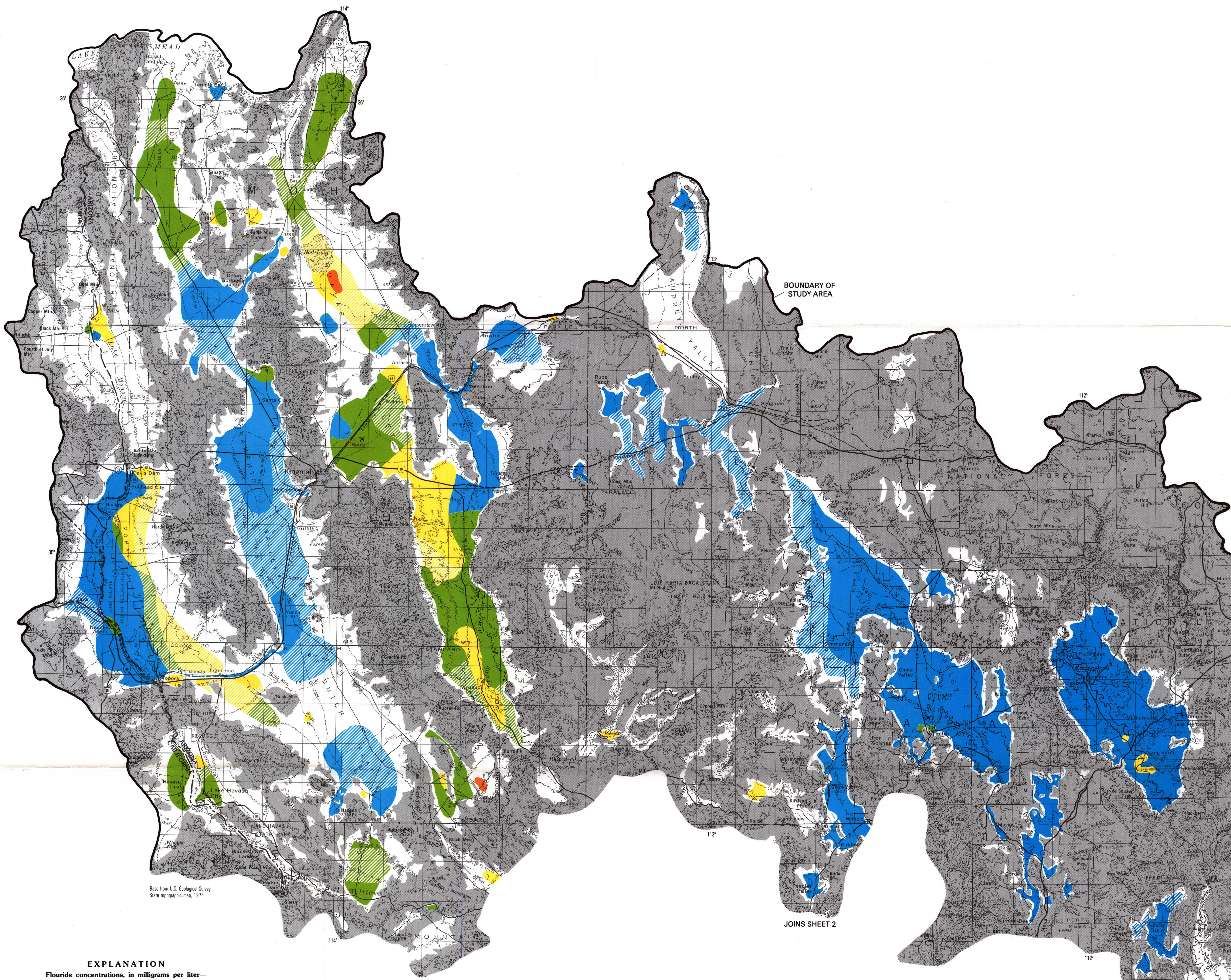
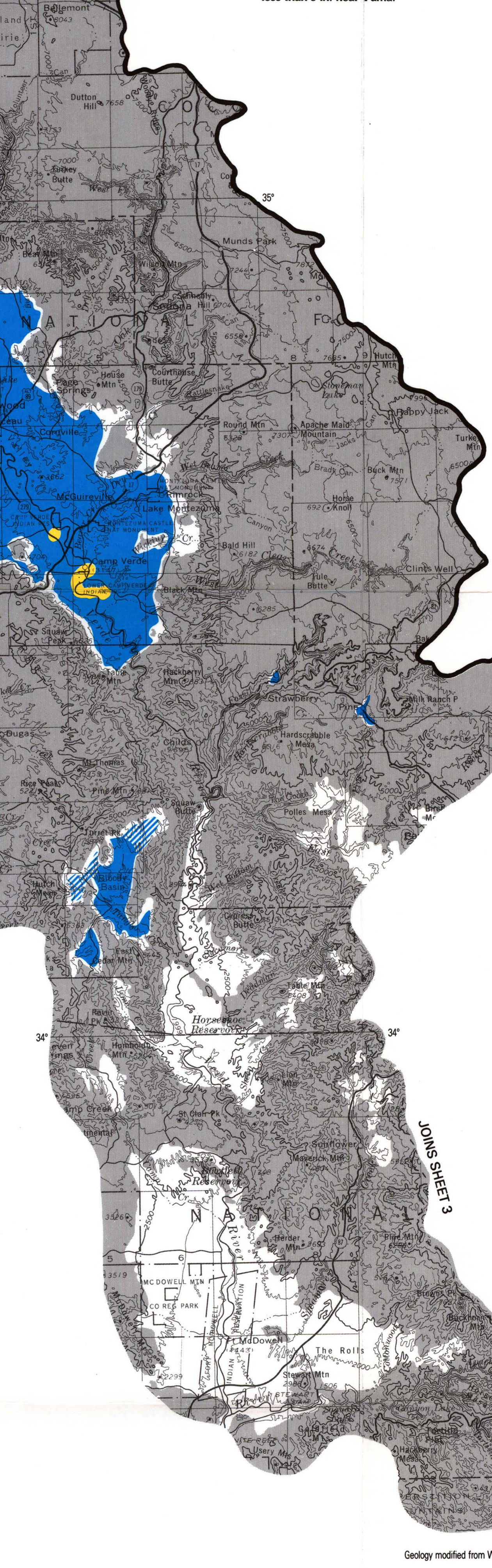




