UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ESTIMATED AVERAGE ANNUAL ALKALINITY OF SIX STREAMS ENTERING DEEP CREEK LAKE GARRETT COUNTY, MARYLAND

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ABSTRACT

Deep Creek Lake in Garrett County, Maryland drains an area of about 65 square miles. There is concern that acid rain combined with acid mine drainage from coal mining in the basin will exceed the capacity of the lake to buffer the acid input from these sources. This study was done during 1983 to determine the sources of alkalinity to the lake, and to make a rough estimate of the amount of alkalinity that enters the lake from six streams that drain carbonate and noncarbonate bedrock formations.

Bedrock in the basin is predominantly sandstone and shale of Devonian to Pennsylvanian age. The Mississippian Greenbrier Formation, which crops out in 5 percent of the basin, is the only calcareous rock unit. Four streams draining the Greenbrier and two streams draining noncarbonate formations were sampled to assess the contribution of alkalinity to Deep Creek Lake. The average annual alkalinity of six sampled streams ranged from 7.6 to 36.8 tons per year per square mile of drainage area. The average total alkalinity contributed to Deep Creek Lake by these streams is 161 tons per year as calcium carbonate. Mass-balance calculations based on very limited data indicate that this alkalinity is derived from both carbonate rocks (Greenbrier Formation) and from weathering and hydrolysis of silicate minerals. Other sources may contribute alkalinity to Deep Creek Lake, but could not be quantified within the scope of this study.

No changes in stream water quality were found that could be directly attributed to the stream having crossed the boundary from one noncarbonate bedrock formation to another. Inflow to streams from adjacent or underlying carbonate bedrock was apparent in several streams from increased values of pH and conductance.

INTRODUCTION

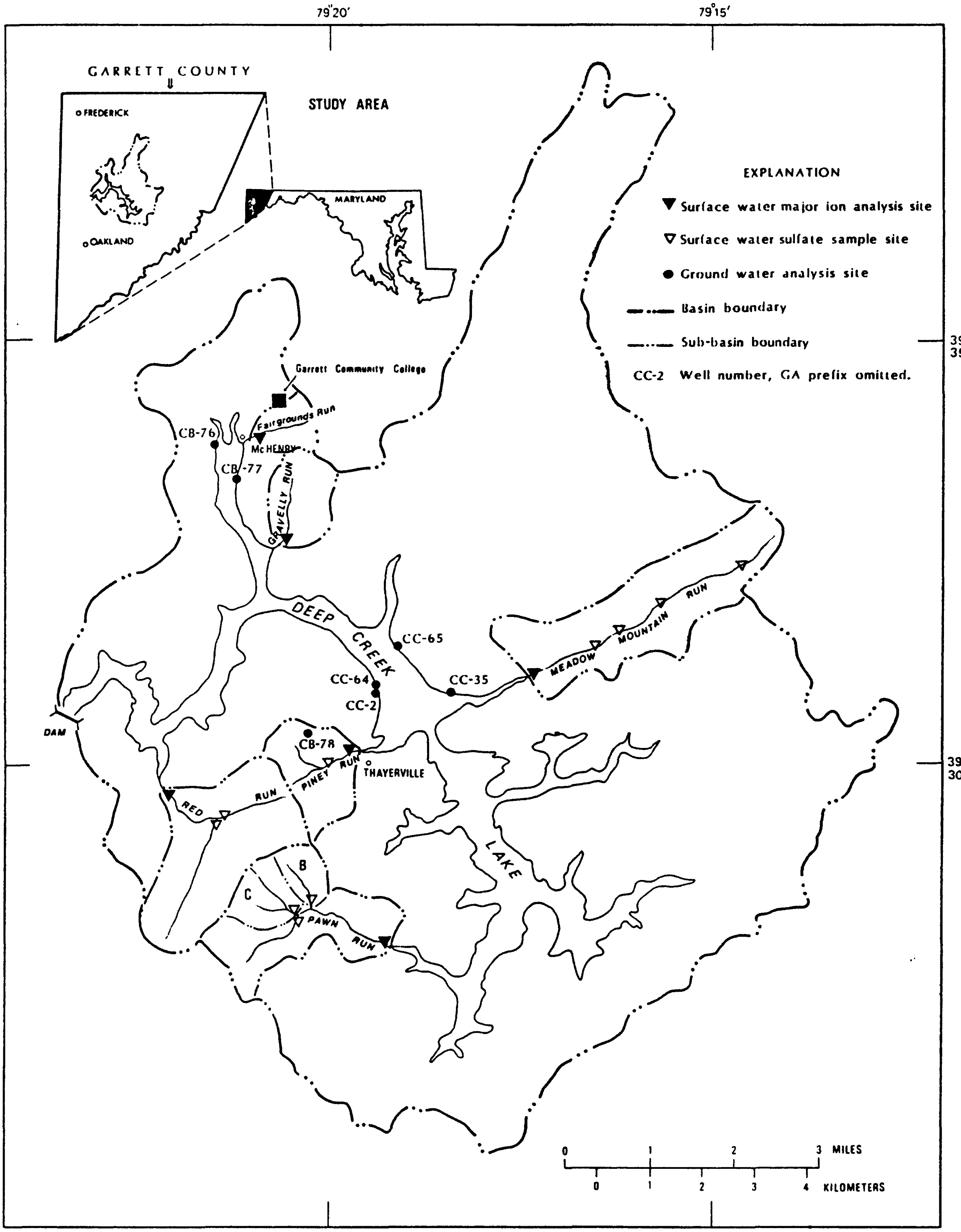
Study Background

There is concern that acid rain combined with acid mine drainage from coal mining will exceed the ability of Deep Creek Lake (fig. 1) to buffer the acid input from these sources. A study is presently being made by Martin Marietta Corporation, and Garrett Community College to determine the magnitude of these acid inputs. Preliminary results of their study show that, although the acid input is considerable, alkalinity in the lake has remained almost constant. Reports from this study include Scott and others (1982), Campbell and others (1983), Ferrier (1981), and Ferrier and Risoldi (1983).

The U.S. Geological Survey, in cooperation with the Maryland Power Plant Siting Program, has undertaken the study reported herein to investigate the contribution of alkalinity from the Greenbrier Formation to Deep Creek Lake. This formation is the only bedrock in the drainage basin of the lake that contains limestone (carbonate).

Purpose and Scope

Specific objectives of this report are to (1) describe the chemical quality of base flow in streams that drain the Greenbrier Formation, (2) make a rough assessment of the amount of alkalinity contributed by the Greenbrier Formation to Deep Creek Lake, and (3) determine if changes in chemical quality of base flow occur when a stream crosses several geologic formations. Six streams that enter Deep Creek Lake were selected for study in order to meet the above objectives. Four of the streams drain the Greenbrier Formation; one stream drains the Mauch Chunk Formation that directly overlies the Greenbrier Formation and was reported by Ferrier (1981) to contain alkalinity values above those of other noncarbonate formations; and one stream drains the Jennings, Hampshire, and Pocono Formations. The investigation included 648 in-stream measurements of temperature, conductivity and pH at 216 sites, 28 field determinations of alkalinity, and 18 streamflow measurements. Water samples from six streams and five ground-water wells were analyzed for major ions by the U.S. Geological Survey laboratory in Doraville, Ga.



BASE IS MARYLAND GEOLOGICAL SURVEY, 1:62,500 GEOLOGIC MAP OF GARRETT COUNTY

Figure 1.-- Location of study area, stream basins, and sampling sites.

Other streams entering Deep Creek Lake, including Cherry Creek which contains acid mine drainage, were not included in this study. These other streams are, however, included in the Garrett Community College study of acid input to the lake.

Physiographic Setting

Garrett County is the westernmost county of Maryland, and is in the Appalachian Plateau physiographic province of the Appalachian Highlands division of North America. Deep Creek Lake, in central Garrett County, has an area of approximately six mi^2 (square miles). The lake was formed in 1924 when a dam was constructed on Deep Creek by the Pennsylvania Electric Company as a water source for hydroelectric power generation. The dam impounds runoff from a 65 mi^2 area (fig. 1), which is mostly forested. Land use in the drainage basin includes recreation, agriculture, and mining of both coal and limestone.

Precipitation

Average annual precipitation measured by the National Weather Service (NOAA) at Oakland, Md., about 10 miles southwest of Deep Creek Lake, is 47.11 in. (inches) for 1941-1970. Average monthly precipitation ranges from 2.91 in. in October to 4.78 in. in July. March through August are the normally wetter months of the year, providing 57 percent of annual precipitation. September through February are somewhat drier, providing the remaining 43 percent of the yearly total.

Previous Studies

Previous geologic studies of the Deep Creek Lake area are reported in Clark and others, 1902a,b; Amsden, 1953; and Amsden and others, 1954. Nutter and others, 1980, presented a compilation of water-well records, chemical-quality data, ground-water use, coal test-hole data and surface-water data in Garrett County. This last report also includes a section on gas-well records in Garrett County compiled by Schwarz and Edwards. Numerous studies have been made that relate the chemical quality of stream water to the geology of the stream basin. A selected bibliography of these reports, and other studies that provide background for the methods used in this study, are given in Appendix I. No previous work is known in which average annual alkalinity loads of streams have been calculated.

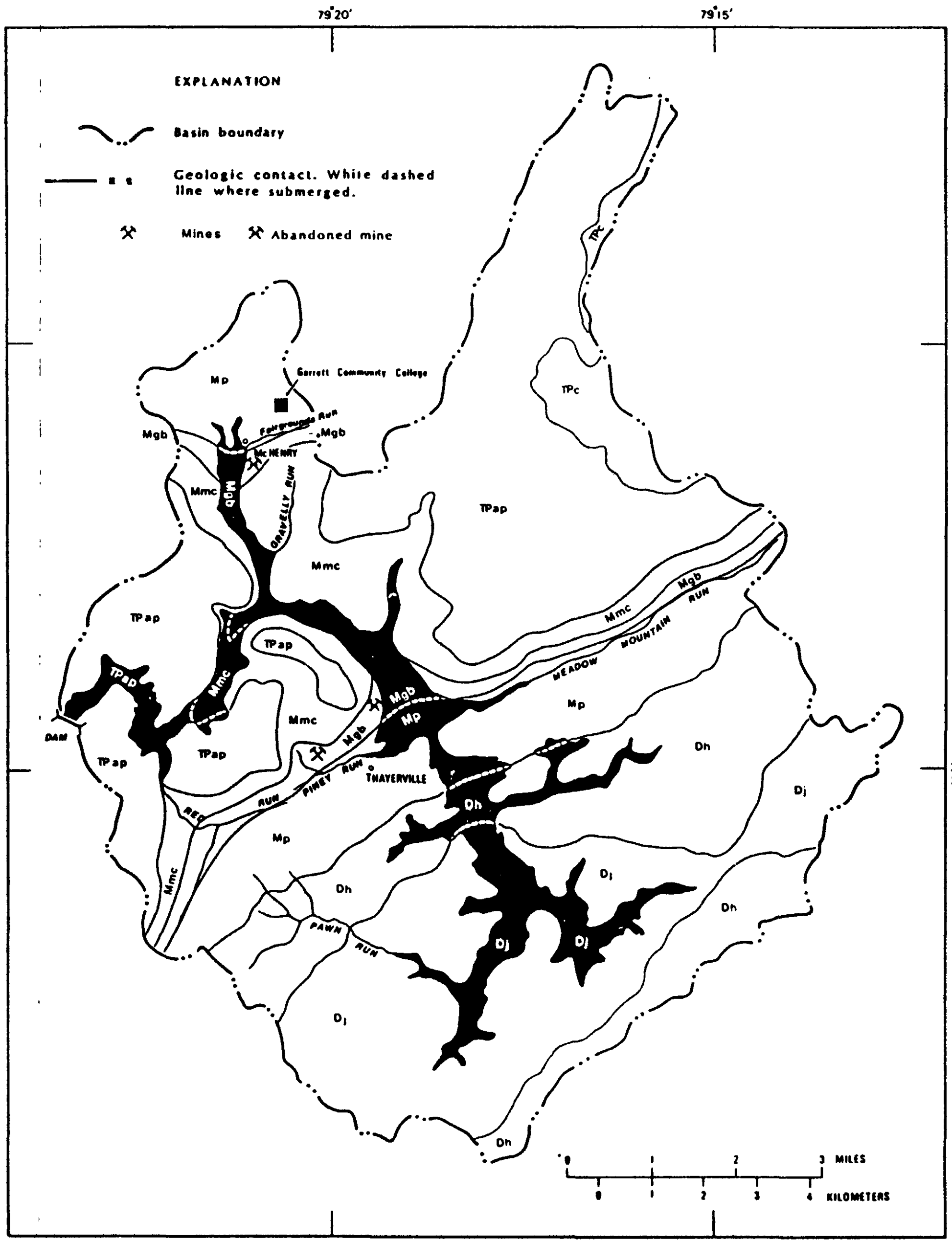
Geologic Setting

Bedrock of the Deep Creek area is consolidated sedimentary rock of Late Devonian, Mississippian and Pennsylvanian age. Seven formations crop out in the area, most of which are sandstone, siltstone, and shale. Thickness of these formations is estimated to be 9300 ft (feet) (Amsden, 1953). The bedrock formations of the Deep Creek Lake area are briefly described on figure 2, and the percentage of total outcrop area of each of these formations is:

	Outcrop area as a percentage of the drainage basin
Conemaugh, Allegheny, and Pottsville Formations	32
Jennings Formation	20
Hampshire Formation	18
Pocono Formation	14
Mauch Chunk Formation	11
Greenbrier Formation	5

Unconsolidated material overlying bedrock is from 20 to 40 in. thick over most of the area (Stone and Matthews, 1974), but the depths to bedrock are greater in peat bogs and alluvial channels. Almost all of the soils are described by Stone and Matthews as acidic to extremely acidic which are in the range of pH 4.0 to 6.0.

The Greenbrier Formation is the only formation in the area containing a significant percentage of carbonate rock. It may, therefore, be a major source of alkalinity in the hydrologic system. The lower member of the Greenbrier Formation, the Loyalhanna Limestone Member, is a dense gray limestone which has been extensively quarried and mined for agricultural and road-building purposes. Limestone from the Loyalhanna is presently being mined about 0.6 mi (miles) west-northwest of Thayerville by the Browning Limestone Company. The underground workings are about 2000 ft wide along the strike of the formation and about 1500 ft downdip. Only one water-bearing fracture, which produces



BASE IS MARYLAND GEOLOGICAL SURVEY, 1:62,500 GEOLOGIC MAP OF GARRETT COUNTY

Figure 2. -- Geologic map of the Deep Creek Lake area.
(Modified from Amsden, 1953 and Clark, 1902.)

DESCRIPTION OF MAP UNITS

Pennsylvanian

TPc — CONEMAUGH FORMATION

Includes strata between top of Upper Freeport coal bed and base of Pittsburg coal bed. Predominantly gray and brown claystone, shale, siltstone, and sandstone; part below Barton coal bed characterized by several red beds, calcareous claystone and fossiliferous marine shales. Thickness 825 to 925 feet.

TPap — ALLEGHENY FORMATION and POTTSVILLE FORMATION, UNDIVIDED

Allegheny and Pottsville Formations, mapped together as a stratigraphic unit, comprise those beds between top of Mauch Chunk Formation and top of Upper Freeport coal bed. Lower part of Pottsville Formation consists of medium- to coarse-grained sandstone, commonly conglomeratic at its base; upper part of Pottsville and Allegheny Formations composed of interbedded sandstone, siltstone, claystone, shale, and coal beds. Thickness 300 to 600 feet.

Mississippian

Mmc — MAUCH CHUNK FORMATION

Brown to greenish-brown, fine-grained, micaceous sandstone, and red and green to greenish-brown shale; sandstone typically thin-bedded (less than 3 inches) and cross-bedded. No fossils observed. Thickness 500 to 700 feet.

