DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Prepared in cooperation with
THE WEST VIRGINIA GEOLOGICAL AND ECONOMIC SURVEY

OPEN FILE REPORT 92-140

INTRODUCTION

Dissolved fluoride in drinking water affects human health, especially the dental health of children. Fluoride concentrations of about 1.0 mg/L (milligrams per liter) in drinking water reduce the number of dental cavities in children. Long-term exposure to fluoride concentrations that exceed 4.0 mg/L in drinking water, however, can cause serious bone disorders in humans. For this reason, the U.S. Environmental Protection Agency (USEPA) set a Maximum Contaminant Level (MCL) for fluoride of 4.0 mg/L in drinking water (U.S. Environmental Protection Agency, 1986). The USEPA set a Secondary Maximum Contaminant Level (SMCL) for fluoride of 2.0 mg/L; children who continuously drink water with fluoride that exceeds this concentration can develop dental fluorosis, a condition characterized by pitting and brownish staining of permanent teeth (U.S. Environmental Protection Agency, 1986). Maximum Contaminant Levels (MCL's) are enforceable standards set for health reasons, and Secondary Maximum Contaminant Levels (SMCL's) are aesthetic levels set to prevent taste or odor problems.

Large public suppliers of drinking water monitor the concentration of fluoride and adjust it to the optimum level of about 1.0 mg/L. Household or domestic water supplies, however, are usually not treated for fluoride. In West Virginia, most of the private domestic drinking water is obtained from ground water pumped from nearby wells. Thus, information about the distribution of fluoride in ground water is particularly important to the State health agencies. This study was conducted by the U.S. Geological Survey from 1990 through 1991 in cooperation with the West Virginia Geological and Economic Survey.

Purpose and Scope

This report describes the distribution of fluoride in ground water of West Virginia. Fluoride data for this study were obtained from the U.S. Geological Survey's water-quality data base (QWDATA). The period of record for these data is from the 1940's to 1990, although most data are from the 1970's to the 1980's. Fluoride data were retrieved for ground-water analyses from 1,699 wells and 190 springs. Fluoride concentrations were subdivided into four ranges for data analysis and report preparation on the basis of the following criteria: (1) a detection limit of 0.1 mg/L for fluoride, (2) an optimum fluoride concentration of 1.0 mg/L, and (3) an SMCL of 2.0 mg/L for fluoride. These four ranges of concentration were less than or equal to 0.1 mg/L, 0.2 to 0.9 mg/L, 1.0 to 2.0 mg/L, and greater than 2.0 mg/L. The locations of samples from wells were plotted for each of these four ranges to show the distribution of fluoride in ground water in West Virginia. Trilinear diagrams were plotted for fluoride samples in each of these four ranges to show variations in water chemistry with respect to fluoride concentration. The distribution of fluoride in ground water in West Virginia also was examined with respect to topography, well depth, and geology.

This report, which describes the general distribution of fluoride in ground water and the relation of fluoride concentration to other factors, should not be used to estimate concentrations of fluoride at specific locations because of the limitations of the data. Accurate well-depth data are not available for many wells in West Virginia. In fact, little information is available for many wells drilled before 1984 in West Virginia, when legislation was enacted to require well drillers to file well-completion reports with the State. Even with accurate well-depth data, it is difficult to determine the depth at which water enters a well because of the complexly fractured nature of rocks in West Virginia. Except for wells drilled into the Ohio and Kanawha River alluvium, ground water enters a typical well in West Virginia through fractures and bedding-plane partings adjacent to the uncased part of the well. A typical well in West Virginia is cased from land surface to the top of bedrock.

An accurate measurement of the depth of ground-water inflow from a geologic unit to a well can only be made in the alluvial aquifer, where the well is screened in the 10- to 15-foot depth interval directly above the bedrock. Underlying geologic units that contribute ground water to wells installed in fractured rock (most wells in the West Virginia data base are of this type) have been categorized by topographic setting, well depth, and geologic age.

Previous Investigations

Although no reports were found in the literature that dealt specifically with fluoride in West Virginia, fluoride concentrations in ground water have been tabulated or discussed in a number of river-basin reports, county ground-water reports, basic-data reports for river basins, and ground-water atlases. Basin reports on the Monongahela River (Friel and others, 1967), Little Kanawha River (Bain and Friel, 1972), Tug Fork (Bader and others, 1989), and Elk River (Mathes and Ward, 1990) include tabulated fluoride data and discussions of fluoride in ground water.

