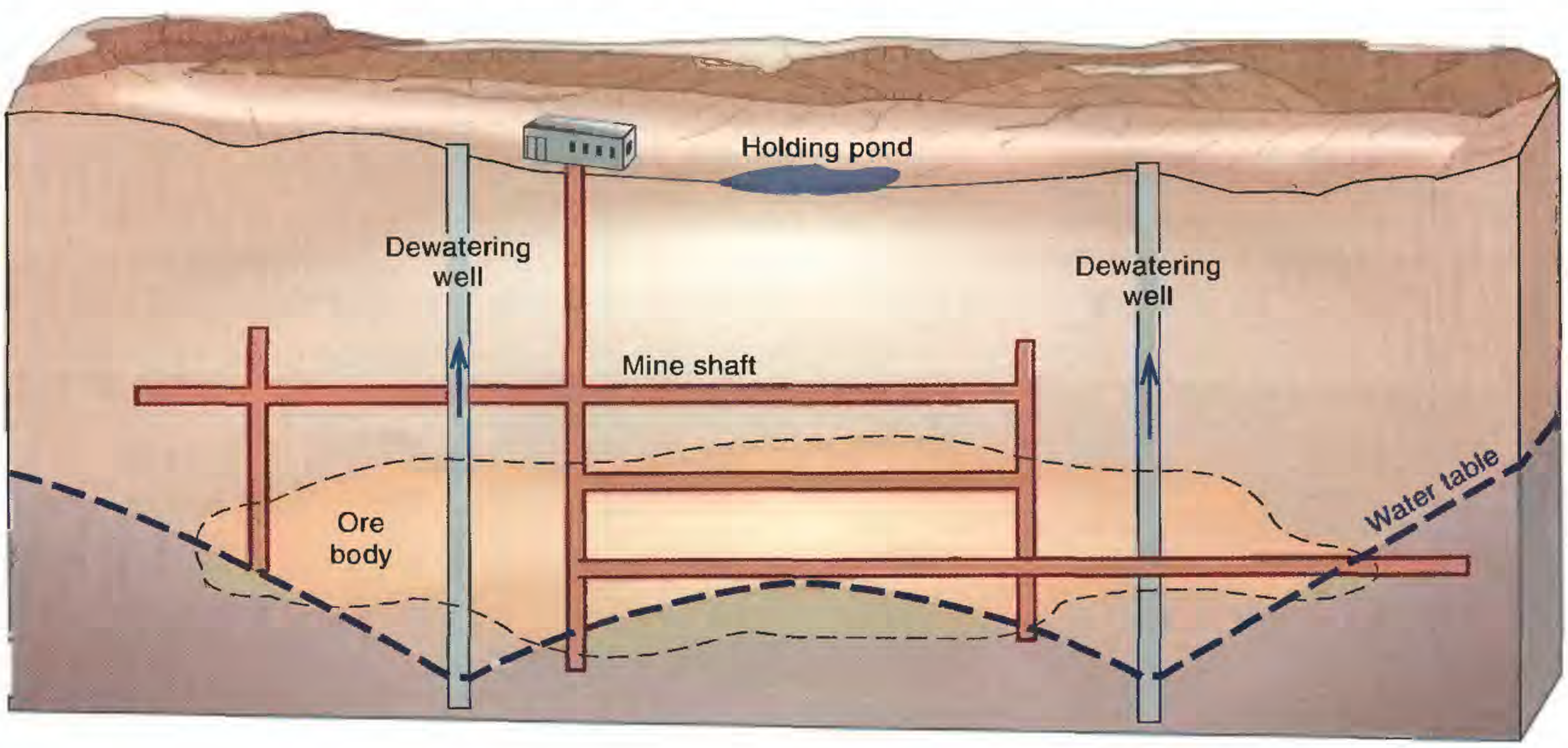
How do uranium ore bodies form? *Ground water containing small amounts of dissolved uranium moves through the aquifer until it reaches an oxygen-poor zone. This zone may be caused by organic matter or materials that use oxygen, for example, a rotting log. The small amounts of dissolved uranium form mineral deposits that, through time, become concentrated ore bodies.*

WHAT IS THE SOURCE OF RADIOACTIVITY IN THE PUERCO RIVER?

