NOTES

ON

HYDROLOGY

And the Application of its Laws to the Problems of Hydraulic Engineering

BY

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PREFACE.

These notes are intended to form the basis for an introductory study of the fundamental phenomena of Hydrology, on which the applied science of Hydraulic Engineering should be based.

The volume of literature covering many of the various branches of this subject is very great. Unfortunately, however, there is no single treatise which discusses the entire subject, and which can be utilized as a text-book or reference book, to which the student may turn when investigating the various branches of this science.

The lack of such a work is the reason for the preparation of these notes, which are intended to be used in connection with various publications to which references are given.

From the nature of this subject, it is almost needless to state that very little new or original matter is included in these notes. The principles and laws of Hydrology must, of necessity, be based almost entirely on extended and long-continued observations, consequently the writer has utilized the observations available from a great many sources, and for long periods of time. As far as possible, the sources of the various data, cuts, formula, etc., have been acknowledged, some of the tables have been photographed from other publications, in order to facilitate the publication of these notes (which have been prepared between June and September), hence the typographical work and illustrations are not entirely homogeneous, but the desirable data rather than the typographical method of its presentation has been the main object of this edition.

Daniel W. Mead.

Chicago, Ill., September, 1904.

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CHAPTER I.

INTRODUCTION.

1. **Hydrology.**—The fundamental basis of all hydraulic engineering problems is Hydrology—the science of water. Hydrology in its broadest extent treats of the properties, laws and phenomena of water, of its physical, chemical and physiological relations, of its distribution and occurrence over the earth's surface and within the geological strata, and of its sanitary, agricultural and commercial relations.

The subject may be considered under several heads:

First. Descriptive Hydrography, treats of the oceans, lakes, rivers, and other waters, with special reference to their relations to sanitation and their use for agriculture, navigation and commerce.

Second. Hydrogeology, treats of the geology of water, and includes that part of geological science which has to do with the relation of water occurring on or within the structure of the earth, and its relations to the earth's structure.

Third. Hydrometeorology, treats of the science of meteorology, with special relation to the water in the atmosphere, its precipitation and evaporation, and the relations of these factors to the structural condition of the earth's surface.

Fourth. Hydrometry, treats of the measurement of waters.

Fifth. Hydromechanics, is that branch of mechanics which treats of the laws of equilibrium and motion of water or other fluids.

Sixth. Hydraulic Engineering, includes those branches of engineering practice which have to do with the design and construction of structures and works for the utilization and control of water for the use and benefit of mankind.

2. Necessity for General Knowledge of Hydrology.—At least a limited understanding of hydrological principles is prerequisite to the successful solution of the simplest problems in hydraulic engineering. For the purpose of investigating the more complicated problems a more detailed knowledge of this science is essential, and the more extended the knowledge of this subject, the greater the assurance of the successful solution of all such problems.

A knowledge of construction, which, for hydraulic engineering purposes, must include a knowledge of hydromechanics, has been sometimes considered all that is essential for the success of hydraulic works.

Hydrography, hydrogeology, and hydrometeorology have been frequently neglected, and the result has often been stable construction but practical failure in the ultimate object which it was intended to achieve.

Each essential feature in the design of any engineering work must be understood, and the importance of each feature must be carefully considered and thoroughly appreciated in order to achieve the greatest measure of success.

3. Failures Due to Lack of Hydrological Knowledge.—Failures more or less serious have resulted, from the neglect to investigate the primary hydrological conditions, and to appreciate the importance of fundamental hydrological knowledge, in almost every branch of hydraulic engineering. Water power installations have been built without sufficient knowledge of the regime of the stream on which their success depended, with resulting failures more or less serious.

Public water supply systems have been designed and constructed to utilize supplies of water which have later been found much too limited for the purpose for which they were intended to be utilized, and expensive changes in the works have thus been made necessary; or such works have been constructed in locations where the supplies have afterwards been found to be polluted and undesirable, with similar expensive results.

Cities have been founded in needlessly exposed positions, and left unprotected, or so poorly protected as to be subject to great financial damage and loss of life from floods.* Extensive damages have also been caused to farm and agricultural communities from similar causes.

Great losses have been sustained, property ruined, and unsanitary conditions created by the overflow of storm water from sewers and drains of improper design. Dams and reservoirs have washed out because of the insufficient provision of spillways, or insufficient knowledge of the underlying geological strata and of its improper protection.** Bridges have been destroyed, and adjacent property flooded and damaged because of the provision of insufficient waterways. Large and needless expenditures have been made for irrigation projects, where insufficient supplies of water were obtainable. Many of these unfortunate results have been due to the lack of investigation, and of a thorough understanding of the fundamental knowledge, which it is the province of hydrology to discuss.

4. Variations in Hydrological Phenomena.—Much of the fundamental data which must be considered in these problems is exceedingly variable, much more so, in fact, than the ordinary observer would suspect. It is a common idea that taking the season through, the average rainfall is practically the same for each year, and the cursory observer is apt to draw similar conclusions in regard to the annual flow of streams. Extended observations will show that such is not the case, and that these phenomena vary almost as widely as many of the meteoric phenomena, on which to a considerable extent, they depend.

The uncertainty of many meteoric phenomena is proverbial. The great variation in the character of the season throughout a period of years is very marked. The irregularity in the occurrence of rain and snow, of storms and sunshine, is

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* Report on the Protection of the City of Elmira, N. Y., against Floods. By F. Collingwood. Report Feb. 12th, 1890. Prevention of Floods in Stoney Brook. Boston City Document, No. 159, p. 89. The Lesson of Galveston. W. J. McGee. Nat. Geo. Mag., Oct., 1900. Destructive Flood in the U. S. in 1903. E. C. Murphy. Water Supply Paper No. 96.

** Johnstown Flood. See Eng. News, June 1st, 8th, 15th and 22nd, July 13th and August 17th, 1889. The Austin Dam. Prof. T. U. Taylor. Water Supply Paper No. 40.

a matter of common observation. The observer is therefore naturally led to expect that other phenomena, dependent largely or partially on meteoric conditions will be subject to a similar variation, and be equally uncertain.

A few casual observations, in which these great variations are seen, might lead to the belief that meteoric phenomena follow no law, or at least follow laws so complicated and involved as to be hopelessly obscure. They might also lead the observer to the conclusion that no ascertainable relation existed between the rainfall and stream flow, or between other inter-dependent hydrological phenomena.

Accurate and continuous observations, however, show that while great variations exist, they are limited in character and extent, and that the mutual relations between the various factors of hydrology and meteorology, while complicated, are nevertheless fixed, and by extended observation can be rendered sufficiently determinate to enable valuable deductions to be based on them.

5. **Factors of Safety in Engineering Work.**—In all engineering work the lack of exact information, as to the actual conditions which will prevail, and which will influence the character and usefulness of a structure during its life, requires that, in order to provide for unforeseen contingencies, a factor of safety shall be used, and the structure is made much stronger than the average condition would apparently make necessary. If in many hydraulic problems a similar factor were considered, it would be seen that the probable inaccuracies are much less than in many other engineering works, and although there is much chance for improved designs, and much need of extended observations and research, yet the applied science of hydraulic engineering is, in exactness, fully abreast with most other branches of engineering.