Fluoride concentrations in ground water are tabulated in county ground-water reports for the Parkersburg area (Jeffords, 1945), Harrison County (Nace and Bieber, 1958), Monongalia County (Carlston, 1958), Jefferson and Berkeley Counties (Bieber, 1961), and Marshall County (Shultz, 1988). Fluoride data are tabulated in basic data reports for the Monongahela River (Ward and Wilmoth, 1968), Little Kanawha River (Friel and Bain, 1971), upper part of the New River (Chisholm and Frye, 1976), Potomac River (Friel and others, 1975), Coal River (Morris and others, 1976), and Elk River (Tarver and others, 1976). Fluoride data also are tabulated in ground-water atlases for the Little Kanawha River (Hobba, 1980), Elk River (Ferrell, 1984a), Coal River (Beckwith, 1984), Ohio River tributaries (Shultz, 1984a), Monongahela River (Hobba, 1984), Kanawha River tributaries (Ferrell, 1984b), upper part of the New River (Shultz, 1984b), and Gauley River (McAuley, 1985).

Fluoride data from the previously mentioned reports are stored in the U.S. Geological Survey's water-quality data base (QWDATA). Many of the data have been published in the Water Resources Data Reports for West Virginia, published annually from 1963 to the present (1991).

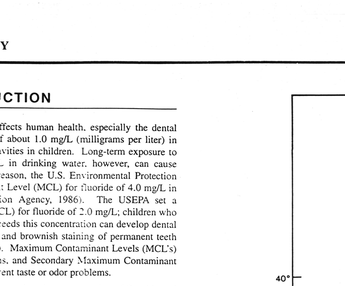

Figure 1.-- Location of sample sites where fluoride analysis were performed.

Conversion Factors and Abbreviated Water-Quality Unit

Multiply	By	To Obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer

Abbreviated water-quality unit used in report: Chemical concentration is expressed in milligrams per liter (mg/L).

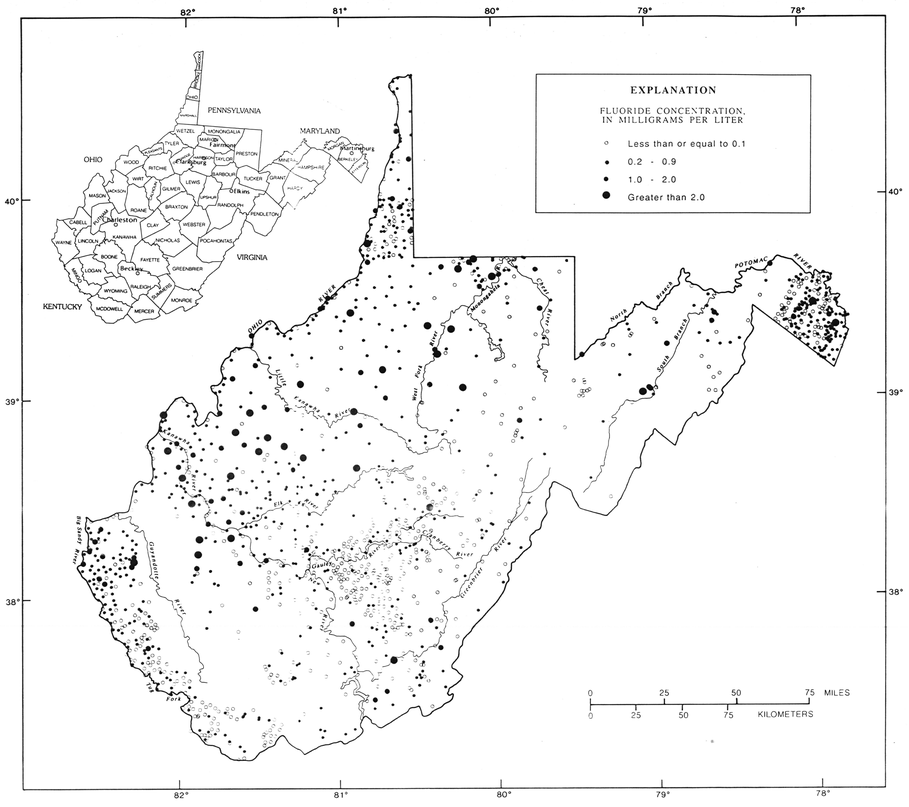

Figure 2.-- Map of fluoride distribution in ground water from wells.