In addition to radioactive elements that occur naturally in water and sediment, radioactive elements were released to the Puerco River (1) through mine-water discharge for a 22-year period between 1960-61 and from 1967 to 1986 and (2) by a catastrophic spill of uranium-mine tailings and mine water on July 16, 1979.

HISTORY OF URANIUM MINING

From the late 1950's to the mid-1980's, uranium was mined extensively throughout the Colorado Plateau region, including the Church Rock Mining District of New Mexico in the Puerco River basin. Several large uranium mines and a processing mill released contaminated mine water to a small tributary of the Puerco River known as Pipeline Arroyo. Because the ore deposits lie beneath the water table, water draining to mine tunnels was pumped and released to Pipeline Arroyo. This process is known as mine dewatering. The mine water contained 100 to 1,000 times more gross-alpha activity (from dissolved uranium and radium) than generally is found in natural runoff in the Little Colorado River basin. Some of this water also was used by the mill to process the mined ore in highly acidic leaching ponds. Before the mid-1970's, untreated water from the mines and the processing mill was discharged directly to Pipeline Arroyo. After the mid-1970's, mine operators began to comply with Federal standards that regulate mine discharges. Although treatment reduced gross-alpha activity from radium in most releases by 85 percent between 1975 and 1982, concentrations of uranium in the mine effluent still averaged about 1,000 micrograms per liter, about 50 times the limit for drinking water of 20 micrograms per liter proposed by the U.S. Environmental Protection Agency (1991; table 1). Mine-dewatering effluent flowed downstream to join with treated sewage from Gallup, New Mexico. In the absence of floods, the combined mine and sewage water formed a continuously flowing stream as far as Chambers, Arizona—a total length of about 70 miles. Mine dewatering released an estimated total of 510 tons of uranium and 260

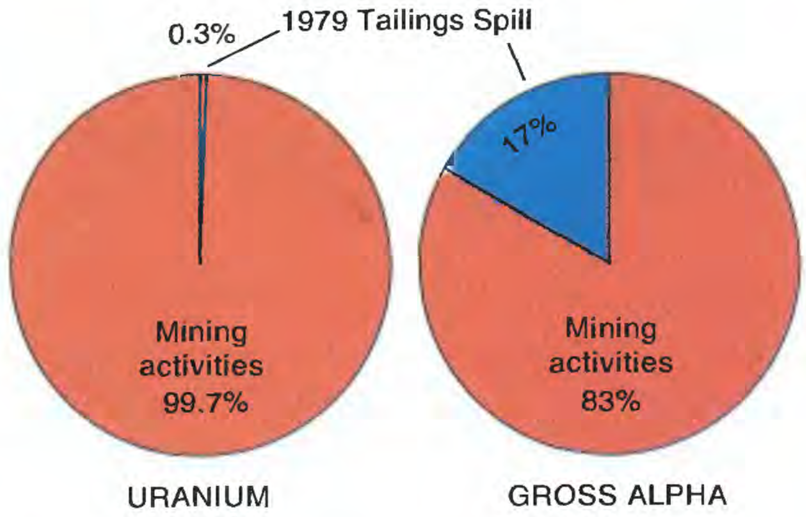


***How is a mine dewatered?**—Water is pumped through large wells to the surface in order to lower the water table surrounding the underground tunnels. Mine water containing radioactive elements was released to the Puerco River.*

trillion picocuries of gross-alpha radioactivity to the Puerco River over a 22-year period.

On July 16, 1979, the failure of an earthen dam, which held back uranium-mining and milling wastewater and sediment, released about 94 million gallons of highly acidic liquid and 1,100 tons of uranium-mine tailings to the Puerco River through Pipeline Arroyo. This liquid, which contained an estimated 1.36 tons of uranium and 46 trillion picocuries of gross-alpha activity, flowed downstream more than 50 miles, past the New Mexico-Arizona State line to the New Lands area. The spill—the largest single release of uranium-mine tailings and uranium-mill wastewater in United States history—greatly increased public awareness about radioactivity in the environment and its effects on public health. Despite the large size of the spill, far more radioactive elements were released gradually by mining over a period of more than two decades. At least 300 times more uranium and 6 times more total gross-alpha activity were released by day-to-day pumping from the underground mines than was released by the spill.