INTRODUCTION

Fluoride occurs widely in ground water in the study area. In many areas fluoride concentrations exceed the maximum contaminant level (MCL) established by the U.S. Environmental Protection Agency (1977) and are a major problem in providing water for public supply. On the basis of the range of annual average maximum daily air temperatures from 65 to 90°F in the study area, the MCL for fluoride is between 1.4 and 1.8 milligrams per liter (mg/L).

This hydrologic atlas presents maps that show the areal distribution of fluoride in ground water in the alluvial basins of Arizona and parts of neighboring States. The maps were compiled using more than 5,000 fluoride analyses from the water-quality data files of the U.S. Geological Survey. The atlas has been prepared as part of the Southwest Alluvial Basins, Regional Aquifer-System Analysis study.

Human ingestion of fluoride in small concentrations has a beneficial effect by preventing tooth decay. Concentrations in excess of the MCL may cause dental fluorosis (mottling of the teeth). The extent of fluorosis may be proportional to the concentration above the MCL. Chronic poisoning of livestock has been reported where the ground water contained fluoride concentrations of 10 to 15 mg/L; the recommended upper limit for fluoride concentrations for livestock is 2.0 mg/L (Gough and others, 1979).

PHYSIOGRAPHIC SETTING

The study area encompasses about 82,000 mi^2 of the Basin and Range Physiographic Province (Fenneman, 1931) in Arizona and small parts of California, Nevada, and New Mexico. Within the study area, the Basin and Range Physiographic Province has been further subdivided on the basis of hydrologic characteristics into the Central highlands water province and the Basin and Range lowlands water province (U.S. Geological Survey, 1969).

The mountains and basins in the study area were formed by large-scale faulting during the Basin and Range disturbance. The faulting created a series of north-trending upthrown and downthrown blocks that were transformed by erosion and deposition into the present mountains, basins, and valleys. The mountains consist mainly of Precambrian to middle Tertiary igneous and metamorphic rocks. Tertiary volcanic and sedimentary rocks are present in many mountain ranges. Paleozoic and Mesozoic sedimentary rocks also form parts of some mountains but are less abundant. The basin-fill deposits consist of sedimentary and volcanic rocks of late Cenozoic age (Wilson and others, 1969).