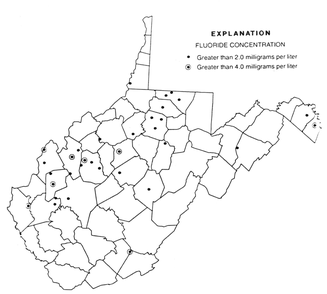

Figure 3.-- Fluoride concentrations greater than 2.0 mg/L.

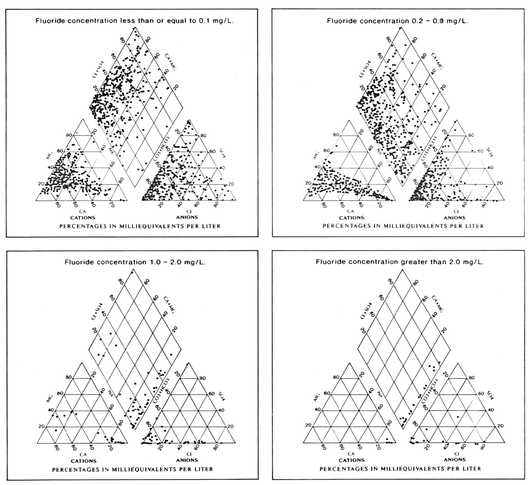

Figure 4.-- Variation of water chemistry with fluoride concentration.

DISTRIBUTION OF FLUORIDE IN GROUND WATER

Fluoride concentrations in ground water in West Virginia range from less than 0.1 to 12 mg/L (fig. 1). In contrast, maximum fluoride concentrations in springs do not exceed the USEPA's SMCL of 2.0 mg/L. For this reason, and because the source aquifers feeding the springs are unknown, fluoride data for springs are not discussed further in this report, except in table 1.

Most ground-water samples with fluoride concentrations greater than 2.0 mg/L were from the northwestern part of West Virginia (fig. 2). Likewise, ground-water samples with fluoride concentrations less than 0.1 mg/L tend to be concentrated in the southern and eastern parts of West Virginia. The distribution of fluoride concentrations greater than 2.0 mg/L (the USEPA SMCL) and 4.0 mg/L (the USEPA MCL), indicates that most fluoride concentrations greater than 2.0 mg/L are present in a broad band across northwestern West Virginia (fig. 3). An examination of fluoride data from ground water in adjacent States indicates that this band of high fluoride concentrations extends into and covers most of Kentucky to the southwest, and to a lesser extent, extends into eastern Ohio and southwestern Pennsylvania to the north.

Although figures 2 and 3 provide information about the areal distribution of fluoride concentrations, they do not provide information about the changes in concentrations with depth. For this reason, the information in these figures should not be used to estimate concentrations of fluoride at specific locations.

The distribution of fluoride concentrations in ground water with respect to topographic setting, well depth, and geologic age of aquifer is summarized in tables 1- 4. Fluoride concentrations greater than 2.0 mg/L are found in water from wells drilled into all geologic units except the Holocene (alluvium), Lower Pennsylvanian, and Silurian aquifers (table 2). Elevated fluoride concentrations are found in water from wells drilled in all topographic settings and to all depths (tables 3 and 4). The variation of water chemistry with respect to fluoride concentrations in ground water is shown in figure 4. The chemical controls and equilibria responsible for these variations are beyond the scope of this report.

Table 1.--Fluoride concentrations exceeding 1.0 milligram per liter, by topographic setting, well depth, and geologic age of aquifer
[mg/L, milligrams per liter; > , greater than; < , less than]