During the peak of mining from 1977 to 1982, 2.34 billion gallons or 75 gallons per second of mine water was released annually. A similar volume of sewage effluent was released to the Puerco River at Gallup each year. Hydrologists estimate that more than half the water released by mining entered the ground or evaporated before reaching Gallup. The mine water contained high levels of radioactivity, whereas the radioactivity of treated sewage was negligible. Although the resulting mixture still exceeded U.S. Environmental Protection Agency (USEPA) standards for dissolved gross alpha and dissolved uranium, sewage effluent significantly diluted the contaminants in mine water downstream from Gallup. Most of the radioactivity in the mine water was from readily dissolved uranium, whereas radioactivity from the spill was caused primarily by radium and thorium, which attach to sediment.



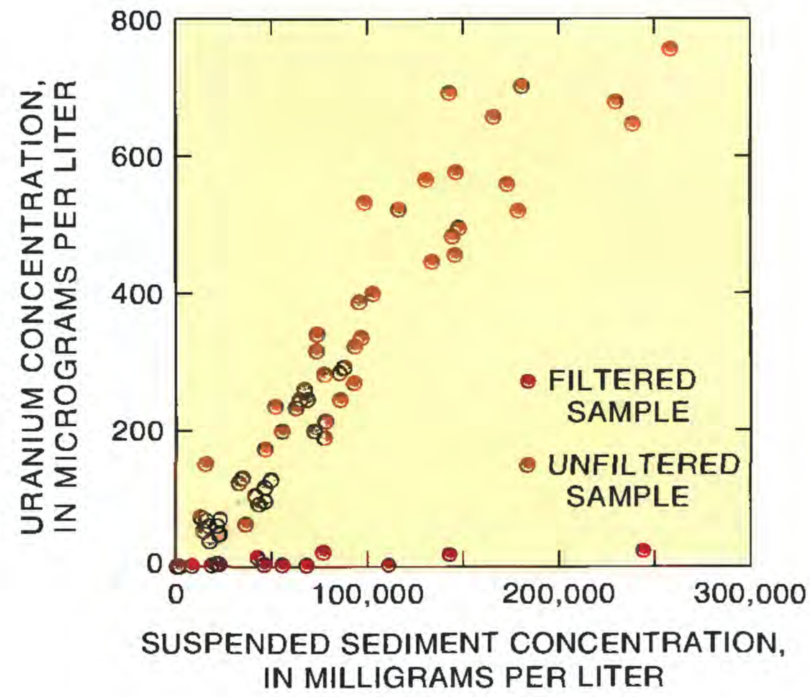
Despite the large size of the spill, far more radioactive elements were released gradually to the Puerco River by uranium-mining activities over a 22-year period.

The spill released sediment containing radium and thorium that was quickly diluted with large amounts of noncontaminated sediment from the river. Subsequent natural runoff moved the radioactive sediments downstream. Three months to a few years following the spill, several scientific studies[1] concluded that no trace of sediment containing radium and thorium from the spill could be identified, although the Puerco River was still receiving high amounts of dissolved uranium from mine dewatering. These studies were limited in scope and inconclusive in regard to long-term effects of the mining releases on streamflow and ground water downstream from the mines, particularly across the State line in Arizona. Although the effects of the spill were no longer detectable in 1985, water from the Puerco River still frequently exceeded the recommended standard for uranium and Federal and State standards for total and dissolved gross alpha; radium-226; selenium; molybdenum; and for total arsenic, copper, manganese, and lead. Economic conditions forced the mines to close by the early 1980's, although mine dewatering continued until February 1986.

[1]Weimer and others, 1981; Millard and others, 1983, 1984; Arizona Department of Environmental Health Services, 1986; Miller and Wells, 1986; Gallaher and Cary, 1986.

IS RADIOACTIVITY CONTAMINATING THE PUERCO AND LITTLE COLORADO RIVERS?

