PRELIMINARY ASSESSMENT OF WATER QUALITY IN THE ALLUVIAL AQUIFER OF THE PUERCO RIVER BASIN, NORTHEASTERN ARIZONA

By Robert H. Webb, Glen R. Rink, and Dean B. Radtke

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Index terms for this report are as follows: *Radioactivity, *Radioactivity Effects, *Mining, *Streamflow, Groundwater Contamination, Infiltration, Puerco River, New Mexico, Arizona.

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CONTENTS

ILLUSTRATIONS

TABLES

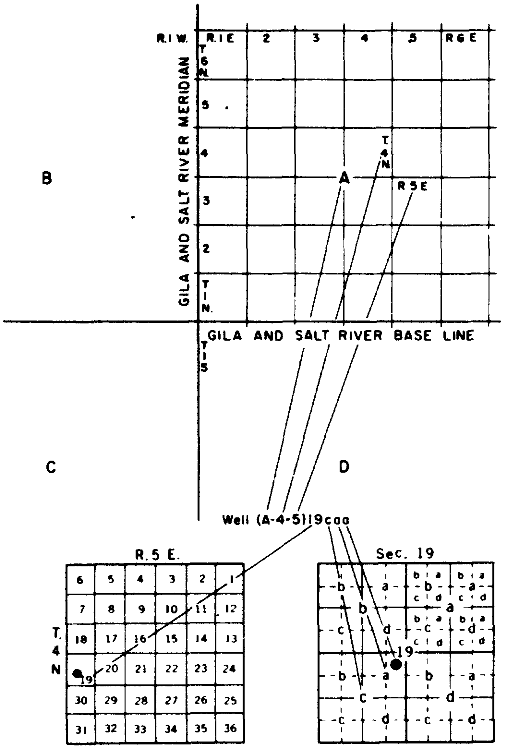
CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for the terms in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.0929	square meter (m^2)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons (Mgal)	3,785	cubic meter (m^3)
parts per million (ppm)	1	milligrams per gram (mg/g)
ton, short	0.9072	megagram (Mg)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

Well-numbering system in Arizona.



The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (A-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 N., R. 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

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ABSTRACT

The quality of ground water in the alluvial aquifer of the Puerco River basin, northeastern Arizona, was evaluated in order to assess potential contamination from uranium mining and milling operations in New Mexico. A total of 14 wells and 1 spring were sampled to determine if a contaminant plume of radionuclides or trace elements is present. The water is characterized by high dissolved solids with a median of 698 milligrams per liter and high concentrations of alkalinity, sodium, and sulfate. Except for iron, manganese, and strontium, the concentrations of trace elements generally are below the applicable U.S. Environmental Protection Agency and State of Arizona maximum contaminant levels. Gross alpha activity has a median of 27 picocuries per liter and ranges from 4 to 42 picocuries per liter. Uranium, which accounts for most of the gross alpha activity, has a median concentration of 19 micrograms per liter and ranges from 1 to 38 micrograms per liter. Twenty to 84 percent of the gross alpha activity was derived from other undetermined radionuclides. Other radionuclides, including radium-226 and radium-228, generally are not present in activities greater than 5 picocuries per liter in the water.

Statistical analysis of the water-quality data suggest that no contaminant plume can be defined on the basis of samples from existing wells. The contamination in the alluvial aquifer apparently does not change in the downstream direction along the Puerco River. The geochemistry of radionuclides indicates that most radionuclides from the uranium-decay series are immobile or only slightly mobile, whereas uranium will not precipitate out of solution but may be removed by sorption in the alluvial aquifer.

page 4 follows

PART I. EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Ground water in the alluvial aquifer of the Puerco River basin may not be safe for human consumption because of historic radionuclide and trace-element releases associated with uranium mining. Previous studies have indicated that effluent from mining activities and natural runoff contained amounts of radionuclides and trace elements above the maximum contaminant levels allowable for drinking water. In addition, failure of a tailings-pond dam at a uranium mill near Gallup, New Mexico in July 1979 released large amounts of radionuclides and trace elements into the Puerco River.

The purpose of this study was to determine if the alluvial aquifer of the Puerco River basin is contaminated by radionuclides, trace elements, or other constituents that either occur naturally or are associated with uranium mining and milling operations in New Mexico. The scope of the study was limited to a reconnaissance-level sampling of 14 wells and 1 spring and an evaluation of existing data and reports. The first report completed in the study (Webb and others, 1987) provided preliminary estimates of the areal extent and severity of the contamination.

The purpose of this report is to provide a preliminary assessment of the water quality of the alluvial aquifer of the Puerco River basin. This assessment includes a characterization of general water-quality conditions in the alluvial aquifer, a determination of whether or not areal and (or) temporal changes in water quality have occurred, and a preliminary analysis of aquifer geochemistry to define what processes control the movement of radionuclides and trace elements.

Major findings given in this report are:

- ⊙ On the basis of a one-time sampling of 14 wells and 1 spring, the water quality of the alluvial aquifer is characterized as having high concentrations of dissolved solids and generally high concentrations of sulfate, iron, and manganese. Concentrations of these constituents measured in the Puerco River basin are exceeded in many public water supplies in the United States (Durfor and Becker, 1964).

- ⊙ Activities of radionuclides are variable but generally low (gross alpha minus uranium and radon generally less than 15 picocuries per liter and radium-226 and radium-228 generally less than 5 picocuries per liter). Radionuclides in the water generally are below the maximum contaminant levels of the U.S. Environmental Protection Agency and the State of Arizona. Concentrations of trace-elements are low (generally less than U.S. Environmental Protection Agency and Arizona maximum contaminant levels).

page 8 follows

- Radionuclide activities, trace-element concentrations, and common ions do not appear to be related directly to distance from or along the river.

- Radionuclide activities have fluctuated with time but may have increased in some wells sampled as a result of the failure of a tailings-pond dam northeast of Gallup, New Mexico, in July 1979. Concentrations of other constituents appear to have changed little with time, except near the Arizona-New Mexico border where concentrations of sulfate increased dramatically in a well 50 ft from the river as a result of the failure of the tailings-pond dam.

- Processes that may control the movement of radionuclides and other constituents in the alluvial aquifer of the Puerco River include solution and precipitation reactions, sorption including ion-exchange reactions, volatilizations, and biological uptake or release. Results of a solution-equilibrium analysis of the chemical environment of the alluvial aquifer suggest that most radionuclides from the uranium-decay series are immobile or only slightly mobile due to precipitation and sorption. Uranium, however, is mobile because it should not precipitate out of solution and may be only slightly sorbed to clay particles.

- Additional sampling of new and existing wells drilled into the alluvial and bedrock aquifers and analysis of information derived from this sampling are needed to better define the areal extent and severity of contamination and the processes that control the movement of radionuclides and other constituents in ground water in the Puerco River basin.

- Although there are radionuclides present in the ground water, knowledge gained in additional sampling and study of processes that control the movement of radionuclides may permit the design of safe public water supplies from this aquifer.

PART II. TECHNICAL REPORT

INTRODUCTION

The Puerco River, which has a drainage area of about 3,000 mi^2, is in the southeastern part of the Colorado Plateau (fig. 1). The river originates in the Chuska and Zuni Mountains in northeastern Arizona and northwestern New Mexico and flows west-southwest to the confluence with the Little Colorado River east of Holbrook, Arizona. Peak streamflow occurs in response to spring runoff and summer thunderstorms that produce flash floods. Before 1950, the Puerco River was an ephemeral alluvial stream (Kaufmann and others, 1976). In the period between the 1950's and the mid-1980's, streamflow in the upper part of the basin (fig. 1) changed from ephemeral to perennial to at least the Arizona-New Mexico border and possibly as much as a few miles downstream from Chambers, Arizona (Shuey, 1986). The source of the perennial streamflow was effluent from dewatering activities associated with uranium mines northeast of Gallup, New Mexico. Effluent that was discharged from a sewage-treatment plant in Gallup was also a contributing factor.

Extensive historic samples collected between 1975 and 1985 indicated that effluent from the mining activities and natural runoff contained high amounts of radionuclides--lead-210, radium-226, radium-228, and uranium--as well as many trace elements--specifically lead, molybdenum, and selenium--and sulfate. In July 1979, a tailings-pond dam failed at a uranium mill northeast of Gallup (fig. 1). Large amounts of thorium-230, thorium-232, radium-226, radium-228, uranium, and sulfate were released into the Puerco River (Weimer and others, 1981).

Because of the radionuclide and trace-element contamination in the basin, there is concern that ground water in the alluvium of the Puerco River may not be safe for human consumption. In 1985, the Navajo and Hopi Indian Relocation Commission (NHIRC) funded a study of ground-water quality in the Puerco River basin prior to relocation of Navajo Indians into an area south of Sanders and Chambers, Arizona. Conflicting results from studies funded by NHIRC (Western Technologies, Inc., 1985) and Arizona Department of Health Services (ADHS, 1986a and b) and a study by Shuey (1986) suggest that the extent of contamination in the Puerco River basin of Arizona is not well defined. At a meeting of representatives of NHIRC; Indian Health Service, Bureau of Indian Affairs; U.S. Environmental Protection Agency (EPA); and U.S. Geological Survey in July 1986, NHIRC and EPA requested that the U.S. Geological Survey assess ground-water quality in the Puerco River basin to determine if this resource was contaminated. This study was completed in cooperation with the Navajo and Hopi Indian Relocation Commission.

Purpose and Scope

The purpose of this study was to determine if the alluvial aquifer of the Puerco River basin is contaminated by radionuclides, trace elements, or other constituents that either occur naturally or are related to uranium mining and milling operations in New Mexico. The area of study is along the Puerco River in Arizona between Lupton and Petrified Forest National Park (fig. 1).

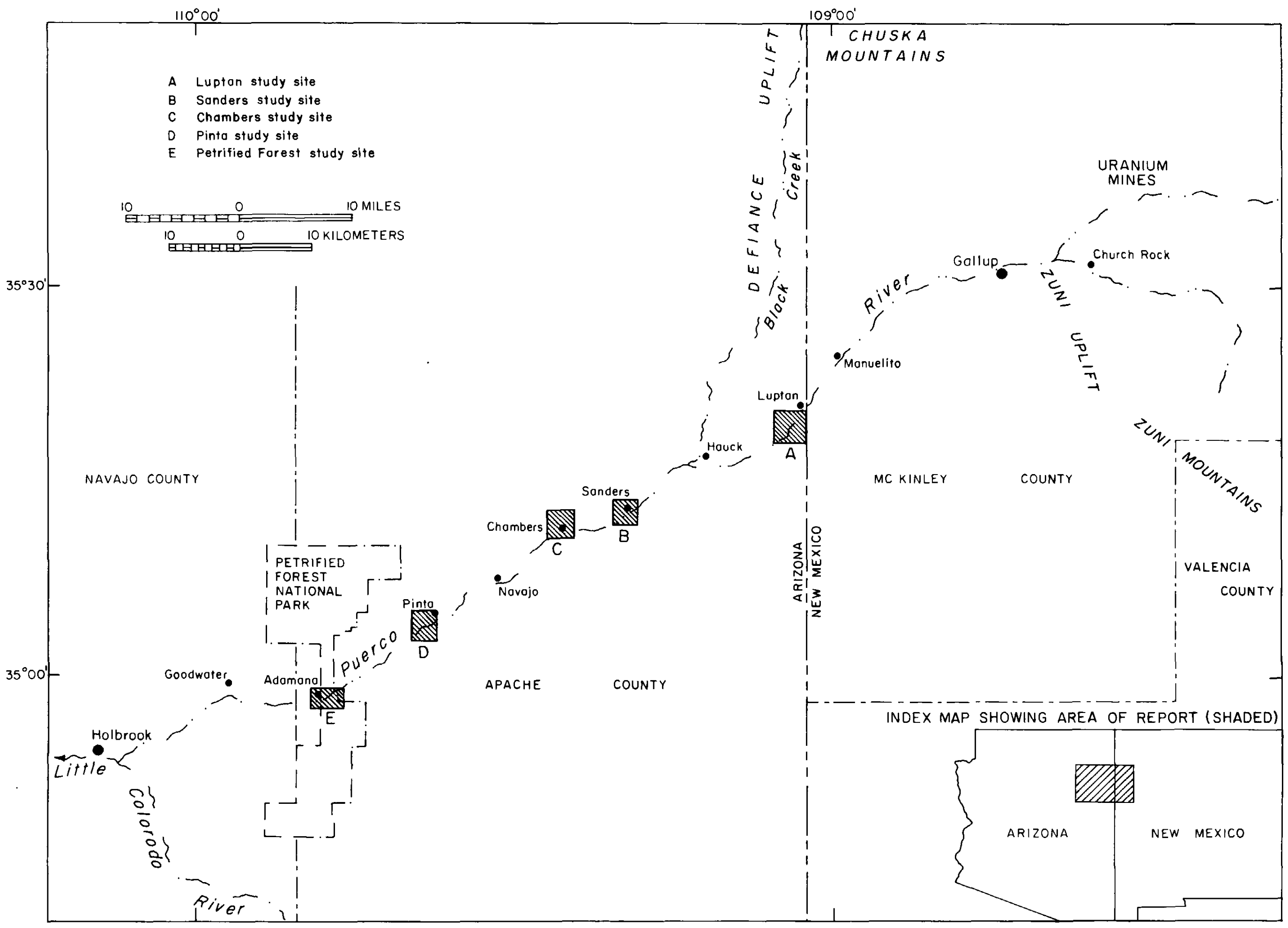

Figure 1.--Puerco River basin in northeastern Arizona and northwestern New Mexico and locations of study sites

Sulfate, radionuclides and trace elements that either occur naturally or are related to uranium mining and milling operations in New Mexico (fig. 1) may have contaminated the alluvial aquifer. The scope of the study was limited to a reconnaissance-level sampling program and an evaluation of existing data. The data collected in this study were compared to historic data and maximum contaminant levels[1] of the State of Arizona and the EPA in a previous report (Webb and others, 1987).

The purpose of this report is to provide a preliminary assessment of the water quality of the alluvial aquifer of part of the Puerco River basin. This assessment includes a characterization of quality of ground water in the alluvial aquifer, a determination of whether or not areal and (or) temporal changes in water quality have occurred, and a preliminary analysis of aquifer geochemistry to define what processes control the movement of radionuclides.

Acknowledgments

The authors thank the following people for permission to sample their private wells for water quality: Raymond Fitzgerald, Doug Hart, Ena Hoover, Larry Maennche, Joanna McDonald, and Mrs. Marvin Porter. Pat Paulsell, Jr., provided access to the Arizona Windsong well at Sanders. Paul Kanitz, Navajo Tribal Utility Authority and Indian Health Service; Marion Clarke, Petrified Forest National Park; Gerry Walters, Santa Fe Railway; and Chuck Bent, Puerco Elementary School at Sanders provided access to wells and gave permission to take samples. Dan Owens, Navajo Tribal Utility Authority; Ed Swanson, Arizona Department of Health Services; Terry Curley, Indian Health Services; Michelle Moustakas, U.S. Environmental Protection Agency; Chris Shuey, Southwest Research Center; Marian Clarke, Petrified Forest National Park; and Gerry Walters, Santa Fe Railway provided unpublished water-quality data on the wells sampled in this study. Chris Shuey, Michelle Moustakas, and Ed Swanson provided background literature on the radionuclide releases from mining activities in New Mexico. Discussions of radionuclide geochemistry with Robert A. Zielinski and Chuck Busch, U.S. Geological Survey, resulted in a marked improvement of the manuscript. John Rote, U.S. Geological Survey, assisted with the collection of samples. DeWayne Cecil and Edward Landa, U.S. Geological Survey, critically reviewed the manuscript.

BACKGROUND

Maximum Contaminant Levels in Water

Radionuclides of natural origin and those released by mining activities are derived from the natural radioactive decay of uranium. Natural radionuclides undergo spontaneous transformations in

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[1] As used in this report, maximum contaminant level (MCL) refers to the EPA primary and secondary MCLs and the State of Arizona MCLs for drinking water, the State of Arizona maximum allowable limits for surface water, and the State of Arizona maximum permissible limits for radionuclides.

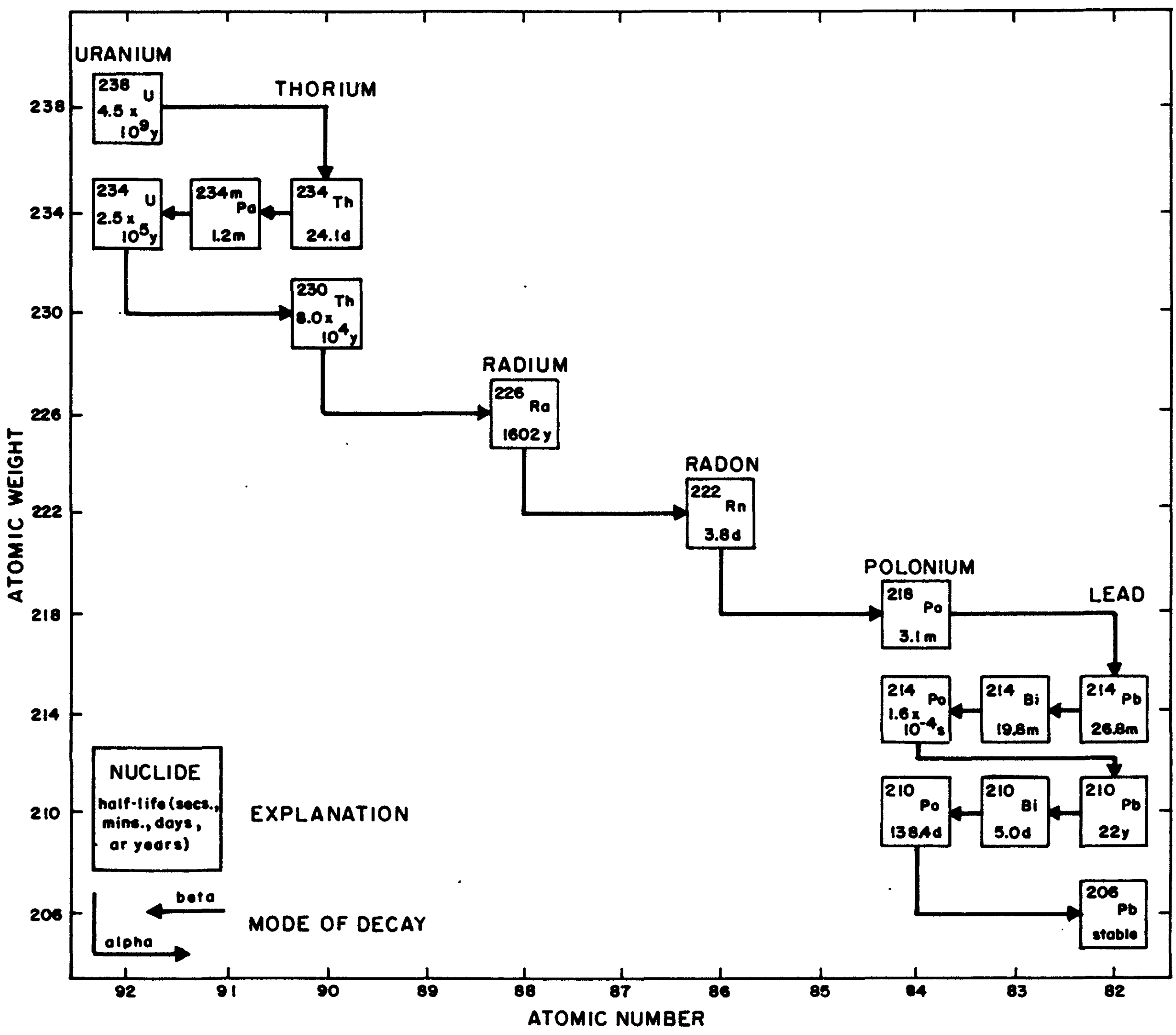

Figure 2.--Dominant radioactive-decay series of uranium-238 (from Landa, 1980, fig. 2).

their nuclei that cause the emission of alpha and beta particles and to a lesser extent, gamma rays (Faure, 1977). The amount of radioactivity produced can be measured either as total or gross alpha and beta activity or as total decay for each element. Three decay series occur in nature (Aswathanarayana, 1986); the dominant decay series for uranium-238 is shown in figure 2.