6. **Fundamental Laws Fixed.**—While the fundamental laws of hydrology are unchanging, the factors which control its phenomena are so numerous that they result in wide variations in the relation of similar phenomena in different localities. As with all physical phenomena, similar causes, when acting under similar conditions, produce similar results, but

the causes, and the varying conditions under which they act, must be carefully investigated and thoroughly understood, in order that the result may be rightly anticipated. With the great variation in the circumstance of occurrence, it is therefore unsafe to apply data obtained from one locality, under one set of conditions, without modifications, to an entirely different locality with radically different conditions, and expect similar results.

7. **Complexity of Factors.**—The geological, topographical and meteorological conditions often vary, to a considerable extent, with every degree of latitude or longitude, or even with less extended differences in locality, and each location has, therefore, to a limited extent, laws unto itself, which must be investigated and determined before correct conclusions can be drawn. There are, however, geographical limits, where similar physiographical and climatic conditions prevail, and where hydrological conditions are so similar that conclusions based on the data of one locality, can be applied, with only slight modifications, to other localities within such limits. If this were not the case, a science of hydrology would be impossible.

8. **Purpose of Study.**—It is particularly to the study of these geographical limits, as well as to the study of the laws and relations of hydrological phenomena, that attention should be given. For this reason it is the purpose of these notes to outline,

First. The study of general physiographic features of the earth, and their general hydrographic relations.

Second. The study, in a more specific way, of the physiographical and hydrological conditions of the United States. And,

Third. The study, in greater detail, of the hydrology of certain localities, where certain important laws are perhaps best exemplified.

It is the further purpose of these notes to emphasize more particularly the most desirable lines for hydrological study, and the necessary or desirable direction and extent of hydrological investigations, and to give such references as shall indicate the work which has been already done in this field, and the sources from which available information and detailed data may be obtained.

LITERATURE.

The most important literature relating to Hydrology will be found in the publications of the United States Geological Survey. It is contained in the Annual Reports, Bulletins, Professional Papers and Water Supply and Irrigation Papers; also in the Annual Reports of the Reclamation Service.

The Bulletins and Monthly Weather Review of the United States Weather Bureau also contain much of value on this subject. Much special information is also contained in the Annual Reports of the Chief Engineer of the U. S. Army, The Annual Reports of the Mississippi River Commission, and in numerous special Reports to Congress.

Detailed reference to the principal publications will be found under the special chapter to which the subject matter of these publications more especially refer.

CHAPTER II.

WATER.

9. **Water.**—Water was considered to be an element or primary form of matter until about 1783, when the fact of its composition was determined by the experiments of Watt, Cavendish and Lavoisier.*

Water occurs in nature in solid, liquid and gaseous form, within a range of ordinarily observed temperatures. There are four critical temperatures for water, viz.:

32° F., or 0° C., at which pure water freezes or solidifies under one atmosphere pressure.

39.2° F., or 4° C., which is the approximate point of maximum density of pure water.

62° F., or 16.67° C., which is the British Standard temperature.

212° F., or 100° C., which is the boiling point of pure water under one atmosphere pressure.

62° F. is the temperature of water used as a basis in calculating the specific gravity of bodies in England and America.

Water is never found in nature in a chemically pure state on account of its high solving and transporting properties, but always contains other forms of matter, to a greater or less degree, either in a state of solution or suspension.

10. **Density of Water.**—The density of water, or its relative weight and volume, depends on its purity and temperature.

The relative density, expansion and weight of water at various temperatures is shown in Table 1.

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* See James Watt and the Discovery of the Composition of Water, by Prof. T. E. Thorpe. Sci. Am. Sup. No. 1179, Aug. 6th, 1898.

TABLE 1.

TABLE OF DENSITY, EXPANSION AND WEIGHT OF PURE WATER AT VARIOUS TEMPERATURES.

TEMPERATURE		RELATIVE		WEIGHT IN POUNDS	
C.	F.	VOLUME	DENSITY	PER CUBIC FOOT	PER U. S. GALLON
10	14.0	1.00185	.998146	62.279	8.3357
9	15.8	1.00163	.998371	62.293	2 8.3275
8	17.6	1.00137	.998628	62.310	8.3297
7	19.4	1.00114	.998865	62.324	8.3316
6	21.2	1.00092	.999082	62.338	8.3333
5	23.0	1.00070	.999302	62.352	8.3353
4	24.8	1.00056	.999437	62.360	8.3364
3	26.6	1.00042	.999577	62.369	8.3375
2	28.4	1.00031	.999692	62.376	8.3385
1	30.2	1.00021	.999786	62.382	8.3394
0	32.	1.00012	.999877	62.389	8.3401
1	33.8	1.00007	.999930	62.392	8.3405
2	35.6	1.00003	.999969	62.394	8.3407
3	37.4	1.00001	.999992	62.395	8.3409
4	39.2	1.00000	1.000000	62.396	8.3411
5	41.	1.00001	.999994	62.397	8.3409
6	42.8	1.00003	.999973	62.394	8.3407
7	44.6	1.00006	.999939	62.393	8.3406
8	46.4	1.00011	.999890	62.389	8.3402
9	48.2	1.00017	.999829	62.384	8.3399
10	50.	1.00025	.999753	62.380	8.3390
11	51.8	1.00034	.999664	62.375	8.3383
12	53.6	1.00044	.999562	62.368	8.3374
13	55.4	1.00055	.999449	62.362	8.3365
14	57.2	1.00068	.999322	62.354	8.3354
15	59.	1.00082	.999183	62.345	8.3342
16	60.8	1.00097	.999032	62.336	8.3330
16.67	62.	1.001078	.9989232	62.329	8.3322
17	62.6	1.00113	.998869	62.326	8.3317
18	64.4	1.00131	.998695	62.315	8.3302
19	66.2	1.00149	.998509	62.304	8.3287
20	68.	1.00169	.998312	62.291	8.3270
21	69.8	1.00190	.998104	62.278	8.3253
22	71.6	1.00212	.997886	62.265	8.3234
23	73.4	1.00235	.997657	62.250	8.3215
24	75.2	1.00259	.997419	62.235	8.3196
25	77.	1.00284	.997170	62.220	8.3174
26	78.8	1.00310	.996912	62.204	8.3153
27	80.6	1.00337	.996664	62.186	8.3130
28	82.4	1.00365	.996367	62.169	8.3107
29	84.2	1.00393	.996082	62.151	8.3083
30	86.	1.00423	.995786	62.132	8.3058
35	95.	1.00583	.994170	62.032	8.2933
40	104.	1.00765	.99235	61.919	8.2773
45	113.	1.00967	.99034	61.792	8.2605
50	122.	1.01189	.98811	61.654	8.2419
55	131.	1.01423	.98578	61.508	8.2224
60	140.	1.01671	.98329	61.353	8.2017
65	149.	1.01943	.98057	61.183	8.1790
70	158.	1.02237	.97763	61.000	8.1544
75	167.	1.02547	.97453	60.807	8.1287
80	176.	1.02871	.97129	60.605	8.1016
85	185.	1.03202	.96798	60.398	8.0740
90	194.	1.03552	.96448	60.180	8.0448
95	203.	1.03922	.96078	59.949	8.0141
100	212.	1.04311	.95689	59.705	7.8981
120	248.	1.05992	.94008	58.657	7.8412
140	284.	1.07949	.92051	57.436	7.6781
160	320.	1.10149	.89851	56.063	7.4946
180	356.	1.12678	.87322	54.485	7.2836
200	392.	1.15899	.84101	52.476	7.0149

This table is partially derived from Kopp's Table, with interpolations by Oldberg.* The figures for density and expansion below zero ° C. are from determinations by M. Despretz, and those at temperatures above the boiling point are from experiments by Hirn.