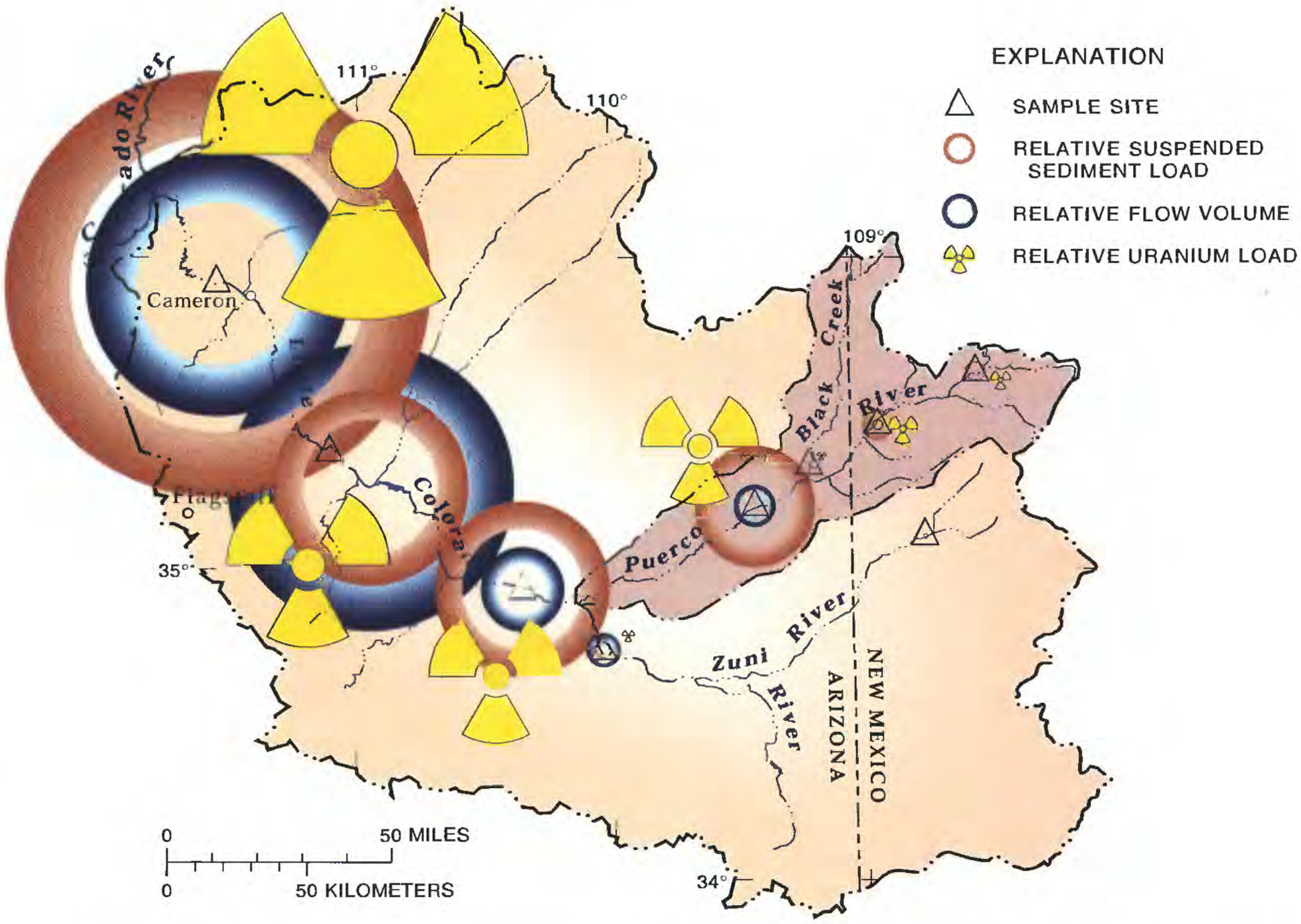
Samples of water from the Puerco and Little Colorado Rivers were collected during the study to evaluate water quality under a variety of flow conditions. The most important factor determining the level of radioactivity and amount of trace elements in river water is the amount of sediment in the water. The amount of uranium in muddy water increases in direct proportion with increasing amounts of sediment. Water containing little or no sediment has low levels of radioactivity and generally meets the USEPA standards (table 1) that are considered safe for wildlife, irrigation, and livestock. Before 1985, mine water in the Puerco River exceeded standards for dissolved gross alpha and uranium. From 1988 to 1991, 93 out of 95 samples of filtered river water met the Federal standard for drinking water of 15 picocuries per liter for total gross-alpha activity, and 20 out of 23 filtered samples were below the proposed Federal standard of 20 micrograms per liter for uranium. Throughout the study area, unfiltered samples containing sediment had high levels of both radioactive and nonradioactive contaminants. In comparison with the filtered samples, unfiltered samples contained as much as 10 times more uranium and generally exceeded Federal drinking-water standards for total uranium (51 out of 54 samples), total gross alpha (82 out of 91 samples), total gross alpha plus gross beta (82 out of 91 samples), and total radium-226 plus radium-228 (41 out of 41 samples). Also, unfiltered samples exceeded the corresponding State of Arizona standard in every measured instance for beryllium, chromium, copper, lead, manganese, and nickel. The Puerco River and the Little Colorado River below the confluence with the Puerco River are muddy streams. During flash floods, these reaches typically carry more sediment (and therefore