Radionuclides in the uranium-238 decay series are harmful to human health in large quantities because of both radiation-induced carcinogenicity, or <u>radiotoxicity</u>, and <u>chemical toxicity</u> that is similar to the effects of heavy metals (Lappenbusch and Cothern, 1985). The <u>half life</u>

of a radionuclide is the time required for the mass to decrease by one half. The half lives of radionuclides released by mining activities range from seconds to billions of years (fig. 2). The amount of radionuclides in water is usually presented as an <u>activity</u> in units of picocuries per liter (pCi/L). The relation between the concentration of the radionuclide, in micrograms per liter and picocuries per liter for any radionuclide is calculated from

$$C = 10^{-19.05} \cdot W \cdot T \cdot D, \qquad (1)$$

where

C = Concentration, in micrograms per liter;
W = Atomic weight;
T = Half life, in seconds; and
D = Activity, in picocuries per liter.

Equation (1) indicates that radionuclides with short half lives produce greater amounts of activity than radionuclides with long half lives for the same concentration.

The MCLs applicable to the Puerco River basin in Arizona are in table 1. The amount of radium-226 in water supplies forms a basis for monitoring natural radionuclides in drinking-water supplies in the United States (fig. 3). On the basis of radiotoxicity, the EPA primary MCL is 5.0 pCi/L for total radium-226 plus radium-228. The MCL for gross alpha activity minus uranium and radon is 15 pCi/L, and the MCL for total gross beta activity is 50 pCi/L (table 1). The MCLs have not been established for uranium in drinking water. On the basis of chemical toxicity, 0.035 milligrams per liter (mg/L) of uranium is a recommended limit (Lappenbusch and Cothern, 1985). State of Arizona regulations also require that if the identity or concentrations of any radionuclide in a mixture of radionuclides in water is unknown, the limiting value for the regulation is 30 pCi/L (table 1).

History of Radionuclide Releases in the Puerco River Basin

Uranium mining began in the 1950's in the Puerco River basin northeast of Gallup, New Mexico (fig. 1). Discharge of effluent waters from the mines created perennial flow in the Puerco River as far downstream as Chambers, Arizona, until mining ceased in the 1960's. Mining resumed in 1969, and effluent waters from the mines created perennial flow in the river as far as Chambers until mining stopped again in February 1986 (Shuey, 1986). Effluent waters from the mines were a potential source of radionuclides in the Puerco River basin, although the amount of radionuclides in effluent water from mining activities in the 1950's and early 1960's is unknown.

Permits under the National Pollutant Discharge Elimination System (NPDES) were required when the mines reopened in 1969 in an attempt to control the level of radioactive material in effluent water. Under the conditions of the permits, effluent water could contain as much as 3 pCi/L

Table 1.--Maximum contaminant levels for selected constituents in water, Puerco River basin, Arizona

[Maximum contaminant levels, in milligrams per liter, total recoverable concentration unless noted. Dashes, no established maximum contaminant levels; D, dissolved concentration or activity; I, insoluble activity]

Constituent	U.S. Environmental Protection Agency[1]	State of Arizona					
		Drinking water[2]		Surface water [3] [4]			All water[4]
		Community water system	Noncommunity water system	Domestic water source	Aquatic and wildlife	Agricultural and livestock	
Arsenic........	0.05	0.05	0.10	0.05D	0.05D	0.20	-------
Barium.........	1	1.	2.	1.00D	--------	-------	-------
Boron..........	-------	-------	-------	-------	--------	-------	-------
Cadmium........	0.010	0.01	0.02	0.01	0.01D	0.05	-------
Chloride.......	[5]250	(6)	(6)	-------	--------	-------	-------
Chromium, total........	0.05	0.05	0.5	0.05D	0.05D	1.00	-------
Copper.........	[5]1	(6)	(6)	1.00D	0.05D	0.50	-------
Dissolved solids.......	[5]500	(6)	(6)	(6)	(6)	(6)	-------
Fluoride.......	4.0	1.4-2.4	6.0	-------	--------	-------	-------
Gross alpha (picocuries per liter)....	[8]15	[8]15	[8]15	-------	--------	-------	-------
Gross alpha plus gross beta (picocuries per liter)........	-------	-------	-------	30	30	30	30
Gross beta (picocuries per liter)....	50	-------	-------	-------	--------	-------	-------
Iron...........	[5]0.3	(6)	(6)	-------	--------	-------	-------
Lead...........	0.05	0.05	0.1	0.05D	0.05D	0.10	-------
Lead-210 (picocuries per liter)....	-------	-------	-------	100D 200,000I	100D 200,000I	100D 200,000I	100D 200,000I
Manganese......	[5]0.05	(6)	(6)	-------	--------	-------	-------
Mercury........	0.002	0.002	0.004	0.0020	0.0002	0.0100	-------
pH (units).....	[5]6.5-8.5	(6)	(6)	-------	6.5-9.0	6.5-9.0	-------
Polonium-210 (picocuries per liter)....	-------	-------	-------	700D 30,000I	700D 30,000I	700D 30,000I	700D 30,000I

See footnotes at end of table.

Table 1.--Maximum contaminant levels for selected constituents in water, Puerco River basin, Arizona--Continued

Constituent	U.S. Environmental Protection Agency[1]	State of Arizona					
		Drinking water[2]		Surface water [3] [4]			All water[4]
		Community water system	Noncommunity water system	Domestic water source	Aquatic and wildlife	Agricultural and livestock	
Radium-226 (picocuries per liter)....	(10)	(10)	(10)	30D 30,000I	30D 30,000I	30D 30,000I	30D 30,000I
Radium-228 (picocuries per liter)....	-------	-------	-------	30D 30,000I	30D 30,000I	30D 30,000I	30D 30,000I
Radium-226 plus radium-228 (picocuries per liter)........	5	5	5	5	5	5	-------
Selenium.......	0.01	0.01	0.02	0.010D	0.050	0.050	-------
Silver.........	0.05	0.05	0.10	0.050D	0.050D	-------	-------
Sulfate........	[5]250	(6)	(6)	-------	--------	-------	-------
Thorium-230 (picocuries per liter)....	-------	-------	-------	2,000D 30,000I	2,000D 30,000I	2,000D 30,000I	2,000D 30,000D
Uranium, total.	[11]0.035	[12]0.035	[12]0.035	45	45	45	45
Zinc...........	[5]5	(6)	(6)	5.000D	0.500D	25.00	-------

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[1] U.S. Environmental Protection Agency, 1986a, Maximum contaminant levels (subpart B of part 141, National Interim Primary Drinking Water Regulations: U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1986, p. 524-528. Unless noted, all values in this column are primary drinking water maximum contaminant levels and apply to water in public water systems..

[2] McClennan, J.J., 1984, Official compilation of administrative rules and regulations: Phoenix, Arizona, State of Arizona report, Supplement 84-3, p. 68-84. Unless noted, all values in these columns are primary drinking water maximum contaminant levels and apply to water in public water systems.

[3] McClennan, J.J., 1986, Official compilation of administrative rules and regulations: Phoenix, Arizona, State of Arizona report, Advance Supplement 86-4, p. 1-49. Unless noted, all values in this column are maximum allowable limits and apply to surface water in the Puerco River basin.

Table 1.--Maximum contaminant levels for selected constituents in water, Puerco River basin, Arizona--Continued

[4] State of Arizona Atomic Energy Commission, 1977, Rules and regulations, title 12: Phoenix, Arizona, State of Arizona report, Supplement 77-3, p. 1-113. These standards (maximum permissible levels) apply to all waters released from external sources in unrestricted areas.

[5] U.S. Environmental Protection Agency, 1986b, Secondary maximum contaminant levels (Section 143.3 of part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1986, p. 587-590. These regulations are not Federally enforceable but are intended as guidelines for the States and apply to water in public water systems.

[6] To be monitored. No maximum contaminant level.

[7] Fluoride maximum contaminant levels are a function of mean annual maximum daily air temperature.

[8] Includes radium-226 but excludes radon and uranium. See figure 3 for the flow-chart regulations on interpretation of gross alpha results.

[9] If either the identity or the concentration of any radionuclide in the mixture is not known, see footnote 4.

[10] If radium-226 exceeds 3 picocuries per liter, radium-228 must be measured. See fig. 3.

[11] Recommended levels (Lappenbusch, W.L., and Cothern, C.R., 1985, Regulatory development of the interim and revised regulations for radioactivity in drinking water--past and present issues and problems: Health Physics, v. 48, p. 535-551).

[12] Glyn G. Caldwell, M.D., Arizona Department of Health Services, written commun., 1985. These values apply to chemical toxicity.

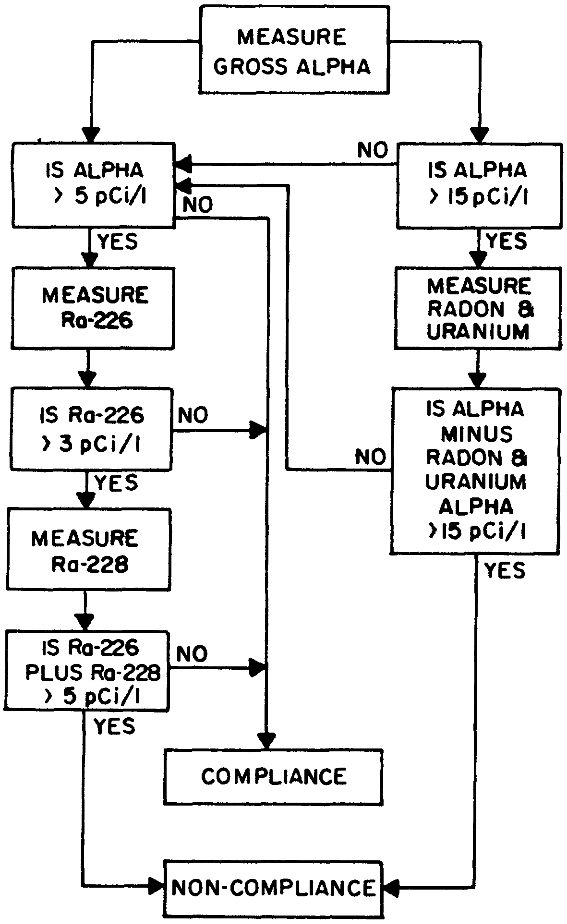

Figure 3.--Flow chart of gross alpha activity used in monitoring public drinking-water supplies (from Lappenbusch and Cothern, 1985).

of dissolved radium-226, as much as 10 pCi/L of total radium-226, and as much as 2.0 mg/L of total uranium (Chris Shuey, Southwest Research and Information Center, Albuquerque, New Mexico, written commun., 1987). Shuey (1986) reported 63 violations of the NPDES permits between 1980 and 1983.

Additional discharges of radionuclides into the Puerco River occurred after a tailings-pond dam failed at the United Nuclear Corporation's Church Rock Mill on July 16, 1979 (Millard and others, 1984; Shuey, 1982; Weimer and others, 1981). An estimated 94 million gallons (Mgal) of liquid were released into the Puerco River (Weimer and others, 1981). The liquid contained an estimated 18,000 tons of suspended sediment in addition to 1,100 tons of tailings eroded from the bottom of the tailings pond (Donald Hendricks, U.S. Environmental Protection Agency, written commun., 1982). The total amount that entered the Puerco River is probably less than these amounts because of retention of sediments behind an emergency catchment dam and postspill cleanup efforts (Weimer and others, 1981). A liquid sample taken from the tailings pond before the spill had activities of 210 pCi/L of radium-226 and 10,225 pCi/L of thorium-230. The pH of the liquid was 1.9, and the concentration of uranium was about 4 mg/L (Weimer and others, 1981).

The mines continued to discharge effluents allowed under the NPDES permits after the spill of 1979. Activities of gross alpha and radium-226 were as high as 400 and 2.5 pCi/L, respectively, in two samples measured in October 1981 (B.M. Gallaher, New Mexico Environmental Improvement Division, written commun., 1982). Activities of lead-210 and polonium-210 ranged from 4.5 to 10 pCi/L, and 3.4 to 10 pCi/L, respectively, and activity of thorium-230 ranged from 0.1 to 3.9 pCi/L (B.M. Gallaher, written commun., 1982). Treated mine water discharged into the Puerco River had gross beta activities that ranged between 320 and 660 pCi/L in 1982 (Chris Shuey, written commun., 1987). Effluent from one mine had maximum total uranium concentrations that ranged from 1.5 to 2.7 mg/L and a concentration of 1.6 mg/L over 9 months of 1982 (June Buzzell, U.S. Environmental Protection Agency, written commun., 1983).

Water-Quality Investigations Related to Radionuclide Releases

Surface water in the Puerco River had high concentrations of radionuclides and trace elements in the mid-1970's. In two samples taken at the Arizona-New Mexico border in 1975 and 1976, gross alpha activities were 330 and 100 pCi/L, and gross beta activities were 1,640 and 81 pCi/L (W.J. Shelley, Kerr-McGee Nuclear Corporation, written commun., 1979). Between 1975 and May 1979, radium-226 activities ranged from 0.1 to 22 pCi/L, and total uranium concentrations ranged from 0.2 to 0.9 mg/L. Selenium concentrations ranged from <0.001 to 0.035 mg/L and exceeded 0.01 mg/L in 5 of 10 samples collected between 1975 and May 1979 (W.J. Shelley, written commun., 1979). Near the uranium mines in New Mexico, selenium concentration in the Puerco River was 0.04 mg/L (U.S. Environmental Protection Agency, 1975); however, the concentration was 0.01 mg/L at Gallup.

The effect of discharges allowed under the NPDES permits and discharges in violation of permits on the quality of ground water in the Puerco River basin in Arizona is not known. Kaufmann and others (1976) studied ground-water contamination near uranium mines and milling operations in the Puerco River basin upstream from Gallup, New Mexico (fig. 1). In 71 ground-water samples that they collected near uranium mines throughout northwestern New Mexico, only 6 wells had activities of radium-226 above 3.0 pCi/L. Gross alpha activities exceeded 15 pCi/L in 33 of 71 wells (Kaufmann and others, 1976). Although radionuclide and trace-element activities in some of the samples were above the MCLs presented in table 1, Kaufmann and others (1976) concluded that none of the 13 wells sampled in the Puerco River basin were contaminated by radionuclides.

Water and sediments were sampled extensively throughout the Puerco River basin after the spill of 1979. Activities of thorium-230 in sediments commonly exceeded 30 picocuries per gram (pCi/g) as far as 40 mi downstream from the mine (Weimer and others, 1981). After the spill of 1979, thorium-230 activity in sediments decreased with time to an average of 9 pCi/g in the same reach (Millard and others, 1984). Sediments collected from the Puerco River in Arizona at Chambers and Petrified Forest National Park (fig. 1) in 1979 had activities of thorium-230 between 1 and 8 pCi/g (E.K. Swanson, Arizona Department of Health Services, written commun., 1986).

On July 16, 1979, radionuclide activities in unfiltered samples from the Puerco River were 6,910 pCi/L of uranium, 12,000 pCi/L of thorium-230, 1.0 pCi/L of radium-226, 260 pCi/L of lead-210, and 38 pCi/L of polonium-210 at sites in New Mexico (Millard and others, 1984). The maximum gross alpha activity was 130,000 pCi/L on the day of the spill near the Church Rock Mill and 26,000 to 40,000 pCi/L at Gallup, New Mexico (Shuey, 1982).

After the spill of 1979, shallow wells in the alluvial aquifer of the Puerco River were monitored in New Mexico and Arizona. The wells in New Mexico that were adjacent to the Puerco River revealed some contamination by radionuclides (Gallaher and Cary, 1986). Gross alpha activity increased from a pre-spill average of 12 pCi/L to a postspill high of 304 pCi/L with concomitant increases in the concentrations of total uranium (Shuey, 1982). Increases and fluctuations in gross alpha, uranium, and sulfate are shown in data from the wells in Arizona (Shuey, 1982).

Radionuclides and trace elements have been monitored sporadically in the Puerco River at Chambers since 1979 (Webb and others, 1987). Total gross alpha activities have fluctuated between 12 and 11,200 pCi/L between 1979 and 1985 in the Puerco River at Chambers. The Arizona Department of Health Services (ADHS, 1986a) measured 34 violations of Arizona MCLs in 11 samples of surface water at five sites on the Puerco River in Arizona in February, April, and June 1985. The violations included elevated activities of gross alpha, gross beta, and radium-226 and elevated concentrations of total arsenic, copper, lead, and selenium. During a flood on July 16, 1986, Chris Shuey (written commun., 1987) measured gross alpha activities of 1,700 to 2,200 pCi/L and gross beta activities of 1,800 to 2,100 pCi/L in the Puerco River near Lupton.

Trace-element concentrations also exceeded Arizona MCLs for surface water in 11 samples collected in 1985 and 1986 (ADHS, 1986a). Concentrations of total arsenic, copper, manganese, lead, and dissolved selenium at five sites in Arizona were above the Arizona MCLs (table 1) in samples taken in February, April, and June 1985 (ADHS, 1986a). Chris Shuey (written commun., 1987) measured concentrations of arsenic, copper, and lead that exceeded Arizona MCLs in July 1986.

Measurements of surficial sediments from the Puerco River have shown high radionuclide activity (Weimer and others, 1981) and trace-element concentrations (ADHS, 1986a), whereas other historic measurements have shown low concentrations and activities. Miller and Wells (1986) reported longitudinal variations of 600 to 1,900 parts per million (ppm) of barium in the channel of the Puerco River in New Mexico in samples collected in 1984. Samples collected in 1986 had barium concentrations of 600 to 710 ppm in Arizona (Webb and others, 1987). Copper concentrations measured in 1984 ranged from 20 to 100 ppm in New Mexico (Miller and Wells, 1986), whereas copper concentrations were less than 10 ppm in 1986 in Arizona (Webb and others, 1987). Webb and others (1987) report normal concentrations or activities of trace elements and radionuclides in surficial-sediment samples collected in 1986.

Sampling of surface and ground water in the Puerco River basin between 1975 and 1986 has indicated that MCLs shown in table 1 have been exceeded many times for several trace elements and radionuclides. The source of the elevated concentrations may be related either to mining or to natural sources. Natural radionuclide activities and trace-element concentrations in Black Creek, a tributary of the Puerco River that has not had uranium mining in its drainage basin (fig. 1), however, do not exceed Arizona MCLs for surface water (ADHS, 1986a; Chris Shuey, written commun., 1987). On the basis of chemical data from three wells in the alluvium of the Puerco River basin in Arizona, Harrell and Eckel (1939) indicate pre-mining concentrations of 285 mg/L of sulfate, 44 mg/L of chloride, and 754 mg/L of total dissolved solids. Scott and Barker (1962) report median values of 0.008 mg/L for uranium and 0.1 pCi/L for radium in ground water in a region that includes the Puerco River basin. No trace element or radionuclide data are available for surface water for the period before the mining activities of the 1950's or for the period before the resumption of mining in 1969. Arizona Department of Health Services (1986b) used a statistical model of flood-recurrence interval and suspended-sediment concentrations to show that radium-226 activities in mine effluents alone were sufficient to cause violations of Arizona maximum allowable limits for surface water in the Puerco River.

