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Water Quality of Hydrologic Bench Marks— An Indicator of Water Quality in the Natural Environment

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Part E

Water Quality of Hydrologic Bench Marks— An Indicator of Water Quality in the Natural Environment

By James E. Biesecker and Donald K. Leifeste

C O N S E R V A T I O N   N E T W O R K S

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Water Quality of Hydrologic Bench Marks— An Indicator of Water Quality in the Natural Environment

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ABSTRACT

Water-quality data, collected at 57 hydrologic bench-mark stations in 37 States, allow the definition of water quality in the "natural" environment and the comparison of "natural" water quality with water quality of major streams draining similar water-resources regions. Results indicate that water quality in the "natural" environment is generally very good. Streams draining hydrologic bench-mark basins generally contain low concentrations of dissolved constituents. Water collected at the hydrologic bench-mark stations was analyzed for the following minor metals: arsenic, barium, cadmium, hexavalent chromium, cobalt, copper, lead, mercury, selenium, silver, and zinc. Of 642 analyses, about 65 percent of the observed concentrations were zero. Only three samples contained metals in excess of U.S. Public Health Service recommended drinking-water standards—two selenium concentrations and one cadmium concentration. A total of 213 samples were analyzed for 11 pesticidal compounds. Widespread but very low-level occurrence of pesticide residues in the "natural" environment was found—about 30 percent of all samples contained low-level concentrations of pesticidal compounds. The DDT family of pesticides occurred most commonly, accounting for 75 percent of the detected occurrences. The highest observed concentration of DDT was 0.06 microgram per litre, well below the recommended maximum permissible in drinking water. Nitrate concentrations in the "natural" environment generally varied from 0.2 to 0.5 milligram per litre. The average concentration of nitrate in many major streams is as much as 10 times greater.

The relationship between dissolved-solids concentration and discharge per unit area in the "natural" environment for the various physical divisions in the United States has been shown to be an applicable tool for approximating "natural" water quality. The relationship between dissolved-solids concentration and discharge per unit area is applicable in all the physical divisions of the United States, except the Central Lowland province of the Interior Plains, the Great Plains province of the Interior Plains, and the Basin and Ridge province of the Intermontane Plateaus. The relationship between dissolved-solids concentration and discharge per unit area is least variable in the New England province and Blue Ridge province of the Appalachian Highlands. The dissolved-solids concentration versus discharge per unit area in the Central Lowland province of the Interior Plains is highly variable.

A sample collected from the hydrologic bench-mark station at Bear Den Creek near Mandaree, N. Dak., contained 3,420 milligrams per litre dissolved solids. This high concentration in the "natural" environment indicates that natural processes can be principal agents in modifying the environment and can cause degradation. Average annual runoff and rock type can be used as predictive tools to determine the maximum dissolved-solids concentration expected in the "natural" environment.

INTRODUCTION

The United States is currently undergoing a growth of population and industry. This growth has and will continue to markedly alter the environment of this Nation. Hydrology—particularly water quality—is directly and significantly affected by environmental changes. In the report entitled "Restoring the quality of our environment," by the President's Science Advisory Committee, Environmental Pollution Panel (1965), it is stated that "Pollution touches us all. We are at the same time polluters and sufferers from pollution. Today we are certain that pollution adversely affects the quality of our lives. In the future, it may affect their duration."

In planning the optimum utilization of the Nation's most valuable resource—water—it is essential to understand the impact of man's activities on water quality. In turn, to evaluate this environmental impact, the water quality in its "natural" environment must be described. Water-quality data collected as part of the U.S. Geological Survey's Hydrologic Bench-Mark Program will provide the basis for this description. The hydrologic bench-mark network is comprised of selected stream basins which are expected to remain in their present or natural condition. Locations of the hydrologic bench-mark stations are shown in figure 1 and are listed in table 1. As described by Cobb and Biesecker (1971), the basins were selected on the basis of the following criteria:

1. No manmade storage, regulation, or diversion currently exists or is probable for many years.
2. Ground water within the basin will not be affected by pumping from wells.
3. Conditions are favorable for accurate measurement of streamflow, water quality, ground-water conditions, and precipitation.
4. The probability of special natural changes is minimal.

OBJECTIVES

The objectives of this report are twofold. The primary objective is to describe the water quality of streams draining the hydrologic bench-mark basins. Dissolved-solids, heavy metals, nitrate, and pesticidal contents of the streams are described. Janzer and Saindon (1972) reported the radiochemical analyses of surface waters from hydrologic bench-mark basins. Data on the biological characteristics of these "natural" basins currently being collected will be published in a future report. All the water-quality data for the hydrologic bench-mark stations are published, by water years, in the annual series of State basic-data reports

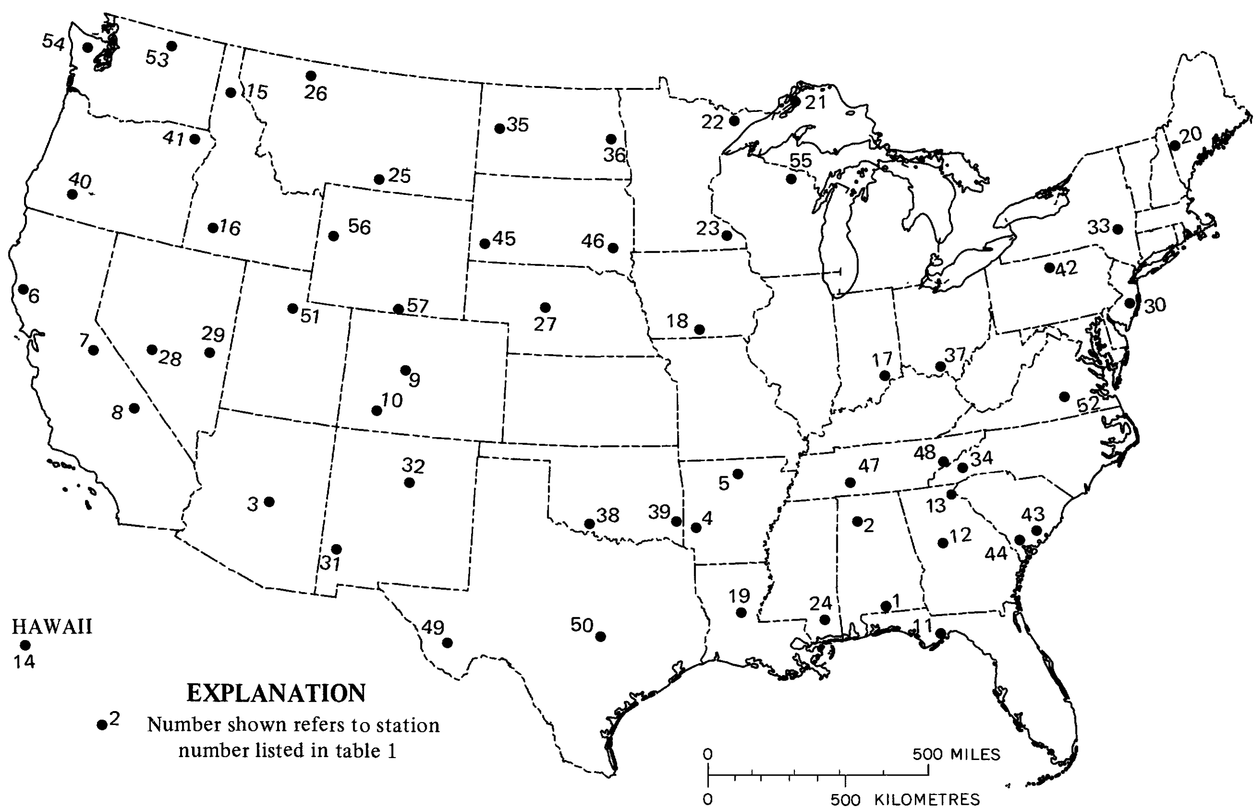

FIGURE 1.—Locations of hydrologic bench-mark stations.

TABLE 1.—*Locations of hydrologic bench-mark stations*

Station No.	Basin location	Station No.	Basin location
1	Blackwater River near Bradley, Ala.	30	McDonalds Branch in Lebanon State Forest, N.J.
2	Sipsey Fork near Grayson, Ala.	31	Mogollon Creek near Cliff, N. Mex.
3	Wet Bottom Creek near Childs, Ariz.	32	Rio Mora near Tererro, N. Mex.
4	Cossatot River near Vandervoort, Ark.	33	Esopus Creek at Shandaken, N.Y.
5	North Sylamore Creek near Fifty Six, Ark.	34	Cataloochee Creek near Cataloochee, N.C.
6	Elder Creek near Branscomb, Calif.	35	Bear Den Creek near Mandaree, N. Dak.
7	Merced River near Yosemite, Calif.	36	Beaver Creek near Finley, N. Dak.
8	Wildrose Creek near Wildrose Station, Calif.	37	Upper Twin Creek at McGaw, Ohio.
9	Halfmoon Creek near Malta, Colo.	38	Blue Beaver Creek near Cache, Okla.
10	Vallecito Creek near Bayfield, Colo.	39	Kiamichi River near Big Cedar, Okla.
11	Sopchoppy River near Sopchoppy, Fla.	40	Crater Lake near Crater Lake, Oreg.
12	Falling Creek near Juliette, Ga.	41	Minam River at Minam, Oreg.
13	Tallulah River near Clayton, Ga.	42	Young Womans Creek near Renovo, Pa.
14	Honolii Stream near Papaikou, Hawaii.	43	Scape Ore Swamp near Bishopville, S.C.
15	Hayden Creek below North Fork, near Hayden Lake, Idaho.	44	Upper Three Runs near New Ellenton, S.C.
16	Wickahoney Creek near Bruneau, Idaho.	45	Castle Creek near Hill City, S. Dak.
17	South Hogan Creek near Dillsboro, Ind.	46	Little Vermillion River near Salem, S. Dak.
18	Elk Creek near Decatur City, Iowa.	47	Buffalo River near Flat Woods, Tenn.
19	Big Creek at Pollock, La.	48	Little River above Townsend, Tenn.
20	Wild River at Gilead, Maine.	49	Limpia Creek above Fort Davis, Tex.
21	Washington Creek at Windigo, Isle Royale, Mich.	50	South Fork Rocky Creek near Briggs, Tex.
22	Kawishiwi River near Ely, Minn.	51	Red Butte Creek near Salt Lake City, Utah.
23	North Fork Whitewater River near Elba, Minn.	52	Holiday Creek near Andersonville, Va.
24	Cypress Creek near Janice, Miss.	53	Andrews Creek near Mazama, Wash.
25	Beauvais Creek near St. Xavier, Mont.	54	North Fork Quinault River near Amanda Park, Wash.
26	Swiftcurrent Creek at Many Glacier, Mont.	55	Popple River near Fence, Wis.
27	Dismal River near Thedford, Nebr.	56	Cache Creek near Jackson, Wyo.
28	South Twin River near Round Mountain, Nev.	57	Encampment River near Encampment, Wyo.
29	Steptoe Creek near Ely, Nev.		

compiled and distributed by the Water Resources Division, U.S. Geological Survey. Copies of these reports are available from the district offices in the various States.