Mgb — GREENBRIER FORMATION

Calcareous shale and sandstone, and argillaceous and arenaceous limestone. Lower part gray to red, cross-bedded, arenaceous limestone (Loyalhanna Limestone Member). Upper part calcareous shale and sandstone, typically red, interbedded with greenish-gray to reddish-gray, argillaceous limestone. Marine fossils common above the Loyalhanna Member. Thickness 200 to 300 feet.

Upper Devonian

Mp — POCONO FORMATION

Strongly cross-bedded, platy sandstone with some siltstone and shale; sandstone commonly medium-grained, but may be coarse or conglomeratic; weathered color dominantly gray or brown, but some beds red and reddish-brown. Fragmentary plant fossils observed. Hampshire-Pocono contact gradational. Thickness 700 to 1,200 feet.

Dh — HAMPSHIRE FORMATION

Interbedded red and reddish-brown (rarely green) sandstone, siltstone, and shale; sandstone and siltstone beds commonly cross-bedded. No fossils observed. Contact with Jennings Formation and with Pocono Formation gradational. Thickness 1,400 to 2,000 feet.

Dj — JENNINGS FORMATION

Interbedded yellowish-gray, brown, and olive-brown shale, siltstone, and sandstone, with a few conglomerate beds; typically evenly bedded. Marine fossils common, generally preserved as internal and external molds. Contact with Hampshire Formation gradational; base not exposed. Estimated thickness 4,000 to 5,000 feet.

3-5 gal/min (gallons per minute), has been intersected in this mine thus far. Some solution enlargement of joints and bedding planes in the Loyalhanna Limestone Member is exposed in the east end of an inactive quarry which is about 0.7 mi north of Thayerville. At this location the top of the Loyalhanna is probably within 25 ft of undisturbed ground surface.

The unnamed upper member of the Greenbrier Formation is a red to gray calcareous shale and sandstone. Exposures in local quarries show that the upper member weathers much more rapidly than the Loyalhanna Limestone Member. Joints and bedding planes in an 8-10 foot-thick calcareous sandstone within the upper member are commonly enlarged by solution.

The most recent geologic map of Garrett County (Amsden, 1953) does not delineate the geology below the surface of Deep Creek Lake. A previous map prepared by Clark and others (1902a), however, shows the Greenbrier Formation cropping out below the spillway elevation of the lake from Thayerville to McHenry. The extent of this outcrop, now below the lake surface, is about 1.27 mi^2. All other outcrops of the Greenbrier Formation in the drainage area of Deep Creek Lake are about 2 mi^2.

Hydrologic Setting

Characteristics of the six stream basins investigated for this study (fig. 1) follow:

Unnamed drainage at McHenry (Fairgrounds Run): - This drainage is unnamed on recent topographic maps. Because it enters Deep Creek Lake from the Garrett County Fairgrounds, it is referred to informally in this report as Fairgrounds Run. The stream has a length of 0.9 mi and drains an area of 0.41 mi^2. Approximately 34 percent of the drainage area lies in the Greenbrier Formation. Land use within the basin includes residential, agricultural, institutional, and commercial activities. The basin is predominantly open field and pastureland, with some sparse woodland.

Gravelly Run: - This stream has a length of 1.2 mi and drains 0.70 mi^2. About 150 acres of the headwaters of Gravelly Run are open agricultural land. The remainder of the basin is a densely wooded residential area. The Greenbrier Formation does not crop out in the drainage area, but directly underlies the Mauch Chunk Formation in which Gravelly Run is developed.

Meadow Mountain Run: - The length of this stream is 3.5 mi, and its drainage area is 2.86 mi^2. The Greenbrier Formation crops out along the north side of the stream, and comprises 17.5 percent of the drainage basin of Meadow Mountain Run. The basin is predominantly forested but there is minor residential development near the mouth of the stream and along the southern basin boundary. Numerous beaver dams form ponds along the stream and a 50-acre swamp occurs within the upper half of the basin.

Pawn Run: - This multi-branched stream has a length of 2.3 mi and a drainage area of 2.14 mi^2. Land use is agricultural and residential; about half of the basin is forested, and the remainder is open fields. Pawn Run drains across three geologic units: the Jennings, Hampshire, and Pocono Formations. The Jennings Formation occupies about 18 percent of the lowermost part of the basin. The Hampshire Formation underlies the central 64 percent of the basin, and the Pocono Formation occupies the remaining 18 percent of the drainage area. Two branches of the stream drain the Hampshire and Pocono Formations, and the main stem of Pawn Run drains the Hampshire and Jennings Formations.

Red Run: - This stream, which drains Hammel Glade, has a length of 2.7 mi and a drainage area of 2.44 mi^2. Hammel Glade is a swamp of about 250 acres in the center of a roughly triangular shaped drainage basin. The basin is predominantly forested; the remainder is cultivated fields. Residential land use is restricted to the margins of the basin. Hammel Glade lies on top of the Greenbrier Formation, which comprises 24 percent of the drainage area.

Piney Run: - This stream is not shown or named on recent topographic maps, but the name "Piney Run" is used locally. The length of the stream is 1.4 mi and the drainage area is 0.96 mi^2. About half of the basin is forested, and the remainder is open land used for agriculture or mining. The Greenbrier Formation underlies about 26 percent of the basin, and is presently mined extensively for use as agricultural limestone and construction material.

Ground-water basic data for Garrett County were reported by Nutter and others (1980). Table 2 of their report shows that wells in the Greenbrier Formation are 2-3 times more productive than wells in other geologic formations. Nutter reported the mean yield of 48 wells in the Greenbrier Formation to be 32.6 gal/min and the median yield to be 14 gal/min.

Two springs were reported by local residents to have been flooded by the filling of Deep Creek Lake. Both springs were in the Greenbrier Formation. The first spring entered Deep Creek about 0.4 mi south of McHenry, and the second about 0.2 mi south of Deep Creek Cemetery. The first was reported to have a large, constant flow, but the discharge of the second spring was reported to be variable. No descriptions of these springs were found in previous reports.

General Aqueous Chemistry

Buffering capacity refers to the ability of a solution to neutralize acid (Hem, 1970, p. 152). Alkalinity, which is a measure of this buffering capacity, may be determined by titrating a water sample with a standard solution of strong acid to a pH of 4.5. The alkalinity of many natural waters is due primarily to the presence of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions. These species neutralize acid (H^+ ions) according to the equations

$$CO_3^{2-} + H^+ \rightleftharpoons HCO_3^- \qquad (1)$$

and

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \qquad (2)$$

Because carbonate and bicarbonate ions are major contributors to alkalinity, it is common practice to express alkalinity in terms of an equivalent weight of calcium carbonate. According to this convention, alkalinity is defined as

$$\text{Alkalinity as } CaCO_3 \text{(mg/L)} = \frac{1000 \times 0.82 \times \text{volume of } 0.01639 \text{ N } H_2SO_4 \text{(mL)}}{\text{Volume of sample (mL)}} \qquad (3)$$

While alkalinity may be expressed in terms of calcium carbonate, other weak acids such as boric, phosphoric, and silicic acid may also contribute to the alkalinity of a water sample.

Alkalinity-producing carbonate and bicarbonate ions may be derived from congruent dissolution of carbonate rocks according to the equation

$$CaCO_3 + H^+ \rightleftharpoons Ca^{2+} + HCO_3^- \quad (4)$$

Alkalinity-producing bicarbonate ions may also be added to solution by the weathering of some non-carbonate rocks. The hydrolysis of silicate minerals produces bicarbonate according to the following generalized equations (Drever, 1982):

Plagioclase feldspar

$$1.77Na_{0.62}Ca_{0.38}Al_{1.38}Si_{2.62}O_8 + 2.44CO_2 + 3.67H_2O \rightleftharpoons \quad (5)$$

Kaolinite

$$1.23Al_2Si_2O_5(OH)_4 + 1.10Na^+ + 0.68Ca^{2+} + 2.44HCO_3^-$$

$$+2.20SiO_2$$

Potash feldspar

$$0.13KAlSi_3O_8 + 0.13CO_2 + 0.195H_2O \rightleftharpoons$$

(6)

Kaolinite

$$0.065Al_2Si_2O_5(OH)_4 + 0.13K^+ + 0.13HCO_3 + 0.26SiO_2$$

Biotite

$$KMg_3AlSi_3O_{10}(OH)_2 + 0.51CO_2 + 0.26H_2O \rightleftharpoons$$

(7)

Kaolinite

$$0.037Al_2Si_2O_5(OH)_4 + 0.073K^+ + 0.22Mg^{2+} + 0.15SiO_2$$

$$+0.51HCO_3^-$$

Noncarbonate rocks that contain feldspars and biotite outcrop in the Deep Creek Lake area. Therefore, silicate hydrolysis may also contribute alkalinity to the Deep Creek Lake hydrologic system. Finally, alkalinity may be generated by a variety of biologically-mediated oxidation reactions. For example, biodegradable organic material may be oxidized according to the generalized equation

$$CH_2O + O_2 \rightleftharpoons CO_2 + H_2O \qquad (8)$$

Carbon dioxide generated by this reaction may then dissociate to form bicarbonate

$$CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^- \qquad (9)$$

This bicarbonate may then contribute to the total alkalinity of a particular water.

Acknowledgments

Personnel of the Browning Limestone Co., and the Deep Creek Lake State Park (Maryland Department of Natural Resources) provided access and assistance during water sampling. Many landowners and residents provided access and historical data that were invaluable. D. Ferrier and M. Risoldi of Garrett Community College provided data on precipitation and Deep Creek Lake water chemistry.

METHODS OF STUDY

Geologic Investigation

The Greenbrier Formation was checked for outcrops, sinkholes, mines and prospects, by walking the entire surface outcrop area of the formation within the Deep Creek Lake drainage basin. This outcrop area (Amsden, 1953) was investigated during early May before vegetal masking of outcrop features occurred. Active and inactive limestone mines and quarries were investigated for structural and depositional features.

Additional geologic and hydrologic information was obtained from Brenneman Well Drilling Company, Accident, Md., Browning Limestone Company, contractors involved in sewerline construction around the lake, State Park personnel, farmers, residents, and businesses throughout the Deep Creek Lake basin. Results of the geologic investigation are incorporated in the preceding "Geologic Setting" section.

Hydrologic Investigation

Four of the streams selected for study (Fairgrounds, Meadow Mountain, Red and Piney Runs) drain the Greenbrier Formation. They were therefore included as potential contributors of alkalinity to Deep Creek Lake. Gravelly Run does not drain the Greenbrier Formation, but was included in the study because of the atypically high alkalinity reported by Ferrier (1981). Pawn Run, which drains three noncarbonate formations, was included in the study in order to determine if changes in water quality could be detected as a stream crossed different geologic formations.

Assessment of stream water quality was done by a two-man team that waded each stream from the mouth to that point in the headwaters at which streamflow became negligible. Measurements of temperature, pH, and conductance were taken each 0.1 mi where possible. Temperature, pH, and conductance are the most easily and rapidly measured water properties, and were therefore used as indicators of either constancy or change of stream water quality. A large change in any of these three properties between two consecutive sampling locations suggested that a significant amount of ground water was entering the stream between those points. The stream was then sampled for comparative alkalinity and sulfate analyses. Some reaches of Meadow Mountain, Pawn and Red Runs were not investigated because either dense vegetation or private property prevented access.

Water-Quality Sampling

Measurements of temperature, pH, and conductivity were made in the streams with a Hydrolab[1] multiparameter portable unit (identification no. W-379182). The unit was calibrated daily

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

against laboratory standard solutions. Samples for alkalinity and sulfate analysis were collected in hand-held 250-milliliter (mL) plastic bottles, triple rinsed in sampled water. Samples were taken in that part of the stream having the greatest velocity, using a depth-integrated sampling technique. Alkalinity was determined from the samples when the field party returned to the vehicle containing the titrating equipment. Fifty mL of unfiltered, untreated sample were titrated with 0.01639N sulfuric acid to an endpoint of pH 4.5 using an electromagnetic stirrer and a Sargent-Welch pH meter, model PBL (identification no. W-314659). Sulfate samples were filtered through a .45-micron membrane filter at this time, and prepared for shipment to the USGS Central Laboratory in Doraville, Georgia. Sulfate samples collected during May and June were incorrectly prepared for analysis, and therefore were discarded.

Each sample for major-ion analysis was collected by the following method. Ten 1-liter hand-dipped samples were taken as rapidly as possible across the stream, and composited in a 15-liter churn splitter. The water was thoroughly mixed, and the following sample bottles filled:

1. One 8-oz acid-rinsed plastic bottle, filtered (.45 micron filter), acidified with HNO_3.

2. One half-liter plastic bottle, filtered, untreated.

3. One half-liter acid rinsed plastic bottle, unfiltered, acidified with HNO_3.

4. One 8-oz dark-plastic bottle, unfiltered, $HgCl_2$ added, chilled, maintained at or below 4 degrees Celsius.

5. One 8-oz plastic bottle, unfiltered, chilled, maintained at or below 4 degrees Celsius.

6. One 8-oz plastic bottle, unfiltered, untreated.

These six samples of water were then packed in ice and shipped to the U.S. Geological Survey Central Laboratory in Doraville, Georgia for analysis.

The same major-ion analyses were performed on both ground water and surface water samples so that components of these two sources could be compared. Calcium, iron, magnesium, manganese, potassium, silica, and sodium are rock components, and concentration values of these cations is necessary for geochemical interpretation of the hydrologic system. Chloride, phosphate, and nitrate are indicators of non-geologic sources, and color is an indicator of organic material. Sulfate, in the Deep Creek area, may be attributable to precipitation, leachate from coal mining operations, agricultural application, or depositional inclusions within the Greenbrier Formation. Laboratory analytical methods, precision, and quality assurance procedures are fully documented in Skougstad and others (1979).

Flow measurements were made at the mouth of each stream, or at the first suitable measuring section located above that point. Some additional flow measurements were made in Meadow Mountain and Pawn Run. All flow measurements except one were made using a wading rod and a Price pygmy meter (identification no. 8009303). Measurements were made at 0.2 and 0.8 of the depth below the water surface at water depths greater than 1.5 feet. In shallower water, a single measurement was made at 0.6 of the depth below the water surface. Not less than 25 vertical profiles were made at each site equally spaced along a line perpendicular to the direction of stream flow. This method of flow measurement is described by Rantz (1982). Measurement of flow in Fairgrounds Run in August was made with a stopwatch and calibrated bucket.

Mass-Balance Computation

The amount of alkalinity that each source contributes to Deep Creek Lake cannot be precisely determined with the limited data that are available. However, rough estimates of alkalinity contribution from silicate hydrolysis and carbonate rock dissolution may be made based on mass-balance calculations. A chemical mass-balance calculation (Garrels and MacKenzie, 1967), is a budget showing sources from which dissolved constituents in a water are derived. The general equation describing this type of chemical mass balance is (Drever, 1982)

$$\text{Rock + atmospheric input = altered rock + solution} \qquad (10)$$

Because the mineralogy and chemical composition of rocks and altered rocks in the Deep Creek Lake area are not precisely known, a unique mass balance of the hydrologic system is not possible. In addition, this technique cannot evaluate the relative contribution of biological activity to alkalinity. In view of these limitations, the approach taken in this report is to assume average mineral compositions of rocks (equations 4, 5, 6, and 7) and assume that kaolinite is the predominant weathering product of silicate hydrolysis (equations 5, 6, and 7). An example of how mass-balance calculations may be used to estimate the source of chemical components of stream water is shown in table 1.