Historical Data on Streamflow and Water Quality of the Puerco River at Chambers, Arizona

The U.S. Geological Survey has maintained a gaging station on the Puerco River at Chambers since 1971 (White and Garrett, 1986). Although the gaging station does not record streamflow below 500 ft^3/s, the distribution of peak streamflow discharges greater than 3,000 ft^3/s (fig. 4) illustrate the episodic nature of natural flow in the Puerco River. Most peak discharges above 3,000 ft^3/s have occurred during the summer months, although some also have occurred in December, January, February, and March (fig. 4). Any streamflows greater than 3,000 ft^3/s are heavily laden with sediments eroded from the headwaters or the sides and bed of the channel. Samples to determine the quality of surface water have been collected at many sites along the Puerco River (ADHS, 1986a). A total of

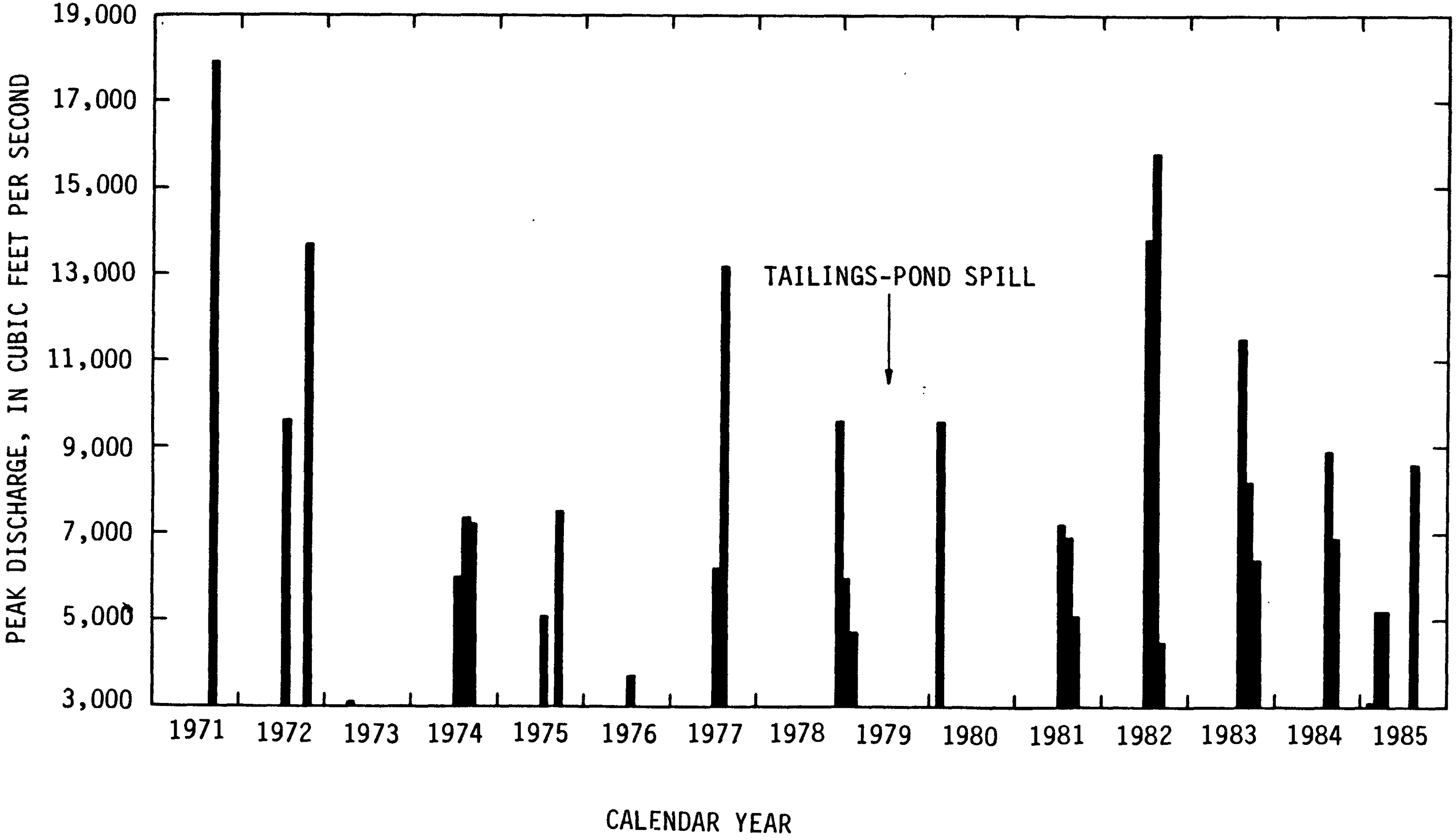

Figure 4.--Peak streamflows for floods greater than 3,000 cubic feet per second for the Puerco River at Chambers, Arizona.

29 water-quality samples have been collected at or near the gaging station at Chambers (Webb and others, 1987). Of these, samples collected in 1982, 1983, and 1984 were analyzed by the U.S. Geological Survey.

Historic data indicate high concentrations of several trace elements (ADHS, 1986a) and high radionuclide activities (fig. 5; table 1). The concentrations are related statistically to suspended-sediment concentrations (ADHS, 1986b; Chris Shuey, written commun., 1987). Dissolved and suspended gross alpha and gross beta activities have fluctuated widely with time (fig. 5). Concentrations of total uranium, chloride, and sulfate fluctuated in 1979 apparently as a result of the tailings-pond spill (fig. 5). After 1980, changes in concentrations of these constituents are not well known. Only three samples were measured for these constituents between May 1980 and May 1985. Concentration of total uranium averages about 0.1 mg/L between 1980 and 1985. The amount of dissolved uranium is not completely known, but total and dissolved data for 1985 (ADHS, 1986a) indicates that the concentration of dissolved uranium is 30 to 70 percent of the total concentration.

Hydrogeologic Setting

Puerco River provides surface flow for livestock watering, some agricultural use, and recharge of ground water in the alluvial aquifer, which is an important source for domestic use (Mann and Nemecek, 1983). The population is expected to expand from a few hundred to as many as 5,000 to 10,000 people in the area of Chambers and Sanders, Arizona, as a result of the relocation of Navajo Indians into the area. Use of ground water will change from livestock watering to domestic and public supply as a result of this demographic shift; however, available surface water in the Puerco River will be used for livestock and agriculture and will be supplemented with ground water from the alluvium during periods of no flow.

The bedrock in the Puerco River basin consists of Paleozoic and Mesozoic sedimentary rocks that dip slightly to the northeast. Steeply-dipping fault zones that trend north and south displace these rocks. The Defiance and Zuni Uplifts occur to the north and east, respectively (Cooley and others, 1969). Rocks of Tertiary and Quaternary age, including the Tertiary Bidahochi Formation, generally are undeformed. Major uranium and minor coal deposits are in the Jurassic Morrison Formation to the east and northwest of Gallup (Hackman and Olson, 1977). Uranium minerals also occur in the Petrified Forest Member of the Triassic Chinle Formation in the western half of the basin. Natural erosion of exposed bedrock that contains uranium minerals and minerals that contain other radionuclides is the source for background radiation in the regional water resources and sediments (Weimer and others, 1981).

The alluvial aquifer consists of interbedded gravel, sand, silt, and clay (Mann and Nemecek, 1983). The thickness and areal extent of the aquifer are unknown, but several wells in the alluvial aquifer are 200 ft deep and do not encounter bedrock. The stratigraphy and variability of the sediments that compose the alluvial aquifer in the Puerco River basin are not known.

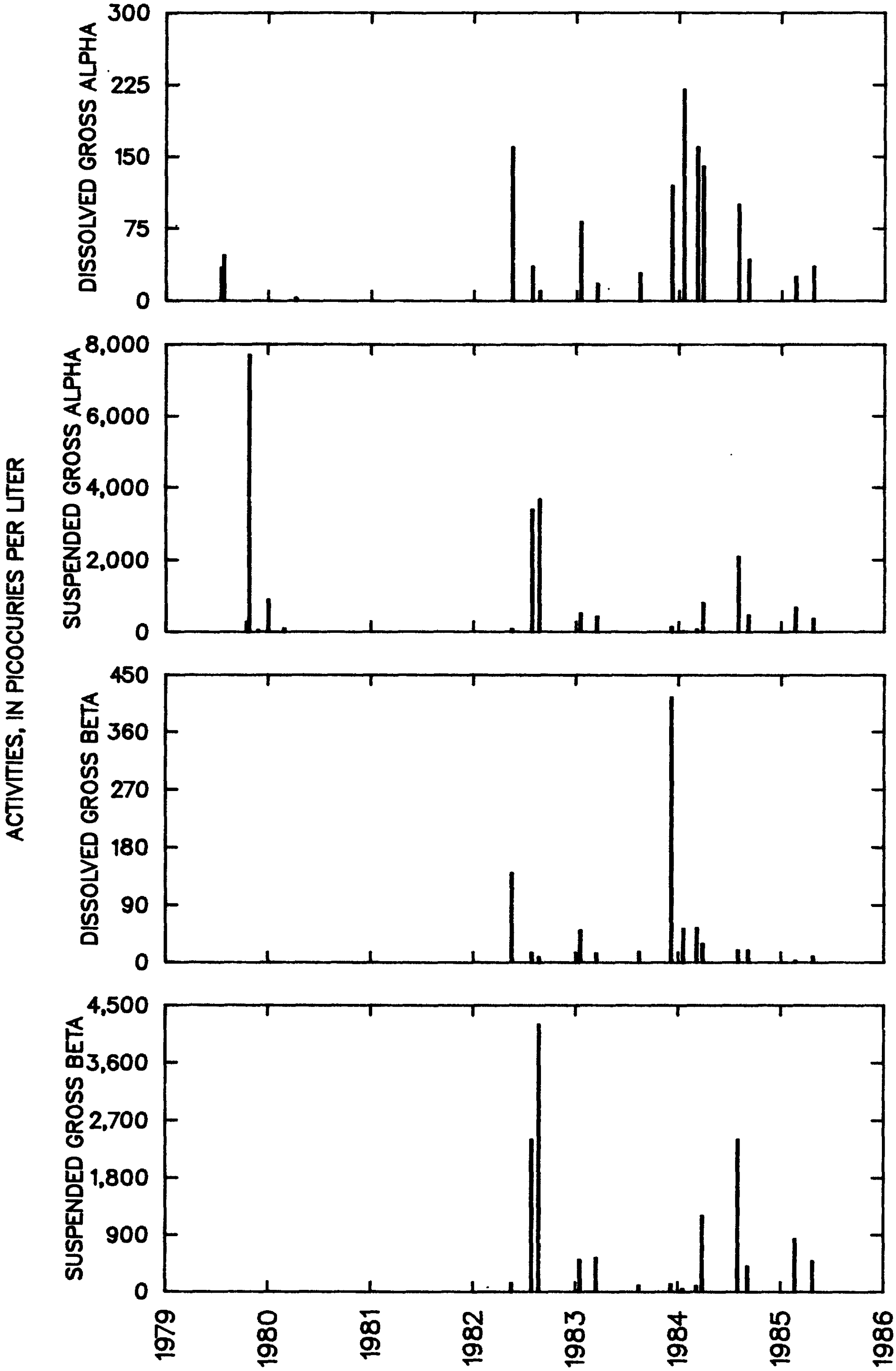

Figure 5.--Temporal variations of selected chemical constituents in the Puerco River at Chambers, Arizona.

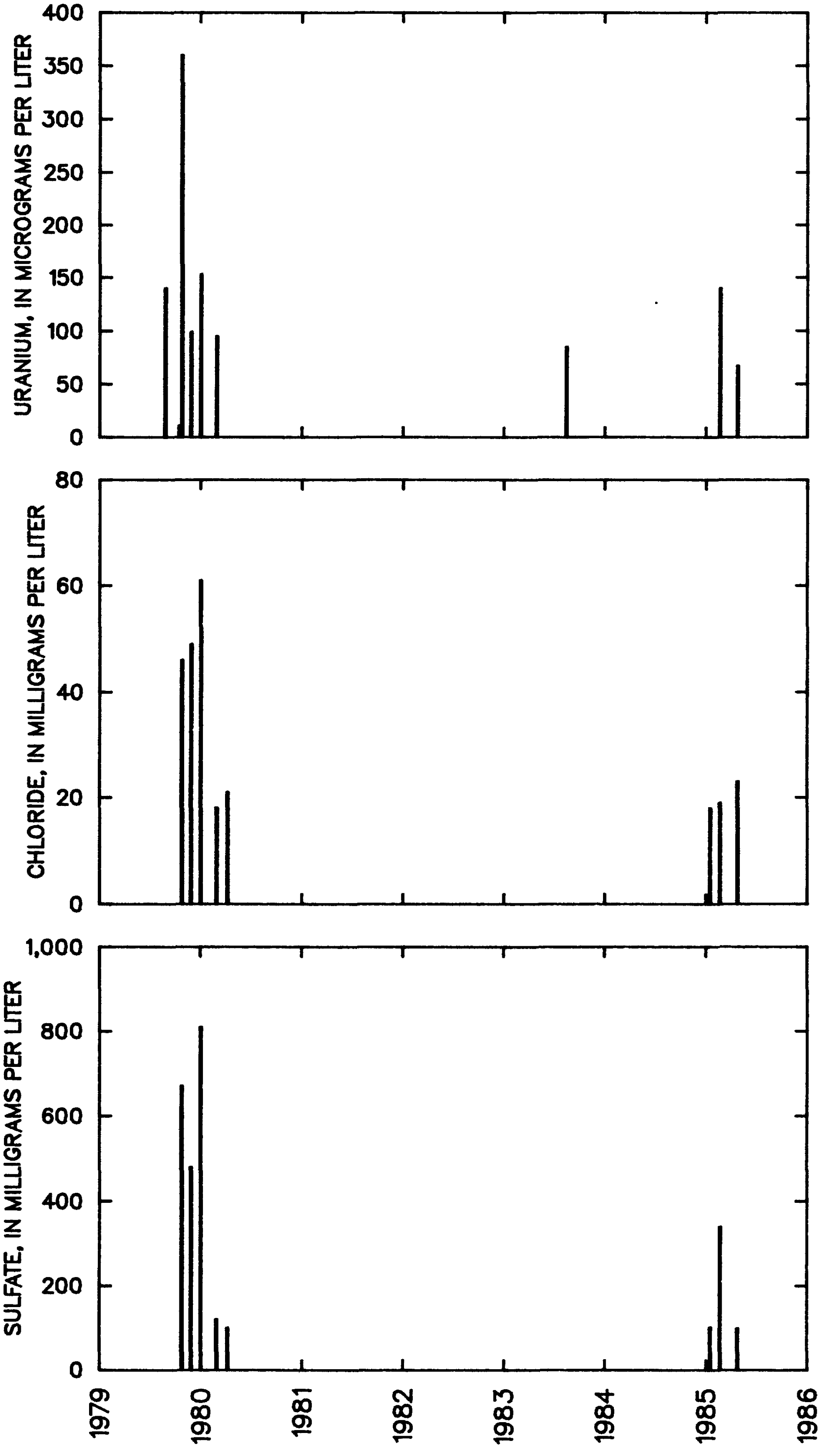

Figure 5.--Temporal variations of selected chemical constituents in the Puerco River at Chambers, Arizona--Continued.

Base flow in the Puerco River, augmented by mine drainage as well as sewage effluent from Gallup, occurs primarily in the channel in New Mexico. As flow moves into Arizona, however, the surface flow decreases as the water infiltrates into the alluvium. Disparate events such as flows entering the Puerco River from undisturbed tributary basins and the tailings-pond dam spill in July 1979 cause large fluctuations in activities of radionuclides that enter Arizona (fig. 5). Streamflow may cause remobilization of sediments deposited after the tailings-pond dam spill (ADHS, 1986b), providing another mechanism to create large fluctuations in the activity of radionuclides carried by the Puerco River into Arizona. Extensive monitoring of surface water in the Puerco River indicates that water that recharges the alluvial aquifer in Arizona is of widely fluctuating quality.

The alluvial aquifer of the Puerco River is hydraulically connected with the Bidahochi Formation and sandstone beds of the Chinle Formation (Mann and Nemecek, 1983). Because there are no large withdrawals from the adjacent bedrock aquifers in the vicinity of the river, it is possible that there is little movement of water between the alluvial and bedrock aquifers. Radionuclide contamination of the alluvial aquifer, therefore, may be greatest in areas close to the channel and may diminish with distance from the channel. A <u>contaminant plume</u>, or discrete area of contaminated water in the alluvial aquifer that extends away from the contaminant source, may be present along the Puerco River. The fluctuating quality of recharge waters and the varying distances that streamflows extend along the river leads to an expectation of fluctuations of contaminants in the alluvial aquifer.

DATA COLLECTION

A sampling strategy was designed to determine whether a contaminant plume is present in the alluvial aquifer. Five study sites along the river through the area of interest were selected (fig. 1). The study sites consisted of existing wells in the alluvial aquifer on either side of and adjacent to the Puerco River. Wells at varying distances from the river were needed to assess the lateral extent of radionuclide distribution and to define the lateral extent of a potential contaminant plume at each study site. Analysis of ground water in wells in the five study sites may provide information on the longitudinal distribution of the contaminant plume. Some of the wells that were selected for sampling were chosen because prior sampling offered an opportunity to evaluate changes in contaminant levels. Use of existing wells, however, creates problems because the depth of the well and location of well intakes could not be controlled. Analyses included selected trace elements, such as selenium, lead, and other metals with high historic concentrations in the Puerco River, and naturally occuring radionuclides. Total concentrations of trace elements and activities of radionuclides were measured because most MCLs are for the total concentration or activity (table 1).

Ground-water and surficial-sediment samples were collected during December 1-6, 1986. Five study sites were established (fig. 1), and each site had two to four wells (table 2; figs. 7-11). Depths of two of the wells are not known (table 2) although all yield water from the alluvial aquifer. The positions of the well intakes are not known except for Begay Well (A-22-31)08aad01, which is hand dug and is permeable for

Table 2.--Well names and numbers used in this report

Study site	Well name	Well number	Unique identification	Depth (feet)	Water use	Approximate distance from Puerco River (feet)
Lupton	Begay well	(A-22-31)08aad01	351933109041701	10	Unused	50
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	102	Stock	800
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	102	Unused	5,500
Sanders	Sanders School well	(A-21-28)13cbc01	351254109194501	160	Public supply	100
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	175	Public supply	100
Sanders	Private well	(A-21-28)13cdc01	351241109193101	111	Private	1,200
Sanders	Private well	(A-21-28)14daa01	351302109195901	145	Private	2,200
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	---	Unused	0
Chambers	Private well	(A-21-28)30aaa02	351152109241601	---	Private	600
Chambers	Private well	(A-21-28)30aaa01	351157109241701	40	Private	1,000
Chambers	ATSF Well No. 3	(A-21-27)25cad01	351119109255301	91	Public supply	1,000
Pinta	Private well	(A-19-25)11daa01	350338109384801	55	Private	1,100
Pinta	Private well	(A-19-25)01bba01	350451109383401	54	Private	2,200
Petrified Forest	Petrified Forest Well No. 2	(A-18-24)09abb01	345850109475001	100	Public supply	1,000
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	---	Stock	2,100

entire depth, and ATSF Well No. 3 (A-21-27)25cad01, Project 77-712 (A-23-31)09ddb01 and Navajo Windmill 18T-347A (A-22-31)18cad01 (Appendix A). Water-quality samples collected from most of the wells can be assumed to represent depth-integrated samples of the alluvial aquifer.