The second objective of this report is to compare the quality of water of streams in the "natural" environment with the water quality of major streams draining the same hydrologic regions of the United States defined and used by the Water Resources Council (1968, p. 1-24).

WATER QUALITY IN THE "NATURAL" ENVIRONMENT

"Natural" water quality varies spatially and temporally—controlled primarily by climate, the kind of rocks and soils through which it moves, and the time it is in contact with these materials. Natural water quality is also influenced by biochemical reactions, by wind- or stream-transported sediments, and by evaporation.

The concentration of substances dissolved in water undergoes continual change as water passes through the hydrologic cycle. Water escapes to the atmosphere by evaporation as salt-free vapor. Precipitation, the purest of all liquid water, contains only small amounts of dissolved solids, gases, and dust particles. Runoff accumulates the soluble minerals from the upper layer of soil. Water passing through the soil and reaching an aquifer leaches additional minerals from the aquifer matrix. Because ground-water velocities are generally very slow,

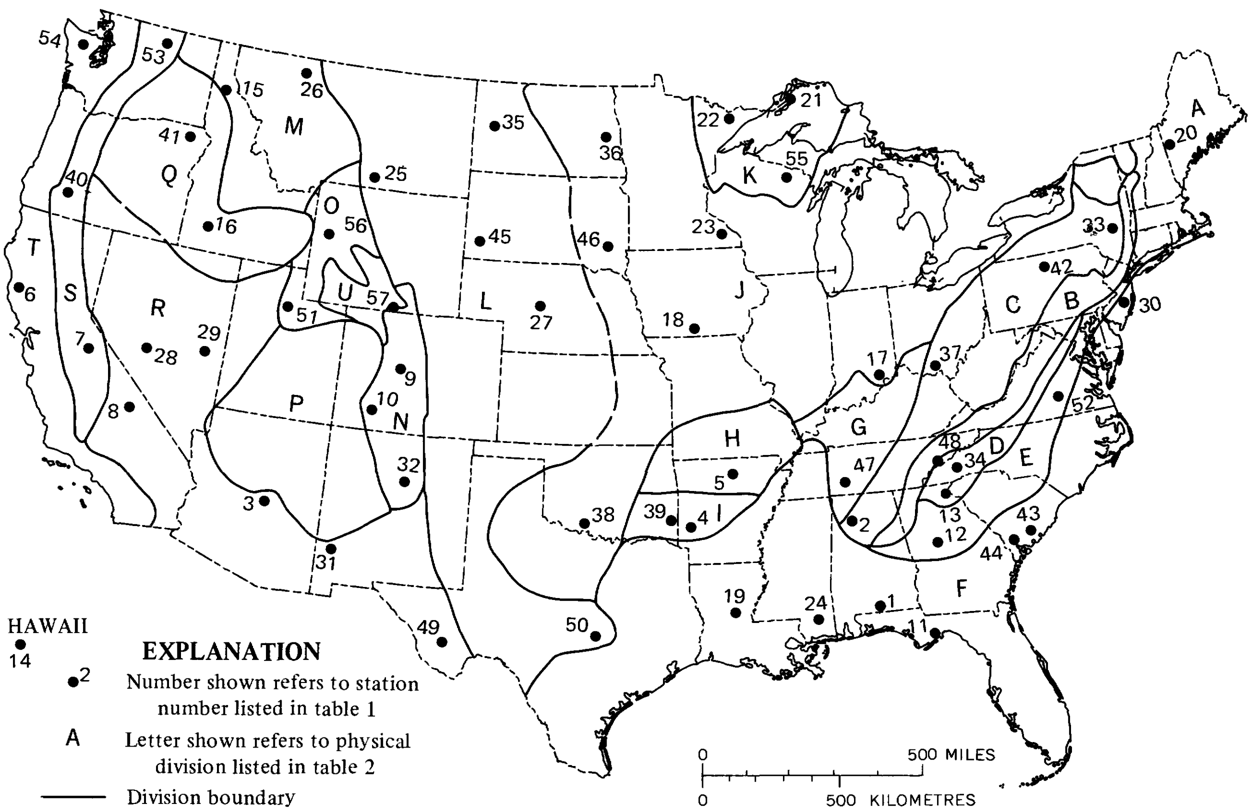

FIGURE 2.—Physical divisions of the United States (Fenneman, 1928).

water that reaches the water table is in contact with the rocks of an aquifer for a much longer time than it is in contact with the atmosphere or the soil. In the "natural" environment much of the dissolved-mineral content of ground water and of baseflow of streams is derived from aquifer minerals.

DISSOLVED-SOLIDS CONCENTRATION

Regionalization of "natural" water-quality characteristics is essential to predict the impact of man's various activities on water quality. One approach to regionalize water-quality characteristics is to use the physiographic divisions described by Fenneman (1928) as hydrologic divisions. These physical divisions are based on similar topographic and geographic features. The physical divisions of the conterminous United States listed in table 2 are shown in figure 2, which also shows the location of the hydrologic bench-mark network stations.

There are numerous ways to approach the analyses of water-quality data. For this report the authors have chosen to describe the variability of selected water-quality characteristics at a particular site and compare this variability with that at other sites within a given physical division as described by Fenneman (1928). In this manner major similarities or differences can be compared with other geologic and hydrologic characteristics of the various hydrologic bench-mark stations. One water-quality characteristic useful in interpretation is dissolved-solids concentration because it represents an integrated index of numerous dissolved inorganic substances. The relationship between dissolved-solids concentration and discharge per unit area gives quantitative information about the hydrologic system of the various physical divisions.

The relationship between water discharge per unit-drainage area, in cubic feet per second per square mile (cubic metres per second per square kilometre), and dissolved-solids concentration, in milligrams per litre, for hydrologic bench marks within a given physical division is frequently similar. Figure 3 presents the unit-area discharge–dissolved-solids relationship for all

TABLE 2.—*Physical divisions of the United States*

Letter	Province
A	New England province of the Appalachian Highlands.
B	Valley and Ridge province of the Appalachian Highlands.
C	Appalachian Plateaus province of the Appalachian Highlands.
D	Blue Ridge province of the Appalachian Highlands.
E	Piedmont province of the Appalachian Highlands.
F	Coastal Plain province of the Atlantic Plain.
G	Interior Low Plateaus province of the Interior Plains.
H	Ozark Plateaus province of the Interior Highlands.
I	Ouachita province of the Interior Highlands.
J	Central Lowland province of the Interior Plains.
K	Superior Upland province of the Laurentian Upland.
L	Great Plains province of the Interior Plains.
M	Northern Rocky Mountains province of the Rocky Mountain System.
N	Southern Rocky Mountains province of the Rocky Mountain System.
O	Middle Rocky Mountains province of the Rocky Mountain System.
P	Colorado Plateaus province of the Intermontane Plateaus.
Q	Columbia Plateaus province of the Intermontane Plateaus.
R	Basin and Range province of the Intermontane Plateaus.
S	Cascade-Sierra Mountains province of the Pacific Mountain System.
T	Pacific Border province of the Pacific Mountain System.
U	Wyoming Basin of the Rocky Mountain System.

bench-mark basins draining four selected physical divisions—the New England and Blue Ridge provinces of the Appalachian Highlands, the Central Lowland province of the Interior Plains, and the Rocky Mountain System.

Four hydrologic bench-mark stations are located in the New England and Blue Ridge provinces of the Appalachian Highlands. The unit-area discharge-dissolved-solids relationship for each of these is shown in figure 3*A*. Cataloochee Creek near Cataloochee, N.C. (station 34), exhibits the most variable unit-area discharge-dissolved-solids relationship—the range of dissolved-solids concentration is only 8 mg/l (milligrams per litre). The maximum concentration is 19 mg/l and the minimum concentration is 11 mg/l for a tenfold change of unit-area discharge, 0.5 to 5.0 $ft^3\ s^{-1}\ mi^{-2}$ (cubic feet per second per square mile) or 0.037 to 0.366 $m^3\ s^{-1}\ km^{-2}$ (cubic metres per second per square kilometre). For all practical purposes, a variation in concentration of only 8 mg/l dissolved solids can be considered as virtually constant.

Water-quality information is available for five hydrologic bench-mark basins draining the Central Lowland province of the Interior Plains. The unit-area discharge–dissolved-solids relationship of these five basins (fig. 3*B*) is highly variable. One reason is probably the wide range in climate over this large area. However, by subdividing the physical division north of Oklahoma, it can be shown that all stations in the northern part of the physical division exhibit similar unit-area discharge–dissolved-solids characteristic curves. Hydrologic bench-mark basins draining the Rocky Mountain System—physical divisions M, N, and O, as shown in table 2 and figure 2—exhibit remarkably similar unit-area discharge–dissolved-solids curves (fig. 3*C*).

The use of unit-area discharge-median dissolved-solids curves for the various physical divisions permits more generalization and comparison of water-quality characteristics of streams draining the natural environment of the various physical divisions. Figure 4 presents unit-area discharge–median dissolved-solids relationships for the various physical divisions. The unit-area discharge-dissolved-solids relationships for the streams draining the hydrologic bench-mark basins located in the southern part of the Central Lowland province of the Interior Plains (J), the Great Plains province of the Interior Plains (L), and the Basin and Range province of the Intermontane Plateaus (R) are not sufficiently similar to be represented by a median curve. Pertinent statistical characteristics of the median curves shown in figure 4 are presented in table 3. Table 3 also describes the statistical dispersion characteristics of the group of curves within each physical division. The unit-area discharge-dissolved-solids relationships for streams draining the Great Plains province are most dispersed.