11. **Expansion of Water.**—The determinations of the expansion of water at various temperatures by various observers is given in Table 2, which is taken from a paper by Alex Morton.**

The differences in these observations are due to the personal errors to which all such observations are subject.

Morton offers a formula, based on the mean value of these various determinations (See Column eleven, Table 2), from which formula Column twelve in this table is calculated.

This formula, arranged for Fah. degrees, is as follows:

$$V = \frac{a\,t + b\,t^2 + c\,t^4}{T^2}$$

T=the absolute temperature measured from 461.2° F. below 0° F.

t=the temperature measured from that of maximum density 39.2° F.

V=the volume of water—the volume at maximum density being equal to 1.0000.

Constants.

a=0.2863

b=0.5726

c=0.0000026913

The expansion of water, and the relative weights of one cubic foot at various temperatures, based on this formula, are shown graphically in Diagram I.

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* See Weights and Measures, Oldberg, page 163; also the Density of Water at different temperatures, A. F. Nagle; Vol. 13, Trans. Am. Soc. M. E., page 396.

** On the Expansion of Water, Alex. Morton. Van Nostrand's Eng. Mag., p. 436, Vol. 7.

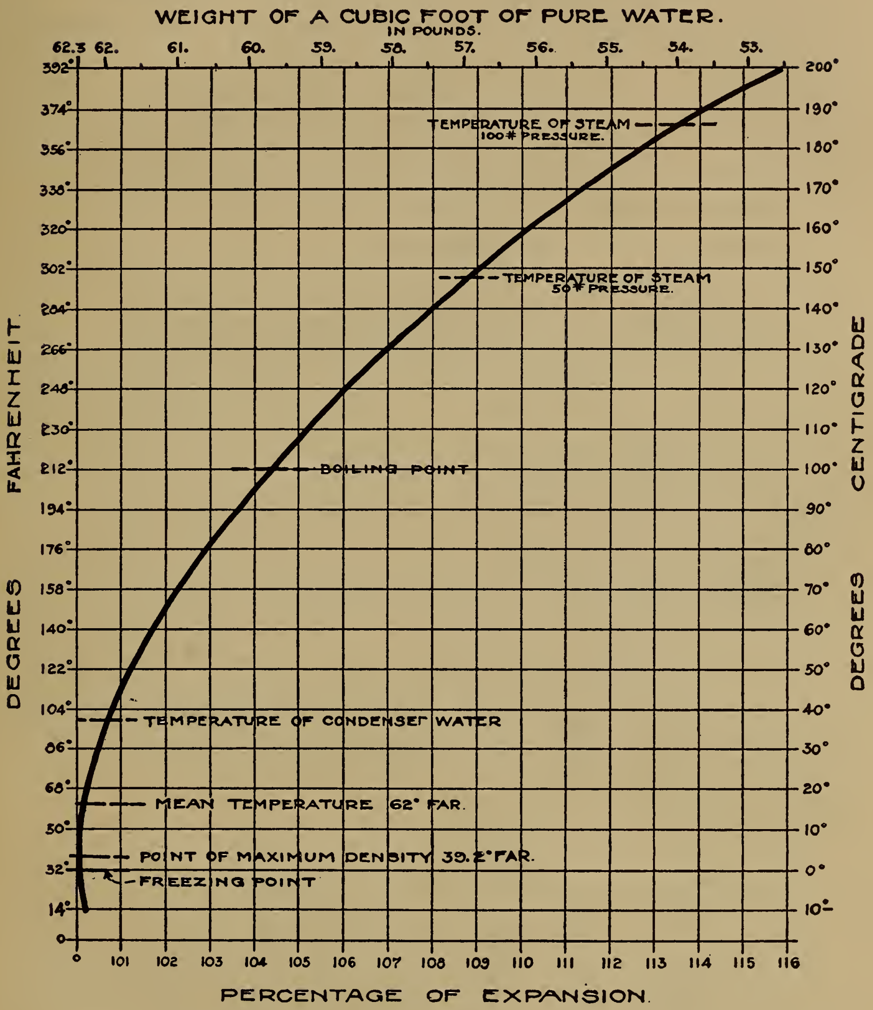
TABLE 2.

Expansion of Water, according to various abserves.

Temperature Centigrade.	Temperature Fahrenheit.	Kopp. 1847.	Is Pierre. 1845-52.	Despretz. 1839.	Hagen. 1865.	Matthiessen. 1866.	Rosetti.		Weidner. 1866.	Mean values.	By Formula.
							1866.	1868.			
-10	14.0	....	1.001804	....	....	....	....	....	1.001904	1.001854	....
- 8	17.6	....	1.001272	1.001373	....	....	....	....	1.001346	1.001330	....
- 6	21.2	....	1.000866	1.000918	....	....	....	....	1.000893	1.000892	....
- 4	24.8	....	1.000557	1.000562	....	....	....	1.000516	1.000549	1.000546	1.000521
- 2	28.4	....	1.000317	1.000308	....	....	....	1.000296	1.000302	1.000308	1.000300
0	32.0	1.000123	1.000119	1.000137	1.000127	....	1.000134	1.000136	1.000137	1.000130	1.000130
1	33.8	1.000070	1.000065	1.000078	1.000069	....	1.000073	1.000075	1.000081	1.000072	1.000074
2	35.6	1.000031	1.000028	1.000033	1.000029	....	1.000033	1.000032	1.000040	1.000032	1.000034
3	37.4	1.000008	1.000007	1.000008	1.000006	....	1.000008	1.000008	1.000014	1.000008	1.000009
4	39.2	1.000000	1.000001	1.000000	1.000001	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
5	41.0	1.000006	1.000007	1.000008	1.000010	1.000006	1.000006	1.000006	....	1.000008	1.000009
6	42.8	1.000026	1.000034	1.000031	1.000034	1.000028	1.000027	1.000029	....	1.000030	1.000033
7	44.6	1.000061	1.000072	1.000071	1.000072	1.000066	1.000062	1.000058	....	1.000066	1.000071
8	46.4	1.000109	1.000123	1.000122	1.000125	1.000119	1.000109	1.000106	....	1.000116	1.000123
10	50.0	1.000247	1.000267	1.000268	1.000269	1.000271	1.000250	1.000246	....	1.000260	1.000267
12	53.6	1.000437	1.000461	1.000472	1.000464	1.000479	1.000450	1.000443	....	1.000458	1.000464
14	57.2	1.000679	1.000707	1.000715	1.000709	1.000742	1.000700	1.000691	....	1.000706	1.000710
16	60.8	1.000969	1.000998	1.001021	1.001001	1.001054	1.000990	1.000992	....	1.001004	1.001005
18	64.4	1.001307	1.001331	1.001390	1.001339	1.001412	1.001350	1.001346	....	1.001354	1.001346
20	68.0	1.001690	1.001713	1.001790	1.001721	1.001814	1.001750	1.001742	....	1.001746	1.001732
24	75.2	1.002589	1.002584	1.002710	1.002612	1.002731	1.002660	1.002620	....	1.002644	1.002631
28	82.4	1.003689	1.003613	1.003741	1.003666	1.003780	1.003700	1.003661	....	1.003681	1.003690
32	89.6	1.004816	1.004804	1.004940	1.004872	1.004981	1.004870	1.004889	....	1.004874	1.004899
36	96.8	1.006172	1.006142	1.006240	1.006223	1.006261	1.006190	1.006275	....	1.006215	1.006249
40	104	1.007632	1.007682	1.007730	1.007711	1.007730	1.007690	1.007738	....	1.007695	1.007733
45	113	1.009665	1.009683	1.009850	1.009756	1.009751	1.009710	1.009708	....	1.009712	1.009765
50	122	1.011891	1.011936	1.012050	1.011994	1.011969	1.011841	1.011907	....	1.011941	1.011983
55	131	1.014225	1.014480	1.014450	1.014415	1.014376	....	1.014307	Kremers. 1861.	1.014375	1.014379
60	140	1.016715	1.017232*	1.016980	1.017009	1.016964	....	1.016867	1.016988	1.016919	1.016945
65	149	1.019428	1.020068*	1.019670	1.019764	1.019724	....	1.019602	....	1.019636	1.019675
70	158	1.022372	1.023059*	1.022550	1.022675	1.022648	....	1.022529	....	1.022555	1.022565
75	167	1.025672	1.026200*	1.025620	1.025734	1.025727	....	1.025615	....	1.025674	1.025610
80	176	1.028708	1.029483*	1.028850	1.028933	1.028953	....	1.028836	1.028938	1.028869	1.028870
85	185	1.032021	1.032892*	1.032250	1.032661	1.032318	....	1.032211	....	1.032212	1.032162
90	194	1.035525	1.036413*	1.035660	1.035766	1.035813	....	1.035162	....	1.035675	1.035666
95	203	1.039222	1.040043*	1.039250	1.039287	1.039429	....	1.039298	....	1.039297	1.039322
100	212	1.043125	1.043773*	1.043150	1.042969	1.043159	....	1.043116	1.043100	1.043130	1.043130
Temperature Centigrade of maximum density		4°.08	3°.86	4°.00	38.87	4°.00	48.07	4°.04	4°.00	4°.00	4°.0 Cent., or 89.2 Fah.