Representative samples of water in the alluvial aquifer were collected using U.S. Geological Survey techniques (Wood, 1976). Wells with electric lifts were pumped, and the discharge was monitored until temperature, dissolved oxygen, pH, and specific conductance of the water became constant. Samples were taken from spigots as close to the well head as possible. If possible, the well head was isolated from storage tanks to prevent back flow. Windmills were operated for several days where possible, and samples were taken when temperature, pH, and specific conductance of the water were constant. Begay Well, (A-22-31)08aad01, which has a cement casing (fig. 6), was pumped with an electric-suction pump until temperature, pH, and specific conductance of the water were constant.

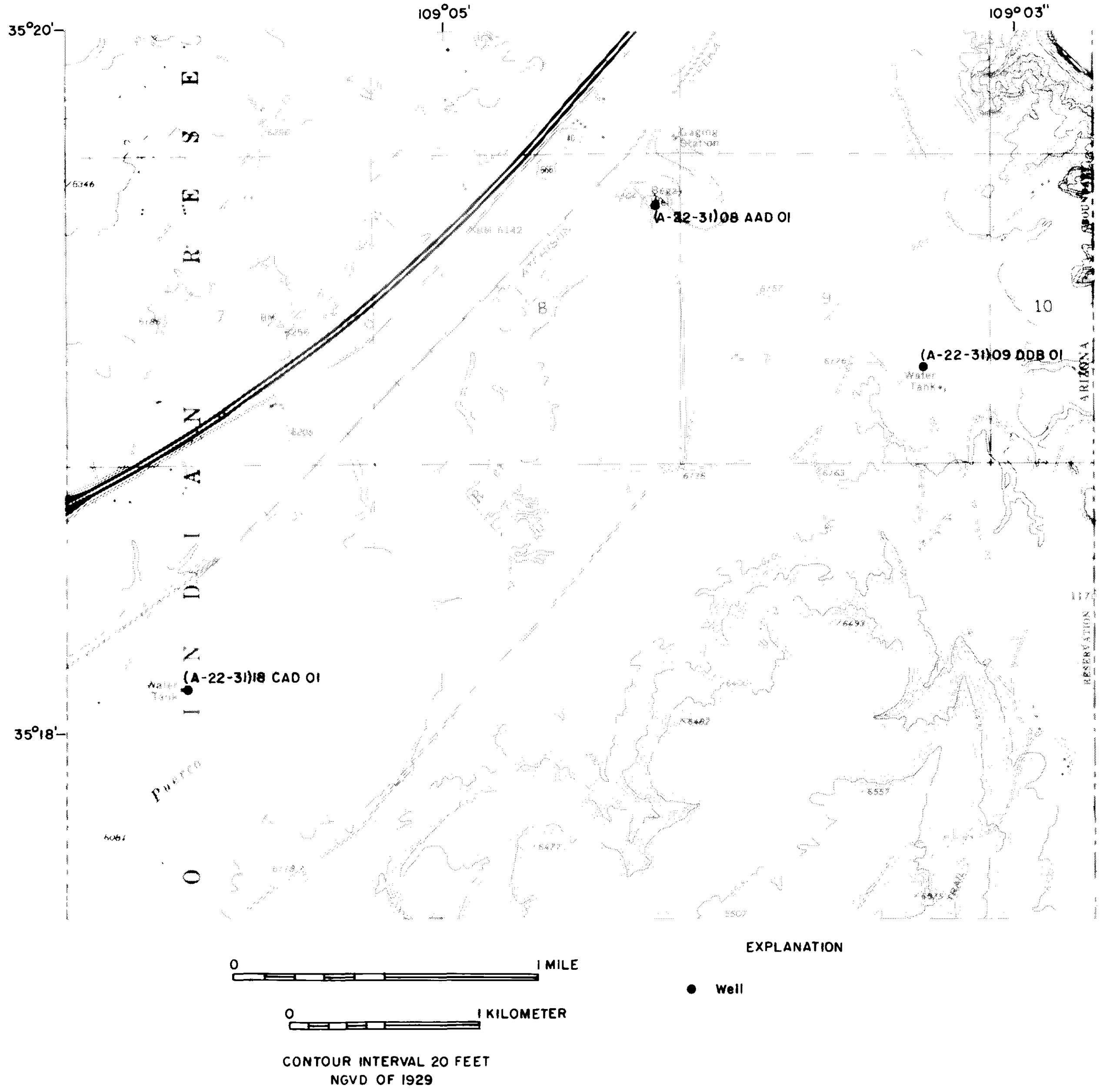

Figure 6.--Wells at Lupton, Arizona.

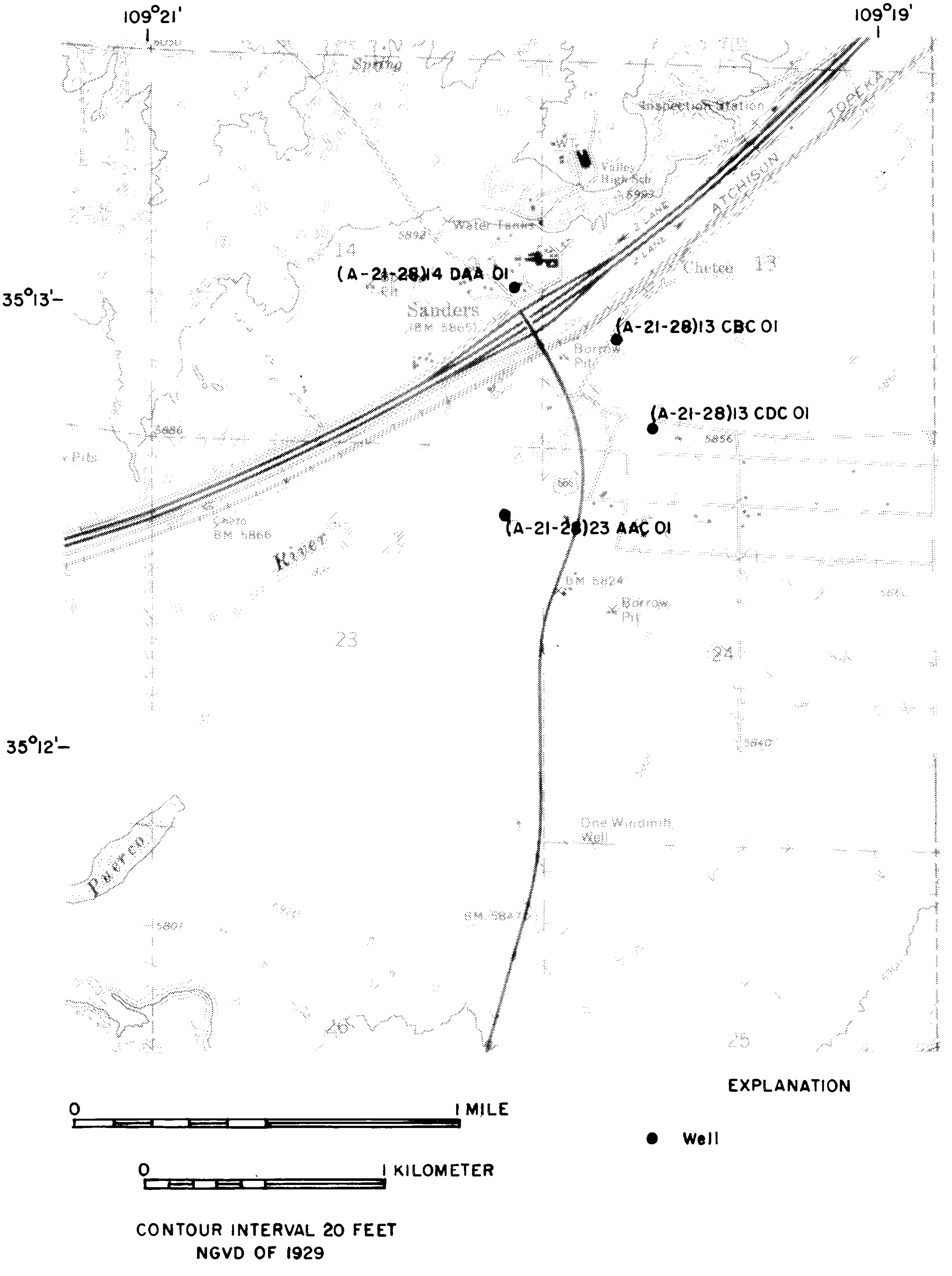

Figure 7.--Wells at Sanders, Arizona.

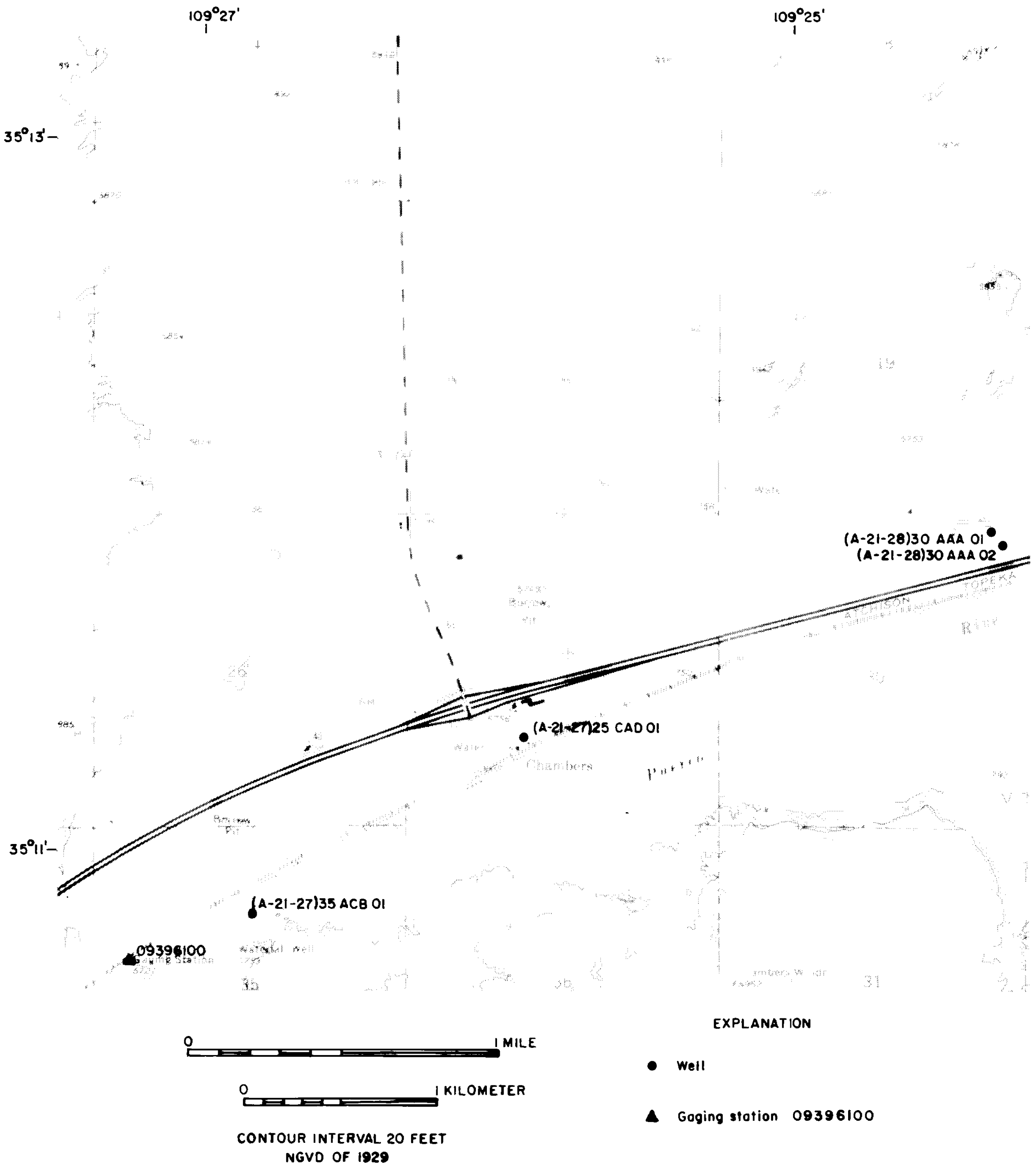

Figure 8.--Wells at Chambers, Arizona.

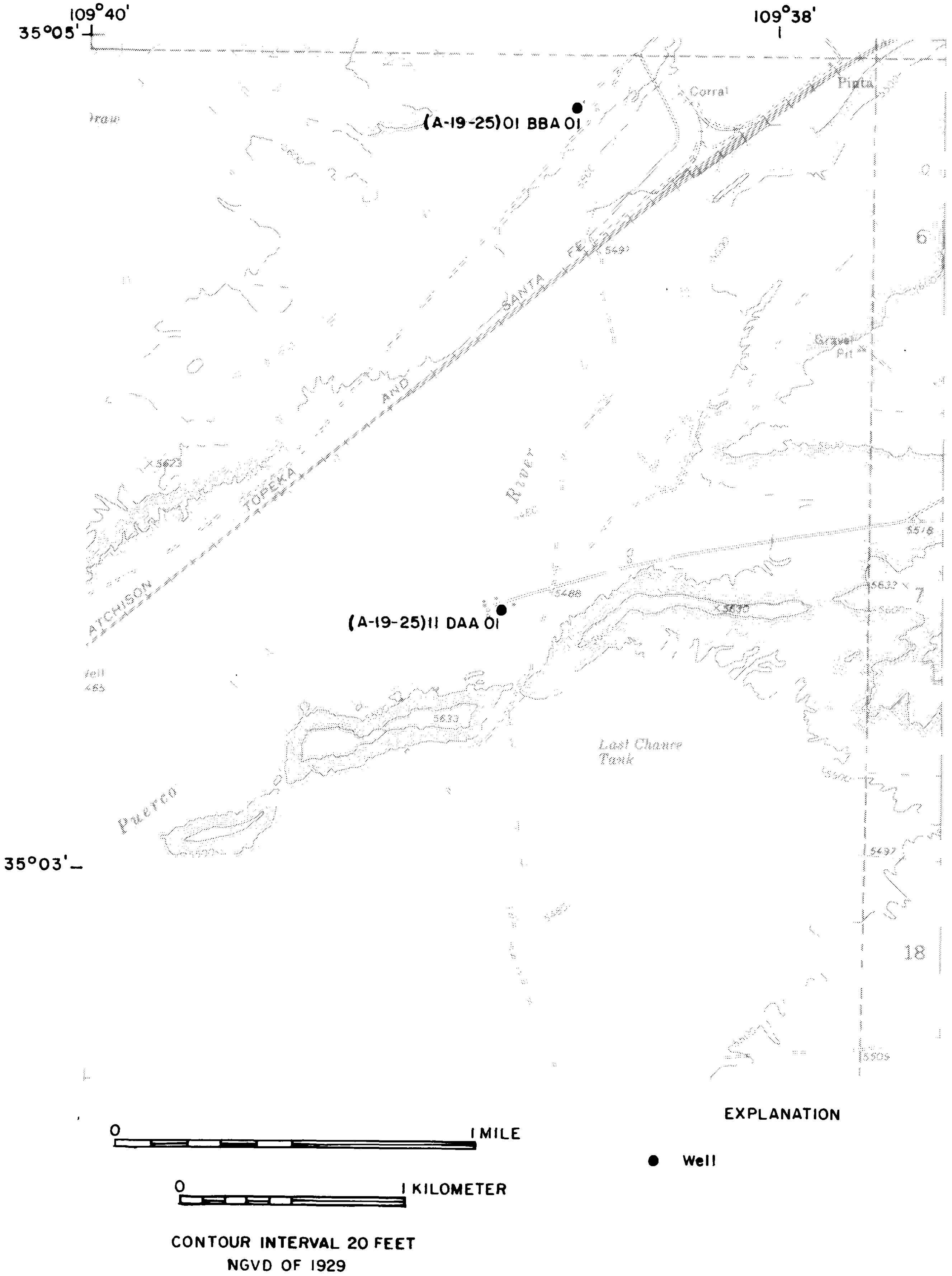

Figure 9.--Wells at Pinta, Arizona.

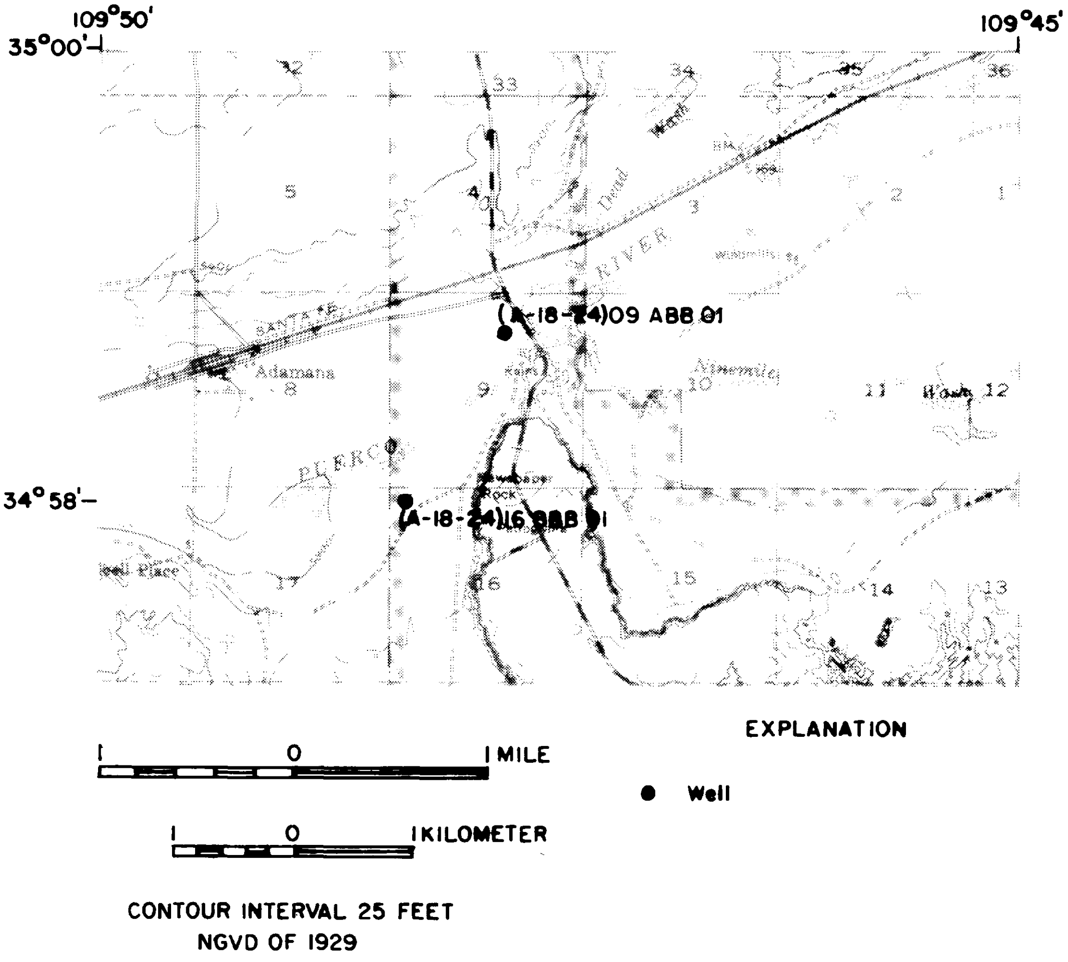

Figure 10.--Wells at Petrified Forest, Arizona.