Streams in hydrologic bench-mark basins in the New England province and the Blue Ridge

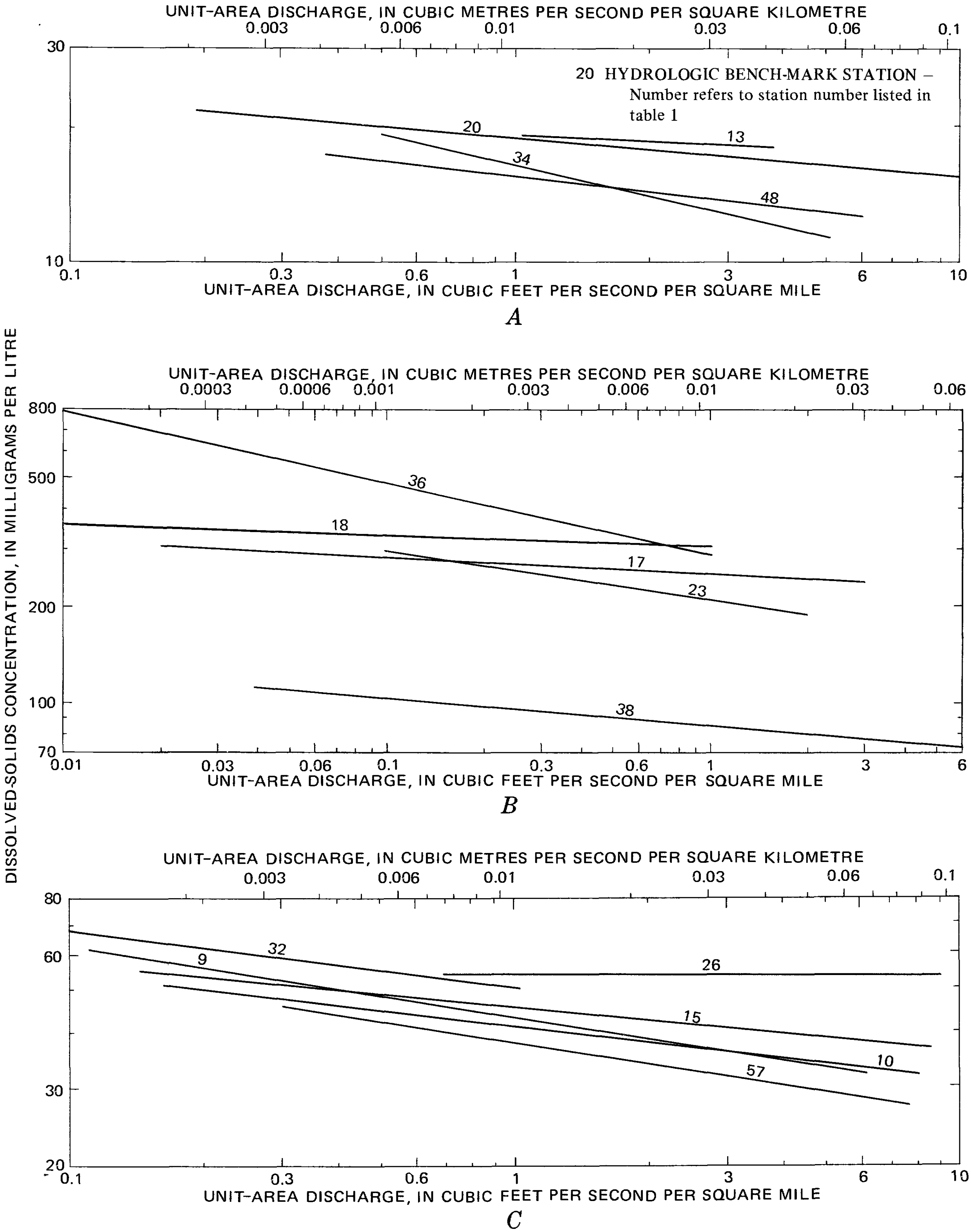

FIGURE 3.—Unit-area discharge-dissolved-solids relationship for hydrologic bench-mark stations in (*A*) the New England and Blue Ridge provinces of the Appalachian Highlands, (*B*) the Central Lowland province of the Interior Plains, and (*C*) the Rocky Mountain System.

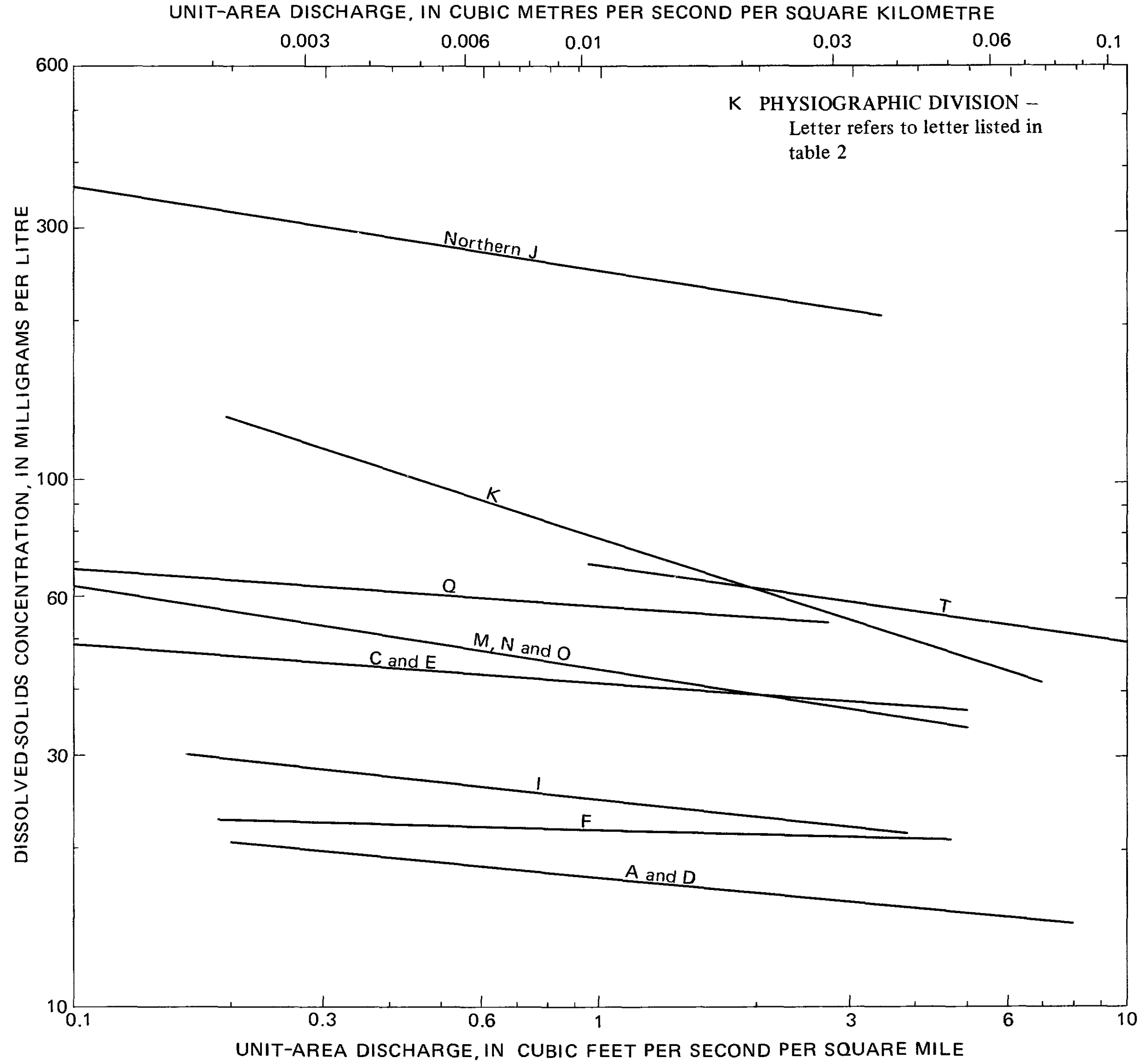

FIGURE 4.—Unit-area discharge-median dissolved-solids-concentration curves for various physical divisions.

province of the Appalachian Highlands (A and D) contain less dissolved minerals than do the streams draining hydrologic bench-mark basins in any other part of the country. "Natural" waters containing the most dissolved minerals are from those streams draining the bench-mark basins located in the Interior Plains. For example, one sample collected from Bear Den Creek near Mandaree, N. Dak. (station 35), contained 3,420 mg/l dissolved solids. Hydrologic bench-mark streams draining the Coastal Plain province of the Atlantic Plain (F) exhibited the least variation in the unit-area-discharge-dissolved-solids relationship.

PESTICIDES

The term "pesticides" refers to those chemical compounds used for the control or destruction of animal or plant organisms that may be considered nuisances, or pests. The widespread use of pesticides has enabled man to achieve greater agricultural productivity, improved comfort, and better health. However, this widespread use

TABLE 3.—*Statistical characteristics of the unit-area discharge–median dissolved-solids relationships for the various physical divisions*

Physical division[1]	Median dissolved-solids concentration for discharge of 1.0 $ft^3\ s^{-1}\ mi^{-2}$	Distribution of dissolved-solids concentration for discharge of 1.0 $ft^3\ s^{-1}\ mi^{-2}$			Slope of median curve
		Maximum	Minimum	Range	
A and D	18	19	16	3	0.096
C and E	42	69	28	41	.072
F	22	34	15	19	.022
I	25	29	21	8	.12
J	(2)	300	84	216	(2)
Northern J[3]	250	300	220	80	.16
K[4]	77	82	72	10	.32
L	(2)	420	20	400	(2)
M, N, O	45	54	38	16	.14
Q	59	70	49	21	.060
R	(2)	175	64	111	(2)
T	70	72	68	4	.15

[1]Letters refer to those listed in table 2.
[2]Median values not meaningful because of excessive scatter.
[3]North of Oklahoma.
[4]Basins draining alluvium.