DIAGRAM 1.

EXPANSION CURVE OF PURE WATER.



12. **Weight of Water.**—The determination of the weight of water is also subject to similar errors of observation.

Determination of the weight of pure water by various observers are shown in Table 3.

The maximum variation in these weights is inconsiderable, and usually of little practical importance, being only about .05 of one per cent.

For ordinary hydraulic computations the small importance of such differences becomes more obvious when we consider the great variation in the weight of water, as ordinarily encountered by the engineer, and which is caused by matter in solution and suspension. These factors are often unknown and usually neglected in actual practice. Variations of one or two per cent. are usually of little importance in practical work, but may become so under some conditions.

TABLE 3.

WEIGHTS OF WATER, ACCORDING TO VARIOUS OBSERVERS.

Authority	Weight of a cubic inch at 62° Fah. in grains	Weight per cubic ft. at 62° Fah.	Weight per cubic ft. at 39°.2 Fah.
W. J. M. Rankin	252.595	62.355	62.425
Act of Parliament	225.458	62.322	62.388
H. J. Cheney	252.286	62.279	62.440
English Board of Trade		62.2786	62.348
F. A. P. Barnard *	252.488	62.329	62.396

13. **Units of - Measurement.**—Water may be measured in many units. The equivalents of the principal ones which are liable to be encountered or used in the practice of the engineer, are given in Table 4.

EQUIVALENT MEASURES AND WEIGHTS OF WATER AT 4° CENTIGRADE—39.2° FAHRENHEIT.

U. S. Gallons	Imperial Gallons	Liters	Cubic Meters	Pounds	Cubic Feet	Cubic Inches	Circular Inch 1 Foot Long
1	.83321	3.7853	.0037853	8.34112	.13368	231	24.5096
1.20017	1	4.54303	.004543	10.0108	.160439	277.274	29.4116
.264179	.22012	1	.001	2.20355	.035316	61.0254	6.4754
264.179	220.117	1000	1	2203.55	35.31563	61025.4	6475.44
.119888	.099892	.453813	.0004538	1	.0160266	27.694	2.9411
7.48055	6.23287	28.3161	.0283161	62.3961	1	1728	183.346
.004329	.003607	.0163866	.0000164	.0361089	.0005787	1	.10613
.0408	.034	.1544306	.0001544	.340008	.005454	9.4224	1

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* F. A. P. Barnard, "The Metric System," Boston, 1879, p. 174.

TABLE 5

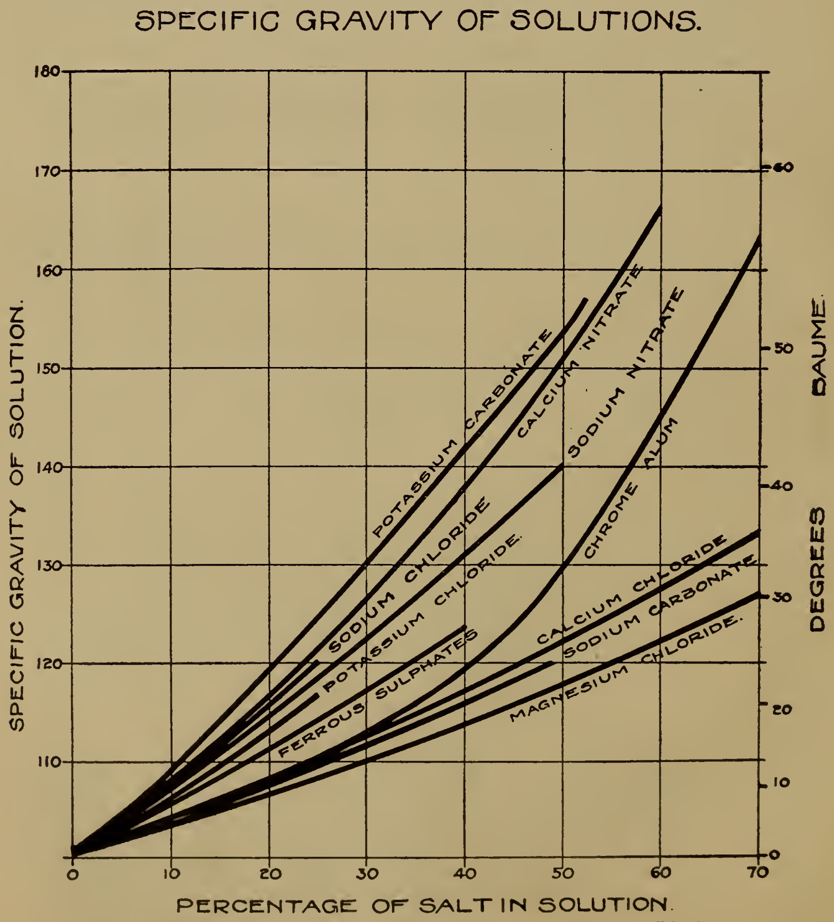
SPECIFIC GRAVITY AND WEIGHTS OF NATURAL WATERS.