The ground-water sample was then split into subsamples at each well. Subsamples for common ions such as sulfate and chloride were filtered through a 0.45-micron filter, and cations were acidified with nitric acid to a pH of less than 2. The common-ion analytical results, therefore, represent the dissolved concentration of the constituent. Subsamples for trace elements such as arsenic and cadmium were not filtered but were acidified with nitric acid to a pH of less than 2. The trace- element analytical results, therefore, represent the total recoverable (dissolved, suspended, and colloidal) concentration of the constituent. Subsamples for radionuclide analysis were neither filtered nor acidified in the field, but were acidified in the laboratory approximately 2 weeks after the date of collection. The common-ion and trace-element subsamples were analyzed by the U.S. Geological Survey, Arvada, Colorado; the radionuclide samples were analyzed by Accu-Labs Research, Incorporated[2], of Wheat Ridge, Colorado. Three replicate samples were analyzed from the Sanders Elementary School well, (A-21-28)13cbc01, for quality-assurance purposes. Radionuclide concentrations that are measured from radioactive decay are expressed in picocuries per liter plus or minus a counting error. The counting error expressed in Appendix A and the tables containing data is plus or minus one standard deviation of the counting statistics of radioactive decay. Errors associated with sampling are not included in the counting error.

The U.S. Environmental Protection Agency MCL requires correction of gross alpha for uranium and radon if the activity of gross alpha exceeds 15 pCi/L (table 1). Radon is a radioactive but chemically inert gas (Spencer, 1986) that is removed from samples before gross alpha is measured. Uranium concentrations, which were determined chemically instead of radiometrically, are expressed in either milligrams per liter or micrograms per liter. The concentration of uranium in micrograms per liter can be multiplied by 0.667 to obtain an activity in picocuries per liter; however, this conversion requires the assumption of an activity ratio of uranium-234 to uranium-238 of 1.0, which may not be valid in ground water (Cothern and others, 1983).

Activities of uranium-234 and uranium-238 were not measured in samples collected in December 1986. Isotopic activities of uranium were measured in samples collected in September 1979 at Begay Well, (A-22-31)08aad01, and in April 1985 at Project 77-712 (A-22-31)09ddb-1 near Lupton. The activity ratios of uranium-234 to uranium-283 are 0.93 and 1.50 for the samples at Begay Well and Project 77-712, respectively. The factor used for conversion of uranium concentrations in micrograms per liter to uranium activity in picocuries per liter may vary between 0.64 and 0.83 on the basis of the two historic activity ratios of uranium-234 and uranium-238 in the Puerco River basin.

CHARACTERIZATION OF QUALITY OF GROUND WATER

The quality of water in the sampled wells is characterized by high dissolved solids (greater than 500 mg/L), generally high sulfate (greater than 250 mg/L), and manganese (greater than 50 μg/L) concentrations, variable activities of radionuclides, and low

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[2] Use of firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

concentrations of trace elements (Appendix A; table 1). Average and median concentration or activities of selected constituents are given in table 3. Median concentrations of total dissolved solids is 698 mg/L, and the concentrations of alkalinity, sodium, and sulfate comprise most of this total. Concentrations of dissolved solids, sulfate, and chloride are not unusual in comparison with samples measured in the 1930's (Harrell and Eckel, 1939).

Total gross alpha activity has a median of 27 pCi/L and ranges from 4 to 42 pCi/L (tables 3 and 4). Total gross beta activity has a median of 6 pCi/L (table 4) and ranges from 1 to 19 pCi/L (Appendix A). Uranium concentration normally is about 4.5 μg/L in ground water in the United States (Cothern and others, 1983) and has ranged from 0.1 to 6.1 μg/L in samples from the region that contains the Puerco River basin (Scott and Barker, 1962). Uranium in the 14 wells and 1 spring in the Puerco River basin ranges from 1 to 38 μg/L (Appendix A) and has a median of 19 μg/L. Other radionuclides, including radium-226, radium-228, lead-210, and thorium-230 generally have activities less than 1 pCi/L (Appendix A). The only well in which the activity of radium-226 plus radium-228 exceeds 5 pCi/L is a private well in Sanders, (A-21-28)14daa01 (fig. 7).

Gross alpha activity after uranium is subtracted ranges from -2 to 21 pCi/L (table 4). Uranium concentrations explain most of the gross alpha activity. The lowest activity of gross alpha after uranium was subtracted reflects inaccuracy in either laboratory-measurement technique of either gross alpha or uranium or conversion of uranium-concentration values from micrograms per liter to picocuries per liter (table 4; see "Data Collection"). On the basis of the historic uranium-234 to uranium-238 activity ratios, either two or five activities of gross alpha minus uranium exceed 15 pCi/L. The isotopic activities of uranium-234 and uranium-238 were not measured in this study; therefore, the exact activities of gross alpha minus uranium cannot be determined.

The sum of gross alpha and gross beta activities, which is a measure of the total radioactivity, ranges from 7 to 57 pCi/L with a median of 28 pCi/L (table 5). All measured radionuclides were summed and compared with gross alpha plus gross beta activities for each well (table 5). The percentage of the gross alpha plus gross beta explained by the measured radionuclides ranges from 20 to 84 percent. The difference between the gross alpha plus gross beta and the measured radionuclides can be attributed to measurement error in the gross alpha and gross beta activities and the different techniques used to measure the activities of specific radionuclides. However, the fact that as much as 84 percent of the radioactivity is unexplained suggests that other radionuclides that were not measured are present in the ground water.

Trace-element concentrations are low (less than the MCLs) in the sampled wells (Appendix A). For example, the median concentration of arsenic, which is high (greater than 50 μg/L) in surface water in the Puerco River (ADHS, 1986a), is 1 μg/L (table 3) and ranges from less than 1 to 12 μg/L. Strontium concentration, however, ranges from 0.38 to 3.4 mg/L (Appendix A) and has a median of 0.84 mg/L in the 14 wells and 1 spring (table 3). The normal concentration of strontium in ground water, however, ranges from 0.002 to 1.0 mg/L (Coughtrey and others, 1985).

Table 3.--Average and median concentrations or activities of selected constituents measured in 15 ground-water samples from the Puerco River basin, December 1-6, 1986

[Values in parentheses are medians; includes values less than the detection limit that were considered equal to the detection limit in the arithmetic mean. The average and median pH are 7.7 and 7.8, respectively. The average and median temperatures are 15 °C and 14 °C, respectively.]

Common Ions
(Values are in milligrams per liter, dissolved)

Alkalinity	345	(341)	Potassium	2.8	(2.0)
Calcium	80	(75)	Silica	14	(14)
Chloride	91	(61)	Sodium	230	(230)
Fluoride	0.8	(0.8)	Sulfate	340	(280)
Magnesium	19	(15)			

Selected Trace Elements
(Values are in micrograms per liter, total recoverable)

Aluminum	260	(20)	Lead	<6	(<5)
Arsenic	<2.2	(1)	Manganese	<240	(140)
Barium	<110	(<100)	Selenium	<44	(<39)
Boron	400	(380)	Strontium	1,000	(840)
Cadmium	<2	(<1)	Vanadium	<44	(<39)
Copper	18	(9)	Zinc	85	(70)
Iron	540	(360)			

Radionuclides
(Values are in picocuries per liter except as noted, total)

Gross alpha	22	(27)	Radium-228	<0.7	(0.3)
Gross beta	7	(6)	Thorium-230	0.1	(0.0)
Lead-210	0.5	(0.4)	Uranium (micrograms per liter)	19	(19)
Radium-226	0.4	(0.1)			

Table 4.--Activities of gross alpha and gross alpha minus uranium for wells in the Puerco River basin, December 1-6, 1986

Study site	Well name	Well number	Gross alpha (picocuries per liter ± CE)[1]	Gross alpha minus uranium (picocuries per liter)
Lupton	Begay	(A-22-31)08aad01	27±9	12
	Project 77-712	(A-22-31)09ddb01	40±6	15
	18T-347A	(A-22-31)18cad01	28±10	10
Sanders	School	(A-22-28)13cbc01	[2]29±6	[2]16
			[2]20±5	[2]9
			[2]16±4	[2]5
		Median	20	9
	Windsong	(A-21-28)23aac01	20±5	15
	Private	(A-21-28)14daa01	34±7	21
	Private	(A-21-28)13cdc01	14±4	7
Chambers	ATSF No. 3	(A-21-27)25cad01	15±5	4
	Private	(A-21-28)30aaa01	27±8	14
	Private	(A-21-28)30aaa02	28±7	13
	Waterfall Spring	(A-21-27)35acb01	9±4	-2
Pinta	Private	(A-19-25)11daa01	42±8	17
	Private	(A-19-25)01bba01	4±4	-2
Petrified Forest	Petrified Forest No. 2	(A-18-24)09abb01	5±4	4
	Windmill	(A-18-24)16bbb01	23±6	12

[1] CE is counting error expressed as ±1 standard deviation.

[2] Replicate samples.

Three replicate samples from the Sanders Elementary School well, (A-21-18)13cbc01 (fig. 7), had similar concentrations of common ions but appreciable differences in the activities of radionuclides. The concentrations of alkalinity, sulfate, chloride, calcium, magnesium, sodium, and potassium were virtually identical for all three samples (Appendix A). Except for iron and copper, major differences in the concentrations of trace elements were not measured. Gross alpha activity ranges from 16 to 29 pCi/L (table 4), whereas the gross beta activity is 6 pCi/L for all three samples. Total uranium is 16 μg/L in two samples and 20 μg/L in one sample (Appendix A). Variations in activities or concentrations of some constituents may be an artifact of not using filtered samples for quality assurance.

AREAL AND TEMPORAL VARIATIONS IN WATER QUALITY

Principal-component analysis was used to determine if the wells could be segregated into contaminated and uncontaminated classes on the basis of the concentrations or activities of selected constituents. The existence of these classes would enable an interpretation of a contaminant plume along the Puerco River. Principal-component analysis is a statistical method for graphically illustrating similarities and differences among multivariate samples by analyzing the eigen vectors from a correlation matrix (McCuen and Snyder, 1986). Samples are then arranged graphically to express the maximum variance. Although principal-component analysis calculates as many axes as variables, the results are presented in two dimensions on the two axes, called <u>principal axis 1</u> and <u>principal axis 2</u>, that explain the maximum amount of variance.

Constituents used in the principal-component analysis of data collected in December 1986 were pH, alkalinity, sulfate, chloride, calcium, magnesium, sodium, strontium, and uranium (Appendix A). Sulfate, strontium, and uranium concentrations and pH were used because these constituents may reflect the amount of contamination. Other constituents, the dominant ions in water (Hem, 1985), may not have changed in concentration as a result of mining. Changes in sulfate, strontium, and uranium in relation to other constituents may also indicate contamination.

The principal-component analysis graph (fig. 11) does not allow a conclusion with respect to the presence of distinct classes of water quality. The variance explained is 87 percent and 11 percent, respectively, for principal axes 1 and 2 (fig. 11) for a total variance explained of 98 percent. Wells that have the highest activities of radionuclides (for example, (A-19-25)11daa01, a private well at Pinta) plot adjacent to wells with lower activities of radionuclides (for example, (A-21-27)25cad01, ATSF Well No. 3 at Chambers). In general, wells with higher activities of radionuclides plot with greater values on principal axis 2 than do wells with lower activities of radionuclides. Lack of separation of the wells into distinct classes, however, precludes the determination of the presence or absence of a contaminant plume.

Radionuclide activities are not related directly to the distance of the well from the Puerco River. In comparing distance from the river (table 2) with radionuclide activities (tables 4 and 5), the wells with the highest radionuclide activities are not necessarily the wells closest to the river. For example, the Petrified Forest Well No. 2 (A-18-24)16bbb01

Table 5.--Activities of gross alpha plus gross beta and total measured radionuclides for wells in the Puerco River basin, December 1-6, 1986

Study site	Well name	Well number	Gross alpha plus gross beta (picocuries per liter	Total measured radionuclides (picocuries per liter)	Percentage of gross alpha plus beta measured (picocuries per liter
Lupton	Begay	(A-22-31)08aad01	31	17	53
	Project 77-712	(A-22-31)09ddb01	48	26	55
	18T-347A	(A-22-31)18cad01	38	14	36
Sanders	School	(A-22-28)13cbc01	[1]35	[1]15	[1]42
			[1]26	[1]12	[1]46
			[1]22	[1]12	[1]54
		Median	26	12	46
	Windsong	(A-21-28)23aac01	21	6	30
	Private	(A-21-28)14daa01	53	21	39
	Private	(A-21-28)13cdc01	21	7	36
Chambers	ATSF No. 3	(A-21-27)25cad01	18	13	71
	Private	(A-21-28)30aaa01	[2]<29	14	47
	Private	(A-21-28)30aaa02	40	19	48
	Waterfall Spring	(A-21-27)35acb01	16	12	77
Pinta	Private	(A-19-25)11daa01	57	27	47
	Private	(A-19-25)01bba01	9	8	84
Petrified Forest	Petrified Forest No. 2	(A-18-24)09abb01	7	1	20
	Windmill	(A-18-24)16bbb01	27	16	60

[1] Replicate samples.

[2] Gross beta activity is less than 2 picocuries per liter for this well.

is approximately 1,000 ft from the Puerco River, whereas a private windmill, (A-18-24)16bbb01, across the river is approximately 2,100 ft from the channel (table 2). Gross alpha plus gross beta activity is 7 pCi/L in the Petrified Forest Well No. 2, whereas the activity is 27 pCi/L in the private windmill (table 5). Similar differences can be observed in wells at varying distances from the Puerco River at other study sites.

Radionuclide activity does not appear to vary consistently among the study sites. The highest gross alpha plus gross beta activities--48 to 57 pCi/L--were measured in the Lupton, Sanders, and Pinta study sites (table 5). The wells that have the highest concentration of uranium--38 μg/L--are in the Lupton and Pinta study sites. Contamination of the alluvial aquifer, therefore, is not related to the distance of the study site from the headwaters of the Puerco River.

Historical water-quality data were available for some of the wells that were sampled in December 1986. Of the 14 wells and 1 spring sampled, historic data were available for 7 wells and 1 spring (Webb and others, 1987). Only samples taken in December 1986, and in 1969, 1974, and 1975 were collected and analyzed by the U.S. Geological Survey. The other samples were collected by other agencies, notably EPA and the Indian Health Service, and were analyzed by several different laboratories.

Records for Begay Well, (A-22-31)08aad01 (table 2 and fig. 6) include 32 water-quality measurements including measurements for December 1986. Temporal variations of gross alpha, chloride, and sulfate (fig. 12) show that concentrations or activities have fluctuated with time. For example, concentrations of sulfate rose from about 500 mg/L to as much as 1,600 mg/L after the spill of 1979 and declined after 1981 (fig. 12). Gross alpha activities also fluctuated during the same period. Gross alpha activities measured in 1986 are not unusual compared to the highest historic activities, although the activity in 1986 is the highest measured between 1979 and 1986. This difference may have resulted from pumping the well before sampling, which apparently was not done for other samples, or from different laboratory techniques.

A total of 22 water-quality measurements have been made for the Sanders School well, (A-21-28)13cbc01 (table 2, fig. 7). A comparison of concentrations in 1969 with concentrations in 1986 indicates a slight increase in chloride and sulfate but little long-term fluctuation (fig. 13). Gross alpha activity, however, fluctuates from 0 to 29 pCi/L (fig. 13).

The main well for Petrified Forest National Park, (A-18-24)09abb01 (table 2, fig. 10), has 31 water-quality measurements including the sampling of December 1986. With the exception of an anomalous concentration of sulfate measured in 1977, the activities of gross alpha and concentrations of chloride and sulfate are nearly constant in the 11 years of record (fig. 14).

Historic variations in ground-water quality (figs. 12-14) reflect the fluctuations in quality of water available for recharge in the Puerco River (fig. 5). Activities of radionuclides in ground water have fluctuated with time but appear to have increased in some wells as a result of the failure of a tailings-pond dam in New Mexico in 1979. Concentrations of other constituents, such as chloride, appear to have changed little with time except at Begay Well (fig. 12), which is 50 ft from the Puerco River, as a result of the failure of the tailings-pond dam.

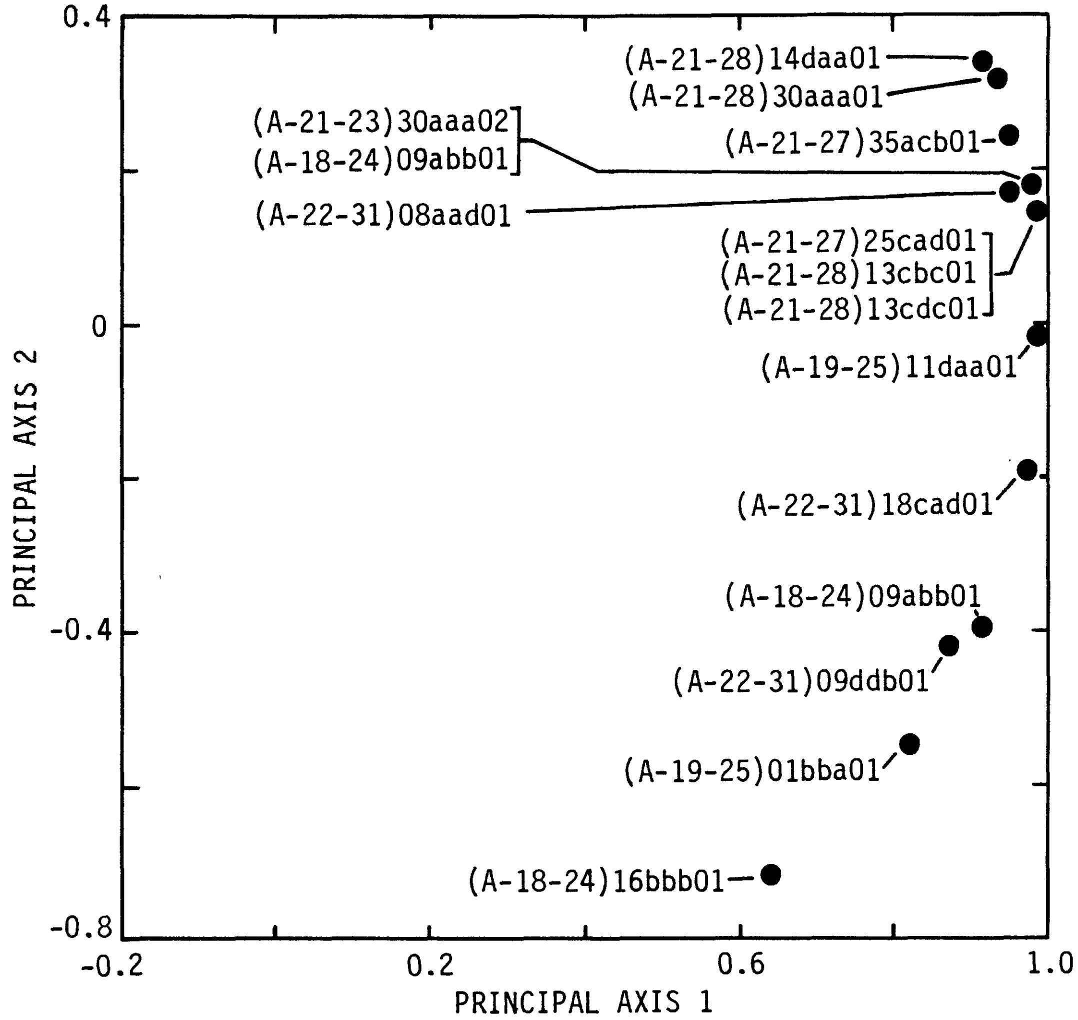

Figure 11--Principal-component analysis for selected constituents in 14 wells and 1 spring in the Puerco River basin, December 1-6, 1986. The axes represent first and second components from the analysis.