TABLE 4.—*Pesticide analyses of water samples collected at hydrologic bench-mark stations, 1968–70 water years*

Pesticidal compound	Aldrin	DDD	DDE	DDT	Dieldrin	Endrin	Heptachlor	Lindane	2, 4-D	2, 4, 5-T	Silvex
Number of analyses	213	213	213	213	213	213	213	213	176	176	175
Number of positive occurrences	0	6	2	36	4	0	0	3	3	4	1
Maximum observed concentration ($\mu g/l$)	---	.02	.01	.06	.02	---	---	.01	.10	.02	1.5

has also created many environmental problems, documented fish kills being an example.

Samples collected from the bench-mark stations were analyzed for 11 pesticide compounds (table 4). Table 4 also shows the number of stream samples analyzed, the number of positive occurrences, and the maximum observed concentration. There were 213 analyses for aldrin, DDD, DDE, DDT, dieldrin, endrin, heptachlor, and lindane; 176 analyses for 2, 4-D, and 2, 4, and 5-T; and 175 analyses for silvex. Fifty-nine positive occurrences were detected in the observations during the 3-year period reported herein. Of these 59 positive occurrences, DDT was detected 36 times, DDD 6 times, and DDE 2 times. These results show that the DDT family accounted for 44 of the 59 positive occurrences; therefore, at bench-mark stations, as in major streams, the DDT family of pesticides is the most commonly occurring, accounting for about 75 percent of the detected occurrences. As shown in table 4, the maximum observed concentration of DDT was 0.06 $\mu g/l$ (microgram per litre), well below the recommended permissible drinking-water maximum of 42 $\mu g/l$ (U.S. Federal Water Pollution Control Administration, 1968, p. 20).

Pesticide levels in some of the major streams of the United States are available (Manigold and Schulze, 1969; Breidenbach and others, 1967). Results of a 1964 nationwide synoptic survey (Breidenback and others, 1967) showed that dieldrin appeared (positive or presumptive) in 74 percent of all grab samples. Manigold and Schulze (1969) reported results of monthly measurements for the 24-month period of October 1966 to September 1968 at 20 sites on streams west of the Mississippi River. These data showed that DDT and its metabolites, DDD and DDE occurred most frequently; 82 percent of all occurrences were due to these com-

TABLE 5.—*Pesticide analyses of bottom sediments, hydrologic bench-mark stations, 1968-70 water years*

Pesticidal compound	Aldrin	DDD	DDE	DDT	Dieldrin	Endrin	Heptachlor	Lindane
Number of analyses	126	126	126	126	126	126	126	126
Number of positive occurrences	0	39	28	40	4	0	0	6
Maximum observed concentration ($\mu g/kg$)	0	96	29	43	4.5	0	0	1.7

pounds. Each of the 12 pesticide compounds looked for were detected at least once during the 24-month period.

Table 5 shows the results of analysis of bottom sediments from the bench-mark stations. Stream sediments generally act as accumulators of organic materials in water and serve as integrators of stream conditions over long time periods. The accumulation period is generally that time span between runoff events when bottom sediments may be transported downstream. Bottom sediments therefore should be better indicators of the presence of pesticides than is the stream water itself. As given in table 5, DDT or its metabolites were detected in 107 of the 126 samples of sediments analyzed. Dieldrin was detected in four samples, and lindane in six. These data indicated widespread low-level occurrence of pesticides in the "natural" environment. In some bench-mark basins limited agricultural activities and in other basins pest control spraying in State and National forests could account for the pesticide residues detected; however, it seems that atmospheric transport might play a significant role in the continental distribution of pesticide residues.

MINOR METALS

Because minor metals can greatly affect the potential utility of water and also control or alter ecosystems, they are another group of water-quality indicators of great importance. Minor metals were determined in samples collected from streams draining hydrologic bench-mark basins. The number of analyses performed are summarized in table 6. Concentrations of arsenic, barium, cadmium, hexavalent chromium, cobalt, copper, lead, mercury, selenium, silver, and zinc were determined. Of 642 analyses for 11 minor metals, only 3 concentrations were found to be in excess of drinking-water standards—2 selenium concentrations out of 16 samples and 1 cadmium concentration out of 81 samples. Of the 642 analyses, 414 analyses showed zero concentration of the particular metal analyzed. Table 7 lists the U.S. Public Health Service (1962) drinking water standards for the minor metals analyzed and the maximum concentrations observed in samples collected at hydrologic bench-mark stations.

THE INFLUENCE OF MAN

As population and industry expand in any area, human and industrial wastes are un-

TABLE 6.—*Minor-metal analyses, hydrologic bench-mark stations, 1968-70 water years*

Minor metal	Total	Arsenic	Barium	Cadmium	Hexavalent chromium	Cobalt	Copper	Lead	Mercury	Selenium	Silver	Zinc
Number of determinations performed	642	58	22	81	9	70	126	108	3	16	18	131
Number of samples containing zero concentration	414	45	15	71	4	61	87	71	1	5	11	43
Number of samples containing concentrations in excess of U.S. Public Health Service drinking-water standards	3	0	0	1	0	(1)	0	0	(1)	2	0	0

1No established drinking-water standards.

TABLE 7.—*Minor-metal drinking-water standards and observed maximum values, 1968-70 water years*

Minor metal	Arsenic	Barium	Cadmium	Hexavalent chromium	Cobalt	Copper	Lead	Mercury	Selenium	Silver	Zinc
U.S. Public Health Service drinking-water standards (μg/l)	50	1,000	10	50	([1])	1,000	50	([1])	10	50	5,000
Maximum observed concentration (μg/l)	20	500	20	30	11	40	50	0.5	22	50	300

[1]No established drinking-water standards.

TABLE 8.—*Hydrologic bench-mark stations and major stream stations for selected water-resources regions*

Water-resources region	Hydrologic bench-mark station	U.S. Geological Survey station	Location of selected major streams
North Atlantic	20, 30, 33, 42	1-1840	Connecticut River at Thompsonville, Conn.
		1-3580	Hudson River at Green Island, N.Y.
		1-4635	Delaware River at Trenton, N.J.
		1-6385	Potomac River at Point of Rocks, Md.
South Atlantic-Gulf	2, 11, 12, 13, 24, 43, 44, 52	2-0660	Roanoke River at Randolph, Va.
		2-1290	Pee Dee River near Rockingham, N.C.
		2-2360	St. Johns River near De Land, Fla.
		2-4295	Alabama River at Clairborne, Ala.
		2-4895	Pearl River near Bogalusa, La.
Missouri	18, 25, 26, 27, 35, 57	6-1855	Missouri River near Culbertson, Mont.
		6-3265	Yellowstone River near Sidney, Mont.
		6-4810	Big Sioux River near Dell Rapids, S. Dak.
Arkansas-White-Red	4, 5, 9, 19, 38, 39	7-0770	White River at De Valles Bluff, Ark.
		7-2291	Canadian River near Noble, Okla.
		7-2635	Arkansas River at Little Rock, Ark.
		7-3444	Red River near Hosston, La.
		7-3620.65	Ouachita River below Camden, Ark.
Columbia-North Pacific	15, 16, 40, 41, 54, 56	13-1545	Snake River at King Hill, Idaho.
		14-1057	Columbia River at The Dalles, Oreg.
		14-1910	Willamette River at Salem, Oreg.

avoidably added to the water of the developing region. Salts, metals, pesticides, nutrients, and other substances associated with man's activities are superimposed on the substances which occur naturally in water. One way of evaluating the effect of man's activities on the water quality of a given region is to compare the unit-area discharge and dissolved-solids-concentration relation for hydrologic bench-mark basins to that of major streams draining a given region. The Water Resources Council (1968, p. 2-3) established water-resources regions for the United States in base year 1965 (fig. 5). Table 8 lists all water-resources regions which have at least four hydrologic bench-mark stations and also lists locations of major streams where water-quality data are collected in the respective regions. Comparison of the water-quality characteristics at the bench-mark stations and major stream stations will indicate the effect of man's activities on the water quality in the various water-resources regions.

Table 9 lists the population density and average runoff for the North Atlantic, South Atlantic-Gulf, Missouri, Arkansas-White-Red, and Columbia-North Pacific Water-Resources Regions. Figures 6-10 show the unit-area discharge-dissolved-solids-concentration relationship for the various hydrologic bench-mark stations and selected major river basins draining the respective water-resources regions. Examination of these figures indicates the relationship between water quality in the natural environment and water quality of major streams in these various regions. The most consistent relationship between water quality in the natural environment and water quality of major streams occurs in the North Atlantic

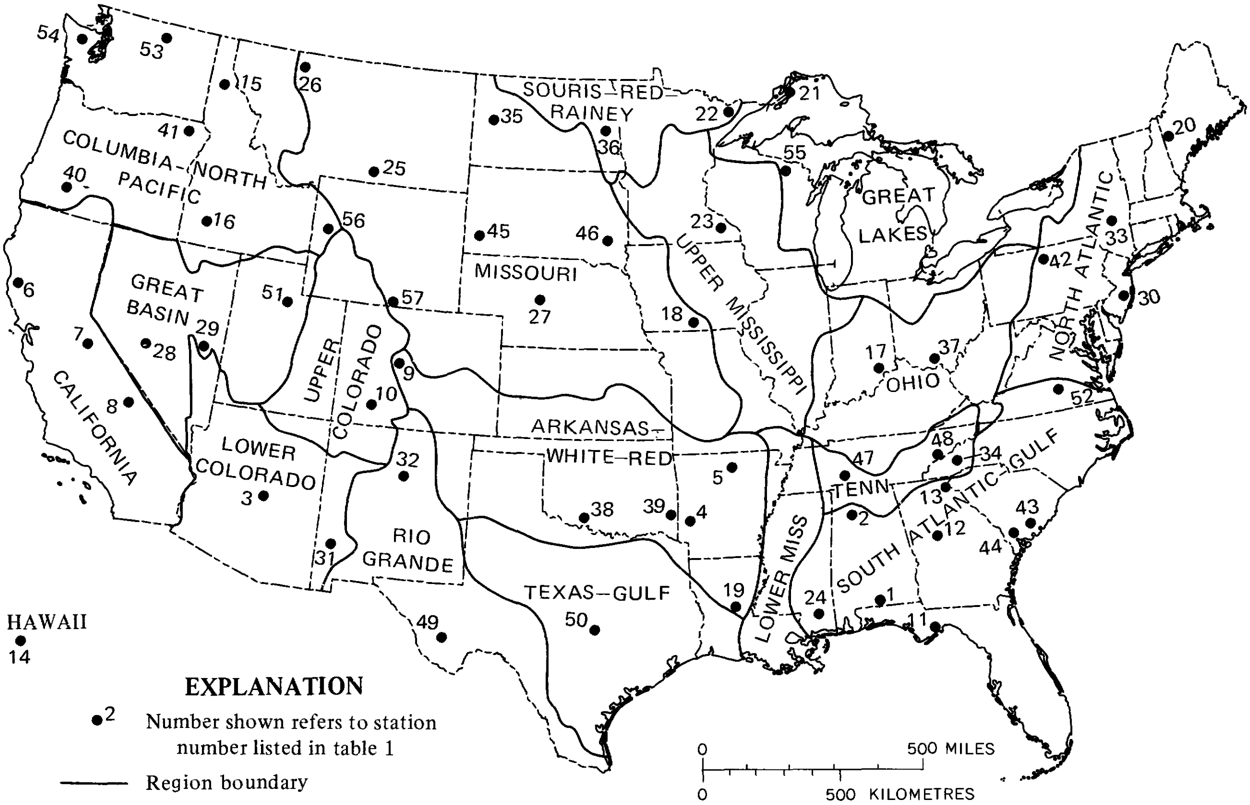

FIGURE 5.—Water-resources regions of the United States.

