Background Contribution of Rocks to Phosphate Content of Water Supply, South Fork Rivanna River Drainage Basin, Albemarle County, Virginia

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ABSTRACT

Phosphorus concentrations in rocks underlying the South Fork of the Rivanna River basin range from 567 to 1833 parts per million and average 1145 ppm, a value very close to the world average for igneous rocks, 1134 ppm. More than 90% of the natural phosphorus in rocks occurs as dispersed trace (1% or less by volume) amounts of fluorapatite in Late Precambrian and Cambrian metamorphic rocks. The remainder occurs in very local, uncommon phosphate minerals of little significance to the phosphate background abundance.

Very little phosphorus is dissolved by ground water from natural weathering processes. Ninety-nine of 161 water wells studied showed concentration of less than 0.01 ppm orthophosphate. Only 33 wells showed values of .04 to .16 ppm causing a markedly skewed frequency distribution with an arithmetic mean of 0.02 ppm. Wells with high concentrations of orthophosphates were confined to farmland along and between Moorman's River and Mechum River, and the suburbs of Crozet and Charlottesville.

The phosphorus contribution from the weathering of various rock types is of no importance to algae buildup in public water supplies of the South Fork of the Rivanna River basin.

Introduction

This study is in response to a request for geological information on the contribution from rocks to the concentration of phosphorus in water of the drainage basin of the South Fork of the Rivanna River, Albemarle County, Virginia. (Figure 1).

Phosphorus is naturally present in rocks, soils, water, and all living organisms. On the surface of the earth its overall concentration is 0.10-0.12% P, greater than that of carbon 0.03% (Van Wazer, 1961). Phosphorus is essential to all life through its role in cell biochemistry. It is enriched in living systems from more dilute natural concentrations.

In unpolluted water phosphorus concentrations range from .001 - 0.2 parts per million but most values lie between .00 - .05 ppm Wetzel, 1975. Phosphorus is not known to be toxic to man, animals, or fish (Brown, and others, 1970) since the excess is not absorbed or easily excreted. However, the stimulation of an unusually abundant growth of algae and other nuisance organisms from relatively modest additions of phosphorus to the public water supplies of the drainage basin is a continuing problem.