Sample group	Total number of samples	Number of samples > 1.0 mg/L	Percentage of samples > 1.0 mg/L	Number of samples > 2.0 mg/L	Percentage of samples > 2.0 mg/L
All wells	1,699	95	6	34	2
Topographic setting					
Hilltop	233	8	3	4	2
Hillside	389	19	5	9	2
Valley	579	48	8	18	3
Well depth					
0-100 feet	890	32	4	8	1
101-200 feet	335	27	8	12	4
201-300 feet	85	10	12	3	4
> 300 feet	92	20	22	9	10
Geologic age of aquifer					
Holocene (alluvium)	127	4	3	0	0
Permian	136	15	11	7	5
Upper Pennsylvanian	225	37	16	14	6
Middle Pennsylvanian	52	4	8	2	4
Lower Pennsylvanian	356	1	< 1	0	0
Mississippian	66	3	5	2	3
Devonian	70	6	9	1	1
Silurian	8	0	0	0	0
Ordovician	60	1	2	1	2
Cambrian and Precambrian	79	4	5	1	1
All springs	190	2	1	0	0

SUMMARY

Fluoride concentrations in West Virginia ground water range from less than 0.1 to 12 mg/L. Most fluoride concentrations that exceed 2.0 mg/L are located at sites clustered in the northwestern part of the State. Fluoride concentrations that exceed 2.0 mg/L are found in wells drilled to all depths, wells drilled in all topographic settings, and wells drilled into most geologic units.

Table 2.--Concentrations of fluoride in water samples from geologic units of various ages
[<, less than]

Geologic age of aquifer	Number of samples	Fluoride concentration, in milligrams per liter: Minimum	Maximum	Median
Holocene (alluvium)	127	<0.1	2.0	0.1
Permian	136	<.1	4.4	.2
Upper Pennsylvanian	225	<.1	8.8	.3
Middle Pennsylvanian	52	<.1	12	.2
Lower Pennsylvanian	356	<.1	1.2	.1
Mississippian	66	<.1	8.4	.1
Devonian	70	<.1	3.9	.2
Silurian	8	<.1	.3	.1
Ordovician	60	<.1	3.0	.2
Cambrian and Precambrian	79	<.1	4.5	.3

Table 3.--Concentrations of fluoride in water samples from wells located in various topographic settings
[<, less than]

Setting	Number of samples	Fluoride concentration, in milligrams per liter: Minimum	Maximum	Median
Hilltop	233	<0.1	8.4	0.1
Hillside	389	<.1	12	.2
Valley	579	<.1	8.8	.2

Table 4.--Concentrations of fluoride in water samples from wells of various depths
[> , greater than; < , less than]

Depth (feet)	Number of samples	Fluoride concentration, in milligrams per liter: Minimum	Maximum	Median
0-100	890	< 0.1	3.6	0.2
101-200	335	< .1	12	.2
201-300	85	< .1	4.4	.2
> 300	92	< .1	8.4	.4

SELECTED REFERENCES

Bader, J.S., Mathes, M.V., and Runner, G.S., 1989, Water resources of the Tug Fork of Big Sandy River basin, West Virginia, Kentucky, and Virginia and Twelvepole Creek basin, West Virginia: West Virginia Geological and Economic Survey River Basin Bulletin 8, 113 p.

Bain, G.L., and Friel, E.A., 1972, Water resources of the Little Kanawha River basin, West Virginia: West Virginia Geological and Economic Survey River Basin Bulletin 2, 122 p.

Beckwith, D.S., 1984, Ground-water hydrology of the Coal River basin, West Virginia: West Virginia Department of Natural Resources, map report, 1 sheet, scale 1:250,000.

Bieber, P.B., 1961, Ground-water features of Berkeley and Jefferson Counties, West Virginia: West Virginia Geological Survey Bulletin 21, 81 p.

Carlston, C.W., 1958, Ground-water resources of Monongalia County, West Virginia: West Virginia Geological Survey Bulletin 15, 42 p.

Chisholm, J.L., and Frye, P.M., 1976, Records of wells, springs, chemical analyses of water, biological analyses of water, and standard streamflow data summaries from the upper New River basin in West Virginia: West Virginia Geological and Economic Survey Basic Data Report 4, 78 p.

Ferrell, G.M., 1984a, Ground-water hydrology of the Elk River basin, West Virginia: West Virginia Department of Natural Resources, map report, 1 sheet, scale 1:250,000.

Ferrell, G.M., 1984b, Ground-water hydrology of the minor tributary basins of the Kanawha River, West Virginia: West Virginia Department of Natural Resources, map report, 1 sheet, scale 1:250,000.

Friel, E.A., and Bain, G.L., 1971, Records of wells, springs, and test borings, chemical analyses of water, sediment analyses, standard streamflow data summaries, and selected drillers' logs from the Little Kanawha River basin in West Virginia: West Virginia Geological and Economic Survey Basic Data Report 2, 76 p.