The study area includes about equal proportions of valleys and mountains. Altitudes range from 150 ft above sea level near Yuma to more than 11,000 ft above sea level in the Central highlands province. The central and southwestern part of the Basin and Range lowlands province between Phoenix and Yuma is a region of low northwest-trending mountain ranges separated by extensive desert basins. The basins in this region make up about 80 percent of the total area. The northwestern and southeastern parts of the Basin and Range lowlands province typically contain long narrow north-trending valleys and mountains that are approximately equal in areal extent. The Central highlands province is mountainous and contains fewer and smaller intermontane basins than does the Basin and Range lowlands province. With the exception of Verde and Big Chino Valleys, these basins typically are narrow and shallow, and the basin fill may be only a thin veneer of alluvium along a stream channel. Average annual precipitation is highly variable and ranges from 35 in. or more in the eastern mountainous areas to less than 5 in. near Yuma.

OCCURRENCE OF GROUND WATER

The ground water stored in the basin-fill deposits of the intermontane basins is the main source of water for most cities. The ground water in storage is the result of accumulation over thousands of years; recharge to the ground-water system is limited in most basins. Phoenix, the largest city in Arizona, obtains much of its water from ground water. Tucson, the second largest city in Arizona, and other communities in the study area are totally dependent on ground water for their water supply.

Ground water in the individual basin aquifers is recharged by infiltration of precipitation and runoff along mountain fronts, infiltration along rivers and streams that generally traverse the centers of basins, and underflow from adjacent basins of higher altitude. Mountain-front recharge occurs in an indeterminate zone that begins at the mountain-alluvium interface and extends basinward an unknown and probably variable distance. The basins along the Colorado River receive virtually all recharge from infiltration of river water directly into the alluvium. The Salt and Gila Rivers near Phoenix also recharge alluvium adjoining the rivers.

Ground water is discharged from the basin aquifers as base flow in streams, evapotranspiration, and underflow to adjacent basins of lower altitude. In recent years, development of ground water for irrigation and public supply has been an additional discharge process. Pumping of ground water is the predominant discharge process in several basins.

Ground water generally occurs under unconfined or water-table conditions, but confined or artesian conditions may exist where extensive fine-grained sediments are present. Artesian conditions occur in the Safford area and in San Pedro and San Simon Valleys.

GEOCHEMISTRY OF FLUORINE

Fluorine occurs in rocks and water in the ionized form, fluoride. In the formation of igneous rocks, the fluoride ion generally is concentrated in residual fluids of cooling magmas; fluoride occurs in fumarolic deposits, pneumatolytic and hydrothermal deposits, pegmatites, and volcanic glass (Goldschmidt, 1958). In Arizona, fluoride occurs in the mineral fluorite in epithermal veins that fill fissures and brecciated zones along faults. Large replacement bodies of fluorite are not found. Schist and volcanic rocks are the chief host rocks in areas of fluorite production (Arizona Bureau of Mines, 1969). Fluoride also occurs in mica or hornblende (Hem, 1970). The occurrence of fluoride in ground water is related to several controls: (1) Availability of the fluoride ion in rocks, (2) mineral equilibrium reactions, and (3) exchange or sorption-desorption reactions on clay minerals.

Calcium concentrations may be an important control of fluoride in ground water through precipitation or dissolution of the mineral fluorite. Equilibrium with fluorite appears to control the higher fluoride concentrations (greater than 5 mg/L) in several basins. Under equilibrium conditions, smaller concentrations of calcium(Ca) permit larger fluoride(F) concentrations in solution:

$$Ca^{+2} + 2F^{-} \longrightarrow CaF_2 \qquad (1)$$

or

$$[Ca^{+2}] \cdot [F^{-}]^2 = Ksp \text{ (solubility product) fluorite.} \qquad (2)$$

Brackets indicate activity or thermodynamic concentration of calcium and fluoride.

Because the solubility product is proportional to the activity of fluoride squared, large concentrations of dissolved fluoride may occur if the ground water is depleted in calcium and a source of fluoride ions is available for dissolution. For example, using the Ksp value of $10^{-10.57}$ at 25 °C and a calcium activity of 40 mg/L, the equilibrium activity of fluoride would be 3.2 mg/L (Hem, 1970).

