Data of Geochemistry

Sixth Edition

Chapter G. Chemical Composition of Rivers and Lakes

GEOLOGICAL SURVEY PROFESSIONAL PAPER 440-G

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849

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MICHAEL FLEISCHER, *Technical Editor*

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By DANIEL A. LIVINGSTONE

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DATA OF GEOCHEMISTRY, SIXTH EDITION

Michael Fleischer, Technical Editor

The first edition of the Data of Geochemistry, by F. W. Clarke, was published in 1908 as U.S. Geological Survey Bulletin 330. Later editions, also by Clarke, were published in 1911, 1916, 1920, and 1924 as Bulletins 491, 616, 695, and 770. This, the sixth edition, has been written by several scientists in the Geological Survey and in other institutions in the United States and abroad, each preparing a chapter on his special field. The current edition is being published in individual chapters, titles of which are listed below. Chapters already published are indicated by boldface.

CHAPTER A. The chemical elements
B. Cosmochemistry
C. Internal structure and composition of the Earth
D. Composition of the earth's crust
E. Chemistry of the atomsphere
F. **Chemical composition of subsurface waters,** by Donald E. White, John D. Hem, and G. A. Waring
G. **Chemical composition of rivers and lakes,** by Daniel A. Livingstone
H. Chemistry of the oceans
I. Geochemistry of the biosphere
J. Chemistry of rock-forming minerals
K. **Volcanic emanations,** by Donald E. White and G. A. Waring
L. Phase equilibrium relations of the common rock-forming oxides except water
M. Phase equilibrium relations of the common rock-forming oxides with water and (or) carbon dioxide
N. Chemistry of igneous rocks
O. Chemistry of rock weathering and soils
P. Chemistry of bauxites and laterites
Q. Chemistry of nickel silicate deposits
R. Chemistry of manganese oxides
S. **Chemical composition of sandstones, excluding carbonate and volcanic sands,** by F. J. Pettijohn
T. **Nondetrital siliceous sediments,** by Earle R. Cressman
U. Chemical composition of shales and related rocks
V. Chemistry of carbonate rocks
W. Chemistry of iron-rich rocks
X. Chemistry of phosphorites
Y. **Marine evaporites,** by Frederick H. Stewart
Z. Continental evaporites
AA. Chemistry of coal
BB. Chemistry of petroleum, natural gas, and miscellaneous carbonaceous substances
CC. Chemistry of metamorphic rocks
DD. Abundance and distribution of the chemical elements and their isotopes
EE. Geochemistry of ore deposits
FF. Physical chemistry of sulfide systems
GG. The natural radioactive elements
HH. Geochronology
II. Temperatures of geologic processes
JJ. Composition of fluid inclusions

CONTENTS

ILLUSTRATIONS

TABLES

DATA OF GEOCHEMISTRY

CHEMICAL COMPOSITION OF RIVERS AND LAKES

By Daniel A. Livingstone

DUKE UNIVERSITY, DURHAM, NORTH CAROLINA

ABSTRACT

This paper is a compilation of representative chemical data, many previously unpublished, for the lake and river waters of the world. The rate of chemical denudation for the continents of the world ranges from 6 long tons per square mile for Australia to 110 long tons per square mile for Europe. The rivers of the world deliver 3.9 billion tons of dissolved material to the sea each year, and the average concentration of the important constituents in parts per million is: bicarbonate 58.4, sulfate 11.2, chloride 7.8, nitrate 1.0, calcium 15.0, magnesium 4.1, sodium 6.3, potassium, 2.3, iron 0.67, and silica 13.1, for a total of 120 ppm of dissolved solids. Although these 10 constituents account for most of the dissolved material, all but 37 of the naturally occurring elements have been detected in lake or river water. The principal gaps in geochemical data for lakes and rivers are long-term downstream averages for the general composition of large tropical rivers and trace-element analyses for large rivers everywhere.

INTRODUCTION

Atmospheric precipitation is the principal source of the water substance that makes up lakes and rivers on the earth's surface. This is not pure water, but is in equilibrium with atmospheric gases, and in addition contains some dissolved and suspended mineral matter, part of which is the original nucleus of crystal or droplet condensation, and part taken up by the crystal or droplet during its passage through the atmosphere.

Although a headwater stream or a lake with a small catchment area, particularly in regions of relatively insoluble rocks, may contain water that is almost identical in chemical composition with rain water, it is usual for lakes and rivers to contain much more suspended and dissolved material than this. As water percolates through the soil, it attacks the mineral constituents physically and chemically, leaching out the more soluble fractions. This water ultimately finds its way into rivers with more or less delay in basins filled with standing water, while evaporation from the water surface tends to increase the salt concentration in the water. More salts may be leached out of the suspended material in the stream, or, alternatively, salts may be removed from the water by the suspended or bottom material through a variety of sorptive processes. Organisms living in the water may take up dissolved material, particularly nutrients such as phosphate, nitrate, and silicate (Lund, 1950) that tend to be in short supply, and drastically reduce its concentration in the water. At intervals large numbers of these organisms may die, suddenly releasing their concentrates into the waters around them, and producing a local and temporary concentration of the elements characteristic of protoplasm.

Because of these changes, a river or lake is a complex dynamic system. Its chemistry cannot be adequately described in terms of static analysis, but must include some information about the potentialities of the system as well as information about the composition of its water at a particular moment. Investigation of these chemical potentialities is much more time consuming than chemical analysis of a single water sample and for some practical purposes it is not necessary, but the serious shortage of attempts to measure it introduces grave uncertainties into the geochemical data for this part of the biosphere.

ACKNOWLEDGMENTS

This review was prepared during tenure of three National Science Foundation grants and during part-time employment with the U.S. Geological Survey.

A very large part of the basic data for lakes and rivers lies in unpublished files and reports. In searching for this material I had the aid of water chemists in many parts of the world and of a large part of the world's governmental quality-of-water agencies. I am very grateful for the help they freely and unstintingly gave. An especial debt of gratitude is due to the following people and organizations who have provided unpublished analyses for inclusion in this volume: Dr. Eville

Gorham; Dr. Jun Kobayashi; Dr. D. S. Rawson; Dr. Simón Visser; the Laboratório de Análises Físico-químicas e Micrográficas, Campanhia' das Águas de Lisboa; the Afghanistan Geological Survey; the Geological Survey of Pakistan; the Tehran Water Board; the Hydro-Electric Commission, Hobart, Tasmania; the South Australian Engineering and Water Supply Department, Adelaide; the Government Chemical Laboratories, Perth, Australia; the Ammistrazione Fiduciaria Italiana della Somalia; Repartição Técnica de Indústria e Geologica, Provincía de Moçambique; Repartição Central dos Serviços de Geologia e Minas, Provinciá de Angola; the Chemistry Division, Ministry of Health, Kaduna, Nigeria; the Federal Department of Chemistry, Lagos, Nigeria; the Service Géologique, French West Africa; the Service des Etudes Scientifiques, Ministère de l'Algérie; the Direcíon de Geología, Ministerio de Minas e Hidrocarburos, Venezuela; Ministerio de Fomento y obras Publicas, Peru; and my colleagues in the U.S. Geological Survey, particularly Dr. W. H. Durum and the water chemists working in California, Nevada, Oregon, and Washington.

Very generous linguistic assistance was provided by Dr. J. R. Bailey, Dr. Humio Osaki, and Dr. Athos Ottolenghi. Miss Eveline Bowers, Miss Helen Oyler, and Mr. Emerson Ford helped with bibliographic problems. Dr. F. B. Barker, Dr. Walter Durum, Dr. Eville Gorham, and Dr. John D. Hem have read the manuscript and made many helpful criticisms. Since beginning this review 5 years ago I have had the unfailing support and encouragement of my wife, Bertha, who has also helped to revise the manuscript and check the tables. During the same time Dr. Michael Fleischer has helped me in every way that an editor could—finding obscure papers, preparing translations from Russian, discussing general questions of geochemistry, providing kind words of encouragement when the literature search seemed endless, and gently exercising editorial restraint.

ISOTOPIC COMPOSITION OF LAKE AND RIVER WATER

In addition to the variation in the suspended and dissolved load of lake and river water, there is a considerable variation in the composition of the pure water substance itself. It has long been known that there are variations in the density of pure water from natural sources, and in the last few years a number of studies of the isotopic composition of natural water samples have been made. Mass spectrography has permitted the determination of the stable isotopes, while low-background counting methods have permitted the assay of even the short-lived mass-three isotope of hydrogen.

Oxygen–17 does not appear to have been measured in natural waters. In air and commercial oxygen the O^{18}/O^{17} ratio is 4.9 ± 0.2 (Murphey, 1941), so the natural variations in oxygen–17 content of water are probably barely measurable with present mass-spectrographic methods. Oxygen–18 has been measured by a number of investigators, each referring the results to some arbitrary standard. The largest body of results referred to a single standard appears to be that of Dansgaard (see table 1), who used a Danish oxygen standard with 0.1950 atom-percent of oxygen–18. It appears from the data, which are reproduced in table 1, that the O^{18}/O^{16} ratio is higher in climates where there is a great deal of post-precipitational evaporation, leading to a loss of the lighter isotope.

TABLE 1.—*Oxygen–18 content of lakes and rivers*

[Analyses by Dansgaard (1954). The reference used was a Danish CO_2 standard with 0.1950 atoms percent of O^{18}]

Locality	Date	O^{18} atoms/ 10^4O^{16} atoms
Pasig River, Manila, Philippine Islands	--------	19.82
River water, Minglasulla, Cebu, Philippine Islands	Aug. 7, 1953	19.73
Water fall, Maxwill, Taiping, Malaya	July 19, 1953	19.74
Waterfall Gardens, Penang	Aug. 1, 1953	19.77
Me-Yome River, Prae, Siam	June 29, 1953	19.72
River water, Bangkok	Sept. 30, 1953	19.71
Hoogly River, Ganges	Aug. 12, 1953	19.72
Ravi River, Madhopur, Pakistan	July 8, 1953	19.77
Little Fugela, Winterton, Natal	Jan. 14, 1954	19.81
Seven Mile Stream, Hilton Road, Natal	Jan. 31, 1954	19.82
Ukamba Stream, Natal National Park	Jan. 14, 1954	19.82
Mulunguzi Stream, Zomba Plateau, Nyasaland	June 7, 1953	19.79
Namadzi Stream, Nyondtwe	June 14, 1953	19.75
Perana River, Posadas Misiones, Argentina	Oct. 6, 1953	19.80
River water, San Nicolas, Buenos Aires	Oct. 13, 1953	19.78
Lugan River, Delta of Tigra	Oct. 12, 1953	19.82
San Juan River, Rosario, Santa Fe, N. Mex	Sept. 11, 1953	19.92
Lake Nahuel, Huapsi, Neuguen, Argentina	Sept. 8, 1953	19.70
Lake at West Vancouver, Canada	June 19, 1953	19.68
Mosquito Creek, North Vancouver, Canada	June 19, 1953	19.67
River water, Salta, Argentina	Nov. 20, 1953	19.58
Do	Nov. 20, 1953	19.60
Red River, Godhavn, Greenland	Nov. 20, 1952	19.58

A large number of analyses for deuterium given by Friedman are reproduced in table 2. It is evident that evaporational fractionation is involved here. In another study, Clarke and others (1954) found that the deuterium content of Thames water was near the oceanic value. The slight evaporative enrichment in the oceanic Thames basin appears to be sufficient to equal the impoverishment during evaporation from the ocean.

Tritium, though much less abundant, can be measured because it is a beta-emitter. Libby has summarized his data on the tritium content of fresh waters of the world, and they are presented in table 3. This isotope has a half-life of 12 years and the time since leaving the atmosphere, as well as the partition due to evaporation or melting, determines its concentration in natural waters.

Some early measurements of water density are of interest in connection with isotope concentration. For example, it has been claimed that the water in the depths of Lake Baikal (Mendelejev, 1935, Ingerson, 1953) is somewhat denser than surface water, but the isotopes concerned have not been measured. In view of the very considerable body of evidence for vertical mixing in Lake Baikal (Tolmachev, 1957a, 1957b), this result must be viewed with suspicion until such time as it has been verified by mass-spectrometric methods.

TABLE 2.—*Deuterium content of lakes and rivers*

[The working standard contained 0.0148±0.0001 mole percent deuterium. Recalculated from Friedman (1953)]

Locality	Date	Atoms H^2/10^5 atoms H^1
Columbia River, Trail, British Columbia	July 17, 1943	13.3
Violin Lake, Trail, British Columbia	June 26, 1944	13.5
Do	Nov. 6, 1943	13.5
Do	Sept. 23, 1943	13.8
Juneau Glacier, 235 ft below surface		13.8
Juneau Glacier, 155 ft below surface		13.8
Grasshopper Glacier, Park County, Mont		13.2
Salt Lake boat harbor, Great Salt Lake, Utah	Aug. 19, 1948	14.1
Gullmar Fjord, west coast of Sweden	Apr. 29, 1952	15.1
Mississippi River, Baton Rouge, La	May 3, 1948	14.9
Mississippi River, Clinton, Iowa	June 2, 1948	[1] 14.6
Platte River near Ashland, Nebr [1]	May 7, 1948	[1] 14.9
St. Lawrence River, Ogdensburg, N.Y [1]	June 11, 1948	[1] 14.9
Susquehanna River at Marietta, Pa [1]	May 29, 1948	[1] 14.8
Apalachicola River, Chattachoochee, Fla [1]		[1] 15.4
Sacramento River, Verona, Calif [1]		[1] 14.6
San Joaquin River, Vernalis, Calif [1]	July 7, 1948	[1] 14.5
Connecticut River, Thompsonville, Conn	June 17, 1948	14.5
Ohio River, Louisville, Ky	June 4, 1948	14.8
Arkansas River, Van Buren, Ark	June 3, 1948	15.3
Rio Grande near Mission, Tex	Apr. 1–30, 1948	15.3
Missouri River, Kansas City, Mo	June 12, 1948	13.8
Red River near Colbert, Okla	March–April 1948	15.3
Red River of the North, Oslo, Minn [1]	July 12, 1948	[1] 14.8
Colorado River at Yuma, Ariz	June 4, 1948	13.8
Snake River near Clarkston, Wash [1]		[1] 13.9
Roanoke River near Scotland Neck, N. C	June 17, 1948	15.0
Monongahela River, near Morgantown, W. Va	Mar. 26, 1943	14.6

[1] Craig and Boato (1955, p. 406) say that these determinations must be discarded, the containers being faulty and evaporation having occurred.

Density measurements are more valuable as indicators of problems to be investigated by more refined tools than as sources of hydrologic information.

CHEMICAL COMPOSITION OF LAKE AND RIVER WATER

NATURE AND CAUSES OF VARIATIONS IN COMPOSITION

River water is extremely variable in chemical composition. To begin with, there may be a considerable variation in the chemistry of the rainwater that is falling on a river basin. Gorham (1958) has studied the chemistry of the daily precipitation in the lake district of England over a period of 1 year and has found variation in the concentration and composition of the salts in rainwater depending on the previous history of the air mass from which it falls (fig. 1). After deposition there is more or less concentration of the salt content by evaporation of moisture from the surface of the drainage basin. This produces variations in chemical content not only from basin to basin, but also from time to time.

TABLE 3.—*Tritium content of lakes and rivers*

[Analyses from Libby (1955)]

Locality	Date	Atoms H^3/10^{18} atoms H^1
	1953	
Mississippi River, St. Louis, Mo	Jan. 31	5.6 ±0.6
Do	Feb. 4	4.5 ±0.6
Do	Feb. 10	6.0 ±0.9
Do	Feb. 20	6.4 ±0.5
Do	Mar. 17	5.4 ±2.4
Do	Apr. 17	6.0 ±0.4
Do	July 22	7.3 ±0.4
Mississippi River, Rock Island, Ill	Jan. 29	2.5 ±0.3
Do	Feb. 6	3.7 ±0.4
Do	Feb. 24	4.4 ±0.2
Do	Mar. 16	3.2 ±0.2
Do	Apr. 17	5.3 ±0.3
Do	June 30	7.2 ±0.7
Mississippi River, Memphis, Tenn	Feb. 4	6.0 ±1.0
Mississippi River, New Orleans, La	Feb. 8	4.7 ±0.3
	1952	
Sangamon River, Decatur, Ill	Aug. 6	1.15±0.08
	1953	
Arkansas River, Conway, Ark	Mar. 20	3.12±0.10
River Elbe, Hamburg, Germany	Aug. 31	2.57±0.12
River Weser, Bremen, Germany	Sept. 1	1.76±0.10
River Rhone, Lyons, France	Sept. 10	2.64±0.16
River Main near Würzburg, Germany	Sept. 13	1.76±0.19
River Loire, Digoin, France	Sept. 9	2.11±0.14
Stream near Cambridge, England, about 1 mile below spring source		1.25±0.10
River Donau, near Ulm, Germany	Sept. 12	2.13±0.38
River Mosel, near Metz, France	Sept. 7	2.15±0.12
River Seine, near Nogent, France	Sept. 8	1.80±0.3
River Fulda, near Kassel, Germany	Sept. 24	2.35±0.1
River Rhine, between Geisenheim and Rüdesheim	Sept. 7	2.1 ±0.2
River Marne, Joinville, France	Sept. 8	2.1 ±0.2
	1954	
Shasta Dam, Calif	Jan. 30	2.7 ±0.1
El Rito de los Frijoles, Jemez Mountains, N. Mex	Feb. 7	27.2±0.4
Rio Grande, northwest of Santa Fe, N. Mex	Feb. 7	6.6 ±0.2
Winsor Creek, just above junction with Pecos, Cowles, N. Mex	Feb. 22	9.9 ±0.2
Rio Guajataca at Lares, Puerto Rico	Mar. 2	0.7 ±0.2
Rio Arecibo at Utuado, Puerto Rico	Mar. 2	1.1 ±0.2
River Tomokoa, Fla., on Route 92 near Daytona Beach	Mar. 19	45.4±0.6
Alafia River, Fla., on route 60 about 20 miles east of Tampa	Mar. 22	60 ±3
Mean of three samples of University of Chicago tap water, believed to be representative of Lake Michigan		1.64±0.04
Lake behind Shasta Dam, Calif	Before Feb. 15	2.7 ±0.15
Effluent from Schoharie Reservoir, Allaben, N.Y	Feb. 6	8.4 ±0.3
Roundout Reservoir, Palisades, N.Y	Feb. 6	7.2 ±0.3

The most important factor introducing temporal variability into river-water chemistry, however, seems to be the relative contribution of ground water and surface runoff, as they are affected by changes in discharge. In general, the contribution of ground water to a river tends to be relatively stable, but the contribution of surface runoff tends to be variable. When rainfall on the basin has been light or absent for some protracted period of time, the nourishment of the stream is almost entirely by ground water. When rainfall is heavy, and particularly when it is concentrated in short periods of time, the nourishment of the swollen stream may be almost entirely by runoff. Ground water, by its long-standing intimate contact with rocks

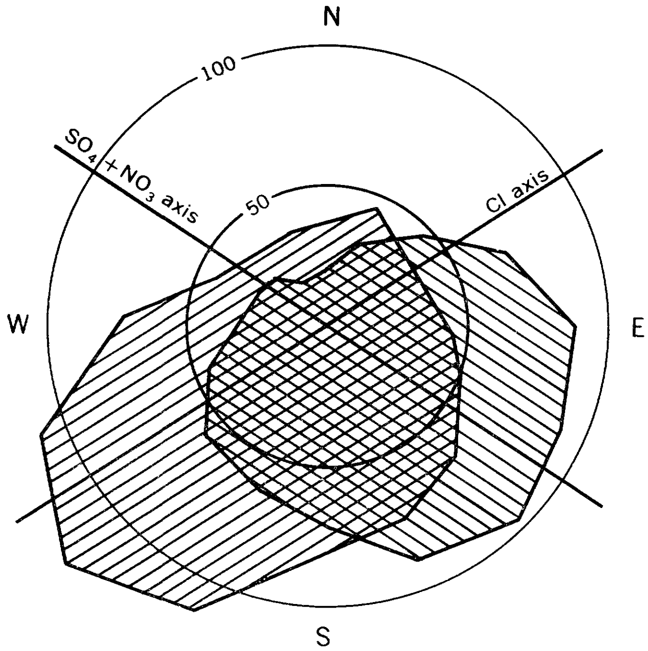

FIGURE 1.—Mean daily supply of chloride and sulfate plus nitrate in relation to wind direction. The inner and outer circles delimit 50 and 100 meq/100 m², respectively. High chloride is characteristic of winds from a southwesterly direction, that is, from the sea, whereas sulfate and nitrate are high in winds blowing from the industrial regions lying east and southeast of the station in the English Lake district where the rain was collected. After Gorham (1958). Reprinted by permission of the Royal Society, London.

and mineral soil, is usually much more concentrated than surface runoff, the more so because it is usually in contact with the mineral material of the soil under conditions of oxygen and carbon dioxide tension that are particularly favorable to the solution of many mineral components. As a result, the concentration of dissolved matter of river water usually bears an inverse relation to discharge, although the relation is seldom simple. The water of heavy rains has less opportunity to be concentrated by evaporation and is usually less concentrated to begin with than the water of light showers. These combined effects cause rivers at high stage to be less concentrated than rivers at low stage. Although it is usually difficult to separate the various concentration processes, their net effects are usually greatest in arid lands. For example, the Moreau River, S. Dak., with an annual discharge of 2 inches over the 1,570 square miles of its drainage basin, has a total ion content that ranges from 160 to 3,400 ppm (parts per million) during a single year. Monthly analyses for the principal elements are given in table 4. This may be contrasted with a range from 36 to 57 ppm for Mayo River, N.C. (table 5), from a humid region with an annual discharge of 17 inches over the 260 square miles of its drainage basin.

It is impossible to appreciate the full extent of the dependence of river chemistry on discharge from the comparison of monthly means, which smooth out the more dramatic fluctuations. Complete data do not appear to be available for any stream showing violent

TABLE 4.—*Moreau River at Bixby, S. Dak., showing changes in chemical composition of a stream in a semiarid region*

[The drainage area above the sampling station is 1,570 square miles and the data, which cover the water year October 1949–September 1950, have been recalculated from U.S. Geol. Survey (1955b)]

Date of Sample	Mean discharge (cfs)	pH	Percent													Total ions (ppm)
			SiO_2	Fe	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	F	NO_3	B	
1949																
Oct. 1–3	3.2	8.9	0.2	0.002	0.5	1.0	29	0.3	2.6	22	43	0.9	0.02	0.05	0.02	3,400
Oct. 4–12	16	8.9	.3	.002	.6	.6	29	.2	3.2	34	31	.7	.02	.08	.02	2,430
Oct. 13–26	7.0	8.5	1.3	.010	1.7	.5	26	.5	1.7	38	30	.6	.03	.22	.02	1,200
Oct. 27–31	8.0	8.3	1.0	.005	1.9	.2	28	.4	1.7	39	28	.6	.02	.09	.02	1,450
Nov. 1–30	4.1	8.4	.8	.005	2.3	.5	27	.3	1.2	37	31	.6	.02	.06	.02	1,740
Dec. 1–21	3.2	8.4	.4	.002	1.3	.9	27	.3	1.2	37	32	.6	.01	.02	.02	3,810
1950																
Mar. 6–9	123	8.4	3.0	.003	3.0	.8	25	.9	.0	31	35	.7	.07	.39	.02	540
Mar. 10	100	7.3	1.5	.004	4.4	1.4	23	.8	.0	20	47	1.9	.04	.40	.01	890
Mar. 14–Apr. 1	126	7.2	3.2	.009	4.9	1.4	21	1.1	.0	32	35	.7	.09	.54	.02	410
Apr. 3	2,900	7.2	8.1	-------	7.5	1.4	15	3.2	.0	35	25	.3	.25	2.73	.06	160
Apr. 4–6	2,800	7.1	6.4	.015	9.2	2.8	16	1.6	.0	33	38	1.2	.08	.80	.04	250
Apr. 7	6,590	7.4	5.4	.027	10.1	2.6	11	1.3	.0	49	19	.7	.07	.64	.03	300
Apr. 11–14	1,260	7.2	5.0	.011	9.1	2.5	15	1.2	.0	31	35	.7	.06	.61	.03	340
Apr. 15–17	7,600	7.4	5.6	.014	8.2	2.1	15	1.2	.0	37	29	.9	.07	.37	.04	270
Apr. 18–20	1,350	7.5	3.1	.005	9.1	2.5	15	1.1	.0	25	43	.6	.05	.66	.03	390
Apr. 21	363	7.1	2.1	.007	8.6	3.2	16	.9	.0	22	48	.6	.04	.26	.04	540
Apr. 22–26	280	7.3	2.1	.003	6.7	2.5	19	.8	.0	24	45	.7	.03	.28	.02	610
Apr. 27	160	7.5	1.5	.004	7.3	2.5	18	.6	.0	21	48	.6	.02	.14	.02	810
Apr. 28–May 15	470	7.5	2.0	.002	7.2	2.8	18	.7	.0	18	50	.6	.03	.18	.01	800
May 16–31	45	8.0	1.5	.001	5.6	2.6	20	.6	.0	23	46	.6	.02	.14	.01	1,170
June 1–30	30	7.9	.5	.002	3.8	4.5	23	.5	.0	19	50	.6	.03	.07	.01	2,000
July 1–31	14	7.9	.5	.002	4.6	2.6	22	.5	.0	18	52	.6	.03	.06	.01	1,800
Aug. 1–5	4.1	7.9	.6	.002	2.1	1.6	25	.5	.0	24	45	.9	.04	.07	.02	1,890
Aug. 6–8	75	7.9	2.1	.024	3.1	.7	24	.9	.0	33	35	1.1	.08	.53	.06	660
Aug. 9–31	6.7	8.3	.7	.004	1.8	.8	26	.5	.6	32	37	.7	.03	.15	.03	1,430
Sept. 1–19	4.5	8.3	.6	.003	1.4	1.1	27	.4	.8	29	39	.8	.03	.08	.03	1,760
Sept. 20–24	34	7.8	1.9	.054	2.1	.4	26	.7	.0	33	35	.9	.07	.26	.04	920
Sept. 25–30	5.2	8.3	.7	.004	1.8	.8	27	.5	.8	34	34	.7	.04	.08	.00	1,440

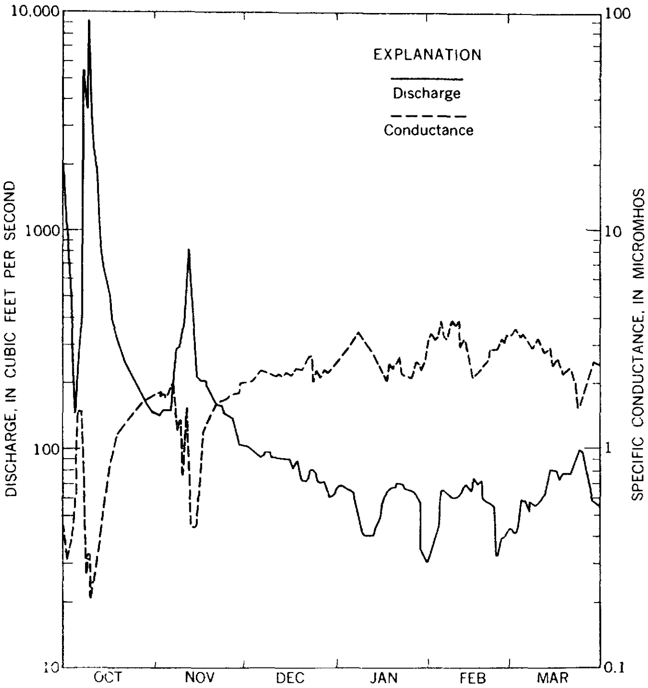

FIGURE 2.—Relation of specific conductance to mean daily runoff of the Saline River near Russell, Kansas, during part of 1946 and 1947. After Durum (1953). Reprinted by permission of the American Geophysical Union.

fluctuations of discharge on a daily basis, but daily measurements of specific conductivity are available for many rivers in the United States. An example is provided by the Saline River, Kans., in figure 2.

In addition to these temporal variations in the chemistry of rivers, there are also spatial ones. It has been known for a long time that the content of dissolved matter of river water tends to increase from source to mouth. This tendency is particularly marked in regions of interior drainage, but it is also present in rivers emptying into the sea. A further complication is introduced by heterogeneities in river water at any particular level in the drainage profile. When two rivers meet, or when large amounts of chemically different water are introduced into a river in some other way, for example, by a large spring or a sewage outflow, there may not be complete mixing for a long distance downstream, as Heide (1952) has shown.

In any large river system the composition of the dissolved salts is different in the various head-water tributaries, but these local irregularities, which reflect variations in the nature of the rocks in the various parts of the drainage system, tend to cancel each other as one proceeds downstream, and there is a tendency for the composition of the water in the downstream parts of rivers to resemble one another. This has led to the concept of a general or mean composition of river water (Rodhe, 1949) and to some speculation that ion-exchange reactions with the suspended load or with the soil might be buffering river water and reducing it to a common composition in all parts of the world.

TABLE 5.—*Mayo River near Price, N.C.*

[Drainage area above sampling station 260 square miles. Note the relatively small variations in water chemistry of this humid-climate stream with rather constant discharge. Data from U.S. Geol. Survey (1954b)]

Date	Discharge (cfs)	Total dissolved solids (ppm)
1949		
Oct. 1–10	302	45
Oct. 11–20	273	44
Oct. 21–31	399	41
Nov. 1–10	470	39
Nov. 11–20	288	57
Nov. 21–30	271	43
Dec. 1–10	249	39
Dec. 11–20	299	38
Dec. 21–30	301	38
1950		
Jan. 1–10	270	40
Jan. 11–20	267	42
Jan. 21–31	323	39
Feb. 1–10	389	39
Feb. 11–19	354	39
Feb. 20–28	295	39
Mar. 1–10	254	40
Mar. 11–20	294	38
Mar. 21–31	383	38
Apr. 1–10	315	39
Apr. 11–20	256	39
Apr. 21–30	239	40
May 1–10	354	40
May 11–20	677	36
May 21–31	493	37
June 1–10	427	44
June 11–20	284	44
June 21–30	350	39
July 1–10	282	41
July 11–20	227	44
July 21–31	271	41
Aug. 1–10	196	44
Aug. 11–20	203	41
Aug. 21–31	370	41
Sept. 1–10	350	41
Sept. 10–20	360	42
Sept. 21–30	238	45

This implies a very large exchange capacity for the participating solids in the system, which poses some difficulty when we remember that the uniformity of river water is most pronounced in the downstream parts, where the simple geometry of streams renders the contact between water and solids minimal. It also seems to be unnecessary, for the similarity of the various large river waters is apparently quite adequately explained as a result of the integration of the chemical composition of their tributaries. The larger the drainage basin of a river, the closer, on the average, will the chemical composition of its rocks approach the mean chemical composition of the surface rocks of the earth, and the closer will the composition of the water which it empties into the sea approach the mean composition of all waters. The same line of argument holds for that part of the salt which is of meteoric origin. There does not seem to be any need to invoke sorption reactions to explain the general uniformity of the water of large rivers.

This does not mean that sorption reactions can be neglected in river chemistry. For some elements, particularly the heavy metals, they are of the greatest importance, and they have some effect on the contribution of river salt to sea water, but they do not seem to be of great importance in controlling the general composition of river waters.

Because of the great temporal and spatial variability of river water, a single sample from a river can give only a very inadequate measure of its chemistry. Particularly in lands with a very great seasonal variation in rainfall, such an estimate may be in error by several orders of magnitude. This is the quality of the data available, however, and the analysts have to rely frequently on a single sample to characterize major rivers, particularly those in tropical and arctic regions. It is very gratifying to have a few rivers to which it is possible to given annual weighted means of water composition at a number of points.

Chemical investigations of river water are usually made to provide background information concerning the utility of the water for industrial and agricultural purposes. The ions that reduce the potability of the water, or that produce objectionable hardness, are the principal ones measured. A few minor elements essential to plant or animal nutrition, such as boron, fluorine, and fixed nitrogen are often included. Occasionally heavy metals that may be of interest in measuring industrial pollution, such as lead, arsenic, chromium, zinc, and copper, are included in routine analyses of this sort.

A substantial number of analyses have been made by limnologists. These are, in general, of little value for geochemical purposes because the elements determined are usually those that have biological importance, such as oxygen, phosphorus, and nitrogen in its various combined forms. In a few cases, particularly for lakes in remote parts of the world, the major constituents of the dissolved mineral matter of lake and river water have been determined. Although these analyses have a special value, as they often come from lands devoid of industrial development and hence of other analytical data, they are to be found in a very small percentage of limnological papers, even of those whose titles suggest a chemical emphasis.

Data that have been collected specifically for geochemical purposes are extremely scarce. For the most part they are restricted to a single element or a small group of related elements, although some geochemists working with trace elements are careful to present data for the principal mineral constituents of the waters under analysis. These are the most valuable sources of data, but they are also the most scarce.

The most common geologic purpose for which the chemical data dealing with river waters are used is the calculation of the amount and nature of the substance that is removed from the land by river waters and deposited in the sea. It should be understood that the data available for this purpose are scarce, incomplete, and not always accurate. By accepting them at face value and ignoring the uncertainties involved a spurious appearance of reliability can be given to the calculated results, but they will, in fact, be less reliable than ones incorporating a certain number of reasonable assumptions.

The first source of error lies in the incompleteness of the data. In general, it is only the highly industrialized nations of the temperate zones that make routine chemical analyses of river water. As a result many great river systems of the world, particularly in the tropics and the Arctic, have been analyzed, if at all, only by an occasional interested traveler. The samples collected in this way are usually transported elsewhere for analysis, and in the meantime they are stored in glass bottles that exchange a variable quantity of soluble material with the water.

Even in the countries where water analyses are routinely made, there is rather inadequate coverage. As was demonstrated above, the concentration of river water bears an inverse relation to the discharge. If the discharge shows a great seasonal variation, a single sample will not suffice for a calculation of the quantity of dissolved material carried to the sea, even if the annual variation of discharge is accurately known. It is necessary to carry a systematic program of sampling over a period of at least 12 months in order to determine the chemical load of a stream. Even this will not, of course, take into account variations due to wetter and dryer years.

The U.S. Geological Survey has made long-term investigations of a number of streams, so it is possible to avoid the errors due to discharge variations in a number of American rivers. The procedure is to take a series of daily samples and to combine them into composite samples, usually every 10 days, for analysis. This, in effect, yields a series of simple 10-day averages for the chemical nature of the water. Such simple averages will suggest that the river water of the sampling period is somewhat less dilute than it actually is, and a closer approach to the true mean concentration is sometimes achieved by combining the daily water samples in quantities proportional to the discharge on the days they were collected.

Errors of this sort will be minimal in considering the chemical discharge of large streams into the ocean, for such streams do not display as marked fluctuations as their small tributaries. These errors may be more important in computing the salt discharge into basins of internal drainage.

A more serious error, and one that affects all the data that are available for stream transport of mineral substances, stems from general carelessness in discriminating between dissolved and colloidal or suspended material and a cavalier disregard for all the mineral matter that does not meet the arbitrary criteria of solution set up by a particular investigator.

For purposes of practical industrial water chemistry the errors introduced by these habits of thought and analytical procedure may not be important. Obviously the bedload of a stream will have little effect upon its suitability as a source of boiler water, but in calculations of the role of streams in geochemical cycles these errors are more serious. The few careful investigations, such as Strakhov's (1948) work with iron in natural waters, deal with a very small number of elements only.

The implicit assumption behind this practice of ignoring all mineral matter that is not dissolved in stream water seems to be that mineral matter is present in only two states, as true solutions and as suspensions, and that the suspended material consists of unmodified rock, so that transport of the solid material effects no chemical fractionation of the earth's mantle. The transport of clay, silt, sand, and gravel has been regarded as the sphere of the geomorphologist rather than of the geochemist.

For material of large-grade size this may be almost true. Gravel carried by streams is probably not changed very much chemically from the parent rock from which it came, although one would like to have more definite evidence of this. One should know to what extent it is unmodified primary rock, and to what extent it is the residue from which the elements being carried in true solution by rivers have been removed.

It is in considering the finer grades, however, that the seriousness of ignoring suspended material becomes apparent. Even such readily ionized and extremely soluble elements as sodium and chlorine can be bound in considerable quantity to fine mineral particles by various sorption processes, of which the most important is probably ion exchange. Data concerning the sorptive capacities of suspended river solids are extremely scarce. The study of Carritt and Goodgal (1954) on Chesapeake Bay silts shows that the sorptive capacity may be considerable, and further that it may be influenced by surrounding conditions, such as pH, in such a way that ions strongly sorbed to the river silt when it is in fresh water may be released as soon as the river water mixes with the sea. The opposite transfer is also possible. A river silt may enter the sea with its sorptive capacity at a very low level of saturation, and may, on entry into the ocean, immediately pick up a large quantity of ionized material from the sea water and precipitate it on the ocean floor. This is a separate process from the chemical precipitation of certain dissolved components which has been recognized ever since it became apparent that there were discrepancies between the chemistry of the sea and that of the rivers that nourished it.

The pernicious variability of filtration procedures already referred to must be considered. If a sample is carefully filtered, the analysis should give a figure that is representative of the dissolved material, using the term "dissolved" to mean "consisting of aggregates small enough to pass the particular filter used." If the sample is not filtered prior to analysis, then not only dissolved material, but also any sorbed material removed by the method of analysis, will be included in the result.

In the absence of exhaustive data on the sorptive capacity and saturation of river silts, it is impossible to evaluate the magnitude of this error exactly. It will vary from element to element and from river to river. For the principal components in most rivers it will not be of very great importance. The quantity of suspended material usually carried by streams is hardly an order of magnitude greater than the quantity of dissolved material, according to usual methods of discriminating between them. As only a small part of the suspended material consists of sorbed components, estimates of the total amount of mineral matter carried by rivers or of the principal components of the mineral matter are unlikely to be seriously in error.

Any complete consideration of the geochemical role of rivers, however, cannot be restricted to the major elements that are strongly ionized, but must include the trace elements, plus more abundant elements that vary widely in solubility under the conditions that prevail in the hydrosphere.

Elements so scarce that they tend to limit the growth of aquatic organisms provide another example of the danger of trying to carry out geochemical calculations with only the dissolved component of river solids. Phosphorus, for example, may be reduced to so low a level in waters that is is not detectable in inorganic solution. Under such circumstances an analysis for phosphate ion will be completely misleading. There may be appreciable phosphorus in the water in the bodies of plants and animals or in the form of dissolved organic materials. The same is true for nitrogen and silicon, and doubtless for other elements as well. The river forms a dynamic system in which the biological elements are continually exchanging, and at a particular time the fraction of the total mobile phosphorus, nitrogen, or silicon that is dissolved in the water may vary from an indetectable amount to almost the whole of it.

Strakhov (1948) has investigated the state of iron in natural waters and has come to the conclusion that for this element, under most circumstances, the proportion of the total amount that is transported in a dissolved form in river waters is very small. The fraction of geochemical significance is bound on the surfaces of the fine mineral grains carried in suspension. Vernadskii (1948, in the Discussion of Strakhov's paper) has further pointed out that even Strakhov overestimated the importance of the dissolved iron, for the solubility product of ferric iron is such that an insignificant amount is in simple solution under ordinary conditions in most river waters. This need not concern us, however, for we are more interested in using "dissolved iron" in the sense of the analysts who report this entity in their analyses than in a rigorous physico-chemical way. Shapiro (1957) has shown that some iron may be dissolved in natural waters, despite the low solubility of ferric ion. Organic compounds of moderate molecular weight stabilize the iron and keep it in solution.