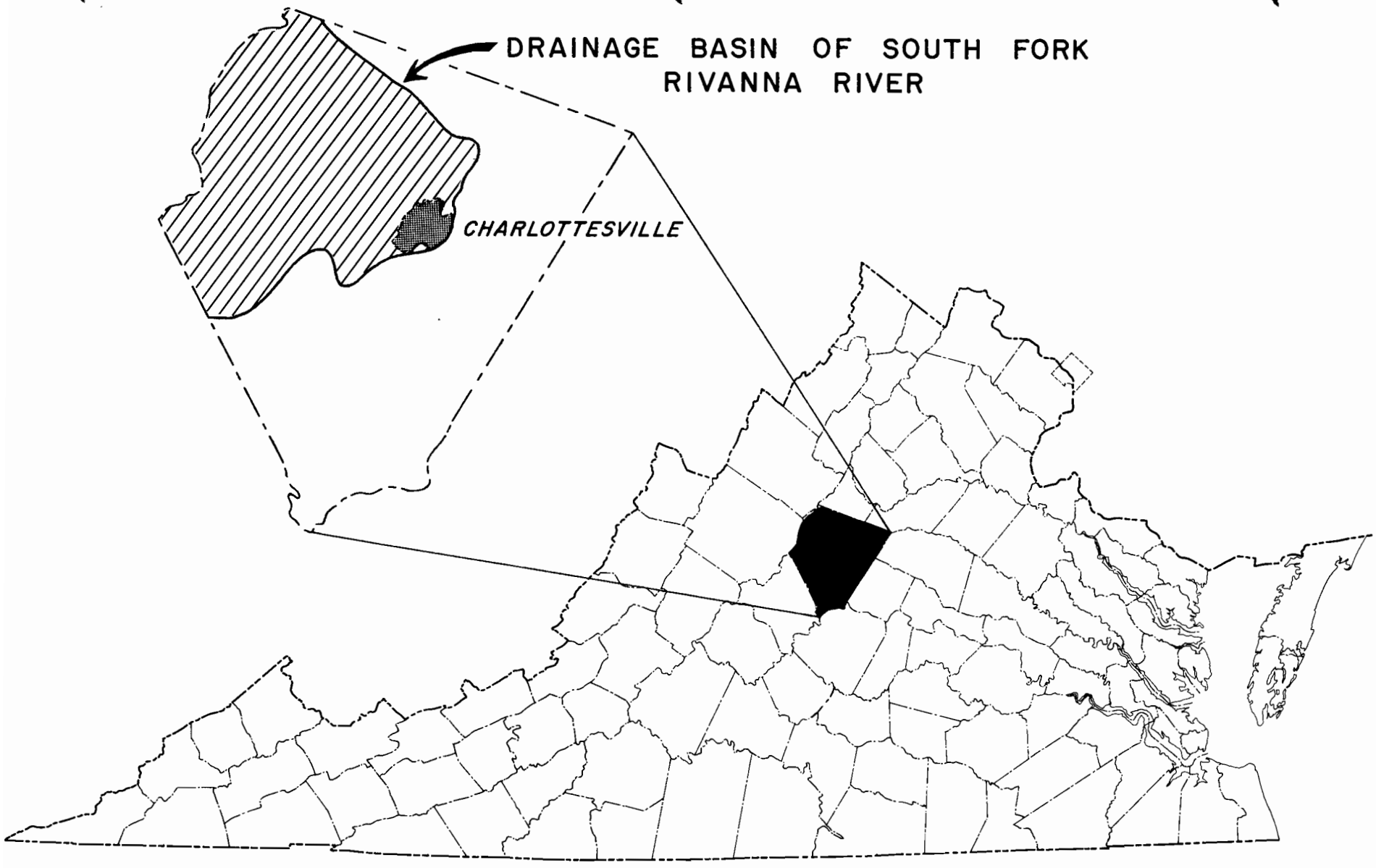

Fig. 1 Location of Area of Investigation

Sources of Phosphorus in Water

Phosphorus occurs in water as soluble inorganic phosphates, colloids, and as soluble and insoluble organic compounds. The major primary source of phosphorus in the drainage basin is widely disseminated traces ($< 1\%$) of phosphatic minerals, largely fluorapatite $Ca_5 (PO_4)_3 (F, OH)$, in igneous and metamorphic rocks. Calculated as the element, phosphorus occurs in rocks in general, without special enrichment, in concentrations of 200 to 2,000 parts per million (Appendix 2), and in rocks of Albemarle County in the 500-1900 ppm range (Table 1).

Fluorapatite is said to be nearly insoluble and no data on its solubility is given in standard references. Whitlockite, $Ca_3 (PO_4)_3$ dissolves in cold distilled water yielding only 4 ppm as phosphorus (Weast, 1974) but with CO_2 the solubility increases to 28 ppm (Ehlert and Henysel, 1912). These solubilities are very low compared to primary mono-phosphate $Ca (H_2PO_4) \cdot H_2O$ a component of fertilizers, which yields 2385 ppm as phosphorus. (Weast, 1974).

Slow decomposition by CO_2 - charged water and bacterial action release soluble phosphate which is partly absorbed by plants and animals, and partly reprecipitated with calcium, iron, and aluminum, particularly in the clay fractions of soil. Phosphorus in the soil ranges from 20 to 8,300 ppm (Fuller, 1972). Once liberated from phosphate-bearing rock, phosphorus alternates between "inorganic" and "organic" phosphorus compounds. Plants take soluble (available) phosphorus from the soil and synthesize phospholipids and other phosphorus compounds. This is the beginning of the biologic cycle of phosphorus. Animals feeding on plants change the plant phosphorus into tissue phosphates and phosphoproteins, and the excess is excreted in urine and feeces. Approximately 3/4 of the phosphorus

present in animal feces is non-absorbed phosphorus food which is attacked by bacteria and changed to phosphate.

Phosphorus is essential for life. Its compounds are used for energy transport in the cell mitochondria and in making the gene molecules DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). Phosphorus occurs in living tissue as nucleoproteins, ortho and polyphosphate esters, phospholipids, phosphagens, sugar phosphates, mixed anydrides of organic acids, and orthophosphoric acid. Phosphorus is used by plants and animals in pH buffering, formation of soluble complexes with cations, and precipitation of orthophosphatic ions as highly insoluble hydroxylapatite in bones, teeth and shells.

In general biologic systems concentrate phosphorus from very dilute natural sources and return it to enrich their environment in it through various biological cycles. Examples of the abundance of phosphorus in natural living systems are listed in Appendix 2.