Table 1.--Sample Mass-Balance Calculation

Stream: <u>Meadow Mountain Run</u>

$$0.06\ \text{Biotite} + 0.31\ CO_2 + 0.16H_2O \rightleftharpoons 0.022\ \text{Kaolinite} + .044K^+ + 0.13\ Mg^{2+} + 0.09\ SiO_2 + 0.31\ HCO_3^-$$

Water Composition

(Millimoles per liter)

PROCESS		SiO_2	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	PO_4^{2-}	K^+	Na^+
Anal.from table 4		.09	.48	.05	.10	.24	.05	-	.02	.06
Rainfall 1/	(-)	-	-	.02	.04	.01	-	-	-	.02
	Remainder	.09	.48	.03	.06	.23	.05	-	.02	.04
Biotite	(-)	.09	.31	0	0	0	.13	-	.04	-
	Remainder	0	.17	.03	.06	.23	-.08	-	-.02	.04
Gypsum	(-)	0	0	0	.06	.06	-	-	-	-
	Remainder	0	.17	.03	0	.21	-.08	-	-.02	.04
Calcite	(-)	-	.17	-	-	.17	-	-	-	-
	Remainder	0	0	.03	0	.04	-.08	-	-.02	.04
Road Salt	(-)	-	-	.03	-	-	-	-	-	.03
	Remainder	0	0	0	0	.04	-.08	-	-.02	.01

1/ Peters and Bonelli, 1982.

$$\text{Limestone alkalinity} = \frac{HCO_3^- \text{ from calcite}}{\text{Total } HCO_3^-} \times 100 = \frac{.17}{.48} \times 100$$

Therefore, limestone alkalinity = 35%
silicate alkalinity = 65%

Computation of Alkalinity Contribution of Project Streams

Alkalinity contributed to Deep Creek Lake by the six project streams was estimated from data collected during this study, long-term streamflow data, and data collected by Garrett Community College (Ferrier, 1981). The method used in these calculations is described by Toler (1982), and includes the following steps:

1. Graphs were constructed of alkalinity as $CaCO_3$ (mg/L) versus flow in $(ft^3/s)/mi^2$ for both Garrett Community College and USGS data for each of the six project streams. Data were plotted on log-log paper, and a best-fit straight line was drawn through the data points by visual inspection (fig. 3).

2. Daily flow durations of percent time versus flow in $(ft^3/s)/mi^2$ were plotted for the following stations:

    Youghiogheny River near Oakland, Md
    Youghiogheny River at Friendsville, Md.
    Bear Creek at Friendsville, Md.
    Casselman River at Grantsville, Md.

A generalized curve was then drawn by visual inspection that best represented the average of all four curves. (fig. 4).

3. Discharge in $(ft^3/s)/mi^2$ was determined from the generalized flow duration curve for the midpoints (column 3) of the percent-time intervals shown in column 1 of table 2, which uses Fairgrounds Run as an example. Values for this computation are given in column 4 of this table.

4. At each of the values in column 4, a corresponding value of alkalinity (column 5) was picked from each of the graphs prepared in step 1.

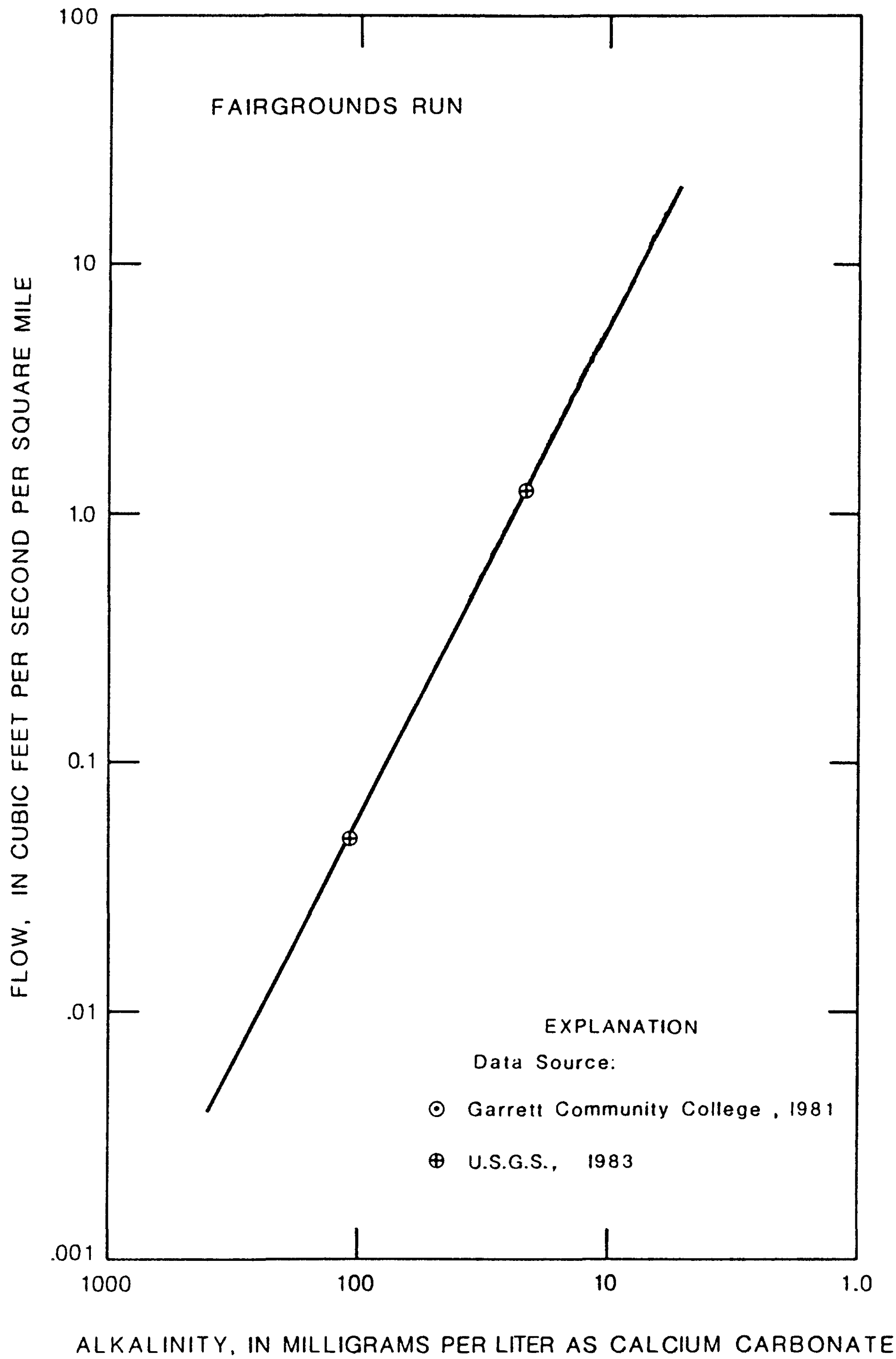


Figure 3. -- A, Alkalinity versus flow in project streams.

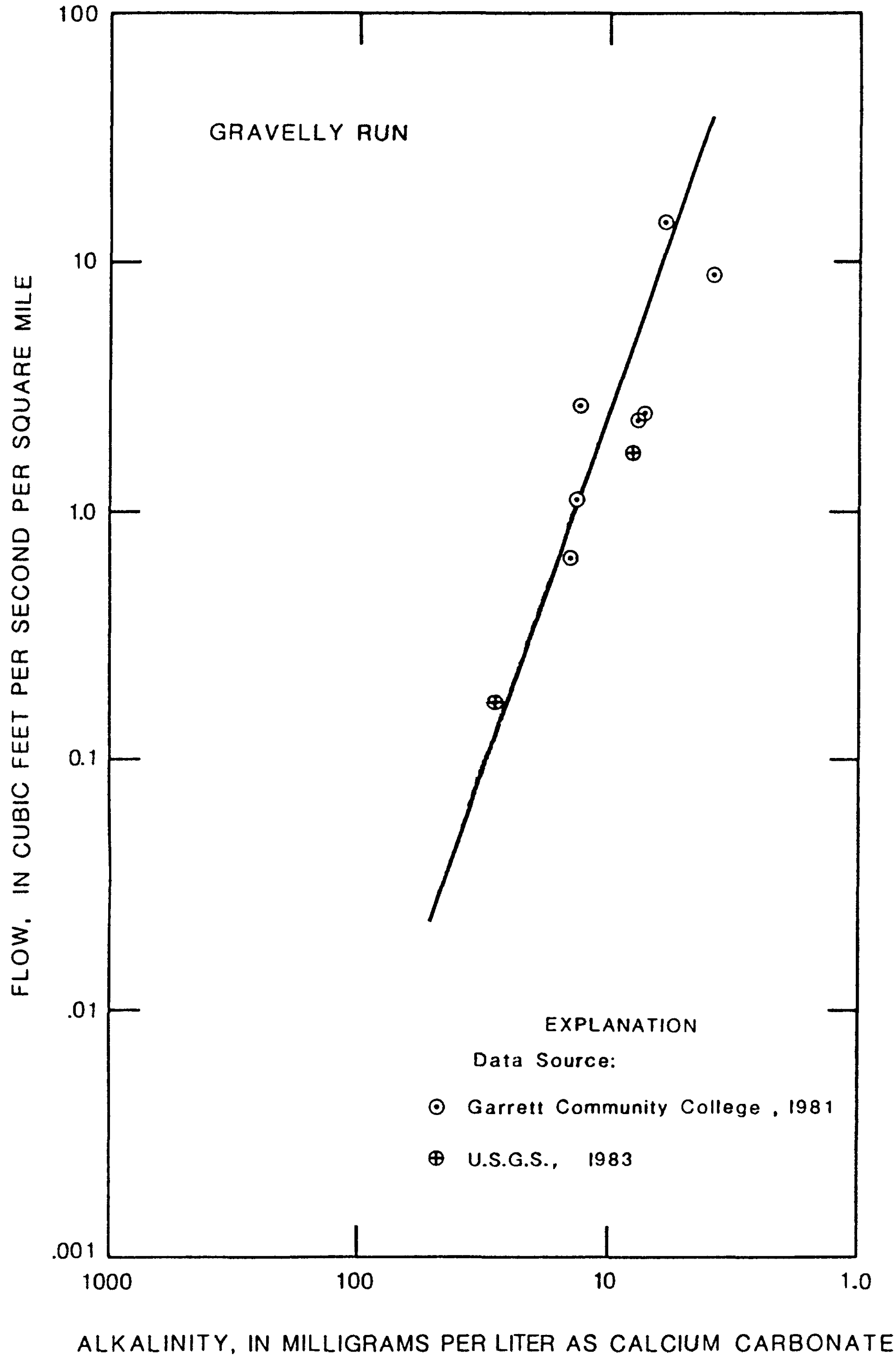


Figure 3. continued -- B.

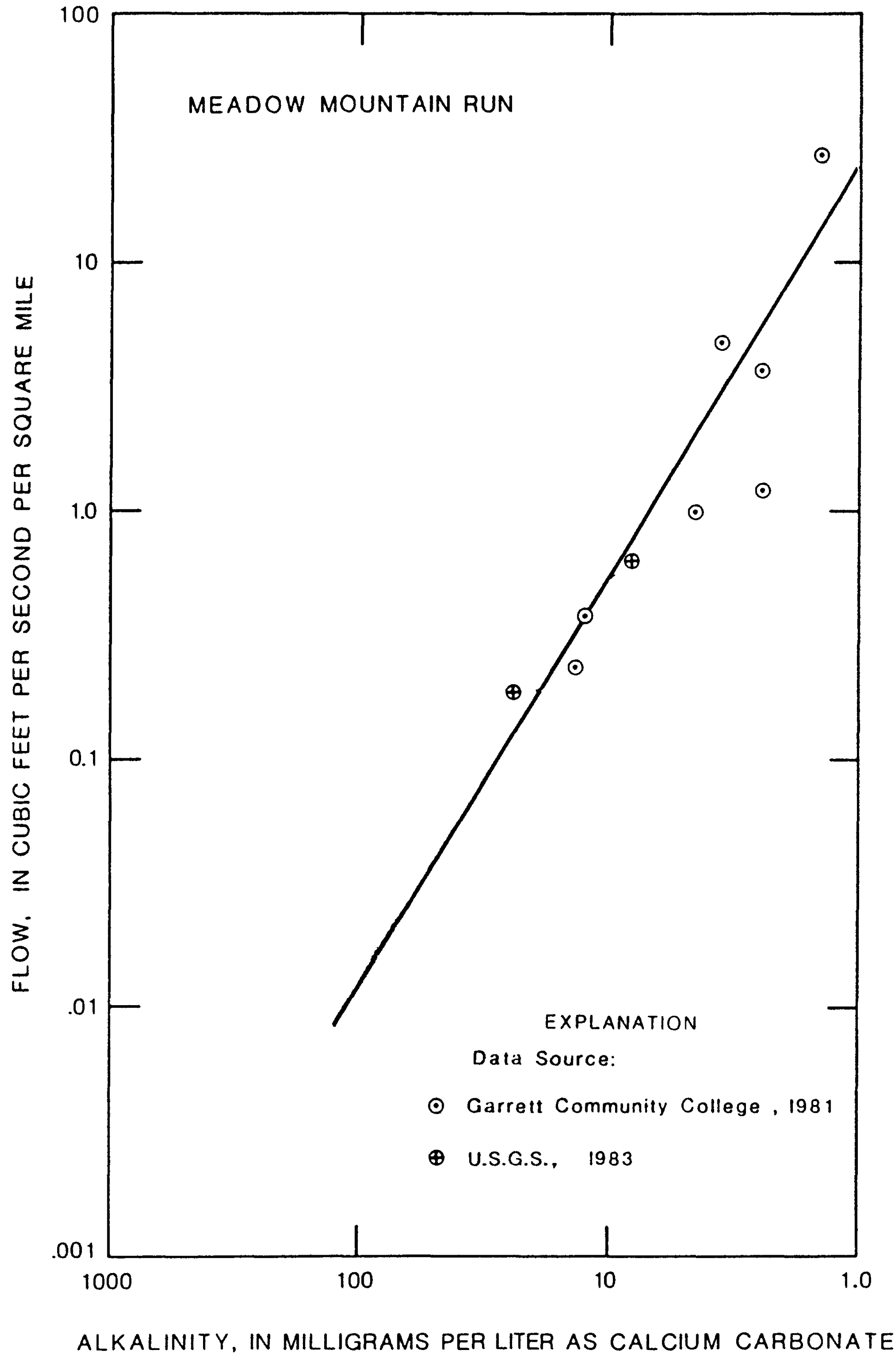


Figure 3 continued -- C.