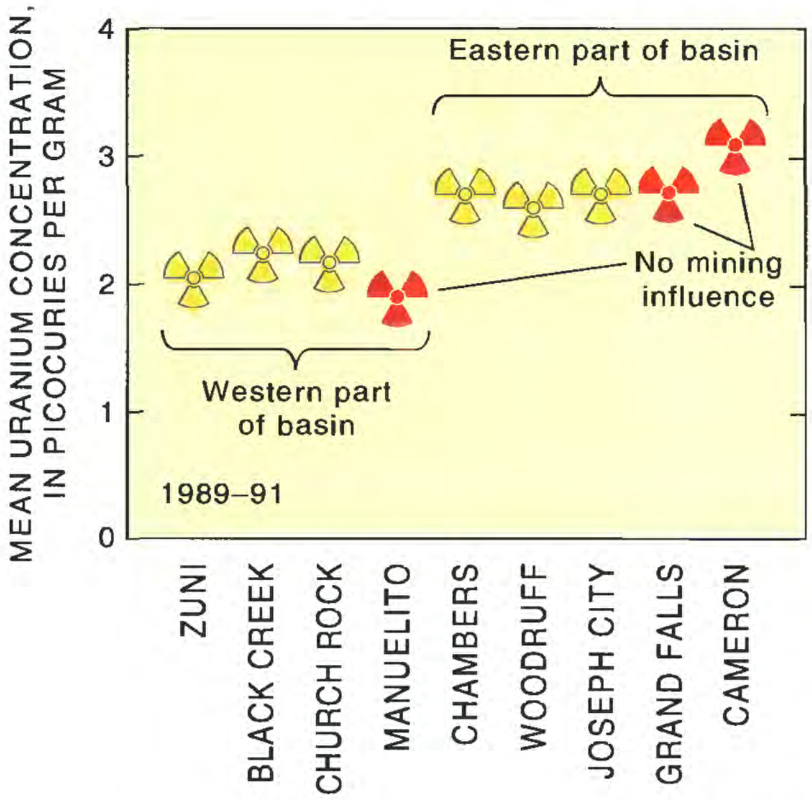
The concentration of uranium in a river water sample is directly related to the amount of suspended sediment. These samples were collected from 1988 to 1991 from all nine gages. Most filtered water samples met the USEPA drinking-water standard for total gross alpha and total uranium.

more of both radioactive and nonradioactive trace elements) than other reaches in the study area, such as the upper Little Colorado River at Woodruff, the Zuni River, and Black Creek.

As one moves downstream along the Puerco and Little Colorado Rivers, the amount of land drained becomes larger and the amount of water, sediment, and radioactivity from uranium that passes by each gage in a given year also becomes larger. The total sediment and therefore the total uranium transported past the Black Creek and Zuni gages each year is insignificant compared with that transported past the gage near Cameron. Comparing all the sites, the radioactivity for the same amount of sediment varies only slightly. The highest activity was observed at Black Creek and Zuni River. If mining had caused an increase in radioactivity in the Puerco River, one would expect to see the highest radioactivity in sediment collected closest to the mines; but that is not what was found. Radioactivity from uranium, radium, and thorium in sediment samples collected downstream from the



Relative magnitudes of annual flow volume, suspended-sediment load, and—consequently— uranium load increase downstream within the Little Colorado River drainage basin, 1991.