The natural background level of phosphorus concentrations in reservoir water is a complex result of the sum of inorganic and organic materials being washed into the drainage system from leaching of reciprecipitated phosphates in the soil, from decomposing plants and animals and their bones, shells and excrement, and from dust particles and microbial debris in the atmosphere. To this man adds industrial effluents, phosphatic detergents, sweage, and runoff from farm animals and inorganic fertilizers.

Phosphorus in Ground Water

Chemical analyses of water from 161 wells in Albemarle County show an arithmetic mean of 0.02 ppm orthophosphate (R.M. Sterrett, personal communication 1979; analyses by Virginia State Water Control Board) but a frequency plot of this data shows that a large majority, 99, show no detectable phosphate at the time of analysis (Figs. 3,4). This data was then contoured by computer and the SYMAP printout of high phosphate wells (.04 -.16 ppm) shown in Figures 2 and 4 indicates 1) that there is no relationship to major rock type (Figure 2) 2) that wells with high phosphate lie along and between Moorman's River and Mechum River and in the suburbs of Crozet and Charlottesville and probably reflect runoff from fertilizers, detergents and seepage from suburban septic tanks.

The total phosphorus in 161 well water samples averaged 0.03 ppm with a few analyses as high as 0.61 ppm. The Virginia Department of Health reports six different components of "total phosphorus". Consideration of this aspect is beyond the scope of this report. However, it is clear that phosphate concentrations derived from rock weathering are generally in the "0.00X" ppm range. Other sources of phosphorus, both natural biologic and manmade, are considerably greater than this level and completely mask any slight changes from various rock types.

Phosphorus in Surface Water

Phosphorus concentrations in surface water reflect more strongly natural organic and manmade additions. These concentrations are more variable and can depend upon the weather and the season. For example, U.S. Geological Survey monitoring station #02031500 on Moorman River on the northfork near White Hall showed 0.04 ppm (July 16, 1968) but a more recent analysis (April 1979) by

another investigator (Kirk Nordstrom, Dept. of Environmental Sciences, University of Virginia, personal communication) showed 0.01 - 0.02 soluble phosphate and in Mechum River from 0.01 to 0.07 ppm. Detailed consideration of seasonal variation of surface waters of the basin has been conducted by consultants for the Rivanna watershed and are beyond the scope of this report.