Iron is an extreme example, but it is not alone. The behavior of manganese, cobalt, and nickel must be rather similar. One must not lose sight of the solubility of the solid silicates, including not only the diatoms, sponges, and other minute silica particles in the river, but also the silica in the glass bottles that are still commonly used as sample containers. The last source of error is most likely to be serious for strongly alkaline waters. Hutchinson (1937) found the following increases in the silica content of some water samples from Indian Tibet between the time of their collection in the field and their analysis in the United States:

	SiO_2 *content at the time of collection in Tibet (ppm)*	SiO_2 *content after shipment to U.S.A. in glass bottles (ppm)*
Tso Moriri	6	14
Tso Kav	2	25
Khyagar Tso	2	23
Yaye Tso	6	9
Mitpal Tso	26	24
Pangur Tso	2	168
Pangong Tso	1	17
Ororotse Tso	2	8

Besides these sampling errors there is a certain amount of error in the analytical procedures used to determine the composition of water samples. In earlier editions of this work considerable effort was devoted to selecting trustworthy analyses. To a great extent this was possible, because the analyst responsible for a particular analysis was usually known, and something of his skill and experience were known as well. In the much larger scientific community of today it is impossible to have a critical familiarity with the competence of more than a small fraction of the analysts concerned, and, perhaps for this practical reason, the analyst is less often specified in the published account of an analysis. For papers having several authors, one might presume that the analyses had been carried out by the authors themselves, but frequently the analytical responsibility is shared by an entire organization. Obviously untrustworthy or outmoded analyses have been avoided.

Another method of distinguishing good from bad analyses that was used in the earlier editions was to check the equivalence of anions and cations reported in the analyses. Apart from the possibility of compensating errors, which it cannot reveal, this method has the objection that uncertainties arise about the position of dubiously ionized components.

In this edition the most suitable of the available analyses were chosen, which means, for a large part of the earth's surface, all available analyses. These explanatory notes are intended as a general caveat concerning the reliability of the results.

Temporal variations in the chemical content of rivers, as we have seen, are associated principally with variations in river discharge. To some extent lakes, particularly those of arid regions, become more concentrated as the level falls, but this is not the principal cause of changes in lake-water chemistry. Lakes in general are chemically more stable than streams and they do not show such striking changes in the amount and proportions of the principal dissolved substances.

Very concentrated lakes in cold arid lands may display an annual chemical cycle, as the lowered temperature of winter causes the water to fall below the saturation temperature of one or more of the materials that dissolved in the water during the heat of summer. When this happens salts crystallize out of the water, and their concentration falls. In addition, because the least soluble salts come out first, the percentage composition of the remaining mineral substance is altered.

Even less concentrated lakes may display wide annual fluctuations in concentration if they are shallow in relation to their ice cover. Figure 3, for example, shows how the chloride and magnesium contents of a shallow Arctic lake increased by freezing out of salts into the water that remains under the winter ice. Imikpuk, the lake described in the figure, occasionally receives some sea water, but a similar change is to be expected even in completely fresh Arctic waters.

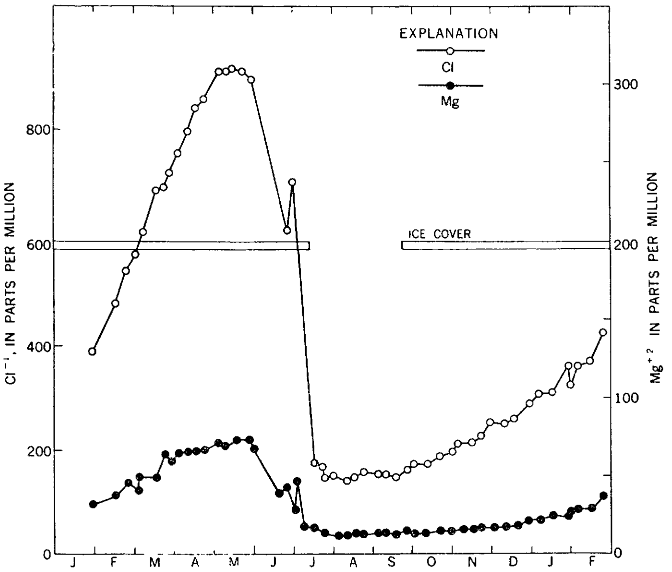

FIGURE 3.—Seasonal changes in the chemical composition of Imikpuk, a small lake in Alaska near the Arctic Ocean. After Boyd (1959). Reprinted by permission of Ecology.

Such seasonal changes are of rather restricted extent. In most lakes the major ions, except the components of the carbonate buffer system, remain relatively constant in amount, and large changes in water chemistry are restricted to the scarcer biologically important substances.

There are also diurnal changes in water chemistry, but these are known to involve only the dissolved gases, oxygen and carbon dioxide. During the day, photosynthetic plants remove carbon dioxide from the water and use it in the manufacture of carbohydrate, giving up oxygen at the same time. During the night the respiration of plants and animals reverses the process.

In very productive lakes, under the control of carbonate buffer systems, uptake of carbon dioxide by photosynthesizing plants occasionally may cause very dramatic changes in pH, as first the free CO_2, then the HCO_3, and finally carbonate is used in photosynthesis. The latter step is accomplished by the hydrolysis of calcium carbonate, and leaves calcium hydroxide in the water. An example is given in figure 4.

Oxygen is easily and accurately measured, and forms part of a great number of chemical analyses of lake waters and of river waters as well. Most of these have been spot analyses taken at a single and unspecified time of day, and yield very little information of value about the oxygen content of the water over a period of 24 hours. Recently there has been much interest among limnologists in using diurnal oxygen change as a measure of biological productivity (fig. 5), and one may expect a great increase in the amount of information about the magnitude of changes in this gas. At present it is evident that the change is great in productive lakes but may not be measurable in unproductive ones, and that the diurnal oxygen change in a single body of water may change with the season.

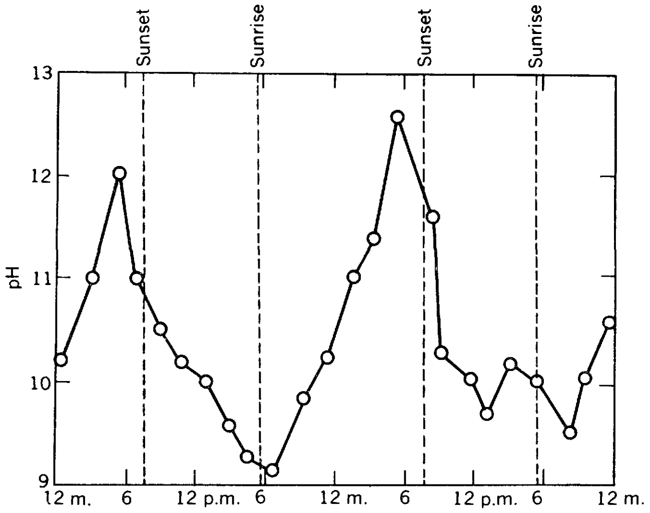

FIGURE 4.—Diurnal pH changes in a small freshwater lake near Cape Town. After Schütle and Elsworth (1954). Reprinted by permission of Blackwell Scientific Publications, Ltd., Oxford, England.

In a shallow lake that mixes freely to the bottom, gas changes are only diurnal, for diffusion from the atmosphere makes up any net loss or gain that may take place over 24 hours. Many lakes do not mix freely to the bottom, however, and in the stagnant lower layers of these the gas changes are cumulative and have a profound effect on other aspects of the deep-water chemistry as well.

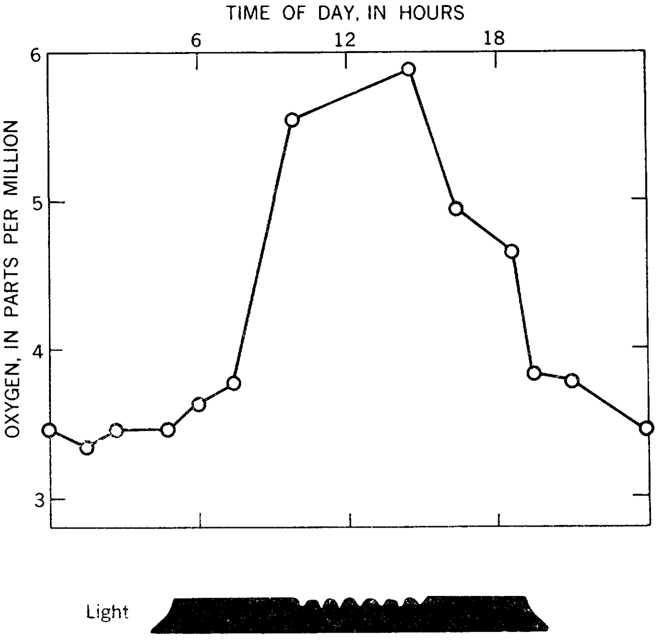

FIGURE 5.—Diurnal oxygen change in Silver Springs, Fla. After Odum (1956). Reprinted by permission of American Society of Limnology and Oceanography, Inc.

Stratification is commonly the result of surface heating by the sun. The warm surface water is lighter than the deep water beneath it, and so resists the tendency of the wind to stir it into the depths. Whether or not a permanent stratification is set up depends on the temperature range involved, upon the rate at which the lake warms up at the beginning of the summer in temperate lands or the sunny dry season in the tropics, upon the wind strength, and upon the size and shape of the lake. The wind is able to work effectively on a lake several miles long and may mix it to a depth of some tens of feet. If the total depth of the lake is not greater than that, it will not stratify. On the other hand, a small farm pond sheltered by thick woods may be mixed only to a depth of few inches.

A thermally stratified lake may be considered as two compartments: an upper freely circulating epilimnion and a lower, nearly stagnant hypolimnion. The zone of rapidly changing temperature that separates the two compartments is commonly known as the thermocline or clinolimnion.

An homologous stratification may be set up by differences in salt content of the deep and shallow water in a lake. This may happen if salt springs flow into the bottom, in a coastal lake if sea water at spring high tide flows over the sill that separates the lake basin from the sea, or as a result of internal biological processes. It may also occur in semiarid lakes if a shift in drainage of a nearby river causes it to pour fresh water over the salt water in the lake basin. Stratification because of salt differences is known as meromixis and usually lasts for many years or even indefinitely. Its principal difference from thermal stratification is this permanence, for thermal stratification breaks down every time the surface water cools enough for the wind to mix it into the depths. The chemical results of meromixis are cumulative and are usually more pronounced than those of seasonal thermal stratification.

The chemical differences that develop between surface and deep water in a stratified lake are of biological origin. In the upper zone light is plentiful and photosynthesis is actively carried on. This removes carbon dioxide from the water and adds oxygen to it. Diffusion from the atmosphere tends to restore gaseous equilibrium at the water surface, and turbulent mixing tends to carry this water down into the depths, so that there is no permanent change in the gas content of the epilimnion. On a bright day, however, when the plant community is actively photosynthesizing, temporary changes will occur, as mentioned above in connection with the diurnal gas changes of natural waters. The amount of oxygen found at a depth of a few feet under such conditions may be substantially more than the water would hold if saturated at atmospheric pressure. Although such water is sometimes said to be supersaturated with oxygen, it is not actually supersaturated at the ambient pressure. When the oxygen content exceeds the saturation value under the ambient conditions, bubbles form. This phenomenon is commonly observed in dense plant beds growing in the upper few meters of clear productive lakes.

Conditions in deep water are rather different. Light is scarce and photosynthesis much reduced. Respiration, however, continues apace, not only the respiration of the animal community, but also the respiration of the host of reducing organisms, particularly bacteria, that are engaged in breaking down the organic substance that settles from the productive epilimnion.

Oxygen is used up and carbon dioxide is produced in the hypolimnion. There is no possibility of rapid replenishment by diffusion from the atmosphere, which is sealed off by the thermocline, and the gas changes are cumulative. In meromictic lakes the gas changes will accumulate for many years.

The change from oxidizing to reducing conditions leads to the appearance of much nitrite, ammonia, hydrogen sulfide, and ferrous iron in the water. It also causes the release from the bottom sediments of a considerable quantity of phosphorus and silica. The seasonal cycle of events has been studied by Mortimer (1941–42) in Esthwaite Water, a productive lake in the English lake district that stratifies very strongly during the summer and to some extent also during the winter. Some of these results are shown in figure 6.

If a strong wind blows across a stratified lake, the light surface water of the epilimnion will tend to pile up on the downwind side of the lake. This may be so pronounced as to strip all of the epilimnion from the upwind side, exposing hypolimnetic water of very different chemical composition. After the wind stops blowing a standing wave of very great amplitude will exist at the boundary between light and dense water, and this wave may continue to oscillate for many days.

It is evident that any system showing as many temporal and spatial variations in chemical content as a deep lake will be inadequately represented by the chemical analysis of a single sample taken at some point on the surface. In a lake with strong meromixis such a sample will not even provide a rough idea of the mean composition of the water. Limnologists are aware of this state of affairs, but their chemical analyses are usually very incomplete; geologists who are, in general, more scrupulous about including all the major ions in their chemical analyses, tend to sample lakes as if they were temporally and spatially homogeneous.

With these general words of warning about the state of present knowledge of the chemistry of lakes and rivers, we may proceed to an examination of the data.

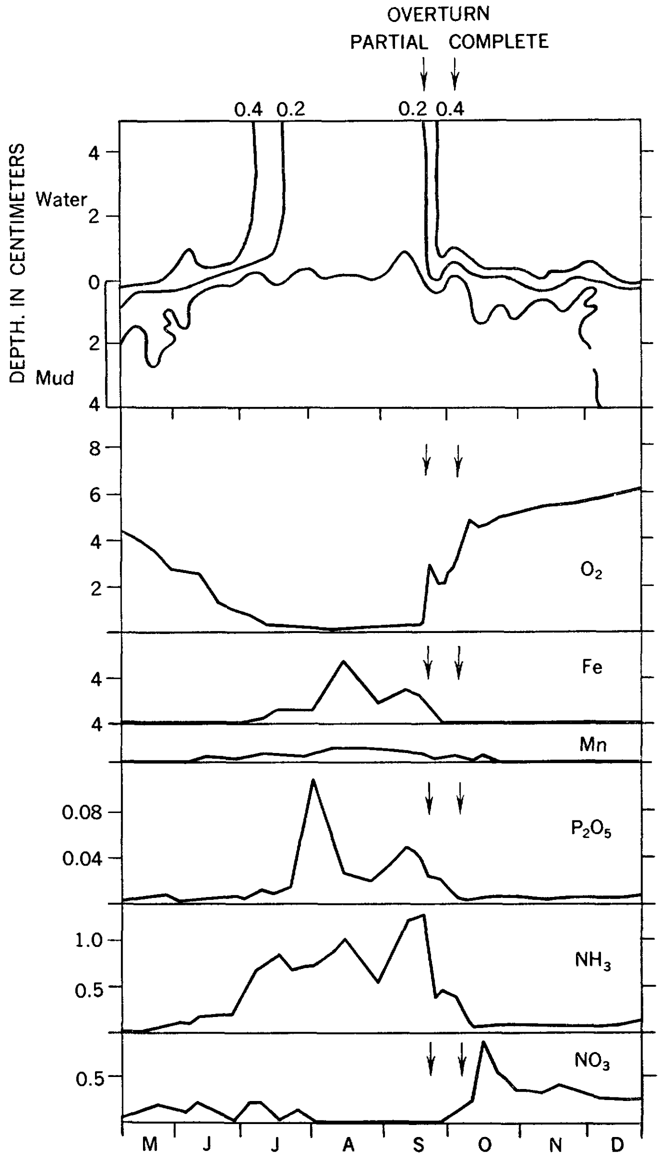

FIGURE 6.—Redox potential near the mud-water interface and concentrations of dissolved substances in the water just over the mud surface of Esthwaite Water, England, during 1940. Redox potential (E_7) in volts, O_2=dissolved oxygen, Fe=ferrous iron, Mn=manganese, P=phosphate as P_2O_5, NH_3=ammonia, NO_3=nitrate nitrogen, all is in parts per million. After Mortimer, 1941–42. Reprinted by permission of Blackwell Scientific Publications, Ltd., Oxford, England.

GENERAL ANALYSES

NORTH AMERICA

An overwhelming mass of chemical data exists for the rivers of North America. Most of the analyses have been made as part of a systematic sampling program of the Water Resources Division of the U.S. Geological Survey and have been published in a series of Water-Supply Papers: Collins, Howard, and Love (1943); Collins and Love (1944); Howard and Love (1945); Howard (1948); U.S. Geological Survey (1947 1948]; 1949b; 1950 [1951]; 1952; 1953a, b; 1954a, b, c, d; 1955a, b, c, d, e; 1956a, b, c; 1957a, b, c; 1958a, b, c, d, e; 1959a, b, c, d, e, f; 1960a, b, c, d, e). In addition, many reports deal with individual states. The following is a selection from a very large number of references; generally only the most recent ones of a series are cited.

U.S. Geological Survey (1960f, g, h); Saunders and Billingsley (1950); Geurin (1951); Geurin and Jeffery (1957); Smith and others (1949); California Department of Water Resources (1956, 1957); Lamar (1944); Cherry (1961); Hershey (1955); Lamar and Laird (1953); Lamar, Krieger, and Collier (1955); Hembree, Colby, Swenson, and Davis (1952); Lamar (1943); Pauszek (1952); Pauszek and Harris (1951); McAvoy (1957); Woodward and Thomas (1960); White (1947); Lamar and Schroeder (1951); Ohio River Valley Water Sanitation Commission (1950 [1951]); Murphy (1955); Dover (1956, 1959); Beamer (1953); Pennsylvania State Planning Board (1947); Pauszek (1951); Hastings and Rowley (1946); Irelan and others (1950); Irelan (1957); Hughes and Jones (1961); Connor, Mitchell, and others (1959); Lamar and Whetstone (1947); Whetstone and McAvoy (1952); Kapustka (1957).

The older data are collected in Clarke (1924a). Inventories of published and unpublished data may be found in Northcraft and Westgarth (1957), U.S. Federal Inter-Agency River Basin Commission (1948, 1954, 1956), and Westgarth and Northcraft (1956).

Lake sampling has not been nearly as comprehensive. There are extensive sets of data both in government publications and the limnological literature, but most of the analyses are deficient because some important major ions have been neglected, or because of insufficient sampling. Despite the wealth of data there are serious gaps in the coverage even of the rivers. There does not exist, for example, any really adequate series of chemical data for the lower Mississippi.

Outside of the United States information is far more scarce. It has not been possible to locate a reasonably complete analysis of a single river in Mexico, and the coverage for Canada is very poor. There are only a few scraps of information for the whole MacKenzie River system, and the chemistry of most of the northern lakes and rivers is completely unknown. This is particularly unfortunate because of the opportunities Canada affords for the study of the geochemical regimen of rivers that are completely within the tundra zone. Even the waters of the well-settled parts of the country, however, are represented by only a few spot samples, and it is not possible to draw up a reliable long-term mean for any Canadian river.

ST. LAWRENCE RIVER BASIN

A representative series of analyses is presented in tables 6 and 7. The St. Lawrence basin is a well-watered region and the concentration of dissolved salts is not high. A very marked difference is apparent, however, between the waters draining the chemically resistant rocks of the Canadian shield, with total dissolved salts often well below 50 ppm, and those draining the sedimentary rocks of the southern Great Lakes region, with total dissolved salts mostly between 100 and 500 ppm. Some of the Canadian shield waters, such as the Saguenay River, are very dilute, but they are ordinary calcium bicarbonate waters and are not otherwise remarkable. Some rivers in the St. Lawrence system, in particular the streams flowing into Lake Erie from the south, such as the Cuyahoga (table 6, analysis I) are subject to heavy industrial pollution.

ATLANTIC COAST DRAINAGE

A selection of analyses representing waters of the Atlantic Coast from Nova Scotia to Florida is presented in tables 8, 9, and 10. This is also a well-watered area, and most of its waters are rather dilute.

TABLE 6.—*Analyses, in parts per million, of water from the St. Lawrence River basin*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
HCO_3^{-1}	26.2	126.1	134.2	210.5	229.3	102.1	15.3	27.5	120	30.5	43.3	16.9	6.7	6.1	100.7
SO_4^{-2}	8.5	16.8	13.6	58.8	124.2	13.1	8.9	8.0	82	7.2	12.0	5.3	5.0	3.1	5.3
Cl^{-1}	1.0	3.4	3.0	36.2	14.8	1.8	1.5	1.6	32	1.1	1.6	1.0	.8	.5	1.5
F^{-1}	----	----	----	----	----	----	----	----	.2	----	----	----	----	----	----
NO_3^{-1}	1.33	.50	.08	2.13	1.58	1.5	1.10	.62	4.3	.26	.52	.72	5.8	.60	.40
Ca^{+2}	9.0	36.0	39.5	66.6	87.3	31.8	7.5	10.5	54	16.0	15.6	6.2	4.8	3.6	28.2
Mg^{+2}	3.6	4.8	6.3	20.1	24.1	4.8	2.8	3.0	12	3.2	4.1	1.6	1.3	1.5	4.8
Na^{+1}	3.8	5.3	1.8	21.2	15.7	2.7	1.1	3.6	21	5.2	3.6	2.4	3.3	------	6.8
K^{+1}	----	----	----	----	----	----	----	----	3.4						
Fe	.15	None	.05	.25	.06	.7	.08	.22	.06	.02	.05	.24	.15	.20	.5
SiO_2	3.0	4.8	6.0	9.5	9.9	6.5	1.4	5.8	6.7	6.6	6.6	13.5	4.2	3.0	9.4
Total dissolved solids	56.6	198	205	425	507	165	39.7	60.8	336	70.1	87.4	47.9	32.1	>18.6	158

A. Lake Nipissing at North Bay, Ontario; depth sample 2 miles from shore. May 26, 1939. Leverin (1947), analysis 613.
B. Lake Couchiching at Orillia, Ontario; depth sample 3 miles from shore. July 17, 1934. Leverin (1947), analysis 15.
C. Lake Simcoe, Ontario. Depth sample at mouth of Kampenfeldt Bay. Aug. 12, 1935. Leverin (1947), analysis 222.
D. Thames River at Chatham, Ontario. Mean of 6 analyses from 1934–40, Leverin (1947), analyses 17, 223, 338, 355, 488, 737.
E. Grand River at Brantford, Ontario. Mean of 9 analyses from 1934–42. Leverin (1947), analyses 20, 266, 337, 352, 467, 486, 597, 736, and 842.
F. Trent River at Trenton, Ontario. Mean of 4 analyses, 1934–37. Leverin (1947 analyses 23, 229, 336, 339, 375, and 849.
G. Lake Temiskaming at Haileybury, Ontario. Depth sample 1 mile from shore, Aug. 27, 1937. Leverin (1947), analysis 363.
H. Ottawa, River at Hawkesbury, Ontario. Mean of 8 analyses, 1934–38. Leverin (1947), analyses 2, 3, 207, 335, 346, 347, 496, and 583.
I. Cuyahoga River at Botzum, Ohio. U.S. Geol. Survey (1952). Mean for Oct. 1946–Sept. 1947.
J. Magog River at Sherbrooke, Quebec. June 26, 1942. Leverin (1947), analysis 850.
K. Richelieu River at St. Johns, Quebec. Mean of 4 samples, 1935–42. Leverin (1947), analyses 219, 318, 799, and 851.
L. St. Charles River at Chateau d'Eau, Quebec. Mean of 4 samples, 1934–39. Leverin (1947), analyses 13, 213, 322, and 634.
M. St. Maurice River at Three Rivers, Quebec. Mean of 5 samples, 1934–41. Leverin (1947), analyses 9, 211, 321, 635, and 802.
N. Saguenay River at Riverbend, Quebec. July 12, 1935. Leverin (1947), analysis 217.
O. Nipigon River at Nipigon, Ontario. Aug. 2, 1937. Leverin (1947), analysis 362.

TABLE 7.—*Analyses, in parts per million, of water from the Great Lakes and St. Lawrence River*

	A	B	C	D	E	F	G	H	I	J	K	L
HCO_3^{-1}	50.0	52.1	76.3	100.0	117.7	121	113.5	110.1	108.8	87.5	85.8	84
SO_4^{-2}	4.8	6.3	13.2	13.1	22.1	28	20.3	21.5	21.4	18.6	16.0	20
Cl^{-1}	1.5	2.1	2.9	4.2	14.8	17	15.6	15.7	16.1	12.0	10.4	16
F^{-1}	----	----	----	----	----	.1	----	----	----	----	----	.0
NO_3^{-1}	.52	.61	.61	1.32	.79	1.2	.85	.82	.68	.07	.89	.4
Ca^{+2}	14.1	14.6	22.8	27.6	38.1	39	36.9	35.7	36.5	29.3	27.6	28
Mg^{+2}	3.7	4.2	6.4	7.5	8.5	8.7	7.8	8.4	8.3	6.4	5.9	5.8
Na^{+1}	3.4	2.6	4.4	2.4	7.7	8.2	8.9	8.0	8.5	6.6	4.1	8.0
K^{+1}						1.4						1.1
Fe	.36	.06	.02	.04	.06	.03	.06	.06	.04	.06	.05	.02
SiO_2	4.1	5.4	5.2	5.6	6.0	2.1	3.7	3.9	6.5	5.7	9.9	1.7
Total dissolved solids	82.5	88.0	132	162	216	227	208	204	207	166	161	165

A. Lake Superior. Mean of 6 samples taken from various places on the lake, at depths from 12 to 20 ft. Leverin (1947), analyses 359, 559, 900, 901, 947, 948.
B. St. Mary's River at Sault Ste Marie, Ontario. Mean of 5 analyses, 1936–38. Leverin (1947), analyses 326, 356, 357, 557, 558.
C. Georgian Bay at Collingwood, Ontario. June 12, 1942. Leverin (1947), analysis 843.
D. St. Clair River at Point Edward, Ontario. Mean of 4 analyses, 1934–37. Leverin (1947), analyses 18, 224, 327, 353.
E. Lake Erie at Fort Erie, Ontario (outlet into Niagara River). Mean of 6 analyses, 1934–38. Leverin (1947), analyses 22, 227, 329, 350, 466, 598.
F. Lake Erie at Huron, Ohio. Mean of 7 analyses, Sept. 1950–Sept. 1951. U.S. Geol. Survey (1955c).
G. Lake Ontario at Toronto, Ontario. Mean of 7 samples, 1934–38. Leverin (1947), analyses 21, 228, 330, 351, 465, 485, 596.
H. St. Lawrence River at Kingston, Ontario. Mean of 8 samples, 1934–42. Leverin (1947), analyses 24, 230, 331, 464, 484, 595, 735, 846.
I. St. Lawrence River at Cornwall, Ontario. Mean of 9 samples, 1934–42. Leverin (1947), analyses 25, 231, 332, 374, 463, 594, 734, 801, 844.
J. St. Lawrence River at Montreal. Mean of 10 samples, 1934–42. Leverin (1947), analyses 7, 26, 208, 232, 333, 345, 348, 349, 632, 847.
K. St. Lawrence River at Sorel, Quebec. Mean of 3 samples, 1934–36. Leverin (1947), analyses 8, 220, 334.
L. St. Lawrence River at water works plant at Levis, Quebec, Aug. 1958. Durum, Heidel, and Tison (1960). Analysis includes Ag, 0.00094 ppm; Al, 0.276 ppm; B, 0.013 ppm; Ba, 0.030 ppm; Co, 0.000 ppm; Cr, 0.012 ppm; Cu, 0.0043 ppm; Li, 0.00041 ppm; Mn, 0.021 ppm; Mo, 0.0017 ppm; Ni, 0.0013 ppm; P, 0.000 ppm: Pb, 0.0037 ppm; Rb, 0.0014 ppm; Sr, 0.066 ppm; Ti, 0.021 ppm.

TABLE 8.—*Analyses, in parts per million, of water from the Atlantic Coast drainage in Canada*

	A	B	C	D	E	F	G	H	I	J	K	L
HCO_3^{-1}	14.6	87.8	0.7	17.1	3.1	6.7	11.6	4.5	52.9	0.0	2.7	8.7
SO_4^{-2}	7.7	5.2	4.3	9.0	4.2	4.8	5.5	6.4	9.2	6.2	5.4	5.8
Cl^{-1}	75.5	11.5	6.1	22.0	2.4	.70	.7	3.3	2.3	7.5	5.2	5.0
NO_3^{-1}	3.54	.71	.42	.20	.99	.84	.49	.58	.40	------	------	------
PO_4^{-3}	.83	.56	.66	.77	------	------	------	------	------	------	------	------
Ca^{+2}	6.4	33.8	3.6	7.2	3.5	5.5	7.2	3.9	16.9	1.1	2.3	3.6
Mg^{+2}	6.9	2.3	2.5	3.2	1.2	2.4	2.0	3.2	5.0	4.7	.5	.8
Na^{+1}	39.5	6.5	5.5	10.7	3.4	3.1	3.2	5.6	3.1	5.0	3.2	3.4
K^{+1}										4.2	.6	.5
Fe	.05	.40	.23	.15	.04	.16	.28	.18	.10	------	------	------
SiO_2	8.0	2.3	3.0	6.6	1.6	5.0	4.4	4.8	4.7	------	------	------
Total dissolved solids	163	151	27.0	76.9	20.4	29.2	35.4	32.5	94.6	>28.7	>19.9	>27.8

A. Dalvay Pond at Dalvay, Prince Edward Island, Sept. 19, 1940. Depth sample. Leverin (1947), analysis 728.

B. Ellerslie Creek, Ellerslie, Prince Edward Island. July 10, 1940. Leverin (1947), analysis 724.

C. Mean of 9 samples from the Moser River basin, Nova Scotia, 1939–40. Leverin (1947), analyses 645, 646, 719, 647, 721, 648, 718, 720, 723.

D. Wallace River, Nova Scotia. Aug. 9, 1940. Leverin (1947), analysis 717.

E. Chain of lakes 7 miles from St. Andrews, New Brunswick. Mean of 8 samples taken Oct. 16, 1941. Leverin (1947), analyses 804–811.

F. Northwest Miramichi River at Redbank, New Brunswick. Mean of 3 analyses 1939–41. Leverin (1947), analyses 640, 731, 797.

G. Southwest Miramichi River at Quarryville, New Brunswick. Mean of 3 analyses, 1939–41. Leverin (1947), analyses 639, 730, 798.

H. Grand Lake, New Brunswick. Mean of 2 analyses, 1939–40. Leverin (1947), analyses 642, 733.

I. St. John River at Woodstock, New Brunswick. Mean of 3 analyses, 1936–40. Leverin (1947), analyses 324, 643, 732.

J. Mean of 10 lakes on granite in Halifax County, Nova Scotia, Dec. 1955. Gorham (1957a, p. 14), analyses 1–10.

K. Mean of 9 lakes on slate or quartzite in Halifax County, Nova Scotia, Dec. 1955 Gorham (1957a, p. 14), analyses 11–19.

L. Mean of 4 lakes on or receiving drainage from Carboniferous strata, Halifax County, Nova Scotia, Dec. 1955. Gorham (1957a, p. 14), analyses 20–23.

Not all these are calcium bicarbonate waters. In the coastal regions where the influence of sea spray is strong there is much more sodium and chloride than calcium and carbonate. (See, for example, Dalvay Pond, analysis A, and the mean of 10 lakes on granite in Halifax County, table 8, analysis J, where there is no detectable bicarbonate.) Sulfate concentration is high in many of these waters. In the dilute waters the absolute amount is not high, and much of it may be from sea spray. But in the more concentrated waters from coal mining areas, for example, the Lehigh, Delaware, and Susquehanna Rivers, much of the sulfate is of sedimentary origin. Mining operations frequently expose pyrite to oxidation and result in a great increase in the rate in which sulfur is leached from the country rock in these areas. (See table 9, analysis E.)

TABLE 9.—*Analyses, in parts per million, of water from the Atlantic Coast drainage in the northern United States*

	A	B	C	D	E	F	G	H	I
HCO_3^{-1}	11	16	21	33	0	111	88	48	93
SO_4^{-2}	43	9.6	12	22	72	32	20	74	25
F^{-1}	.1	.2	.1	.1	.1	.1	.1	.0	.0
Cl^{-1}	2.4	2.2	1.8	3.8	2.3	14	22	9.5	5.0
NO_3^{-1}	2.3	.9	1.0	3.2	.9	4.6	5.9	2.2	1.2
Ba^{+2}	------	------	------	------	------	------	------	.025	.028
Ca^{+2}	13	6.3	7.8	13	14	34	23	28	32
Sr^{+2}	------	------	------	------	------	------	------	.025	.106
Mg^{+2}	4.5	1.4	2.0	4.2	5.2	9.8	5.0	11	4.9
Li^{+1}	------	------	------	------	------	------	------	.0035	.0022
Na^{+1}	3.4	1.9	21	3.5	3.3	9.9	23	7.8	4.8
K^{+1}	1.3	.8	1.0	1.3	1.4	2.2	3.3	1.8	2.0
Rb^{+1}	------	------	------	------	------	------	------	.0021	.0019
Fe	.03	.03	.03	.04	.08	.04	.08	.02	.07
Al	------	------	------	------	------	------	------	.027	.304
Mn	------	------	------	------	.31	.00	------	.0021	.035
SiO_2	4.6	3.6	2.8	3.8	5.1	5.7	5.7	.2	4.9
Total dissolved solids	85.6	42.9	70.5	87.9	105	223	196	183	173

A. Lehigh River at Catasauqua, Pa. Oct. 1944 to Sept. 1945. U.S. Geol. Survey (1949b).

B. Delaware River at Dingmans Ferry, Pa. Oct. 1950 to Sept. 1951. U.S. Geol. Survey (1955c).

C. Delaware River at Belvedere, N.J. Oct. 1944 to Sept. 1945. U.S. Geol. Survey (1949b).

D. Delaware River at Trenton, N.J. Oct. 1944 to Sept. 1945. U.S. Geol. Survey (1949b).

E. West Branch Susquehanna River at Lock Haven, Pa. Oct. 1945 to Sept. 1946. U.S. Geol. Survey (1950 [1951]).

F. Frankstown Branch Juniata River at Huntingdon, Pa. Oct. 1947 to Sept. 1948. U.S. Geol. Survey (1953a).

G. Codorus Creek near York, Pa. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).

H. Susquehanna River at hydroelectric plant spillway at Conowingo, Md. Sept. 11, 1958. Durum, Heidel, and Tison (1960). Analysis includes Ag, 0.00025 ppm; B, 0.016 ppm; Co, 0.000 ppm; Pb, <0.0021 ppm; Ti, <0.0021 ppm.

I. Hudson River at Ford Motor Co. powerplant at Green Island, N.Y. Oct. 29, 1958. Durum, Heidel, and Tison, 1960. Analysis includes Ag, 0.00015 ppm; B, 0.009 ppm; Co, 0.000 ppm; Cr, 0.030 ppm; Cu, 0.0086 ppm; Mo, 0.000 ppm; Ni, 0.012 ppm; P, 0.000 ppm; Pb ,0.0029 ppm; and Ti, <0.0014 ppm.

TABLE 10.—*Analyses, in parts per million, of water from the Atlantic Coast drainage in the southern United States*

	A	B	C	D	E	F
HCO_3^{-1}	20	27	14	136	241	299
SO_4^{-2}	3.1	3.3	5.6	28	32	45
F^{-1}	.0	.0	.2	.2	.2	.5
Cl^{-1}	2.4	2.9	12	29	98	88
NO_3^{-1}	.33	.42	.1	1.2	1.8	3.3
Ca^{+2}	4.0	6.2	5.5	41	63	72
Mg^{+2}	1.2	1.4	1.7	9.1	13	21
Na^{+2}	3.2	3.8	7.4	22	72	70
K^{+1}	1.3	1.3	.7	1.2	2.3	2.8
Fe	.4	.11	.05	.02	.10	.03
SiO_2	10.0	11	2.4	9.3	21	18
Total dissolved solids	45.9	57.4	49.7	277	544	620

A. Savannah River near Clyo, Ga. May 1938 to Apr. 1939. Lamar (1944).

B. Altamaha River at Doctortown, Ga. May 1937 to Apr. 1938. Lamar (1944).

C. Kissimmee River near Okeechobee, Fla. Mar. 1940 to Feb. 1941. Collins, Howard, and Love (1943).

D. Lake Okeechobee 5 miles north of Clewiston, Fla. Mean of 17 analyses, July 1950 to Sept. 1951 U.S. Geol. Survey (1955c).

E. West Palm Beach Canal at Loxahatchee, Fla. Nov. 1950 to Sept. 1951. U.S. Geol. Survey (1955c).

F. Hillsboro Canal at Shawano, Fla. Oct. 1950 to Sept. 1951. U.S. Geol. Survey (1955c).

There are minor differences between the waters of the Atlantic Coast drainage, even within a small area, as shown by the analyses by Gorham (1957a) of lake waters from three kinds of rock in a single county in Nova Scotia. The general picture is one of rather dilute water and a remarkable uniformity from the Gulf of St. Lawrence to Florida, where the concentration of calcium-bicarbonate waters is again more than 500 ppm. There are undoubtedly small pockets of hard surface water farther north—for example, in the regions of dolomite outcrop on Cape Breton Island—and probably small streams with much saltier water as well, for salt springs are known from the Atlantic Coast drainage, but these aberrant waters are too local in occurrence to affect the general composition of the major streams, and too scarce to have been detected in the sampling that has been done so far.

EASTERN TRIBUTARIES OF THE GULF OF MEXICO

West of peninsular Florida rather dilute calcium carbonate waters are again found (table 11).

TABLE 11.—*Analyses, in parts per million, of water from the eastern tributaries of the Gulf of Mexico*

	A	B	C	D	E	F	G	H	I
HCO_3^{-1}	118	54	20	57	63	47	20	63	45
SO_4^{-2}	23	3.2	4.5	.6	4.2	4.4	3.1	6.0	13
F^{-1}	.1	.1	.1	.1	.0	.1	.0	------	.1
Cl^{-1}	10	2.7	3.3	3.9	2.6	1.9	1.4	2.8	12
NO_3^{-1}	.7	.6	1.2	.5	.6	.7	.24	.57	.3
Ca^{+2}	44	17	3.8	16	15	12	3.8	17.0	13
Mg^{+2}	3.8	1.0	1.3	.8	4.3	2.8	1.2	1.7	2.2
Na^{+1}	5.0	2.7	4.9	3.8	2.6	2.3	2.5	7.7	9.9
K^{+1}	.3	.8	1.5	1.1	1.0	1.1	1.0	2.2	1.7
Fe	.04	.05	.05	.096	.04	.03	.02	.58	.392
SiO_2	7.6	8.7	11	7.9	7.1	7.5	10	22	8.6
Total dissolved solids	213	90.9	51.7	91.8	100	79.8	43.3	124	106

A. Withlacoochee River near Holder, Fla. Oct. 1950 to Dec. 1951. U.S. Geol. Survey (1955c).
B. Flint River at Bainbridge, Ga. Oct. 1941 to Sept. 1942. Collins, Howard, and Love (1943).
C. Chattahoochee River at Columbus, Ga. Weighted average for Oct. 1940 to Sept. 1941. Collins, Howard, and Love (1943).
D. Apalachicola River at State Highway 20 near Blounstown, Fla. Dec. 17, 1958. Durum, Heidel, and Tison (1960). Analysis includes Ag, 0.00011 ppm; Al, 0.073 ppm; B, 0.0050 ppm; Ba, 0.042 ppm; Co, 0.000 ppm; Cr, 0.0022 ppm; Cu, 0.0021 ppm; Li, 0.000096 ppm; Mn, 0.0050 ppm; Mo, 0.000 ppm; Ni, 0.0046 ppm; P, 0.000 ppm; Pb, 0.0062 ppm; Rb, 0.0010 ppm; Sr, 0.034 ppm; Ti, <0.0008 ppm.
E. Conasauga River at Tilton, Ga. Oct. 1942 to Sept. 1943. Howard and Love (1945).
F. Oostanaula River at Rome, Ga. Oct. 1941 to Sept. 1942. Collins and Love (1944).
G. Etowah River near Cartersville, Ga. Oct. 1938 to Sept. 1939. Lamar (1944).
H. Tombigbee River near Epes, Ala. Analysis recalculated from Clarke (1924b).
I. Mobile River at Mt. Vernon Landing, Ala. Dec. 16, 1958. Durum, Heidel, and Tison, 1960. Analysis includes Ag, 0.00013 ppm; Al, 0.186 ppm; B, 0.0033 ppm; Ba, 0.075 ppm; Co, 0.000 ppm; Cr, 0.0020 ppm; Cu, 0.0035 ppm; Li, 0.0017 ppm; Mn, 0.041 ppm; Mo, 0.000 ppm; Ni, 0.0069 ppm; P, <0.098 ppm; Pb, 0.015 ppm; Rb, 0.0013 ppm; Sr, 0.068 ppm; Ti, 0.0036 ppm; and Zn, 0.000 ppm.