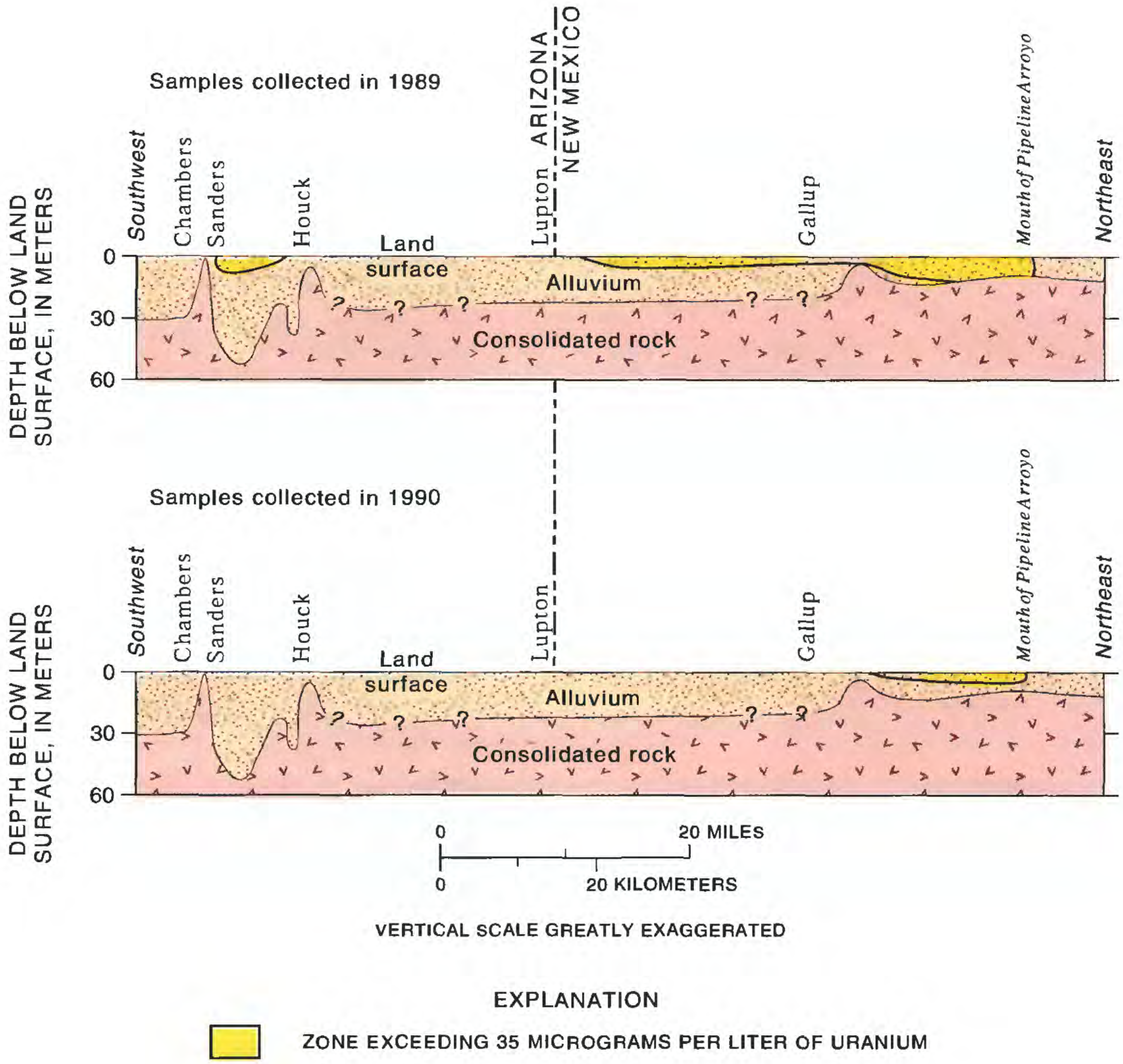
Uranium activity of suspended sediment is higher for samples from the eastern part of the Little Colorado River basin than from the western part. Similar distributions were observed for radium and thorium.

uranium mines near Church Rock, Manuelito, and Chambers was not significantly different from samples collected at Black Creek and Zuni River—where no uranium mining has occurred. The radioactivity of a given quantity of sediment was greater for samples from the eastern part of the Little Colorado River basin (Puerco and Zuni Rivers and Black Creek) than for samples from the western part. Differences in the radioactivity of sediment appear to be related to geographical differences in geology, rather than whether a sample was collected downstream from a uranium mine. The study found no evidence indicating that streamflow from the Puerco River was still contaminated. The amount of uranium and radium carried by water and sediment past the gaging station near Church Rock was about 26 times lower in 1991 than that of a typical year during mining.

WHAT IS THE EFFECT OF MINING ON GROUND WATER?