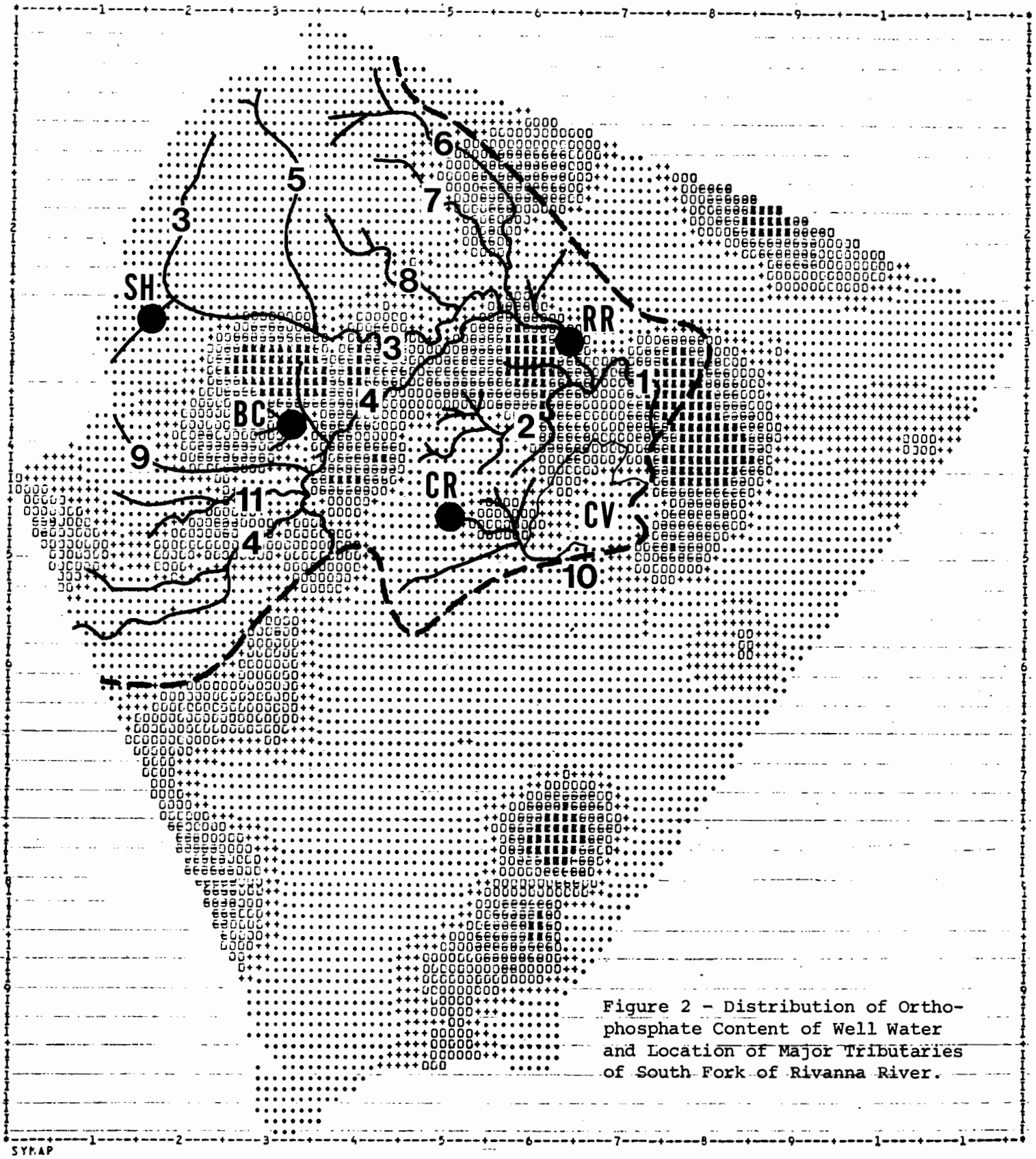

Figure 2 - Distribution of Orthophosphate Content of Well Water and Location of Major Tributaries of South Fork of Rivanna River.

SYMAP

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
(*MAXIMUM* INCLUDED IN HIGHEST LEVEL ONLY)

WATER WELL DATA FOR ALBEMARLE COUNTY, VIRGINIA

ORTHO-PHOSPHATE IN WATER IN PARTS PER MILLION

CONTOUR INTERVALS SELECTED BY COMPUTER PROGRAM

MINIMUM	0.00	.01	.02	.04	.08
MAXIMUM	.01	.02	.04	.08	.16
SYMBOLS	....1....	++++2++++	000030000	000040000	■■■■5■■■■
	.....	+++++++++	000000000	000000000	■■■■■■■■■
	.....	+++++++++	000000000	000000000	■■■■■■■■■
FREQ.	95	6	20	17	16

Fig. 2 Diagramatic Sketch of Main Tributaries of South Fork of Rivanna River.

1 - South Fork of Rivanna River
2 - Ivy Creek
3 - Moorman's River
4 - Mechum River
5 - Doyle's River
6 - Buck Mountain Creek
7 - Piney Creek
8 - Rocky Creek
9 - Lickinghole Creek
10- Moore's Creek
11- Stockton Fork

CV - Charlottesville
RR - South Fork Rivanna River Reservoir
CR - Charlottesville Reservoir, Ragged Mountain
BC - Beaver Creek Dam, Crozet Reservoir
SH - Charlottesville Reservoir, Sugar Hollow