PROCESSES CONTROLLING THE MOVEMENT OF RADIONUCLIDES

Radionuclide activities in the Puerco River at Chambers (fig. 5) are high compared with historic activities in wells (figs. 12-14). Total uranium concentrations have been approximately 100 μg/L in the Puerco River (fig. 5), but concentrations of dissolved uranium are unknown. Median concentration of total uranium in wells sampled in December 1986 is 19 μg/L (table 3). Activities of thorium-230 and radium-226 have been very high in surface waters and suspended sediments (Weimer and others, 1981; ADHS, 1986a) but do not occur in significant activities in the ground water. Geochemical processes related to sediments in the surface water, clays in the aquifer, and chemistry of the ground water may be reducing the radionuclide activity before the recharge water reaches the wells.

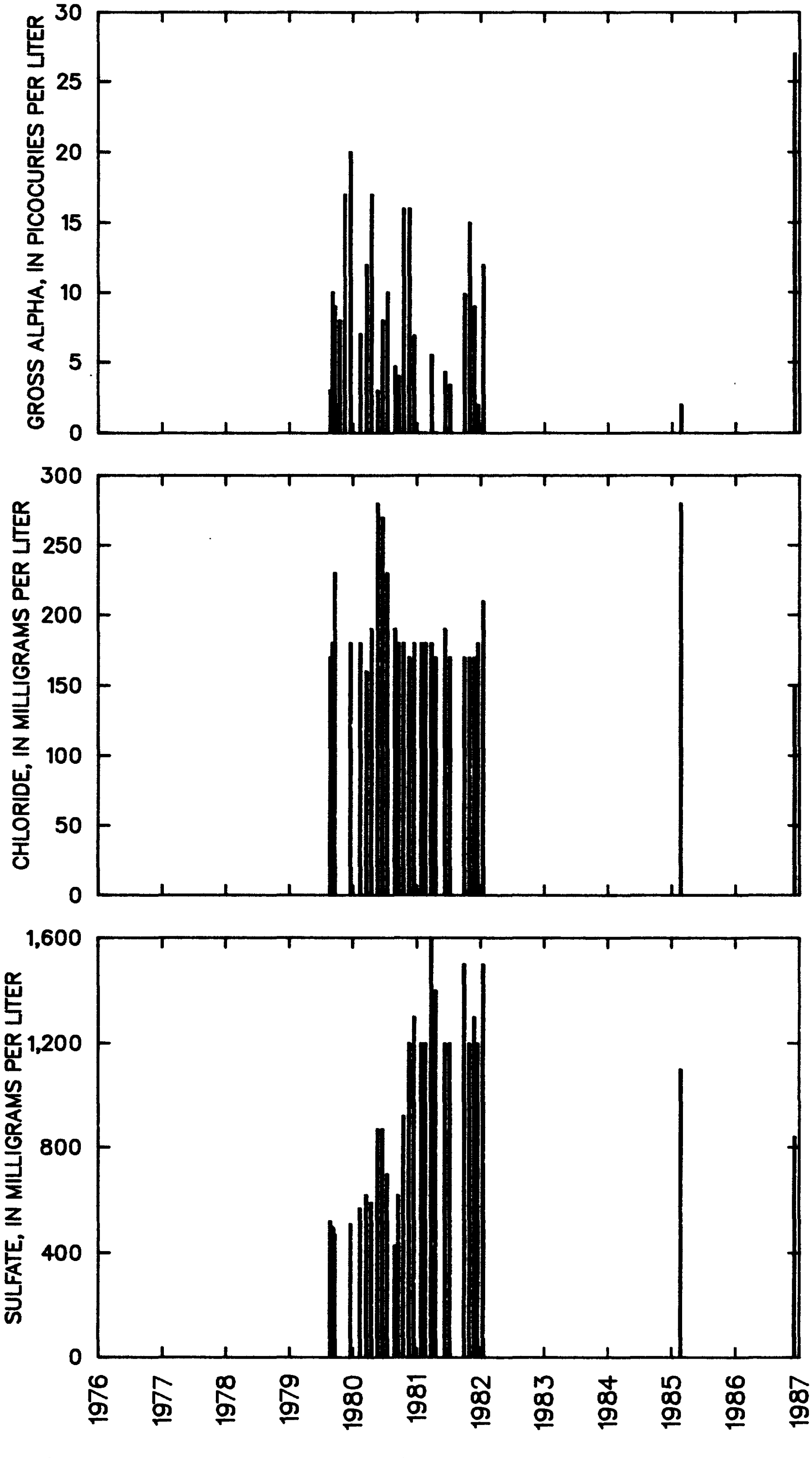

Figure 12.--Temporal variations of selected chemical constituents in Begay Well, (A-22-31)08aad01, near Lupton, Arizona.

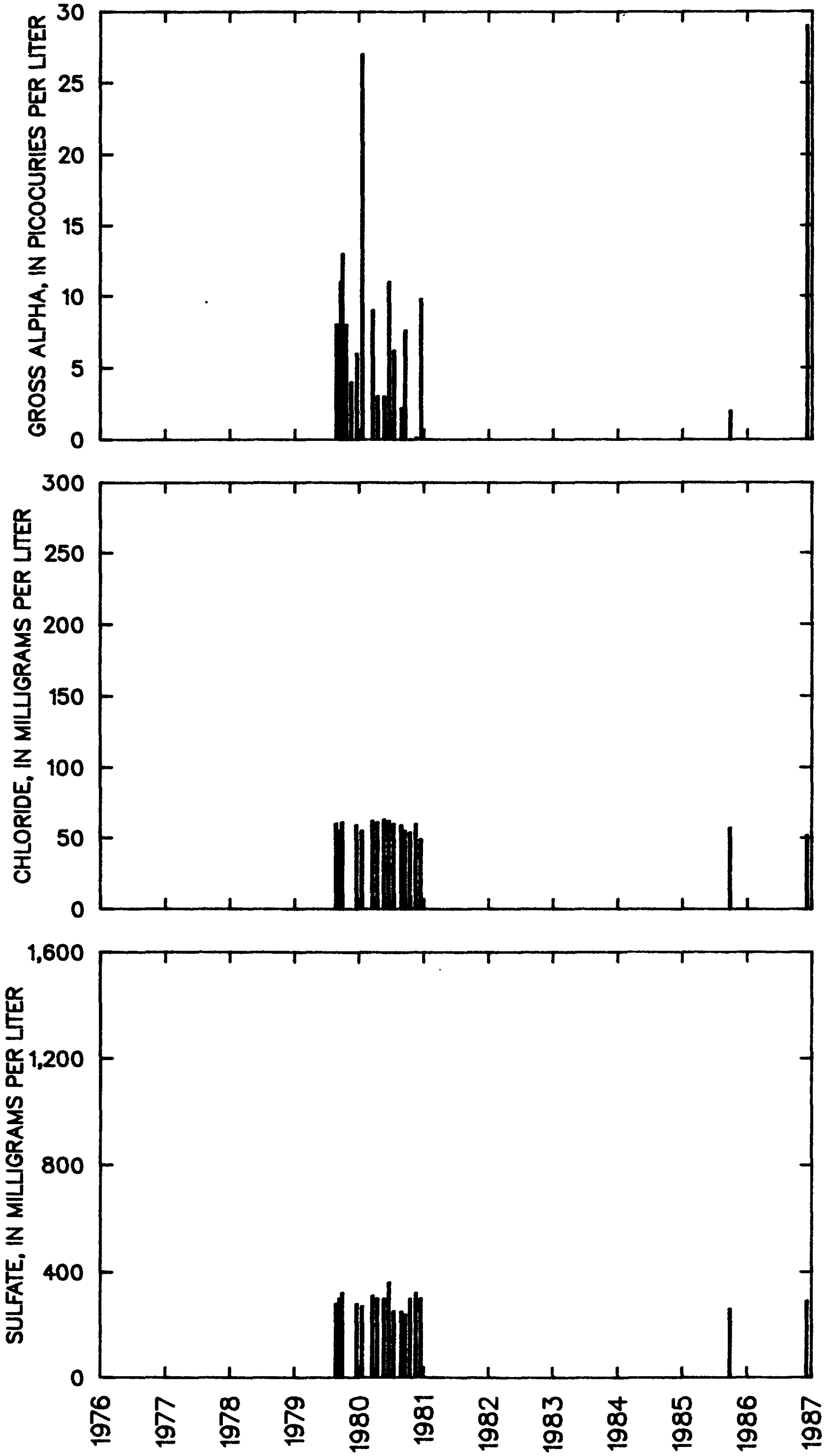

Figure 13.--Temporal variations of selected chemical constituents in Sanders Elementary School well, (A-21-28)13cbc01, at Sanders, Arizona.

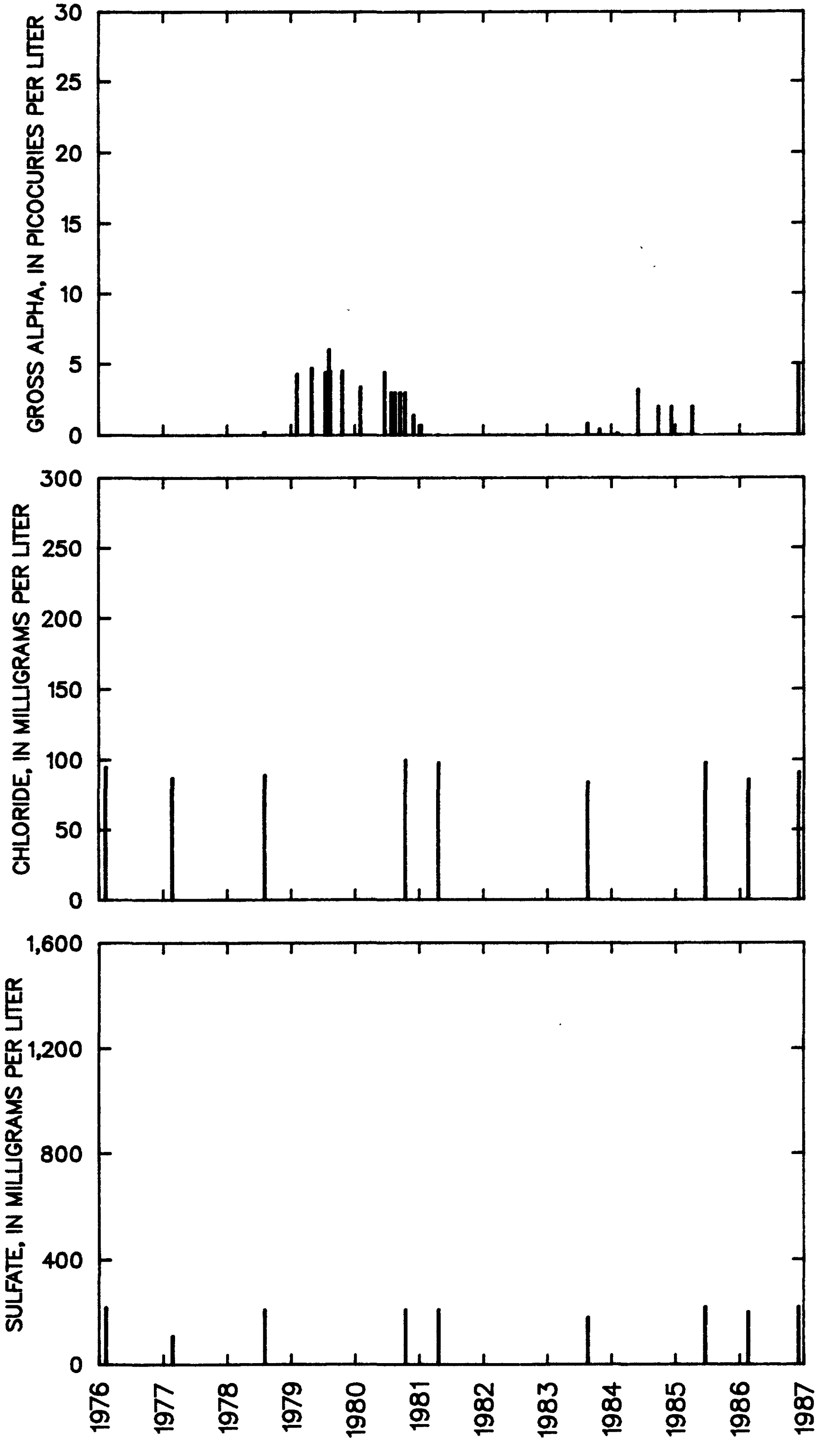

Figure 14.--Temporal variations of selected chemical constituents in Petrified Forest Well No. 2, (A-18-24)09abb01, Petrified Forest National Park, Arizona.

Two of the processes that are responsible for removal of natural radionuclides from water as it moves through the aquifer are chemical reactions and sorption. One chemical process that could remove a radionuclide from solution is the precipitation of a mineral that contains the radionuclide as a result of supersaturation (Stumm and Morgan, 1970). Certain radionuclides, especially radium isotopes, may coprecipitate by substitution for a different element, such as barium, in a mineral that is precipitating (Langmuir and Reise, 1985). Sorption involves many processes, including ion exchange of radionuclides with other cations on clays (Beard and others, 1980) and adsorption on the surfaces of particles, and reactions with organic compounds that cause adsorption, ion exchange, or uptake in plants (Landa, 1980). Sayre and others (1963) and Beard and others (1980) provide a more detailed description of the sorption process. Other processes, such as volitilization and biological activity, may remove natural radionuclides from the water.

To test the importance of chemical reactions, a solution-equilibrium computer model (Kharaka and Barnes, 1973) that includes the reactions involving uranium (Yousif Kharaka, U.S. Geological Survey, written commun., 1987) was used to determine the solubility of uranium minerals. Thermodynamic data for uranium are given by Langmuir (1978). The concentrations for trace elements and uranium, measured as total concentrations, were assumed to be dissolved concentrations. The suspended and colloidal concentrations, therefore, are assumed to be negligible. Finally, oxidizing conditions were assumed because of the measured dissolved-oxygen concentrations (Appendix A).

The solution-equilibrium model apportions measured concentrations of an element or compound among different chemical species. These species include cations, or positively charged ions; anions, or negatively charged ions; and complexes, which can be positively charged, negatively charged, or electrically neutral compounds. The ability of the chemical species to remain in solution is calculated from the Gibbs free energy ($\Delta G°$) of the minerals that could form as a result of precipitation of the chemical species. If $\Delta G°$ is greater than 0 kilocalories per mole (kcal/mole) for a chemical reaction, precipitation will occur; if $\Delta G°$ is less than 0 kcal/mole, dissolution of the mineral will occur if it is present in the aquifer (Kharaka and Barnes, 1973). Stumm and Morgan (1970), Hem (1985), and Kharaka and Barnes (1973) give more information on the chemical reactions.

The concentrations from all 15 water samples collected in December 1986 (Appendix A) were used in the solution-equilibrium model. Uranium-bearing minerals that could precipitate from the ground water have negative values of $\Delta G°$ for the all 15 ground-water samples. These results indicate that uranium should not precipitate out of ground water. To test whether the waters were close to saturation, and because concentrations that might be indicative of a contaminant plume could not be identified, the average concentrations of the 15 samples (table 3) also were input into the solution-equilibrium model. For modeling purposes, the uranium concentration was increased in the average sample from 19 μg/L to 100 μg/L, which is the average total concentration in surface water (fig. 5), and to 360 μg/L, which is the highest total concentration measured in the Puerco River at Chambers (fig. 5). These concentrations are high because 30 to 70 percent of the total uranium is either in suspended sediments or colloids. The negative values of $\Delta G°$ for all samples with the highest concentrations of uranium (table 6) indicate that uranium should not precipitate out of the ground water.

Sorption is a potential mechanism that may decrease the amount of uranium in solution. Uranium is strongly sorbed into organic compounds or clays, although the peak of sorption occurs at pH levels between 5 and 6 (Ames and Rai, 1978). Uranium complexes change from being cationic, or positively charged, to anionic, or negatively charged, at a pH of around 6 (Ames and Rai, 1978; Langmuir, 1978). Uranium can be adsorbed onto particles with amorphous iron oxyhydroxide coatings, and the amount of adsorption is highest between pH levels of 5.5 and 8.5 (Langmuir, 1978). In the alluvial aquifer of the Puerco River, where the pH is generally between 7.5 and 8.0, uranium will not precipitate out of the ground water but may be sorbed on iron-oxyhydroxide-coated particles. The data collected in this study (Appendix A) indicates that uranium is mobile in the alluvial aquifer.

Other radionuclides have a different behavior. At pH levels of 7.5 to 8.0, thorium predominantly exists as thorium hydroxide (Langmuir and Herman, 1980), a mineral that has low solubility (Ames and Rai, 1978). On the basis of thermodynamic data given in Langmuir and Herman (1980), the equilibrium activity of thorium-230 is 0.2 pCi/L in the average water in the alluvial aquifer (table 3). Thorium is readily adsorbed on clays (Ames and Rai, 1978; Beard and others, 1980) and is virtually completely sorbed at pH levels greater than 6.5 (Langmuir and Herman, 1980). Thorium, therefore, is virtually immobile in a neutral or alkaline environment except when transported on sediment in surface water. The lack of thorium-230 activities that are significantly greater than 0 (table 3, Appendix A) further indicates the immobility of thorium in ground water.

Radium-226 and radium-228 are chemically similar to barium (Ames and Rai, 1978) and form sulfate and carbonate complexes (Langmuir and Riese, 1985). Calculations for the equilibrium concentrations if all free carbonate ions are bound in radium carbonate complexes indicate that 180 mg/L of total radium (about $1.8 \cdot 10^{11}$ pCi/L of radium-226) could dissolve in the water. Radium activities in natural waters are regulated by coprecipitation in other minerals and sorption (Langmuir and Riese, 1985). Coprecipitation may occur in barite ($BaSO_4$), which has a $\Delta G°$ of 1.2 kcal/mole in the average concentrations measured in the Puerco River basin. Radium may be sorbed on clays (Landa, 1980), although physical and chemical factors governing the sorption are not well known (Beard and others, 1980). Ames and Rai (1978) report a correlation between the cation-exchange capacity of clays and the sorption of radium.

Published data on radium do not allow a conclusion with respect to its mobility in ground water in the Puerco River basin, but data suggest that radium may be sorbed too strongly to clays to allow transport as dissolved species. The high amount of sorption is also suggested by a significant correlation of radium-226 activity and suspended sediments in the Puerco River (ADHS, 1986b) and low radium activity in surface water and ground water near uranium mines or mills (Kaufmann and others, 1976; Yang and Edwards, 1984). Whereas radium may be soluble as $RaSO_4^\circ$ and $RaCO_3^\circ$, radium probably is limited in the alluvial aquifer of the Puerco River basin because of coprecipitation and sorption.