MISSISSIPPI RIVER DRAINAGE

Some recent fairly complete analyses for the Mississippi system are presented in tables 12–15. An older set of data from the Mississippi River is included in table 15(H), because it is the best information about the mean composition of this remarkable river. It needs to be replaced by a complete modern analysis of water collected over a period of 12 months.

The Mississippi basin is moderately well watered and is underlain largely by sedimentary rocks. The result is usually water with hundreds of parts per million total dissolved solids. The salts making up the dissolved material vary considerably, but sulfate tends to be more important than carbonate in the Ohio and its tributaries, and also in the tributaries of the more arid parts of the western Mississippi drainage (E, table 14). In most Mississippi waters, calcium is the dominant cation, though again there are exceptions, with sodium becoming more important in the arid parts. In highly industrialized parts of the Ohio branch, some waters (G, table 13) are concentrated by pollution and contain a great deal of chloride as well as sulfate and bicarbonate. In Pennsylvania (C–E, table 13), acid mine wastes contribute much sulfate to some rivers.

TABLE 12.—*Analyses, in parts per million, of water from the Ohio River, main stem*

	A	B	C	D	E	F	G	H
HCO_3^{-1}	5	25	34	29	63	64	100	92
SO_4^{-2}	124	126	126	68	69	71	58	58
F^{-1}	.2	.3	.3	.3	.5	.3	.4	.4
Cl^{-1}	14	15	48	19	19	20	19	18
NO_3^{-1}	2.3	1.9	2.1	4.6	2.0	2.3	2.0	2.0
Ca^{+2}	29	32	46	27	33	35	38	39
Mg^{+2}	8.3	8.6	10.0	6.0	7.7	6.7	9.0	8.4
Na^{+1}	18	18	30	17	15	15	12	13
K^{+1}	2.3	2.8	3.2	2.6	3.6	3.1	2.6	2.6
Fe	.03	.05	.06	.12	.06	.17	.05	.05
Al	1.3	------	------	------	------	------	------	------
Mn	.50	------	------	------	------	------	------	------
SiO_2	5.8	6.7	6.2	7.3	7.9	5.7	6.2	6.0
Total dissolved solids	211	236	306	181	221	223	247	240

A. Ohio River at South Heights [17], Pa. Mean of 36 analyses. Oct. 1945 to Sept. 1946. Pennsylvania State Planning Board (1947, p. 122).
B. Ohio River at Dam 13 [114]. Analyses B–H represent 12-day weighted averages for Sept. 18–29, 1950, and are from Ohio River Valley Water Sanitation Commission (1950 [1951], table 2).
C. Ohio River at Dam 19 [192].
D. Ohio River at Dam 31 [359].
E. Ohio River at Dam 39 [531].
F. Ohio River at Dam 43 [633].
G. Ohio River at Shawneetown, Ill. [858].
H. Ohio River at Dam 53 [963].
The figures in brackets represent the distance in miles below Pittsburgh, Pa.

TABLE 13.—*Analyses, in parts per million, of water from the Ohio drainage of the Mississippi system*

	A	B	C	D	E	F	G
HCO_3^{-1}	45	18	0	1	2	61	85
SO_4^{-2}	19	47	279	70	108	74	135
F^{-1}	.1	.1	.2	.1	.1	.3	.5
Cl^{-1}	95	25	7.4	2.0	3.6	7.7	477
NO_3^{-1}	1.1	.5	2.6	2.5	2.7	13	5.1
Ca^{+2}	28	20	47	17	21	36	201
Mg^{+2}	5.9	4.2	17	5.5	7.4	9.8	16
Na^{+1}	45	14	16	2.0	13	7.8	141
K^{+1}	2.8	2.1	3.9	1.3	1.9	2.8	4.4
Fe	.08	.26	.56	.07	.10	.06	.07
Al	------	------	------	1.3	------	------	------
Mn	------	.13	2.2	.5	.4	.00	.05
SiO_2	3.5	4.6	12	6.8	4.8	5.2	6.6
Total dissolved solids	246	136	388	110	165	218	1,072

A. Allegheny River at Warren, Pa. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
B. Clarion River near Piney, Pa. Oct. 1946 to Sept. 1947. U.S. Geol. Survey (1952).
C. Kiskiminetas River at Leechburg, Pa. Oct. 1946 to Sept. 1947. U.S. Geol. Survey, (1952).
D. Casselman River at Harnedsville, Pa. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954b).
E. Youghiogheny River at Sutersville, Pa. Oct. 1947 to Sept. 1948. U.S. Geol. Survey (1953a).
F. Mahoning River at Warren, Ohio. Oct. 1946 to Sept. 1947. U.S. Geol. Survey (1952).
G. Tuscarawas River at Newcomerstown, Ohio. Oct. 1946 to Sept. 1947. U.S. Geol. Survey (1952).

TABLE 14.—*Analyses, in parts per million, of water from the northwestern part of the Mississippi system*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
CO_3^{-2}	------	------	------	------	------	4.4	6.0	------	27.5	------	1	------	3	------
HCO_3^{-1}	136	152	165	120	191	143	124	107	110	149	249	206	244	195
SO_4^{-2}	30	26	40	56	1,000	179	133	73	125	637	76	396	64	111
F^{-1}	.2	.1	.3	.2	------	.3	.2	.3	.3	.6	.6	.9	1.1	.4
Cl^{-1}	4.3	11	4.4	4.5	40	10	.5	.8	2.0	55	5.7	32	7.6	184
NO_3^{-1}	7.9	6.1	.6	.8	11	2.2	1.6	1.8	2.6	2.0	1.8	2.1	2.4	1.8
Ca^{+2}	37	42	40	35	179	53	32	14	21	185	18	107	53	77
Mg^{+2}	11	9.9	11	8.2	32	16	14	5.0	7.8	42	1.7	31	15	13
Na^{+1}	5.9	9.6	15	19	309	55	50	46	80	102	108	100	34	131
K^{+1}	4.4	4.1	3.2	1.9	4.6	4.5	2.5	11	6.6	4.5	5.7	9.8	10	9.6
Fe	.25	.11	.02	.04	------	.03	.02	.23	.22	.03	.16	.02	.06	.07
SiO_2	12	12	24	18	------	17	12	9.8	10	16	41	26	49	21
Total dissolved solids	249	273	304	264	>1,770	484	376	269	393	1,190	509	911	483	744

A. Iowa River at Iowa City, Iowa. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1955b).
B. Cedar River at Cedar Rapids, Iowa. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1955b).
C. Wind River at Dubois, Wyo. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
D. Wind River at Riverton, Wyo. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
E. Fivemile Creek near Shoshone, Wyo. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1955b).
F. Bighorn River at Thermopolis, Wyo. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
G. Little Missouri River at Medora, N. Dak. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
H. Heart River near South Heart, N. Dak. Oct. 1947 to Sept. 1948. U.S. Geol Survey (1953a).
I. Grand River at Shadehill, S. Dak. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
J. Cheyenne River near Hot Springs, S. Dak. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
K. White River near Kadoka, S. Dak. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1955b).
L. South Platte River at Julesburg, Colo. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
M. Republican River at Trenton, Kans. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1954a).
N. Saline River near Wilson, Kans. Feb. 1948 to Sept. 1950. U.S. Geol. Survey (1955b).

TABLE 15.—*Analyses, in parts per million, of water from the lower Mississippi River and its tributaries*

	A	B	C	D	E	F	G	H	I	J	K	L
HCO_3^{-1}	174	169	177	150	21	196	104	116	101	28	26	4
SO_4^{-2}	16	4.7	4.8	5.4	3.6	20	53	25.5	41	4.3	5.8	7.2
F^{-1}	.1	.1	.1	.0	Tr.	.4	.2	--------	.1	.3	.2	.1
Cl^{-1}	6.4	3.9	2.8	3.3	2.3	4.6	159	10.3	15	2.6	4.2	486
NO_3^{-1}	1.6	1.9	2.0	2.7	1.3	1.2	3.0	2.7	1.9	1.9	2.0	1.5
Ca^{+2}	42	36	31	30	5.9	49	44	34	34	6.3	7.1	48
Mg^{+2}	11	12	17	13	1.2	10	9.6	8.9	7.6	1.5	1.9	13
Na^{+1}	8.1	4.2	4.9	3.0	2.3	12	95	13.8	11	4.6	4.1	238
K^{+1}	2.4	1.5	1.7	1.7	1.0	3.6	3.5		3.1	1.0	1.2	11
Fe	.07	.07	.11	.05	.09	.04	.14	.14	.02	.04	.03	.07
SiO_2	18	9.1	12	10	7.1	15	9.3	11.7	5.9	7.5	7.6	16
Total dissolved solids	280	243	253	219	45.8	312	481	223	221	58	60.1	825

A. St. Francis River at Marked Tree, Ark. Nov. 1949 to Sept. 1950. U.S. Geol. Survey (1954c).
B. White River at Batesville, Ark. Oct. 1945 to Sept. 1946. U.S. Geol. Survey (1950 [1951]).
C. Black River at Black River, Ark. Oct. 1945 to Sept. 1946. U.S. Geol. Survey (1950 [1951]).
D. White River at Newport, Ark. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954c).
E. Little Red River near Heber Springs, Ark. Nov. 1949 to Sept. 1950. U.S. Geol. Survey (1954c).
F. Cimarron River at Ute Park, N. Mex. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954c).
G. Arkansas River at Dardanelle, Ark. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1953b).
H. Mississippi River at New Orleans. Mean of 52 composite samples taken daily between Apr. 23, 1905 and Apr. 28, 1906. J. S. Porter, analyst. Recalculated from Clarke, 1924b.
I. Mississippi River just above bridge on U.S. Highway 190, near Baton Rouge, La. March 13, 1959. Durum, Heidel, and Tison, 1960. Analysis also includes Ag, 0.000 ppm; Al, 1.010 ppm; B, 0.015 ppm; Ba, 0.072 ppm; Co, 0.000 ppm; Cr, 0.006 ppm; Cu, 0.0090 ppm; Li, 0.0018 ppm; Mn, 0.046 ppm; Mo, 0.000 ppm; Ni, 0.013 ppm; P, <0.184 ppm; Pb, 0.004 ppm; Rb, 0.0074 ppm; Sr, 0.061 ppm; Ti, 0.072 ppm; V, <0.0055 ppm; and Zr, 0.000 ppm.
J. Ouachita River near Malvern, Ark. Oct. 1946 to Sept. 1947. U.S. Geol. Survey (1952).
K. Ouachita River at Arkadelphia, Ark. Oct. 1959 to Sept. 1950. U.S. Geol. Survey (1954c).
L. Smackover Creek near Smackover, Ark. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954c).

RIO GRANDE BASIN

Rainfall is light in the Rio Grande basin and most of its waters are quite concentrated, at least during seasons of low discharge. Representative data presented in table 16 show that the more dilute waters, with total dissolved salts less than 1,000 ppm, tend to be calcium bicarbonate ones, whereas the more concentrated waters, such as waters from the Pecos, are dominated by calcium sulfate or sodium sulfate. The more concentrated stations on the Pecos have a high content of chloride as well, partly because of the regional lithology, but none of the rivers can be characterized as a sodium chloride water as table 17 shows, although there are sodium chloride waters, at least locally, in the Rio Grande basin.

COLORADO RIVER BASIN

Precipitation in the basin of the Colorado River is spatially variable. This variability is reflected in the quality of its water. Even the few selected data in table 18 show a twentyfold range in the yearly mean concentration of two rivers. Once again the dilute waters are calcium bicarbonate, with sodium, sulfate, and chloride important where the concentration is greater.

NORTH AMERICAN CLOSED BASINS

The waters of the closed basins of western North America may be conveniently considered as a unit. Some of the more nearly complete recent analyses are presented in tables 19, 20, 21, and 22. (See also Lenore Lake and Soap Lake, table 23.) Additional analyses

TABLE 16.—*Analyses, in parts per million, of water from the Rio Grande and its tributaries*

	A	B	C	D	E	F	G	H	I	J
HCO_3^{-1}	121	134	158	183	102	95	139	140	113	183
SO_4^{-2}	84	61	7.1	130	733	1,020	1,620	1,710	2,040	238
F^{-1}	.5	.5	.5	.5	.4	.4	.7	.7	1.2	------
Cl^{-1}	10	6.4	5.1	25	59	90	755	1,290	1,530	171
NO_3^{-1}	1.5	1.1	.4	2.0	.7	1.0	4.2	5.5	2.5	------
Ca^{+2}	39	41	40	65	266	366	497	481	601	109
Mg^{+2}	8.4	8.4	4.7	12	39	54	139	174	200	24
Na^{+1}	29	20	12	49	48	60	488	828	926	117
K^{+1}	5.4	3.5	3.1	4.8	3.2	4.7	10	22	24	6.7
Fe	.5	.04	.03	.05	.05	.17	.07	.7	.09	[1] 2.7
SiO_2	32	23	26	27	13	19	20	19	19	30
Total dissolved solids	331	299	257	498	1,264	1,710	3,673	4,671	5,457	881

[1] Calculated from combined $Fe_2O_3+Al_2O_3$ on basis that Fe alone was present.

A. Rio Grande near Lobatos, Colo. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954c).
B. Rio Grande at Otowi Bridge near San Ildefonso, N. Mex. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954c).
C. Rio Guadalupe at its mouth near Jemez Springs, N. Mex. June 1949 to Sept. 1950. U.S. Geol. Survey (1954c).
D. Rio Grande at San Acacia, N. Mex. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954c).
E. Pecos River near Guadalupe, N. Mex. Oct 1942 to Sept. 1943. Howard and Love (1954).
F. Pecos River below Alamogordo Dam, N. Mex. Oct. 1943 to Sept. 1944. U.S. Geol. Survey (1947 [1948]).
G. Pecos River near Artesia, N. Mex. Oct. 1943 to Sept. 1944. U.S. Geol. Survey (1947 [1948]).
H. Pecos River at Red Bluff, N. Mex. Oct. 1943 to Sept. 1944. U.S. Geol. Survey (1947 [1948]).
I. Pecos River near Orla, Tex. Oct. 1944 to Sept. 1945. U.S. Geol. Survey (1949b).
J. Rio Grande at Laredo, Tex. Analysis recalculated from Clarke (1924b).

TABLE 17.—*Analyses, in milligrams per liter, of water from west Texas and Mexico*

[Analyses A–H are from Deevey (1957, p. 278, 283), which also contains several analyses and some less complete ones, Guatemalan Lakes]

	A	B	C	D	E	F	G	H	I
HCO_3^{-1}	56.0	90.1	158.6	153.7	156.1	86.8	458	252.3	70.8
SO_4^{-2}	3,930	1.0	555	968	995	24.0	.2	12.4	2,959.0
Cl^{-1}	12,990	24.5	560	378	13,090	17.1	21.3	17.0	138.3
NO_3^{-1}	.149	.179	.176	.176	.298	------	------	------	------
P (total)	.030	.148	.085	.045	.025	.080	.020	.079	------
Ca^{+2}	954	19	38	186	308	14	3.2	2.0	813.0
Mg^{+2}	7.8	.2	.1	3.5	71.6	1.2	2.5	1.1	253.4
Na^{+1}	9,200	28.3	642	544	8,250	36.8	175.3	110.2	104.9
K^{+1}									2.7
Al_2O_3	------	------	------	------	------	------	------	------	20.0
Fe	1.082	.245	.142	.280	.140	.105	.175	.175	------
SiO_2	1.7	47.6	16.3	23.6	25	10	14	50	69.5
Density	------	------	------	------	------	------	------	------	1.005
Total dissolved solids	27,100	211	1,970	2,260	22,900	190	675	445	4,430

A. Salt Flat ditch, Hudspeth County, Tex., June 12, 1940.
B. Intermittent stream in Fern Canyon, Jeff Davis County, Tex., June 19, 1940.
C. Balmorhea Lake, Jeff Davis County, Tex., June 21, 1940.
D. Fort Stockton Lake, Pecos County, Tex., June 20, 1940.
E. La Sal Vieja, Willacy County, Tex., Nov. 27, 1941.
F. Presa de Hipolitom Coahuila, Mexico, June 19, 1941.
G. Lake Pátzcuaro, Michoacán, Mexico, July 13, 1940.
H. Lake Chapala, Jalisco, Mexico, July 13, 1940.
I. Laguna Chichan Kanab, Yucatan. Analysis from Pasquel (1950, table facing p. 208).

TABLE 18.—*Analyses, in parts per million, of water from the Colorado River system and the Sacramento River*

	A	B	C	D	E	F	G	H	I
HCO_3^{-1}	42	107	256	179	235	163	183	79	62
SO_4^{-1}	5.2	101	794	230	231	256	289	11	5.2
F^{-1}	.3	.2	.2	.3	.3	.3	.2	.4	.0
Cl^{-1}	1.1	38	24	49	70	75	113	7.1	4.0
NO_3^{-1}	0.8	1.3	2.0	2.2	1.9	1.4	1.0	.6	.0
Ca^{+2}	9.6	55	148	75	91	84	94	12.9	14
Mg^{+2}	1.9	11	81	28	28	27	30	7.0	2.7
Na^{+1}	3.8	26	166	70	80	88	124	10.5	7.7
K^{+1}	2.7	3.5	6.1	4.0	5.8	2.9	4.4	1.3	.9
B	.00	.00	------	------	------	------	.052	.10	.010
Fe	.14	.06	.06	.03	.09	.05	.01	.08	.112
Al	------	------	------	------	------	------	.012	.06	0.60
SiO_2	9.3	7.4	9.9	12	14	13	14	19	20
Total dissolved solids	76.8	351	1,490	650	757	711	853	149	117

A. Colorado River at Hot Sulfur Springs, Colo. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1953b).
B. Eagle River below Gypsum, Colo. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1953b).
C. San Rafael River near Green River, Utah. Oct. 1948 to Sept. 1949. U.S. Geol. Survey (1953b).
D. Colorado River at Lees Ferry, Ariz. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954d [1955]).
E. Colorado River near Grand Canyon, Ariz. Oct 1949 to Sept. 1950. U.S. Geol. Survey (1954d [1955]).
F. Yuma main canal below Colorado River siphon at Yuma, Ariz. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954d [1955]).
G. Colorado River at bridge on U.S. Highway 80 at Yuma, Ariz. Sept. 16, 1958. Durum, Heidel, and Tison (1960). Analysis includes AG, 0.0010 ppm; Ba, 0.152 ppm; Co, 0.000 ppm; Cr, 0.024 ppm; Cu, 0.0088 ppm; Li, 0.035 ppm; Mn, 0.021 ppm; Mo, 0.0069 ppm; Ni, 0.030 ppm; P, 0.000 ppm; Pb, <0.0080/ppm; Rb, <0.0080 ppm; Sr, 0.802 ppm; Ti, <0.0080 ppm; and Zr, 0.000 ppm;
H. Sacramento River at Rio Vista, Calif., 1956. California Dept. of Water Resources (1957, p. A-282).
I. Sacramento River at tower bridge on Capital Street, Sacramento, Calif. Nov. 25, 1958. Durum, Heidel, and Tison (1960). Analysis includes AG, <0.000086 ppm; Ba, 0.031 ppm; Co, 0.000 ppm; Cr, 0.0044 ppm; Cu, 0.0029 ppm; Li 0.0021 ppm; Mn, 0.0063 ppm; Mo <0.00043 ppm; Ni, 0.0071 ppm; P, 0.000 ppm; Pb, 0.0045 ppm; Rb, 0.0010 ppm; Sr, 0.046 ppm; Ti, <0.00086 ppm; and V, <0.086 ppm.

TABLE 19.—*Analyses, in parts per million, of water from the Basin-Range province and adjacent closed basins*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
HCO_3^{-1}	232	[1]8,166	[1]6,668	[1]26,430	69	[1]187	[1]639	55	48	571	[1]1,390	[1]870	[1]1,200	[1]2,040	53	6,296
SO_4^{-2}	4,139	<10	21.8	7,530	8.5	4,960	257	2.0	1.0	135	264	1.6	307	576	1.2	103,680
F^{-1}	1.6	----	----	23	.2	4.9	4.8	.1	.1	----	.8	7.0	10	6.0	----	----
Cl^{-1}	9,033	905	5,945	15,100	1.0	21,400	109	3.5	2.2	1,725	1,960	22	1,160	3,330	1.2	1,668
NO_3	1.2	----	----	2.4	.2	----	.50	.1	.0	----	1.6	2.2	.4	3.5	.3	
PO_4^{-3}	----	----	----	38	----	----	----	----	----	----	----	----	----	----	----	----
Ca^{+2}	505	8	Nil	11	13	1,230	2.0	9.2	8.4	20	10	4.5	6.9	17	7.5	640
Mg^{+2}	581	24	30.7	32	2.5	148	.2	3.2	2.7	18	113	49	.9	8.9	2.9	22,838
Sr^{+2}	----	5.3	----	96	----	----	.24	----	----	----	----	----	----	----	----	----
Li^{+1}	1.9	1.2	----	8.5	----	----	.16	----	----	----	----	----	----	----	----	----
Na^{+1}	6,249	3,390	6,199	21,400	9.2	14,100	423	6.1	4.3	1,321	1,630	220	1,370	3,180	6.5	7,337
K^{+1}	112	731	332	1,120	2.3	594	17.1	1.6	1.4	70	134	59	11	7.5	2.1	891
B	5.0	360	221	157	.10	60	.84	.00	.00	----	----	.03	19	38	----	----
Fe	----	----	----	.21	----	----	----	.00	.03	----	.00	.03	1.3	.08	----	----
SiO_2	20.8	20	----	.0	41	49	70.0	9.6	16	28	1.4	10	63	28	33	----
Specific gravity	1.012	1.006	1.009	1.0470	----	----	----	----	----	----	----	----	----	----	----	----
Total dissolved solids	20,900	13,600	>19,400	71,900	147	42,700	1,520	90.4	84.1	3,890	5,510	1,250	4,150	9,240	108	>143,000

[1] Includes CO_3.

A. Salton Sea near Nullett Island, Imperial County, Calif. Collected Feb. 3, 1954. Unpublished U.S. Geol. Survey analysis by Henry Kramer.
B. Little Borax Lake, Lake County, Calif. Collected Oct. 6, 1956. Unpublished U.S. Geol. Survey analysis by C. E. Roberson.
C. Borax Lake, Lake County, Calif. Collected Mar. 24, 1954. Unpublished U.S Geol. Survey analysis by Henry Kramer.
D. Mono Lake near Lee Vining, Mono County, Calif. Collected Sept. 11, 1956. Unpublished U.S. Geol. Survey analysis. Cu and Zn looked for but not found.
E. Rush Creek near Mono Lake, Calif. Collected Oct. 21, 1953. U.S. Geol. Survey (1955a).
F. Pons at Bad Water, Death Valley, Calif. Collected April 17, 1954. U.S. Geol. Survey (1955a).
G. Amargosa River near Beatty, Nev. Unpublished U.S. Geol. Survey analysis.
H. South end of Lake Tahoe at Bijou, Nev. Collected Sept. 21, 1953. U.S. Geol. Survey (1955a).
I. Truckee River at Farad, Calif. Collected Sept. 22, 1953. U.S. Geol. Survey (1955a).
J. Winnemucca Lake, Nev. Clarke (1924b, p. 160).
K. Pyramid Lake at Sutcliffe, Nev. Collected Sept. 19, 1955. Unpublished U.S. Geol. Survey analysis.
L. Eagle Lake near Susanville, Calif. Collected May 4, 1954. Unpublished U.S. Geol. Survey analysis.
M. Lower Alkali Lake near Eagleville, Calif. Collected May 5, 1954. U.S. Geol. Survey, (1955a).
N. Middle Alkali Lake near Cedarville, Calif. Collected May 5, 1954. U.S. Geol. Survey (1955a).
O. Abert Lake near Valley Falls, Oreg. Collected Aug. 21, 1956. Unpublished U.S. Geol. Survey analysis.
P. Hot Lake, Wash. Collected Aug. 22, 1955. Analysis by Bur. Reclamation, Eng. Laboratories Branch, Denver, Colo., *in* Anderson (1958, p. 267).

TABLE 20.—*Analyses, in parts per million, of water from the Devil's Lake basin, North Dakota, from Swenson and Colby (1955)*

	A	B	C	D	E	F	G	H
CO_3^{-2}	125.1	----	----	73	----	358	----	43
HCO_3^{-1}	539.0	1,424	565	708	230	1,410	223	464
SO_4^{-2}	4,977.9	13,600	3,460	7,360	8.4	3,600	194	13,000
F^{-1}	----	1.4	.6	1.4	.2	.8	.6	3.4
Cl^{-}	900.3	2,870	787	1,600	1.5	800	21	1,670
NO_3^{-1}	----	74	2.7	3.0	1.6	3.0	6.6	2.1
Ca^{+2}	26.3	110	60	120	42	80	45	41
Mg^{+2}	530.5	1,420	306	708	14	92	36	590
Na^{+1}	2,108.3	6,180	1,680	3,470	8.2	2,810	71	6,370
K^{+1}	199.7	41	176	216	14	104	15	185
Fe	14.8	.05	.04	.40	.04	.60	.02	.09
SiO_2	26.6	14	9.4	49	12	38	25	17
Total dissolved solids	9,450	25,700	7,050	14,300	332	9,300	637	22,400

A. Devils Lake, 1907.
B. Devils Lake, Nov. 20, 1948.
C. Devils Lake, July 7, 1950.
D. Black Tiger Bay, Township 152.
E. Dry Lake, Township 155.
F. Free Peoples Lake, Township 151.
G. Round Lake, Township 153.
H. Stink Lake, Township 155.

TABLE 21.—*Analyses, in parts per million, of water from concentrated lakes in British Columbia*

[All of these analyses are recalculated from Cummings (1940)]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	53,600	118,330	102,810	10,280	3,020	2,400	6,200	1,800
SO_4^{-2}	Trace	6,240	25,470	8,360	195,710	160,800	203,900	85,700
Cl^{-1}	800	6,660	7,240	520	1,690	200	700	1,100
Ca^{+2}	Trace	----	----	380	----	Trace	Trace	800
Mg^{+2}	Trace	470	890	160	42,400	34,900	34,200	14,500
Na^{+1}	20,900	48,280	52,880	7,440	13,660	10,900	34,400	13,800
K^{+1}	----	4,630	1,760	----	1,570	----	----	----
Specific gravity at 16° C	1.0485	1.108	1.146	1.022	1.283	1.1895	1.240	1.1075
Total dissolved solids	>75,300	>185,000	>191,000	>27,100	>258,000	>209,000	>279,000	>118,000

A. Eighty-Three Mile Lake, Green Timber Plateau (p. 6).
B. Goodenough Lake, Green Timber Plateau (p. 8).
C. Last Chance Lake, Green Timber Plateau (p. 16).
D. Long Lake, Green Timber Plateau (p. 25).
E. Basque Lake No. 1, near Ashcroft (p. 45).
F. Lake No. 7 north of Kamloops (p. 51).
G. Iron Mask Lake near Kamloops (p. 36).
H. Lake No. 4, near Iron Mask Lake (p. 37).

TABLE 22.—*Analyses, in parts per million, of water from closed lakes of Saskatchewan*

[All these analyses are from Rawson and Moore (1944). The same paper contains about 45 less complete analyses of southern Saskatchewan lake waters]

	A	B	C	D	E	F	G	H
CO_3^{-2}	236	96.2	37.2	34.4	16.0	45.8	28.0	------
HCO_3^{-1}	554	483	296	364	274	387	243	173
SO_4^{-2}	51,720	9,086	5,009	1,302	594	581	361	2.75
Cl^{-1}	23,295	147	65	178	105	13.5	8.7	3.75
Ca^{+2}	514	71.5	121	44.0	59.9	21.9	36.0	25.3
Mg^{+2}	11,160	1,590	1,018	167	70.8	141	7.5	3.43
Na^{+1}	17,950	1,547	411	527	252	160	89.7	7.3
K^{+1}	1,017	110	180	16.6	22.4	28.2	7.5	3.43
Fe[1]	159	6.3	8.4	3.9	1.7	1.4	.6	.6
SiO_2	20	4	17	14	10	7.8	6.8	5.9
Total dissolved solids	107,000	13,100	7,160	2,650	1,410	1,390	789	225

[1] Calculated from analytical results expressed as combined Fe_2O_3 and Al_2O_3 on the assumption that Fe_2O_3 only was present.

A. Little Manitou Lake, July 7, 1940.
B. Redberry Lake, June 13, 1940.
C. Stoney Lake, July 1, 1940.
D. Last Mountain Lake, July 11, 1940.
E. Echo Lake, July 6, 1940.
F. Jackfish Lake, May 29, 1940.
G. Murray Lake, Aug. 11, 1940.
H. Montreal Lake, July 1940.

are given in the early editions of this book and in Carpelon (1958). Some incomplete analyses of sodium sulfate lakes may be found in Tomkins (1954). The arid-land lakes are remarkable not only for their high concentrations of dissolved salts, but for the great variation in the composition of these salts. These standing waters have a long history of evaporation, in the course of which the less soluble salts have been precipitated and lost to the solution. Some of them may subsequently have been freshened by the addition of dilute water, and then concentrated again. The outcome of even a simple one-step concentration by evaporation depends to a great extent on the exact proportions of the ions in the original solutions, so a wide variety of results is possible. A water that has been modified greatly in this way is sometimes said to be highly evolved.

COLUMBIA RIVER BASIN AND OTHER NORTHWESTERN WATERS

A selection of analyses for the Columbia River system is presented in table 23. Most of the basin is well watered and the rivers tend to be dilute calcium bicarbonate waters, although there are some rather arid parts of the basin as demonstrated by Soap Lake. The other northwestern waters listed in table 24 are also dilute calcium bicarbonate ones, although some, such as the Fraser River at New Westminster, British Columbia, contain considerable magnesium. It should be remembered, however, that there is no sharp line of division between these dilute rivers of the well-watered coast and the very concentrated closed lakes of the interior. The coastal waters have been analyzed because they are used for municipal water supplies; the interior lakes have been analyzed because they form a source of commercial salts. Waters of intermediate salinity are less likely to attract the attention of chemical analysts, and so there are no data for them.

ALASKA WATERS

A selection of analyses of lakes and rivers in Alaska is presented in table 25. Most of the waters are of the calcium bicarbonate types, except at the coast, where sea spray may be very important, or where local bedrock geology exerts a strong influence. Notice, in the latter connection, Gypsum Creek on the Glenn Highway. Although there are some significant departures from it, a tendency exists for the humid

TABLE 23.—*Analyses, in parts per million, of water from the Columbia River system*

	A	B	C	D	E	F	G	H	I	J	K	L
HCO_3^{-1}	67.7	103	63.4	95	85	116.5	66	69	108	212	[1] 9,110	[2] 17,400
SO_4^{-2}	18.0	12	8.9	4.5	9.0	19.2	9.4	12	19	29	2,180	6,020
F^{-1}	------	.2	------	.2	.3	------	------	------	.5	------	------	------
Cl^{-1}	1.5	1.3	1.1	.8	1.2	1.3	2.0	3.2	4.9	12	1,360	4,680
NO_3^{-1}	.10	.4	.62	.4	.5	.27	.7	.5	.3	1.8	3.2	------
Ca^{+2}	18.5	27	19.3	23	21	30.4	17	17	23	30	3.0	3.9
Mg^{+2}	8.0	6.7	4.4	6.0	5.7	9.0	3.7	3.9	6.2	18	20	23
Na^{+1}	2.2	1.9	4.2	1.1	2.5	12.2	3.2	7.5	16	34	5,360	12,500
K^{+1}		1.5		1.3	2.2		2.5	1.8	.0			
B	------	------	------	<.1	------	------	------	------	.0039	------	------	------
Fe	.07	.07	.05	.04	.04	.05	.14	.06	.280	------	------	------
SiO_2	3.8	8.3	5.3	5.5	9.4	10.6	12	9.9	13	43	22	101
Total dissolved solids	120	162	107	138	137	200	117	125	191	380	18,000	40,700

[1] Includes 3,020 ppm CO_3^{-2}.
[2] Includes 5,130 ppm CO_3^{-2}.

A. Columbia River at Golden, British Columbia. July 10, 1937. Leverin (1947), analysis 388.
B. Kootenai River at Porthill, Idaho. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954d [1955]).
C. Columbia River at Trail, British Columbia. July 29, 1938. Leverin (1947), analysis 576.
D. Flathead River at Columbia Falls, Mont. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954d [1955]).
E. Pend Orielle River at Metaline Falls, Wash. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954d [1955]).
F. Okanagan Lake at Kelowna, British Columbia. Taken at a depth of 25 ft in the middle of the lake, July 12, 1938. Leverin (1947), analysis 577.
G. Similkameen River at Oroville, Wash. Oct. 1949 to Sept. 1950. U.S. Geol. Survey (1954d [1955]).
H. Columbia River at Cascade Locks, Oreg. Aug. 11, 1911 to Aug. 14, 1912. Van Winkle (1914).
I. Columbia River below the Dalles Dam, about 3 miles above the Dalles, Wash. Dec. 1, 1958. Durum, Heidel, and Tison (1960). Analysis includes Ag, 0.00015 ppm; Al, 0.238 ppm; Ba, 0.048 ppm; Co, 0.000 ppm; Cr, 0.018 ppm; Cu, 0.0038 ppm; Li, 0.0039 ppm; Mn, 0.014 ppm; Mo, 0.0021 ppm; Ni, 0.010 ppm; P, 0.000 ppm; Pb, 0.0050 ppm; Rb, 0.0014 ppm; Sr, 0.112 ppm; V, 0.0052 ppm; and Zn, 0.000 ppm.
J. Park Lake near Coulee City, Wash. Nov. 24, 1950. Unpublished U.S. Geol. Survey analysis.
K. Lenore Lake near Soap Lake, Wash. Nov. 24, 1950. Unpublished U.S. Geol. Survey analysis.
L. Soap Lake near Soap Lake, Wash. Nov. 24, 1950. Unpublished U.S. Geol. Survey analysis.

TABLE 24.—*Analyses, in parts per million, of some other northwestern waters*

	A	B	C	D	E	F
HCO_3^{-1}	36.0	61.0	64	43.9	15.9	7.9
SO_4^{-2}	6.4	10.0	7.6	12.8	6.6	7.4
Cl^{-1}	5.5	1.5	.0	1.2	5.0	1.1
NO_3^{-1}	.44	.00	.5	.35	1.0	.00
Ca^{+2}	7.9	19.8	17	12.8	9.2	6.4
Mg^{+2}	2.6	4.5	2.9	2.8	10.2	2.4
Na^{+1}	4.7	1.9	1.3	4.4	-----	-----
K^{+1}			.6		-----	-----
Fe	.03	.07	.11	.21	.12	.05
SiO_2	5.6	7.3	4.5	3.2	1.5	.5
Total dissolved solids	69.2	106	98.5	81.7	>49.5	>25.8

A. Thompson River at Kamloops, British Columbia. July 27, 1938. Leverin (1947), analysis 579.
B. Fraser River at Hope, British Columbia. Dec. 4, 1938. Leverin (1947), analysis 586.
C. Fraser River at Mission City, British Columbia. Oct. 1, 1958, Durum, Heidel, and Tison (1960). Analysis includes F, 0.0 ppm; Ag. 0.00007 ppm; Al, 0.526 ppm; B, 0.011 ppm; Ba, 0.018 ppm; Co, 0.0019 ppm; Cr, 0.0060 ppm; Cu, 0.0025 ppm; Li, 0.00018 ppm; Mn, 0.032 ppm; Mo, 0.000 ppm; Ni, 0.012 ppm; P, 0.073 ppm; Pb, 0.0018 ppm; Rb, 0.00095 ppm; Sr, 0.018 ppm; Ti, 0.016 ppm; and Zn, 0.000 ppm.
D. Fraser River at New Westminster, British Columbia. Aug. 19, 942. Leverin (1947), analysis 899.
E. Untreated water supply of Nanaimo, British Columbia, from a dam 3 miles from the city. Sept. 6, 1938. Leverin (1947), analysis 553.
F. Untreated water supply of Prince Rupert, British Columbia, from a lake 7 miles from the city. July 16, 1943. Leverin (1947), analysis 968.

coastal regions of southern Alaska to have very dilute water with about 25 ppm of total dissolved solids, whereas the drier interior and arctic parts have 100 or 200 ppm. The great increase in salinity over a 2-week period of Ikrowik Lake near the Arctic coast at Point Barrow is probably due to sea-spray transport by summer gales during the short ice-free season.

MACKENZIE AND HUDSON BAY DRAINAGES

The information available for the Mackenize River system (table 26) suggests that the waters are a calcium bicarbonate type of moderate dilution. The two analyses from the Mackenize River show it to be remarkably similar to the lower Mississippi River in concentration and suggest that the Mackenzie River must have some tributaries more highly concentrated than the ones which have been analyzed.