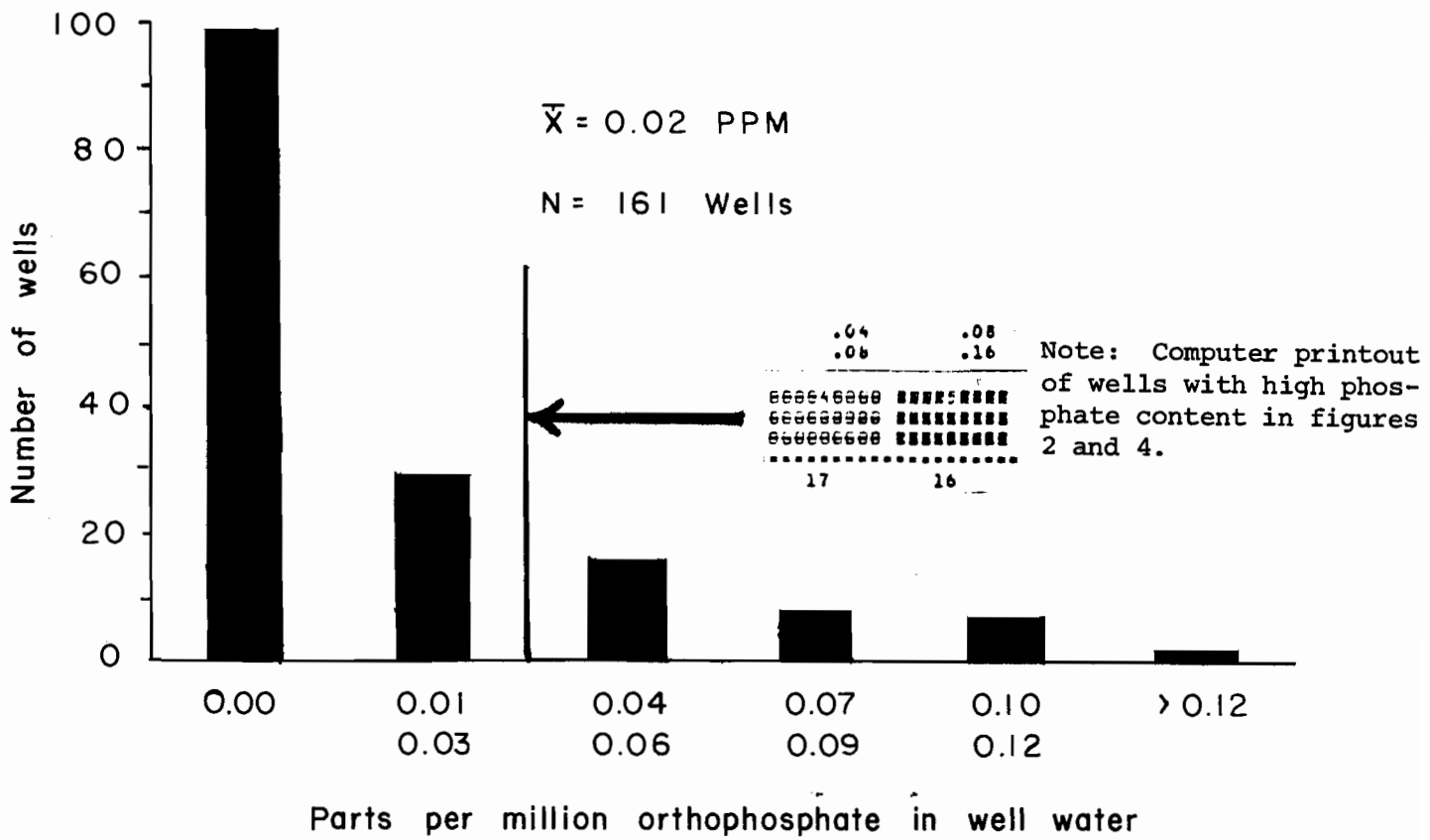

Figure 3 - Orthophosphate Content of 161 Albemarle County Watter Wells

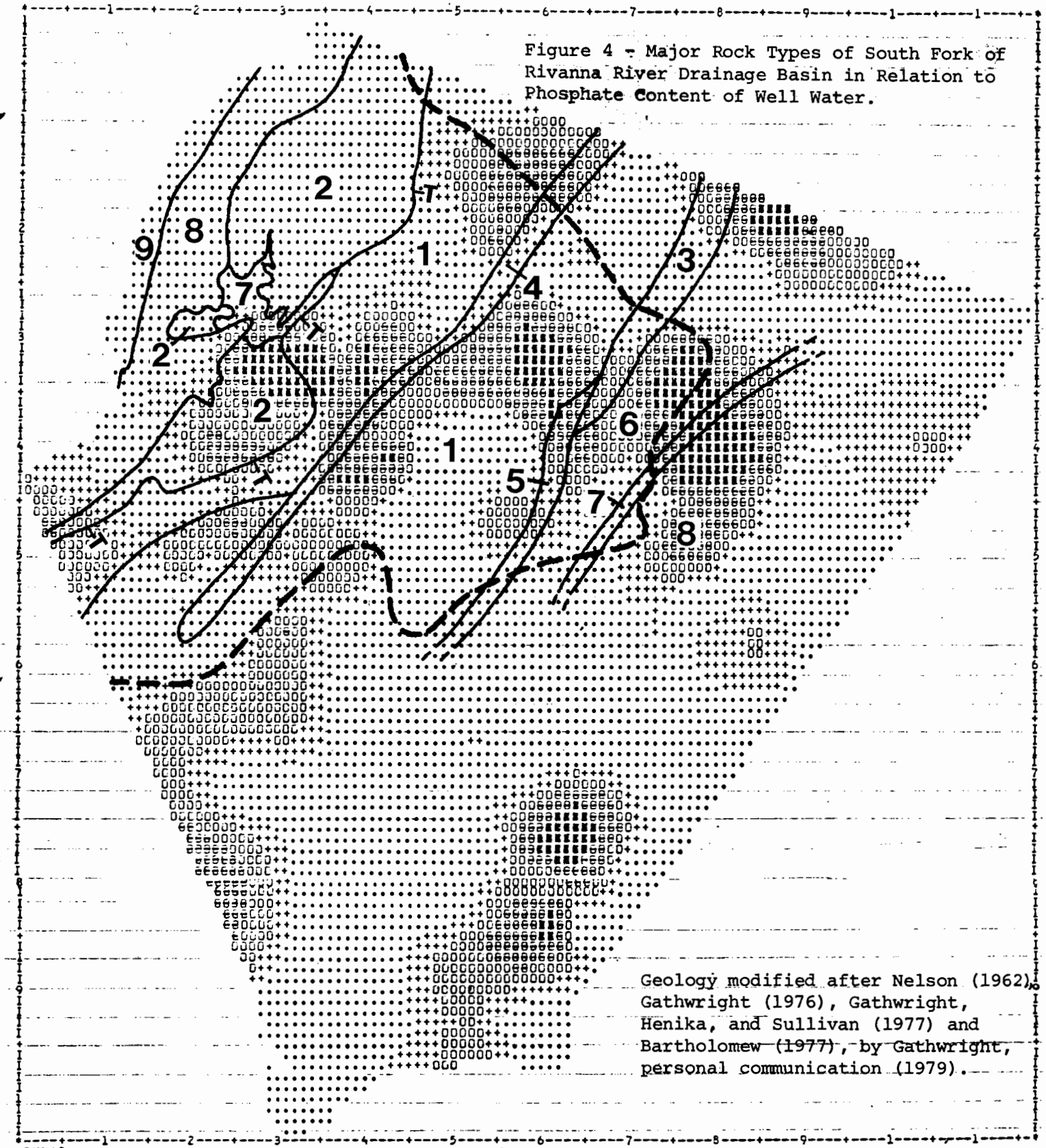

Figure 4 - Major Rock Types of South Fork of Rivanna River Drainage Basin in Relation to Phosphate Content of Well Water.

Geology modified after Nelson (1962), Gathwright (1976), Gathwright, Henika, and Sullivan (1977) and Bartholomew (1977), by Gathwright, personal communication (1979).

SYMAP

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
(↑MAXIMUM↑ INCLUDED IN HIGHEST LEVEL ONLY)

WATER WELL DATA FOR ALBEMARLE COUNTY, VIRGINIA

ORTHO-PHOSPHATE IN WATER IN PARTS PER MILLION

CONTOUR INTERVALS SELECTED BY COMPUTER PROGRAM

MINIMUM	0.00	.01	.02	.04	.08
MAXIMUM	.01	.02	.04	.08	.16
SYMBOLS	....1....	++++2++++	000030000	000040000	■■■■5■■■■
	.....	+++++++++	000000000	000000000	■■■■■■■■■
	.....	+++++++++	000000000	000000000	■■■■■■■■■
FREQ.	95	6	20	17	16

Fig. 4 Major Rock Types in Drainage Basin

Cambrian	9 -	Harpers and Weverton Formations: quartz-chlorite-sericite phyllite sandstone ferruginous quartzite
Late Precambrian	8 -	Catoctin Formation: chlorite-albite schist (greenstone) actinolite-chlorite schist (greenstone) amygdaloidal metabasalt epodote quartz breccia phyllitic metatuff lithic sandstone and phyllite
Late Precambrian	7 -	Swift Run Formation: quartz sericite schist quartz-sericite-chlorite schist schistose lithic sandstone
Late Precambrian	6 -	Lynchburg Formation: quartz biotite gneiss graphitic schist sericite schist greywacke meta siltstones pyritic slate
Late Precambrian	5 -	Rockfish conglomerate: coarse sandstone boulder conglomerate
Late Precambrian	4 -	Mechum River Formation: phyllite schist conglomerate greywacks slate
Late Precambrian	3 -	Robertson River Formation: hornblende quartz monzonite
Late Precambrian	2 -	Pedlar Formation: granodioritic granulite gneiss