TABLE 9.—*Population density and average runoff for selected water-resources regions*[1]

Water-resources region	Area (sq mi)	Population in 1960	Population density (persons per sq mi)	Average runoff (in.)
North Atlantic	172,000	43,900,000	255	19.95
South Atlantic-Gulf	276,000	19,700,000	71	15.01
Missouri	515,000	7,800,000	15	2.21
Arkansas-White-Red	282,000	7,100,000	25	7.13
Columbia-North Pacific	274,000	5,400,000	20	16.07

[1]From Water Resources Council (1968, p. 1-1 to 1-5).

Region. All hydrologic bench-mark stations draining the North Atlantic Region contain less than 40 mg/l of dissolved solids. The selected major streams draining the region contain from 40 to 300 mg/l of dissolved solids. One of the reasons the effects of man on water quality is so apparent in the North Atlantic Region is the fact that, although it represents only about 5 percent of the area of the country, population of the region accounts for about 25 percent of the population of the United States. This region contains the largest urbanized complex in the Nation, and discharge of wastes to water and resulting degradation of water quality is a severe problem in many areas.

Streams draining the natural environment of the South Atlantic-Gulf Water-Resources Region also contain relatively low concentrations of dissolved solids. Generally, major streams draining this region contain more dis-

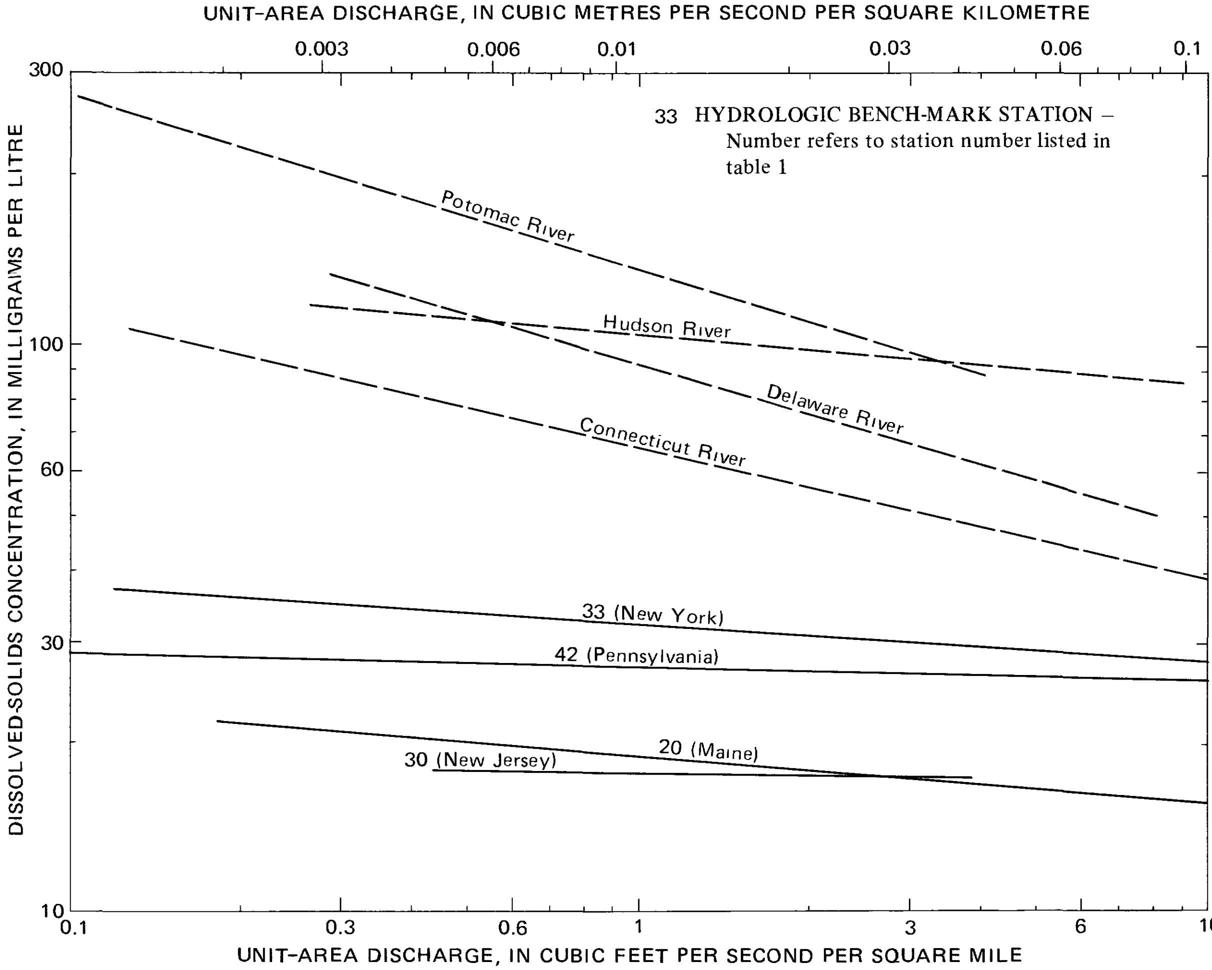

FIGURE 6.—Unit-area discharge versus dissolved-solids concentration for streams draining hydrologic bench-mark stations and major river basins in the North Atlantic Region.

solved solids than streams draining the natural environment. The St. Johns River, which drains populous northeast Florida, contains the most dissolved solids of major streams in this region. Major streams generally contain more dissolved solids than streams draining the natural environment of this region, but the relationship is not nearly so pronounced as it is in the North Atlantic Region. One reason is that the population density in this region is only about one-fourth as high as the population density in the North Atlantic Region.

The Missouri Water-Resources Region has the lowest population density and lowest average runoff of the five regions listed in table 9. Both factors contribute to a nonsystematic relationship between water quality and the natural environment and the water quality of the major streams draining this region. Streams draining the natural environment of this region indicate that poor water quality can result from a natural process, as well as from a man-induced process. The role of natural processes in environmental degradation was recently emphasized by the late William T. Pecora, then Director of the U.S. Geological Survey, in a commencement address (1970) at the George Washington University in which he scored what he termed an "environmental myth"—the belief by many people that man alone is degrading and polluting his environment by our modern society. Dr. Pecora gave the following examples to demonstrate that natural processes are principal agents in modifying the environment: "Many have long believed that water issuing from natural springs is pure and

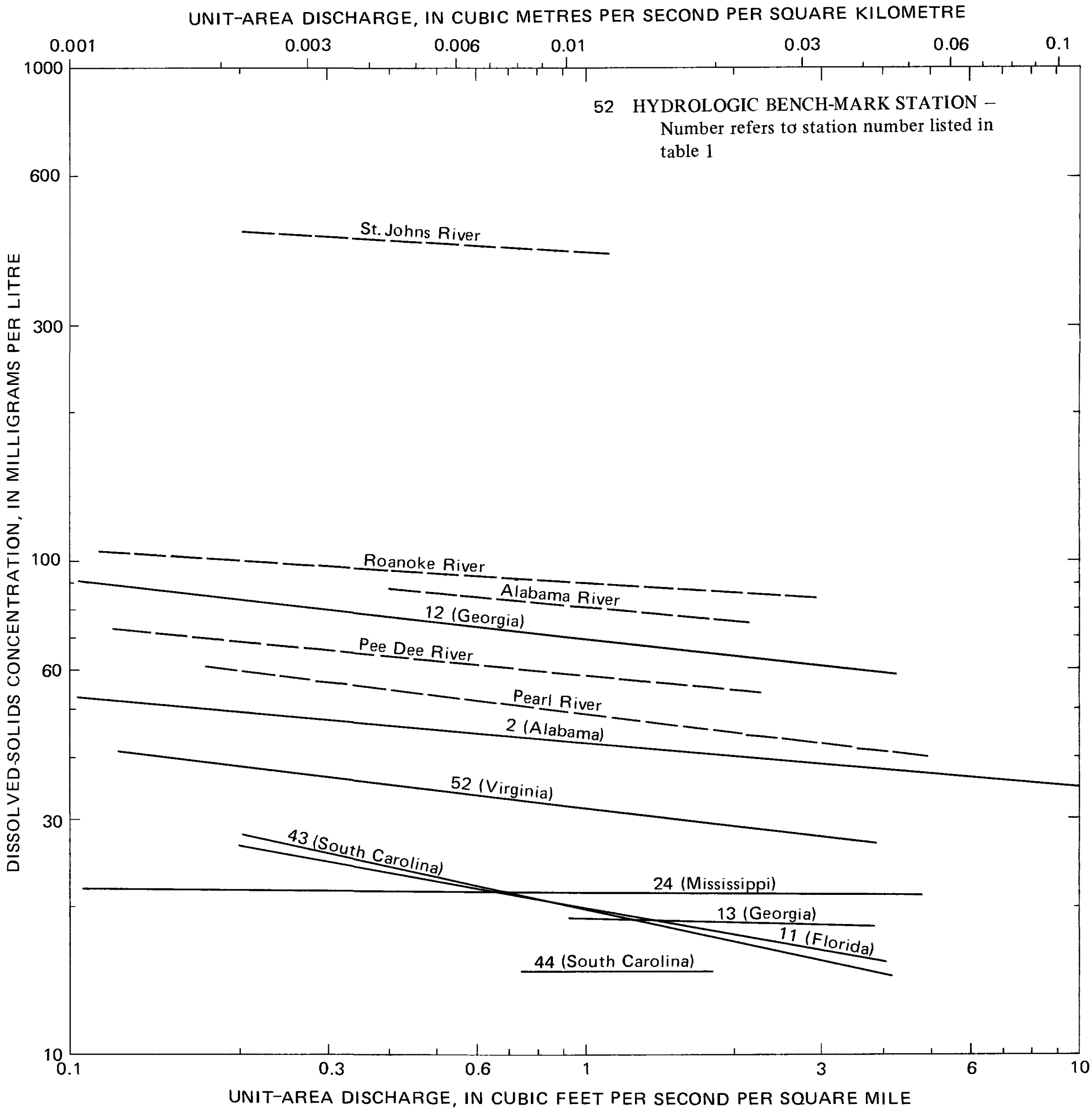

FIGURE 7.—Unit-area discharge versus dissolved-solids concentration for streams draining hydrologic bench-mark stations and major river basins in the South Atlantic-Gulf Region.

beneficial to health because of its purity. The springs issuing into the Arkansas and Red Rivers carry 17 tons of salt per minute. The Lemonade Springs in New Mexico carry 900 pounds of sulfuric acid per million pounds of water, which is ten times the acid concentration of most acid-mine streams in the Nation."