A strong correlation of fluoride with pH suggests that exchange of hydroxyl ions for fluoride may be occurring and probably that exchange or sorption-desorption reactions are additional controls of fluoride concentrations in solution. During weathering of rocks and release of available fluoride into solution, the fluoride ions may initially exchange for hydroxyl groups on montmorillonitic clays where the fluoride can be available for further exchange. This exchange of fluoride for hydroxyl ions would be favored by the lower, near neutral, pH conditions of recharge areas and by the electronegativity of fluoride and identical size of the fluoride and hydroxyl ions. As pH values increase downgradient through silicate hydrolysis reactions, greater concentrations of hydroxyl ions may affect the exchange of hydroxyl for fluoride ions thereby inceasing the concentrations of fluoride in solution. Because the solubility product of fluorite is not attained in the ground water of most basins, exchange or sorption-desorption reactions appear to be important controls (Robertson, 1984).

DISTRIBUTION OF FLUORIDE IN BASINS

The ground water in many basins contains concentrations of fluoride that exceed the MCL. Fluoride concentrations are closely related to the geology and hydrology of individual basins. Large concentrations of fluoride are particularly associated with rhyolitic and andesitic volcanic rocks. These rock types appear to be a major source of fluoride; the mineral fluorite, if present, may also be an important source. Fluoride concentrations in recharge areas generally are small, less than 1 mg/L, but commonly increase downgradient.

SELECTED REFERENCES

Arizona Bureau of Mines, 1969, Mineral and water resources of Arizona: Tucson, The University of Arizona, p. 348–357.

Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., 534 p.

Goldschmidt, V. M., 1958, Geochemistry: London, Oxford University Press, 730 p.

Gough, L.P., Shacklette, H.T., and Case, A.A., 1979, Element concentrations toxic to plants, animals, and man: U.S. Geological Survey Bulletin 1466, 80 p.

Hem, J.D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Kister, L.R., 1973, Quality of ground water in the lower Colorado River region, Arizona, Nevada, New Mexico, and Utah: U.S. Geological Survey Hydrologic Investigations Atlas HA-478, 2 sheets.

Kister, L.R., Brown, S.G., Schumann, H.H., and Johnson, P.W., 1966, Maps showing fluoride content and salinity of ground water in the Willcox basin, Graham and Cochise Counties, Arizona: U.S. Geological Survey Hydrologic Investigations Atlas HA-214, 6 p.

Metzger, D.G., and Loeltz, O.J., 1973, Geohydrology of the Needles area, Arizona, California, and Nevada: U.S. Geological Survey Professional Paper 486-J, 54 p.

Metzger, D.G., Loeltz, O.J., and Irelan, Burdge, 1973, Geohydrology of the Parker-Blythe-Cibola area, Arizona and California: U.S. Geological Survey Professional Paper 486-G, 130 p.

Olmsted, F.H., Loeltz, O.J., and Irelan, Burdge, 1973, Geohydrology of the Yuma area, Arizona and California: U.S. Geological Survey Professional Paper 486-H, 227 p.

Robertson, F.N., 1984, Solubility controls of fluorine, barium, and chromium in ground water in alluvial basins of Arizona, in Hitchon, Brian, and Wallick, E.I., eds., Practical application of ground water geochemistry, First Canadian/American Conference on Hydrogeology, Banff, Alberta, Canada, June 22–26, 1984, Proceedings: Columbus, Ohio, National Water Well Association, p. 96–102.

U.S. Environmental Protection Agency, 1977, National interim primary drinking water regulations: U.S. Environmental Protection Agency Report, EPA-570/9-76-003, 159 p.

U.S. Geological Survey, 1969, Annual report on ground water in Arizona, spring 1967 to spring 1968: U.S. Geological Survey Water-Resources Report 38, 54 p.

Wilson, E.D., Moore, R.T., and Cooper, J.R., 1969, Geologic map of Arizona: Arizona Bureau of Mines and U.S. Geological Survey, 1:500,000, 1 sheet.