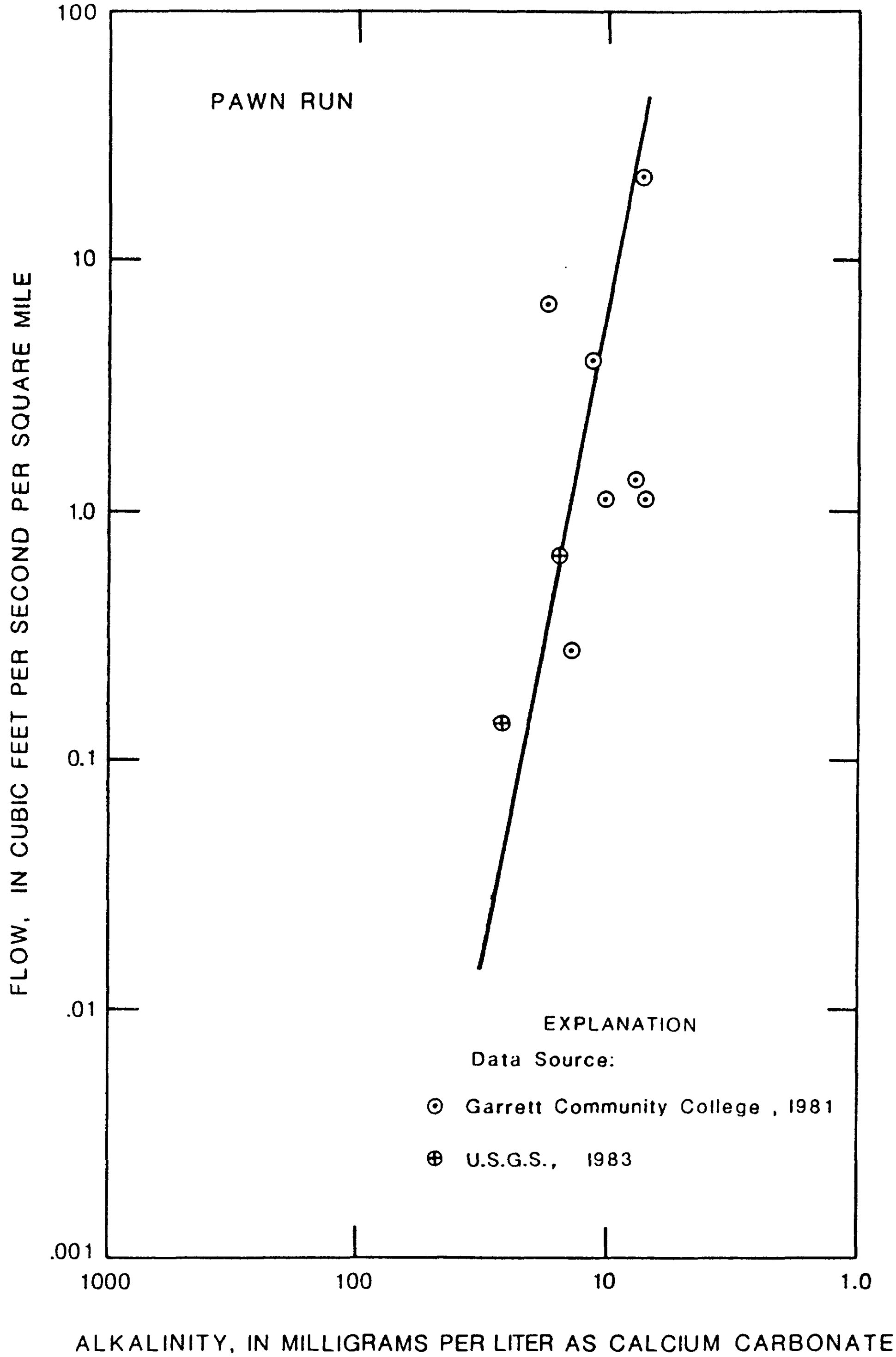


Figure 3. continued -- D.

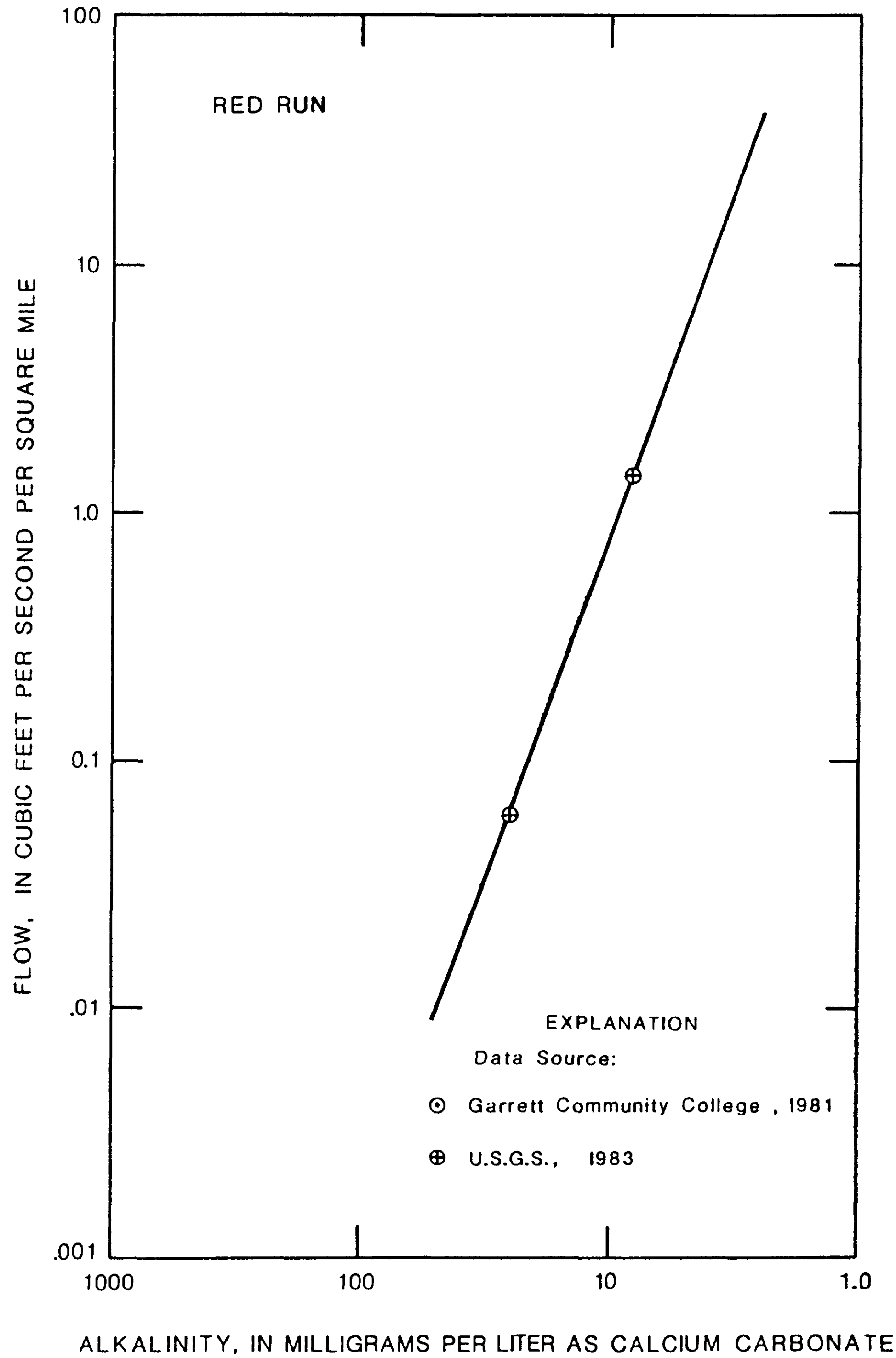


Figure 3. continued -- E.

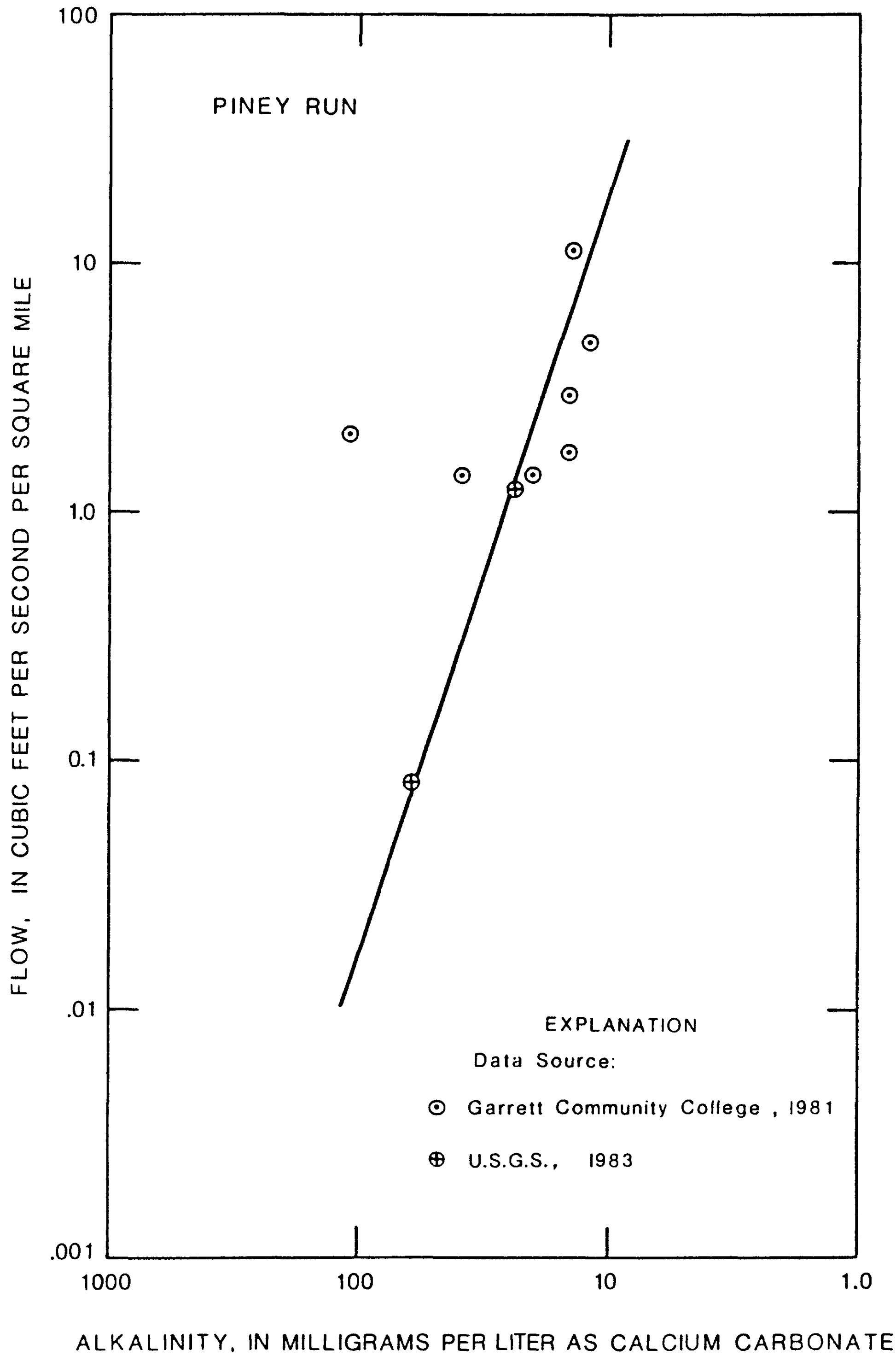


Figure 3. continued -- F.

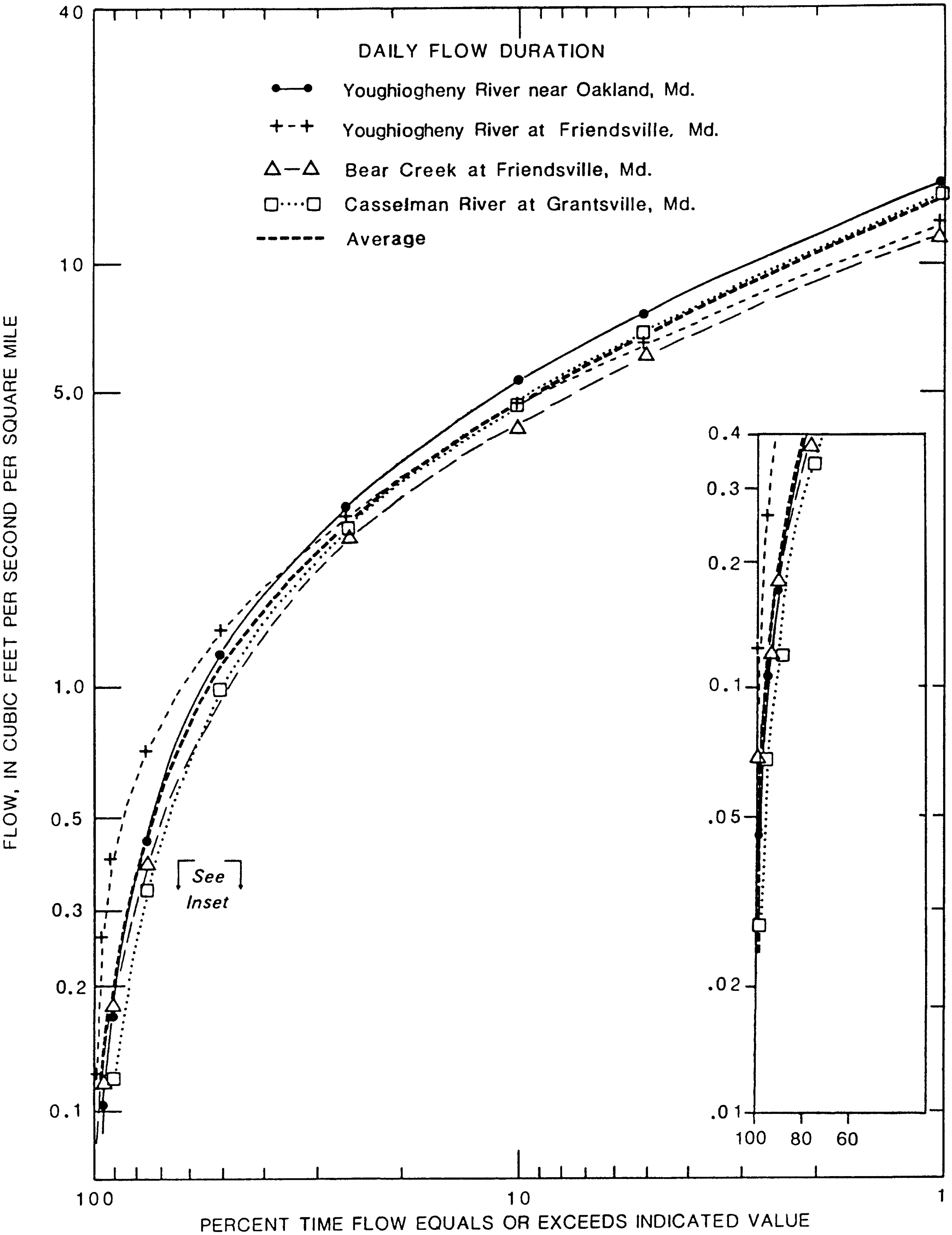


Figure 4. -- Daily flow duration curves of gaged streams in Garrett County.

TABLE 2. SAMPLE COMPUTATION OF AVERAGE ANNUAL ALKALINITY

Stream - Fairgrounds Run Drainage Area 0.41 mi^2

COLUMN							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PERCENT INTERVAL OF FLOW DURATION	DURATION INTERVAL (PERCENT)	MID-ORDINATE OF INTERVAL	DISCHARGE [$(ft^3/s)/mi^2$] AT MID-ORDINATE	ALKALINITY (mg/L) AT MID-ORDINATE DISCHARGE	DISCHARGE (ft^3/s)	ALKALINITY (tons/day as $CaCO_3$)	COLUMN (2) x COLUMN (7)
0.0 - 2.0	2.0	1.0	14.0	6.5	5.74	0.1006	0.2012
2.0 - 2.5	0.5	2.25	10.0	7.8	4.10	0.0863	0.0432
2.5 - 4.5	2	3.5	8.2	8.5	3.36	0.0770	0.1540
4.5 - 8.5	4	6.5	6.1	9.8	2.50	0.0661	0.2644
8.5 - 15	6.5	11.75	4.3	11.8	1.76	0.0560	0.3640
15 - 25	10	20	2.95	14.2	1.21	0.0463	0.4630
25 - 35	10	30	2.07	17.1	0.85	0.0392	0.3920
35 - 45	10	40	1.54	19.8	0.63	0.0336	0.3360
45 - 55	10	50	1.16	22.8	0.48	0.0295	0.2950
55 - 75	20	65	0.69	30.0	0.28	0.0227	0.4540
75 - 95	20	85	0.26	49	0.11	0.0145	0.2900
95 - 100	5	97.5	0.084	85	0.03	0.0069	0.0345
TOTALS	100						3.2913

Average daily alkalinity = (TOTAL, COLUMN 8) x (0.01) = 0.032913 tons/day

Average annual alkalinity = (Average daily alkalinity) x (365) = 12.01 tons/year

Average annual alkalinity yield = 12.01 T/yr ÷ drainage area (0.41 mi^2) = 29.3 tons/year/square mile

5. The flows $(ft^3/s)mi^2$ listed in column 4 were then multiplied by the drainage area for each project stream, giving flow in ft^3/s for each alkalinity value in column 5. These values are shown in column 6.