Data collected at the hydrologic bench-mark station located at Bear Den Creek near Mandaree, N. Dak. (station 35, fig. 8), further emphasize that waters containing high concentrations of dissolved minerals do exist in the natural environment. For instance, a sample collected at the Mandaree station contained 3,420 mg/l of dissolved solids. Examination of figure 10 shows a wide scatter for the hydro-

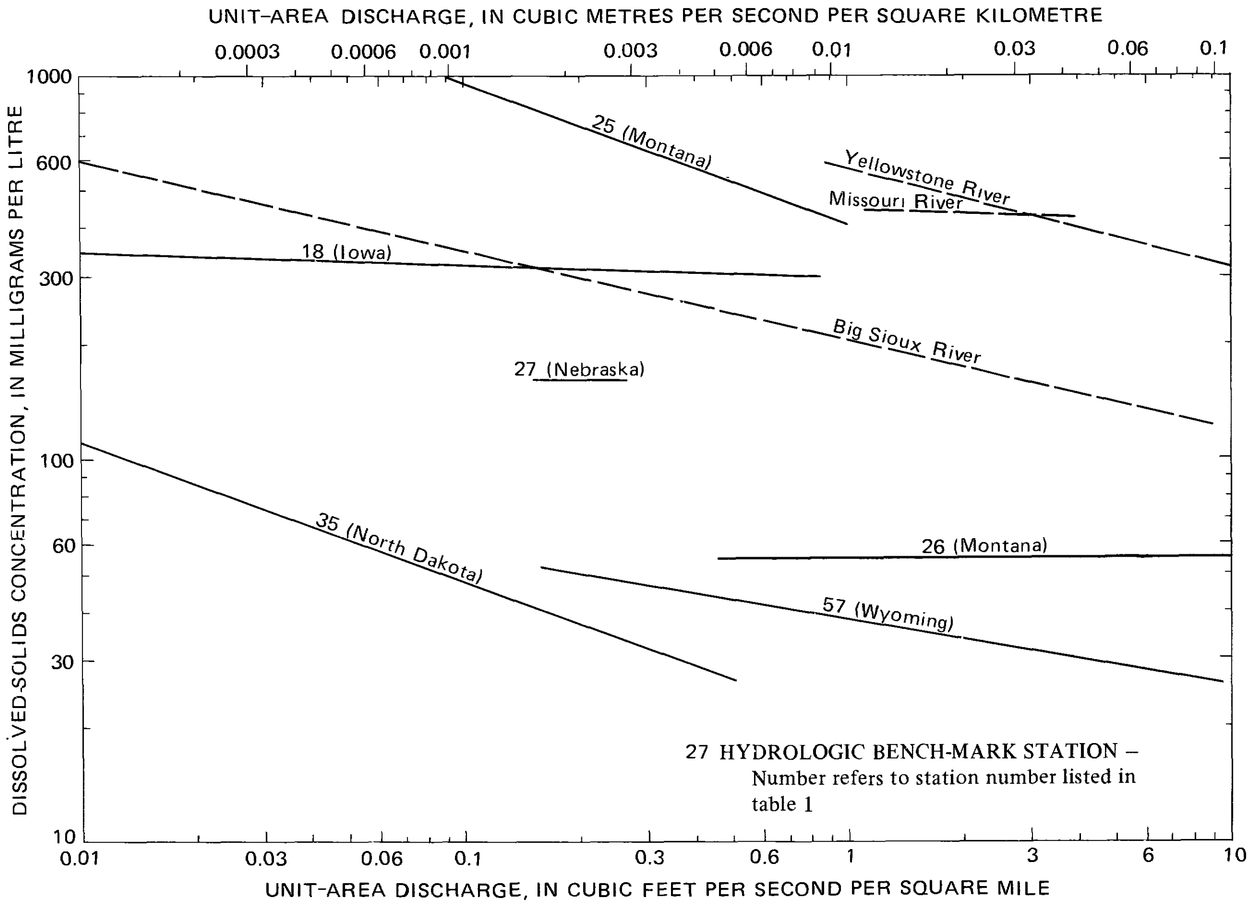

FIGURE 8.—Unit-area discharge versus dissolved-solids concentration for streams draining hydrologic bench-mark stations and major river basins in the Missouri Region.

logic bench-mark stations and major streams draining this region, with water at several of the bench-mark stations containing appreciably more dissolved solids than the major streams. All major streams draining the Arkansas-White-Red Water-Resources Region (fig. 9) contain higher dissolved-solids concentrations than the hydrologic bench-mark stations draining the same region.

NITRATE

Table 10 summarizes nitrate nitrogen concentration for those streams draining hydrologic bench-mark stations and major streams listed in table 8. Comparison of the average median values shows that man's activities have influenced nitrate concentration the least in the South Atlantic-Gulf Region and the greatest in the North Atlantic Region, again demonstrating the effects of the large urbanized complex in the northeast. Significantly higher median values are apparent in the Arkansas-White-Red, Columbia-North Pacific, and Missouri Regions, reflecting the effects of agricultural use of nitrogen fertilizers. The highest average maximum values in major streams occur in the agriculturally dominated Arkansas-White-Red and Missouri Regions. The highest average maximum nitrate concentrations in bench-mark stations occurred in the Missouri Region, reflecting the strong influence of bench-mark site No. 18, one of the few bench-mark basins where cultivated crops are grown.

Data in table 10 indicate that average median nitrate concentrations of streams draining hydrologic bench marks range from 0.2 to 0.5 mg/l. Average nitrate concentrations in many major streams are as much as 14 times greater than natural concentrations and vary geo-

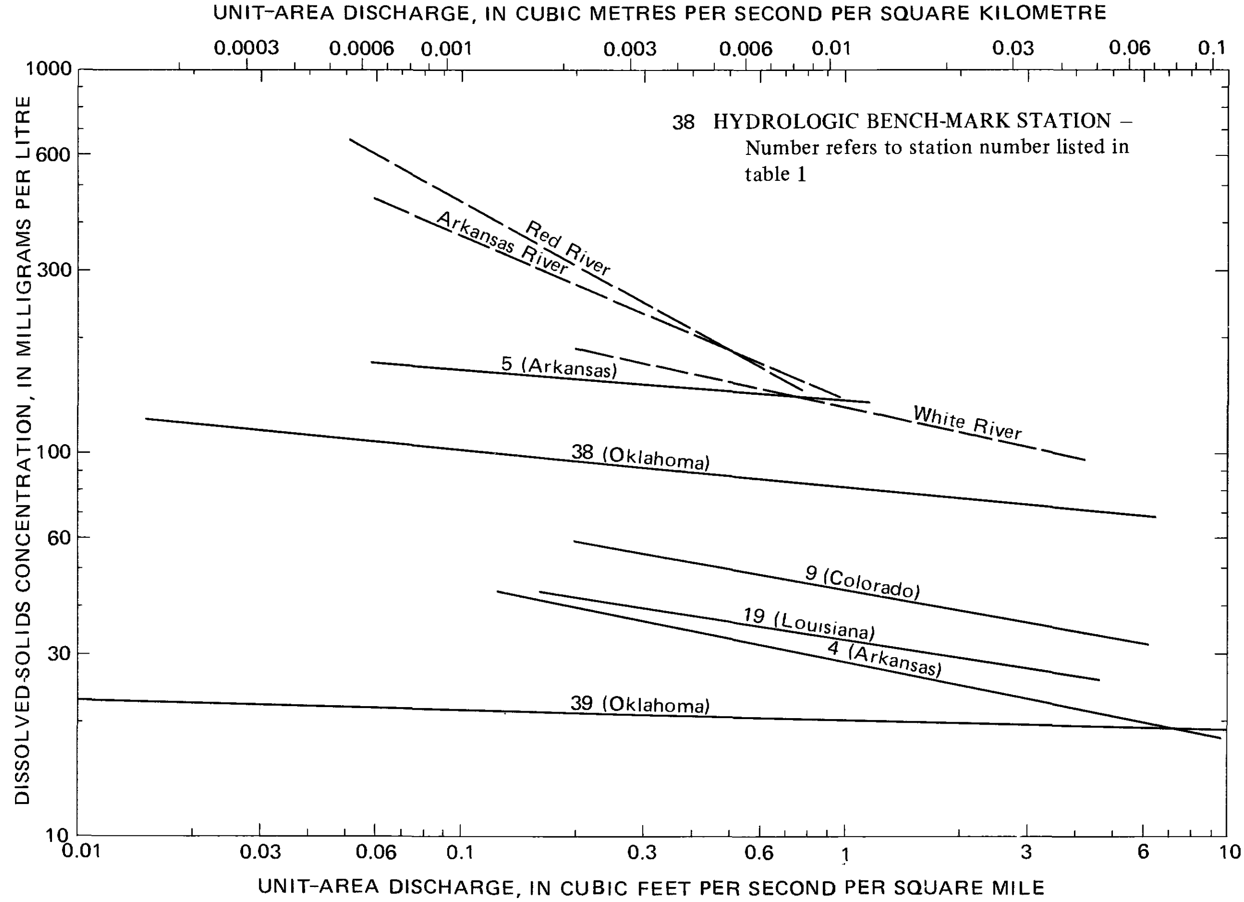

FIGURE 9.—Unit-area discharge versus dissolved-solids concentration for streams draining hydrologic bench-mark stations and major river basins in the Arkansas-White-Red Region.