TABLE 25.—*Analyses, in parts per million, of Alaskan waters*

	A	B	C	D	E	F	G	H	I	J	K
HCO_3^{-1}	8	12	122	24	121.8	113.5	129	171	67.8	56	57
SO_4^{-2}	2.4	4.1	3.2	9.1	27.6	17.1	29	22	17.6	16	16
F^{-1}	.1	.1	.1	.4	.02	.02	.1	.1	.2	.1	.1
Cl^{-1}	14	40	21	1.5	1.6	4.6	2.2	.7	7.2	1.3	.9
NO_3^{-1}	.3	.2	.4	.4	.72	.73	.8	.3	.74	.66	.9
PO_4^{-3}	-----	-----	.0	.0	-----	-----	-----	<.195	-----	-----	-----
Ca^{+2}	2.5	5.9	31	5.6	35.9	31.2	38	47	22.9	18	19
Mg^{+2}	1.9	3.9	9.4	3.2	8.7	6.0	7.9	8.9	3.4	3.2	3
Na^{+1}	7.0	18	8.0	2.5	4.0	7.3	5.3	3.2	7.2	1.8	2.9
K^{+1}								1.4			
Fe	.05	.01	.04	.03	.08	.02	.05	.18	.20	.04	.02
Mn	.00	.00	.00	.00	-----	-----	-----	.181	-----	-----	-----
SiO_2	.0	.9	1.0	.4	7.4	11.0	12	13	8.0	3.9	9.2
Total dissolved solids	36.3	85.1	196	47.1	208	192	224	268	135	101	109

	L	M	N	O	P	Q	R	S	T	U	V	W
HCO_3^{-1}	11	28	-----	11	40	26	22	8	7	12	8	10
SO_4^{-2}	2.1	7.7	2,820	1.8	29	7	18	3.1	1.8	2.6	1.8	2
F^{-1}	.4	.1	-----	-----	.1	-----	-----	-----	-----	-----	-----	-----
Cl^{-1}	1.0	1.2	5.5	.8	1.1	.3	4	1	2.2	1.5	1.8	1.2
NO_3^{-1}	1.2	1.70	-----	.1	.63	.0	.2	.1	.2	.1	.1	.2
PO_4^{-3}	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Ca^{+2}	2.6	10.1	378	4.4	20	8.5	7.5	1.2	.8	2.8	.8	1.2
Mg^{+2}	1	1.1	268	.5	4.2	1.1	2	.9	.6	.6	.8	.8
Na^{+1}	1.8	2.4	-----	1.5	2.9	1.8	7.1	2.1	2.7	2.3	2.5	2.3
K^{+1}												
Fe	.11	.05	.54	.08	.01	-----	-----	-----	.00	-----	-----	.01
Mn	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
SiO_2	6.2	3.9	73	2.9	2.9	4	3.3	1	.9	.6	1	1.7
Total dissolved solids	27.4	56.3	>3,550	23.1	101	48.7	64.1	17.4	16.2	22.5	16.8	19.4

A. Ikrowik Lake near Point Barrow. June 30, 1951. U.S. Geol. Survey analysis quoted in Livingstone, Bryan, and Leahy (1958).
B. Ikrowik Lake near Point Barrow. July 13, 1951. U.S. Geol. Survey analysis quoted in Livingstone, Bryan, and Leahy (1958).
C. East Oumalik Lake, near edge of Arctic Coastal Plain. July 26, 1951. U.S. Geol. Survey analysis quoted in Livingstone, Bryan, and Leahy (1958).
D. Chandler Lake, Brooks Range. Aug. 22, 1951. U.S. Geol. Survey analysis quoted in Livingstone, Bryan, and Leahy (1958).
E. Yukon River at Eagle. Mean of the analyses of 16 composite samples, Apr. to Sept. 1951. Whetstone (1951).
F. Tanana River near Tok Junction. Mean of the analyses of 13 composite samples, Mar. to Sept. 1951. Whetstone (1951).
G. Tanana River at Big Delta. Mean of the analyses of 35 composite samples, Oct. 1950 to Sept. 1951. Whetstone (1951).
H. Yukon River at Mountain Village, Alaska. Jan. 7, 1959. Durum, Heidel, and Tison (1960). Analysis includes Ag, <0.0002 ppm; Al, <0.082 ppm; B, 0.013 ppm; Ba, 0.109 ppm; Co, 0.000 ppm; Cr, 0.0070 ppm; Cu, 0.0025 ppm; Li, 0.0020 ppm; Mo, 0.0012 ppm; Ni, 0.017 ppm; Pb, 0.0086 ppm; Rb, 0.000 ppm; Sr, 0.123 ppm; Ti, <0.0020 ppm; and Zn, 0.000 ppm.
1 Susitna River at Gold Creek. Mean of the analyses of 9 composite samples, May to Sept. 1951. Whetstone (1951).
J. Eklutna Creek at Eklutna Lake near Palmer. Mean of the analyses of 11 composite samples, Dec. 1950 to Sept. 1951. Whetstone (1951).
K. Ship Creek near Anchorage. Mean of the analyses of 31 composite samples, Oct. 1950 to July 1951. Whetstone (1951).
L. Brown Slough at Bethel, Sept. 13, 1951. Whetstone (1951).
M. Kenai River at Cooper Landing. Mean of the analyses of 6 composite samples, Oct. and Nov. 1951. Whetstone (1951).
N. Gypsum Creek, mile 112 Glenn Highway, Sept. 10, 1949. Moore (1950, p. 10).
O. South Branch Worthington River near Wortmanns, Aug. 7, 1951. Whetstone (1951).
P. Gold Creek, Juneau. Mean of the analyses of 3 samples. Oct. 1948 to July 1949. Moore (1950).
Q. Lemon Creek, Juneau. Oct. 10, 1948. Moore (1950).
R. Mendenhall River, Juneau. Oct. 10, 1948. Moore (1950).
S. Dorothy Creek, Juneau. Apr. 14, 1949. Moore (1950).
T. Purple Creek, Metalaska. Mean of 2 analyses, one for an unspecified date in 1948, the other for Apr. 23, 1949. Moore (1950).
U. Maybeso Creek, Hollis. Apr. 26, 1949. Moore (1950).
V. Ella Creek near Ketchikan, Apr. 22, 1949. Moore (1950).
W. Perseverance Creek, Ketchikan. Oct. 11, 1948. Moore (1950).

Table 26.—*Analyses, in parts per million, of water from the Mackenzie drainage*

	A	B	C	D	E	F	G	H
HCO_3^{-1}	34.6	24.6	88.8	111.5	82.5	64.8	132	125
SO_4^{-2}	9.2	.6	16.9	25	16	10.2	28	28
Cl^{-1}	------	1.4	12	12	6	15	.7	7.5
F^{-1}	------	------	------	------	------	------	------	.0
NO_3^{-1}	------	.04	Nil	------	------	.9	.6	.5
Ba^{+2}	------	------	------	------	------	------	------	.065
Ca^{+2}	4.9	2.6	26.1	3.1	25	15	35.5	37
Mg^{+2}	3.5	1	6.2	7	5.7	6.5	8.5	8.4
Li^{+1}	------	------	------	------	------	------	------	.001
Na^{+1}	5.2	[1] 5.8	[1] 8	12	3	[1] 10.1	[1] 7.6	7
K^{+1}	------	------	------	------	------	------	------	.9
Rb	------	------	------	------	------	------	------	.0016
Fe	------	Nil	.67	------	------	.07	Tr.	.04
Co	------	------	------	------	------	------	------	.005
Cu	------	------	------	------	------	------	------	.011
Al	------	------	1	------	------	Tr.	Tr.	1.41
B	------	------	------	------	------	------	------	.013
Mn	------	Nil	------	------	------	------	------	.06
Cr	------	------	------	------	------	------	------	.012
SiO_2	------	.4	6.4	------	------	2	1.2	3.4
Total dissolved solids	>57.4	36.4	166	>171	>138	125	214	219

[1] Sodium by difference only.

A. Amethyst Lake near Jasper, Alberta. July 1952. Rawson (1953, p. 198).
B. Cree Lake, Saskatchewan. Dec. 1956. Analyst, E. C. Bailey. Rawson (1959, p. 18).
C. Slave River at Fort Smith, Northwest Territory, Nov. 1946. Analysis by S. S. Copp, quoted in Moore (1949, p. 4).
D. Great Slave Lake, main lake, off Slave Delta, Northwest Territory. June 22, 1946. Rawson (1950, p. 60).
E. Christie Bay, Great Slave Lake, Northwest Territory. July 5, 1946. Rawson (1950, p. 60).
F. Kam Lake, Yellowknife, Northwest Territory. Aug. 1947. Rawson (1950, p. 4).
G. Mackenzie River at Fort Simpson, Northwest Territory. Aug. 1948. Rawson (1950, p. 4).
H. Mackenzie River about 3 miles upstream from separation, at Arctic Red River, Northwest Territory, Canada. July 24, 1958. Durum, Heidel, and Tison (1960). Analysis includes Mo, 0.000 ppm; Ni, 0.036 ppm; P, 0.259 ppm; Pb, 0.0029 ppm; Sr, 0.096 ppm; Ti, 0.0084 ppm; and Zn, 0.000 ppm.

Waters of the Hudson Bay drainage (table 27) range from rather dilute rivers flowing over well-watered parts of the Canadian shield, with total dissolved solids of about 50 ppm, to moderately concentrated rivers flowing over the less well watered sedimentary rocks of the wheatlands, such as the Assiniboine River with almost 700 ppm. Some additional analyses for Mackenzie and Hudson Bay waters may be found in Rawson (1942, 1957).

WEST GREENLAND

In the general absence of information from the Arctic parts of the North American continent, the analyses of Böcher (1949) from West Greenland (table 28) have a particular value. Although none of his water samples are from the extreme north of Greenland where polar desert conditions are most pronounced, they nevertheless show some interesting trends toward the evolution of a desert water. The dilute lakes consist of a solution of sodium and calcium bicarbonate, but in the more concentrated ones calcium is almost absent, and there is considerable enrichment of the other ions. It is quite evident from the range of waters found in this pioneering study that much material has to be gathered before a clear understanding of Arctic water chemistry is gained.

A word of caution is in order about the high silica content of these waters. The samples had been stored in glass of an unspecified kind for many months before analysis, and it is quite possible that in Greenland, as in Arctic Alaska, silica is much lower than these figures imply.

EURASIA

The quality of the data from Europe and Asia is very inconsistent. The major waters of Europe were first analyzed almost a century ago, and since that time very few complete analyses for major ions have been made in western Europe. Almost the only exception to this is Britain, where, largely owing to the efforts of a single man, there exists a large amount of modern analytical data for lake waters. For the rest, it has not been possible to discover any sizable quantity of complete recent analyses, and the data that were included in the 1924 edition of this work, were almost all accumulated by workers in the 19th century. As these old analyses were made before the need for multiple sampling was recognized, many of them are spot analyses. Because they were made before the development of accurate methods for many of the minor constituents, their reliability is open to some question.

It is surprising that there should be no complete modern analyses for waters in western Europe because there has been a great deal of interest and activity in water analysis during the last half century. Limnologists in the Alps, in northern Germany, and in Scandinavia have been extremely active, and have compiled a tremendous amount of information about the elements of biological importance. Some of these studies have contributed greatly to our knowledge of the hydrochemistry of minor elements, and we shall refer to them in a later section of this work. There has also been a great deal of strictly geochemical work dealing with one or a small number of related elements in a single river system, such as the work of Heide and his co-workers (Heide, 1952; Heide and Kaeding, 1954; Heide, Lerz and Bohm, 1957; Heide and Moencke, 1956; Heide and Singer, 1954) on the Saale, and a large amount of very important work on the geochemistry of rain in Scandinavia, but there appears to have been very little work on the general composition of lake and river waters. A partial exception is provided by the data of Almestrand and Lundh (1951) which are deficient only in sodium, and Coin's very interesting essay on the factors influencing water chemistry (Coin, 1946).

TABLE 27.—*Analyses, in parts per million, of water from the Hudson Bay drainage*

[Analyses P-V are unpublished data for the Churchill River drainage in Saskatchewan provided by Dr. D. S. Rawson]

	A	B	C	D	E	F	G	H	I	J	K
HCO_3^{-1}	11.6	11	39.7	83.6	45.8	36.3	54	22.6	149	55.4	284.7
SO_4^{-2}	7	36.3	13.5	186.1	8.9	5.1	5.6	7.1	35	8.8	204.2
Cl^{-1}	3.5	1.2	7.7	25.5	1.4	.8	.9	1.1	32	1	14.6
NO_3^{-1}	2	2.3	.9	.40	.52	.47	.67	.64	.1	1.2	.75
Ca^{+1}	7.7	8.9	13.1	66	15.5	13.3	17.5	8	35	17.4	81.2
Mg^{+2}	2.6	3.6	4.8	19.5	6	3.4	5.6	2.6	13	5.5	39.6
Na^{+1}	2	3.5	6.2	31.3	4	4.9	3	5	25	4.7	52.6
K^{+1}									3.1		
Fe	.75	.16	.11	.11	.22	.22	.16	.09	.01	.15	.04
SiO^2	2.1	3	1.2	6.3	11.6	4.5	5.5	4.6	2.2	6.1	18.7
Total dissolved solids	39.3	70	87.2	419	93.9	69	92.9	51.7	294	100	696

	L	M	N	O	P	Q	R	S	T	U	V	W
HCO_3^{-1}	93.3	156.4	143.5	122.5	244.9	175.8	133.8	105.6	399	196	30.2	65
SO_4^{-2}	21.2	29.8	33.8	35.2	16.7	1.03	2.7	2.9	16.4	6.4	.7	.4
Cl^{-1}	6	1.2	1.3	1.3	.7	nil	nil	nil	1.7	1.4	2.9	1.6
NO_3^{-1}	1	.44	.44	.61	---	---	---	---	---	---	.04	.8
Ca^{+2}	25	40	38.2	36.8	47.1	31.1	27	20.4	23.7	43.5	4.1	14
Mg^{+2}	9.2	12.9	12.3	11.7	22.4	11.6	8.5	2.3	60.2	5.4	nil	4.3
Na^{+1}	9.8	7.5	8.7	7.7	14.3	9.3	3.6	5.3	18.9	3.6	[1] 9.2	3.2
K^{+1}												
Fe	.40	.15	.14	.08	---	---	---	---	---	ca. 2	nil	.06
SiO_3	19.2	7.2	6.3	8	1	7.5	ca. 3	6.5	6	1	.4	1.4
Total dissolved solids	185	256	245	224	347	236	179	143	526	259	47.5	91.8

[1] Sodium by difference only.

A. Lac Blouin at Bourlamaque, Quebec. June 20, 1939. Leverin (1947), analysis 611.
B. Lac Dufault north of Noranda, Quebec. Mean of 2 analyses, 1937–39. Leverin (1947), analyses 371, 610.
C. Gull Lake at Kirkland Lake, Ontario. Mean of 2 analyses, 1937–39. Leverin (1947), analyses 372, 614.
D. Pearl Lake at Timmins, Ontario. Apr. 9, 1937. Leverin (1947), analysis 370.
E. Abitibi River at Iroquois Falls, Ontario. Mean of 2 analyses, 1937–39. Leverin (1947), analyses 365, 606.
F. Mattagami River at Smooth Rock Falls, Ontario. Mean of 2 analyses, 1937–39. Leverin (1947), analyses 368, 607.
G. Kapuskasing River at Kapuskasing, Ontario. Mean of 2 samples, 1937–39. Leverin (1947), analyses 366, 608.
H. Rainy River at Fort Frances, Ontario. Mean of 3 analyses, 1937–43. Leverin (1947), analyses 358, 560, 937.
I. Nelson River near Amery, Manitoba. Apr. 9, 1959. Durum, Heidel, and Tison (1960). Analysis includes F, 0.0 ppm; Ag, 0.000 ppm; Al, 0.089 ppm; B, 0.0036 ppm; Ba, 0.056 ppm; Co, 0.000 ppm; Cr, 0.0047 ppm; Cu, 0.0042 ppm; Li, 0.0081 ppm; Mn, <0.0028 ppm; Mo, 0.000 ppm; Ni, 0.0078 ppm; P, 0.000 ppm; Pb, 0.022 ppm; Rb, <0.0028 ppm; Sr, 0.086 ppm; Ti, 0.0059 ppm; V, 0.000 ppm; and Zn, 0.000 ppm.
J. Lake of the Woods at Kenora, Ontario. Mean of 4 analyses, 1937–43. Leverin (1947), analyses 360, 561, 562, 943.
K. Lake Winnipeg at Gimli, Manitoba. Depth sample 2 miles offshore, July 27, 1937. Leverin (1947), analysis 380.
L. Assiniboine River at Brandon, Manitoba. Mean of 4 analyses, 1937–43. Leverin (1947), analyses, 379, 571, 895, 945.
M. Red Deer River at Red Deer, Alberta. Mean of 3 analyses, 1937–43. Leverin. (1947), analyses 385, 572, 944.
N. South Saskatchewan River at Saskatoon, Saskatchewan. Mean of 4 analyses, 1937–43. Leverin (1947), analyses 382, 565, 893, 939.
O. North Saskatchewan River at Prince Albert, Saskatchewan. Mean of 3 analyses, 1937–43. Leverin (1947), analyses 384, 567, 938.
P. Beaver River at bridge east of Minnow Lake, June 3, 1957. Analyst, J. Ingram.
Q. Canoe Lake, 19 miles west of Beauval, Saskatchewan. Collected in the center of the lake Aug. 13, 1957. Analyst, J. Ingram.
R. Lac la Ronge. Aug. 3, 1957. Analyst, J. Ingram.
S. Lac la Plonge, center of the lake. July 4, 1957. Analyst, J. Ingram.
T. Little Loon Lake, 2 miles east of Glaslyn, Saskatchewan. June 23, 1939. Analyst, J. E. Moore.
U. Waskesiu Lake. May 23, 1957. Analyst, J. Ingram.
V. Wollaston Lake, Fish Plant. Mar. 6, 1957. Analyst, E. C. Bailey. Rawson, 1959.
W. Churchill River east of island off Drachm Point, 8 miles south of Churchill, Manitoba. Sept. 25, 1958. Durum, Heidel, and Tison (1960). Analysis includes F, 0.0 ppm; Ag, 0.00037 ppm; Al, 0.103 ppm; B, 0.013 ppm; Ba, 0.038 ppm; Co, 0.000 ppm; Cr, 0.0036 ppm; Cu, 0.0095 ppm; Li, 0.00095 ppm; Mn, 0.0026 ppm; Mo, 0.000 ppm; Ni, 0.0056 ppm; P, 0.000 ppm; Pb, 0.0040 ppm; Rb, 0.0011 ppm; Sr, 0.037 ppm; Ti, 0.0031 ppm; and Zn, 0.000 ppm.

TABLE 28.—*Analyses, in milligrams per liter, of water from lakes in continental west Greenland*

[Analyses from Böcher (1949). Analysis I by K. Rørdam, all others by Werner Christensen]

	A	B	C	D	E	F	G	H	I
HCO_3^{-1}	64	37	29	67	43	317	397	[1] 1,286	[2] 1,966
SO_4^{-2}	2	2	0	6	1	2	2	45	91
Cl^{-1}	12	7	4	9	6	154	169	708	903
Ca^{+2}	11	7	3	13	11	25	30	32	0
Mg^{+2}	5	4	2	7	4	41	62	236	308
Na^{+1}	12	4	6	6	0	114	65	514	824
K^{+1}							44	206	66
SiO_2	7	10	9	13	11	15	13	10	------
Total dissolved solids	113	71	53	121	76	668	782	3,040	4,160

[1] Includes 408 mg/l CO_3.
[2] Includes CO_3.

A. Menyanthes Lake, elev 400 m.
B. Kløftsøerne, elev 300 m.
C. Small lake with Sphagnum, elev 400 m.
D. Lake near Mt. Keglen.
E. Tasersuatsiag.
F. Lake near Strømfjordshavn.
G. Lille Saltsø, Aug. 20, 1946.
H. Store Saltsø.
I. Tarajornitsog.

The situation is very different in eastern Europe, where the initial exploratory phase of water chemistry was entered rather recently, after the development of rapid analytical methods. The result has been a great flood of work on the geochemistry of surface waters. Both general analyses and special studies of particular elements (see, for example, Alekin and Moricheva (1956), a careful analysis of the carbonate system) are being carried out, and there are also many important papers dealing with the principles of hydrochemistry. Unfortunately only a very small part of the published work is available in America.

Another focus of hydrochemical research, the only other one in Eurasia, is in Japan. There, as in the Soviet Union, exploratory hydrochemistry using modern methods is combined with serious geochemical studies, both broad and intensive. For the rest of the

Eurasian landmass there are only scattered analyses, most of them incomplete.

It is evident from even the small number of analyses presented in table 29 that the waters of Portugal are varied and interesting. Only the Alviela water is of a typical calcium bicarbonate type. In the others there is almost as much magnesium as calcium in three out of four waters, and there is more sodium than either magnesium or calcium in the same three. Sulfate is more important than bicarbonate in two waters, and there is a considerable amount of chloride as well. In a more dilute water these proportions of chloride, sulfate, and sodium might be attributed to sea-spray, but in these waters, with several hundred parts per million of total dissolved solids, it is likely that the ions come from sedimentary rocks in the watersheds of the rivers. It is evident that the Iberian peninsula would repay close hydrochemical study.

The British Isles have a diversity of water chemistry that befits their geology. The more concentrated waters, with several hundred parts per million of total dissolved solids, are predominantly calcium bicarbonate types, but variations from this must be expected. Notice, for instance, the high sodium content of the Roach in Lancashire (table 34). There may be streams draining coal measures with much more sulfate than any of the waters listed in tables 30–34.

Table 29.—*Analyses, in parts per million, of water from Portugal*

[Analyses from unpublished data provided by the Labóratório de Análises Físico-químicas e Micrográficas of the Companhia das Águas de Lisboa]

	A	B	C	D	E	F
HCO_3^{-1}	104	72.4	17.4	21.4	216	192
SO_4^{-2}	127.9	96.5	12.3	8.4	11.4	11.6
Cl^{-1}	24.9	28.4	7.4	9.6	39.1	19.5
NO_3^{-1}	3.5	Tr.	Tr.	Tr.	2.5	3.9
Ca^{+2}	52.9	19.2	3.2	3.4	58.7	36.4
Mg^{+2}	14.5	10.2	3.3	3.1	10.9	3.7
Na^{+1}	}27.2	46.2	7.5	6.6	26.4	44.5
K^{+1}						
Fe (dissolved)	.260	.10	.04	.20	.034	.05
Mn (dissolved)	.028	Tr.	Tr.	.02	.00	Tr.
AsO_4	.000	.000	.001	.000	.000	.000
SiO_2	9.8	9.2	8	10	9.8	3.4
Total dissolved solids	365	282	59.1	62.7	375	315

A. Rio Tejo at Valada. Dec. 19, 1957.
B. Rio Tejo at Valada. July 24, 1957.
C. Rio Zézere at Albufeira de Castelo de Bode. Aug. 20, 1951.
D. Rio Zézere at Albufeira de Castelo de Bode. Feb. 1, 1951.
E. Alviela at Entrada dos Barbadinhos. Sept. 19, 1957.
F. Alviela at Barbadinhos. Feb. 15, 1957.

Table 30.—*Analyses, in parts per million, of water from Shropshire meres, England*

[*From Gorham (1957c, p. 175)*]

	A	B	C	D	E	F
HCO_3^{-1}	15.3	32.9	34.8	63.4	90.2	185
SO_4^{-2}	16.8	11	13.4	28.3	22.1	49.9
Cl^{-1}	16.1	14	13.7	16.5	18.6	19.6
NO_3^{-1}	.13	.89	.22	7.09	.22	1.28
PO_4^{-3}	.99	.03	.012	.15	1.2	.12
Ca^{+2}	7.20	10.4	11.6	27.4	30.4	71
Mg^{+2}	1.8	1.4	1.4	3.1	2.6	6.2
Na^{+1}	8.1	7.6	7.6	8.3	11.3	11
K^{+1}	8.2	7.4	8.6	5.1	9.8	5.5
SiO_2	1	.4	1	2.2	2	2.4
Total dissolved solids	75.6	86	92.3	162	188	352

A. Newton Mere, Shropshire. Nov. 1954.
B. Blake Mere, Shropshire. June 1955.
C. Kettle Mere, Shropshire. June 1955.
D. White Mere, Shropshire. Nov. 1954.
E. Ellesmere, Shropshire. June 1955.
F. Crose Mere, Shropshire. June 1955.

Table 31.—*Miscellaneous analyses, in parts per million, of water from England*

[Analyses A–B are from Gorham (1956, p. 376). Analyses C–H are recalculated from Gorham (1957e, p. 23)]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	Nil	Nil	Nil	Nil	96.9	122	178.7	189.1
SO_4^{-2}	10.2	17.7	13	25.9	57.6	72	100	120
Cl^{-1}	5.9	5.9	9.8	17.5	23.8	23.8	33.6	45.5
NO_3^{-1}	------	------	.31	.22	10.9	2.35	.35	2.53
PO_4^{-3}	------	------	.003	.06	.12	.33	.21	.87
Ca^{+2}	.7	3.8	1.8	7.6	38.8	52	67	73
Mg^{+2}	.6	.9	.84	2.5	12.5	11.8	19.9	22.6
Na^{+1}	3.8	4.6	5.3	9	12.2	14.3	20.5	29.9
K^{+1}	.2	.5	1.2	2.3	3.9	4.3	4.7	6.2
SiO_2	.5	.4	1	1.4	8.2	1.3	2.6	2.6
Total dissolved solids	21.9	33.8	33.3	66.5	265	304	428	492

A. Pool on top of bog, Bog Hill, Moor House Nature Reserve.
B. Drain, Bog Hill, Moor House Nature Reserve.
C. A small lake near Sandiway, Cheshire, Jan. 1955.
D. Oak Mere, Cheshire. Oct. 1954.
E. Budworth Pool, Cheshire. Oct. 1954.
F. Rostherne Mere, Cheshire. Oct. 1954.
G. Pick Mere, Cheshire. Oct. 1954.
H. Budworth Mere, Cheshire. Oct. 1954.

Table 32.—*Analyses, in parts per million, of water from Scotland*

[Data are from Gorham (1957b, p. 146). Samples were collected July 21–25, 1955, in the Cairn Gorm–Strath Spey district]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	0.2	Nil	1.0	16.9	4.7	7.6	32.6	17.3
SO_4^{-2}	.9	2.8	3.1	4.9	2.5	4.0	5.7	5.8
Cl^{-1}	.9	4.7	2.7	7.6	3.8	7.1	9.0	8.5
NO_3^{-1}	<.05	<.05	.30	.05	<.05	<.05	.10	.05
Ca^{+2}	.2	.3	1.3	5.9	1.4	2.7	9.5	5.8
Mg^{+2}	.1	.4	.2	.9	.3	.5	1.4	.9
Na^{+1}	.8	2.8	2.0	5.2	3.3	5.4	7.8	6.5
K^{+1}	.2	.4	.2	.8	.4	.6	1.5	1.0
SiO_2	1.9	.9	2.2	1.2	3.5	6.3	4.5	4.5
Total dissolved solids	5.3	12.4	13	43.5	20	34.3	72.1	50.4

A. Lochan, Coire an Lochain, beneath Cairn Lochan.
B. Lochan Dubh a' Chadha.
C. Loch Einich.
D. An Lochan Uaine.
E. Loch Morlich.
F. Loch an Eilein.
G. Artificial loch at Drumintoul Lodge.
H. Loch Pityoulish.

Table 33.—*Analyses, in parts per million, of water from western Ireland*

[All data are from Gorham (1957d, p. 238). Samples collected May 6–8, 1956]

	A	B	C	D	E	F	G
HCO_3^{-1}	Nil	4.4	6.9	4.6	10.4	4.9	22.0
SO_4^{-2}	7.7	3.2	3.6	4.6	5.1	7.0	7.4
Cl^{-1}	20.6	7.3	10.4	12.7	11.8	22.5	23.6
Ca^{+2}	.8	1.8	3.1	2.8	4.2	3.4	8.7
Mg^{+2}	1.8	.5	.7	1.1	.8	1.2	1.5
Na^{+1}	12.5	4.7	5.9	7.1	7.3	13.1	13.7
K^{+1}	.5	.2	.3	.5	.5	.6	.8
Total dissolved solids	>43.9	>22.1	>30.9	>33.4	>40.1	>52.7	>77.7

A. Blanket bog pools, Gowlan East.
B. Upper Lake, Killarney.
C. Muckross Lough, Killarney.
D. Lough Shindilla, Connemara.
E. Lough Agraffard, Connemara.
F. Craiggamore Lough, Connemara.
G. Garraunbaun Lough, Connemara.

TABLE 34.—*Analyses, in parts per million, of water from rivers in Britain*

[These data are from Suckling (1943, p. 339, 341, 342)]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	42	318	168	204	204	294	180	492
SO_4^{-2}	15.4	59.6	94	24	29	29	161	30
Cl^{-1}	24.7	19.8	15	9.9	26	24	71	19
NO_3^{-1}	3.5	7	9	10.5	18	18	10	18
Ca^{+2}	18.1	106	34	68	80	110	41	159
Mg^{+2}	1.5	2.8	18	3	Tr.	3	15	5
Na^{+1}	17.8	38.1	48	16	24	17	122	31
SiO_2	7	4.5	8	11	11	13	14	10
Total dissolved solids	130	556	394	346	392	508	614	764

A. Holyford River, Devon.
B. Avon River, Caine, Wiltshire.
C. Taff River, Glamorganshire.
D. Windrush River, Oxfordshire.
E. Newbourne Stream, Suffolk.
F. Colne River, Hertfordshire.
G. Roach River, Lancashire.
H. Mullingar Stream, Ireland.

The dilute waters, particularly of lakes on resistant rocks, have a composition not very different from that of rain water, as has been pointed out by Gorham (1958). Bicarbonate is not detectable in some of these waters, which tend to be solutions of sodium sulfate and chloride. In the western part of the British Isles, where sea-spray influence is strong, sodium and chloride are the dominant ions—notice particularly the composition of water from the blanket bog pools of Gowlan East in western Ireland. All the waters of western Ireland show the same tendency, and it is detectable in Scotland even as far from the sea as the Cairn Gorms (Loch Bubh a' Chadha, for example) where direct sea spray cannot be of significance and the sodium chloride is carried in the rain.

For the rest of western Europe we must depend on the old analyses, except for Ohle's 1935 analysis of Tonteich, although there exists a huge body of more recent data that does not include all of the major ions. The papers by Lohammar (1938), and Ohle (1934, 1940) may be mentioned in particular. A sample of the old analyses is presented in table 35 and others are presented or referred to in earlier editions of this book. Most of these are waters with several hundred parts per million of total salt, most of it calcium bicarbonate. The deep water of Lac Ritom however, shows the kind of dissolved salt accumulation that may be expected in the waters of a meromictic lake.

Some analyses from the Rhine (A–D) and Elbe (E–H) systems are presented in table 36 and some from the Danube system (A–E) and several other rivers are presented in table 37. All are normal calcium bicarbonate waters.

A few analyses for Sweden and Estonia are presented in table 38. There is considerable variation in the concentration of Swedish waters, those from lowland sedimentary rocks being more concentrated than those from upland hard rocks. Although they lack a few major ions and so are not reproduced here, the analyses by Lohammar (1938) of the waters of Sweden contain much useful information, and, as they provide uniform analyses for many waters from various geological environments, they have formed the factual basis for a number of geochemical discussions (Rodhe, 1949; Gorham, 1955). The Köverjarv near Jussi in Estonia is noteworthy for the extreme dilution of its waters.

TABLE 35.—*Some analyses, in parts per million, of waters from west Europe*

[All these data except H are recalculated from Clarke (1924b), after various authors]

	A	B	C	D	E	F	G	H	I	J
HCO_3^{-1}	202	82.8	91	102	103	49	109	0.00	220	104
SO_4^{-2}	21.8	2.3	7.7	42.2	40.5	57.9	1,658	351	33.6	13
Cl^{-1}	7.5	2.9	1.9	1	.79	------	------	16.6	1.1	15
NO_3^{-1}	11.3	------	------	5.7	------	------	------	1.56	------	------
NO_2^{-1}	------	------	------	------	------	------	------	.002	------	------
PO_4^{-3}	------	------	------	------	------	------	------	.0037	------	------
Ca^{+2}	74	19.2	26	45.3	42.3	27.1	525	82.4	56	36.2
Mg^{+2}	1.6	1.8	.92	2.7	3.5	6.7	118	20.7	14	5.3
Na^{+1}	7.3	9.3	6.1	5	3.8	1.5	2.1	12.2	3.5	8.9
K^{+1}	2.2	2.2	3.4	1.6	.38	2.	3.6	1.2	3.5	3.8
Fe	.18	3.8	2.2	------	[1] .5	------	[1] 8.3	6.6	.06	------
Al	.24	3.6	------	1.9	------	------	------	4.4	.83	.25
Mn	------	------	------	------	------	------	------	.60	------	------
SiO_2	24.4	42.3	40.4	23.8	8.6	2.8	10	41.	3.6	1.8
Total dissolved solids	353	170	180	231	203	147	2,430	538	336	188

[1] Computed from oxides on the basis that only Fe_2O_3 was present.

A. The Seine at Berey, France. Analysis by H. Sainte-Claire Deville, 1848.
B. The Loire near Orleans, France. Analysis by Deville, 1848.
C. The Garonne at Toulouse, France. Analysis by Deville, 1848.
D. The Rhone at Geneva, Switzerland. Analysis by Deville, 1848.
E. Lac Leman, Switzerland. Analysis by R. Brandenbourgh cited in Forel (1884).
F. Lac Ritom, above Airolo, Canton Ticino, Switzerland. Surface water. Analysis by F. E. Bourcart, 1906.
G. Lac Ritom, lower layer of water, below 13 m depth. Analysis by Bourcart, 1906.
H. Tonteich near Reinbeck, Germany. 0.5 m depth, Apr. 25, 1935. Data from Ohle, 1936.
I. Kochelsee, Germany.
J. Hallstättersee, Upper Austria. Mean of two analyses, summer and winter. Analyses by N. von Lorenz, 1898.

Data for lakes and rivers of the Mediterranean area of Europe are very few. Stankovic (1931) presents analyses lacking sodium and potassium for 10 Aegean lakes.

TABLE 36.—*Analyses, in parts per million, of water from the Rhine and the Elbe and their tributaries*

[These data are recalculated from Clarke (1924b), after various authors]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	145	176	146	113	5	63	202.8	106
SO_4^{-2}	11.1	13.2	19.8	19.4	1	24.5	19.8	22
Cl^{-1}	.83	.95	6.5	11.3	3.3	12.1	7.2	8.7
NO_3^{-1}	------	------	2.9	------	------	1.89	2	2.1
Ca^{+2}	41	55.7	56.6	41.6	.7	16.6	58.4	31
Mg^{+2}	7.2	4.8	7	6.1	1.1	7	7.1	5.4
Na^{+1}	2.3	1.2	3.7	10.1	1.7	10.5	8.7	9
K^{+1}	2.8		1.9	6.4	.8	3.5	5.4	4.7
Fe	------	------	[1] 1.1	[1] .98	Tr.	.69	[1] 1.4	1.07
Al	------	------				1.1		
SiO^2	2.9	2.1	4.8	5.7	6	5.6	9	10.6
Total dissolved solids	213	254	250	215	19.6	146	322	201

[1] Recalculated from $Fe_2O_3+Al_2O_3$ on the basis that Fe alone was present.

A. Lake of Zurich, Switzerland. Analysis by Moldenhauer 1857.
B. The Rhine at Basel, Switzerland. Analysis by J. S. F. Pagenstecher, 1837, cited by Roth.
C. The Rhine near Mainz, Germany. Analysis by E. Egger, 1887.
D. The Rhine at Arnheim, Germany. Analysis by J. W. Gunning, 1854.
E. The Saale near its source. Analysis by E. Spaeth, 1889.
F. The Saale at Blankenstein, Germany. Analysis by A. Schwager, 1891.
G. The Elbe at Celakowitz, above the mouth of the Iser.
H. The Elbe at Tetschen, near the Bohemian frontier.

So much information exists for the waters of the Soviet Union that it is possible to give only a small sample here. Analyses for a number of rivers, some of them very important ones, are presented in tables 39 and 40. Additional information may be found in Blidin and Aslanov (1952); Durov (1952); Forsch (1936); Fortunatov (1932); Oseroff (1926); Polyakov and Kuznetzov (1940); Valyashko (1939); Vesclovskii, Golokov, and Tarasov (1954); Bochkarev (1959). Occasionally sodium displaces calcium or sulfate displaces carbonate as principal ions. Of the rivers listed, only the Ishim, with its 1,200 ppm of total salts and its high chloride content, seems to show any trace of the evolution displayed by the rivers of the Rio Grande system and other arid parts of the American West, but there must be streams of such high concen-

TABLE 37.—*Analyses, in parts per million, of water from Central Europe*

[All these data are recalculated from Clarke (1924b), after various authors]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	104	9.5	232	167	148	124	32.8	170
SO_4^{-2}	10.5	5.5	15.4	14.7	20.7	64	21.6	16.9
Cl^{-1}	4.9	8.3	2.6	2.4	2.1	49	5	4.8
NO_3^{-1}	.23	1.8	.50	2.1	------	------	------	------
Ca^{+2}	22.8	13.1	58.3	43.9	40.4	52	25.7	50.8
Mg^{+2}	9	.7	13.5	9.9	10.5	8.7	3	7.9
Na^{+1}	3.4	3	3.2	2.8	1.4	28.8	5.9	2.8
K^{+1}	2	1.3	2.1	1.6	------	5.4	4.9	.69
Fe	.23	.18	.09	.33	Tr.	------	[1] 2.1	[1] .77
Al	.50	2.4	.86	------	------	------	------	------
SiO_2	3.9	9.8	3.5	5.6	1.8	10.5	11.6	8
Total dissolved solids	161	55.6	332	250	225	342	113	263

[1] Computed from $Fe_2O_3 + Al_2O_3$ on the assumption that Fe alone was present.

A. The Naab. Analysis by A. Schwager, 1893.
B. The Ilz. Analysis by Schwager, 1893.
C. The Danube above the Naab. Analysis by Schwager, 1893.
D. The Danube above Vienna (20 km) at Greifenstein. Mean of 23 analyses, by J. F. Wolfbauer, of samples taken at intervals of 16 days throughout the year 1878.
E. The Danube at Budapest. Analysis by M. Ballo, 1878.
F. The Weser at Rekum, 41 km above its mouth. Mean of 2 analyses by F. Seyfert, 1893.
G. The Oder near Breslau. Sample taken at high water. Analysis by O. Luedecke, 1907.
H. The Vistula at Culm. Analysis by G. Bischof, 1863.

TABLE 38.—*Analyses, in parts per million, of water from Estonia, Sweden, and Norway*

[Analyses C–E are recalculated from Clarke (1924b, after Hofman-Bang]

	A	B	C	D	E	F
HCO_3^{-1}	<1.4	--------	19.5	21.3	50.9	12
SO_4^{-2}	<4	1.2	.8	1.1	69.6	5
Cl^{-1}	<2	3.3	.9	1.1	5.8	3.5
NO_3^{-1}	--------	--------	--------	Tr.----	.23	.0
PO_4^{-3}	< .013	--------	--------	--------	--------	.0
Ca^{+2}	<1	23.3	2.2	4.3	49.9	6
Mg^{+2}	<1	19.3	.1	.06	3.8	.0
Na^{+1}	--------	Tr.----	1.9	2.2	5.9	1.5
K^{+1}	--------		1.7	1.5	3.1	.8
Fe	< .07	.2	[1] .1	[1] .27	[1] 2.3	.13
Al	--------	--------				
SiO_2	> .18	1.6	1.5	3.4	11	3.4
Total dissolved solids	--------	>48.9	28.7	35.2	203	32.3

[1] Computed from $Fe_2O_3+Al_2O_3$ on the basis that Fe only was present.

A. Köverjärv near Jussi, east Estonia. Riikoja (1940, p. 177–178).
B. Vasulajärv near Laane, east Estonia. Riikoja (1940, p. 268).
C. The Byske-elf, Sweden, July. Analysis by O. Hofman-Bang, 1905.
D. The Ljusnan, Sweden, June. Hofman-Bang, 1905.
E. The Fyris, Sweden, October. Hofman-Bang, 1905.
F. The Glomma at Kykkelsrud power station, Askim, Norway. Dec. 7, 1958. Durum, Heidel, and Tison (1960). Analysis includes F, 0.0 ppm; Ag, 0.000032 ppm; Al, 0.030 ppm; B, 0.0007 ppm; Ba, 0.018 ppm; Co, 0.000 ppm; Cr, 0.0012 ppm; Cu, 0.0014 ppm; Li, 0.014 ppm; Mn, 0.0054 ppm; Mo, 0.000 ppm; Ni, 0.0021 ppm; Pb, 0.0018 ppm; Rb, 0.0017 ppm; Sr, 0.015 ppm; Ti, 0.00097 ppm; V, 0.000 ppm; and Zn, <0.027 ppm.