6. Alkalinity, in tons of $CaCO_3$ per day (column 7), was then determined for each percent time interval for each stream by multiplying the alkalinity value in column 5 by the corresponding flow in column 6 and by a constant (0.002697), which converts the results into tons/day.

7. Weight of equivalent $CaCO_3$ per day for each percent time interval (column 7) was then multiplied by the interval percent (column 2) times 0.01 and the resulting values summed to give average daily alkalinity as tons/day as $CaCO_3$. Multiplying this value by 365 gives the average annual carbonate load in tons/year as $CaCO_3$. Dividing this value by the drainage area gives the yield in tons/year/mi^2 for each stream basin.

WATER QUALITY

Surface Water

Field values of temperature, conductance, and pH; field determination of alkalinity, and laboratory analyses of individual samples taken for sulfate analyses are shown in table 3. Graphs of these properties are shown in figure 5. Laboratory analyses of surface water samples for major-ion concentrations are shown in table 4.

Fairgrounds Run

The sample taken for major-ion analysis was collected just after the annual county fair had been held at the fairgrounds. Since the fair is held every year, the analysis (table 4) is typical of the chemical quality of Fairgrounds Run during summer base flow. The results of the analysis show the effects of runoff from the animal barns adjacent to the stream and the influence of the Greenbrier Formation. Elevated concentrations of chloride, phosphorus, and potassium are characteristic of effluent from animal manure. Addition of this effluent has probably deoxygenated the water causing reducing conditions that allow iron and manganese to go into solution. The elevated

Table 3. Surface water sampling locations and field data.

Date	Time	Miles above mouth	Temp °C [1]	Conductivity (µS @25°C) [1]	pH [1]	Alkalinity mg/L as $CaCO_3$ [2]	Sulfate mg/L [3]	Sample collected for major-ion analysis, table 4	Comments
FAIRGROUNDS RUN									
5-12-83	0845	0.0	15.0	117	6.6	22			Flow 0.5 ft^3/s
		0.1	14.8	116	6.5				
		0.15	14.8	119	6.5				
		0.3	19.2	115	6.4				
		0.325	20.5	114	6.3				
		0.35	18.6	110	6.2				Double G Ranch barnyard
		0.35	18.0	111	6.0				Pond
		0.35	15.7	102	5.9				Spring
		0.35	24.0	146	6.4				S. inflow
		0.375	19.0	109	5.9				
		0.40	8.3	141	5.4				House spring
		0.42	9.5	72	5.3				
		0.43	8.4	55	5.3				
	1130	0.62	8.3	56	5.1				Dry above the location
8-16-83	0900	0.0	15.7	258	6.95	106	11 [4]	Yes	Flow 0.02 ft^3/s
		0.15	17.7	359	7.11				
		0.25	16.4	189	6.75				
	1030	0.30	19.7	174	7.10				Dry above this location
GRAVELLY RUN									
5-13-83	0830	0.0	11.3	34	6.3	8			Flow 1.2 ft^3/s
		0.01	10.3	23	6.3				S. inflow
		0.03	12.1	44	6.4				
		0.08	11.7	44	6.4				
		0.1	11.6	44	6.4				
		0.2	12.2	44	6.5				
		0.32	12.6	44	6.4				
		0.4	12.4	43	6.6				
		0.45	11.6	43	6.6				
		0.55	10.7	44	6.6				S. inflow
		0.55	10.9	42	6.6				N. inflow
		0.6	10.4	44	6.6				
		0.65	10.6	48	6.5				
		0.7	11.3	54	6.4				
		0.72	14.9	48	6.3				
		0.73	15.1	40	6.4				
		0.8	16.2	51	6.3				
	1500	0.8	13.2	53	6.3				Spring inflow Dry above this location

Date	Time	Miles above mouth	Temp °C [1]	Conductivity (µS @25°C) [1]	pH [1]	Alkalinity mg/L as $CaCO_3$ [2]	Sulfate mg/L [3]	Sample collected for major-ion analysis, table 4	Comments
GRAVELLY RUN (continued)									
8-09-83	1300	0.0	19.6	69	7.4	28	9.1 [4]	Yes	Flow 0.12 ft^3/s
		0.01	15.2	64	7.1				S. inflow
		0.01	23.2	70	7.5				Mainstem
		0.1	19.0	66	7.5				
		0.2	19.4	64	7.3				
		0.35	16.9	62	7.5				
		0.5	17.7	66	8.0	55	9.0		Flow ~5 gal/min
	1600	0.65	18.4	81	7.7				Dry above this location
MEADOW MT. RUN									
6-15-83	0900	0.2	14.5	36	6.5				
		0.3	14.5	36	6.4				
		0.35	15.0	36	6.4	8			Flow 1.84 ft^3/s
		0.4	15.0	36	6.6				
		0.5	15.0	36	6.7				
		0.6	15.0	35	6.9				
		0.6	9.0	34	6.9				Inflow
		0.7	15.5	35	6.9				
		0.8	16.0	35	6.8				
		0.9	16.0	35	6.8				
		1.1	16.0	38	6.9				
		1.3	18.0	39	6.8				West end of swamp
		1.5	19.0	43	6.7				
		1.7	19.5	45	6.7				
		1.9	20.0	44	6.9				
		2.1	20.0	46	6.9				
		2.3	15.0	44	7.0				
		2.8	14.0	63	7.0				East end of swamp
		3.0	14.0	66	6.9				
		3.1	14.5	61	6.7	5			Flow 0.14 ft^3/s
	2000	3.3	15.0	42	6.8				
8-15-83	1015	0.12	13.0	58	6.2	24	9.9 [4]	Yes	Flow 0.54 ft^3/s
		0.18	13.6	51	6.6	20			N. inflow
		0.4	16.3	48	6.5	15	11		
		0.5	14.0	45	6.6				
		0.75	12.0	40	6.2				
		1.3	15.5	39	6.0	8	12		
	1515	2.1	12.7	31	5.3	4	7.9		Swamp

Date	Time	Miles above mouth	Temp °C [1]	Conductivity (µS @25°C) [1]	pH [1]	Alkalinity mg/L as $CaCO_3$ [2]	Sulfate mg/L [3]	Sample collected for major-ion analysis, table 4	Comments
PAWN RUN									
6-14-83	1200	0.25	13.5	80	6.8	16			Flow 1.43 ft^3/s
		0.3	14.0	79	6.7				
		0.4	14.5	79	6.5				
		0.5	14.5	83	6.6				
		0.6	14.5	88	6.6				
		0.7	15.0	102	6.6	18			Flow 1.36 ft^3/s
		0.8	15.0	93	6.7				
		0.9	15.0	92	6.8				
		1.0	15.0	92	6.9				
"B" Branch		1.1	13.0	77	6.7	14			Flow 0.22 ft^3/s
Mainstem		1.1	15.5	93	6.8	16			Flow 1.01 ft^3/s
Mainstem		1.2	15.0	95	6.9				
Mainstem		1.3	13.0	59	6.8	10			Flow 0.49 ft^3/s
"C" Branch	2000	1.3	16.0	143	6.9	24			Flow 0.37 ft^3/s
PAWN RUN									
Mainstem									
8-13-83	1040	0.25	14.1	98	7.0	27	9.2 [4]	Yes	Flow 0.30 ft^3/s
		0.6	14.9	97					
		0.8	14.0	94					
		1.05	13.9	101					
		1.06	14.0	101					
	1345	1.3	14.0	49		12	5.9		
		1.6	15.6	132					
		1.8	18.3	188					
"B" Branch									
		0.01	13.2	103	7.0				
		0.34	15.2	72	7.0				
		0.52	13.9	69	6.8				
"C" Branch									
	1645	0.01	14.3	138	7.0	28	9.9		
		0.35	20.2	184	7.1				
	1800	0.6	16.9	220	7.4				

Date	Time	Miles above mouth	Temp [1] °C	Conductivity [1] (µS @25°C)	pH [1]	Alkalinity [2] mg/L as $CaCO_3$	Sulfate [3] mg/L	Sample collected for major-ion analysis, table 4	Comments
RED RUN									
5-11-83	1100	0.0	6.5	43	6.7	8			Flow 3.44 ft^3/s
		0.01	7.0	43	6.7				
		0.02	7.2	42	6.6				
		0.03	7.3	41	6.6				
		0.04	7.5	43	6.5				
		0.05	7.6	44	6.5				
		0.06	7.8	44	6.4				
		0.065	7.9	44	6.5				
		0.07	8.1	44	6.4				
		0.08	8.3	45	6.4				
		0.09	8.5	46	6.3				
		0.1	8.5	46	6.4				
		0.12	9.0	46	6.4				
		0.13	9.1	46	6.4				
		0.14	8.5	27	6.4				Inflow from E
		0.16	9.2	46	6.4				
		0.17	9.2	46	6.3				
		0.18	9.3	46	6.3				
		0.20	9.3	47	6.2				
		0.21	9.6	21	6.1				Inflow, ~5 gal/min
		0.26	9.4	47	6.3				
	1207	0.3	9.5	47	6.4				
	1300	0.4	11.2	47	6.2				
		0.42	11.3	46	6.3				
		0.46	11.3	46	6.2				
		0.5	11.4	45	6.1				
		0.55	11.3	45	6.1				
		0.6	12.9	46	6.2				
		0.62	16.9	142	6.5				Inflow from SW
		0.7	13.4	44	6.3				
	~1430	1.0	13.2	41	6.3				

Date	Time	Miles above mouth	Temp [1] °C	Conductivity [1] (μS @25°C)	pH [1]	Alkalinity [2] mg/L as $CaCO_3$	Sulfate [3] mg/L	Sample collected for major-ion analysis, table 4	Comments
RED RUN (continued)									
North Branch		1.05	13.7	57	6.1				
		1.08	13.9	60	6.2				
		1.1	13.1	61	6.2				
		1.2	12.3	59	6.3				
		1.3	10.5	58	6.3				
		1.32	9.9	61	6.3				
		1.38	9.5	55	6.4				
		1.4	9.5	61	6.4				
5-11-83		1.50	11.9	59	6.3				
		1.60	19.4	60	6.5				
	1709	1.70	20.1	60	6.5				Mayhew Inn road
RED RUN									
South Branch									
5-11-83	1445	1.01	13.1	6.1	37				
5-12-83	1030	1.01	7.8	6.3	40				
		1.03	8.0	6.2	40				
		1.05	8.1	6.1	39				
		1.07	8.4	6.0	38				
		1.10	8.6	6.2	37				
		1.12	8.6	6.0	37				
		1.14	8.9	6.1	37				
		1.17	9.1	5.9	36				
		1.20	9.3	6.0	35				
		1.25	11.4	6.2	59				Inflow from N
		1.30	9.1	5.9	30				
		1.35	9.0	5.75	31				
		1.45	9.1	5.5	31				
		1.80	9.9	5.9	28				
		2.10	10.7	5.9	35				
		2.40	9.9	6.1	67				

Date	Time	Miles above mouth	Temp [1] °C	Conductivity [1] (µS @25°C)	pH [1]	Alkalinity [2] mg/L as $CaCO_3$	Sulfate [3] mg/L	Sample collected for major-ion analysis, table 4	Comments
RED RUN 8-10-83	1015	0.0	16.0	75.5	6.6	25	11 [4]	Yes	Flow 0.15 ft^3/s
		0.15	16.4	75.4	6.7				
		0.1	16.6	81	6.65				
		0.15	16.0	88	6.8				
		0.2	16.6	90	7.0				
		0.25	16.7	90	6.9				
		0.3	16.5	90	6.6				
		0.4	19.7	91	6.8				
		0.5	19.0	86	6.95				
		0.6	20.5	86.5	7.1				
		0.7	28.5	79	7.2				
		0.8	26.8	77	7.1				
		0.9	24.4	75	6.6				
		1.0	21.7	79	6.6				
RED RUN North Fork		1.01	20.3	94.5	6.4	42	11		
RED RUN South Fork		1.01	22.6	76	6.8	32	9.1		
		1.1	22.7	75	6.8				
		1.25	25.4	74	7.05				
	1600	1.4	24.1	84	7.1				
PINEY RUN 5-13-83	1500	0.0	15.8	82	6.5	24			Flow 1.2 ft^3/s
		0.01	16.2	87	6.9				
		0.05	16.4	87	7.0				
		0.10	16.1	86	7.0				
		0.12	16.1	85	7.0				
		0.14	11.6	31	7.0				Inflow from S
		0.18	16.5	86	7.0				
		0.20	16.5	83	7.0				
		0.22	16.8	84	7.1				

Date	Time	Miles above mouth	Temp °C [1/]	Conductivity (μS @25°C) [1/]	pH [1/]	Alkalinity mg/L as $CaCO_3$ [2/]	Sulfate mg/L [3/]	Sample collected for major-ion analysis, table 4	Comments
PINEY RUN (continued)									
		0.28	14.2	85	7.1				Inflow from E
		0.3	17.3	81	7.0				
		0.35	17.3	73	7.0				
		0.40	17.2	71	7.0				
		0.50	14.5	46	6.9				Inflow from S
		0.50	17.6	75	6.8				Mainstem below
		0.55	17.3	70	7.0				
		0.60	17.1	68	7.0				
		0.62	16.3	54	6.9				Trib from W
		0.62	17.4	71	6.8				Main from N
		0.65	16.8	76	6.9				
		0.70	16.0	75	6.9				
		0.75	15.4	77	6.9				
		0.80	15.2	78	7.0				
		0.82	14.1	77	7.0				
	1930	0.85	13.8	76	7.0				
PINEY RUN									
8-11-83	1100	0.0	15.5	367	7.6	62	130 [4/]	Yes	Flow 0.08 ft³/s
		0.1	16.0	390	7.8				
		0.2	16.0	342	7.8				
		0.3	16.1	307	7.8				
		0.4	16.0	245	7.8				
		0.5	15.7	198	8.0				Below inflow from S
		0.5	15.6	106	7.7				Inflow from S
		0.5	15.8	219	8.2	62	28		Above inflow
		0.6	15.8	167	8.0				Trib from W
		0.6	16.0	253	8.3				Main above trib
		0.7	15.9	142	7.9				
		0.8	15.7	147	7.6				
	1500	0.9	15.1	143	7.5				

1/ In-stream measurement.
2/ Alkalinity samples titrated in the field.
3/ All sulfate analyses by USGS Central Laboratory, Doraville, Georgia.
4/ Sulfate from major ion analyses given in table 4.