TABLE 10.—*Nitrate concentration of hydrologic bench-mark stations and selected major streams draining various water-resources regions, 1968–70 water years*

Water-resources region	Nitrate concentration (mg/l)			
	Hydrologic bench marks[1]		Selected major streams[1]	
	Average maximum	Average median	Average maximum	Average median
North Atlantic	1.7	0.3	5.9	2.9
South Atlantic-Gulf	1.7	.5	2.1	.4
Missouri	4.9	.4	7.4	1.0
Arkansas-White-Red	1.0	.2	16	1.9
Columbia-North Pacific	1.0	.2	6.1	1.0

[1]Sites listed in table 8.

graphically, being dependent mostly on population density and intensity of agricultural use of the land.

ANALYSIS OF SEVERAL FACTORS AFFECTING "NATURAL" WATER QUALITY

In the natural environment the quantity and type of chemical constituents dissolved in water depend mainly on the type of rocks with which the water comes in contact, on length of contact time, and on rainfall. Rocks are composed of minerals, most of which are resistant to solution by water. Over great periods of time, however, appreciable amounts of these minerals can be dissolved. Different rock types vary in

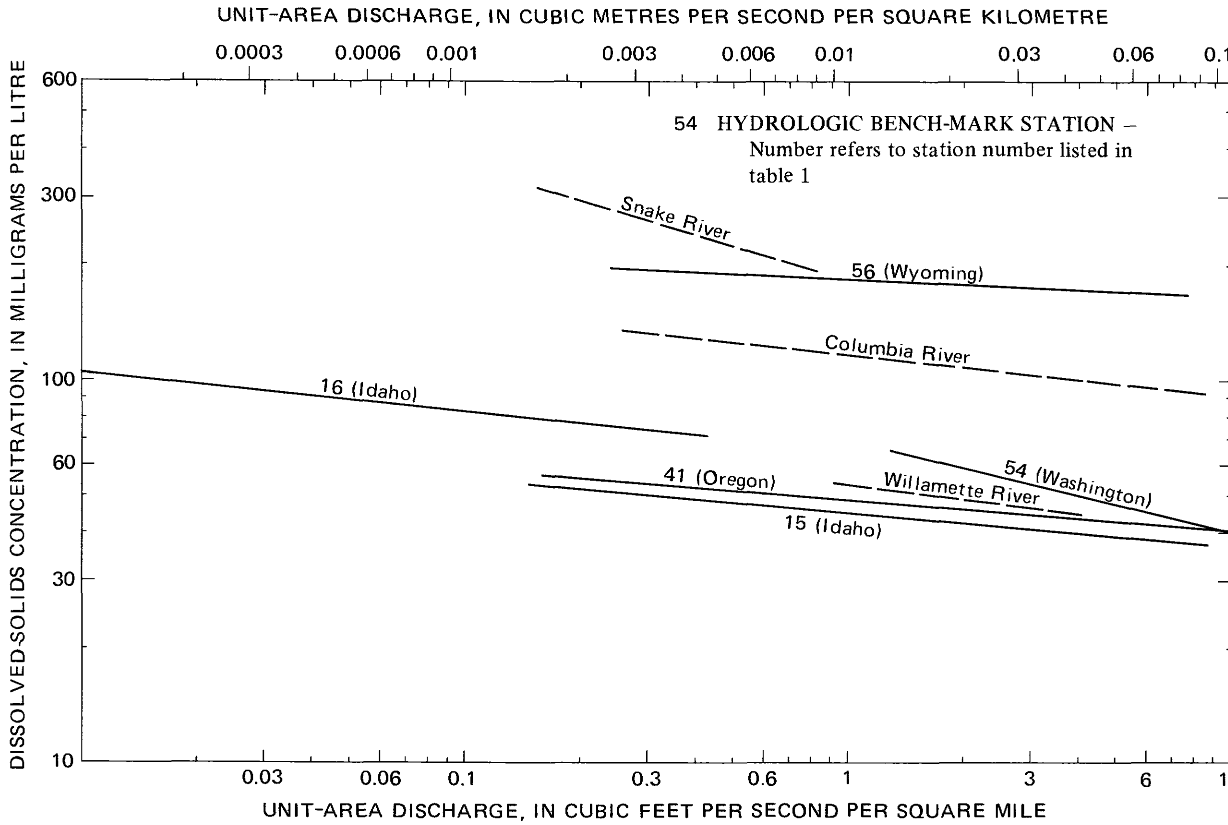

FIGURE 10.—Unit-area discharge versus dissolved-solids concentration for streams draining hydrologic bench-mark stations and major river basins in the Columbia–North Pacific Region.

resistance to solution. Some rocks—granite, for instance—are not readily dissolved by water, but other rocks, such as limestone, are readily soluble.

When precipitation and the resulting runoff are insufficient to redissolve salts accumulating as a result of evaporation, these salts accumulate in the soil or on exposed streambeds. Salt residues, common in many parts of the arid Western United States, are seldom seen in humid areas.

The combined effect of these two hydrologic factors—rock type and runoff—on water quality is illustrated in figure 11, which shows the relationship between maximum dissolved-solids concentration and average annual runoff (mainly a function of precipitation) for streams draining various rock types. Data used in the preparation of figure 11 are summarized in table 11.

The curves in figure 11 are a function of several natural phenomena—the solubility of the minerals composing the rock type, the rate of solution of those minerals, the flow-through rate of the water within the rock, the amount of precipitation, and the dissolved-solids concentration in the precipitation. In regions of low average annual runoff—where water containing maximum dissolved-solids concentrations has been in contact with the rocks for a long period of time and is little affected by dilution due to runoff—relatively insoluble sand and gravel exhibit the lowest concentrations of dissolved solids, and volcanic rocks and limestone showing progressively greater concentrations. This progression is what one would expect on the basis of both the solubility and the rate of dissolution of the rocks. An explanation of some of the other characteristics shown by the curves in figure 11 requires that other properties than solubility and rate of solution be taken into account also.

Ground water in the most permeable rocks—limestone and basalt—has maximum velocity for a given energy gradient. Because water moves through these rocks and into surface streams relatively rapidly, contact time is short; consequently, less material is dissolved from limestone and basalt in areas with low average annual runoff than from less soluble rocks with which the water is in contact for a longer period of time. In areas of higher average annual runoff, however, the rate of dissolution of volcanic rocks and limestone is high enough that dilution by the increased runoff is minimal, and maximum dissolved-solids concentrations are greater than in the less soluble rocks. This relationship is shown in figure 11 by the lesser slopes of the curves for volcanic rocks and limestone and their intersection with the curves for the less readily soluble rocks—granite, shale, sandstone, schist, and gneiss. The nearly horizontal curve for sand and gravel reflects the insolubility of that rock type, and its dissolved-solids intercept is probably more dependent on the dissolved-solids concentration in precipitation falling on the basin than on solution of minerals in the rock.

The characteristic curves for shale and sandstone and those for the metamorphic rocks—schist and gneiss—exhibit similar characteristics. This suggests that one of the most easily traced progressions of rock metaphorism, from shale through slate and schist to gneiss (Shelton, 1966), does not greatly affect the dissolved-solids concentration of water draining these rocks.

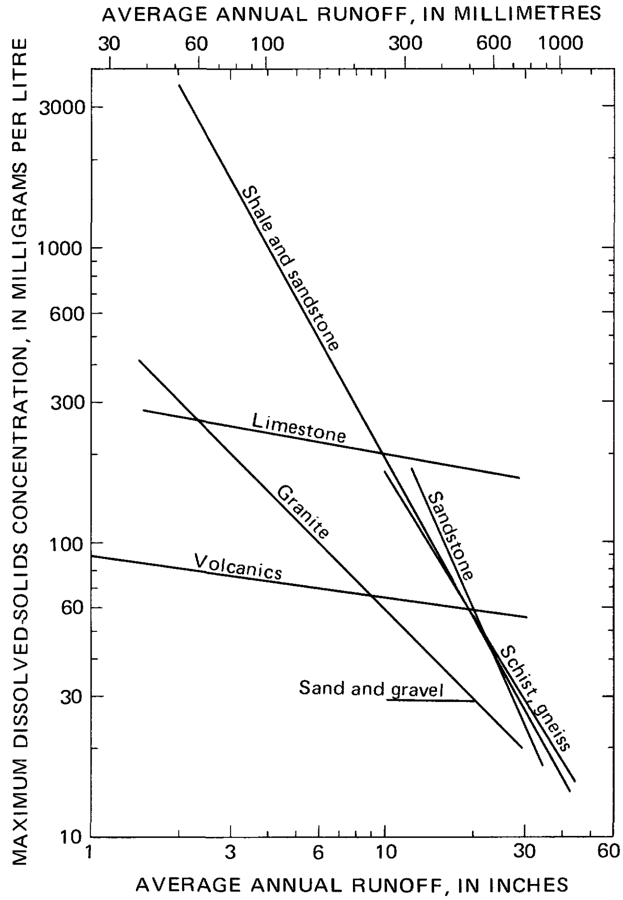

FIGURE 11.—Relationship between maximum dissolved-solids concentration and average annual runoff for hydrologic bench-mark stations draining various rock types.

TABLE 11—*Selected hydrologic characteristics, hydrologic bench-mark stations*

[N.D., not determined]

Station No.[1]	State	Drainage area (sq mi)	Physical division[2]	Principal rock type	Average annual runoff (in.)	Maximum dissolved-solids concentration[3] (mg/l)
1	Alabama	86.8	F	([4])	23	N.D.
2	...do	91.3	C	([4])	26	70
3	Arizona	36.4	R	Granite	2	258
4	Arkansas	89.4	I	Shale, sandstone	23	48
5	...do	58.4	H	Limestone	19	186
6	California	6.50	T	Marine sedimentary	50	88
7	...do	181	S	Granite	25	27
8	...do	23.7	R	Metamorphized sedimentary rocks	.02	N.D.
9	Colorado	23	N	Schist	18	61
10	...do	72.1	N	Schist, conglomerate	20	51
11	Florida	97.9	F	Limestone	25	153
12	Georgia	72.2	E	Gneiss, schist	14	103

See footnotes at end of table, p. 18.