Location	**Source**	Mineral Matter Grains per Gallon	Specific Gravity	**Weight at 62° F.**		**Authority**
				Per Cu. Ft.	Per U. S. Gal.	
	Pure Water	0.00	1.00000	62.329	8.3322	
Springs and Wells—						
Saline County, Mo.	Salt Spring	1183.88	1.0150	63.264	8.4572	Missouri Geo. Survey, Vol. III
Saline County, Mo.	Blue Lick Spring	658.61	1.0071	62.772	8.3914	" " " " "
St. Louis, Mo.	Belcher Deep Well	550.26	1.0059	62.697	8.3814	" " " " "
Clinton, Mo	Artesian Well	106.25	1.0009	62.385	8.3397	" " " " "
Louisiana, Mo.	Artesian Well	545.71	1.0071	62.772	8.3914	" " " " "
Brunswick, Mo.	Artesian Well	929.01	1.0138	63.189	8.4472	" " " " "
Lebanon, Mo.	Magnetic Well	16.71	1.0002	62.341	8.3339	" " " " "
Denver, Colo.	Spring	3538.66	1.063	66.256	8.8571	Eakins U. S. Geo. Survey
Mountain City, Tenn.	Grau Spring	67.12	1.00038	62.353	8.3354	Chatard U. S. Geo. Survey
Oceans and Lakes—						
Atlantic	....	....	1.0275	64.043	8.5613	Chandler
Gulf of Mexico	....	....	1.0252	63.9	8.5422	Merriman
Utah	Great Salt Lake	....	1.17	72.925	9.7487	Chandler
California	Mono Lake	3028.71	1.045	65.134	8.7071	Chatard U. S. Geo. Survey
Nevada	Large Soda Lake	7309.22	1.101	68.624	9.1738	" " " "
Dead Sea	....	....	1.172	73.05	9.7653	Watt's Dict. of Chemistry
Lake Erie	....	....	1.000107	62.336	8.3331	Chandler
Lake Michigan	....	....	1.000113	62.336	8.3331	"
California	Owens Lake	4300.95	1.0625	66.225	8.8530	Chatard U. S. Geo. Survey
Yellowstone Park	Yellowstone Lake	10.07	1.00014	62.338	8.3334	Bulletin 47, U. S. Geo. Survey
Rivers—						
Mississippi River	....	....	1.00006	62.333	8.3327	Chandler
Philadelphia	Schuylkill River	....	1.00068	62.371	8.3379	"
Delaware River	....	....	1.000059	62.333	8.3327	"
New York	Croton River	....	1.00008	62.334	8.3329	"
Boston	Cochituate River	....	1.000053	62.332	8.3326	"
England	Thames at Twickenham	....	1.0003	62.348	8.3347	Watt's Dict. of Chemistry
France	Seine above Paris	....	1.000151	62.338	8.3335	Chandler
France	Garrone	....	1.000149	62.338	8.3334	Boisgaraud (D'Aubuisson)
Yellowstone Park	Hot River	101.71	1.00157	62.427	8.3453	Bulletin 47 U. S. Geo. Survey
Yellowstone Park	Fire Hole River	25.46	1.00031	62.342	8.3348	" " " " "

14. Specific Gravity of Waters.—As water takes into solution various substances with which it comes in contact, or when it carries in suspension large quantities of foreign matter, its relative weight is materially increased.

In Table 5 are given the relative specific gravities and weights of various natural waters.

15. Relation of Mineral Matter to Specific Gravity of Water.—The effect of varying amounts of mineral matter on the specific gravity of water is graphically shown in Diagram 2.*



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* R. K. Mead, Chemists' Pocket Manual.

These curves are each drawn for a particular temperature, but the temperature is not uniform for all curves.

The temperature for which each curve is drawn is as follows:

Calcium nitrate	17.5° C.
Calcium chloride	18.3° C.
Chrome alum	17.5° C.
Ferrous sulphate	15.° C.
Magnesium chloride	24.° C.
Potassium carbonate	15.° C.
Sodium carbonate	23.° C.
Sodium chloride	15.° C.
Sodium nitrate	25.2° C.

16. **Weight of Natural Water.**—From Table 5, it will be noted that, under ordinary conditions, the waters of springs and rivers will weigh between 62.3 and 62.5 lbs. per cubic foot, depending upon the amount of impurities and on the temperature of the water. The waters of some mineral springs are found to weigh as high as 63.3 lbs. per cubic foot, sea water reaches 64 lbs. per cubic foot, and the water of the Dead Sea reaches 73 lbs. per cubic foot. For ordinary computations, therefore, 62.4 or 62.5 lbs. per cubic foot may be used. 62.5 is sometimes a convenient number for a computation as it equals 1000 ounces avoirdupois.

17. **Solution.**—All natural waters however free from visible impurities, contain in solution more or less of the various substances which they have encountered in their natural history, and which, under ordinary circumstances, may be solid, liquid, or gaseous.[*]

The laws governing the solution of solids are as follows:

First, the quantity of a solid which may be dissolved by a liquid is fixed and limited, and is always the same at the same temperature.

Second, a liquid saturated by the solution of one solid is capable of dissolving another.

Third, the solubility of a solid increases with the temperature.

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[*] See Water Supply. William Ripley Nichols. Introductory Chapter, p. 16.

There are, however, some exceptions to the third law, as will be noted by reference to Diagram 4.

Diagram 3 and Diagram 4 are graphical representation of the relative solubility of various salts at different temperatures.

DIAGRAM 3.