Late
Precambrian 1 - <u>Lovingston Formation</u>:

augen gneiss
granitic gneiss
biotite gneiss
biotite schist
cataclastic gneiss
amphibolite

Rockfish Valley Fault

Abundance of Phosphorus in Rocks of Albemarle County

Eight whole rock analyses from Albemarle County show concentration of phosphorus to be 567-1833 ppm. (Table 1) The average phosphorus concentration of these rocks is 1145 ppm, which is very close to the world average for igneous rocks, 1134 ppm (Le Maitre, 1976). World abundances for phosphorus in various rock types are listed in Appendix for comparison.

Table 1 Phosphorus in Albemarle County Rocks

Rock Type	PPM Phosphorus
Hypersthene granodiorite[1]	1833
Metabasalt, Catoctin Formation[2]	1353
Diabase, Triassic[3]	698
Diabase, Triassic[4]	1265
Diorite[5]	1091
Diorite, weathered[6]	1265
Phyllite, Swift Run[7]	567
Phyllite, Mechum River[8]	1091
mean =	1145
range	567-1833

1. SE foot of Blue Ridge, Browns' Gap, Geolog. Soc. Am. Bull. 27, Watson & Cline (1916)

2. 1.5 miles west of Carter's Bridge
   Watson (1923), Econ. Geol., v. 18, p. 738

3. Esmont Quadrangle, U.S. Geol. Surv. Bull. 29
   Roberts (1928)

4. Alberene Quadrangle, U.S. Geol. Surv. Bull. 29
   Roberts (1928)

5. North Garden, Merrill (1897)
   Washington, U.S. Geol. Surv. Prof. Paper 99, p. 1003

6. North Garden, Merrill (1897)
   Furcron's source for both #7 and #8.

7. Charlottesville East Quadrangle, Furcron, A. 8. (1969)
   Georgia Geol. Surv. Bull. 80, p. 57-88
   U.S. Highway 250 at Marshall St.

8. Crozet Quadrangle, U.S. Highway at Mechum River.

Phosphate Mineralogy

There are more than 200 species of phosphate minerals, most are rare. At least 25 phosphate minerals have been reported for Virginia (Dietrich, 9170; Mitchell and Bland, 1963,1964). By far the most abundant (probably more than 95%) mineral is fluorapatite Ca_5 (F, OH, Cl) $(PO_4)_3$ which occurs in small amounts in igneous and metamorphic rocks of the Blue Ridge and in several pegmatites in the west and central western part of the Piedmont (Dietrich, 1970, p.52). Gathwright, Henika, and Sullivan, 1977) report apatite in thin sections of mylonitic biotite gneiss collected from the Lovingston Formation, the granodiorite of the Pedlar Formation, and metadiabase dikes and sills located western Albemarle County. Quantitatively the bulk of the remaining phosphate is probably found in local zones of dispersed traces of xenotime,(YPO_4) and monazite,(Ce, La, Y, Th) PO_4 in pegmatites and granitic rocks.

A small occurrence of weinschenkite (Y, Er) $PO_4 \cdot 2H_2O$ has been noted in Albemarle County west of Charlottesville, as thin white crusts on weathered, augite-rich dike rocks (R. S. Mitchell, in Dietrich 1970, p. 291) but its contribution is negligible because of its very restricted occurrence.

A rare apatite-ilmenite dike rock, nelsonite, which contains up to as much as 25% apatite (Moore, 1940; Fish and Swanson, 1964) occurs in small, local pods in nearby Nelson and Amherst counties, but no enrichments of this type are known within the Rivanna River drainage basin.

Summary

On the basis of available geochemical and geological data there is no relationship between the abundance of phosphate in ground or surface waters to rock types exposed within the South Fork of the Rivanna River watershed. Although it is the ultimate source of phosphorus, apatite-bearing rock contributes very little phosphate to the Sugar Hollow, Beaver Creek Dam, Ragged Mountain, and South Fork Rivanna River reservoirs.

The major sources of phosphorus are natural organic and man-made, the latter mostly from fertilizer runoff, detergents, seeping septic tanks or raw sewage. A minor portion of this is from industrial waste. The phosphorus contribution from the weathering of various rock types is of neglible importance to algae buildup in public water supplies of the South Fork of the Rivanna River basin.