Hydrologists studied ground-water flow patterns and water chemistry near the Puerco River to determine which parts of the alluvial aquifer downstream from Pipeline Arroyo were recharged by mine water containing radioactive elements. Natural ground water (not affected by human activities) and ground water that originated as sewage effluent has lower concentrations of dissolved uranium than ground water that was recharged by mine-dewatering effluent. In parts of the alluvial aquifer not affected by mining, ground water contained less than 13 micrograms per liter of dissolved uranium. Samples that contained uranium concentrations greater than 13 micrograms per liter indicated where ground water was recharged by mining releases. Contaminated water samples generally were from reaches of the channel that were identified as natural recharge areas on the basis of water-level information.

During the study, approximately 20 percent of the wells in Arizona and 33 percent



Concentrations of dissolved uranium in ground water under the Puerco River were greater for samples collected in 1989 than for samples collected in 1990.

of the wells in New Mexico had elevated concentrations of uranium, indicating contamination from mining releases. In 1989, a zone of dissolved uranium greater than 35 micrograms per liter and as high as 870 micrograms per liter extended beneath the Puerco River from the mouth of Pipeline Arroyo to the area near the Arizona-New Mexico State line. The highest concentrations of uranium were measured closest to the mines. Concentrations of uranium tended to be highest in water samples collected in the first few feet beneath the streambed. Farther downstream, samples from near-stream wells between Lupton and Houck contained concentrations of uranium that are similar to natural levels, indicating that this reach of the Puerco River is not significantly affected by mining releases. In the Sanders reach in the New Lands area (between Houck and Chambers, Arizona), water chemistry shows near-stream ground water as a mixture of natural runoff and artificial recharge from treated sewage and mine water. A smaller zone of uranium contamination was detected along the channel in this area. Water from a few alluvial wells in the Sanders reach contained concentrations of uranium that exceeded 35 micrograms per liter. These wells generally were less than 300 to 400 feet from the river and less than 40 feet deep. On the basis of these data, uranium probably did not migrate far from the streambed. In 1990, the contaminated zones were smaller than in 1989. Uranium concentrations appear to be declining in shallow near-stream wells.

Because water is lost by evaporation through the dry streambed during most of the year, dissolved uranium in ground water from mine effluent has not traveled far from the river channel in the New Lands area. In fact, 80 percent of all wells within 700 feet of the river met Federal drinking-water standards for all measured radioactive elements, with the exception of radon. No evidence suggests that the occurrence of radon is related to mining.

Natural Radioactivity Exceeds Standards in Some Alluvial and Bedrock Wells Not Affected by Mining

As discussed earlier, the presence of radon is common in ground water in many parts of the United States. In the alluvial aquifer of the Puerco River basin, activities of radon ranged from less than 80 to 1,100 picocuries per liter. Radon activities in more than half the sampled alluvial wells exceeded the proposed maximum contaminant level for drinking water of 300 picocuries per liter. Radium-226 is the parent nuclide for radon-222. The presence of radon appears to be related to radium that is distributed on fine-grained sediments throughout the alluvial aquifer.

Levels of radioactivity in some areas within the sedimentary rock may be significantly higher than in the alluvial aquifer. Two samples greatly exceeded recommended limits for radioactive elements out of samples collected from six wells that were drilled into sedimentary rock that underlies the alluvial aquifer in the New Lands area. One well drilled through alluvial deposits into the sedimentary bedrock at the Arizona Department of Transportation facility near Sanders contained 15,000 picocuries per liter of radon and 280 micrograms per liter of uranium. A second well at the Indian Ruins trading post near Sanders contained 14 picocuries per liter of radium. Dissolved gross-alpha activities ranged from less than 1 to 380 micrograms per liter for the six wells, and gross-beta activities ranged from 3.4 to 210 picocuries per liter. Chemical data and ground-water flow patterns indicate that levels of radioactivity in the sedimentary rock unit are unrelated to mining.

WHAT ARE THE IMPLICATIONS OF THE STUDY FINDINGS?

WHAT ARE THE LONG-TERM EFFECTS OF PAST URANIUM MINING ON THE PUERCO AND LITTLE COLORADO RIVERS?