CURVES OF SOLUBILITY

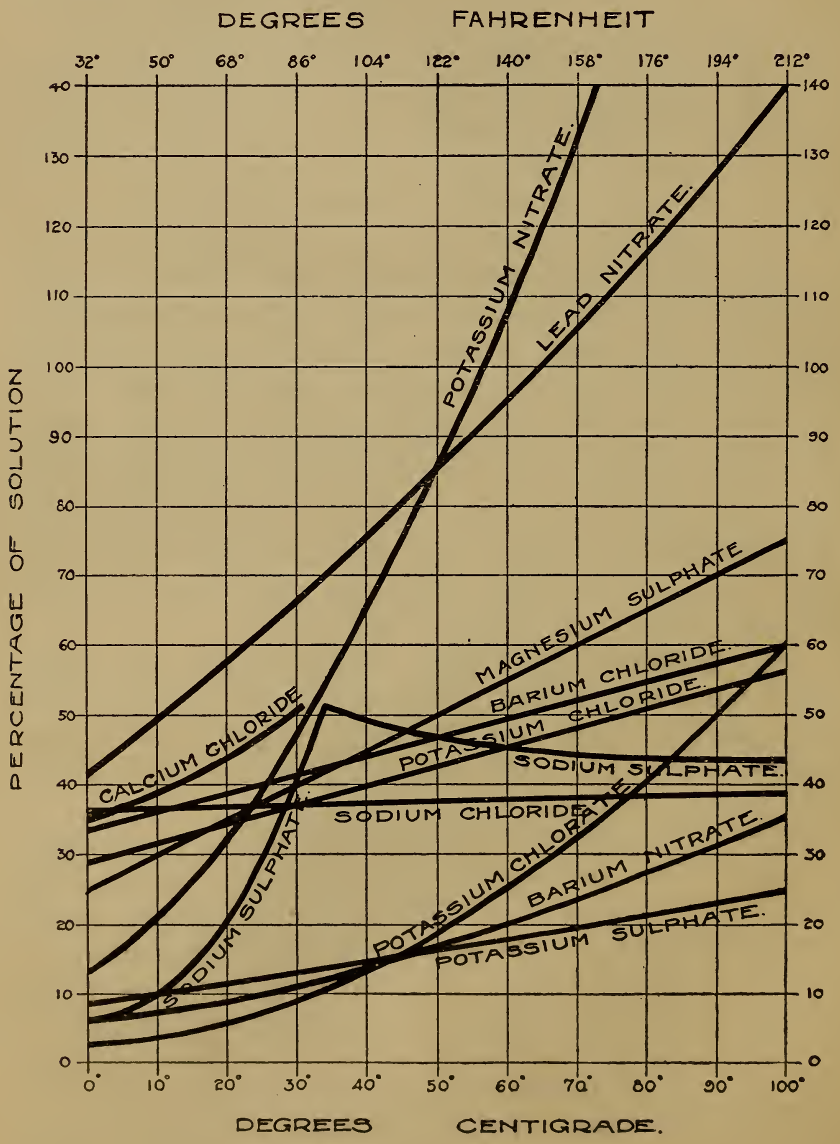
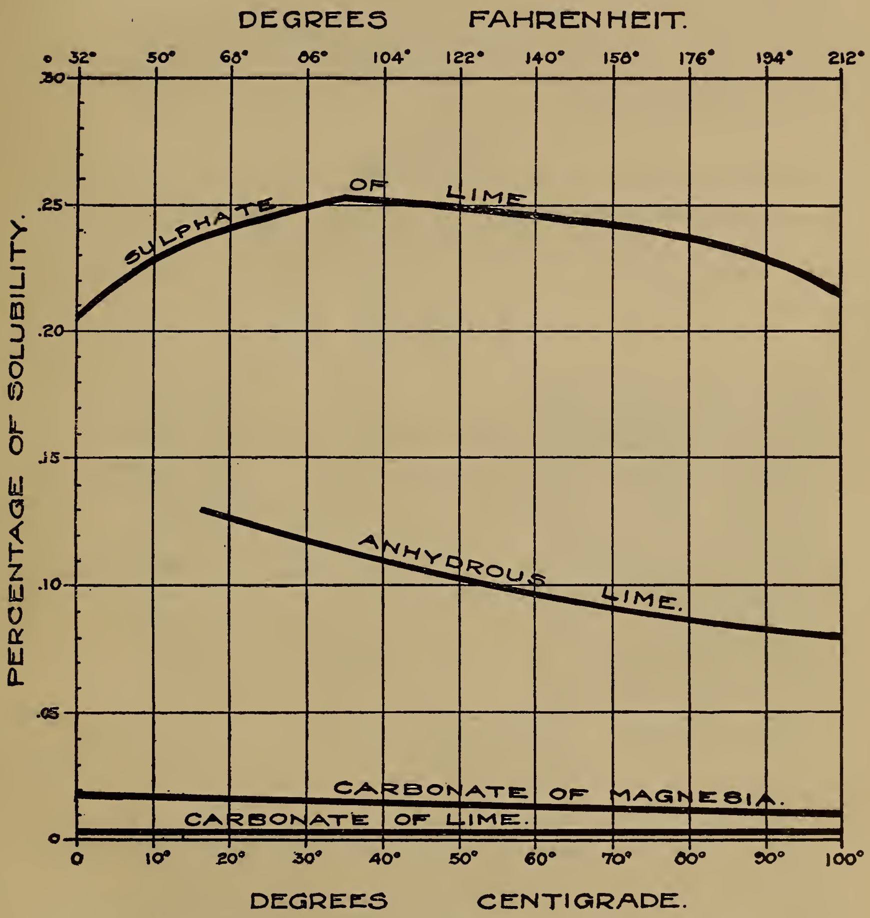


DIAGRAM 4.

CURVES OF SOLUBILITY
OF
SLIGHTLY SOLUBLE SALTS.



18. **Solution of Gases.**—The solution of gases, where no chemical reaction takes place, is subject to the following laws:

First, at a given temperature and pressure a liquid will always dissolve the same quantity of gas.

Second, the volume of gas dissolved is in proportion to the atmospheric pressure.

Third, Mixed gases are dissolved as though each gas were separate.

Rain water always contains in solution a certain amount of the natural gases of the atmosphere, which are, however, dissolved, not in proportion to their occurrence in the atmosphere, but more nearly to the solubilities of the gases.

In artesian water oxygen is seldom present. Spring and ground waters are usually deficient in oxygen.

Deep waters and waters of springs which have been under pressure carry in solution larger percentages of carbonic acid gas than normal waters.

TABLE 6.

GASES CARRIED IN SOLUTION BY VARIOUS SPRING AND ARTESIAN WATERS, CUBIC INCHES PER GALLON.

	Oxygen	Nitrogen	Carbonic Acid	Sulphuretted Hydrogen	Authority
Albany, N. Y. (Artesian Well)			184.00		Wm. Mead
Balston, N. Y. (Lithia Spring)			426.11		F. Chandler
Avon, N. Y. (Sulphur Spring)	.97	3.88	22.04	27.63	H. M. Baker
Saratoga,N.Y.(ColumbiaSpg.)			272.06		John H. Steele
Bedford, Va. (Spring)	1.32	3.33	6.98		Wm. Gilham
Salt Sulphur Spring, W. Va.			34.56	19.12	D. Stuart
Athens, Ga. (Helicon Spring)	3.12	10.98	5.97		H. C. White
Talladega Spring, Alabama			......	82.00	W. C. Stubbs
Blue Lick Spring, Ky.			60.11	10.24	J. F. Judge & A. Fennel
Versailles, Ill. (Magnetic Spg.)			24.00		G. A. Mariner
Alpena, Mich. (" Well)		.24	8.40	35.36	S. P. Driffield
Lansing, Mich. " "			235.55		Dr. Jennings
Ems. Germany, (Springs)			117.81		
Carlsbad, Bohemia (Springs)			134.98		

The quantity of dissolved gases in a water affords, to some extent, a measure of its natural history, and also of its sanitary condition.

The following is the analysis of the Thames River, England, by Professor Miller, and shows the cubic centimeters of dissolved gases per litre.*

Location	Carbonic Acid Gas	Oxygen	Nitrogen
Kingston	30.3	7.4	15
Hammersmith	......	4.1	15.1
Somerset House	45.2	1.5	16.2
Greenwich	55.6	.25	15.4
Woolwich	48.3	.25	14.5

*See Parkes Manual of Practical Hygiene. Vol. 1, P. 75.