Friel, E.A., Hobba, W.A., and Chisholm, J.L., 1975, Records of wells, springs, and streams in the Potomac River basin, West Virginia: West Virginia Geological and Economic Survey Basic Data Report 3, 96 p.

Friel, E.A., Wilmoth, B.M., Ward, P.E., and Wark, J.W., 1967, Water resources of the Monongahela River basin, West Virginia: West Virginia Department of Natural Resources, 118 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3rd ed.): U.S. Geological Survey Water-Supply Paper 2254, 203 p.

Hobba, W.A., Jr., comp., 1980, Ground-water hydrology of the Little Kanawha River basin, West Virginia: West Virginia Geological and Economic Survey Map WV-10, 1 sheet, scale 1:250,000.

Hobba, W.A., Jr., 1984, Ground-water hydrology of the Monongahela River basin, West Virginia: West Virginia Department of Natural Resources, map report, 1 sheet, scale 1:250,000.

Jeffords, R.M., 1945, Ground-water conditions along the Ohio River at Parkersburg, West Virginia: West Virginia Geological Survey Bulletin 10, 57 p.

Johnson, P.W., and Rhett, J.M., 1981, Fluoride concentrations in water from four principal coastal plain aquifer systems, South Carolina: U.S. Geological Survey Water Resources Investigations Open-File Report 81-140, 11 p.

Kula, Katherine, and Hansen, H.J., 1989, Fluoride supplementation and the concentration of fluoride in ground water from eastern and southern Maryland: Journal of the Maryland State Dental Association, v. 32, no. 3, 8 p.

Mathes, M.V., and Ward, S.M., 1990, Water resources of the Elk River basin, West Virginia: West Virginia Geological and Economic Survey River Basin Bulletin 6, 37 p.

McAuley, S.D., 1985, Ground-water hydrology of the Gauley River basin, West Virginia: West Virginia Department of Natural Resources, map report, 1 sheet, scale 1:250,000.

Morris, F.D., Bader, J.S., Chisholm, J.L., and Downs, S.C., 1976, Hydrologic data for the Coal River basin, West Virginia: West Virginia Geological and Economic Survey Basic Data Report 5, 215 p.

Nace, R.L., and Bieber, P.B., 1958, Ground-water resources of Harrison County, West Virginia: West Virginia Geological and Economic Survey Bulletin 14, 43 p.

Peters, N.E., and Bonelli, J.E., 1982, Chemical composition of bulk precipitation in the north-central and northeastern United States, December 1980 through February 1981: U.S. Geological Survey Circular 874, p. 24.

Robertson, F.N., 1985, Occurrence and solubility controls of trace elements in ground water in alluvial basins of Arizona, in Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States, Southwest alluvial basins of Arizona: American Water Resources Association Monograph Series No. 7, p. 69-80.

Shultz, R.A., 1984a, Ground-water hydrology of the minor tributary basins of the Ohio River, West Virginia: West Virginia Department of Natural Resources, map report, 1 sheet, scale 1:250,000.

Shultz, R.A., 1984b, Ground-water hydrology of the Upper New River basin, West Virginia: West Virginia Department of Natural Resources, map report, 1 sheet, scale 1:250,000.

Shultz, R.A., 1988, Ground-water hydrology of Marshall County, West Virginia, with emphasis on the effects of long wall coal mining: U.S. Geological Survey Water-Resources Investigations Report 88-4006, 147 p.

Tarver, G.R., Downs, S.C., Chisholm, J.L., and Frye, P.M., 1976, Hydrologic data for the Elk River basin, West Virginia: West Virginia Geological and Economic Survey Basic Data Report 6, 106 p.

U.S. Environmental Protection Agency, 1986, U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1986, p. 524-528, 567-568, 587-590.

Ward, P.E., and Wilmoth, B.M., 1968, Records of wells, springs, and test borings, chemical analyses of ground water, and selected drillers' logs from the Monongahela River basin in West Virginia, 1968: West Virginia Geological and Economic Survey Basic Data Report 1, 73 p.

For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225

DISTRIBUTION OF FLUORIDE IN GROUND WATER OF WEST VIRGINIA

By M.V. Mathes and M.C. Waldron
Charleston, West Virginia

1993