EXPLANATION

Flouride concentrations, in milligrams per liter—Where fluoride data are available for interpretation, areas of different fluoride concentrations are indicated by solid colors. Control is extended to a maximum of 4 miles in areas where hydrology, geology, and geochemistry are sufficiently known. Where data are not sufficient and concentrations are inferred, areas are indicated by hachured lines

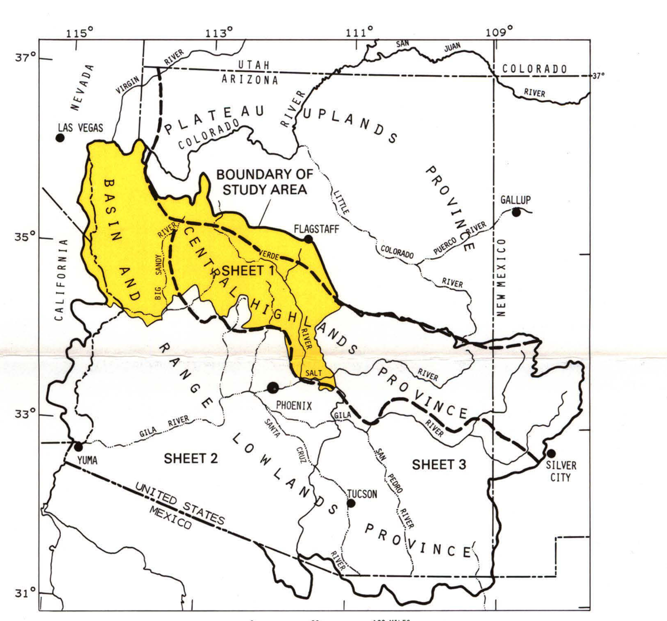
- **0 to 1**
- **1 to 2**
- **2 to 5**
- **5 to 10**
- **No data**
- **Bedrock of the mountains**

NORTHWESTERN ARIZONA AND ADJACENT PARTS OF CALIFORNIA AND NEVADA

Ground water in most basins in the northwestern part of the study area generally contains fluoride concentrations of less than 2 mg/L. Fluoride concentrations commonly are less than 2 mg/L in Sacramento and Detrital Valleys. Fluoride concentrations in the Big Sandy basin are between 1 and 2 mg/L except in the northwest and southwest areas where concentrations are between 2 and 5 mg/L. In the peripheral areas of Hualapai Valley, fluoride concentrations are between 1 and 2 mg/L but are between 5 and 10 mg/L in a small central area south of Red Lake playa. The large fluoride concentrations in the ground water in this area may indicate a buried playa. On the basis of one sample from Red Lake playa, fluoride concentrations in the ground water within the playa area are less than 5 mg/L. The small concentration, if representative, indicates that the ground water moves under the playa area to the northwest, in contrast to surface drainage which converges toward the playa. If ground water were also converging toward and discharging at the playa, large increases in fluoride would occur through evaporative concentration. Small fluoride concentrations normally occur in the flood-plain deposits adjacent to the Colorado River. Concentrations that exceed 2 mg/L occur locally in wells that tap the older alluviums, which are adjacent to the flood-plain aquifer and compose the piedmont (Metzger and Loeltz, 1973).

Most of the ground water in Verde Valley contains less than 1 mg/L of fluoride. The small fluoride concentrations may be a result of large solute calcium concentrations and precipitation of fluorite (equation 2). The principal aquifer, the Verde Formation of late Tertiary age, is a lacustrine dolomitic limestone throughout most of the area, and the ground water contains larger concentrations of calcium and magnesium than in other basins. In the southern part of the valley, the formation becomes a limey lacustrine deposit of silt, clay, and evaporites and the ground water evolves from a calcium to a sodium type, which may cause the larger fluoride concentrations of 2 to 5 mg/L. In Chino Valley and most other areas in the Central highlands province, fluoride concentrations are less than 1 mg/L.

Granite and gneiss are the predominant rock types throughout most of the Basin and Range lowlands in this area and appear to be associated with lower fluoride concentrations. Basalt is predominant in Verde Valley and the Central highlands. Andesite and other volcanic rocks commonly are adjacent to the Colorado River.



INDEX MAP SHOWING STUDY AREA AND ARIZONA'S WATER PROVINCES

CONVERSION FACTORS

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

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
square mile (mi^2)	2.590	square kilometer (km^2)

SCALE 1:500 000

CONTOUR INTERVAL 500 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

DISTRIBUTION OF FLUORIDE IN GROUND WATER IN THE ALLUVIAL BASINS OF ARIZONA AND ADJACENT PARTS OF CALIFORNIA, NEVADA, AND NEW MEXICO

By
Frederick N. Robertson and W. B. Garrett

1988

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