The above shows how the dissolved gases vary as the waters become contaminated, the carbonic acid gas increasing, the oxygen diminishing, the nitrogen remaining stationary. The same result is seen in the following analysis of the dissolved oxygen of the Seine above and below Paris, given in cubic centimeters per litre.*

Corbeil	(above Paris)	9.32
Antenil	(below the city, but above the sewer outlets)	5.99
Epinay,	(below all sewers)	1.05
Point de Passy,	(47 kilometers from last place named)	6.12
Mantes	(31 kilometers from above)	8.96
Verccon,	(41 kilometers from above)	10.40

The percentages of solution of various gases at various temperatures, as determined by Bunsen and Carius, is shown in Table 7.

TABLE 7.

Temperature.	Oxygen.	Nitrogen.	Air.	Carbonic Acid.	Hydrogen.	Ammonia.
0	0·04114	0·02035	0·02471	1·7967	0·01930	1049·6
1	0·04007	0·01981	0·02406	1·7207	"	1020·8
2	0·03907	0·01932	0·02345	1·6481	"	993·3
3	0·03810	0·01884	0·02287	1·5787	"	967·0
4	0·03717	0·01838	0·02237	1·5126	"	941·9
5	0·03628	0·01794	0·02179	1·4497	"	917·9
6	0·03544	0·01752	0·02128	1·3901	"	895·0
7	0·03465	0·01713	0·02080	1·3339	"	873·1
8	0·03389	0·01675	0·02034	1·2809	"	852·1
9	0·03317	0·01640	0·01992	1·2311	"	832·0
10	0·03250	0·01607	0·01953	1·1847	"	812·8
11	0·03189	0·01577	0·01916	1·1416	"	794·3
12	0·03133	0·01549	0·01882	1·1018	"	776·3
13	0·03082	0·01523	0·01851	1·0653	"	759·6
14	0·03034	0·01500	0·01822	1·0321	"	743·1
15	0·02989	0·01478	0·01795	1·0020	"	727·2
16	0·02949	0·01458	0·01771	1·9753	"	711·8
17	0·02914	0·01441	0·01750	0·9519	"	696·9
18	0·02884	0·01426	0·01732	0·9319	"	682·3
19	0·02858	0·01413	0·01717	0·9150	"	668·0
20	0·02838	0·01403	0·01704	0·9014	"	654·0

19. Condition of Mixed Solutions.—The presence of certain substances in solution sometimes modify the solving qualities of a liquid in regard to other substances. Carbonic acid gas has a marked action in increasing the solubility of certain salts, as shown by Table 8.

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*See Nichols' Water Supply, P. 61.

TABLE 8.

PER CENT. OF SOLUBILITY OF SALTS IN WATERS UNDER VARIOUS CONDITIONS.

	Pure Water, at 32° F.	Carbonated Water	Pure Water, at 212° F.	Insoluble at
Carbonate of Lime....	.0016	.67	.0016	302° F.
Sulphate of Lime......	.2	.....	.22	302° F.
Carbonate of Magnesia	.0182	·67	.0104	
Phosphate of Lime....	.....	.075	.....	212° F.
Oxide of Iron.	.....	.....	.....	212° F.

20. **Effects of Solution on Boiling Point.**—The solution of a salt affects the boiling point of the water in which it is contained. This increases with the degree of saturation. The freezing temperature, and temperature of maximum density also change with the degree of saturation.

TABLE 9.

BOILING POINT OF WATER WITH VARIOUS PROPORTIONS OF SODIUM CHLORIDE IN SOLUTION.

	Degrees F.	Degrees C.
Pure Water,	212	100
with 5 per cent. Na. Cl.	214.7	101.5
10 " "	217.4	103.
15 " "	220.3	104.6
20 " "	223.3	106.3
25 " "	226.2	107.9

The boiling point of various saturated solutions as determined by M. LeGrand, is shown in Table 10.

TABLE 10.

Boiling Point of Saturated Saline Solutions

Name of salt.	Weight of salt per 100 of water.	Boiling-point. Degrees C.
Sodium chloride	41·2	108·4
Potassium chloride	59·4	108·3
Calcium chloride	325·0	179·5
Ammonium chloride	88·9	114·2
Barium chloride	60·1	104·4
Strontium chloride	117·5	117·8
Sodium nitrate	224·8	121·0
Ammonium nitrate	2·0	180·0
Calcium nitrate	362·0	151·0
Sodium carbonate	48·5	104·6
Potassium carbonate	205·0	135·0
Sodium phosphate	112·6	106·6
Potassium chlorate	61·5	104·2

The boiling point of water, as well as the other critical temperatures, varies with the barometric pressure, increasing as the pressure increases, and decreasing as the pressure decreases.

Table 11 shows the boiling point of pure water corresponding to barometric pressure and altitude above sea level.

TABLE 11.

BOILING-POINT OF WATER CORRESPONDING TO BAROMETRIC PRESSURE AND ALTITUDE ABOVE THE SEA-LEVEL.

Boiling-point		Barometer		Altitude	Boiling-point		Barometer		Altitude
F°.	C°.	Inches	mm.	Feet	F°.	C°.	Inches	mm.	Feet
184	84.4	16.79	426.5	15221	200	93.3	23.59	599.2	6304
185	85.0	17.16	436.0	14649	201	93.8	24.08	611.6	5764
186	85.5	17.54	445.5	14075	202	94.4	24.58	624.3	5225
187	86 1	17.93	455.4	13498	203	95.0	25.08	637.0	4697
188	86.6	18.32	465.3	12934	204	95.5	25.59	650.0	4169
189	87.2	18.72	475.6	12367	205	96.1	26.11	663.2	3642
190	87.7	19.13	486.0	11799	206	96.6	26.64	676.7	3115
191	88.3	19.54	496.3	11243	207	97.2	27.18	690.4	2589
192	88.8	19.96	507.0	10685	208	97.7	27.73	704.3	2063
193	89.4	20.39	517.9	10127	209	98.3	28.29	718.6	1539
194	90.0	20.82	528.8	9579	210	98.8	28.85	752.8	1025
195	90.5	21.26	540.0	9031	211	99.4	29.42	747.3	512
196	91.1	21.71	551.3	8481	212	100.0	30.0	762.0	sea
197	91.6	22.17	563.1	7932	below	sea	level		level
198	92.2	22.64	575.0	7381	213	100.5	30.59	777.0	–512
199	92.7	23.11	587.0	6843					

21. **Suspension.**—Suspension differs materially from solution. In suspension, the substance still retains its physical identity, although it may be held in an exceedingly finely divided state, and thus be carried in suspension for indefinite periods.

Water at rest soon deposits the heavier particles carried in suspension, but when in motion, is capable of transporting large amounts of material. This fact is well shown by Table 12, which is from experiments on different types of Ohio River water at Cincinnati.*

TABLE 12.

Subsidence of Suspended Matter in Quiescent Waters

Periods of Subsidence—Hours.	Suspended Matter in Parts Per Million.		Per Cent Removed.	
	Type I.	Type II.	Type I.	Type II.
0	2333	205	0	0
1	932	81	60	55
3	653	80	72	56
6	396	79	83	56
12	350	73	85	58
24	300	61	87	63
48	259	44	89	67
72	210	36	91	70
96	186	31	92	72

In this table Type 1 is said to be characteristic of the Ohio River water during the earlier stages of a heavy freshet, when the water carries in suspension large quantities of silt and fairly coarse clay.

Type 2 is characteristic of the water during the latter stages of the rise, when the matter in suspension is finer.