Table 6.--Values of ΔG° for minerals of uranium and lead in an average sample of ground water from the Puerco River basin with uranium concentrations of 0.019, 0.100, and 0.360 milligrams per liter

[Thermodynamic data for uranium minerals are from Langmuir, 1978. Values are presented as Gibbs Free Energy (ΔG°) in kilocalories per mole and are calculated from the average concentrations of constituents in ground water given in table 3]

Solid-phase mineral		ΔG° Concentrations of uranium (milligrams per liter)		
Formula	Name	0.019	0.100	0.360
UO_2CO_3	Rutherfordine	-3.9	-3.0	-2.3
UO_3	Gummite	-10.2	-9.3	-8.5
$UO_2(OH)_2$	-------------	-7.6	-6.6	-5.9
$K_2(UO_2)_2(VO_4)_2$	Carnotite	-6.7	-4.8	-3.3
$Ca_2(UO_2)_2(VO_4)_2$	Tyuyamunite	-4.8	-2.9	-1.4
$Ca_2(UO_2)_2(HSiO_4)_2$	Uranophane	-14.7	-12.8	-11.3
$UO_2(OH)_2.H_2O$	Schoepite	-5.8	-4.9	-4.2
$MgUO_4$	-------------	-15.7	-14.7	-14.0
$CaUO_4$	-------------	-3.6	-2.7	-1.9
$BaUO_4$	-------------	-11.7	-10.8	-10.0
UO_2F_2	-------------	-22.1	-21.1	-20.4
$PbCl_2$	Cotunnite	-10.7	-----	-----
$PbCO_3$	Cerrussite	0.4	-----	-----
PbO	Litharge	-6.9	-----	-----
PbO	Massicot	-7.1	-----	-----
$PbSO_4$	Anglesite	-3.5	-----	-----
$Pb_3(VO_4)_2$	-------------	2.6	-----	-----

Lead-210 is expected to have the same chemical properties as stable lead. Lead-210, which has a half life of 22 years (fig. 2), can produce an activity of 1 pCi/L at a concentration of $1.3 \cdot 10^{-8}$ µg/L. Values of ΔG° calculated from the average concentration suggest that two of six potential minerals are supersaturated at a lead concentration of 6 µg/L (table 6). Cerrussite ($PbCO_3$), one of the two supersaturated minerals (table 6), dominates the chemistry of lead in carbonate-rich waters at a pH of 8 (Stumm and Morgan, 1970). Lead also can be adsorbed by clay particles. The net effect of the chemical processes on the mobility of lead-210 in the alluvial aquifer of the Puerco River is unknown.

DISCUSSION

Ground water sampled in the Puerco River basin in Arizona contained variable radionuclide activities. Radium-226 plus radium-228 activities exceeded 5 pCi/L in only one well, whereas gross alpha plus gross beta activity exceeded 30 pCi/L in half of the wells. Absence of significant activities of radium-226 plus radium-228 in the alluvial aquifer also was noted in ground water in the headwaters of the Puerco River (Kaufmann and others, 1976). This was unexpected in light of high total radionuclide activities in surface water that recharges the aquifer (ADHS, 1986b). Radium-226 and radium-228 may be only slightly mobile in the chemical environment of the alluvial aquifer and are probably sorbed or coprecipitated from the recharging waters onto clay particles.

Uranium was the greatest contributor of alpha radiation in ground water. Uranium activities account for most of the activities of gross alpha (table 4). Uranium species in ground water are soluble up to the highest total concentrations measured in the surface water (table 6). The average concentration of uranium in ground water--19 µg/L--was only one-fifth the average total concentration in surface water but probably is only slightly less than the average dissolved concentrations. Uranium, therefore, may be sorbed in the alluvial aquifer, possibly on iron-oxyhydroxide-coated particles. This sorption is not great enough to totally remove uranium from ground water in the vicinity of the wells.

Radionuclides that were not measured in the samples from December 1986 accounted for 20 to 84 percent of gross alpha plus gross beta activities (table 5). Many of these radionuclides are beta emitters that may include thorium-234, lead-214, and bismuth-214 (fig. 2) or radionuclides from other natural decay series (Aswathanarayana, 1986). Fission products, such as strontium-90, were not expected in uranium mining wastes and were not measured. Future sampling plans should include analyses to determine which natural radionuclides and fission products are present in ground water.

The quality of the recharging water is dependent on the source of the streamflow. Radionuclides and trace elements commonly are transported in rivers as sorbed species on suspended sediment (Sayre and others, 1963; Brandvold and others, 1981). Because of this transport mechanism, trace-element concentrations and radionuclide activities in the Puerco River can be expected to vary according to the sediment source. Streamflows originating from some tributaries, such as Black Creek (fig. 1), have lower concentrations of trace elements and activities of radionuclides than flows originating from uranium-source areas. On the basis of data from existing wells, a contaminant plume could not be identified either by statistical techniques (fig. 13) or by simple comparison of concentration change with distance along or from the river.

SUGGESTIONS FOR ADDITIONAL STUDIES

Additional study is needed to better define the areal extent and severity of contamination and the processes that control the movement of radionuclides and other constituents in surface water and ground water in the Puerco River basin. Development of water supplies in the alluvial aquifer in the vicinity of Chambers and Sanders would benefit from such study. The quality of surface water that recharges the alluvial aquifer has fluctuated greatly (fig. 5) and has probably caused the fluctuations in activities of radionuclides in the alluvial aquifer. Collections of samples at the existing gaging stations at Chambers and at a new gaging station between the Arizona-New Mexico border and Sanders, Arizona, (fig. 1) would provide data on future changes in quality of surface water. Because radionuclides and trace elements are associated with large sediment discharges (ADHS, 1986b), monitoring of water-quality changes during high streamflows on the Puerco River and selected tributaries may provide data on the source and transport process of radionuclides and trace elements.

Quality of water in existing wells has only a slight health risk (see Part III. Health Risk Assessment), but monitoring of radionuclides on a quarterly or annual basis is desirable (New Mexico Environmental Improvement Division, 1982). The use of existing wells did not reveal a contaminant plume in the Puerco River basin. The presence of a contaminant plume may be obscured because some of the existing wells yield a depth-integrated sample of water in the aquifer. Some areas, particularly the parts closest to the river (fig. 6), might contain contaminated water in the upper part of the aquifer that is moving slowly downward and (or) laterally.

Use of existing wells exacerbates the problem of determination of the extent of contamination. As shown in figure 15, radionuclides and trace elements enter ground water as recharge and travel through part of the aquifer that is unsaturated part of the time. Water that may be carrying contaminants can move either laterally to greater depths or in the downstream direction in the saturated part of the aquifer. Direction of movement is determined by hydraulic properties of the alluvial aquifer, which were not determined in this preliminary study. Variations in the strata of the alluvium (fig. 15) will complicate ground-water movement. Existing wells, which were drilled to varying depths and which have intake openings at varying depths (fig. 15) generally are not suitable for sample collection if the goal of the study is to define the three-dimensional distribution of a contaminant. For example, an existing well with intakes below clay layers (fig. 15) may be at least temporarily shielded from contaminated recharge waters. Locations of most intakes for the wells used in this study are unknown (Appendix A).

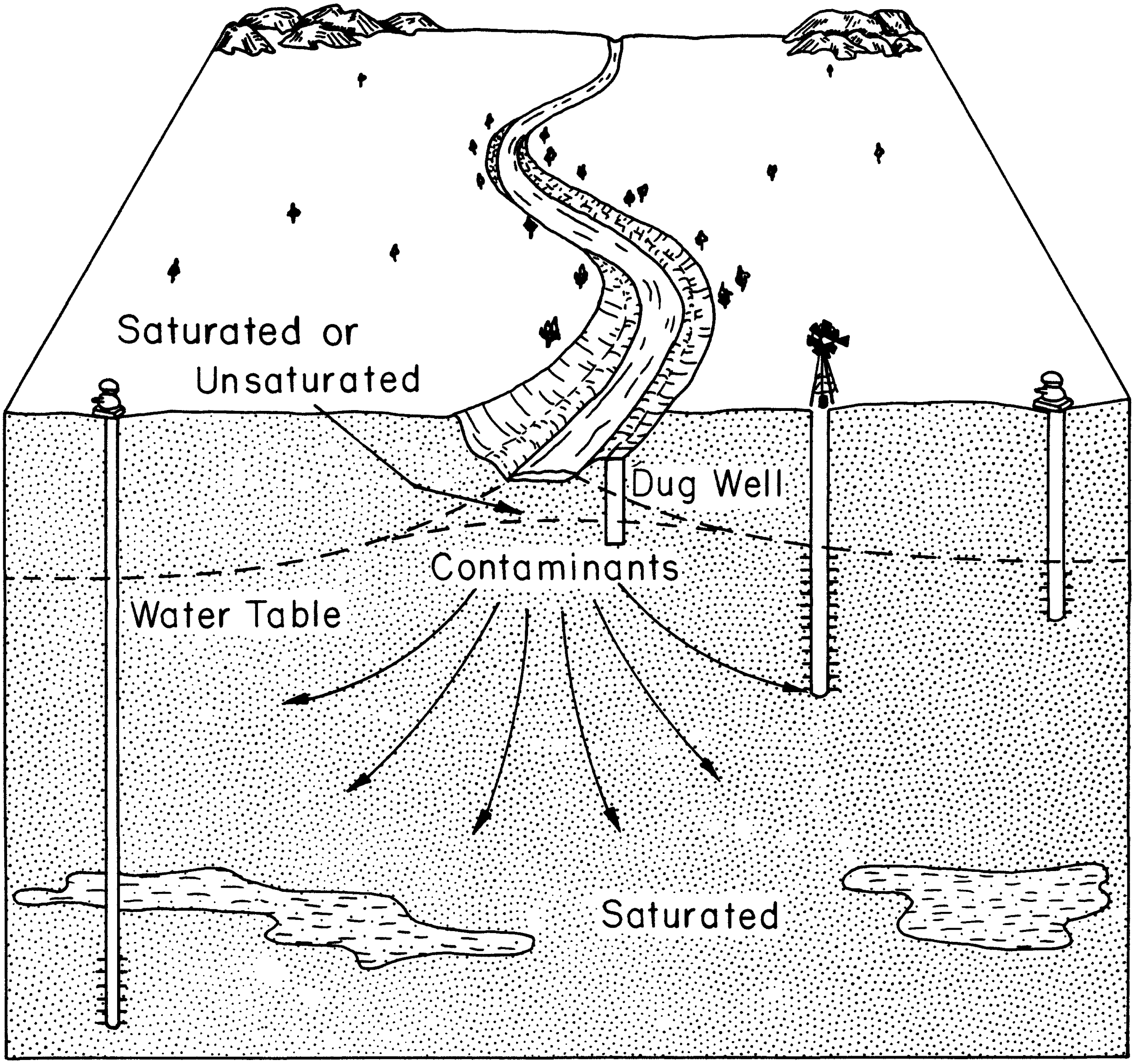

Figure 15.--Idealized cross section of the alluvial aquifer in the Puerco River basin.

One-time sampling of existing wells is not sufficient to define, in detail, the areal extent and severity of contamination or processes that control the movement of radionuclides and trace elements in ground water in the Puerco River basin. Besides existing wells, sampling of new wells drilled into the alluvial and bedrock aquifers with casings perforated at various depths is needed to ascertain lateral and vertical gradients in hydraulic conductivity and changes in water quality. To provide information pertinent to anticipated water-supply development, new wells could be located at or upgradient from planned water-supply wells. The drilling and sampling of new wells would help determine the chemical and physical characteristics of the aquifer, degree of hydraulic connection between the alluvial and bedrock aquifers, direction and rates of ground-water flow and contaminants, and processes that control the movement of ground water and contaminants. Such information could be used to design wells for public water supplies so that areas of contamination could be avoided.

Sampling of water and soils in the unsaturated zone would be useful to determine if and how radionuclides and trace elements from recharging surface water are attenuated with depth into the alluvial aquifer. If attenuation does occur and processes controlling this attenuation are known, the unsaturated zone could be managed to minimize contaminant transport to the alluvial aquifer.

The cost of future analyses of water quality can be reduced for many of the samples. Most trace elements have low concentrations, and these concentrations may need to be determined only periodically, whereas compliance with drinking water MCLs requires sampling for a wide range of constituents (table 1). Because of their geochemistry, most natural radionuclides, especially radium-226, radium-228 and thorium-230, should not be present in high activities. Analytical results may be improved by performing total gamma or alpha scans, which determine all sources of radionuclides within the sample, rather than analyzing water samples for specific radionuclides. Use of scans could also reveal sources of unexplained radioactivity in the existing wells (table 5).

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PART III. HEALTH RISK ASSESSMENT

By

Richard A. Coddington
U.S. Environmental Protection Agency

The views and conclusions contained in this section are those of the U.S. Environmental Protection Agency and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Geological Survey.

HEALTH RISK ASSESSMENT

By

Richard A. Coddington

U.S. Environmental Protection Agency

INTRODUCTION

We have reviewed your report entitled "Distribution of Radionuclide and Trace-elements in Ground Water, Grasses, and Surficial Sediments Associated with the Alluvial Aquifer along the Puerco River, Northeastern Arizona--A Reconnaissance Sampling Program" (U.S. Geological Survey Open-File Report 87-206) as you requested with regard to health risk of well waters. The review does not consider the time difference when performing averaging calculations on some of the radionuclide samples although older samples may not be representative of present ground water quality.

The wells which were sampled evidently are used as a source of water for human consumption and/or stock watering. Our risk assessments assume a lifelong consumption per person of two liters per day; consumption less than this would reduce the risk. Risk estimates associated with stock watering are not provided in this review. Our review compared the quality of each of the wells sampled with Federal Drinking Water Primary (40 CFR Part 141) and Secondary (40 CFR Part 143) Standards without regard as to whether or not each well would qualify as a public water system according to the regulatory definition (40 CFR Part 141.2).

Primary Maximum Contaminant Levels

Drinking water regulations fall into two basic categories: Primary and Secondary. The National Primary Maximum Contaminant Levels (MCLs) are enforceable regulations which, according to the EPA, establish how clean public, potable drinking water supplies must be to protect public health.

A total of 14 wells and 1 spring were sampled during the most recent round of analyses (December 1986). The quality of water in three of the wells exceeded the Primary Maximum Contaminant Level (MCL) for gross alpha particle activity of 15 picocuries (pCi)/liter (excluding uranium and radon) while the quality of water in two wells were at the MCL. These conclusions are based on the most recent data and using the highest alpha activity level from the well with the split sample analyses. However, if historical data were averaged with the new data, and the split sample results were also averaged, only one well would exceed the MCL for gross alpha particle activity. The gross alpha particle activity level in the other four wells would fall below the MCL.

The gross alpha particle activity standard was designed primarily as a screening device to measure for compliance with the MCL for radium. Additionally, the standard serves as a gross indicator for high levels of other natural radionuclides. The quality of water in one well exceeded the Primary MCL for radium-226 and radium-228 of 5 pCi/l using the results from the December 1986 sampling round. However, if the historical radium data from this well was averaged with the 1986 results, the resulting number would fall below the MCL.

The measured gross alpha particle activity level in the five wells (after excluding for uranium and ignoring historical data or split samples) that were at the MCL or higher ranged from 15 pCi/l to 21 pCi/l. Radon is not expected to be present in the water samples since the radon will be dissipated in the gross alpha measurement procedure. The well with the highest gross alpha particle activity level also was the one that exceeded the MCL for radium. The combined radium-226 and radium-228 level, after excluding historical data, was 7.4 pCi/l (radium-226 = 4.3 pCi/l and radium-228 = 3.1 pCi/l).

The gross alpha particle activity (excluding uranium) is theoretically due to all the other alpha emitting natural radionuclides present in the water sample. The gross alpha particle activity measurement in water samples is subject to counting errors, and the efficiency of the measurement is affected by total dissolved solids and assumptions concerning the equilibrium of uranium-234 and uranium-238. These factors may have accounted for some of the gross alpha activity levels remaining after adjusting for uranium. If the assumption is that all the measurements are true, the unaccounted for gross alpha activity must be attributed to radionuclides not measured. Of the radionuclides not measured, polonium-210 is the most likely radionuclide to be the contributor based on the fact that, in the uranium-238 decay series, it is the only alpha emitter with a long enough half-life to be present in the water sample.

Based on the worst case assumption (highest single value), three wells exceeded the gross alpha MCL of 15 pCi/l. The gross alpha particle activity levels for the three wells exceeding the MCL were: Sanders School well (one out of the three samples)--16 pCi/l; the private well at Pinta--17 pCi/l; and the private well at Sanders--21 pCi/l. If it is assumed that the source for the alpha particle activity is polonium-210, a risk factor can be assigned to the excess activity above 15 pCi/l (1, 2, and 6 pCi/l of polonium-210). Using an EPA risk table for polonium-210 on Page 34860 from Federal Register, Volume 51, No. 189, Tuesday, September 30, 1986, the respective excess lifetime cancer risks for 1, 2, and 6 pCi/l are 10.5, 21, and 63 per million persons exposed. The private well at Pinta is also the one that exceeded the MCL when historical data was considered since only current activity measurements were available for this well. Therefore, the risk assessment calculation that applies for this well is the excess lifetime cancer risk for 2 pCi/l (21 per million persons exposed).

Regarding the one well which contained a total radium activity level of 7.4 pCi/l (excluding the historical data), excess lifetime cancer risks for radium-226 and radium-228 can also be obtained from Page 34860 of the Federal Register. Two risk tables are involved, and the excess radium activity level above the MCL should be weighted in proportion to how much radium-226 and radium-118 were in the original measurement. Fifty-eight percent of the original sample was radium-226 and 42 percent was radium-228. Therefore, of the excess 2.4 pCi/l, 1.4 pCi/l can be attributed to radium-226 and 1 pCi/l to radium-228. The excess lifetime risk of 1.4 pCi/l of radium-226 above the MCL is 12.3 per million persons exposed and the excess lifetime risk of 1 pCi/l of radium-228 above the MCL is 6.6 per million persons exposed.

The EPA feels that the gross alpha particle activity MCL provides protection from all alpha emitters that could potentially occur in drinking water, and it also provides a ceiling on the aggregate exposure and aggregate risk to all alpha emitting radionuclides. For all future analyses where the gross alpha particle activity (excluding uranium and radon) exceeds the MCL of 15 pCi/l, all the alpha emitting radionuclides in the water sample should be identified.

The water quality in one well exceeded the Primary MCL for cadmium which is 10 micrograms per liter (μg/l). The level of cadmium in the private well at Pinta was 17 μg/L. For cadmium, a quantitative evaluation of the carcinogencity has not been conducted since there is no conclusive evidence that cadmium is carcinogenic following oral exposure. In humans, the symptoms of cadmium toxicity following acute exposure include nausea, vomiting, diarrhea, muscular cramps and salivation. The kidney appears to be the tissue which is most sensitive to low level chronic oral exposure to cadmium. Since the cadmium levels in this well exceed the MCL by 70 percent, it is recommended that the water not be used for human consumption unless repeat sampling shows that the cadmium concentration is below the MCL.

Secondary Maximum Contaminant Levels

The National Secondary Maximum Contaminant Levels (SMCLs) are, according to the judgement of the Administrator of the EPA, requisite to protect the public welfare. The SMCLs covered by the regulations are those which may adversely affect the aesthetic quality of drinking water. At considerably higher concentrations than the SMCLs, these contaminants may also be associated with adverse health effects.

The U.S. Geological Survey Report summarized the number of wells (out of 14 that exceeded the National SMCLs based on the 1986 sample analyses. Fourteen of the wells and one spring exceeded the SMCL for total dissolved solids. The SMCL for total dissolved solids is 500 milligrams per liter (mg/l). The range of total dissolved solids measured that exceeded the SMCL was 510-1,800 mg/l. The SMCL for total dissolved solids (TDS) was established because high concentrations have adverse taste effects which force consumers to use other water sources. Highly mineralized water also deteriorates distribution and domestic plumbing appliances. A number of public water supplies in the United States provide water with TDS concentrations of 2,000 mg/l or more. Waters containing TDS concentrations in the range of 10,000 mg/l are considered unusable for drinking.

Nine out of the 14 wells and 1 spring exceeded the SMCL for sulfates of 250 mg/l. The range of sulfate concentrations for the 10 wells was 260-840 mg/l. The only observed physiological effect of high sulfate concentrations has been the induction of diarrhea. Sulfate concentrations

page 60 follows

in the range of 600-1,000 mg/l have a laxative effect on a majority of users. Between 200-500 mg/l, the laxative effects generally depend on the sensitivity of the individual and whether the individual was used to the water. Higher concentrations of sulfates also effect the taste of water.