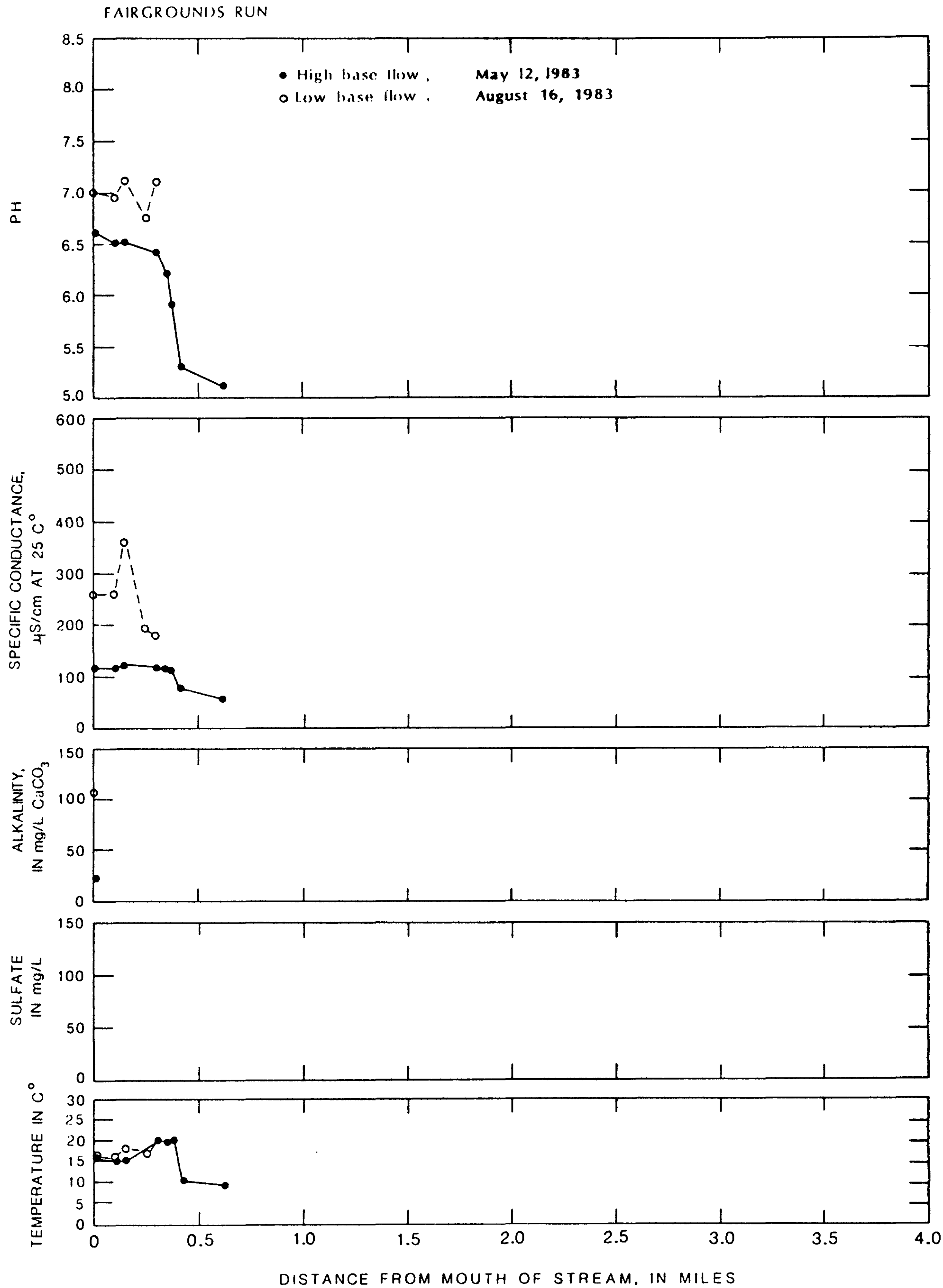


Figure 5. -- Water quality of project streams.
A, high base flow; B, Low base flow.

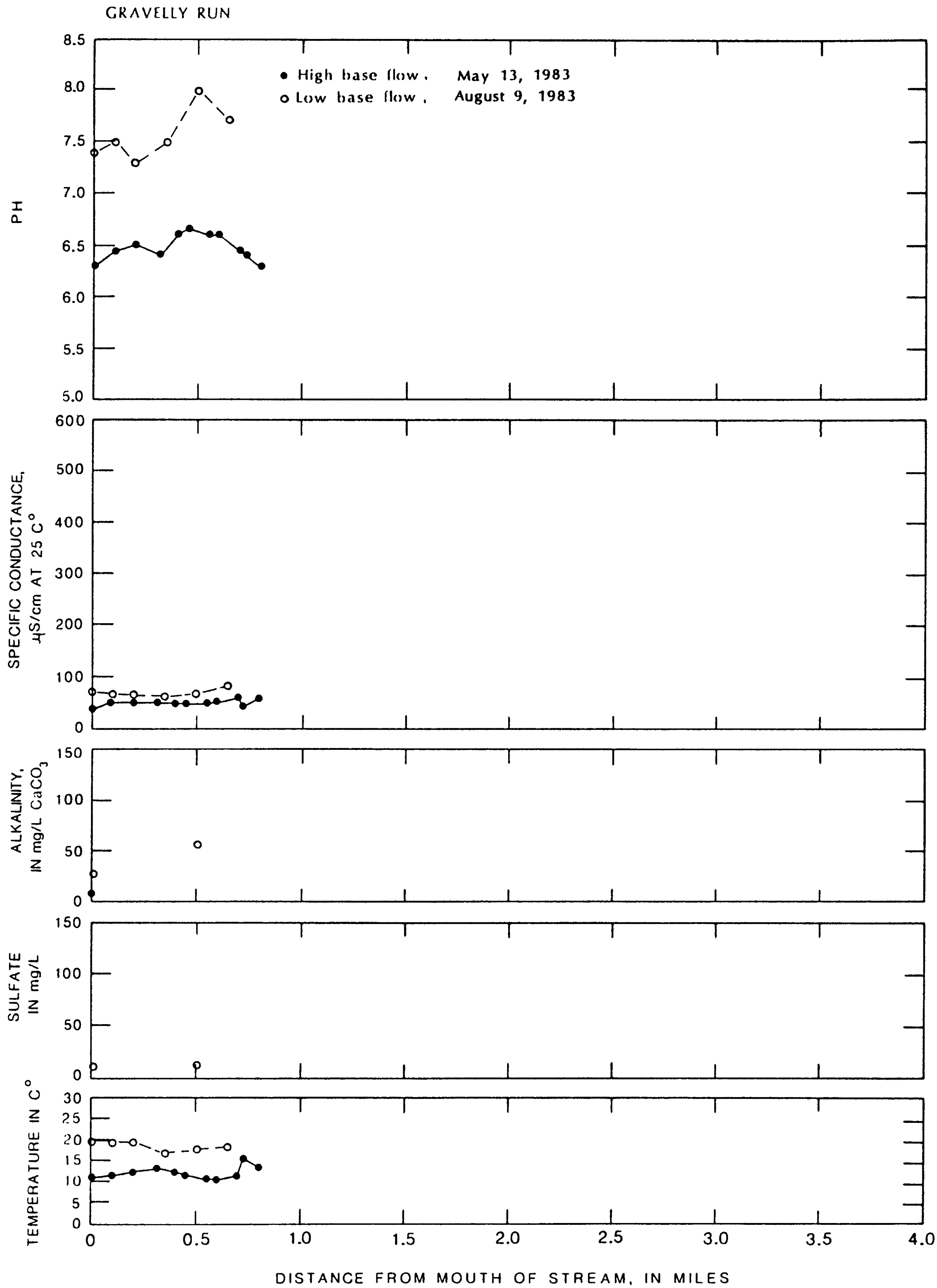


Figure 5. continued -- C, high base flow ; D, low base flow.

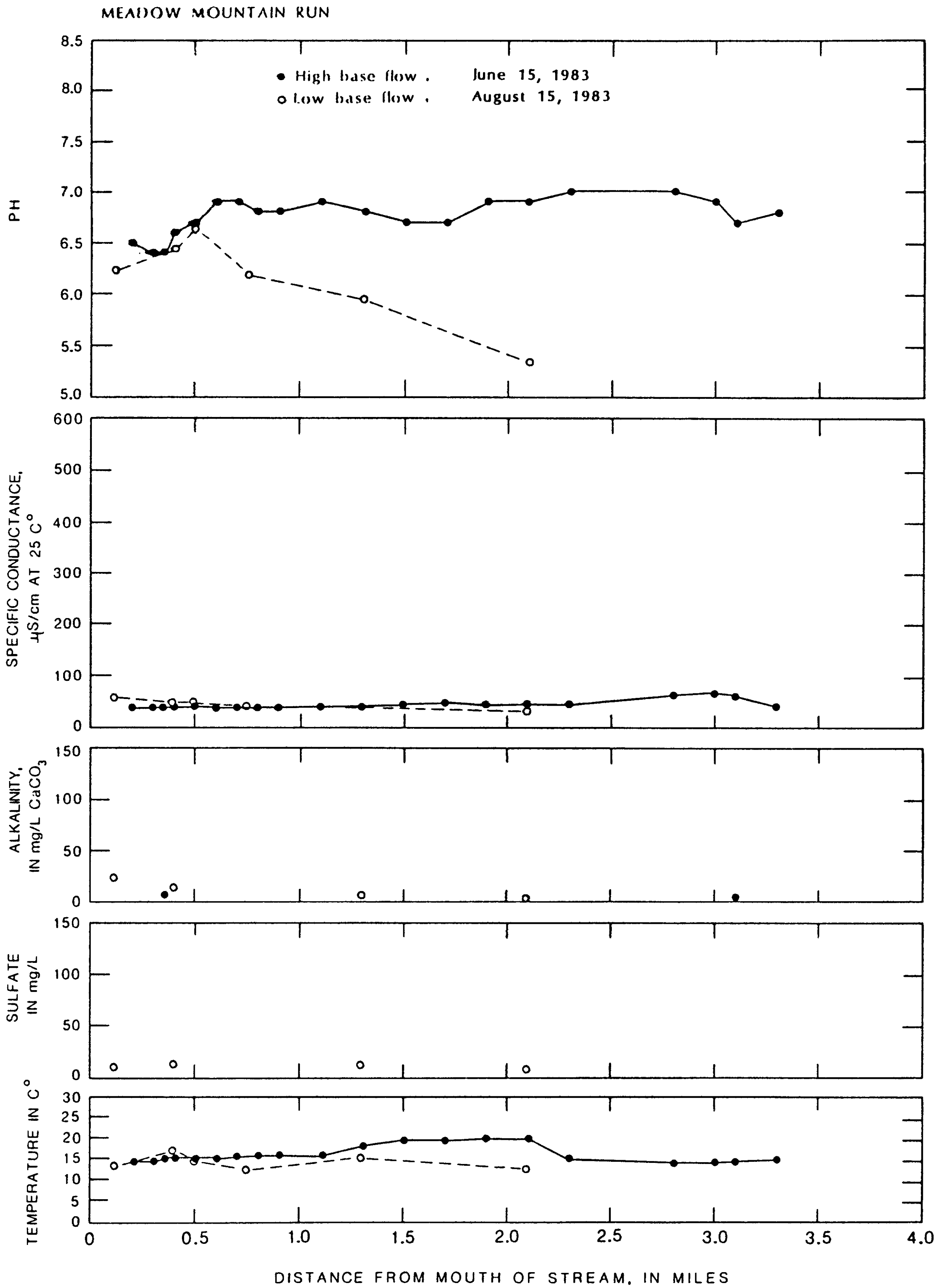


Figure 5. continued -- E, high base flow : F, low base flow.

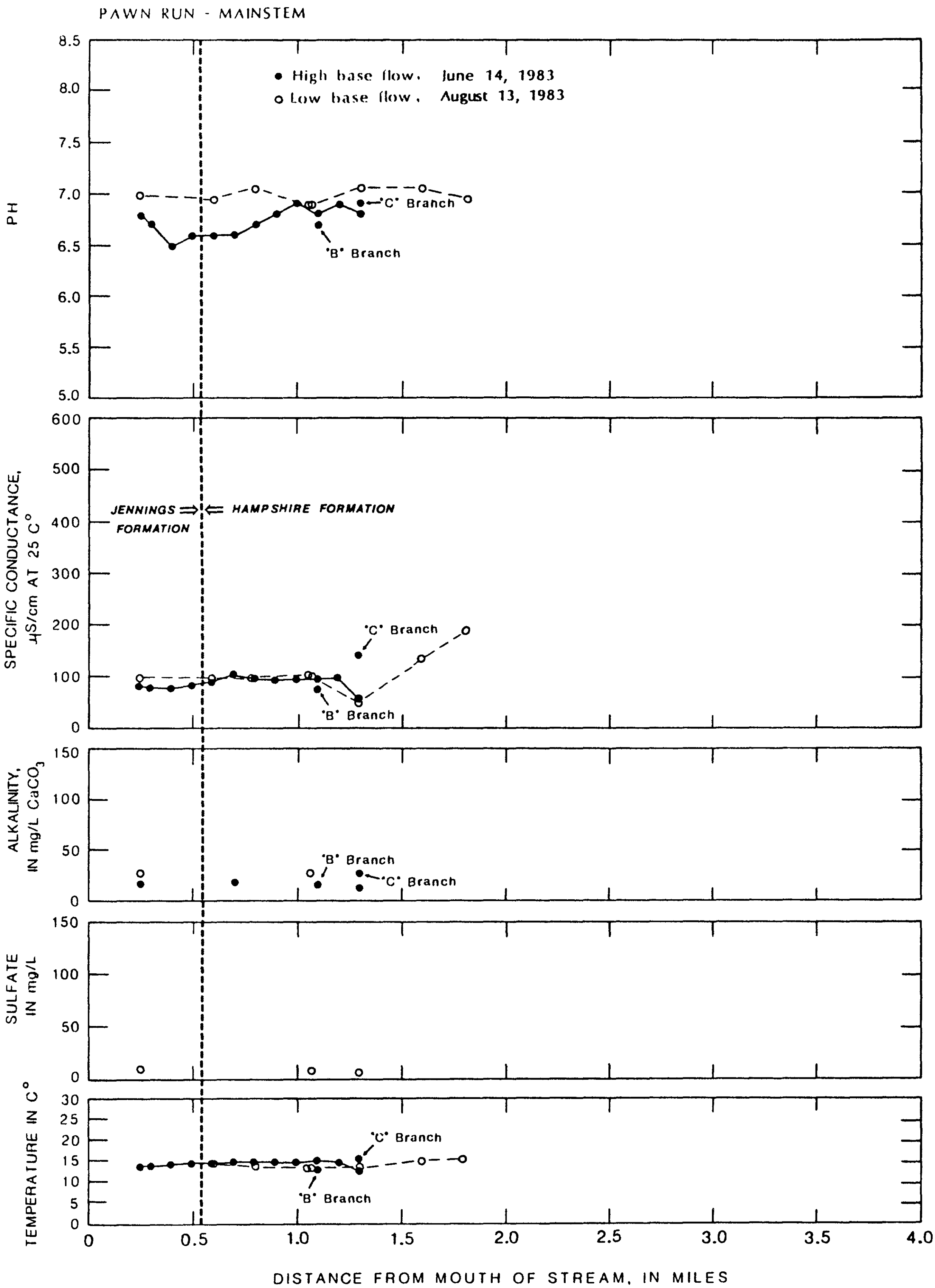


Figure 5. continued -- G, high base flow : H, low base flow.