TABLE 39.—*Analyses, in milligrams per liter, of river water from the U.S.S.R.*

[All analyses from Alekin (1953, table 45)]

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
HCO_3^{-1}	122	24.4	71.6	27.5	80.4	268.4	195.2	231.8	260	246.4	268	108	210.4	218.7	250.7	221.4
SO_4^{-2}	47.1	2.6	3.6	4.5	13.3	24.5	12.9	14.1	112	163	480	18	112.3	108.4	5.6	169.6
Cl^{-1}	14	8	5.2	3.8	38.4	9.8	9.2	3.9	44	171.5	210	17	19.9	14.4	2.3	9
Ca^{+2}	41.4	4.6	21	8	27.4	63.2	55.7	64	82	114	173	37	80.4	84.6	61.5	115.6
Mg^{+2}	9.4	2.1	.3	1.2	5.8	18.3	11.8	7.7	18	17.9	51.5	3	22.3	18.7	14.2	18.2
Na^{+1}	13.4	3.2	9.5	3.8	20.8	12.5	2.3	8.7	52.2	116.3	169	12	12.5	11.3	23	2.5
K^{+1}																
Total dissolved solids	>247	>44.9	>111	>48.8	>186	>397	>287	>330	>568	>829	>1,352	>195	>458	>456	>357	>536

A. Sev. Dvina (d. Zvoz) Aug. 27, 1946.
B. Pechora (s. Ust=Tilma) June 19, 1941.
C. Velikhaia (s. Piatonovo) June 8, 1946.
D. Neva (s. Ivanovskoe) July 9, 1946.
E. Volkhov (g. Novgorod) June 29, 1938.
F. Iuzhn. Bug (s. Aleksandrovsk) Mar. 30, 1939.
G. Dnepr (s. Razumovka) Aug. 27, 1938.
H. Desna (g. Chernigov) Aug. 4, 1939.
I. Don (s. Aksaĭskaia) July, 1939.
J. Sev. Donets (s. Ust-Belokalitvinskaia) Aug. 31, 1939.
K. Kalmius (s. Sartana) Aug. 11, 1939.
L. Kuban (kh. Tikovskii) July 20, 1938.
M. Volga (g. Volsk) Aug. 21, 1940.
N. Oka (Novinki) Aug. 10, 1938.
O. Moskva (s. Tatorovo) Average of 10 samples, 1914–26.
P. Sura (s. Kozlovka) Sept. 2, 1940.

TABLE 40.—*Further analyses, in milligrams per liter, of river water from the U.S.S.R.*

[All analyses from Alekin (1953, table 45)]

	A	B	C	D	E	F	G	H	I	J	K
HCO_3^{-1}	190.3	170.8	272.1	186	265.4	245.9	216.9	378	170.8	153.1	140.4
SO_4^{-2}	132	44.5	166.9	7.4	156.1	345.5	123.4	3,527	71.6	105.3	78.9
Cl^{-1}	13.5	15	18	8	14.2	504.6	24.9	1,548	38.3	35.9	45.4
Ca^{+2}	82.2	52.3	114	33.6	106.2	165.7	89.9	303	47.5	105.8	89.5
Mg^{+2}	21	11.6	25	9.3	27.4	46.7	18.6	379	19.7	1.2	3.2
Na^{+1}	10.3	18.5	17	24.8	11	333.2	21.2	1,769	34.5	1.2	11.4
K^{+1}											
Total dissolved solids	>449	>313	>613	>269	>580	>1,642	>495	>7,900	>382	>402	>369

	L	M	N	O	P	Q	R	S	T	U
HCO_3^{-1}	140.4	102.3	124.6	85.6	78	79.3	124	66.4	73.2	31.7
SO_4^{-2}	39.5	36.2	145.6	13	10.7	15.3	386.7	21.2	4	2.8
Cl^{-1}	8.6	10.8	172	-------	3.2	3.4	529	15.2	2.6	1.5
Ca^{+2}	59.6	41.4	38.6	24.3	18	24.5	81.5	18	19.3	8.2
Mg^{+2}	3.2	3.2	38	5.4	4.8	4.7	77.3	3.8	4	2.1
Na^{+1}	2.9	9.4	132.5	.4	6.9	.1	13	18.8	1.5	.5
K^{+1}										
Total dissolved solids	>254	>203	>651	>129	>122	>127	>1,212	>143	>105	>47

A. Kama (s. Chistopol) Sept. 6, 1940.
B. Chusovaia (d. Shelygi) Sept. 26, 1940.
C. Belaia (g. Ufa) Sept. 2, 1940.
D. Viatka (g. Kirov) Sept. 18, 1940.
E. Ural (g. Chkalov) Aug. 12, 1940.
F. Emba (up. Diussiuke) May 31, 1941.
G. Terek (st. Kargalinskaia) Sept. 26, 1939.
H. Kalaus (s. Petrovskoe) July 25, 1939.
I. Kura (s. Saliania) July 24, 1941.
J. Syr-Daria (Kishl. Kok Bulak) July 14, 1940.
K. Amu-Daria (g. Turt-Kut) July, 1940.
L. Piandzh (s. Tokoi) July 15, 1940.
M. Zeravshan (uste Fan-Daria) July 15, 1940.
N. Nura (s. Romanovskoe) Aug. 2, 1940.
O. Ob (g. Novosibirsk) Aug. 21, 1940.
P. Biai (g. Biĭsk) Oct. 17, 1942.
Q. Irtysh (g. Omsk) July 25, 1940.
R. Ishim (g. Akmolinsk) July 24, 1940.
S. Lena (s. Kiusiup) Sept. 8, 1940.
T. Eniseĭ (g. Krasnoiarsk) Sept. 20, 1936.
U. Iana (g. Verkoiansk) July 15, 1927.

TABLE 41.—*Analyses, in milligrams per liter, of miscellaneous lake waters from the U.S.S.R.*

[Analyses A–O are from Alekin (1953, table 53)]

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
HCO_3^{-1}	59.2	58.6	40.2	48.6	20.4	414.7	112.8	100.6	492.7	240	240	2,640	400	-------	500	215
SO_4^{-2}	4.9	4.4	2.5	2.8	1.3	16.9	4	4.3	893	2,115	7,620	95,200	79,300	46,900	44,500	3,008
$Cl^{-1}+Br^{-1}$	1.8	2	7.7	.8	1.5	62.9	5.2	4.2	574	1,585	61,300	137,800	102,500	142,500	121,600	5,338
Ca^{+2}	15.2	15.2	7.1	12.4	54.2	33.9	23.9	22.1	25.1	114	1,000	210	200	2,900	500	346
Mg^{+2}	4.2	4.4	1.9	2.1	1.6	55.9	5.2	3.3	164	294	5,430	19,200	6,500	19,900	11,200	730
Na^{+1}	6.1	4.9	8.6	1.73	1.5	77.3	11.5	3.5	694	1,475	35,700	97,300	92,230	81,200	82,300	3,174
K^{+1}						21.4										85
Total dissolved solids	>91.4	>89.5	>68	>68.4	>80.5	>683	>163	>138	>2,840	>5,820	>111,000	>352,000	>281,000	>293,000	>261,000	>12,900

A.	Baikal (surface)	Aug. 21, 1925	A. G. Frank-Kamenetskii.
B.	Baikal (1,000 m)	-------	Do.
C.	Ladozhskoe (surface)	-------	I. B. Molchanov.
D.	Teletskoe (surface)	-------	S. G. Lepneva.
E.	Onezhskoe	Sept. 26, 1935	I. B. Molchanov.
F.	Sevan	Aug. 12, 1928	S. I. A. Liatti.
G.	Chudskoe	Sept. 1, 1934	A. A. Sokolov.
H.	Valdaĭskoe	Aug. 28, 1946	O. K. Sokolov.
I.	Balkash	Aug. 19, 1941	V. D. Konshin.
J.	Issyk-Kul	-------	V. P. Matveev.
K.	Sakskoe	Aug. 1, 1931	H. S. Kurnakov.
L.	B. Bogatoe	-------	Do.
M.	Ebeĭty (Kulundiaskaia steppe)	Aug. 12, 1939	Do.
N.	Bogaz-Gol	-------	V. S. Egorov.
O.	Kuchuk	Aug. 29, 1938	E. A. Razumovskai͡a.
P.	Mean of 10 analyses of surface and bottom water of southern Caspian Sea.	Aug. 11–21, 1933.	Analysts, O. P. Oparina and M. T. Golubeva. From Brujewicz (1938).

TABLE 42.—*Analyses, in parts per million, of water from Crimean salt lakes*

[All analyses are from Kurnakov and others (1936)]

	A	B	C	D	E	F	G
HCO_3^{-1}	350	180	1,160	220	220	180	310
SO_4^{-2}	11,790	7,400	46,900	5,390	3,850	21,130	74,200
Cl^{-1}	82,200	49,500	147,800	74,955	121,780	29,200	37,500
Br^{-1}	1,360	210	1,800	170	440	600	90
Ca^{+2}	1,350	1,170	710	4,150	3,280	720	480
Mg^{+2}	5,980	3,300	3,747	7,560	9,465	3,880	6,000
Na^{+1}	45,420	27,700	29,170	32,280	60,400	20,670	47,800
K^{+1}	1,860	1,100	1,129	480	270	550	470
Specific gravity	1.1156	1.0688	1.2529	-------	-------	1.0617	1.1485
Total dissolved solids	>150,000	>90,600	>232,000	>125,000	>200,000	>77,000	>167,000

A. Iagi-moinak, Aug. 13, 1931 (p. 87).
B. Ozero Donuziav (p. 98).
C. Ozero Sultan-Eli (p. 98).
D. Ozero Kyrkskoe (p. 142).
E. Ozero Kiiatskoe (p. 142).
F. Ozero Marfovka (p. 166).
G. Ozero Kopty (p. 166).

tration in the U.S.S.R. As may be seen from table 41, there is no shortage of extremely concentrated lakes. Some lakes such as Ebeity on Kulundinskaia Steppe, Kara-Bogaz-Gol, and B. Bogatoe are dominated by sodium and chloride. Many other lakes in the Crimea (table 42) and Kazakhstan (table 43) have sodium chloride water of high concentration.

Alekin and Brazhnikova (1957) have summarized the chemical composition of the rivers of the U.S.S.R. Their results are presented in table 44. Except for the regions of internal drainage, the U.S.S.R. is characterized by waters of a total dissolved solids content of about 100 ppm and the weighted mean for the river water of all its territory is raised only to 123 ppm by the rivers of the Caspian basin and the basins of in-

TABLE 43.—*Analyses of water from Kazakhstan*

[Analyses A, B, and C have been recalculated from Posokhov (1949)]

	Milligrams per liter			Parts per million				
	A	B	C	D	E	F	G	H
HCO_3^{-1}	1, 272	396	384	900	2, 100	2, 100	930	950
SO_4^{-2}	791	5, 722	3, 633	92, 700	10, 000	9, 820	70	180
Cl^{-1}	140, 475	40, 402	62, 007	30, 600	700	15, 210	240	320
Ca^{+2}	39, 751	2, 502	2, 823	400	300	540	60	170
Mg^{+2}	10, 963	3, 258	3, 560	3, 000	400	1, 510	20	50
Na^{+1}	46, 640	21, 084	32, 628	46, 300	7, 300	11, 100	480	240
K^{+1}	1, 357	164	297	----------	----------	----------	Tr.	50
Total dissolved solids	>241, 000	>73, 500	>105, 000	>174, 000	>20, 800	>40, 300	>1, 800	>1, 960

NOTE.—Posokhov has lumped his data for the hypothetical combinations of Ca, Mg, HCO_3, and CO_3. The data for these columns have been recalculated on the basis that only $CaCO_3$ is involved.

A. Ushtagan Lake, central Kazakhstan. Aug. 23, 1945.
B. Ekibastuz Lake, central Kazakhstan. June 16, 1948.
C. Lake Tuz, central Kazakhstan. June 16, 1948.
D. Lake Sulfatnoe 1, Kustanay region. Dec. 11, 1937. This analysis and analysis E–H are recalculated from Polyakov and Kuznetsov (1940).
E. Lake near suburb Krasni Kordon, Kustanay region. Aug. 11, 1937.
F. Lake Sulfatnoe 2, Kustanay region. June 11, 1939.
G. Lake Pofarnoe, Kustanay region. Aug. 19, 1937.
H. Lake Uchitelskoe, Kustanay region. Aug. 19, 1937.

TABLE 44.—*Average ionic composition, in parts per million, of river water in the territory of the U.S.S.R.*

[These data are from Alekin and Brazhnikova (1957)]

	A	B	C	D	E	F	G	H	I
HCO_3^{-1}	56.3	50.2	59.4	81.8	138.5	30.9	134.2	202	62.2
SO_4^{-2}	14.8	9.2	17.5	7	41.5	5.8	62.1	164.8	18.4
Cl^{-1}	5	5.4	17.7	4	16.5	2.5	18.9	73.6	9.9
Ca^{+2}	17.2	14.1	16.7	19.4	43.4	7.8	50.2	94.1	18.9
Mg^{+2}	3.8	3	4.8	5	8.6	2	9.9	17.9	4.3
Na^{+1}	4.4	5.9	13.8	3	18.5	3.4	19.5	63.2	9.3
K^{+1}									
Total dissolved solids	>102	>88	>130	>120	>267	>52.4	>295	>616	>123

A. Barents and White Sea drainages.
B. Kara Sea drainage.
C. Laptev, eastern Siberian and Chukot Sea drainage.
D. Baltic Sea drainage.
E. Black Sea and Sea of Azov drainage.
F. Bering, Okhotsk, Japan Sea drainages.
G. Caspian Sea drainage.
H. Aral Sea drainage.
I. Entire territory of the U.S.S.R.

ternal drainage. The dominant ions are calcium and bicarbonate, as they are for most of the world.

A very small sample of the available data for Japanese waters is presented in tables 45, 46 and 47. Additional information may be found in papers by Hanya (1953a, 1953b), Hanya and Sugawara (1950), Iwasaki and Nitta (1954a, 1954b), Iwasaki, Nitta, and Tarutani (1953), Kimura and others (1950), J. Kobayashi (1948, 1951b, 1953, 1957), S. Kobayashi (1954), Miyada (1939), Noguchi (1950), Sugawara and Hanya (1948), Sugihara (1951), Takakura (1955), Yamagata (1954), Yamamoto (1952), and Yoshino (1950). A particularly valuable summary may be found in J. Kobayashi (1960). In Japan, volcanic influence on water chemistry is strong, as indicated by the rather high silica levels in the water. In certain localities the water is very acid. Katanuma-ko, a small crater lake, is among the more acid lake waters of the world, having a pH of 1.7 (Hutchinson, 1957). None of the waters for which reasonably complete analyses are available is this acid. But the River Su is rather high in acidity; its sulfuric and hydrochloric acid content comes partly from acid-mine wastes and partly from volcanic gases. The miscellaneous analyses given in table 47 are of interest because of the data they provide for the rarer alkali metals and for zinc and copper.

TABLE 45.—*Analyses, in parts per million, of water from Akita Prefecture, Japan*

[Data recalculated from Kobayashi (1951a)]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	20.7	12.8	21.8	16.1	0.0	16.7	15.3	13.1
SO_4^{-2}	15.4	15.4	8	18.4	41.2	15.4	12.2	11.2
Cl^{-1}	7.9	8.7	10.1	9.9	52.9	12.9	11.5	11.5
NO_3^{-1}	.27	.62	.13	.40	.18	.49	.35	.27
PO_4^{-3}	.01	.00	.00	.03	.03	.01	.01	.01
Ca^{+2}	6.4	17.8	6.1	7.5	9.4	7	6.2	5
Mg^{+2}	1.6	4.3	2.2	2.3	5.3	2	1.9	2.2
Na^{+1}	7.8	8.1	7.4	7.7	8.1	.9	7.8	9.3
K^{+1}	.76	1.03	7.2	.90	1.84	.84	8.1	1.02
NH_4^{+1}	.03	.08	.03	.04	.04	.04	.05	.04
Fe	.04	.04	.03	.14	2.07	.12	.22	.11
SiO_2	34.9	27.4	15.9	20	32.1	17.5	14.7	16.4
Total dissolved solids	95.8	96.3	78.9	83.4	153	73.9	78.3	70.2

A. River Oyu at Furukawa bridge, Kemanai-cho. Mean of 11 analyses, 1942–43.
B. River Kosaka at Setaishi bridge, Kemai-cho. Mean of 11 analyses, 1942–43.
C. River Ani at Takamaga bridge, Shimoonomura. Mean of 11 analyses, 1942–43.
D. River Yoneshiro at Tomine bridge, Tomine-mura. Mean of 11 analyses, 1942–43
E. River Takamatsu at Tohira. Mean of 11 analyses, 1942–43.
F. River Minase at Sennen lock-gate. Mean of 10 analyses, 1942–43.
G. River Omono above River Iwami confluence. Mean of 11 analyses, 1942–43.
H. River Koyoshi at Nagase bridge, Nishitaskizawa-mura. Mean of 12 analyses, 1942–43.

A few analyses for the humid parts of southeast Asia are given in table 48 and some partial analyses for Sunda lakes are given by Ruttner (1930). The analyses of J. Kobayashi (1959) for the Mae Khong are particularly instructive because analyses for the lower reaches of large rivers in the humid tropics are very scarce. The rivers of Thailand, at least, are not as dilute as such rivers are often supposed to be. There are many data in J. Kobayashi (1959) which are not included here, and they show the strong influence of local geology on the chemistry of Thailand rivers. The rivers of the

TABLE 46.—*Analyses, in parts per million, of water from the Kantō districts, Japan*

[These data have been recalculated from Kobayashi (1955)]

	A	B	C	D	E	F	G	H	I	J	K
HCO_3^{-1}	20.2	28.7	12.8	0.0	0.1	24.0	48.9	69.1	42.3	21	28.1
SO_4^{-2}	44.9	14.2	8.4	280	76.9	10.7	29.9	5.3	6.7	31.3	35.2
Cl^{-1}	8.2	4.7	2.2	134.5	18.2	5.5	14.6	2.8	2.9	8.8	5.1
NO_3^{-1}	.31	1.28	.26	.15	5.75	.27	.89	1.51	.80	1.68	2.08
PO_4^{-3}	.01	.01	.00	1.84	.02	.01	.01	.05	.02	.01	.01
Ca^{+2}	15.7	9.2	4.9	33.4	15.3	7	16.5	21.4	10.4	11.9	17
Mg^{+2}	4.3	2.3	1.1	2.5	3.8	1.7	2.1	1.7	1.6	2.9	2.8
Na^{+1}	6.6	6.3	3.3	13.4	8.5	6.6	16.1	7	5.5	6.4	5
NH_4^{+1}	3,54	.09	.02	.23	.09	.13	.10	.05	.13	.07	.05
K^{+1}	1.32	1.20	.74	6.31	3.03	1.12	1.67	1.09	1.85	1.47	1.70
Fe	.04	.13	.03	4.71	.88	.01	.05	.05	.08	.16	.06
SiO_2	35.4	26.3	11.7	61.5	36.4	18	37.5	10.5	50.8	27.8	22.4
Total dissolved solids	141	94.4	45.5	539	169	75	168	121	123	114	120

	L	M	N	O	P	Q	R	S	T	U	V	W
HCO_3^{-1}	33.3	36.9	37.4	62	56	41.5	57.9	45	46.4	55.7	49.4	48
SO_4^{-2}	15.6	13	19.1	18.2	21.1	7.1	10.4	11.9	1.6	8.9	10.4	10.4
Cl^{-1}	5	2.9	7.7	2.1	6.1	.6	2.5	5.8	.8	1.9	1.9	1.9
NO_3^{-1}	.80	.13	.93	.97	1.64	.53	1.82	4.70	.05	1.42	1.37	1.37
PO_4^{-3}	.01	.07	.01	.02	.07	.02	.01	.00	.01	.07	.07	.07
Ca^{+2}	10.4	9.9	12.9	20.9	16.9	12.9	17.8	14.4	8.2	13.9	11.7	11.9
Mg^{+2}	1.7	2	2.9	1.9	3.9	1.1	1.9	3.1	3.4	4.6	3	3.2
Na^{+1}	7.6	.75	7.5	4.4	6.9	3	4.1	5.4	3.3	2.3	5.4	5.1
NH_4^{+1}	.12	.04	.05	.01	.09	.03	.04	.03	.03	.03	.13	.13
K^{+1}	1.57	1.51	1.54	.81	1.38	.61	1	1.04	1.18	1.05	1.11	1.01
Fe	.08	.01	.23	.02	.36	.00	.00	.04	.05	.13	.12	.16
SiO_2	24.1	29.9	21.1	11	16.1	13.7	14.1	20.4	9.3	33.5	29.7	30.9
Total dissolved solids	100	97.1	111	122	131	81.1	112	112	74.3	124	114	114

A. River Naka at Kuroiso-machi. Mean of 6 analyses, 1953–54.
B. River Naka at Akutsu-mura. Mean of 6 analyses, 1953–54.
C. River Tone at Numata-machi. Mean of 6 analyses, 1943–44
D. River Su at Naganohara-machi. Mean of 6 analyses, 1953–54.
E. River Agatsuma at Shibukwa-machi. Mean of 8 anaylses, 1943–44.
F. Lake Haruna at Murota-machi. Mean of 6 analyses, 1953–54.
G. River Usui at Toyooka-Mura. Mean of 6 analyses, 1953–54.
H. River Kanna at Onishi-machi. Mean of 2 analyses, 1944.
I River Kasu at Kasukawa-mura. Mean of 6 analyses, 1953–54.
J. River Tone, at Kawamata-mura. Mean of 12 analyses, 1943–44 and 1953–54.
K. River Watarase at Ashikaga-shi. Mean of 8 analyses, 1943–44.
L. Lake Chujenji at Nikko-machi. Mean of 6 analyses, 1953–54.
M. River Daiya at Nikko-machi. Mean of 6 analyses, 1943–44.
N. River Tone at Sawara-shi. Mean of 12 analyses, 1943–44 and 1953–54.
O. River Ara at Nagatoro. Mean of 6 analyses, 1942–43.
P. River Ara at Akabane-machi. Mean of 7 analyses, 1942–43.
Q. River Tama at Mitake. Mean of 6 analyses, 1942–43.
R. River Tama at Haijima-mura. Mean of 6 analyses, 1942–43.
S. River Tama at Noborito. Mean of 6 analyses, 1942–43.
T. Lake Yamanaka at Minamitsuru-gun. Mean of 6 analyses, 1953–54.
U. River Katsura at Otsuki-machi. April 16, 1943.
V. Lake Sagami at Yose-machi. Mean of 11 analyses, 1953–54.
W. River Sagami at Sagamihara-machi. Mean of 6 analyses, 1953–54.

Korat Plateau, in particular, show high concentrations of sodium and chloride due to the influence of salt oozing from sandstone formations. These rivers show a marked seasonal cycle of concentration. Parts of the Thailand drainage are not in the humid tropics, and the rest are in the region of monsoon climate. Although these rivers, therefore, cannot be taken as representative of rivers such as the Amazon and Congo which drain mostly tropical rain forests, they are probably representative of most of the tropical rivers of Asia.

The single analysis for the Ganges in table 49 suggests a water not very different from that of the Mae Khong, and supports the belief that many tropical rivers may actually contain total dissolved solids closer to 200 ppm than the 100 ppm usually assumed. The other analyses in table 49 are all for more or less concentrated waters. The waters of Afghanistan in particular are in an advanced state of evolution. Auden, Gupta, Roy, and Hussain (1942) have provided a new though incomplete analysis of the water of Sambhar Lake.

Some data for Iran and Turkey are presented in table 50. Almost all the lakes of Iran are highly evolved sodium chloride ones. The dominance of sodium and chloride is so strong, even for waters with a total dissolved solids content of about 5,000 ppm, that one suspects the presence of halite beds in the vicinity.

The Karaj River at Tehran is an ordinary calcium bicarbonate stream, showing that all waters in Iran are not of such strong desert types. It is probable that Kerman-Kanat is only one of many waters intermediate between the highly concentrated sodium chloride lakes and the Karaj River.

The best data for the Dead Sea and the waters flowing into it are presented in table 51. This system has long attracted the attention of travelers, and a number of older analyses may be found in the early editions of this book. Chloride and sodium are high even in the water of Merom. In the saltier water of the Dead Sea sodium is less important and magnesium is the dominant cation. Notice the variations in content of the Dead Sea with depth. The high bromine content has long invited speculation. It appears to be derived from fossil residual brines of Tertiary age (Bentor, 1961).

NEW ZEALAND

The waters of New Zealand are very incompletely known. The analyses given in table 52 are all from hydrothermal districts, and can hardly be typical of

TABLE 47.—*Miscellaneous analyses, in parts per million, of water from Japan*

[Analyses A–N are from Yamagata (1951b); analyses O–V are from Sugihara (1952); analyses O–R appear to be for irrigation water. All the analyses are from the area infected with schistosomiasis in Hiroshima Prefecture]

	A	B	C	D	E	F	G	H	I	J	K
HCO_3^{-1}	22.2	25.6	31.6	46.8	37.8	31	22.4	26.1	24.2	30.5	31
SO_4^{-2}	4.9	----	9	14.4	18.5	13.5	22.4	17.9	3.3	4.1	6.2
Cl^{-1}	7.6	8.9	7.8	4.8	5.5	9.2	11.6	9.9	5.7	6.7	6.3
NO_3^{-1}	----	----	----	----	----	----	----	----	----	----	----
PO_4^{-3}	----	----	----	----	----	----	----	----	----	----	----
Ca^{+2}	4.6	7.9	8.3	13.2	16	9.6	8.9	10.3	7.7	8.7	9.9
Mg^{+2}	2.7	2.8	4	3.2	1.1	4.9	4.5	3.8	2.5	3.1	2.6
Na^{+1}	4.29	4.47	6.04	3.05	3.62	1.86	6.87	6.42	3.33	3.17	3.57
K^{+1}	1.29	1.23	2.66	3.11	2.76	.47	.85	1.37	.54	.56	.50
Fe	----	----	----	----	----	----	----	----	----	----	----
Mn	----	----	----	----	----	----	----	----	----	----	----
Zn	----	----	----	----	----	----	----	----	----	----	----
Cu	----	----	----	----	----	----	----	----	----	----	----
SiO_2	----	----	----	----	----	----	----	----	----	----	----
Li^{+1}	.001	.001	.001	.002	.005	.0002	.0007	.0008	.0005	.0004	.0006
Rb^{+1}	.002	.001	.001	.002	.002	.0004	.0005	.0007	.0003	.002	.0008
Cs^{+1}	.00005	.00005	.0002	.0001	.0002	.0002	----	----	----	----	----
Total dissolved solids	>47.6	>50.9	>69.4	>88.6	>85.3	>70.5	>77.5	>75.8	>47.3	>56.8	>60.1

	L	M	N	O	P	Q	R	S	T	U	V
HCO_3^{-1}	34.4	22	15.1	92	106.4	93.6	112.4	89.8	71.8	61	85.6
SO_4^{-2}	4.3	9.1	1.4	12.3	31.3	14.7	21	6.7	9.5	4.7	2.5
Cl^{-1}	7.5	8.2	7.9	26.5	35.4	26.9	25.3	21.2	13.7	11	9.1
NO_3^{-1}	----	----	----	.04	.46	1.62	2.14	2.90	.85	.00	.04
PO_4^{-3}	----	----	----	.05	.02	.02	.00	.2	.04	.01	.04
Ca^{+2}	10.8	7.5	4	21	38.2	22.9	25.3	18.7	9.3	6.9	2.5
Mg^{+2}	1.6	3.2	2.1	9.9	8.3	5.5	9.7	7.3	7.8	2.1	1.9
Na^{+1}	2.95	4.84	3.58	13.2	15.7	14.6	14.1	13.7	11.4	8.8	13
K^{+1}	.64	.70	.62	2.2	1.6	1.7	2.1	1.3	1.7	.3	.5
Fe	----	----	----	1.1	3.3	9	7.2	3.3	.4	.05	.08
Mn	----	----	----	.02	.48	----	.06	.20	.02	----	----
Zn	----	----	----	.041	.045	.056	.029	.035	.010	----	----
Cu	----	----	----	.012	.008	.017	.010	.007	.004	----	----
SiO_2	----	----	----	8.9	17	10.8	12.8	15	13.4	20.1	20.2
Li^{+1}	.0005	.001	.0004	----	----	----	----	----	----	----	----
Rb^{+1}	.001	.002	.0006	----	----	----	----	----	----	----	----
Cs^{+1}	----	----	----	----	----	----	----	----	----	----	----
Total dissolved solids	>62.2	>55.5	>34.7	187	258	201	232	180	140	115	136

A. Otā River at Tama-mura, Nov. 16, 1949.
B. Chigusa River at Kami-gōri. Nov. 18, 1949.
C. Yodo River at Hira-kata. Nov. 19, 1949.
D. Tenryū River at Nakano-machi. Nov 20, 1949.
E. Ōi River at Nishi-kawa. Nov 20, 1949.
F. Naka River at Mito-shi. Mar. 19, 1950.
G. Kitakami River at Kage-yama. Mar. 18, 1950.
H. Abukuma River at Kamo-ki. Mar. 26, 1950.
I. Kumano River at Shingū. Apr. 9, 1950.
J. Kuzuryū River at Morita. Apr. 12, 1950.
K. Syō River at Ecchū-daimon. Apr. 13, 1950.
L. Jintsū River at Toyama-shi. Apr. 13, 1950.
M. Shinano River at Naga-oka-shi. Apr. 14, 1950.
N. Aka River at Honjo. Apr. 14, 1950.
O. Miyuki-mura, between Ashida and Takaya Rivers.
P. Kanbe-chō, Katayama-buraku.
Q. Miyuki-mura, between the Ashida River and the Fukuyama-Fuchū highway.
R. Miyuki-mura, between the Kamo River and the Fukuyama-Fuchū highway.
S. Takaya River below the junction with the Kamo River, Miyuki-mura.
T. Ashida River at Ubeyama-mura.
U. Ashida River at Ekiya-chō.
V. Ashida River at Fuchū-chō.

TABLE 48.—*Analyses, in parts per million, of water from southeast Asia*

[Analyses A–F are from Kobayashi (1959); analyses G–H are from unpublished data of the Institut Pasteur de Saigon]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	116.9	115.6	100.3	42.4	15.8	82.6	12.2	24.5
SO_4^{-2}	17.1	14.7	12.2	2	.2	3.3	Nil	Nil
Cl^{-1}	6.9	6.2	6.6	61.6	1.1	12.7	Tr.	Tr.
NO_3^{-1}	.02	.04	.04	.10	.02	.08	Tr.	.6
NO_2^{-1}	----	----	----	----	----	----	Nil	Nil
PO_4^{-3}	.01	.00	.00	.00	.00	.01	1.1	1.1
Ca^{+2}	32.1	31.1	26.8	10.9	1.9	19.8	3.6	5
Mg^{+2}	5.9	5.7	4.9	2.3	.7	3.7	.5	.6
Na^{+1}	8.4	7.7	7.5	40	2.4	10.7	.9	4.1
K^{+1}	1.7	1.6	1.4	2.8	1.3	2.5	Nil	Tr.
NH_4^{+1}	.04	.04	.04	.06	.04	.06	Tr.	Tr.
Fe	.00	.00	.00	.11	.02	.04	.3	.3
Al	----	----	----	----	----	----	.8	1.1
SiO_2	14.4	15	13.8	10.8	15.9	16	5.1	6.4
Total dissolved solids	204	198	174	173	39.4	152	24.5	43.7

A. Mae Khong at Chiengsan. Mean of 12 analyses.
B. Mae Khong at Nongkai. Mean of 12 analyses.
C. Mae Khong at Mukdaharn. Mean of 12 analyses.
D. Mun River at Ubolragatani. Mean of 12 analyses.
E. Sai Buri River at Narathiwat. Mean of 12 analyses.
F. Mean of 30 Thailand stations, each analyzed 10–12 times.
G. Lac des Soupirs à Dalat, Vietnam, sample taken in August, during the rainy season.
H. Grand Lac à Dalat, Vietnam, sample taken in August, during the rainy season.

the country. Silica and sodium chloride concentrations in these waters are high. They are, in general, reminiscent of waters in Japan. This is not surprising, as both countries are in the temperate zone, surrounded by the sea, and in areas of crustal instability.

AUSTRALIA

The composition of Australian waters (tables 53, 54, 55, 56, and 57) is extremely varied. In the humid temperate parts of the country, such as Tasmania and the highlands of Victoria, the waters are very dilute, a number of waters containing about 10 ppm of total dissolved solids, excluding silica. The most dilute waters are of the sodium and calcium bicarbonate types. In the less dilute waters the total dissolved material is about 100 ppm and chloride approaches or exceeds bicarbonate in importance.

Most of the available analyses for the surface waters of Australia are from the humid regions of high-population density where surface water is plentiful

TABLE 49.—*Analyses of water from India, Pakistan, and Afghanistan*

[Analyses C–E in milligrams per liter; all other analyses in parts per million]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	292	102	120	80	120	110	230	137
SO_4^{-2}	80. 7	1	18, 600	12, 290	14, 270	17. 3	68. 6	26. 4
Cl^-	563	10. 6	188, 300	191, 500	156, 930	8. 9	43	31. 3
NO_3^{-1}	5. 3	1. 2	----	----	----	----	----	----
Ca^{+2}	37. 7	18. 1	420	580	850	39. 6	46. 6	27
Mg^{+2}	92	7. 7	3, 500	2, 700	5, 980	1. 1	18. 8	13
Na^{+1}	306	11. 6	123, 920	124, 260	96, 400	7. 8	58	26. 9
K^{+1}	----	----	Trace	Trace	Trace	----	----	----
Fe	----	----	<70	Trace	<20	----	----	----
Total dissolved solids	>1380	>152	$>335,000$	$>331,000$	$>275,000$	>185	>465	>262

A. Salt Lake, Calcutta. Analysis from Bose (1940, p. 7).
B. Raw Ganges water, Calcutta, during a time when marine salt was absent. Bose (1940, p. 8).
C. Maimana Lake, Afghanistan. This and the following two analyses are from a certified copy, provided by Afghanistan Geol. Survey report on the Salt Sources of Afghanistan prepared by E. R. Gee of the Geol. Survey of India in 1940.
D. Brine from Namaksar (salt field), Herat, Afghanistan.
E. Brine from natural pools, Tashkurghan, Afghanistan.
F. Chenab at Kanki, Pakistan, Dec. 1959. This and the following 2 analyses are from unpublished data provided by the Geol. Survey of Pakistan.
G. Ravi at Chicha Watni, Pakistan, Mar. 1959.
H. Indus at Mithankof Châchrān, Mar. 1959.

TABLE 50.—*Analyses, in milligrams per liter, of water from Iran and Turkey*

[Data for waters from Iran, analyses A–M are from Löffler (1956); analyses N–O are from unpublished data of the Tehran Water Board. Analysis P is from Tulus (1944, p. 61)]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	98	102	186	156	270	282	282	300
SO_4^{-2}	301	3, 594	1, 895	4, 218	128	145	130	6, 800
Cl^{-1}	3, 895	31, 540	18, 328	36, 950	2, 261	2, 174	2, 101	69, 500
NO_3^{-1}	----	----	----	----	----	----	----	----
NO_2^{-1}	----	----	----	----	----	----	----	----
Br	----	----	----	----	----	----	----	----
Ca^{+2}	61	1, 130	620	1, 274	137	143	147	150
Mg^{+2}	148	1, 290	775	1, 476	114	97	88	3, 710
Na^{+1}	2, 316	18, 370	10, 270	20, 550	1, 220	ca. 1, 200	1, 250	39, 520
K^{+1}	77	370	230	460	38		38	786
Fe	----	----	----	----	----	----	----	----
Mn	----	----	----	----	----	----	----	----
SiO_2	----	----	----	----	----	----	----	----
Density	1. 00451 (17° C)	1. 04098 (17° C)	----	----	1. 0029 (17° C)	1. 0027 (17° C)	1. 0026 (17° C)	----
Total dissolved solids	$>6,900$	$>56,400$	$>32,300$	$>65,100$	$>4,170$	$>4,040$	$>4,040$	$>121,000$

	I	J	K	L	M	N	O	P
HCO_3^{-1}	228	162	420	600	1, 200	162	109	4, 946
SO_4^{-2}	8, 320	136	15, 070	16, 264	306	32	11	2, 368
Cl^{-1}	180, 200	56	180, 500	206, 800	342	12. 5	4. 5	5, 789
NO_3^{-1}	----	----	----	1, 695	----	6	. 04	----
NO_2^{-1}	----	----	----	----	----	. 012	. 003	----
Br	----	----	3, 400	3, 900	----	----	----	----
Ca^{+2}	580	65	609	1, 392	11	56	32	36
Mg^{+2}	4, 383	23	8, 175	8, 834	25	9. 5	2. 5	165
Na^{+1}	109, 400	ca. 46	103, 620	122, 100	730	----	----	7, 707
K^{+1}	951		2, 603	5, 086	29	----	----	435
Fe	----	----	----	----	----	. 0	. 0	----
Mn	----	----	----	----	----	. 0	. 0	----
SiO_2	----	----	----	----	----	16	10	70
Density	1. 1982 (17° C)	1. 0006 (17° C)	1. 20793 (18° C)	1. 211 (15° C)	1. 00138 (18° C)	----	----	1. 0123
Total dissolved solids	$>304,000$	>488	$>314,000$	$>367,000$	$>2,640$	294	169	22, 000

A. Niris Lake at Khan-e-Kat. July 11, 1949.
B. Nargis Lake opposite the mouth of the Gomun. July 23, 1949.
C. Nargis Lake at the mouth of the Gomun. July 23, 1949.
D. Nargis Lake west of the mouth of the Gomun. July 23, 1949
E. Niris inflow at Khan-e-Kat. July 11, 1949.
F. Nargis inflow just above the mouth. July 23, 1949.
G. Spring Lake, Gomun. July 22, 1949.
H. Maharlu Lake at Dubaneh. July 16, 1949.
I. Maharlu Lake at Naharlu. July 15, 1949.
J. Kerman-Kanat north of Kerman. Apr. 20, 1950.
K. Urmia Lake at Bender Danalu. Oct. 10, 1949.
L. Urmia Lake, southwest coast by the salt gardens. Aug. 1949.
M. Kurusch-Göl. Oct. 14, 1949.
N. Karaj River at Tehran, maximum.
O. Karaj River at Tehran, minimum.
P. Lake Van, Turkey.

and dilute enough to be of economic importance. Much of the continent must be characterized by water more or less like that which gradually evaporated from the Lake Eyre basin during 1950 and 1951 (table 57, analyses K–N). The high sodium chloride content of waters of interior Australia has been interpreted to mean that meteoric salt is a very important source of the dissolved material. It could be as easily explained by the precipitation of less soluble salts in closed basins, or, for Lake Eyre, by the solution of sodium chloride that had been precipitated in the drainage basin during the many years when rainfall was insufficient to permit

Table 51.—*Analyses of waters from the Dead Sea system*

[Analyses A, B, G and H in parts per million are from Irwin (1923, p. 430-433). The others in milligrams per liter are from Bentor (1961, p. 241)]

	A	B	C	D	E	F	G	H	I
HCO_3^{-1}	----	----	----	195	237.90	248	Trace	Trace	240
SO_4^{-1}	39	39	34.5	32	174.49	900	500	600	540
Cl^{-1}	230	230	283.0	55	473.50	180,800	166,300	175,000	208,020
Br^{-1}	----	----	2.35	----	4.338	4,100	4,900	7,000	5,920
Ca^{+2}	56	56	49.0	42	80.00	13,000	3,700	17,300	15,800
Mg^{+2}	26	26	----	19	71.42	34,500	41,300	41,400	41,960
Na^{+1}	128	128	131	} 44	{ 253.40	33,500	25,000	14,300	34,940
K^{+1}	----	----	7		{ 14.85	6,300	4,000	4,400	7,560
Rb	----	----	----	----	----	60	----	----	60
SiO_2	17	13	----	----	----	----	Trace	Trace	----
Total dissolved solids	496	492	506.85	387	1,309.898	273,408	246,000	260,000	315,040

A. Waters of Merom.
B. Inlet to Galilee.
C. Lake Tiberias.
D. Yarmuq River near junction with Jordan River.
E. Jordan River at Jericho.
F. Dead Sea (surface water).
G. Dead Sea 5 miles east of Ras Fesch Ka, 120 m depth.
H. Dead Sea 5 miles east of Ras Fesch Ka, 300 m depth.
I. Dead Sea (average).