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Appendix 1, General Abundance of Phosphorus in Rocks

Igneous	Rocks	PPM Phosphorus
1.	Igneous rocks, mean of 25,924 samples from world (Le Maitre, 1976)	1134
2.	Granite, mean of 2485 samples from world (Le Maitre, 1976)	523
3.	Granodiorite, mean of 885 samples from world (Le Maitre, 1976)	785
4.	Quartz monzonite (adamellite) mean 135 samples (Le Maitre, 1976)	829
5.	Quartz diorite, mean of 97 samples, world (Le Maitre, 1976)	1091
6.	Diorite mean of 872 samples (Le Maitre, 1976)	1266
7.	Gabbro, mean of 1451 samples (Le Maitre, 1976)	1047
8.	Diabase, mean of 405 samples	1091
9.	Anorthosite, mean 109 samples (Le Maitre, 1976)	392
10.	Pyroxenite, mean 133 samples (Le Maitre, 1976)	1658

Volcanic Rocks

1.	Rhyolite, mean 670 samples, world (Le Maitre, 1976)	305
2.	Andesite, mean 2600 samples world (Le Maitre, 1976)	980
3.	Basalt, mean 3594 samples, world (Le Maitre, 1976)	1528
4.	Metabasalt, Catoctin Formation Blue Ridge, central Virginia, mean 17 samples (Reed, 1964; Reed, 1955; Reed and Morgan 1971)	1397

Sedimentary Rocks

1.	Sedimentary rocks (Van Wazer 1961)	400
2.	Average shale (Rankamo and Sahama, 1950)	740
3.	Shale, mean 51 Paleozoic samples (Clarke, 1924)	655

Sedimentary Rocks (cont)

4. Precambrian slate, mean 33 samples (Nanz, 1953).....611

5. Mississippi delta sediment, mean 235 samples (Pettijohn, Potter, and Siever, 1972).....786

6. Sandstone, average, compoiste 253 samples (Pettijohn, Potter, and Siever, 1972).....349

7. Quartzite (quartz arenite), 26 samples; no value given (Pettijohn, Potter, Siever, 1972).....very low?

8. Arkose mean of 20 samples (Pettijohn, 1963).....436

9. Greywacke, mean 61 samples (Pettijohn, 1963).....872

10. Lithic arenite, mean 20 samples (Pettijohn, 1963).....436

11. Ferruginous quartzite, mean 16 samples (Joplin, 1963, 1975).....758

12. Stream sand, Oregon River (Whitten, 1966).....1091

13. Cherty rocks, Monterey Formation (Pettijohn, 1963).....916

14. Red clay (Rankama and Sahama, 1950) (Clarke, 1924).....1400

Metamorphic Rocks

1. Metamorphic rocks, mean (Green, 1959).....954

2. Felsic granulites, Australia, mean 28 samples (Joplin, 1963, 1975).....1546

3. Mafic granulites, Australia, mean 21 (Joplin, 1963, 1975).....1502

4. Amphibolite, hornblende schist hornblende gneiss, mean 72 samples, Australia (Joplin, 1963, 1975).....934

5. Amphibolite, maximum (Joplin, 1963, 1975).....3709

6. Quartz mica shcist, mean 23 samples (Joplin, 1963, 1975).....458

7. Pyllites, average 51 samples (Joplin, 1963).....1571

Appendix 2, Phosphorus Abundance in Living Systems

		PPM Phosphorus
1.	Bacteria, range (Boresch, 1935)	13,000-22,000
2.	Bacteria, average	15,000
3.	Fungi, range	3,000-25,000
4.	Fungi, average (Boresch, 1935)	10,000
5.	Algae, range (Boresch, 1935)	400-8,000
6.	Flowering plants, range	200-10,000
7.	Flowering plants (mean) (Boresch, 1935)	3,000
8.	Tree (Beech, F. sylvatica), dry weight (Eckerman, 1924)	
	root wood	170
	root bark	220
	trunk wood	110
	trunk bark	650
	branches	220-700
	leaves	1,300
	buds	2,300
9.	Tree (Pine, P. silvestris), dry weight (Eckerman, 1924)	
	root bark	330
	trunk wood	47
	trunk bark	300
	branches	50-620
	needles	
10.	Bones (Skeletal remains), dry weight (Klement, 1938)	
	mammals	185,500
	birds	180,100
	fishes	184,600
	reptile	169,800
	amphibia	162,700

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