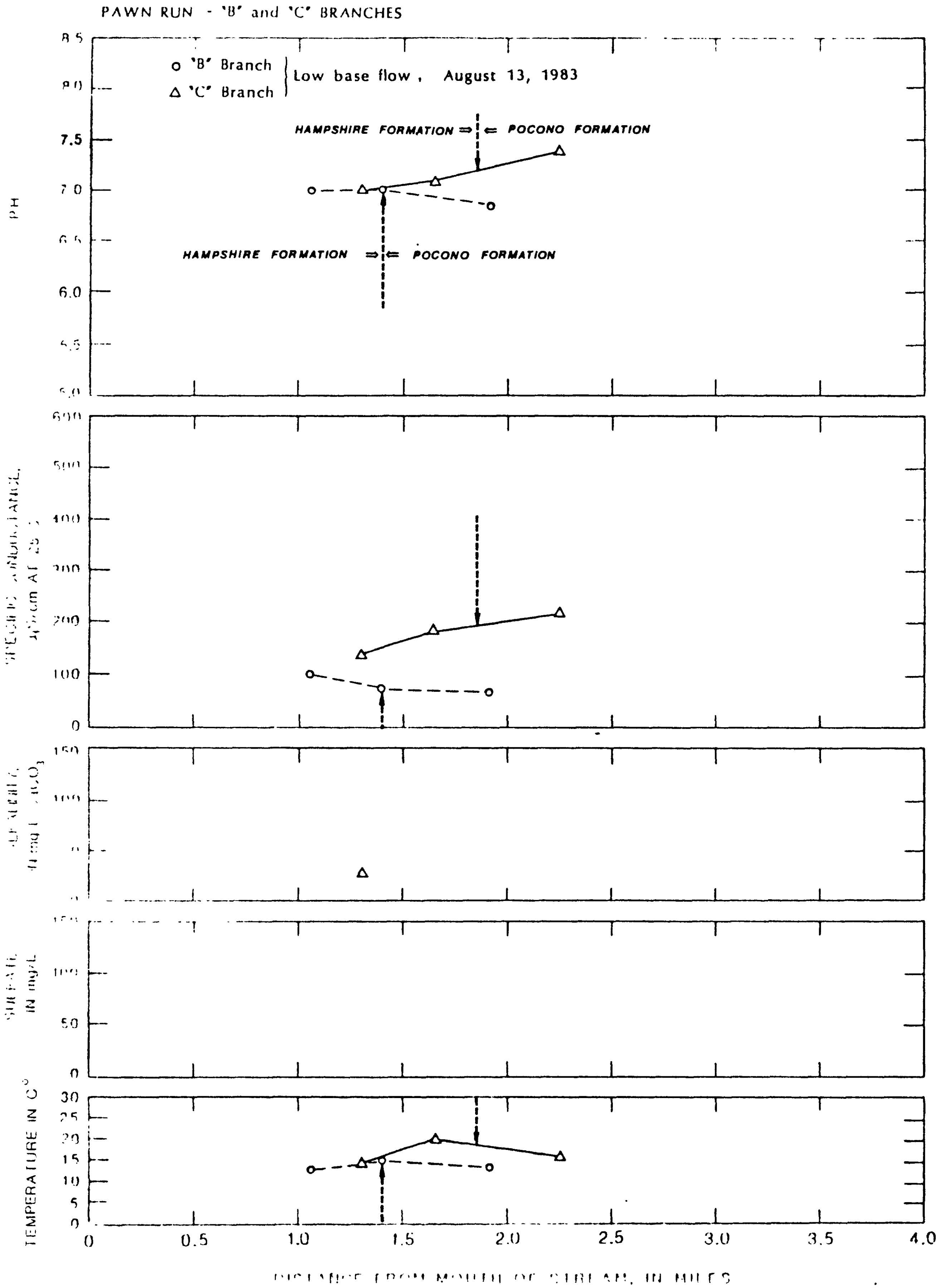


Figure 5. continued -- I, low base flow.

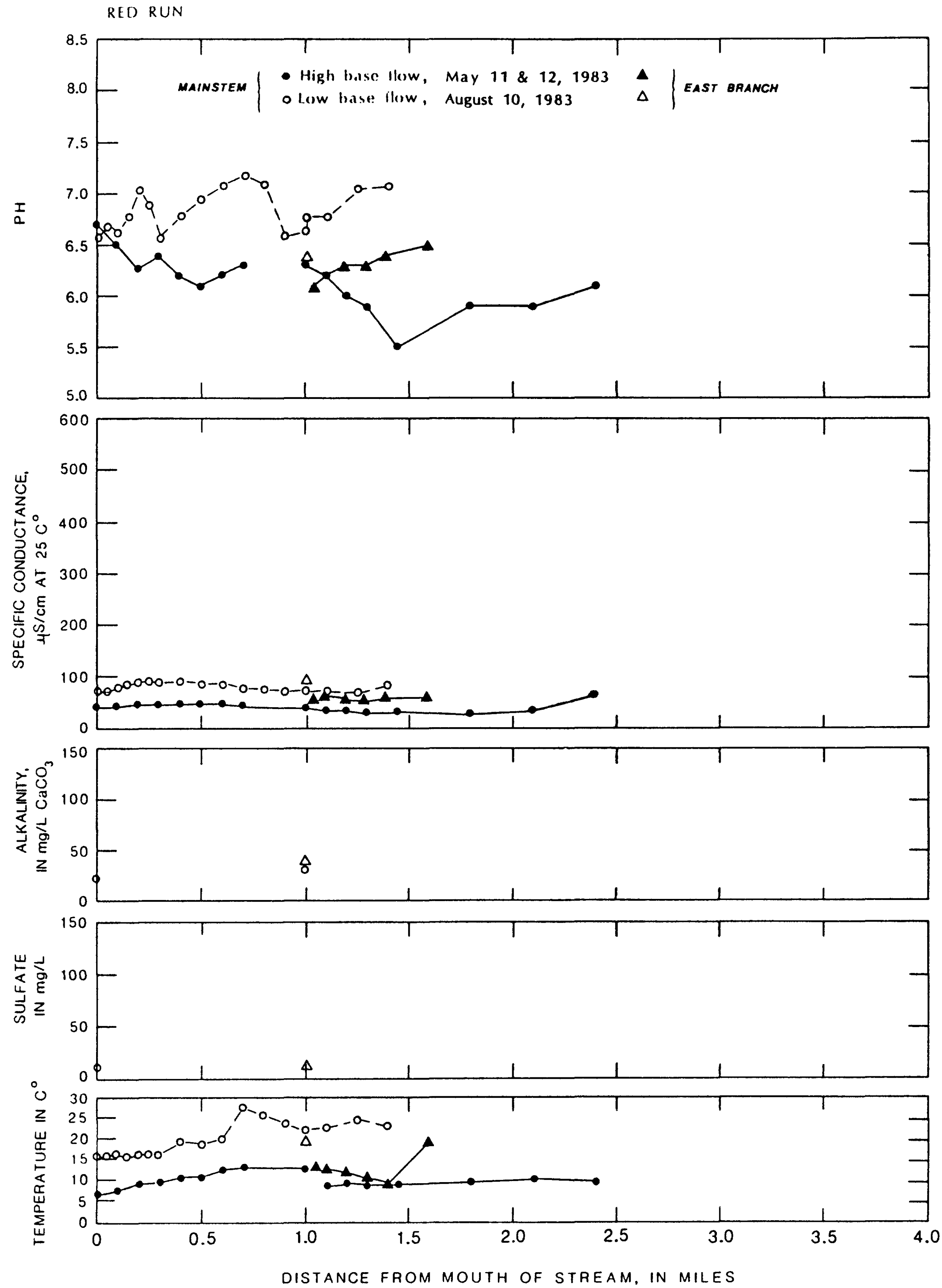


Figure 5. continued -- J, high base flow : K, low base flow.

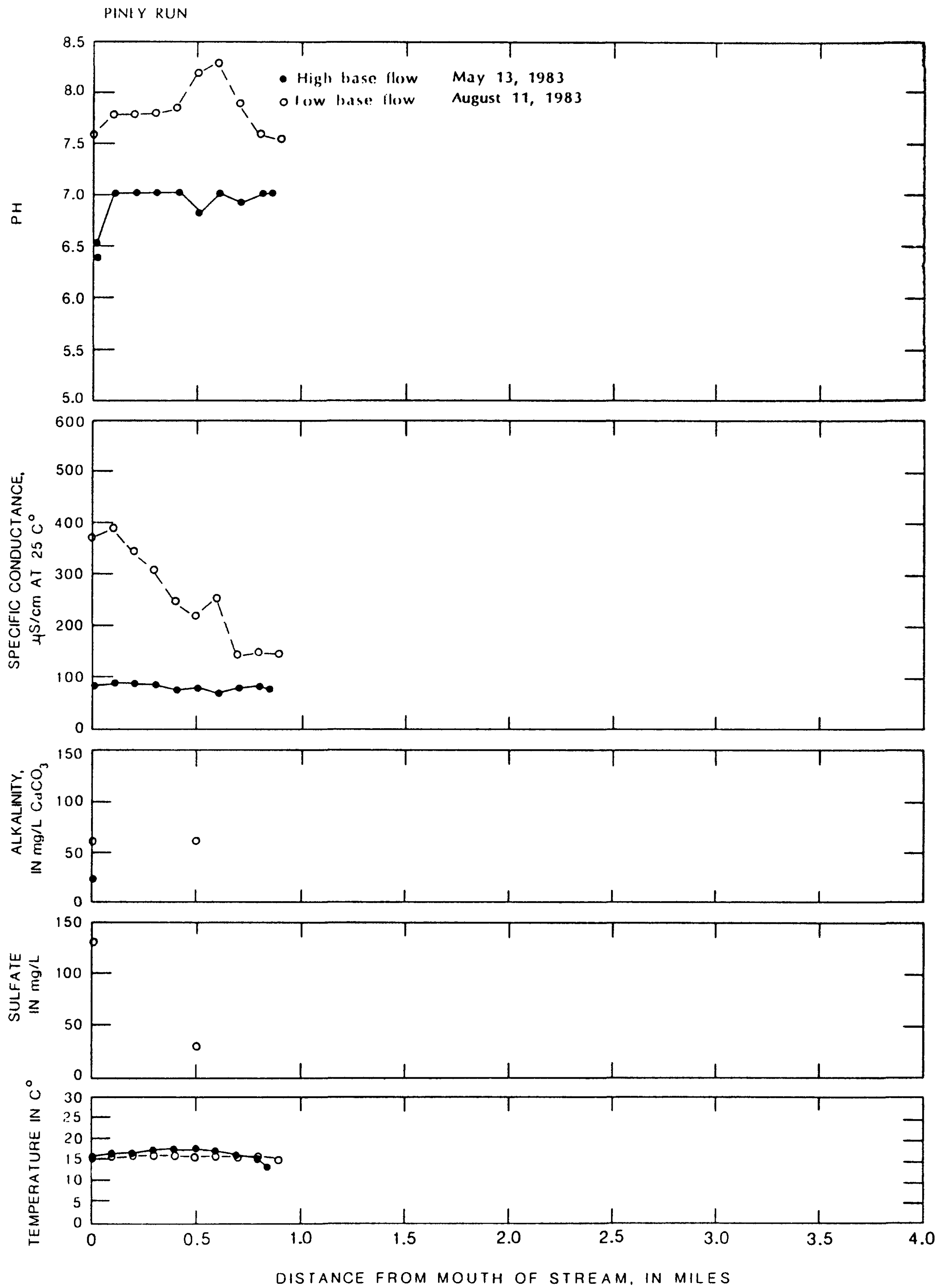


Figure 5. continued -- L, high base flow : M, low base flow.

TABLE 4. CHEMICAL ANALYSES OF SURFACE WATER

(Locations are shown in Figure 1.)

Stream data/constituent	Units	Stream		
Stream name	-	Fairgrounds Run	Gravelly Run	Meadow Mt. Run
Date	-	8/16/83	8/09/83	8/15/83
Flow	ft^3/s	0.02	0.12	0.54
Temperature	°C	15.7	19.6	13.0
Color	Pt-Co units	30	17	75
Specific conductance	(µS) at 25°C	258	69	58
pH	-	7.0	7.4	6.2
Solids, dissolved	mg/L	105	45	45
Solids, residue at 180°C	mg/L	174	59	50
Sodium Adsorption Ratio	-	0.4	0.1	0.1
Nitrogen, NO_2+ NO_3	mg/L	0.5	0.3	0.1
Hardness as $CaCO_3$	mg/L	74	30	29
Hardness, noncarbonate	mg/L	0	2	5
Alkalinity as $CaCO_3$	mg/L	110	28	24
Chloride	mg/L	15	1.6	1.8
Fluoride	mg/L	< 0.1	< 0.1	< 0.1
Silica	mg/L	5.2	5.4	5.5
Sulfate	mg/L	11	9.1	9.9
Calcium	mg/L	25	9.6	9.7
Iron, dissolved	ug/L	1600	100	770
Iron, total recoverable	ug/L	3300	470	3300
Magnesium	mg/L	2.9	1.5	1.1
Manganese, dissolved	ug/L	2300	150	86
Manganese, total recoverable	ug/L	2200	140	100
Phosphate	mg/L	0.58	0.06	0.06
Phosphorus	mg/L	0.19	0.02	0.02
Potassium	mg/L	8.1	0.9	0.6
Sodium dissolved	mg/L	8.0	1.5	1.4
Sodium, percent	-	17	9	9

Stream data/constituent	Units	Stream		
Stream name	-	Pawn Run	Red Run	Piney Run
Date	-	8/13/83	8/10/83	8/11/83
Flow	ft^3/s	0.30	0.15	0.08
Temperature	°C	14.1	16.0	16.1
Color	Pt-Co units	25	55	12
Specific conductance	(μS) at 25°C	98	76	468
pH	-	7.0	6.6	6.9
Solids, dissolved	mg/L	53	49	265
Solids, residue at 180°C	mg/L	87	71	348
Sodium Adsorption Ratio	-	0.3	0.2	0.5
Nitrogen, NO_2 + NO_3	mg/L	1.7	0.6	0.7
Hardness as $CaCO_3$	mg/L	35	31	190
Hardness, noncarbonate	mg/L	8	6	130
Alkalinity as $CaCO_3$	mg/L	27	25	62
Chloride	mg/L	5.9	3.5	6.2
Fluoride	mg/L	< 0.1	< 0.1	< 0.1
Silica	mg/L	6.7	4.9	5.8
Sulfate	mg/L	9.2	11	130
Calcium	mg/L	9.4	9.9	65
Iron, dissolved	ug/L	150	310	42
Iron, total recoverable	ug/L	870	940	280
Magnesium	mg/L	2.7	1.5	7.6
Manganese, dissolved	ug/L	48	30	35
Manganese, total recoverable	ug/L	80	70	50
Phosphate	mg/L	0.21	0.09	-
Phosphorus	mg/L	0.07	0.03	< 0.01
Potassium	mg/L	2.3	0.9	2.9
Sodium dissolved	mg/L	4.1	2.9	14
Sodium, percent	-	19	16	13

concentrations of iron, manganese, chloride, phosphorus, and potassium shown in this analysis are probably an annual occurrence during summer low flow. Mass-balance calculations suggest that almost all of the alkalinity in Fairgrounds Run is derived from carbonate rocks.

The May stream profile (fig. 5A) shows that the headwaters, which drain the Pocono Formation, are acidic. Both pH and conductance increase from mile 0.42 downstream to the mouth of the stream. This increase in both properties suggests that most of the water entering the stream along this reach is from the Greenbrier Formation.

The August stream profile (fig. 5B) suggests that most of the base flow is derived from the Greenbrier Formation, although there are some minor contributions of acidic water from the Pocono Formation. The change in conductance at mile 0.15 is probably caused by seepage from animal barns at the fairgrounds.

Gravelly Run

Stream profiles (figs. 5C and 5D) show that pH increases downstream from the headwaters to about mile 0.5, and then decreases toward the mouth of the stream. Alkalinity also decreases from mile 0.5 to the mouth of the stream.

The pH peak near mile 0.5, and the higher overall value of this property during low base flow is interpreted as introduction of water from the Greenbrier Formation that underlies the Mauch Chunk Formation in which the stream is developed. Comparison of the May and August pH profiles indicates that the inflow of alkaline water near mile 0.5 is not a large contribution to high base flow. Downstream of this area the alkaline water mixes with acidic water that probably comes from the noncarbonate Mauch Chunk Formation.

The major-ion analysis of water from Gravelly Run shows that although the pH is relatively high (pH 7.4), dissolved solids, hardness, alkalinity, calcium, and sulfate are low. Mass-balance calculations suggest that almost half of the alkalinity noted during low base flow may be derived from carbonate rocks. The remainder is probably derived from hydrolysis of silicate minerals.

Meadow Mountain Run

Laboratory analysis of major ions show that this stream has the lowest concentration of dissolved solids, nitrogen, magnesium, phosphate, potassium, and sodium of all the project streams. Values for pH, alkalinity, hardness, and specific conductance are also below those of the other streams. Only total iron and color values equal or exceed those found in other stream analyses. Mass-balance calculations indicate that more than half of the alkalinity shown in the analysis may be derived from silicate hydrolysis rather than from carbonate rocks.