Table 52.—*Analyses, in parts per million, of some lake waters from New Zealand*

[All analyses are recalculated from Phillips (1925, p. 382). Similar data may be found in Phillips and Grigg (1922)]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	20.9	14.1	15.3	[1] 40.2	61.3	16.6	126.9	[1] 73.4
SO_4^{-2}	10.7	12.8	Nil	10.8	8.7	3.7	77.7	2.1
Cl^{-1}	37.3	28.4	40.8	8.9	8.9	12.4	628.3	10.6
NO_3^{-1}	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Ca^{+2}	2.9	4.3	4.6	8.1	2.6	2.6	22.8	12.2
Mg^{+2}	1.2	2	1.2	3.5	1.7	1.9	8.6	3.3
Na^{+1}	45.9	30.8	40.5	22.1	16.1	18	522.2	20.3
Al_2O_3	2.4	2.4	3.6	1.2	3.6	1.6	4	2
SiO_2	15.6	2.6	20.3	7	6.1	8.8	81.4	22.7
Total dissolved solids	137	97.4	126	102	109	65.6	1,470	147

[1] Includes carbonate.

A. Lake Rotorua.
B. Lake Rotoiti.
C. Lake Rotoma.
D. Lake Okareka.
E. Tikitapu (Blue Lake).
F. Rotokakahi (Green Lake).
G. Lake Rotomahana.
H. Lake Rotoaira.

Table 53.—*Analyses, in parts per million, of water from the Northeastern Highland, Victoria*

[From Anderson (1941, 1945)]

	A	B	C	D	E	F	G
HCO_3^{-1}	7.8	3.6	9.1	4.90	43.6	21.2	4.9
SO_4^{-2}	.2	.4	.6	.29	2.5	1.7	.13
Cl^{-1}	.9	1.2	.8	.93	2.8	2.9	2.53
NO_3^{-1}	2.2	.8	Nil	.44	Nil	Nil	.17
Ca^{+2}	1.4	.7	1.4	.95	4.3	2.2	1.41
Mg^{+2}	.6	.2	.7	.42	4.9	1.5	.57
Na^{+1}	1.5	.9	2	1.05	} 5.2	3.2	.92
K^{+1}	.6	1.1	.6	.77			
Total dissolved solids	>15.2	>8.9	>15.2	>9.8	>63.3	>32.7	>10.7

A. Spring Stream, Mt. Hotham (6,000 ft).
B. Crystal Brook, Buffalo Plateau (4,900 ft).
C. Upper Delatite River, Mt. Butler.
D. Upper Kiewa River, Bogong High Plains.
E. Stream near Bright.
F. Rose River near Dondangadale.
G. Rubicon River near Thornton.

Table 54.—*Analyses, in parts per million, of water from saline streams in western Victoria*

[From Anderson (1941). Analyses F-G represent waters flowing into Lake Corangamite during the first rains after drought]

	A	B	C	D	E	F	G
HCO_3^{-1}	278	429	490	37	31.5	72.2	[1] 160.8
SO_4^{-2}	67	17	134	6	18.8	51.9	208.2
Cl^{-1}	738	497	1,390	386	202.6	590.3	1,872
NO_3^{-1}	.2	Nil	Nil	.1	----	7.5	Nil
Ca^{+2}	54	126	180	22	8.4	32.3	58.2
Mg^{+2}	115	71	116	38	144	73.8	205.8
Na^{+1}	325	213	} 726	{ 167	112.3	251.8	907.2
K^{+1}	18	31		{ 6	3.1	25	49.2
Total dissolved solids	>1,600	>1,400	>3,040	>662	>521	>1,110	>3,460

[1] Includes 19.1 CO_3^{-2}.

A. Little River near Township.
B. Merri River near Warrnambool.
C. McKinnons Creek near Hamilton.
D. Deans Hill Creek near Coleraine.
E. Helena River catchment at Mundaring Reservoir, West Australia. Mean of 6 samples, 1909-15.
F. Woady Yallock River.
G. Gnarkeet Creek.

Table 55.—*Analyses, in parts per million, of water from Tasmania*

[From unpublished analyses provided by the Hydro-Electric Commission, Hobart, Tasmania]

	A	B	C	D	E	F
HCO_3^{-1}	8	7	3.6	8.1	5.4	8.1
SO_4^{-2}	Nil	Nil	Nil	4.7	4.8	5
Cl^{-1}	4.5	4	2.5	5	5.5	7
NO_3^{-1}	Nil	Nil	Nil	Nil	Nil	Nil
Ca^{+2}	3.4	3.2	1.6	3	3.2	5
Mg^{+2}	1.2	1	.5	1.7	1.5	1.7
Na^{+1}	3.8	3.6	2	3	2.7	4.1
K^{+1}	.6	.4	.2			
Fe	.43	.35	.2	.11	.11	.38
Al	----	----	----	.55	.55	.84
Mn	.01	.01	.01	----	----	----
SiO_2	----	----	----	3	3.2	3.8
Total disolved solids	>21.9	>19.6	>10.6	29.2	27	35.9

A. Mean of 2 analyses of Arthur Lakes water by the Government Analyst's Branch, Sept. and Oct. 1956.
B. Palmer River near Great Lake. Analyzed by the Government Analyst's Branch, Sept. 1956.
C. Great Lake, Analyzed by the Government Analyst's Branch, Oct. 1956.
D. Derwent River at Intake.
E. Derwent River near Derwent Bridge.
F. Creek, Sec. 18.
D, E, and F analyzed Nov. 1935 by Avery and Anderson, consulting engineers.

TABLE 56.—*Some analyses, in parts per million, of reservoir waters from South Australia*

[Unpublished analyses by the South Australian Engineering and Water Supply Dept., Adelaide]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	101	108	268	138	234	172	120	208
SO_4^{-2}	24	31	86	36	41	65	20	143
Cl^{-1}	117	194	275	220	75	254	222	1,016
Ca^{+2}	20	24	57	30	41	40	34	59
Mg^{+2}	18	23	41	32	38	30	20	71
Na^{+1}	70	109	179	119	47	158	123	604
K^{+1}								
Fe	.21	.19	.1	.14	.2	.13	.34	.3
SiO_2	12	8	4	11	3	7	7	4
Total dissolved solids	362	497	910	586	479	726	546	2,110

A. Happy Valley Reservoir, River Cenluapaninga.
B. Millbrook Reservoir, River Torrens.
C. Baroota Reservoir.
D. Barossa Reservoir.
E. Beetaloo Reservoir.
F. Bundaleer Reservoir.
G. Hindmarsh Valley Reservoir.
H. Tod River Reservoir.

the tributary rivers to reach the lake basin and fill it with water. The amount of chloride falling on interior Australia in the form of rain is quite adequate to account for most of the chloride carried in the rivers (Anderson, 1945) even without taking into account the amount precipitated during fine weather, but there is no assurance that the atmospheric chloride is of immediate marine origin (Hutton and Leslie, 1958). Interior Australia includes many extensive dry lake beds, the salts of which are the final precipitates of highly evolved waters, and it is possible that most of the meteoric chloride is derived from dust blown off the dry salt deposits. Most Australian workers seem convinced of the marine origin of much of the mineral material in the waters of Australia, apparently because the concentrated waters are similar to sea water in composition. It must be noted, however, that in other parts of the world, such as the U.S.S.R., where the meteoric salts are in terrestrial proportions rather than marine proportions, similar evidence is construed to indicate a terrestrial origin of the dissolved substances in surface waters. Without balance sheets for the net flow of atmospheric mineral material across the coastline, it is not possible to come to firm conclusions from such evidence.

Analysis P (table 57) is of some interest because it comes from a locality in the extreme north of Australia. Less complete analyses from the same area suggest that the sodium chloride is not commonly this high. This is a coastal locality and sea spray is undoubtedly important.

The report of the Government Chemical Laboratories of Western Australia (1949) contains fragmentary analyses for many waters of Australia.

AFRICA

Although the water chemistry of no river in Africa, not even the Nile, is adequately known, there has been a great increase in the amount of information about the chemistry of these waters since the last edition of this book was published, and information is being accumulated actively at the present time.

Some analyses for the Nile system are presented in table 58, and others may be found in Aladjem (1926) and in the earlier editions of this book. It is interesting to note the very low sulfate of the White Nile. Much interest has been aroused by the low sulfate content of the waters of East Africa, and it has been claimed, particularly by Beauchamp (1953), that this ion is scarce enough to limit biological productivity. The analyses gathered together in table 58 suggest that sulfate is actually much more abundant than has been believed and it is unlikely that most aquatic organisms suffer a serious shortage of it in East Africa.

TABLE 57.—*Miscellaneous analyses, in parts per million, of water from Australia*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
HCO_3^{-1}	23	36.8	37	106	13.6	7.9	21.2	18.3	17	42.7	120	------	80	------	56.7	6
SO_4^{-2}	1.3	9.5	8	19	1.6	.9	2.3	14.1	11	6.2	1,190	1,700	2,940	6,480	6.7	12
Cl^{-1}	3.4	23.8	18	71	15	4.8	29.6	96	122	10.2	23,170	43,200	67,960	142,000	73.9	65
NO_3^{-1}	Tr.	Tr.	------	------	.6	.74	.5	.72	Tr.	------	------	------	------	------	------	------
Ca^{+2}	3.9	5.3	7.8	17	2.7	1	4.2	6.9	6	------	------	------	------	------	------	------
Mg^{+2}	2.1	3.9	4.8	12	2.1	1	3.9	12	9	9	400	510	910	1,610	4	1.7
Na^{+1}	2.4	16.1	11.4	52	8.3	3.2	14.5	45.5	67	4.9	150	270	300	820	3.	14.9
K^{+1}	1	3			1.7	1.2	3.1		2	6.9	14,880	27,800	43,780	92,200	62.1	43.3
Fe	------	------	------	.7	------	------	------	------	4	2.3	------	------	10	------	------	------
SiO_2	------	------	------	4	------	------	------	------	6	------	------	------	------	------	------	------
Specific gravity	------	------	------	------	------	------	------	------	------	------	------	1.0497	1.0785	1.1667	------	------
Total dissolved solids	>37.1	>98.4	>87	282	>45.6	>20.7	>79.3	>194	>244	>82.2	<39,900	>73,500	>116,000	>243,000	>206	>143

A. Murray River at Tocumwal. Anderson (1945).
B. Murray River above Mildura. Anderson (1945).
C. Murray River at Merbein, Apr. 1928. Anderson (1945).
D. Murray River at an unspecified place in South Australia. Unpublished analysis by South Australian Engineering and Water Supply Dept.
E. Yarra River at Warrandyte. Mean of 2 analyses. Anderson (1945).
F. O'Shannassy River aqueduct. Anderson (1945).
G. Latrobe River above Rosedale. Anderson (1945).
H. Canning River, Western Australia, Oct. 1923. Anderson (1945).
I. Inlet to Mount Eliza Reservoir near Perth. Mean of 8 analyses. Unpublished data provided by the Government Chemical Laboratories, Perth.
J. Lateral 13, Murrumbidgee Irrigation Area, New South Wales. This is essentially Murrumbidgee River water. Mean of 9 analyses, 1945–46. Cassidy, 1949, p. 2. B<0.1.
K. Center Madigan Gulf, Lake Eyre, Oct. 26, 1950. Analysis by T. W. Dalwood. This and the other Lake Eyre analyses are from Bonython, 1955.
L. Level Post Bay, Lake Eyre, Feb. 11, 1951. Analysis by S. M. Shepard.
M. Level Post Bay, Lake Eyre, May 24, 1951. Analysis by T. R. Frost. Br^{-1} <0.01.
N. December Water Station, Lake Eyre, Dec. 13, 1951. Analysis by S. M. Shepard
O. Burnett River, Cassidy (1944, sample 576).
P. Narau Beak, Cape York Peninsula, Queensland. Mar. 16, 1949. Unpublished analysis by the Irrigation and Water Supply Comm., Brisbane.

TABLE 58.—*Analyses, in parts per million, of water from the Nile system*

[Analyses A–H are for the Albert Nile and its tributaries; analyses I–S for the Victoria Nile and its tributaries; analyses F, G, N–Q are from unpublished data made available by the Geol. Survey of Uganda. Analyses T–V, with some other information, may be found in Lucas (1908), and analysis W is from Azadian (1930, p. 38–39.) All other analyses are from a large body of unpublished information provided (1960) by Simón Visser of Makerere College, Kampala]

	A	B	C	D	E	F	G	H	I	J	K	L
HCO_3^{-1}						[1] 115.3	[2] 617.9					
SO_4^{-2}	12.3	9.1	3.8	16.1	12.1	2.5	24.5	4.90	8.25	1.73	0.266	11.76
Cl^{-1}	3.90	35.7	20	1.49	10.2	10	35	6.10	3.76	.746	.117	7.17
NO_3^{-1}	.93	1.18	1.8	1.55	1.30	.2		.558	.172	.558	.172	1.09
PO_4^{-3}		Tr.	Tr.	.047	.009	Tr.	Tr.					
Ca^{+2}	1	14	3.5	.0	2	22.4	13.3	4		.0	1	1
Mg^{+2}						6	48.8					
Na^{+1}	3.87	63	29.1	4.7	52.9				1.78	.83	5.989	16.9
K^{+1}	7.5	78	43	6	189			7.8	1.23	.130	36	12.6
NH_3^{+1}	.24	.63	.70	.51	.34			.051	.182	.153	.240	.196
B												
Fe		.16	.20	2.03	.75	.6	.5					
Al		.007	.03	.22	.024							
Mn		.20	.18	<.02	.11							
SiO_2						16.5	2.2					
Total dissolved solids	>29.7	>202	>102	>32.7	>269	>174	>742	>23.4	>15.4	>4.15	>43.8	>50.7

	M	N	O	P	Q	R	S	T	U	V	W
HCO_3^{-1}		67.1	61	134	85.8			149.2	108.6	85.8	102
SO_4^{-2}	3.4	4.3	2.9	1.9	16.3	3.85	4.23	.44	7.3	4.7	9
Cl^{-1}	7.2	2.1	4.8	2.1	2.8	1.20	4.29	8	2.8	3.4	11.6
NO_3^{-1}	.4	3.4	.42	.30	.42	.87	.81	.44	.14		.003
PO_4^{-3}										.70	
Ca^{+2}	2	9.8	3	5.2	14.2	2	4	17.4	23.8	15.8	25.1
Mg^{+2}		2.8	6.8	15.4	3.8			5.2	6	8.8	7
Na^{+1}	7.8	4.1	4.1	10.8	10.8	6.9		30.7	7.1	15.6	
K^{+1}	4.5	1.6	1.6	2.3	2	7.2	6	11.8	1.7	3.9	
NH_3^{+1}	.119					.41	.068				
B		Nil	.005	.005	.386						
Fe										2.2	
Al											
Mn											
SiO_2								25.6	26.7	20.1	14.1
Total dissolved solids	>25.4	>95.2	>84.6	>172	>137	>22.4	>19.4	249	184	161	>169

[1] Includes 9 ppm carbonate.
[2] Includes 59.8 ppm carbonate.

A. Katonga River near Masaka, Uganda.
B. Outlet of Lake Bunyonyi, Uganda.
C. North part of Ruhuma Swamp near Munja Island, Uganda.
D. Mulindi River at outlet of Muchoya Swamp, Uganda.
E. Kaku River near Uganda-Congo border.
F. Lake George, Uganda.
G. Lake Edward, Uganda.
H. Albert Nile in Murchison Park, Uganda.
I. Outflow of Lake Nabugabo, Uganda.
J. Stream near Lake Nabugabo, Uganda.
K. Kafu River near Masindi, Uganda.
L. Lake Ikimbo, Uganda.
M. Lake Victoria at Gaba.
N. Muyembe River, Uganda.
O. Sipi River, Uganda.
P. Siroko River, Uganda.
Q. Greek River, Uganda.
R. Lake Kyoga, Uganda.
S. Victoria Nile at Paraa Lodge, Uganda.
T. White Nile near Khartoum, mean of three analyses.
U. Blue Nile, mean of three analyses.
V. The Nile, about 3 hr journey below Cairo.
W. The Nile at Giza, mean of monthly analyses, 1924–26.

TABLE 59.—*Analyses, in milligrams per liter, of water from East African lakes*

[All analyses except D are from Beadle (1932, p. 207). Except for the silicate and phosphate, all the analyses were carried out by the Government Chemist, London. Analysis D is from Beauchamp (1954, p. 27)]

	A	B	C	D	E	F	G	H
HCO_3^{-1} [1]	180	336	1,304	------	3,400	35,300	12,300	243
SO_4^{-2}	17	40	56	57.6	46	204	253	4
Cl^{-1}	10	36	429	320	1,300	3,450	1,375	11
NO_3^{-1}	Nil	Trace	Trace	------	------	------	Trace	------
PO_4^{-3}	.4	.96	1.23	.5	.27	1.29	------	------
Ca^{+2}	16	22	5	57	13	26	10	16
Mg^{+2}	7	2	4	------	36	Trace	Nil	7
Li^{+1}	0	0	0	------	0	0	0	------
Na^{+1}	41	126	770	------	2,114	14,360	5,550	22
K^{+1}	19	15	23	------	118	304	256	11
Fe Al	6	36	3	------ ------	Trace	Trace	6	------
SiO_2	20	15.8	4.2	24	------	------	------	------
Specific gravity	1.00024	1.00044	1.00190	------	1.00530	1.03910	1.01383	------
Total dissolved solids	316	630	2,600	------	>7,030	>53,600	>19,800	>314

[1] Includes carbonate.

A. Lake Naivasha.
B. Lake Baringo.
C. Lake Rudolf.
D. Lake Rudolf, Jan. 17, 1953.
E. Crater Lake A.
F. Lake Hannington.
G. Lake Nakuru.
H. Shire River (outlet of Lake Nyasa) at Nchalo, Nyasaland, Nov. 1953.

The swamps of East Africa are very effective in removing dissolved material from the waters flowing through them. Compare, for example, analyses B and C of table 58. Simón Visser (oral communication, 1960) concludes, from the amount of pH change, that part of the removal is by ion exchange and part by adsorption.

The potassium content of some Uganda waters seems very high. The analyst was aware of this anomaly and checked his method carefully for errors. If further work substantiates this high potassium content, it will pose an interesting geochemical problem, particularly as even Kampala rainwater (Simón Visser, oral communication, 1960) contains as much potassium (1.7 ppm) as sodium.

Parts of Africa have a heavy rainfall on old weathered rock surfaces with extensive swamps to purify the rainwater after it falls. The result can be a very dilute water indeed. Some of the Rhodesian lakes in table 60 have less ionic material than silica, while the stream near Nabugabo (table 58, analysis J) must be almost the most dilute surface water in the world. Its conductivity is only 7.5 micromhos—one-quarter that of Kampala rain.

A few analyses for waters of Somalia are presented in table 61. Most of these analyses are for samples that were collected in the rainy season. In the dry season, as the January sample from the Uebi Scebeli shows, the streams of Somalia are much more concentrated. The seasonal variations in dissolved solids, however, are not as great in the Guiba as they are in the Uebi Scebeli. Notice that sulfate is rather high in these streams, especially in the dry season.

The streams of Mozambique exhibit a similar variation in content and composition of dissolved materials, as table 62 shows.

TABLE 60.—*Analyses, in parts per million, of water from Northern Rhodesia and adjacent Tanganyika*

[Analyses are by the Government Chemist, London, and may be found in Ricardo (1938, p. 75)]

	A	B	C	D
HCO_3	425	Nil	3.4	7.6
SO_4^{-2}	2.9	2.3	1.2	.7
Cl^{-1}	25.8	.8	.7	1.4
NO_2^{-1}	<.003	<.006	<.3	<.003
NO_3^{-1}	<.3	1.1	<.003	<.03
PO_4^{-3}	.3	<.05	<.05	<.05
Ca^{+2}	12.2	1.1	.4	.6
Mg^{+2}	4.6	.1	.3	.3
Li^{+1}	Nil	Nil	Nil	Nil
Na^{+1}	149.4	5.1	1.7	3
K^{+1}	19.4	2.2	.7	2.4
Fe	.8	.1	.1	.1
Al	1.5	.1	.2	.1
SiO_2	76.7	16.9	2.9	13.3
Total dissolved solids	719	29.9	11.6	29.5

A. Lake Rukwa, Tanganyika, South Basin.
B. Lake Bangweulu, Northern Rhodesia, open water.
C. Shiwa Ngandu, Northern Rhodesia.
D. Lake Chila, Abercorn, Northern Rhodesia.

TABLE 61.—*Analyses, in parts per million, of water from Somalia*

[Data are from unpublished analyses by George R. Wilson of the Amministrazione Fiduciaria Italiana della Somalia]

	A	B	C	D	E	F	G
HCO_3^{-1}	180	181	176	158	110	81	117
SO_4^{-2}	64	72	84	72	720	80	76
Cl^{-1}	18	26	18	24	140	20	80
Ca^{+2}	62	62	62	61	315	61	62
Mg^{+2}	13	14	12	12	45	13	9
Na^{+1} K^{+1}	15	22	25	17	31	21	44
Total dissolved solids	>352	>377	>377	>344	>1,360	>276	>388

A. Uebi Scebeli at Belet Uen, Sept. 26, 1957.
B. Uebi Scebeli at Bulo Burti, Sept. 26, 1957.
C. Uebi Scebeli at Mahaddei, Sept. 27, 1957.
D. Uebi Scebeli at Agfoi, Sept. 28, 1957.
E. Uebi Scebeli at Agfoi, Jan. 9, 1958.
F. Uebi Scebeli at Genale, Sept. 28, 1957.
G. Guiba near Ionte, Jan. 16, 1958.

The dissolved mineral content of the streams of the humid parts of west Africa is much lower than those of Mozambique, as may be seen from most of the analyses of tables 63, 64, 65, 66, 67, 68, and 69. The head-

Table 62.—*Analyses, in parts per million, of water from Mozambique*

[All analyses are from unpublished data of the Repartição Técnica de Indústria e Geologica of the Provincía de Moçambique]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	246.6	520.2	79.2	144	44.4	7.4	12	1.2
SO_4^{-2}	24.5	322.1	Tr.	5.2	3.8	82.7	10.8	39.7
Cl^{-1}	182.1	84.5	5.9	14.2	53.3	111.6	44	143.4
Ca^{+2}	49.2	124.6	14.6	19.3	1.6	4.3	1.3	5.4
Mg^{+2}	23.8	45.6	4	12.3	3.4	16.4	2.1	4.4
Na^{+1}	119.3	175.8	4.8	20.6	45.1	74.6	34.6	96.6
K^{+1}		5.9		4.6	Tr.			
Fe_2O_3	6	.1	2.7	Tr.	Tr.	3.2	.3	6.8
Al_2O_3	------	4.3		------	------			
SiO_2	51.2	39.8	26.4	16	24.8	31.8	18.7	40.4
Total dissolved solids	703	1,320	138	236	176	332	124	338

A. Rio Inbarombe (Abst. água Maxixe).
B. Rio Mutomodi (Antônio Enes).
C. Rio Messinge (Vila Cabral).
D. Rio Limpopo (Pafúri).
E. Rio Ratani (Nacala).
F. Lagoa Galumuê.
G. Lagoa Nbajosse.
H. Lagoa Legume (Vinanculos).

waters of some of the large west African rivers, such as the Congo, lie in rather dry regions and so there are a few analyses, such as those for lakes Kivu and Tanganyika, with a rather high total dissolved salt content. Rivers such as the Senegal and Konkouré are more representative of the humid tropics. Unfortunately it has not been possible to find analyses of the downstream parts of either the Niger or the Congo, so it is not possible to characterize these streams directly. Between Niamey, for which there is a reasonably complete analysis, and Lokoja above the confluence of the Benué, for which there are a few scraps of data, the bicarbonate, sulfate, and chloride content all decrease, but the silica content rises. The Benué is probably a dilute water. It seems likely, therefore, that the Niger at its mouth is a water high in silicate with somewhat more than 50 ppm of total dissolved solids.

A selection of data for Ghana is given in tables 66, 67, and 68. The high dissolved-solids content of Lake Bosumtwi is noteworthy.

Table 63.—*Analyses, in parts per million, of water from Angola*

These analyses are from the unpublished records of the Repartição Central dos Serviços de Geologia e Minas of the Provincía de Angola. The agreement of anion and cation equivalent sums suggests that the sodium figures have been obtained by calculation]

	A	B	C	D	E
HCO_3^{-1}	30.5	24.4	49	152	54
SO_4^{-2}	Tr.	------	10	24	12.5
Cl^{-1}	7.1	3.5	14	20	16
NO_3^{-1}	.0	------	------	0	0
Ca^{+2}	1.7	2.8	6	26	24.3
Mg^{+2}	2.1	1.2	6	13	12.9
Na^{+1}	10.3	4.6	18	28	4.3
Fe	------	------	.06	------	[1] 3.9
SiO_2	------	------	------	19	21.7
Total dissolved solids	>51.7	>36.5	>103	282	150

[1] Recalculated from $Fe_2O_3 + Al_2O_3$ on the assumption that only Fe_2O_3 was present.

A. Rio Cunene at Colhida, Apr. 14, 1956.
B. Rio Membia, near Macedo de Cavaleiros.
C. Rio Caua at Quissama.
D. Rio Bengo at frente do motor no. 1.
E. Rio Bengo near Boa Vista.

Table 64.—*Analyses, in parts per million, of water from the Congo River basin*

	A	B	C	D	E	F	G	H	I	J
HCO_3^{-1}	1,108.4	97.7	627.6	92.8	169.2	381.8	415.2	12.2	61	18.3
SO_4^{-2}	32.4	15.4	17.8	2.1	5.8	4.3	4	28.8	9.6	19.2
Cl^{-1}	42.4	0	23.8	15.5	8	28.3	28	5.3	0	0
NO_3^{-1}	Trace	0	1.3	1.8	1.3	<.3	1.8	3.1	0	0
NO_2^{-1}	------	0	.003	.003	.003	<.003	.006	0	.02	.02
PO_4^{-3}	------	------	.1	<.05	.05	.1	.6	------	------	------
Ca^{+2}	8.1	0	8.4	12.9	29.6	11.9	15.2	4	18	6
Mg^{+2}	122	3.9	67	9.1	15.7	41.6	43.7	0	1.2	0
Li^{+1}	------	------	.4	<.1	.4	.4	.8	------	------	------
Na^{+1}	202.8	36.8	94.8	16.4	13.2	59.9	64.2	16	0	8.3
K^{+1}	30.7	------	63	2.4	1.7	33.1	33.5	------	------	------
Fe	Trace	0	.1	<.1	<.1	.1	<.1	.3	2.7	1.1
Al	------	------	.4	.3	.2	.2	.3	------	------	------
SiO_2	5	15	9.8	22.4	28.3	6.6	13.5	15	8.1	3
Specific gravity	------	------	1.00071	1.00015	1.00023	1.00044	1.00049	------	------	------
Total dissolved solids	1,550	169	915	176	274	569	621	84.7	101	55.9

A. Lake Kivu. Hundeshagen (1909, p. 203).
B. Murundu River, at Bukavu. Analysis from Clerfayt (1955, p. 189).
C. Ruzizi River, inflow to Lake Tanganyika. Analysis by the Government chemist, London. Quoted by Beauchamp (1939, p. 343).
D. Malagarasi, inflow to Lake Tanganyika. Analysis by the Government chemist, London. Quoted by Beauchamp (1939, p. 343).
E. Luichi, inflow to Lake Tanganyika. Analysis by the Government chemist, London. Quoted by Beauchamp (1939, p. 343).
F. Lake Tanganyika surface water. Analysis by the Government chemist, London, 1937. Quoted by Beauchamp (1939, p. 318).
G. Lake Tanganyika water from 700 m depth. Analysis by the Government chemist, London. Quoted by Beauchamp (1939, p. 343).
H. Basankusu (Ruki River). Nov. 1952. Clerfayt (1956, p. 29).
I. Zongo (Inkiai). June 1951. Clerfayt (1956, p. 29).
J. Zongo (Sele-Wungo). June 1951. Clerfayt (1956, p. 29)

TABLE 65.—*Analyses, in parts per million, of water from Nigeria*

[Analysis B is from the unpublished records of the Chemistry Div. Ministry Health, Kaduna, Nigeria. All others are from the unpublished records of the Federal Depart. Chemistry, Lagos, Nigeria]

	A	B	C	D	E	F
HCO_3^{-1}	11	23	4.5	27	30	21
SO_4^{-2}	Tr.	Nil	Nil	Nil	Tr.	Nil
F^{-1}	.2	.50	Nil	.4	---	Nil
Cl^{-1}	9	2	3.5	8	3	1
NO_3^{-1}	<.5	<.025	Nil	<.5	<.5	Nil
Fe	.08	3.6	.1	.80	1.72	2.20
Cu	---	---	.2	---	---	---
Zn	---	---	.2	---	---	---
SiO_2	20	20	11	56	15	13
Total dissolved solids	40.8	49.1	19.5	92.7	50.2	37.2

A. Niger River at Lokoja, Kabba Province, June 23, 1957.
B. Niger River at an unspecified place, Mar. 1958.
C. Orogodo River at Agbor, Benin Province, May 19, 1951.
D. Ogun River at Iju, Colony Province, June 13, 1957.
E. Ogun River at Iju, Colony Province, July 13, 1956.
F. Ogun River at Iseyin-Oyo Rd., Oyo Province, Aug. 11, 1954.

Although there are a large number of analyses in the unpublished reports of the Ministrè de l'Algerie, the analyses unfortunately do not show the potassium and silica content. A small number are presented in table 70. Some older analyses for rivers of Algeria are given in previous editions of this book. None of these waters is extremely concentrated, because the analysts have been concerned more with drinking water supplies than with the true nature of the waters of Algeria, at least some of which must be as concentrated as any in the world. The well-watered coastal strip is probably adequately represented by the analyses in table 70.

TABLE 66.—*Analyses, in parts per million, of water from Colony, Ghana*

[All analyses from Dunn (1947). For most analyses collection dates are not given]

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
HCO_3^{-1}	39.6	37.2	92.4	78.6	27	21.6	21.6	60	38	43	37.6	52.8	138	156	67.2	126	42
SO_4^{-2}	3.2	2.3	4.3	.5	.2	.4	4.9	4.7	2.8	6.3	3.2	88.6	151.5	2	27.3	15.8	.5
F^{-1}	---	---	---	---	---	---	---	---	.3	---	---	---	---	---	---	---	.2
Cl^{-1}	6	6.6	8.5	9.1	8.4	5.5	7.8	12.6	19	25	5.7	107.5	87.5	22.6	29	37	1.2
NO_4^{-1}	1	.8	.5	.2	.2	.7	.4	2.4	.5	---	1.1	.0	1.1	.7	2.1	.7	.3
Ca^{+2}	5.4	5.9	13.1	13	4.3	5	4.1	9	5.2	8.8	5.9	20.5	49.4	19.5	6.8	21.9	4.5
Mg^{+2}	2.5	.6	1.7	.8	Tr.	1.2	.9	5.8	1.8	3.5	Tr.	3.2	3.1	3.3	3.2	13.1	2.8
Na^{+1}	7.7	11.7	25	19.9	11.1	4.1	10.7	14.9	18.5	21.1	13.2	102.8	120.6	48.3	44.7	30.5	6.7
K^{+1}																	
Fe_2O_3	2.8	9.2	1.2	2	1.6	5.4	1.6	1.2	1.9	3.3	6.2	1.5	.5	1	1	4	1.2
Al_2O_3																	
Mn	---	---	---	---	---	.2	---	---	.3	---	---	---	---	---	---	---	---
SiO_2	19.8	41.6	54.8	38	21.6	10.4	15.8	22	20.2	11.1	23.6	40	66	34.5	45	35.5	65.2
Total dissolved solids	88	116	202	162	74.4	54.5	67.8	133	109	122	96.5	417	618	288	226	285	125

A. River Ofin below junction of Ajimasu and Subin streams.
B. River Ofin at Dunkwa, above junction with River Jimi.
C. Frimpoma stream, Dunkwa.
D. Otin stream, Dunkwa.
E. Enikawkaw stream, Dunkwa.
F. Unnamed stream at Tarkwa.
G. Suhien stream, Koforidua.
H. Okumesu stream, Koforidua, Jan. 1933.
I. Reservoir at Brimsu. Mean of 3 analyses during the months of March and May.
J. Reservoir at Inchaban. Mean of 2 analyses during the months of April and June.
K. River Prah, Bepose bridge. October.
L. Tetteh Pool, Asikaisu, near Kibi.
M. River Adeiso, Adeiso, near Kibi.
N. Zongo Pool, Adeiso, near Kibi.
O. Small stream, Kissiedoo, near Kibi.
P. River Densu at Nsawam. Mean of 2 analyses.
Q. River Volta about 1.5 miles north of Kpong. Apr. 1946.

TABLE 67.—*Analyses, in parts per million, of water from Ashanti, Ghana*

	A	B	C	D	E	F	G	H
HCO_3^{-1}	49.2	57	24	10.8	24	29.4	34.8	[1] 454
SO_4^{-2}	2.1	.5	.7	1	3.3	2.3	3.2	6
F^{-1}	.4	---	---	---	---	---	---	---
Cl^{-1}	6.4	11	7.2	4	4.8	5.6	7	103
NO_3^{-1}	.4	.4	.9	11.9	.6	1	.7	---
Ca^{+2}	7.1	10.8	4.5	4.9	6	4.7	3	12
Mg^{+2}	2.6	2.4	.3	1.2	2	1.1	1.1	28
Na^{+1}	13	12.3	8.8	5.3	11.8	11.4	12.6	204
K^{+1}								36
Fe_2O_3	3.2	6.8	6	1.2	3.6	1.6	1.8	8
Al_2O_3								
SiO_2	27	31.6	40.8	9.6	16.6	33	26.8	16
Total dissolved solids	111	133	93.2	49.9	72.7	90.1	91	867

[1] Includes 117 ppm CO_3^{-2}.

A. Owabi stream, Kumasi. Mean of 8 analyses of samples taken above and below the dam during the months of Feburary, March, June, August, and October.
B. River Aboabo, just south of Kumasi.
C. Stream flowing into Aboabo, close to railway.
D. Stream near Mampong, Ashanti. Mean of 2 analyses.
E. River Adra near Kumasi.
F. River Adega near Kumasi.
G. River Ankonia near Kumasi.
H. Lake Bosumtwi near Isasi. Mean of 2 analyses by W. H. Bennett from depths of 3 and 4 ft below surface.

TABLE 68.—*Analyses, in parts per million, of water from Northern Territories, Ghana*

	A	B	C
HCO_3^{-1}	33	52.6	42.4
SO_4^{-2}	.8	.5	.1
F^{-1}	---	.0	---
Cl^{-1}	.2	3.6	3.8
NO_3^{-1}	.3	.4	---
Ca^{+2}	3.5	8.9	5.4
Mg^{+2}	1.9	3.4	3.4
Na^{+1}	4.2	7	4.6
K^{+1}			
Fe_2O_3	2	.9	.4
Al_2O_3			
Mn	---	Tr.	---
SiO_2	14.4	10.4	6
Total dissolved solids	60.3	87.7	66.1

A. River Naboggo, Pong Tamale. Mean of 2 analyses, October and December.
B. Tamale Reservoir. Mean of 5 analyses, months of Feburary, March, May, November, and December.
C. Small stream, Tamale. Feb. 1933.

TABLE 69.—*Analyses, in parts per million, of water from French West Africa*

[These data are from unpublished work carried out by the Service Géologique of French West Africa]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	30	42	32	26	24.4	24	38	60
SO_4^{-2}	11	15.5	6.3	7	11.9	27	11	5
Cl^{-1}	3	25	4.3	2.5	5.1	7	18	10
NO_3^{-1}	0	0	0	0	0	------	------	0
PO_4^{-3}	------	<1	------	------	------	------	------	------
Ca^{+2}	10	11.5	5.5	6.5	5.4	6	6.5	6.5
Mg^{+2}	1	5	2.4	1	1.1	1	2	2.8
Na^{+1}	2.5	16	4.8	2	11.1	18	20	11
K^{+1}	2.4	1.1	1.6	1				
Fe	------	------	------	------	------	------	------	Tr.
Al	3.5	------	------	1	1.4	[1] 1.5	[1] 2	Tr.
SiO_2	------	------	------	------	------	------	------	3
Total dissolved solids	>63.4	>116	>56.9	>47	>60.4	>84.5	>97.5	98.3

[1] Includes iron, both determined as oxides, so this converted figure may be slightly too low.

A. Senegal River at Kayes. Aug. 26, 1955.
B. Sangalcam River near Dakar. Mar. 15, 1956.
C. Marigot Lué River at Beyla. Mean of 2 analyses, Feb. 27, 28, 1957.
D. Konkouré River at Sonapiti. Apr. 20, 1957.
E. Konkouré River at Kabea. Mean of 7 analyses, Jan. and Apr. 1954.
F. Oua-Oua River at Kindia. Dec. 2, 1954.
G. Niger River at Kourassa. Dec. 10, 1954.
H. Niger River at Niamey. Mean of 3 analyses, Mar. 5, 1951 and Mar. 5, 1953

TABLE 70.—*Analyses, in milligrams per liter, of water from Algeria*

[All analyses are from unpublished reports made available by the Service des Études Scientifiques of the Ministère de l'Algerie]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	291	184	309	173	165	184	297	201
SO_4^{-2}	125	61	229	93	115	273	135	465
Cl^{-1}	161	28	384	56	73	331	72	392
NO_3^{-1} [1]	34	------	30	------	2	29	------	35
Ca^{+2}	122	52	108	56	72	126	87	151
Mg^{+2}	44	16	112	14	17	31	29	66
Na^{+1}	51	21	241	57	55	216	68	270
Total dissolved solids	>828	>362	>1,410	>449	>499	>1,190	>688	>1,580

[1] Nitrate figures represent means of a smaller number of analyses than the major ions.

A. Oued Mekerra at Chanzy, mean of 40 analyses, 1950–54.
B. Oued Sebaou at Pont de Bougie, mean of 150 analyses, 1949–53.
C. Oued el Hammam at Trois Rivieres, mean oi 20 analyses, 1953.
D. Oued Bou Namoussa at La Cheffia, mean of 20 analyses, 1946–52.
E. Oued Kebir de l'Est at Yusuf, mean of 20 analyses, 1951–53.
F. Oued Cheri at Medjez-Amar, mean of 22 analyses, 1951–53.
G. Oued Mazafran at Pont du Fer à Cheval, mean of 30 analyses, 1950.
H. Oued Chelif at Charron, mean of 21 analyses, 1953.

Some additional information about the composition of the waters of Africa may be found in the partial analyses of Harrison and Elsworth (1958), Hutchinson, Pickford, and Schuurman (1932), Macfadyen (1952), and Baker (1958).

SOUTH AMERICA

The waters of South America are very inadequately known, although they have been investigated sporadically for almost a century. For many of the rivers, particularly the southern ones, there are no better data available than the ones which were presented in the last edition of this book. For the northern rivers there exists a large amount of new data—(see for example, Bonazzi (1950) and Bond (1935))—but most of the published analyses are incomplete.

Some analyses for the water of Venezuela are presented in table 71. The Lago de Maracaibo shows the influence of sea salt. The Orinoco is a typical river of the humid tropics, except for being a little high in sodium and a little low in silica. As was the case with Bosumtwi in Ghana, the lakes are considerably more concentrated than the rivers.