Ten out of the 14 wells exceeded the SMCL for manganese of 0.05 mg/l. The range of manganese concentrations for the ten wells was 0.07-1.6 mg/l. The principal reason for limiting the concentration of manganese is that the domestic consumer finds that it produces a brownish color in laundered goods and it impairs the taste of drinking water. Large doses of manganese in laboratory animals cause cirrhosis of the liver. From a human health standpoint, however, data do not indicate at what level manganese would be harmful when ingested. Reported toxic effects in humans are based on inhalation of manganese dust and fumes.

The U.S. Geological Survey Report indicated that 7 out of 14 wells exceeded the SMCL of 0.3 mg/l for iron. Reviewing the data from the individual wells indicated that eight of the wells exceeded the SMCL for iron and one well was exactly at the SMCL. The range of iron concentrations in the eight wells was 0.36-2.3 mg/l. Iron is highly objectionable to the consumer because it imparts a brownish color to laundered goods and plumbing fixtures and imparts a bitter taste to water.

Other Contaminants

The National Primary Drinking Water Regulations for radionuclides did not establish a MCL for uranium. However, future regulations will include a MCL for uranium. Total natural uranium was also measured in the 14 wells and 1 spring during the December 1986 sampling round. It was assumed that the uranium-238 and uranium-234 were in equilibrium in order to convert the concentrations of uranium to activity. The range of natural uranium in the wells was 8-38 μg/l (5.3-25.3 pCi/l). None of the historical uranium levels exceeded 38 μg/l.

Uranium does have a primary chemical toxic effect on humans, and the EPA also considers uranium as a carcinogen based on its absorption similarity with radium in humans. The primary chemical toxic effect of natural uranium is inflamation of the kidneys. The Adjusted Acceptable Daily Intake (AADI) for uranium is 60 μg/l or 40 pCi/l. None of the uranium levels exceeded the AADI.

From EPA risk tables for uranium on page 34860 of the Federal Register, excess lifetime cancer risks can be calculated. The cancer risks from uranium-238 and uranium-234 are approximately the same. For the highest natural uranium level measured of 25.3 pCi/l, the excess lifetime cancer risk per million persons exposed is 35.4.

Our conclusions concerning the water quality in the groundwater samples are based on the data provided by the U.S. Geological Survey. In some cases, data is sporadic or results are from just single samples. It is recommended that further sampling be done to adequately characterize the ground-water quality. Radionuclide sampling should identify all sources of radioactivity in the ground-water samples.

APPENDIX A

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona

[Values are in the following units: ft, feet; in., inches; mm, millimeters; µS/cm, microsiemens per centimeter at 25° Celsius; °C, degrees Celsius; mg/L, milligrams per liter; tons/ac-ft, tons per acre-foot; µg/L, micrograms per liter; pCi/L, picocuries per liter; dashes indicate no data.]

Study site	Well name	Well number	Unique identification	Depth (ft)	Water use	Approximate distance from Puerco River (ft)
Lupton	Begay	(A-22-31)08aad01	351933109041701	10	Unused	50
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	102	Stock	800
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	102	Unused	5,500
Sanders	Sanders School well	(A-21-28)13cbc01	351254109194501	160	Public supply	100
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	175	Public supply	100
Sanders	Private well	(A-21-28)13cdc01	351241109193101	111	Private	1,200
Sanders	Private well	(A-21-28)14daa01	351302109195901	145	Private	2,200
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	---	Unused	0
Chambers	Private well	(A-21-28)30aaa02	351152109241601	---	Private	600
Chambers	Private well	(A-21-28)30aaa01	351157109241701	40	Private	1,000
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	91	Public supply	1,000
Pinta	Private well	(A-19-25)11daa01	350338109384801	55	Private	1,100
Pinta	Private well	(A-19-25)01bba01	350451109383401	54	Private	2,200
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	100	Public supply	1,000
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	---	Stock	2,100

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona--Continued

[C, Concrete; SP, Steel pipe; N, None; P, Piston; T, Turbine; S, Submersible; NA, Not applicable; U, Unknown]

Study site	Well name	Well number	Unique identification	Altitude of land surface (ft)	Water level (ft)	Range in depth of perforations (ft)	Casing		Lift type	Year of construction
							Type	Diameter (in.)		
Lupton	Begay	(A-22-31)08aed01	351933109041701	6,105	6.9	0-10	C	----	N	1960s
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	6,145	36.5	90-108	SP	10	P	1957
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	6,185	46.9	82-102	SP	12	T	1984
Sanders	Sanders School well	(A-21-28)13cbc01	351254109194501	5,820	50	U	SP	10	T	1969
Sanders	Windsong utility well	(A-21-28)23eac01	351224109202401	5,830	59.0	U	SP	12	S	U
Sanders	Private well	(A-21-28)13cdc01	351241109193101	5,840	65.0	U	SP	6	S	U
Sanders	Private well	(A-21-28)14daa01	351302109195901	5,870	NA	U	SP	6	S	1941
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	5,720	NA	U	NA	NA	NA	----
Chambers	Private well	(A-21-28)30aaa02	351152109241601	5,750	23.5	U	SP	6	S	U
Chambers	Private well	(A-21-28)30aaa01	351157109241701	5,750	7.9	U	SP	6	S	1963
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	5,750	38.0	30-91	SP	16	S	1956
Pinta	Private well	(A-19-25)11daa01	350338109384801	5,490	13.9	U	SP	6	S	U
Pinta	Private well	(A-19-25)01bba01	350451109383401	5,510	14.7	U	SP	8	S	U
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	5,316	13.0	U	SP	8	S	1958
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	5,320	U	U	SP	8	P	U

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona

Study site	Well name	Well number	Unique identification	Date	Specific conductance (µS/cm)	pH (Standard units)	pH Lab (Standard units)	Temperature (°C)
Lupton	Begay	(A-22-31)08aad01	351933109041701	12-03-86	2,550	7.80	7.80	11.0
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	12-05-86	1,450	8.25	8.30	11.5
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	12-03-86	910	7.90	8.00	14.0
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	12-04-86	1,100	7.60	7.70	13.0
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	12-04-86	1,100	7.60	7.70	13.0
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	12-04-86	1,100	7.60	7.70	13.0
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	12-02-86	1,060	7.75	7.90	13.0
Sanders	Private well	(A-21-28)13cdc01	351241109193101	12-04-86	860	7.40	7.70	14.0
Sanders	Private well	(A-21-28)14daa01	351302109195901	12-04-86	1,530	7.30	7.50	15.0
Chambers	Waterfall Spring	(A-21-27)35ecb01	351047109265001	12-03-86	1,060	7.80	7.80	14.0
Chambers	Private well	(A-21-28)30aaa02	351152109241601	12-01-86	1,700	7.30	7.80	14.5
Chambers	Private well	(A-21-28)30aaa01	351157109241701	12-04-86	2,100	7.60	7.80	15.0
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	12-01-86	1,300	7.50	7.70	14.5
Pinta	Private well	(A-19-25)11daa01	350338109384801	12-05-86	1,400	7.90	8.10	15.5
Pinta	Private well	(A-19-25)01bba01	350451109383401	12-05-86	1,160	8.10	8.00	15.5
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	12-02-86	1,550	8.00	8.00	16.0
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	12-06-86	1,780	8.15	8.30	14.5

See footnote at end of table.

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona--Continued

Study site	Well name	Well number	Unique identification	Turbidity (NTU)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)
Lupton	Begay	(A-22-31)08aad01	351933109041701	21	611	8.3	95	90	20	470
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	1.0	--	--	--	30	9.3	300
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	0.3	608	2.1	26	18	2.9	190
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	0.1	819	0.5	6	90	16	140
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	0.1	619	0.5	6	92	16	140
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	0.2	619	0.5	6	91	16	140
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	0.2	617	1.0	12	88	15	120
Sanders	Private well	(A-21-28)13cdc01	351241109193101	0.9	618	0.4	5	75	24	63
Sanders	Private well	(A-21-28)14daa01	351302109195901	1.3	619	4.8	59	2 210	53	43
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	0.2	619	0.6	7	47	11	180
Chambers	Private well	(A-21-28)30aaa02	351152109241601	1.4	--	--	--	1 130	32	200
Chambers	Private well	(A-21-28)30aaa01	351157109241701	6.1	820	0.5	6	1 190	59	220
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	0.2	--	--	--	1 100	21	160
Pinta	Private well	(A-19-25)11daa01	350338109384801	0.5	626	0.5	8	41	10	270
Pinta	Private well	(A-19-25)01bba01	350451109383401	19	624	0.5	6	30	6.8	220
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	0.4	631	0.4	5	25	5.8	300
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	--	--	--	--	10	3.2	590

See footnote at end of table.

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona--Continued

Study site	Well name	Well number	Unique identification	Sodium adsorption	Potassium, dissolved (mg/L as K)	Alkalinity Wh Wat total field (mg/L as $CaCO_3$)	Alkalinity Wh Wat total lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)
Lupton	Begay	(A-22-31)08aad01	351933109041701	12	3.2	341	342	840	150	0.5
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	13	1.2	418	--	240	76	0.8
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	11	0.4	368	358	65	31	0.8
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	4	2.0	236	222	290	52	0.8
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	4	2.0	236	224	290	51	0.8
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	4	1.9	236	223	290	51	0.8
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	3	2.9	216	213	280	50	0.5
Sanders	Private well	(A-21-28)13cdc01	351241109193101	2	6.0	261	244	140	36	0.5
Sanders	Private well	(A-21-28)14daa01	351302109195901	0.7	7.9	311	307	480	61	1.0
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	6	7.8	218	--	270	43	0.7
Chambers	Private well	(A-21-28)30aaa02	351152109241601	4	2.5	355	340	480	88	0.5
Chambers	Private well	(A-21-28)30aaa01	351157109241701	4	1.8	249	--	760	140	0.6
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	4	2.6	265	259	340	61	0.8
Pinta	Private well	(A-19-25)11daa01	350338109384801	10	1.5	358	325	330	50	1.2
Pinta	Private well	(A-19-25)01bba01	350451109383401	10	1.8	449	431	100	52	1.1
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	15	1.5	450	442	220	91	1.2
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	43	0.9	678	663	260	390	1.4

See footnote at end of table.

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona--Continued

Study site	Well name	Well number	Unique identification	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Solids, dissolved (tons/ ac-ft	Aluminum, total recoverable (µg/L as Al)	Arsenic total (µg/L as As)	Barium, total recoverable (µg/L as Ba)
Lupton	Begay	(A-22-31)08aad01	351933109041701	9.9	1,790	1,800	2.4	1,100	1	<100
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	6.2	848	910	1.2	80	<1	<100
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	14	556	540	0.76	20	4	<100
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	15	661	750	0.9	<10	1	<100
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	15	692	750	0.94	60	1	<100
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	15	654	750	0.89	40	1	<100
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	13	669	700	0.91	10	1	<100
Sanders	Private well	(A-21-28)13cdc01	351241109193101	11	431	510	0.59	<10	1	<100
Sanders	Private well	(A-21-28)14daa01	351302109195901	7.4	1,040	1,000	1.4	30	<1	<100
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	12	676	700	0.92	20	1	<100
Chambars	Private well	(A-21-28)30aaa02	351152109241601	15	1,090	1,200	1.5	10	1	<100
Chambers	Private well	(A-21-28)30aaa01	351157109241701	15	1,470	1,500	2.0	490	2	<100
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	14	797	860	1.1	20	1	<100
Pinta	Private well	(A-19-25)11daa01	350338109384801	19	1,180	940	1.6	120	5	<100
Pinta	Private well	(A-19-25)01bba01	350451109383401	22	698	700	0.95	2,400	3	200
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	20	938	930	1.3	20	<1	200
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	16	1,600	1,700	2.2	10	12	100

See footnote at end of table.

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona--Continued

Study site	Well name	Well number	Unique identification	Boron, total recoverable (µg/L as B)	Cadmium total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)	Cobalt, total recoverable (µg/L as Co)	Copper, total recoverable (µg/L as Cu)	Iron, total recoverable (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)
Lupton	Begay	(A-22-31)08aad01	351933109041701	650	<1	<1	<1	7	970	<5
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	380	<1	<1	<1	32	1,500	<5
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	590	<1	<1	<1	6	50	9
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	190	<1	<1	<1	9	40	8
Sanders	[1]Sandera School well	(A-21-28)13cbc01	351254109194501	200	<1	<1	1	57	160	<5
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	200	<1	<1	<1	7	50	11
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	170	<1	<1	<1	6	20	<5
Sanders	Private well	(A-21-28)13cdc01	351241109193101	160	<1	<1	<1	5	360	<5
Sanders	Private well	(A-21-28)14daa01	351302109195901	570	<1	<1	30	4	300	6
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	250	<1	<1	<1	4	40	<5
Chambers	Private well	(A-21-28)30aaa02	351152109241601	330	<1	<1	2	10	790	<5
Chambers	Private well	(A-21-28)30aaa01	351157109241701	380	<1	<1	<1	31	1,500	<5
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	250	<1	10	<1	10	190	<5
Pinta	Private well	(A-19-25)11daa01	350338109384801	540	17	<1	<1	27	360	<5
Pinta	Private well	(A-19-25)01bba01	350451109383401	470	4	<1	1	76	2,300	<5
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	610	<1	5	<1	5	390	<5
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	870	<1	<1	1	9	210	<5

See footnote at end of table.

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona--Continued

Study site	Well name	Well number	Unique identification	Manganese, total recoverable (µg/L as Mn)	Molybdenum, total recoverable (µg/L as Mo)	Nickel, total recoverable (µg/L as Ni)	Selenium, total (µg/L as Se)	Silver, total recoverable (µg/L as Ag)	Strontium, total recoverable (µg/L as Sr)	Vanadium, dissolved (µg/L as V)
Lupton	Begay	(A-22-31)08aad01	351933109041701	1,600	6	7	<1	<1	1,600	<20
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	80	11	3	<1	<1	730	<30
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	30	8	<1	5	<1	410	20
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	30	7	<1	1	<1	760	<20
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	30	7	3	1	<1	760	<20
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	30	7	<1	1	<1	780	<20
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	<10	6	<1	3	<1	720	--
Sanders	Private well	(A-21-28)13cdc01	351241109193101	<10	3	1	<1	<1	930	<36
Sanders	Private well	(A-21-28)14daa01	351302109195901	630	4	8	5	<1	3,400	<40
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	<10	7	1	<1	<1	890	<18
Chambers	Private well	(A-21-28)30aaa02	351152109241601	140	7	2	1	<1	1,300	--
Chambers	Private well	(A-21-28)30aaa01	351157109241701	390	6	3	7	<1	1,800	<100
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	190	6	23	2	<1	840	<39
Pinta	Private well	(A-19-25)11daa01	350338109384801	70	33	1	<1	<1	850	--
Pinta	Private well	(A-19-25)01bba01	350451109383401	310	21	<1	<1	<1	380	<65
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	220	14	1	<1	<1	540	<50
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	280	45	<1	<1	<1	500	<140

See footnote at end of table.

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona--Continued

Study site	Well name	Well number	Unique identification	Zinc, total, recoverable (μg/L as Zn)	Gross alpha, total (pCi/L)	Gross alpha, total, counting error (pCi/L)	Gross beta, total (pCi/L)	Gross beta, total counting error (pCi/L)	Lead-210 total (pCi/L)	Lead-210 total count error (pCi/L)
Lupton	Begay	(A-22-31)08aad01	351933109041701	30	27	9.0	4.0	5.0	0.3	0.3
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	280	23	6.0	4.0	3.0	0.4	0.3
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	90	40	6.0	8.0	3.0	<0.1	0.3
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	20	29	6.0	6.0	3.0	0.7	0.4
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	30	20	5.0	6.0	3.0	0.9	0.4
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	10	18	4.0	6.0	3.0	0.9	0.4
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	20	20	5.0	1.0	3.0	0.3	0.4
Sanders	Private well	(A-21-28)13cdc01	351241109193101	70	14	4.0	7.0	3.0	0.4	0.4
Sanders	Private well	(A-21-28)14daa01	351302109195901	450	34	7.0	19	3.0	0.7	0.4
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	10	9.0	4.0	7.0	3.0	0.5	0.4
Chambers	Private well	(A-21-28)30aaa02	351152109241601	80	28	7.0	12	4.0	0.7	0.4
Chambers	Private well	(A-21-28)30aaa01	351157109241701	40	27	8.0	<2.0	4.0	0.4	0.4
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	30	15	5.0	3.0	3.0	0.6	0.4
Pinta	Private well	(A-19-25)11daa01	350338109384801	90	42	8.0	15	3.0	0.6	0.4
Pinta	Private well	(A-19-25)01bba01	350451109383401	100	4.0	4.0	5.0	3.0	0.8	0.4
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	20	5.0	4.0	2.0	3.0	0.3	0.4
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	70	28	10	10	6.0	0	0.3

See footnote at end of table.

APPENDIX A

Water-quality analyses of selected constituents, Puerco River basin, Arizona--Continued

Study site	Well name	Well number	Unique identification	Radium-228, total (pCi/L)	Radium-226, total counting error (pCi/L)	Radium-228, total (pCi/L)	Radium-228, total, counting error (pCi/L)	Thorium-230, total (pCi/L)	Thorium-230, total counting error (pCi/L)	Uranium natural total (µg/L as U)
Lupton	Begay	(A-22-31)08aad01	351933109041701	0.1	0.1	1.3	0.6	0.2	0.2	22
Lupton	Navajo windmill 18T-347A	(A-22-31)18cad01	351810109055301	0	0.1	0	0.5	0	0.1	20
Lupton	Project 77-712	(A-22-31)09ddb01	351858109031701	0.1	0.1	0.3	0.5	0.4	0.2	38
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	0	0.1	0.5	0.6	0	0.1	20
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	0.1	0.1	<0.3	0.4	0.4	0.1	16
Sanders	[1]Sanders School well	(A-21-28)13cbc01	351254109194501	0.1	0.1	<0.3	0.6	0	0.2	16
Sanders	Windsong utility well	(A-21-28)23aac01	351224109202401	0.3	0.1	<0.4	0.6	0	0.1	8.0
Sanders	Private well	(A-21-28)13cdc01	351241109193101	0	0.1	0.4	0.6	0	0.1	10
Sanders	Private well	(A-21-28)14dae01	351302109195901	4.3	0.2	3.1	0.5	0	0.1	19
Chambers	Waterfall Spring	(A-21-27)35acb01	351047109265001	0.9	0.1	<0.1	0.4	0.2	0.1	16
Chambers	Private well	(A-21-28)30aaa02	351152109241601	0	0.1	1.2	1.3	0	0.1	23
Chambers	Private well	(A-21-28)30aaa01	351157109241701	0.1	0.1	0.5	0.5	0.1	0.1	19
Chambers	ATSF No. 3	(A-21-27)25cad01	351119109255301	0.1	0.1	1.2	0.8	0.2	0.1	16
Pinta	Private well	(A-19-25)11daa01	350338109384801	0	0.1	0.7	0.5	0	0.1	38
Pinta	Private well	(A-19-25)01bba01	350451109383401	0.2	0.1	<0.6	0.5	0	0.1	9.0
Petrified Forest	Well No. 2	(A-18-24)09abb01	345850109475001	0.1	0.1	<0.4	0.6	<0.1	0.1	1.0
Petrified Forest	Private windmill	(A-18-24)16bbb01	345757109482001	0	0.2	<0.2	2.8	0	0.3	24

[1] Replicate samples for quality assurance.