TABLE 11—*Selected hydrologic characteristics, hydrologic bench-mark stations*—Continued

Station No.[1]	State	Drainage area (sq mi)	Physical division[2]	Principal rock type	Average annual runoff (in.)	Maximum dissolved-solids concentration[3] (mg/l)
13	Georgia	56.5	D	Gneiss, schist	40	20
14	Hawaii	11.6	---	Volcanic	N.D.	N.D.
15	Idaho	22.0	M	Quartzite	21	60
16	...do	253	Q	Volcanic rocks	.1	140
17	Indiana	38.2	J	Limestone	12	353
18	Iowa	52.5	J	Limestone, shale	6	506
19	Louisiana	51	F	Unconsolidated sand	16	48
20	Maine	69.5	A	Gneiss, schist	34	23
21	Michigan	13.6	K	Sandstone	13	130
22	Minnesota	253	K	Granite, gabbro	10	31
23	...do	101	J	Limestone, sandstone	4	314
24	Mississippi	52.2	F	Unconsolidated sand	20	29
25	Montana	100	L	Shale, sandstone	2-3	1,870
26	...do	31.4	M	Limestone, quartzite	64	56
27	Nebraska	960	L	Unconsolidated sand	3	172
28	Nevada	20	R	Volcanic	3	94
29	...do	11.1	R	Limestone	5	203
30	New Jersey	2.31	F	Unconsolidated sand	13	25
31	New Mexico	69	R	Volcanic rocks	3.5	110
32	...do	53.2	N	([4])	7	72
33	New York	59.5	C	Sandstone	25	44
34	North Carolina	49.2	D	...do	30	20
35	North Dakota	74	L	Sandstone, silt	1	3,420
36	...do	160	J	Shale, till	<1	1,220
37	Ohio	12.8	C	Shale, sandstone	15	83
38	Oklahoma	24.6	J	Granite	3-4	213
39	...do	40.1	I	Shale, sandstone	20-25	29
40	Oregon	26.2	S	Andesite	Lake	
41	...do	240	Q	Volcanic rocks	25	57
42	Pennsylvania	46.2	C	Shale, sandstone	17	36
43	South Carolina	70	F	Unconsolidated sand	15-20	29
44	...do	87	F	...do	14	17
45	South Dakota	51	J	Shale, schist	1.5	292
46	...do	51	J	Till	1	N.D.
47	Tennessee	447	G	Chert	22	65
48	...do	106	D	Shale, sandstone	36	19
49	Texas	52.4	R	Volcanic rocks	.15	126
50	...do	34.2	L	Limestone, marl	3	291
51	Utah	7.25	O	([4])	9-10	447
52	Virginia	8.53	E	Schist, quartzite	13-14	42
53	Washington	22.1	S	Granite	N.D.	N.D.
54	...do	74.1	T	Slate	145	60
55	Wisconsin	131	K	Schist, granite	12	152
56	Wyoming	10	O	Shale, sandstone	19	207
57	...do	72.7	N	Granite	16-18	56

[1]Alphabetical by State.
[2]From Fenneman (1928).
[3]Maximum observed during 1968-70 water years; monthly sampling.
[4]More than two types.

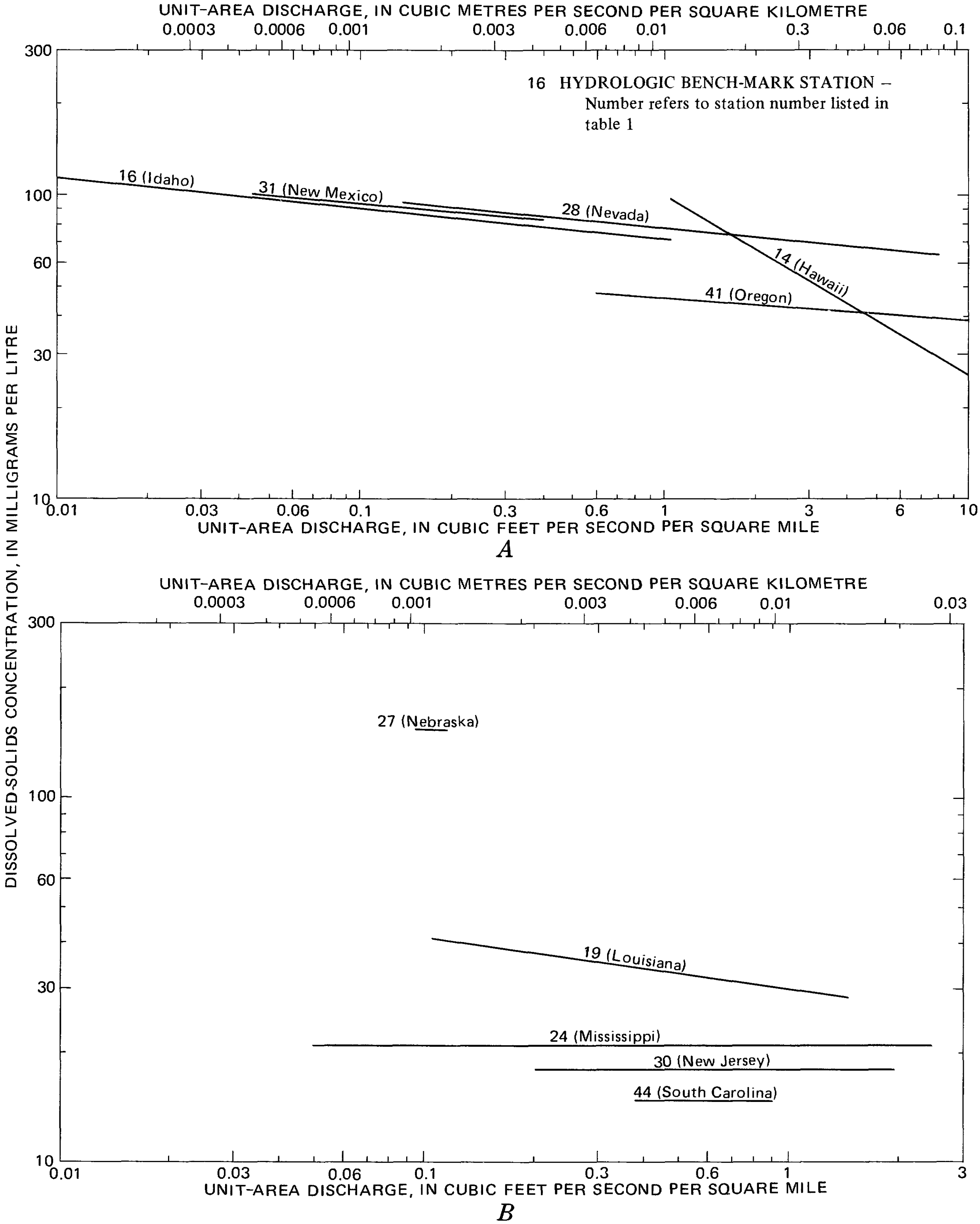

FIGURE 12.—Unit-area discharge-dissolved-solids relationship for hydrologic bench-mark stations draining (*A*) volcanic rocks and (*B*) unconsolidated sand and gravel deposits.

In addition to exhibiting a definite pattern relating maximum dissolved-solids concentration and average annual runoff, streams draining several rock types exhibit similar unit-area discharge-dissolved-solids relationships throughout the entire observed range of flow. Figure 12*A* shows unit-area discharge-dissolved-solids-concentration curves for all streams draining volcanic rocks. Figure 12*B* shows similar curves for all streams draining unconsolidated sand and gravel deposits. Similar plots for other rock types exhibited too much scatter to permit useful generalization. Apparently, rock type alone is not sufficient to characterize inorganic chemical characteristics. Climate, particularly precipitation, must be considered.

SUMMARY

The Hydrologic Bench-Mark Program has yielded data that provide a description of water quality in the "natural" environment and that allow a comparison of this "natural" water quality with the quality of major streams draining the same hydrologic regions of the United States.

The relationship between water discharge per unit drainage area and dissolved-solids concentration is shown to be a useful approach for estimating water quality in the various physical divisions of the United States. Median curves showing this relationship were developed for 11 of the 14 physical divisions and can be used to estimate the dissolved-solids concentration of any "natural" stream if the water discharge per unit area is known. Bench-mark streams draining the Coastal Plain province of the Atlantic Plain had the least variable unit-area discharge–dissolved-solids relationship.

Natural streams in the New England and Blue Ridge provinces of the Appalachian Highlands contain lower concentrations of dissolved minerals than streams draining hydrologic bench-mark basins in any other part of the country. Streams draining bench-mark basins in the Interior Plains contain the highest concentrations of dissolved minerals.

Pesticide data collected on bench-mark streams revealed a widespread low-level occurrence of pesticide residues in the natural environment. The DDT family of pesticides occurred most commonly and accounted for 75 percent of the detected occurrences. The highest observed concentration of DDT was 0.06 μg/l, well below the recommended permissible maximum of 42 μg/l for drinking water (U.S. Federal Water Pollution Control Administration, 1968, p. 20).

Concentrations of potentially toxic minor metals in bench-mark streams were also very low. Of 642 measurements, about 65 percent showed near zero concentrations—only 3 measurements indicated concentrations in excess of U.S. Public Health Service (1962) drinking-water standards.

A comparison of the unit-area discharge–dissolved-solids-concentration relationship between bench-mark streams and major streams draining the same water-resources region reveals a higher dissolved-solids concentration per unit-area discharge for most of the major streams. This relationship is most consistent in the densely populated North Atlantic Region and is reversed in the Missouri Region, where several bench-mark streams contain higher dissolved-solids concentrations than the major streams.

Average median nitrate nitrogen concentration in bench-mark streams range from 0.2 to 0.5 mg/l. Average concentrations in many major streams are as much as 10 times greater. A comparison of average median values shows that man's activities have influenced nitrate concentrations the least in the South Atlantic–Gulf Region and the most in the North Atlantic Region.

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