Considerable progress is being made with the study of the waters of Peru. The object of these studies seems to be practical rather than geochemical, and, unfortunately for present purposes, most of the attention is being given to ground-water supplies, but the analyses of these are remarkably detailed, and a few surface waters also have been analyzed completely. Three of these are presented in table 72 along with some miscellaneous analyses recalculated from the previous edition of this book. The analysis of the Laguna Encantada suggests marine contamination. Lagoa Escondida, though concentrated, is far from the sea and its high sodium and chloride content is probably due to evaporation with precipitation of less soluble

TABLE 71.—*Analyses, in parts per million, of water from Venezuela*

[All data from unpublished analyses of the Direción de Geologia of the Ministerio de Minas e Hidrocarburos of Venezuela]

	A	B	C	D	E	F	G	H	I	J	K	L
HCO_3^{-1}	84	113	22	413	437	130	134	65	108	38	60	125
SO_4^{-2}	147	154	8.8	340	356	10	40	6	18	14	20	38
F^{-1}	.25	.10	.10	2	2	.25	.10	.15	.25	.10	.10	.05
Cl^{-1}	1,140	520	1	42	48	6	5	2	2	24	1	27
NO_3^{-1}	.00	.15	.40	.05	Tr.	.25	.30	.15	1	1.50	.67	.35
NO_2^{-1}	.002	.002	.000	.000	.00	.033	.010	.011	.003	.090	.060	.003
Ca^{+2}	38	46	3.2	24	20	25	51	16	31	18	19	40
Mg^{+2}	92	38	.5	65	81	11	7.2	4.6	8	5	5	11
Na^{+}	614	330	8.7	200	193	9.2	1.9	2.1	1	7.4	2	17
Fe, soluble	.25	Tr.	.25	Tr.	.00	.10	.15	.15	.05	.30	.15	.25
Fe, total	.40	.40	.5	.05	.00	18	14	2.20	4	12	4	2
Mn, soluble	.00	.00	.00	.00	.00	.00	.00	.00	Tr.	Tr.	.00	.05
Mn, total	.00	.00	.00	.00	.00	.30	.15	.00	Tr.	.40	Tr.	.10
SiO_2	50	28	8	14	54	24	12	12	20	21	24	11
Total dissolved solids	2,170	1,230	53.5	1,100	1,190	234	266	110	193	142	136	272

A. Lago de Maracaibo, Feb. 14, 1952.
B. Lago de Maracaibo, Sept. 2, 1952.
C. Rio Orinoco at Puerto Ayacuho, Apr. 11, 1953.
D. Lago at Valencia, 200 m from the coast, Apr. 14, 1956.
E. Laguna de Valencia, north of Isla de Candamo, Sept. 13, 1950.
F. Rio Ouarico, Sept. 21, 1954.
G. Rio Cojedes, near the new Rio Cojedes bridge, Nov. 18, 1953.
H. Rio Portuguesa, Nov. 20, 1953.
I. Motatan Rio, Dec. 22, 1949.
J. Escalante Rio, Nov. 17, 1952.
K. Chama Rio, Nov. 27, 1952.
L. Rio Yaracuy, Dec. 21, 1956.

TABLE 72.—*Miscellaneous analyses, in parts per million, of South American waters*

[Analyses A–C are from unpublished records of the Ministerio de Fomento y Obras Publicas of Peru. This Ministry has accumulated many partial analyses of lake and river waters and many complete analyses of spring and well waters in addition to the few presented here]

	A	B	C	D	E	F	G	H
HCO_3^{-1}	206	199	228	2,004	35	9.4	18.7	17.7
SO_4^{-2}	435	152	5.4	46	10.8	1.7	.8	.5
Cl^{-1}	1,888	28	.000	1,242	5	1	7.5	2.7
Br^{-1}		------	------	Nil	------	------	------	------
I^{-1}	17.8	------	------	Nil	------	------	------	------
NO_3^{-1}	.000	11.7	5.23	.002	.39	.33	.71	.12
NO_2^{-1}	Trace	.000	.056	Nil	------	------	------	------
PO_4^{-3}	.000	.000	.000	Nil	------	------	------	------
Ca^{+2}	526	104	67	14	8	1.2	.28	2.1
Mg^{+2}	90	9.6	6.6	6	3.1	.9	1.9	1
Li^{+1}	7.6	------	.0	Nil	------	------	------	------
Na^{+1}	694	25.2	1.7	1,660	2.1	2.1	8	3.5
K^{+1}	23	5.8	1	[1] 193	.06	.16	1.2	1.1
NH_4^{+1}	.000	.000	Trace	15.6	------	------	------	------
HBO_2	Trace	.000	.000	------	------	------	------	------
Fe	1.46	.46	.05	10	5	1.5	1.6	2.5
Al	4.7	1.56	.02	1.5	------	------	------	------
Pb	Trace	------	------	------	------	------	------	------
Mn	Trace	.0	.0	Nil	------	------	------	------
SiO_2	7.8	18.7	13.9	160	33.9	15.8	40.8	16.8
Total dissolved solids	3,900	556	329	5,350	103	34.1	81.5	48

[1] By calculation.

A. Laguna Encantada, Peru, Jan. 11, 1957, analysis by R. Zapata Valle and E. Camet.
B. Agua de Vitarte, Peru, Oct. 26, 1956, analysis by E. Arciniega and E. Camett. (May be ground water.)
C. Agua de Puquio, Peru, June 10, 1952, analysis by E. Camet and E. Arciniega. (May be ground water.)
D. Lagoa Escondida, Estado de Mato Grosso, Brazil. Campos Paiva (1944, p. 47–48).
E. Barima River above Eclipse Falls, British Guiana. Clarke (1924b, after Harrison and Reid, 1913).
F. Essequibo River above Wataputa Falls, British Guiana, Clarke (1924b, after Harrison and Reid, 1913).
G. Demerara River above Malalli Falls, British Guiana, Clarke (1924b, after Harrison and Reid, 1913).
H. Courantyne River, British Guiana, Clarke (1924b, after Harrison and Reid, 1913).

ions. The rivers of British Guiana are rather dilute and remarkably high in silica.

In addition to the analyses cited here there are more of the same kind in Kyle (1897), and numerous analyses lacking most or all of the major cations in Sioli (1950, 1951, 1953, 1955), Catalano (1927), Manoff (1939), and Freise (1937). Derkosch and Löffler (1961) present data for 9 cations and semiquantitative information about trace elements in 25 Andean lakes.

The best analyses for the Amazon system are recalculated from the previous edition of this book and presented in table 73. There are many recent analyses of water from Amazonia, particularly in a number of papers by Sioli (1950, 1951, 1953, 1955) but they lack most or all of the major cations. It is remarkable that the few scraps of data presented in table 73 should have stood virtually alone for so long, not only as the best information about the Amazon, but also as the best for any large humid tropical river. They have, perforce, figured largely in all global computations of hydrogeochemistry, and they should be replaced by a more nearly comprehensive series of data.

No new data are available for the southern part of South America nor is any work in progress. Pastore and Huidoboro (1952) is said to contain partial analyses of 37 waters of Argentina, but it has not been available for consultation and may deal with wells and springs. A selection of the old data is presented in table 74. The generally high silica content of these waters is their outstanding characteristic.

TABLE 73.—*Analyses, in parts per million, of water from the Amazon River and its tributaries*

[Analyses A–D are from Clarke (1924b)]

	A	B	C	D
HCO_3^{-1}	17.9	41	22.5	24.1
SO_4^{-2}	.8	4.3	2.8	4.8
Cl^{-1}	2.6	2.3	2.2	3.1
Ca^{+2}	5.4	12.5	6.4	7.1
Mg^{+2}	.5	1.5	1.4	1.8
Na^{+1}	1.6	1.1	.7	.9
K^{+1}	1.8	1.4	1.4	1.9
Fe	[1] 1.9	[1] 3	[1] 2.2	[1] 2.8
SiO_2	10.6	11.1	9.1	9.5
Total dissolved solids	43.1	78.2	48.7	56

[1] Computed from $Al_2O_3 + Fe_2O_3$ on the basis that Fe_2O_3 alone was present.

A. The Amazon at Obidos. Mean of 2 analyses by F. Katzer, 1903.
B. The Amazon between the Narrows and Santarem. Analysis by P. F. Frankland.
C. The Tapajos. Analysis by F. Katzer, 1903.
D. The Xingu. Analysis by F. Katzer, 1903.

TABLE 74.—*Analyses, in parts per million, of water from rivers in the southern part of South America*

[Analyses recalculated from Clarke (1924b)]

	A	B	C	D	E	F	G
HCO_3^{-2}	32	35	19.4	126	241	99	58.8
SO_4^{-2}	7	10	1.6	9.2	337	16.8	18.9
Cl^{-1}	11.5	15.9	.2	10.3	261	3.5	5.8
NO_3^{-1}	------	------	2.2	------	------	------	------
Ca^{+2}	5.6	7.3	3.9	26.4	137	24.9	13.7
Mg^{+2}	3	2.8	1.1	5.2	34.8	6.6	2.6
Na^{+1}	15.8	15	1.5	14.5	196	2.3	7.5
K^{+1}	2.8	4.1	1.2	7.5	53.5	7.3	10.6
Fe	2.8	2.2	------	8.2	------	.79	1.52
Al	3	1.6	------	.88	------	------	.26
SiO_2	19.4	20.3	18.5	13.7	74.1	14.7	12.8
Total dissolved solids.	103	114	49.6	222	1,330	176	133

A. Rio La Plata 5 miles above Buenos Aires. Analysis by J. J. Kyle, 1878.
B. The Parana 5 miles above its entry into La Plata. Analysis by J. J. Kyle, 1878.
C. The Uruguay midstream opposite Salto. Analysis by J. J. Kyle, 1878.
D. Rio Primero, Argentina.
E. Rio Saladillo, Argentina. Analysis by A. Doering, 1883.
F. Rio de Arias, Salto, Argentina. Analysis by M. Siewert, 1883.
G. Rio de los Reyes, Jujuy, Argentina. Analysis by M. Siewert, 1883.

GLOBAL COMPUTATIONS

With the data for the composition of some of the major rivers of the world at hand, it is possible to estimate the mean composition of river water and the total amount of chemical substance carried to the sea by the rivers of the world. For this purpose it is necessary to have some information about the area of the land surface of the world and about the runoff of the various rivers. The following computations have been based principally on the discharge tables in a mimeographed copy of the "Recommendation of the International Association of Scientific Hydrology" which was accepted by the Council of the Association and presented to the delegates on September 13, 1957. The tables form the basis for a resolution that a river-sampling net be set up to repair the obvious deficiencies in the data of river chemistry. They are based principally on the work of L'vovich (1945), and appear to be substantially correct, except for a few spelling mistakes and two more important ones. The area of the Niger drainage basin is given as 216,000 square miles, whereas it is actually about 800,000 square miles, and the estimated total discharge for the continent of North America seems to be about 2,000,000 cfs too high.

Additional information was obtained from the "Oxford Atlas" (Lewis and others, 1951) and the "Encyclopedia Britannica" (Yust, 1949) as well as from some manuscript notes made from L'vovich's paper. The original was not available while the computations were being made. For the United States some information was obtained from "Large rivers of the United States" (U.S. Geol. Survey, 1949a).

NORTH AMERICA

For half of North America there are sufficient chemical and discharge measurements to permit a direct computation of the amount of dissolved substance carried by the large rivers. This yields a figure of 92 metric tons per square mile per year. It would be possible to obtain an estimate for the entire continent by taking this as a representative sample, but a more accurate mean can be obtained by weighting these large rivers in proportion to the part of the entire continent that they represent, instead of in proportion to their own drainage areas. The difficulty in making this kind of estimate is that there are some parts of the continent that are climatically very different from any part whose rivers are known, so that a few data from other parts of the world will have to be used.

The data are presented in table 75, supplemented by estimates of conditions in places where they are lacking. The two biggest gaps are in the Arctic regions and in Mexico and Central America. These have been filled by assuming that various parts of the areas concerned were similar to parts of Alaska and South America. A weighted mean of the information in this table leads to an estimate of 85 metric tons per mile being carried each year by the rivers of the North American continent. When proper allowance is given for the way in which bicarbonate is expressed, this figure is about 8 percent above that obtained by Clarke (1924a, b). A slight further correction might be made because this figure is a mean for the amount delivered to the sea by the entire land surface, including closed basins, but it is evident that the agreement between this estimate and the previous one is fairly good. Further information for arctic and tropical North America will permit a more exact estimate of chemical denudation of North America but the present one is certainly of the correct order of magnitude.

TABLE 75.—*Discharge and chemical denudation of North America*

Region	Area (thousands square miles)	Runoff (thousands cubic feet per second)	Total dissolved solids in (ppm)	Chemical analyses used
North Atlantic slope (U.S.)	148	210	116	Hudson River at Hudson.
South Atlantic slope (U.S.).	284	325	155	Tombigbee River near Epes.
Mississippi River	1,250	620	223	At New Orleans.
West Gulf of Mexico U.S.	320	55	881	Rio Grande at Laredo.
Colorado River	246	23	711	Yuma main canal.
Great Basin	215	0	0	------
Pacific basins	117	80	152	Sacramento River at Sacramento.
Columbia River	262	345	125	Columbia River at Cascade Locks.
St. Lawrence River	498	500	161	At Sorel.
Mackenzie River	660	260	214	At Ft. Simpson.
Nelson River	450	125	210	At mouth.
Fraser River	86	94	82	At New Westminster.
Yukon River	360	180	208	At Eagle.
Franklin Territory	554	139	91	Mean of arctic Alaska lakes.
Keewatin Territory	228	114	214	Mackenzie at Ft. Simpson.
Newfoundland	43	43	62	Mean of Moser River, Wallace River, Miramichi River, Andrews lakes and Ellerslie Creek.
Labrador	112	112	62	
Maritime Province	51	51	62	
Hudson Bay (Quebec and Ontario).	592	592	116	Mean of Abitibi, Mattagami, Rainy, and Kapuskasing Rivers.
Alaska south of Yukon	195	214	52	Kenai River.
Alaska north of Yukon	195	49	91	Mean of arctic Alaskan lakes.
Minor coastal streams, British Columbia and elsewhere.	319	351	82	Fraser at New Westminster.
Mexico	758	20 150	881 114	Rio Grande at Laredo. Rio Parana above La Plata.
Guatemala	42	65	114	Rio Parana above La Plata.
British Honduras	9			
Honduras	59			
Salvador	13	383	54	River Orinoco at Puerto Ayacuho.
Nicaragua	54			
Costa Rica	23			
Panama	29			
Sum or mean	8,172	5,100	142	

EUROPE

The chemical denudation of Europe is not easy to estimate because the discharge of that continent is divided among a multiplicity of small rivers. The principal rivers for which data are available are listed in table 76, but they account for less than a quarter of the total discharge. The Volga basin, of course, contributes nothing to the sea, but there is a substantial part of western Europe, particularly Iceland, Fennoscandia, and the British Isles, that must have a heavier runoff than the rivers listed. This area has been estimated at 500,000 square miles, with a discharge of 700,000 cfs. There is no firm base to use for computing the chemical composition of this water, for most of the rivers that have been analyzed are small ones draining very soluble sedimentary rocks in southern England. It may be assumed that the composition is represented by the three rivers in Sweden for which data are available, although this will probably lead to an underestimate of chloride and perhaps of silica. The remainder of Europe has been assumed to be like that part drained by the principal rivers, and a weighted mean leads to the result that about 110 metric tons per square mile are carried away each year. This is the highest rate of chemical denudation of any continent. The figure may be lowered somewhat when data become available for Mediterranean Europe, but it does seem well established that the rate of denudation is high. This is probably due mainly to the moist European climate, although the large areas of fine-grained Pleistocene deposits may also be an important factor.

TABLE 76.—*Discharge and chemical denudation of Europe*

Region	Area (thousands square miles)	Runoff (thousands cubic feet per second)	Total dissolved solids in (ppm)	Chemical analyses used
Danube	315	225	225	At Budapest.
Pechora	126	145	45	S. Ust-Tilma.
Dvina	140	120	247	d. Zvoz.
Rhine	56	76	215	At Arnheim.
Rhone	37	59	231	At Geneva.
Dnepr	177	59	287	S. Razumovka.
Elbe	52	24	201	At Tetschen.
Garonne	22	24	180	At Toulouse.
Don	86	24	568	S. Aksaïskaia.
Well-watered western Europe	500	700	88	Mean of Byske-elf, Ljusnan and Fyris.
Volga and other closed basins.	600	0	----------	
Remainder like the mean of the major rivers.	2,100	1,340	202	Mean of Danube to Don, above.
Sum or mean	4,211	2,796	182	

ASIA

Except for the U.S.S.R. and Japan, most of Asia is hydrologically very little known. The estimate for the discharge for the temperate parts of the Pacific basins, shown in table 77, is close to the discharge rate for the Amur, and intermediate between the rates for the Yangtze and the Hwang Ho. The estimate for the discharge rate of the tropical parts of Asia is intermediate between the rates L'vovich gives for the Malayan Archipelago and the Ganges. The most uncertain part of the whole computation is the tropical section, for here the figures for both discharge and chemical content are of low reliability. They represent a considerable improvement over the data available in 1924, however, and lead to an estimate of 83 metric tons removed in solution per square mile of the Asiatic landmass, a very respectable figure when one considers the extensive areas of desert that contribute nothing to the total.

TABLE 77.—*Discharge and chemical denudation of Asia*

Region	Area (thousands square miles)	Runoff (thousands cubic feet per second)	Total dissolved solids (ppm)	Chemical analyses used
Arctic basin	2,462	2,456	116	Alekin's mean for Arctic basins one-third, Kara Sea, rest two-thirds.
Japan and Korea	279	225	111	River Tone at Sawarashi.
Rest of temperate Pacific basin.	3,000	2,250	52	Alekin's mean for Pacific basins of U.S.S.R.
Tropical drainage, including East Indies.	4,644	7,500	163	Mean of Mae Khong at Mukdaharn and Ganges at Calcutta.
Closed basins	7,600	0	----------	
Sum or mean	17,985	12,431	142	

AFRICA

There are no satisfactory analyses for any major river of Africa, but many data which can be used in estimating the chemical denudation. The basis for such an estimate is shown in table 78. There are no complete analyses for the Orange and the Zambezi, but the Cunene and Limpopo are fair-sized rivers in the same general part of Africa, and probably approach them in chemical composition. The four rivers chosen to represent the miscellaneous humid parts of Africa have been chosen from among a much larger number of analyses of rather dilute tropical waters. The major rivers of Africa, taken by themselves, give a misleading impression of the total runoff. A weighted mean of the chemical composition of African rivers leads to an estimate of 63 metric tons removed each year for each square mile of total land surface.

TABLE 78.—*Discharge and chemical denudation of Africa*

Region	Area (thousands square miles)	Runoff (thousands cubic feet per second)	Total dissolved solids in (ppm)	Chemical analyses used
Nile	1,150	100	161	Below Cairo.
Orange and Zambezi	820	352	144	Mean of Limpopo at Pafuri and Cunene at Colhida.
Congo	1,500	1,600	80	Mean of Bankasu at Ruki and Zongo at Inkiai and Zele-Wungo.
Niger	800	326	98	At Niamey.
Miscellaneous dry regions.	980	226	366	Mean of Uebi Scebeli at Agfoi and Guiba at Ionte.
Miscellaneous wet regions.	2,500	4,000	96	Mean of Rio Bengo at Boa Vista, Senegal at Kayes, Konkouré at Kabea and Owabi at Kumasi.
Closed basins	3,750	0	----------	
Sum or mean	11,500	6,604	121	

AUSTRALIA

Data on which to base an estimate of chemical denudation for Australia are very scant. About one-third of the continent lacks rivers flowing to the sea and may be left out of computation. The perennial rivers, for which there are numerous analyses, are mostly very dilute. They are in regions of abundant rainfall, flowing over rocks some of which are very resistant to weathering and all of which have been leached for a long time. In table 79, these perennial rivers are represented by the water of the Rose River. The intermittent rivers pose something of a problem. The Murray River has a very low discharge rate, as befits a river flowing through a semiarid land, but it is surprisingly dilute. This river shows considerable fluctuation from year to year—during some years it ceases to flow at all—and one cannot help wondering if the discharge figures represent dry years and the chemical analyses wet years. If this is the case the chemical denudation for Australia will be underestimated to some extent, but even these figures of doubtful reliability suffice to show that the smallest continent contributes only a very small amount to the world total for chemical denudation. It appears to yield about 6 metric tons per square mile of total area.

Table 79.—*Discharge and chemical denudation of Australia*

Region	Area (thousands square miles)	Runoff (thousands cubic feet per second)	Total dissolved solids in (ppm)	Chemical analyses used
Perennial rivers	645	323	33	Rose River, Dondangadale.
Intermittent rivers	1,330	31	282	Murray River, South Australia.
Closed basins	995	0		
Sum or mean	2,970	354	59	

SOUTH AMERICA

There are no new data of consequence on which to base an estimate of the chemical denudation of South America. It seems more reasonable to use the Parana as representative of the less well watered parts of the continent than to use the very dilute Uruguay, as Clarke did; this leads, on the basis shown in table 80, to a figure of 73 metric tons of dissolved substance being removed per square mile per year.

Table 80.—*Discharge and chemical denudation of South America*

Region	Area (thousands square miles)	Runoff (thousands cubic feet per second)	Total dissolved solids in (ppm)	Chemical analyses used
Orinoco	340	600	54	At Puerto Ayachuo.
Amazon	2,231	3,600	57	Mean of all 4 analyses.
Parana	890	526	114	Above La Plata.
Uruguay	90	136	50	Opposite Salto.
Remainder similar to Amazon basin.	2,000	3,000	57	Mean of all 4 Amazon analyses.
Remainder similar to Parana basin.	2,000	1,100	114	Parana above La Plata.
Sum or mean	7,551	8,962	69	

WORLD SUMMARY

By multiplying the average chemical denudation of the continents by their size, one arrives at a figure of 3,905,000,000 metric tons for the total amount of mineral material carried in solution each year by the rivers flowing into the sea. This is almost 1,200,000,000 tons greater than the estimate of Clarke in 1924, but it is substantially below the earlier estimate of Sir John Murray (quoted in Clarke, 1924b, p. 63) which was estimated on rather meager data. It is evident from the difference between various independent estimates that an accurate assessment of the chemical substance carried by the rivers has not been reached. Although the current estimate rests on more accurate basic information than the earlier ones, there is some possibility that it may be appreciably too high. Our knowledge of the chemistry of rivers for much of the world, particularly the humid tropics, rests upon a very small number of samples, rather than upon long-term studies during all seasons. Most of the annual discharge of a river having a variable discharge rate occurs during short periods of flood when the dissolved salt content is at its lowest, so infrequent haphazard sampling is likely to result in an overestimate of the mean salinity of the water which the river carries. This error is not likely to affect the figures for Europe and North America, but it might influence the total for South America, Africa, and Asia.

MEAN CHEMICAL COMPOSITION OF WORLD RIVER WATER

Weighted means have been calculated for the chemical composition of the river waters of various continents as well as the world on the same basis as the calculations for chemical denudation. In a few cases it was necessary to supplement incomplete analyses with estimates for silica based on the silica content of similar waters. The Rose River analysis, used as a basis for computing the composition of the permanent rivers of Australia, has had 3.5 ppm of silica added to it, a quantity which is found in the similar dilute waters of Tasmania. The mean figures of Alekin and Brazhnikova (1957) for the Arctic and Pacific drainage systems of the U.S.S.R. lack silica. These have been supplemented by assuming that their silica contents were similar to those of the Mackenzie and St. Lawrence Rivers, respectively. Some important analyses lump sodium and potassium. In calculating world mean composition the combined Na + K of these analyses has been partitioned according to the Na/K ratio of the rest of the waters of the world.

The results of this computation are summarized in table 81. The principal differences between the continents are in the amounts of calcium and bicarbonate ions. The great variation in the nitrate and iron contents is insignificant for reasons that were dealt with at length above. The world mean for nitrate, however, may be of the correct order of magnitude.

The mean for the river water of the world, 120 ppm, is somewhat lower than Clarke's 1924b data suggested,

TABLE 81.—*Mean composition of river waters of the world, in parts per million*

	HCO_3	SO_4	Cl	NO_3	Ca	Mg	Na	K	Fe	SiO_2	Sum
North America	68	20	8	1	21	5	9	1.4	0.16	9	142
South America	31	4.8	4.9	.7	7.2	1.5	4	2	1.4	11.9	69
Europe	95	24	6.9	3.7	31.1	5.6	5.4	1.7	.8	7.5	182
Asia	79	8.4	8.7	.7	18.4	5.6	9.3		.01	11.7	142
Africa	43	13.5	12.1	.8	12.5	3.8	11		1.3	23.2	121
Australia	31.6	2.6	10	.05	3.9	2.7	2.9	1.4	.3	3.9	59
World	58.4	11.2	7.8	1	15	4.1	6.3	2.3	.67	13.1	120
Anions [1]	.958	.233	.220	.017							1.428
Cations [1]					.750	.342	.274	.059			1.425

[1] Millequivalents of strongly ionized components.

provided cognizance is taken of the different way in which he expressed bicarbonate. It is, however, very close to the weighted mean of Conway (1942, 1943) which was based on Clarke's data but took into account the relative abundance of dilute tropical rivers.

MINOR CONSTITUENTS

GENERAL REMARKS

This section deals with constituents represented in so few of the general tables that they demand separate treatment. A number of chemical elements do not seem to have been detected in a single lake or river water. They are tellurium, all the noble gases except argon and radon, indium, thallium, scandium, yttrium, the rare earths, hafnium, germanium, columbium,[1] tantalum, tungsten, rhenium, the platinum and palladium metals, and actinium.

FLUORINE, BROMINE, AND IODINE

Numerous data for fluorine and a few for bromine and iodine are in the tables of general analyses. There is an extensive body of information about the fluorine and iodine content of lakes and rivers because of the medical significance of these elements. There is less information available about bromine.

Most fresh waters have less than the single part per million of fluorine which is regarded as optimal for health of human teeth. In concentrated waters the content may be somewhat higher, but it is usually limited by the low solubility of calcium fluoride. Many analyses include more fluorine than should be dissolved in the presence of accompanying calcium, and it is probably generally true, as Kobayashi (1954) has found, that an appreciable part of the analytically determined fluorine is not present in simple solution. Waters unusually high in fluorine are commonly associated with vulcanism, igneous rocks, or apatite deposits.

The reader seeking data on fluorine in addition to those included in the general analyses may consult the following papers for various parts of the world: Chamberlain (1946); Cherkinskii and others (1953); Gabovich (1952); Gandra (1950); Kobayashi (1954); Kredba and Hamackova (1950); Krepogorskii and Bogusevich (1953); Kubota (1952); Möse and Exner (1952); Novokhatskii and Kalinin (1953); Paraje (1950); Richard and Vialard-Goudou (1954); Tageeva (1943); Tomic (1951, 1954); Van Burkalow (1948); Vinogradov, Danilova, and Selivanov (1937); Walker (1940); Wilson (1954); Mackereth and Heron (1954); Juday, Birge, and Meloche (1938); Konovalov (1959). Konovalov's paper is of particular interest because it permits computation of the mean fluorine content of the rivers of about 80 percent of the entire area of the U.S.S.R. at 0.089 ppm.

Reliable information on the bromine content of lakes and rivers is rather scarce. Correns (1956), reviewing the geochemistry of the halogens, accepts the single value of Behne (1953) for the water of the Grosse Bode as the best available estimate of the bromine content of the river water of the world, but the mean content of U.S.S.R. rivers may be computed from the data of Konovalov (1959) to be 0.019 ppm—more than three times Behne's value. This is almost certainly closer to the global total. There are many other analyses, but most of them are for saline lakes or for rivers influenced by rock-salt deposits or industrial sewage. Some of these data are shown in table 82. From this information it is not possible to tell with assurance whether the Cl/Br ratio of lake and river waters departs significantly from the marine ratio of 294:1, although it is likely to be slightly higher than this.

More data are available for iodine than for bromine. but they have been collected for medical purposes and their geochemical usefulness is somewhat limited. An assortment of data for iodine and bromine that can be used for present purposes is included in table 82. Hutchinson (1957) believes that 0.2 ppb would be a reasonable mean figure for lakes and rivers. This seems rather low. The mean of 1.8 ppb of Goldschmidt

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[1] I am informed by Dr. Heinz Löffler that he has detected minute amounts of columbium in East African high altitude lakes.

TABLE 82.—*Bromine and iodine content of river and lake waters*

Locality	Cl (ppm)	Br (ppm)	Cl/Br	I (ppm)	Cl/I	Author
Laguna Encantada, Peru	1, 888	--------	--------	17. 8	--------	Zapata Valle and Camet (see table 72.)
Lagoa Escondida, Brazil	1, 242	Nil	--------	Nil	--------	Campos Paiva (see table 72).
Dead Sea surface	126, 500	4, 600	28	--------	--------	Terreil (see table 51).
Dead Sea 120 m	166, 300	4, 900	34	--------	--------	Do.
Dead Sea 300 m	175, 000	7, 000	25	--------	--------	Do.
Mean of 7 Crimean salt lakes	77, 562	667	223	--------	--------	Kurnakov and others (see table 42).
Lake Eyre, Australia	67, 960	<. 01	--------	--------	--------	T. R. Frost (see table 57).
Urmia Lake, Iran (2 analyses)	180, 500	3, 400	53	--------	--------	Löffler (1956) (see table 50).
	206, 800	3, 900	53	--------	--------	
Grosse Bode	2. 5	. 006	416	--------	--------	Behne (1953).
Inder Lake (range)	--------	14–260	--------	--------	--------	Volkov (1938).
Saale at Göschwitz, annual mean.	18. 5	. 0106	1, 745	. 0022	8, 410	Heide and Kaeding (1954) (includes more data of the same kind, not given here).
Saale at Kunitz	22	. 0154	1, 429	. 0027	8, 150	Do.
Saale at Leissling	123	. 0217	5, 668	. 0033	37, 300	Do.
El'ton Lake	--------	522–1, 740	--------	--------	--------	Feigelson (1939).
Rivers of the U.S.S.R.	--------	. 019	--------	. 007	--------	Konovalov (1959).
10 South Australian lakes and 1 creek:						
Range	--------	5–272	--------	--------	--------	Cooke (1941).
Mean	--------	102	--------	--------	--------	
13Romanian lakes:						
Range	613–57, 770	Tr.–176. 6	300^{+}	Tr.–2. 2	8, 300^{+}	Petrescu (1940).
Mean	11, 550	16. 2	--------	. 492	--------	
Various Russian rivers:						
Range	--------	. 0005–. 140	--------	--------	--------	Selivanov (1939a, b; 1944; 1946), as summarized in Hutchinson (1957).
Mean	--------	. 021	--------	--------	--------	
Various Russian lakes:						
Range	--------	. 002–. 0101	--------	--------	--------	Do.
Mean	--------	. 0045	--------	--------	--------	
Rivers and springs of the Upper Svanety region:						
Range	--------	--------	--------	. 0002–. 0055	--------	Menzhinskaya (1944).
63 lakes, rivers and reservoirs of the U.S.S.R.:						
Range	--------	--------	--------	0–. 0043	--------	Karger and Chapyzhnikov (1944).
381 public water supplies of the State of São Paulo:						
Range	--------	--------	--------	0–. 010	--------	Cardoso, Gandra, and Nazario (1955).
Mean	--------	--------	--------	. 00173	--------	Do.
Some Finnish lakes	--------	--------	--------	. 00001	--------	Adlercreutz (1928), quoted in Hutchinson (1957, p. 562).
Lake Superior	--------	--------	--------	>. 0001	--------	Hutchinson (1957, p. 562–563).
Biwa-Ko, Japan, mean of 5 depths.	5. 91	--------	--------	. 00294	20, 000	Sugawara, Naito, and Yamada (1956).

(1934) is in better accord with the present information, but even it may be too low. The data gathered by Konovalov (1959) for the rivers of the U.S.S.R. yield a mean figure for iodine of 7.2 ppb.

In addition to the papers to which reference already has been made, the interested reader may wish to consult the following for additional information on the iodine content of lakes and rivers: Bado and Trelles (1937); Buydens (1951); Dzens-Litovskii (1944); Dragomirova (1944); Jarchovsky and Pacal (1954); Grushvitaskii (1938); Nicolaev and Segel (1947); McHargue (1943); Shee (1940).

The available data for the halogen content of river water do not seem to justify any modification of the estimate of the mean content of river water by Correns (1956): F, 0.26 ppm; Cl, 8.3 ppm; Br, 0.006 ppm; and I, 0.0018 ppm.

BORON

Some data for the boron content of lakes and rivers are presented in table 83. Additional information will be found in tables 18, 19, 23, 56, 60, and 72 in the general analyses section, and in the earlier editions of this book. There appears to be a substantial body of information in Maldonado and Guevara (1950), which was not available for consultation. Tageeva (1943) and Glebovich (1946) discuss the geochemistry of boron in the hydrosphere. The California water quality publications for the years 1951–56 (Calif. Dept. Water Resources, 1956, 1957) contain many analyses for boron.

TABLE 83.—*Boron content of lakes and rivers*

Locality	Cl (ppm)	B (ppm)	B/Cl	Author
River Tone, Japan: mean of 10 samples.	6.162	0.345	0.0560	Muto (1956).
Watarase River, Japan: mean of 3 samples.	10.40	.197	.0190	Do.
Kiriu River, Japan: mean of 6 samples.	.158	.207	1.310	Do.
Agatsuma, Japan: mean of 4 samples.	84.2	1.97	.0234	Do.
Okuresawa, Japan: mean of 4 samples.	2.28	1.305	.5724	Do.
Rain water, Kiriu, Japan: mean of 5 samples.	2.44	.098	.0403	Do.
Snow, Kiriu, Japan: mean of 3 samples.	2.53	.107	.0436	Do.
Great Salt Lake, Utah	149,224	43.5	.00029	Odum and Parrish (1954).
6 Florida streams: mean.	7.7	.019	.00285	Do.
5 Florida lakes: mean	6.8	.014	.0030	Do.
Rainwater, Gainesville, Fla.	2	.009	.0043	Do.
Borax Lake, Calif	24,730	995	.0402	Analysis by Melville, quoted in Clarke (1924b).
Greek River, Uganda	2.8	.386	.141	See table 60.
Sipi River, Uganda	4.8	.005	.0014	Do.
Siroko River, Uganda	2.1	.005	.0024	Do.
Inder Lake	------------	198	------------	Bulanov (1939).
64 lakes of Aral-Caspian region: range.	------------	5–2250	------------	Feigelson, Valyashko, and Bergman (1939).
Caspian Sea	------------	470	------------	Feigelson and Kozhevnikova (1938).
Lakes of Mangyshlak peninsula: range.	------------	75–333	------------	Do.
Sultan-Sandzhar Lake	------------	------------	.0053	Dzens-Litovskii (1939).
24 city water supplies in U.S.A.: range.	------------	0.01–1.0	------------	Braidech and Emery (1935).
River waters of the U.S.S.R.	------------	.013	------------	Konovalov (1959).

The boron content of waters in Japan appears to be remarkably high. The rivers Agatsuma and Okuresawa receive water from boron-rich mineral springs, but the boron in the rivers of the Tone system is believed to be meteoric. The boron content of these waters is even higher than it appears by comparison with the other results of table 83 if account is taken of the 10 waters listed in the general tables, from Peru, Australia, Uganda, and the western United States, in which no measurable boron was present. Except for the possibility of gross technical errors in one direction or the other, it may be that the high boron content of waters from Japan, both atmospheric and terrestrial, is a result of the vulcanism of that country, and that the occasional very low figures reported elsewhere are due to biological removal of the element. The latter possibility was explored by Odum and Parrish (1954), and, although they considered it unlikely in their moderately boron-rich Florida waters, it is possible that biological removal of boron may occur in some places.

The most representative body of published data is that of G. S. Konovalov (1959) for the major rivers of the U.S.S.R. The estimate they yield, of 13 ppb, is probably not far from the mean boron concentration of the rivers of the world. A similar set of unpublished data for the rivers of North America and Norway has a mean boron content of 11.6 ppb (W. H. Durum, written communication, 1960).

LITHIUM

There is a considerable scatter in the available data for lithium. Some of the data are presented in table 84. Additional data are in table 59 in the general analyses section. The largest set, 27 analyses, yields a Na/Li ratio of about 1,500, not far above the crustal ratio. It is tempting to ascribe the low Na/Li ratios exhibited by a few waters to an overestimate of lithium, especially since Yamagata (1951 a, b) and Borovik-Romanova, Korolev, and Kutsenko (1954), who were most seriously concerned with the element, obtained rather low figures for its concentration in water. The enrichment of lithium in lake water postulated by Hutchinson (1957) on the basis of some analytical results of Lohuis, Meloche, and Juday (1938) is obviously not a general phenomenon, but it is not possible to be certain from the data available that it does not occur in some waters. There seems to be a tendency for the relatively dilute waters from continental localities to have lower Na/Li ratios than the concentrated continental waters or the waters from oceanic localities.

TABLE 84.—*Lithium content of lake and river waters*

Locality	Li (ppm)	Na (ppm)	Na/Li	Author
Palicer Teich, Yugoslavia.	15.3	1,431	93.5	Protić (1935).
A large number of water samples of different origin.	.001–1	------------	------------	Borovik-Romanova, Korolev, and Kutsenko (1954).
Laguna Encantada	7.6	694	91.3	See table 72.
Agua de Puquio	.0	1.7	>34	Do.
Salton Sea, Calif	1.9	6,249	3,289	See table 19.
Little Borax Lake, Calif.	1.2	3,390	2,825	Do.
Mono Lake, Calif	8.5	21,400	2,518	Do.
Amargosa River, Nev	.16	423	2,544	Do.
Ruzizi River, Tanganyika.	.4	94.8	237	Do.
Malagarasi River, Tanganyika.	<.1	16.4	>164	Do.
Luichi River, Tanganyika.	.4	13.2	33	Do.
Lake Tanganyika surface.	.4	59.9	150	Do.
Lake Tanganyika 700m.	.8	64.2	80	Do.
14 Japanese rivers:				
Range	.0002–.005	1.86–6.87	724–9,814	See table 47.
Mean	.0011	4.15	3,772	Do.
Major North American rivers.	.0033	about 5	ca. 1,500	W. H. Durum (written communication, 1960).

RUBIDIUM

Schmidt (1882, quoted in Hutchinson, 1957) reported 0.055 ppm of rubidium in the water of Lake Peipus. In the light of more recent work, such as the spectrographic studies of Borovik-Romanova (1946), this concentration seems unduly high, and may represent the deficiencies of the chemical methods of his time rather than the rubidium concentration of the hydrosphere. Yamagata (1951b) found the rubidium content of 14 rivers of Japan to range from

0.0003 to 0.002 ppm, with a mean of 0.00116. The Na/Rb ratios ranged from 1,525 to 11,100 and the ratio of the mean values was 3,578. This is very similar to the findings of Borovik-Romanova already referred to, with an average concentration of 0.0016 ppm and a ratio of 4,166. The K/Rb ratio found by both of these workers is slightly in excess of 1,000, or more than 10 times as great as that found by Schmidt. Twenty-seven samples of water from major rivers of North America had a mean rubidium content of 0.0017 ppm (W. H. Durum, written communication, 1960). Rubidium seems to be considerably scarcer in the hydrosphere, from which it is removed biologically and probably chemically as well, than it is in the lithosphere.

CESIUM

The only analyses for cesium appear to be six determinations for rivers in Japan by Yamagata (1951b). He found a range of cesium content between 0.00005 and 0.0002 ppm. The Na/Cs ratio ranged from 9,300 to 89,400 and the ratio of the mean contents was 31,900.

BERYLLIUM

Beryllium appears to have been determined only by Maliuga and Makarova (1956), who found 10 ppm of total dry residue in both the River Il'kikan and the River Gazimura, and by the U.S. Geological Survey, which found between 0.1 and 1 ppb in the Atchafalaya River, Louisiana (W. H. Durum, written communication, 1960).

STRONTIUM

The strontium content of lakes and rivers has been studied most extensively by Odum (1950, 1951, 1957), who found that the Sr/Ca ratio reflected the geologic environment, at least in part. It was high in the presence of evaporite deposits, pegmatites, volcanic rocks, fresh coral limestones, and limestones precipitated directly from sea water. Lower Sr/Ca ratios were found in association with consolidated limestones, replaced limestones, dolomites, nonvolcanic mafic igneous rocks, and humid climate. A selection of Odum's data, together with those of several other authors, is presented in table 85. Bristol Dry Lake is a locality where celestite concretions occur, and the strontium content of the Bristol water sample, which was very concentrated and came from a drainage ditch in the lakebed, is probably close to the maximum to be expected in lake waters.