Stream profiles show considerable differences in constituents and properties between high base flow (fig. 5E) and low base flow (fig. 5F). Both water temperature and pH are higher during high base flow than during low base flow. Conversely, alkalinity and conductivity are higher during low base flow than during high base flow.

The lower temperature of the water during low base flow is probably due to shading by vegetation, and to an increased percentage of ground water in the streamflow. The decrease in pH between June and August is probably caused by deoxygenation of the water by organic decomposition in the numerous swamps and beaver ponds along Meadow Mountain Run. This may also account for the high iron content and color of the water shown in the major-ion analysis.

Increasing alkalinity from the headwaters to the mouth of the stream during low base flow may be due to seepage of carbonate-rich water from the Greenbrier Formation. These inflows are probably small because they are masked during higher streamflow. The rate of contribution of alkaline-rich water from these small inflows apparently increases with proximity to the mouth of the stream.

Pawn Run

This stream was studied in order to determine if water-quality changes could be detected in a stream as it crosses several noncarbonate formations. The main stem of Pawn Run drains the Hampshire and Jennings Formations. Two tributaries, designated "B" Branch and "C" Branch (fig. 1) in this report, have their headwaters in the Pocono Formation. These tributaries flow over the Hampshire Formation before joining the main stem of Pawn Run.

Stream profiles made during high base flow (fig. 5G) show a decrease in pH from the headwaters downstream to mile 0.4 and then a rise between mile 0.4 and mile 0.25, the initial sampling point. Alkalinity, conductivity, and temperature show little change throughout most of the reach of the stream.

Measurements taken in Pawn Run and its tributaries during August (figs. 5H and 5I) show little indication of water-quality change attributable to geologic formations. Temperature, conductivity, and pH of "B" and "C" Branches are distinctly different in the Pocono Formation, but, approach common values in the Hampshire Formation. This suggests that ground water from the Hampshire Formation is less variable chemically than that in the Pocono Formation.

Conductance and pH are higher in the headwater of "C" Branch than in the headwater of "B" Branch or the main stem. This may be due to more rapid weathering and hydrolysis of silicates, possibly caused by earthmoving associated with construction of a ski lift within the basin of "C" Branch.

Temperature and conductance of the main stem of Pawn Run (fig. 5H) decrease downstream in the reach above the confluence of "C" Branch during August. Downstream of that point, temperature and pH are almost constant. Conductance in the headwaters is high, similar to that of the Pocono Formation in "C" Branch, but decreases rapidly to a minimum value just above the confluence of "C" Branch. Below that point, conductance remains nearly constant.

The main stem of Pawn Run crosses the contact between the Hampshire and Jennings Formations near stream mile 0.55. No significant change in water quality occurs during low base flow between mile 0.55 and the initial sampling point near the mouth of the stream.

Red Run

Comparison of high and low base flow profiles (figs. 5J and 5K) of this stream show distinctly different values in pH and conductance. Measurements made during high base flow show a decrease in pH from the headwaters of the main stem to about mile 1.45. This point is at the downstream end of a series of beaver ponds in a large swamp. The low pH (5.5) is assumed to be caused by organic acids formed from vegetal decomposition. Conductance drops by about half through this reach of the stream indicating either precipitation of dissolved components, or dilution by water containing few dissolved solids. Conductance and pH rise between stream mile 1.45 and 1.0 at which point the East Branch of Red Run joins the main stem. Conductance continues to increase, and pH remains constant to stream mile 0.7. This rise in pH between stream mile 1.45 and 1.0 may be caused by inflow of carbonate-rich water from the Greenbrier Formation. Addition of carbonate would also account for the increase in conductance that occurs in the same reach of the stream. Water temperature is, for the most part, a function of solar heating during the time the profile was made. The sharp drop in temperature of the main stem at mile 1.05 marks the break between two days of sampling. The decrease in temperature of the East Branch above the confluence with the main stem, however, is attributable to heavy foliage cover between stream mile 1.1 and 1.5.

The stream profile of Red Run made during low base flow shows that the pH at stream mile 1.4 is slightly above neutral, and the conductance is 84 microsiemens (μS). This is probably mixed ground water from the Greenbrier and Pocono Formations drained by Red Run at this point. At stream mile 1.0, inflow from the East Branch decreases pH of the main stem of Red Run. Peaks in pH values occur at miles 0.7 and 0.2. These peaks may be caused by temperature-redox reactions, or by addition of water from the Greenbrier Formation.

The major-ion analysis of water from Red Run shows that almost all constituents have mid-range values compared to those of the other streams, but the silica and dissolved manganese concentrations are the lowest measured in the project streams. Mass-balance calculations suggest that more than half of the alkalinity that is present during low base flow is derived from carbonate rocks.

Piney Run

The water quality of Piney Run is affected significantly by an operating limestone mine developed in the Greenbrier Formation. The major-ion analysis shows that Piney Run is highest in conductance, dissolved solids, sodium adsorption ratio, hardness, sulfate, calcium, magnesium, and sodium of all the project streams. It also has the lowest values for color, iron, and total manganese.

TABLE 5. CHEMICAL ANALYSES OF GROUND WATER
(Locations are shown in Figure 1.)

Well data/constituent	Units	Well Number GA CB-76	GA CB-77	GA CB-78	GA CC-2
Aquifer name	-	Greenbrier	Greenbrier	Greenbrier	Greenbrier
Sample date	-	5/18/83	5/18/83	5/18/83	3/06/51
Depth, top of sample interval	ft	40	90	120	47
Depth, bottom sample interval	ft	60	90	120	85
Total Depth of Hole	ft	60	90	120	85
Elevation of land surface	ft	2480	2490	2600	2520
Pumping rate	gal/min	10	5	0.5	10
Temperature	°C	10.6	10.8	5.8	-
Color	Pt-Co units	2	1	1	-
Specific conductance	(µS) at 25°C	144	202	250	69
pH	-	7.1	7.1	8.0	6.9
Solids, dissolved	mg/L	78	97	147	44
Solids, residue at 180°C	mg/L	106	154	142	-
Sodium Adsorption Ratio	-	0.0	0.1	0.6	-
Nitrogen, $NO_2 + NO_3$	mg/L	1.0	3.6	< 0.1	-
Hardness, as $CaCO_3$	mg/L	70	94	99	27
Hardness, noncarbonate	mg/L	10	21	13	11
Alkalinity as $CaCO_3$	mg/L	60	73	86	-
Chloride	mg/L	1.5	4.4	1.0	1.4
Fluoride	mg/L	< 0.1	< 0.1	0.2	0.1
Silica	mg/L	5.6	6.4	11	5.9
Sulfate	mg/L	4.4	2.4	35	9.9
Calcium	mg/L	26	35	25	9.6
Iron, dissolved	ug/L	9	6	< 3	-
Iron, total recoverable	ug/L	100	300	40	310
Magnesium	mg/L	1.2	1.5	8.9	0.7
Manganese, dissolved	ug/L	< 1	< 1	< 1	-
Manganese, total recoverable	ug/L	10	< 10	10	60
Phosphate	mg/L	-	0.06	-	-
Phosphorus	mg/L	< 0.01	0.02	< 0.01	-
Potassium	mg/L	0.5	0.4	0.8	0.7
Sodium, dissolved	mg/L	0.7	1.2	12	1.6
Sodium, percent	-	2	3	21	-

	Units	GA CC-35	GA CC-64	GA CC-65
Aquifer name	-	Greenbrier	Greenbrier(?)	Greenbrier(?)
Sample date	-	5/18/83	5/17/83	5/17/83
Depth, top of sample interval	ft	107	60	118
Depth, bottom sample interval	ft	167	90	120
Total Depth of Hole	ft	167	90	120
Elevation of land surface	ft	2480	2485	2480
Pumping rate	gal/min	15	5	15
Temperature	°C	10.1	10.6	9.7
Color	Pt-Co units	< 1	2	3
Specific conductance	(µS) at 25°C	124	74	45
pH	-	6.9	5.8	5.8
Solids, dissolved	mg/L	70	44	31
Solids, residue at 180°C	mg/L	92	79	49
Sodium Adsorption Ratio	-	0.0	0.1	0.1
Nitrogen, NO_2+ NO_3	mg/L	0.1	2.1	1.2
Hardness, as $CaCO_3$	mg/L	58	33	19
Hardness, noncarbonate	mg/L	0	20	14
Alkalinity as $CaCO_3$	mg/L	64	13	5
Chloride	mg/L	0.6	2.7	1.3
Fluoride	mg/L	< 0.1	< 0.1	< 0.1
Silica	mg/L	7.1	5.1	5.9
Sulfate	mg/L	0.6	14	11
Calcium	mg/L	21	11	5.2
Iron, dissolved	ug/L	3	23	120
Iron, total recoverable	ug/L	100	190	190
Magnesium	mg/L	1.3	1.3	1.4
Manganese, dissolved	ug/L	1	3	6
Manganese, total recoverable	ug/L	10	10	10
Phosphate	mg/L	0.09	-	0.03
Phosphorus	mg/L	0.03	< 0.01	0.01
Potassium	mg/L	0.4	0.6	0.5
Sodium, dissolved	mg/L	0.6	1.0	0.9
Sodium, percent	-	2	6	9

Sulfate concentration in Piney Run increases from 28 mg/L at stream mile 0.5 to 130 mg/L at the mouth of the stream during low flow (fig. 5M). This is 2.9 times and 13.5 times, respectively, the average sulfate content (9.6 mg/L) found in the other project streams during low flow. Some of this sulfate may be derived from gypsum in the dolomitic layers associated with the limestone. If this was the only source of sulfate, however, concentration should decrease rather than increase with distance downstream from the point (stream mile 0.65) at which effluent from the mine enters Piney Run. One possibility is that gypsum was added to the cultivated fields adjacent to the stream to improve soil friability.

Stream profiles (figs. 5L and 5M) made during high base flow and low base-flow conditions show differences in pH and conductance, both in concentration and trend. The pH and conductance measured during high base flow are almost constant throughout the entire reach of the stream.

Low base-flow measurements show an increase in pH from the headwaters to stream mile 0.6, and then a decrease downstream to the mouth of the stream. The decrease in pH between stream mile 0.6 and 0.4 is attributed to mixing of the carbonate-rich water from the Greenbrier Formation with lower pH water from the noncarbonate Pocono Formation. The slight decrease in pH, and rapid increase in conductance between stream mile 0.4 and 0.1 may indicate inflow of water containing sulfate.

Mass-balance calculations discussed in a later section, suggest that about one-quarter of the alkalinity in Piney Run is derived from silicate hydrolysis. The source of the remaining alkalinity is from weathering of carbonate rocks.

Ground Water

Six samples of ground water were collected from the Greenbrier Formation for this study. The locations of these samples are shown on figure 1, and the analyses are given in table 5. Five of the analyses are of water from wells, and one, GA CB-78, is of water from a fracture in the limestone mine operated by the Browning Limestone Company. Comparison of carbonate-related properties (conductance, pH, dissolved solids, hardness, alkalinity, and calcium) indicates that GA CB-76, CB-77, CB-78, and CC-35 derive water from the Greenbrier Formation. The analysis of water from the limestone mine (GA CB-78) and that from Piney Run shows the highest concentrations of specific conductance, dissolved solids, sodium adsorption ratio, hardness, sulfate, magnesium, and sodium of all the surface-water and ground-water analyses made for this study. The concentration of sulfate (35 mg/L) shown for GA CB-78 is similar to that found in Piney Run (28 mg/L) at stream mile 0.5. This is a further indication that part of the sulfate concentration detected at the mouth of Piney Run (130 mg/L) may be from a source other than the Greenbrier Formation.

Records of water wells and chemical quality data in Garrett County, Md. compiled by Nutter and others (1980) list chemical analyses of ground water from 48 wells. Five of these wells are in the Greenbrier Formation; one of which is in the project area. This well, GA CC-2 could not be resampled, but its chemical analysis is given in table 5 for comparison to that of GA CC-64. Wells GA CC-2 and CC-64 are estimated to be less than 500 feet apart, along the strike of the Greenbrier Formation.

ESTIMATION OF AVERAGE ANNUAL ALKALINITY

Results of Mass-Balance Calculations

The amount of alkalinity assigned by mass-balance calculations to each source is highly dependent on the assumed composition of bedrock material. However, based on the assumptions stated above, the approximate contribution of alkalinity from silicate hydrolysis and carbonate rock dissolution for project streams are given in table 6.

Table 6.--Sources of alkalinity in project streams

Stream	Alkalinity, percent from:		Greenbrier Formation, percentage of drainage basin
	Silicate hydrolysis	Carbonate rock	
Pawn Run	70	30	0
Meadow Mt. Run	65	35	17.5
Gravelly Run	55	45	0
Red Run	37	63	24
Piney Run	27	73	26
Fairgrounds Run	5	95	34

Although the percentage contributions of alkalinity shown in this table are approximate, they point out some interesting trends. For example, a high percentage of alkalinity in Fairgrounds Run is probably derived from carbonate rocks. In contrast, much of the alkalinity in Pawn Run is probably derived from silicate hydrolysis.

Results of Average Annual Alkalinity Computations

Computations of average annual alkalinity for project streams by the method described previously are summarized in table 7.

Table 7. Average annual alkalinity in project streams

Stream Basin	Drainage Basin area (mi^2)	Average Annual Calcium Carbonate Discharge (tons)	Average Annual Calcium Carbonate Yield (tons/mi^2)
Fairgrounds Run	0.41	12.01	29.3
Gravelly Run	0.70	12.75	18.21
Meadow Mt. Run	2.86	21.85	7.64
Pawn Run	2.14	49.15	22.97
Red Run	2.44	29.88	12.25
Piney Run	0.96	35.38	36.85
Total	9.51	161.02	

CONCLUSIONS

Six streams draining into the lake contribute an estimated average of 161 tons per year of alkalinity as $CaCO_3$. Much of this alkalinity is derived from weathering and solution of carbonate rocks which underlie the stream basins. A part of this alkalinity, however, is derived from the hydrolysis of silicates.

The alkalinity of Piney Run and Fairgrounds Run, which have the highest yields (table 7) has been increased by past and present limestone mining. This activity has exposed carbonate rock to solution by both surface water and ground water at a rate considerably greater than that which would result from normal weathering.

Red Run and Meadow Mountain Run have low average annual alkalinity yields even though they drain the Greenbrier Formation. This is most likely caused by reaction between alkaline components of the water and the organic acids that are generated in the large swamps that lie within these stream basins.

Part of the alkalinity of Gravelly Run is attributed to inflow of carbonate-rich water from the underlying Greenbrier Formation. The remainder is probably derived from silicate hydrolysis of minerals within the Mauch Chunk Formation.

Pawn Run does not drain any carbonate rocks, but nevertheless maintains a neutral pH, and an intermediate alkalinity. Possible sources of some of this alkalinity include application of agricultural limestone to fields and pastures in the headwaters, or unmapped carbonate-bearing members within the Jennings, Hampshire or Pocono Formations. The majority of the alkalinity, however, is probably derived from dissociation of feldspar and mica (biotite) in the bedrock formations of the basin.

The amount of alkalinity contributed to Deep Creek Lake by various other sources such as agricultural liming, flow from submerged springs, and use of crushed limestone in construction may be significant. Quantification of the input from these sources, however, was well beyond the limited scope of this study.

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APPENDIXES

APPENDIX I

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APPENDIX II

Conversion Factors

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

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.0630	liter per second (L/s)
million gallon per day (Mgal/d)	0.0438	cubic meter per second (m^3/s)
inch (in)	25.40	millimeter (mm)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
micromho (μmho)	1.00	microsiemen (μS)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°F = 1.8 \quad + 32$$