The effects of uranium mining can no longer be identified in water and sediment samples from the Puerco or Little Colorado Rivers. Although the river is no longer contaminated by mining, high sediment concentrations cause streamflow to exceed Federal standards for radioactive elements, such as uranium and radium, and for nonradioactive elements, such as beryllium, copper, lead, manganese, and nickel. Although the Puerco River is no longer a primary water supply for humans, it is still used to water livestock and historically was used by humans. Filtered water from both the Puerco and the Little Colorado Rivers generally meets drinking-water standards set by the U.S. Environmental Protection Agency's Safe Drinking Water Act for the dissolved elements measured in this study.

WHAT IF HUMANS AND ANIMALS COME IN CONTACT WITH SEDIMENT FROM THE PUERCO AND LITTLE COLORADO RIVERS?

The levels of radioactivity found in sediment are not harmful in contact with skin and would not pose a health risk unless continually inhaled or ingested over a long period of time. As a routine precaution, humans should avoid breathing dust during wind storms. Hands should be washed before eating, especially outdoors. Livestock should be prevented from drinking water that is heavily laden with sediment.

WHAT ARE THE LONG-TERM EFFECTS OF PAST URANIUM MINING TO GROUND WATER UNDERLYING THE PUERCO RIVER?

Most of the near-stream wells sampled during the 3.5-year study showed no signs of mining contamination, particularly in the Arizona part of the Puerco River basin, where nearly 80 percent of the wells drilled in alluvium showed no evidence of uranium contamination. Two-thirds of near-stream wells sampled in the New Mexico part of the basin also showed no evidence of uranium contamination. Water quality improved significantly between 1989 and 1991 for near-stream wells that were contaminated with dissolved uranium. Many wells, however, contained unsafe levels of radioactivity that were unrelated to mining. More than 50 percent of wells in the shallow alluvial aquifer exceeded the proposed standard for radon. Of six wells that were drilled in sedimentary rock in the New Lands area, samples from two of the wells had unsafe levels of uranium and radium, and one well had unsafe levels of radon.

Radioactive substances on sediment may be transported in floods or carried as wind-borne particles. Breathing dust would not pose a health hazard unless continually inhaled over many years.

WHAT IS THE POTENTIAL RISK TO RESIDENTS WHO LIVE NEAR AREAS WHERE GROUND WATER IS AFFECTED BY MINING?

The likelihood for humans and animals to be exposed to radioactive elements in drinking water depends on the source of the water. Some residents obtain their water from private wells near the Puerco River that are vulnerable to contamination from past uranium mining because the aquifer is shallow.

Most residents of the Puerco River basin in larger communities such as Gallup, Sanders, and the New Lands area get their water from public water-supply systems. These systems rely on deep wells located in geologic formations that are not connected to the Puerco River or its underlying aquifers. Furthermore, the agencies that operate the systems are required to test the water regularly and comply with the U.S. Environmental Protection Agency water-quality standards under the Safe Drinking Water Act. The greatest concern is for residents who get their water from private wells that have not been tested. Water testing would enable these residents to determine if their water is safe to use.

Animals may ingest radioactive elements on sediment. The meat, in turn, may be consumed by humans. This cow was mired in an abandoned uranium-mine pit near Cameron, Arizona.

WHICH WELLS NEAR THE PUERCO RIVER ARE MOST LIKELY TO HAVE PROBLEMS?

The presence of radioactivity is a potential concern for residents who drink water from shallow private wells near the river in New Mexico, particularly those upstream from Gallup closest to the abandoned uranium mines, and shallow wells that are less than 400 feet from the river between Houck and Chambers, Arizona. In addition, water from wells drilled into the sedimentary rock that is near or underlies the Puerco River alluvial aquifer in Arizona could potentially contain natural but hazardous levels of radioactivity.

WHAT WATER TESTS ARE NEEDED?

Analyzing water for gross-alpha activity would serve as a screen for the presence of alpha-emitting substances. The water does not need to be filtered for this test and can be collected directly from a faucet. If the analytical results exceed 15 picocuries per liter, additional samples could be tested for the presence of radium, uranium, and radon. If safe levels of radioactivity (table 1) are exceeded, the water should not be used for drinking or cooking but could be used for other purposes, such as laundry, cleaning, or irrigation. If the water contains high levels of radon, it should not be used in a poorly ventilated building that would allow the buildup of radon gas.

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Petroglyph near the Puerco River, Petrified Forest National Park.

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