Additional information about strontium in water may be found in table 19, in earlier editions of this work, in the papers of Odum and Lohammar cited in table 85, and in papers by Braidech and Emery (1935), Borovik-Romanova, Korolev, and Kutsenko (1954), Maliuga and Makarova (1956), Grushko and Shipitsyn (1948), Nichols and McNall (1957), Horr, (1959), and Skougstadt and Horr (1960).

TABLE 85.—*Strontium content of lakes and rivers*

Locality	Ca (ppm)	Sr/Ca × 1,000	Sr (ppb)	Author
Housatonic River, Conn.	22.9	0.91	45.6	Odum (1957).
Hudson River at Poughkeepsie, N.Y.	18.6	2.65	107.9	Do.
James River at Richmond, Va.	10.5	1.80	41.4	Do.
Delaware River at Newcastle Ferry.	21.3	3.10	144	Do.
Withlacoochee River, Gulf Hammock, Fla.	43.2	3.7	350	Do.
Dunn Creek, St. Johns River, Welaka, Fla.	36.4	10.5	837	Do.
Prairie Creek, Gainesville, Fla.	4.4	1.86	17.9	Do.
Apalachicola, Chattahoochee, Fla.	13.1	1.08	30.9	Do.
Black Warrior River, Tuscaloosa, Ala.	5.1	1.76	19.1	Do.
Hampton Lake, Fla	1.7	3.22	12	Do.
Lake Kanapaha, Gainesville, Fla.	65.2	1.80	256	Do.
Trout Lake, Wis	8.8	2.31	44.4	Do.
Lake Mendota, Wis	22.9	1.77	88.6	Do.
Lake Erie	23.2	2.70	137	Do.
Sebago Lake, Maine	3	1.84	12.1	Do.
8 Connecticut lakes draining ancient crystalline rock.	3.9	1.82	15.4	Do.
10 Connecticut lakes draining Triassic sediments.	16.2	1.13	49.9	Do.
West Rock Pond, on basalt, Conn.	21.9	2.10	100.7	Do.
University Lake, Piedmont of North Carolina.	4.6	3.80	38.3	Do.
Eastwood Lake, draining residual clays of ancient crystalline rocks, N.C.	3.8	3.57	29.7	Do.
Singletary Lake, Coastal Plain, N.C.	.35	3.50	2.7	Do.
Lake Waccamaw, Miocene limestone outcrop, N.C.	6.3	2.39	33	Do.
4 volcanic lakes in the Philippine Islands.	31.1	5.28	357.2	Do.
Great Salt Lake, Utah	228	4.20	2,100	Do.
Lowland Swedish lakes.	----------	----------	50	Lohammar (1938).
Northern Swedish lakes.	----------	----------	14	Do.
Drainage canal in a salt body of Bristol Dry Lake, Calif.	----------	220	962,000	Durrell (1953).
Major North American rivers.	ca. 21	ca. 4.5	90	W. H. Durum (written communication, 1960).

BARIUM

Bowen (1948) found 10 ppb of barium in water from Linsley Pond, but could not detect it in hard waters from Connecticut. Braidech and Emery (1935) found larger quantities, between 30 and 1,000 ppb. The element has also been determined by Grushko and Shipitsyn (1948) and by Maliuga and Makarova (1956). The global Ca/Ba ratio would be about 1,500, accepting Bowen's figure as representative of lakes and rivers, or between 15 and 500, accepting the results of Braidech and Emery. The most representative set of data appears to be unpublished: 34 samples from major North American rivers had a mean content of 54 ppb, suggesting a Ca/Ba ratio of about 400 (W. H. Durum, written communication, 1960).

RADIUM

Radium has attracted attention because of its radioactivity and there is much information about the concentration of this element in natural waters. Data for lakes and rivers are summarized in table 86. Most of this information is brought together and discussed by Lowder and Solon (1956).

There is obviously considerable variation in the radium content of rivers. From the data presented in the table it appears that there was a tenfold discrepancy between the results of Lynch (*in* Lowder and Solon, 1956) and those of Hursh (1954, 1957), the two principal analysts involved, but actually Hursh gives a much larger body of data than those presented, which were selected because the waters had not been treated by flocculation, settling, and filtration before analysis. Among the data for treated waters gathered by Hursh are many radium concentrations as high as those of Lynch. For the Mississippi River, the only water which both have studied, Hursh obtained a higher value than Lynch, even after filtration.

TABLE 86.—*Radium content of lakes and rivers*

Location	Radium (ppm)	Author
Allegheny River, Pa	7×10^{-10}	Lynch, *in* Lowder and Solon (1956).
Do	1.5×10^{-10}	Do.
Ohio River	6×10^{-10}	Do.
Chartiers Creek	4×10^{-10}	Do.
Monongahela River, Pa	3.5×10^{-10}	Do.
Susquehanna River, Pa	5×10^{-10}	Hess (1943), *in* Lowder and Solon (1956).
Stagnant stream water, northwest New York.	$4–17\times10^{-10}$	Lynch, *in* Lowder and Solon (1956).
Stream water, New Jersey	$2–15\times10^{-10}$	Do.
Stream water, St. Louis, Mo	$4–7\times10^{-10}$	Do.
Mississippi River, St. Louis, Mo	$1.2–2.9\times10^{-10}$	Do.
River Thames near Sutton Courtenay, England.	$.1\times10^{-10}$	Jacobi (1949), *in* Lowder and Solon (1956).
Normal surface water, U.S.A., 15 samples.	$3.6–34.1\times10^{-10}$	Love (1951), *in* Lowder and Solon (1956).
Nashua River, Boston, Mass	$.14\times10^{-10}$	Hursh (1954, 1957).
Bull Run River, Portland, Oreg	$.14\times10^{-10}$	Do.
Cottonwood Creek, Salt Lake City, Utah.	$.34\times10^{-10}$	Do.
Calaveras Reservoir, San Francisco, Calif.	$.18\times10^{-10}$	Do.
Green River, Tacoma, Wash	$.02\times10^{-10}$	Do.
Hudson River	$0.33\pm0.04\times10^{-10}$	Rona and Urry (1952).
St. Lawrence River	$.25\pm.04\times10^{-10}$	Do.

Because there is a spread of almost three orders of magnitude in the analytical results, it is not possible to arrive at a reliable global estimate by taking the mean of such a small number of analyses, but for what it is worth the mean is 3.9×10^{-10} ppm. This is only a little higher than the mean of all the available analyses of the Mississippi, including those made after treatment which might be expected to lower the radium content, and probably is of the correct order of magnitude. It is worth noting, however, that most people who have studied the matter believe the radium content of rivers to be one complete order of magnitude lower (Holland and Kulp, 1954, 0.35×10^{-10}; Koczy, 1954, 0.7×10^{-10}; Kohman and Saito, 1954, North America only, 0.3×10^{-10}). The present estimate would indicate a Ca/Ra ratio for river water of 5×10^{10}; the earlier estimates, made on less nearly complete data, would indicate a ratio of about 5×10^{11}.

SELENIUM

Selenium seems to have been studied only in the waters of areas where it is known to be particularly plentiful. Thus, in South Dakota, in an area where the element is locally abundant enough to be poisonous, Searight and his co-workers (Searight and Moxon, 1945; Searight and others, 1946) found 21.4 and 85.5 ppb selenium in 2 ponds, at least one of which was above local ground-water level. The Colorado River system, in the places where it drains seleniferous soils, has contents of the element as high as 2,680 ppb (Williams and Byers, 1935; Byers and others, 1938). From this kind of information, it is hardly possible to arrive at any firm conclusions about the selenium content of lakes and rivers.

ARSENIC, ANTIMONY, AND BISMUTH

Arsenic has been determined in a number of lake and river waters, and some of the data are presented in table 87. The very high figures for New Zealand are from a limited area of hydrothermal activity where the element is unusually abundant, and are not to be taken as representative of the hydrosphere generally. It is possibile that the Saale figures have been increased by industrial pollution and the content of the waters in Portugal, where pollution is less likely, is much lower. Only one water of the six described in table 86 contained

TABLE 87.—*Arsenic content of lake and river waters*

Locality	Arsenic (ppb)	Author
Southern Córdoba, Argentina	40–1,600	Páráje (1950).
Sea of Azov	1–15	Fedosov (1940).
Caspian Sea	3–12	Do.
Waiotapu River, New Zealand	2,400–4,900	Grimmett and McIntosh (1939).
Surface seepage water, Waiotapu Valley.	≦15,000	Do.
Pools, Waiotapu Valley	≦530	Do.
Rio Zézere, Portugal	1	See table 29.
Germany	2–3	von Bulov and Otto (1931), quoted in Hutchinson (1957).
Saale at Göschwitz, Germany mean of 12 monthly samples:		
Dissolved	6.9	Heide and Moenke (1956).
In suspension	2.4	Do.
Saale at various places, range:		
Dissolved	3.5–16.1	Do.
In suspension	.3–6	Do.
Biwa-Ko, Japan	.66–3.26	Sugawara, Naito, and Yamada (1956).
516 California waters with less than 2,000 ppm total dissolved solids:		
Range	0–100	California Dept. Water Resources (1957).
Mean	.4	Do.
20 California waters with more than 2,000 ppm total dissolved solids:		
Range	0–2,000	Do.
Mean	225	Do.

an amount of arsenic detectable with a method sensitive to 1 ppb.

Sugawara, Tanaka, and Kanamori (1956) feel that the older methods for arsenic were unreliable, being subject to contamination, particularly from glassware, and it is possible that the development of more accurate methods will show the present figures to be too high. For the time being, however, it seems that arsenic concentrations of several parts per billion are to be expected in ordinary dilute waters, and that concentrations of 1 ppm or more may be encountered in some concentrated waters or in hydrothermal areas.

Antimony contents of as much as 40 ppb were found by Braidech and Emery (1935) in their spectrographic examination of United States water supplies. This seems rather high, and may reflect contamination from the pipes used to carry the water to the points where samples were taken for analysis. If such a quantity of antimony is actually to be found in natural waters, it should be of some biogeochemical importance, and the subject might repay further investigation.

Grazhdan (1957) lists bismuth among the elements detected in several mineral waters of Turkmenistan. There do not appear to be any quantitative data for this element.

THE RARE GASES

Of the rare gases only argon has been investigated seriously in lake or river water. Sugawara and Tochikubo (1955) provide data for the argon content of five water samples from three lakes in Japan, and these are presented in table 88. The authors attribute the supersaturation of hypolimnetic water to heating of the deep water in situ without mixing. This suggestion has been rejected by Hutchinson (1957), who has, however, no alternative explanation to offer. If there is a substantial ground-water flow into the lakes, they may receive their excess argon in this way, for Sugawara and Tochikubo found that ground waters were frequently supersaturated, apparently as a result of bubbles of air being carried in the ground water to a depth at which there is appreciable solution, but such massive ground-water flow seems even less likely than heating in situ. The question is relevant to the problems of gas exchange in the swim bladders of deep-water fishes and should be investigated in a variety of lakes. Apparently Oana (1957) did not find appreciable supersaturation. In river waters the argon concentration is presumably close to saturation at atmospheric pressure, except in very torrential streams where it might approach saturation at the ambient pressure.

There appears to be some further information about the rare gases in a paper by Dzens-Litovskii (1939), but the abstract available states only that the gases coming off the Sultan-Sanzhar Lake are 5.7 percent methane, 91.8 percent nitrogen and rare gases, and 1.023 percent krypton, xenon, and heavy gases.

TABLE 88.—*Argon content of lake water*

[After Sugawara and Tochikuko (1955)]

Lake	Altitude (m)	Depth (m)	Temperature (°C)	Ar (cc/l)	Perecnt saturation	
					Ar	O
Kizaki-ko, Kitaazumi, Nagano Prefecture	760	0	26	0.25	95	99.8
		28	5.4	.42	106	7.27
Kagamigaike Pond on campus at Nagoya University, Higashiyama, Nagoya		0	23.5	.29	96	95
Nakatasuna-ko, Kitaazumi, Nagano Prefecture	800	0	26.6	.26	100	108.8
		14.5	9.4	.41	130	15.5

With the current ready availability of gas fractometers and mass spectrographs it should be relatively easy to make substantial additions to current knowledge of the rare gases in water.

GALLIUM

Gallium has been recorded once from lake water, by Hutchinson (1944) who concluded from a spectrographic analysis that between 0.1 and 1 ppb was present in the water of Linsley Pond.

GOLD

Hydrochemical prospecting has occasionally been used in an effort to detect commercial deposits of gold, but apparently not with very great success, Kropachev (1935) says that it is useless to seek gold in regions where the waters contain less than 0.06 ppb of the element. Konovalov (1941) says that the gold content of river water is variable and is a poor indicator of the gold content of rocks. Additional information on the gold content of water is apparently given by Zverev, Levchenko, and Miller (1947), but it has not been possible to locate this paper or an informative abstract of it.

MERCURY

Mercury appears to have been determined in river water only by Heide, Lerz, and Bohm (1957), who found that the Saale at Goscwitz had an annual mean concentration of 0.066 ppb in solution and an additional 0.021 ppb in the suspended form. Other stations on the same river had corresponding contents ranging from 0.035 to 0.145 ppb and from 0.004 to 0.046 ppb. The ratio of mercury to lead in river water was very similar to that in igneous and sedimentary rocks and in mollusk shells, but in sea water mercury was relatively about 10 times as abundant, whereas, rainwater, with 0.0002 ppb of mercury, had no detectable lead. Apparently mercury, because of its volatility, cycles quite readily through the atmosphere.

CADMIUM

Cadmium appears to have been detected in river or lake water only once, by Maliuga (1941), who detected between 9.66 and 80.5 ppb in water of the Urov River. This seems rather high, and the mean cadmium content of lakes and rivers is probably below Maliuga's mimimum figure.

COPPER

Copper is removed very easily from solution in natural waters (Murata, 1952; Kimura, Fujiwara, and Nagashima, 1951) both chemically, by precipitation as the carbonate, and by sorption reactions with the suspended material or even the walls of the container used to collect the water sample (Kauranne, 1955). Unless care is given to sampling and filtration procedures, it may be difficult to interpret the results of an investigation of the copper content of lake or river water. Riley (1939), studying the copper cycle in the relatively copper-rich water of lakes in Connecticut, and Heide and Singer (1954), working on the Saale River, have provided some information about the various fractions of copper present in natural waters; their results are summarized in table 89. There is reason to believe that much of Riley's organic fraction was not actually associated with dissolved organic compounds: a large part of it was removable by ultrafiltration and so was associated with colloidal material. Much of the colloidal material in waters of this sort is inorganic rather than organic. Heide and Singer's high figure of 29 ppb reflects industrial contamination. In general the dissolved and suspended copper content of the Saale increases downstream.

TABLE 89.—*Copper content of lakes and rivers*

Locality	Cu (ppb)	Author
Linsley Pond, Conn.:		
Cu ion range	5–66	Riley (1939).
Sestonic Cu, range	0–163	Do.
Organic Cu, range	0–187	Do.
Total Cu, range	11–383	Do.
Total Cu, mean	53	Riley *in* Hutchinson (1957, p. 812).
Lake Quonnapaug, Conn.:		
Cu ion, range	4–99	Riley (1939).
Sestonic Cu, range	0–196	Do.
Organic Cu, range	0–109	Do.
Total Cu, range	9–370	Do.
Total Cu, mean	40.8	Riley *in* Hutchinson (1957, p. 812).
Lake Quassapaug, Conn.:		
Cu ion, range	4–28	Riley (1939).
Sestonic Cu, range	0–76	Do.
Organic Cu, range	0–117	Do.
Total Cu, range	10–203	Do.
Total Cu, mean	40.1	Riley *in* Hutchinson (1957, p. 812).
440 Maine lakes:		
Range	0.07–140	Kleinkopf (1955).
Mean	10.38	Do.
One water, Japan, over a 2-year period:		
Range	0.2–1.3	Morita (1950).
Mean	.6	Do.
Clear waters, Japan	<1	Sugawara, Oana, and Morita (1948).
United States water supplies	5–600	Braidech and Emery (1935).
69 Norwegian streams and springs:		
Range	0–3,200	Vogt and Rosenquist (1942).
Mean	180	Do.
Several rivers remote from industrial contamination, England.	0–36	Atkins (1933).
Lake Windermere, England	15	Riley *in* Hutchinson (1957, p. 811.)
Brown-water tarns, Westmorland, England.	14–17	Do.
Pang-gong Tso, Tibet	10	Do.
Saale River at Göschwitz, mean of 12 monthly analyses:		
Dissolved	12	Heide and Singer (1954).
Suspended	3	Do.
Total	15	Do.
Saale River at 7 sampling stations:		
Dissolved, range	8–29	Do.
Suspended, range	0.5–2.7	Do.
Total, range	8.5–29.9	Do.
536 California waters:		
Range	0–60	Calif. Dept. Water Resources (1957).
Mean	6	
Rivers of the U.S.S.R.: mean	10.5	Konovalov (1959).

The copper content of waters in Japan is not as low as it may appear from the results presented in table 75. These results are probably comparable with the copper ion figures of Riley. Turbid waters in Japan contain much more copper. Thirty-five river waters sampled by the International Association of Hydrology in North America and Norway had a mean copper content of 8.7 ppb (W. H. Durum, written communication, 1960).

Many data are now being provided by dithizone testing of waters in geochemical prospecting programs. These data are, for the most part, of limited geochemical usefulness because little attention is paid to filtration, copper is not always separated from other heavy metals giving a similar result, and the waters sampled tend to be from copper-rich areas and to contain more total copper than average lake and river water.

Taking all the data into account, it is likely that the mean copper content of ordinary fresh waters is about 10 ppb.

In addition to the information presented in table 75, additional copper analyses of lake and river waters may be found in tables 19, 47, and 65 of the general section of this report, in Kleinkopf (1955, 1960), and in Maliuga, (1945). Data for groups of heavy metals, among which copper is probably the most important, may be found in Boyle, Illsley, and Green (1955); Boyle, and others (1958); and Boyle, Pekar, and and Patterson (1956).

COBALT AND NICKEL

There appear to be only four investigations of cobalt in the water of lakes and rivers. The results of Maliuga (1945, 1946) suggest a cobalt content two orders of magnitude greater than that reported by Benoit (1956). The failure of Braidech and Emery (1935) to find more than a trace of cobalt, and that only in 3 waters out of 24, supports the findings of Benoit. It is known, however, that the cobalt content of soils varies enough to make cobalt deficiency a serious problem, at least to ruminants, and it is possible that Maliuga and Benoit have been measuring genuine differences in the cobalt contents of their separate regions. Most major rivers of North America (Durum, written communication, 1960) usually contain no detectable cobalt, but a few samples contain 5 or more ppb. The mean content for 30 samples is 0.89 ppb.

For nickel there are more data, and some of these, together with a summary of the information about cobalt, are presented in table 90. Hutchinson (1957, p. 824–825) has suggested that the single high value of Braidech and Emery is due to contamination and that the normal range of nickel content is from 0 to 10 ppb with a mean of 5 ppb. Taking the new data for rivers of North America into account, it is likely that the global mean is close to 10 ppb. Passamaneck's analysis of water from a mining district shows that some waters may have a nickel content that is an order of magnitude higher.

TABLE 90.—*Cobalt and nickel content of lakes and rivers*

Locality	Co (ppb)	Ni (ppb)	Author
Lake Michigan	0	2	Braidech and Emery (1935).
United States, 24 water supplies.	Traces in 3 waters.	0–300	Do.
Linsley Pond, Conn.:			
Epilimnion (apparently all sestonic).	0.02–0.04	----------	Benoit (1956).
Hypolimnion:			
Dissolved	.02–.04	----------	Do.
Total	.05–.105	----------	Do.
440 Maine lakes:			
Range	----------	0.01–7	Kleinkopf (1955).
Mean	----------	.208	Do.
Lake Baikal	2.3	5	Maliuga (1946).
2 small lakes near Moscow	5.7–6.6	13–19	Do.
21 lakes and rivers, U.S.S.R.	.33–19	1.1–75	Maliuga (1945).
Water from Coppercliff nickel mine district, Ontario.	----------	100	Passamaneck (1945).
Lake Washington, Wash.:			
Dissolved	----------	1.5	Laevastu and Thompson (1956).
Particulate	----------	.3	Do.
Hoh River, Wash.:			
Dissolved	----------	1.6	Do.
Particulate	----------	9	Do.
Sol Duc River, Wash.:			
Dissolved	----------	1.7	Do.
Particulate	----------	1.2	Do.
Running waters of the biosphere.	----------	1.7–12	Pácal (1955).
Major rivers of North America.	.89	11.7	W. H. Durum (written communication, 1960).

SILVER

Both Braidech and Emery (1935) and Kleinkopf (1955, 1960) found silver in every water sample they examined for its presence. The first of these investigations dealt with 24 water supplies in the United States. It is possible that some of the silver was due to contamination, although water from Lake Michigan, which was tested before treatment of any kind, contained 20 ppb of the element, a little below the mean of 28 ppb for all of the waters examined. The range was 10–200 ppb, and the ratio of silver to copper was about 300 times as great as that of the accessible lithosphere (Hutchinson, 1957, p. 828). Kleinkopf found much lower figures, his range being 0.01–3.50 ppb for 440 waters with a mean of 0.094. His Ag/Cu ratio was only about 10 times as great as that of the lithosphere and seems less anomalous, the chemical similarity of the two elements being great enough to suggest that they should behave similarly in the hydrosphere. Thirty-one samples of river water collected by the International Association of Hydrology in North America and Norway contained as much as 1.0 ppb silver with a mean of 0.16 (W. H. Durum, written communication, 1960). The samples had a Ag/Cu ratio similar to those of Kleinkopf.

ZINC

Zinc contents approaching 1 ppm in lakes and rivers have been reported. Kemmerer, Bovard, and Boorman (1923) found 650 ppb in Bear Lake, Idaho; Braidech and Emery (1935) found amounts between 200 and 300 ppb in water from Lake Michigan; and 200 ppb of zinc has been found in the Orogodo River, Nigeria (table 65). Most waters, however, contain much less than this. Braidech and Emery's figures ranged from the high figure for Lake Michigan down to 5 ppb. Kleinkopf (1955, 1960) found between 0.25 and 34.0 ppb in 440 lake waters of Maine, with a mean of 2.50 ppb. Morita (1950) found a variation of between 0.2 and 1.3 with a mean of 0.6 ppb in one water from Japan over a period of 2 years, and a somewhat wider range of figures in a series of lakes—those from mountains ranged from 1.3 to 5 ppb, whereas those from lowlands ranged from 5.6 to 18 ppb. Katanuma-ko, with its very acid water, contained 79 ppb of zinc. Sugihara (table 47) found between 10 and 56 ppb in six river and irrigation waters in Japan with a mean of 36 ppb. Five hundred and thirty-six waters from California (Calif. Dept. Water Resources, 1957) contained 0 to 320 ppb with a mean of 6.7, and the river waters of the U.S.S.R. average 45 ppb (Konovalov, 1959). The mean content of ordinary lake and river water appears to be about 10 ppb of total zinc. There is little direct evidence concerning the state of zinc in natural waters. Murata (1952) and Kimura, Fujiwara, and Nagashi (1951) found it to be less easily lost from solution in natural waters than copper, but the only study in which an attempt was made to separate dissolved from particulate forms of the element appears to be that of Heide and Singer (1954), who found that the Saale at Goschwitz contained, over a period of 12 months, an average of 178 ppb dissolved zinc and 47 ppb in suspension. Excluding a single figure of 3,500 ppb dissolved zinc which was the direct result of industrial pollution, they found a range from 54 to 205 ppb dissolved and 8 to 23 ppb particulate zinc for seven stations on the Saale. Zinc was strongly adsorbed by the sediment and precipitated from the river water in this way.

Some further information about the zinc content of waters may be obtained from the geochemical prospecting papers of Kauranne and of Boyle and his co-workers to which reference already has been made.

TITANIUM

By far the largest body of information about the titanium content of lakes and rivers is that provided by Kleinkopf (1955, 1960), who found between 0.05 and 27.5 ppb in 440 lake waters of Maine with a mean value of 1.60 ppb. Braidech and Emery (1935) found at least a trace in half of the public water supplies they investigated. Untreated water from Lake Michigan, with a content of 70 ppb contained the most, but samples from five other localities contained 20 ppb. Hutchinson (1941) found 50 ppb of titanium in hypolimnetic water from Linsley Pond. Thirty-three samples from major rivers of North America had a mean titanium content of 13.2 ppb (W. H. Durum, written communication, 1960). Nothing is known about the state of the titanium measured by any of these investigators, and it is at least possible that the titanium was all in suspension.

ZIRCONIUM

Zirconium appears to have been detected in lake waters only by Kleinkopf (1955, 1960) who found it to be uniformly present in 440 lake waters of Maine, with a range from 0.05 to 22.5 ppb and a mean of 2.61 ppb.

TIN

The tin content of waters has been studied by Braidech and Emery (1935), who found contents as high as 100 ppb with a mean of 17 ppb in 24 water samples. Water from Lake Michigan, the only untreated surface water included in their study, contained 40 ppb. Kleinkopf (1955, 1960), working with 419 lake waters of Maine, found much less tin. The range in the tin content in the lake waters of Maine was only as high as 2.50 ppb and the mean was 0.038 ppb. These figures are so discordant as to suggest analytical error in one of the investigations.

LEAD

The most valuable set of data for the lead content of lake and river water is that of Kleinkopf (1955, 1960), who found between 0.03 and 115.0 ppb of the element in 440 lakes of Maine. The mean was 2.30. Thirty-three samples of water from major rivers in North America contained an average of 6.6 ppb of lead (W.H. Durum, written communication, 1960). Data of Braidech and Emery (1935) are open to question because of possible contamination from the pipes of the water systems from which they obtained their samples, but their finding of 2 ppb in water from Lake Michigan is concordant with the results of Kleinkopf, although their mean of 26 ppb for the entire series of 24 water supplies seems suspiciously high. Eighteen of 536 waters of California (Calif. Dept. Water Resources, 1957) contained between 5 and 20 ppb of detectable lead. The mean for the entire series was 0.3 ppb.

Lead was among the heavy metals studied by Boyle and his co-workers in the papers to which reference has already been made. Newton (1944) has presented some additional data on the high lead content of rivers polluted by mine wastes.

From the data available it seems likely that the global mean lead content for lakes and rivers lies between 1 and 10 ppb.

VANADIUM

The first analysis of vanadium in lake or river water appears to be that of Braidech and Emery (1935) who found 20 ppb in water from Lake Michigan and failed to detect it in any other of the 24 waters they examined. Bertrand (1950), reviewing the biogeochemistry of the element, was able to cite several analyses for springs but none for lakes and rivers. Paraje (1950), studying 28 water supplies in the southern part of Cordoba, Argentina, found as much as 1,400 ppb with a mean of 320 ppb, but he did not specify the sources of the water supplies and it is likely that most, if not all, were ground waters. In addition, the region is geochemically unusual, being extremely arid and characterized especially by high arsenic concentrations, and is unlikely to have a vanadium content that is typical of ordinary lake and river waters.

The most important study of vanadium in lakes and rivers is that of Sugawara, Naito, and Yamada (1956). They found a range from 0.1 to 1.0 ppb with a mean of 0.91 in 21 samples of river water. Six samples of rain and snow water gave a range between 0.33 and 2.8 with a mean of 1.10 ppb but some of this meteoric vanadium appeared to be associated with soot from the industrial combustion of coal and petroleum, although it was filterable. Lake sediment also was enriched in vanadium, though apparently not biologically, for the plankton did not accumulate it.

Kleinkopf (1955, 1960) found vanadium contents as high as 2.1 ppb and a mean content of 0.112 ppb in 440 lake waters of Maine. This is in reasonable agreement with the results from Japan, and taken all together, the evidence suggests that the vanadium content of ordinary lake and river waters is somewhat less than 1 ppb. The element is widely and rather uniformly dispersed.

CHROMIUM

Braidech and Emery (1935) detected chromium in 22 of the 24 water supplies they studied. The amount ranged as high as 40 ppb with a mean of 5 ppb. Water from Lake Michigan contained 2 ppb. Chromium was also among the elements studied by Kleinkopf (1955, 1960), who found amounts as high as 8 ppb in 440 lake waters from Maine. The mean was 0.177, somewhat lower than that of Braidech and Emery. Five hundred and thirty-six waters of California (Calif. Dept. Water Resources, 1957) contained as much as 20 ppb with a mean of 0.3. Thirty-four samples from major rivers of North America contained as much as 84 ppb chromium with the rather high mean of 10.8 ppb (W. H. Durum, written communication, 1960). With this much information one can only say that the mean chromium content of ordinary lake and river waters probably lies between 0.1 and 10 ppb, but may be a little higher.

MOLYBDENUM

The first measurements of the molybdenum content of lake or river waters appear to be those of Kleinkopf (1955, 1960), who found figures of as much as 2.50 ppb in 419 lake waters from Maine. The mean of his analyses was 0.023 ppb. Geidorov and Efendiev (1958) found a mean content of 6.7 ppb in river waters of the Istisu and Bagyrasakh areas, Azerbaidzhan, which are rich in the element. Braidech and Emery (1935) found traces of molybdenum in some of their waters, but Novokhatskii and Kalinin (1939) were not able to detect its presence in the salt lakes of Kazakhstan. In a recent survey of major rivers of North America figures up to 6.9 ppb were found. The mean for 29 samples was 0.84 ppm, but in more than half of these it was not possible to demonstrate the existence of the element (W. H. Durum, written communication, 1960).

MANGANESE

Very little is known about the state of manganese in lake and river waters. Hutchinson (1957), in his account of the limnological behavior of the element, was forced to reason by analogy with its known behavior in soils, taking into account redox conditions prevailing in lakes.

Kleinkopf (1955, 1960), found a range from 0.02 to 87.5 ppb of manganese in 440 lake waters from Maine. The mean was 3.8 ppb. After a few investigations of variations with depth which did not yield positive results, he investigated only surface waters, but other workers have demonstrated very pronounced changes in manganese concentration with depths in stratified lakes. The most common situation appears to be one in which the manganese content is high in the reduced bottom water; it reaches high concentrations at a somewhat shallower depth than iron, presumably because manganous ion is released from the bottom at a slightly higher redox potential than ferrous iron (Hutchinson, 1957, p. 809). A less common situation occurs in some lakes, notably Ranu Klindungan in Java, which has a very pronounced peak in the manganese curve just below the thermocline with lower concentrations in the deep hypolimnion and a much lower content in the surface water. Ruttner (1930) believed that a manganiferous spring was involved in the case of Ranu Klindungan, but in other lakes, such as Schleinsee, Germany, a similar though less pronounced manganese curve appears to be generated by the accumulation of manganese in the unmixed layers just below the level where oxygen is present in amounts sufficient to precipitate manganous ion from solution (Hutchinson, 1957, p. 810).

Ohle (1934) studying lakes in North Germany found a total manganese content between less than 5 and as much as 200 ppb. The mean was 25 ppb. One lake, Trammersee, had a variation in manganese throughout a single year that covered almost the entire range, from less than 5 ppb to 133 ppb. Juday, Birge, and Meloche (1938) found comparable amounts, 3 to 23 ppb in the surface waters of 8 Wisconsin lakes. The deep water of one lake contained 1200 ppb. Uniformly high manganese contents have been recorded for some waters—for example, 50 to 250 (mean of 140 ppb) for Linsley Pond (Hutchinson, 1957, p. 803–804) and 80 to 120 ppb for the Mississippi River at Fairport, Iowa (Wiebe, 1930). The mean for the rivers of the U.S.S.R. is 11.9 ppb (Konovalov, 1959), but the global average is probably somewhat higher.

Lohammar (1938) has provided a very substantial body of information on the manganese content of waters of Sweden. There seems to be a slight difference in the waters of northern and southern Sweden in this respect. In north Sweden the range was >10–460 ppb, with a mean of 33 ppb, and in south Sweden >10–850 ppb, with a mean of 44 ppb. Waters from northern Sweden have a much higher iron content than those from southern Sweden, and there seems very little doubt that the Fe/Mn ratio is significantly higher for the northern (30) than for the southern (5) waters.

Additional data for manganese may be found in papers by Yoshimura (1931a, b), Ruttner (1937), Einsele (1937, 1940), Yatsula (1959), and Harvey (1949) as well as in tables 9, 12, 13, 25–27, 29, 35, 47, 50, 54, 66, 68, 71, and 72 of the general section of this report.

URANIUM

Because of its radioactivity uranium has been the subject of a number of hydrochemical investigations. Some of the results are summarized in table 91. The variation in the uranium content of natural waters is so great that it would be necessary to have information from all the major river systems in order to draw up a reliable mean figure. A number of important rivers seem to contain about 0.1 ppb, but it would not take many like the Danube to raise the world average to Koczy's (1954) estimate of 1 ppb, which seems to be a reasonable figure.

TABLE 91.—*Uranium content of lakes and rivers*

Locality	Uranium (ppb)	Author
Allegheny River, Pa	<2.5	Lynch, *in* Lowder and Solon (1956).
Allegheny River, Pa	<25	Do.
Ohio River, Pa	<2.5	Do.
Chartiers Creek	50	Do.
Monongahela River, Pa	<25	Do.
Great Salt Lake, Utah	5	Kohman and Saito (1954).
Hudson River, N.Y	.022	Rona and Urry (1952).
St. Lawrence River	.016	Do.
Mississippi River	.040	Do.
Various United States rivers:		
Dissolved	.1	Adams, *in* Holland and Kulp (1954).
Total	.6	Do.
Rivers, North America, range	.016–.040	Kohman and Saito (1954).
Rivers, world average	1	Koczy (1954).
Rivers, central Europe	.16–47	Hoffman (1942).
Danube at Vienna	47	Do.
Surface waters, Wisconsin, Illinois, and Texas.	.13–3.5	Judson and Osmond (1955).
Lake Mendota, Wis	.4	Do.

RADIOACTIVE ISOTOPES

The uranium and radium content of lakes and rivers has been dealt with previously (see p. 45, 50). The other elements in the radium and thorium series which have been investigated are thorium, for which Koczy (1954) gives a figure of 0.02 ppb, and radon, for which Jacobi (1949) gives a range from 1.4×10^{-12} to 2.1×10^{-12} ppb. Protactinium–231, which has the next longest half-life, does not seem to have been detected; the same is true of the elements of the actinium series, which are very scarce.

Lowder and Solon (1956, p. 13) have summarized the information about naturally occurring radioisotopes other than those of the series discussed above. Their table, abbreviated to those elements which may be reasonably expected to be present in measurable amounts in lake and river waters, is reproduced in table 92. Isotopic compositions are not, of course, constant, but will depend on the history of the material analyzed. Marguez and Costa (1955) have detected naturally produced phosphorus–32 and Goel and others (1959) have measured phosphorus–32, phosphorus–33, beryllium–17, and sulfur–35 in rain water, so these isotopes probably are to be expected in some lake and river waters also. Data on the tritium content of lakes and rivers have already been presented in table 3.

Some additional information on radioactivity can be found in Hess (1943 and Love (1951).

STABLE ISOTOPES

Apart from hydrogen and oxygen, isotopic ratios are seldom computed for lakes and rivers. It is evident that most, and probably all, chemical elements in the hydrosphere may be expected to show variations in isotopic proportions. Thode, Wanless, and Wallough (1954) have demonstrated bacterial fractionation of sulfur isotopes. Such fractionation must produce important hetereogenities in the isotopic composition of sulfur, especially in deep meromictic lakes. To take another example from the hydrosphere, Cameron (1953) has reported significant variations in the Br^{79}/Br^{81} ratio of a number of water samples from various sources.

TABLE 92.—*Some singly occurring natural radioisotopes of elements that are chemically detectable in lakes or rivers*

Isotope	Relative isotopic abundance (percent)	Half-life (years)	Author
C^{14}	10^{-8}	5,400	Anderson and Libby (1951).
K^{40}	.0119	1.3×10^{9}	Rankama (1954).
V^{50}(?)	.25	$>10^{12}$	Do.
Rb^{87}	27.85	6.1×10^{10}	Flinta and Ecklund (1954).
Sb^{123}(?)	42.75	Very long	Rankama (1954).
I^{129}(?)		1.72×10^{7}	Hollander, Perlman, and Seaborg (1953).

ORGANIC MATTER

The organic content of lake and river waters has been reviewed recently by Hutchinson (1957) and by Vallentyne (1957). Most of what follows is taken from their reviews.

There does not appear to be any standard method for the determination of the total dissolved-organic content of lake waters, although Hutchinson suggests that loss on ignition of a vacuum-dried sample of filtered water with suitable corrections for loss of chloride and of carbon dioxide from alkaline earth carbonates would provide reasonably accurate figures. The prevalent methods of wet oxidation yield values of the total dissolved-organic material that are about 60 percent too low, to judge from one case that has been critically examined (Hutchinson, 1957, p. 879).

Birge and Juday (1934) have provided data on the proximate composition of the dissolved organic matter of lake waters from Wisconsin, and have found a steady increase in the C/N ratio with increasing total and dissolved organic carbon content. Some of their data are summarized in table 93.

From a theoretical analysis of Birge and Juday's results, Hutchinson concluded that the dissolved organic matter in lake waters consists of two fractions, an autochthonous fraction containing about 24 percent crude protein with a C/N ratio of about 12:1, and an allochthonous fraction containing about 6 percent crude protein, with a C/N ratio of 45–50:1.

Vallentyne (1957) believes that there is substantial evidence for the presence of biotin, glucose, sucrose, thiamin, niacin, and vitamin B_{12} dissolved in lake water. In hydrolyzates of dissolved organic matter the amino acids α-alanine, aspartic acid, cystine, glutamic acid, glycine, histidine, tryptophane, and tyrosine have been

TABLE 93.—*Proximate composition of dissolved organic matter from Wisconsin lake waters containing varying amounts of total organic carbon*

[Data of Birge and Juday (1934)]

Carbon content (mg per l)	Organic seston (mg per l)	Dissolved organic matter (mg per l)	Crude protein (percent)	Ether extract (percent)	Carbo-hydrate (percent)	C/N ratio
1.0–1.9	0.62	3.09	24.3	2.3	73.6	12.2
5.0–5.9	1.27	10.33	19.4	1.3	79	15.1
10.0–10.9	1.89	20.48	14.4	.4	85.2	20.1
15.0–15.9	2.32	31.30	12.9	.2	86.9	22.4
20.0–25.9	2.22	48.12	9.9	.2	89.9	29

identified. An early report by Peterson, Fred, and Domogalla (1925) of the presence of free amino acids in lake waters has never been confirmed, although attempts have been made to do so.

The particulate matter of lakes and rivers may be expected to contain all the organic chemicals that are contained in the plants and animals that form a large part of the undissolved organic content of water. Vallentyne lists several dozen molecular species that have actually been identified in the suspended matter or its hydrolyzate. An even larger number of compounds have been identified in sediments.

A very important advance has been made by Shapiro (1957, 1958) who has found up to 5 mg per liter of yellow organic acid in lake water. This material consists of monocarboxylic hydroxy aliphatic organic acids of molecular weight approximately 450. The acids are apparently unsaturated and nonnitrogenous, and they are capable of keeping iron in a nonprecipitatable state at high pH. Lakes of widely different types appear to have a reasonably uniform complement of organic salts or complexes of these acids and the common inorganic ions. Extreme pH values or concentrations of a single ion may modify the exact pattern. Although neither the acids nor their salts have been completely purified as yet, it appears that a very large part of the dissolved organic matter in lake waters may be in the form of a very small number of closely related compounds. These compounds are important as foods to at least some aquatic organisms. They are known to interact with calcium, magnesium, sodium, potassium, and iron and appear to be involved with cobalt, manganese, copper, and zinc as well.

Goryunova (1954) has found a large amount of polysaccharide in the water of Lake Beloye, only a very small amount of which is starch.

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INDEX