The average amount of sediment carried in suspension by large rivers is shown in Table 13.**

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* Report on Water Purification, Cincinnati, 1899, page 107.

** C. C. Babb, Science, 1893, Vol. XXI, p. 343; also Eng. News, 1893, p. 109.

TABLE 13.

DISCHARGE AND SEDIMENT OF LARGE RIVERS.

River	Drainage area, square miles	Mean annual discharge, second feet	SEDIMENT Total annual tons	Ratio by weight	Depth over drainage area, in.
Potomac	11,043	20,160	5,557,250	1:3575	.00433
Mississippi	1,214,000	610,000	406,250,000	1:1500	.00288
Rio Grande	30,000	1,700	3,830,000	1:291	.00110
Uruguay	150,000	150,000	14,782,500	1:10,000	.00085
Rhone	34,800	65,850	36,000,000	1:1775	.01071
Po	27,100	62,200	67,000,000	1:900	.01139
Danube	320,300	315,200	108,000,000	1:2880	.00354
Nile	1,100,000	113,000	54,000,000	1:2050	.00042
Irrawaddy	125,000	475,000	291,430,000	1:1610	.02005

Table 14 gives the average amount of matter carried in solution by various rivers in the United States.*

TABLE 14.

AVERAGE AMOUNTS OF MATTER CARRIED IN SUSPENSION BY VARIOUS RIVER WATERS.

	Parts per million.
Merrimac River at Lawrence	10
Hudson River at Albany	15
Allegheny River at Pittsburg	50
Potomac River at Washington	80
Ohio River at Cincinnati	230
Ohio River at Louisville	350
Mississippi River at St. Louis Water Works intake	1200
Mississippi River at New Orleans	650

22. Relation of River Flow to Sediment.—Table 15 shows the amount of silt in suspension in the Rio Grande

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* See Report of the Water Supply of the City of St. Louis, 1902, p. 21.

River at El Paso in 1889-90, and its relation to the volume of flow, as determined by the U. S. Geo. Survey.*

TABLE 15.

Silt in the Rio Grande at El Paso.

[Estimates by months.]

Month.	Sediment ratios.	Average discharge.	Weight of water.	Sediment per second.	Sediment per month.
1889.		*Sec. feet.*	*Pounds.*	*Pounds.*	*Tons.*
June	·00468	2,638	165,000	772·2	1,000,570
July	·00201	237	14,810	29·6	39,800
December	·00813	71	4,440	36·1	48,380
1890.					
January	·00295	196	12,250	36·2	48,500
February	·00362	290	18,130	65·5	79,200
March	·00613	424	26.500	162·6	217,700
April	·00585	2,190	136,900	794·6	1,029,800
May	·00347	5,771	360,680	1,248·5	1,671,700
June	·00196	4,404	275,250	539·5	699,200
July	·00131	854	53,375	70·0	93,730
August	·00710	734	45,875	325·7	436,100

The relation of river height to the quantity of sediment carried by the Mississippi River at New Orleans is shown on Diagram 5.**

23. **Density and Pressure.**—Water is found to be reduced in volume about .00005 parts by an increase of a pressure of one atmosphere.* **

The amount of this reduction is shown in the following table:

TABLE 16.

REDUCTION IN VOLUME OF WATER UNDER PRESSURE.

500 lbs. per sq. in. .00144= 2.488 cubic inches per cubic ft.
750 lbs. per sq. in. .00216= 3.732 cubic inches per cubic ft.
1000 lbs. per sq. in. .00288= 5.565 cubic inches per cubic ft.
1500 lbs. per sq. in. .005 = 7.464 cubic inches per cubic ft.
2000 lbs. per sq. in. .00644=11.128 cubic inches per cubic ft.
4000 lbs. per sq. in. .01288=22.256 cubic inches per cubic ft.
6000 lbs. per sq. in. .01932=33.386 cubic inches per cubic ft.

24. **Ice.**—Critical temperature 32° Fah., weight of ice about 57½ lbs. per cubic foot. Submergence of floating ice 11/12 of its mass in pure water, and in sea water above 8/9.

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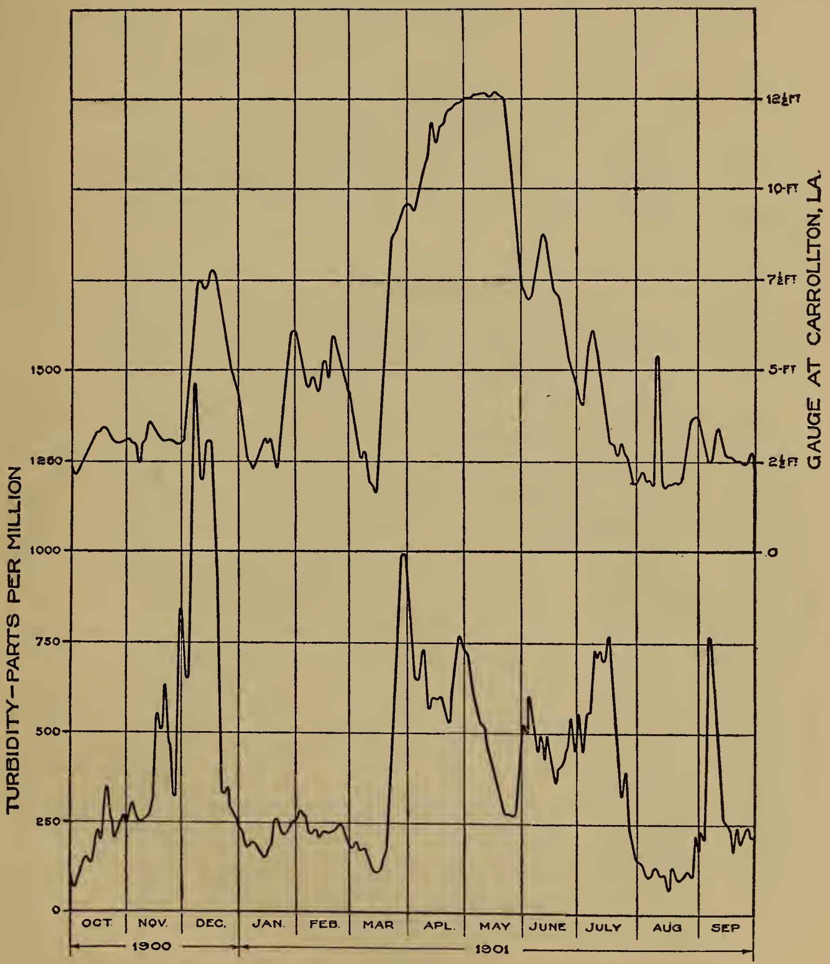
* Eleventh Annual Report U. S. Geo. Survey, Part 2, Irrigation, p. 57.

** Report of Water Purification and Investigation, New Orleans, 1903, p. 34.

*** Bulletin U. S. G. S. No. 92. The Compressibility of Liquids, p. 78.

DIAGRAM 5.

RELATIVE GAUGE HEIGHT AND MATTER IN SUSPENSION
IN MISSISSIPPI RIVER AT NEW ORLEANS, LA.



25. Aqueous Vapor.—Vaporization takes place from water surfaces at all temperatures, and is independent of the presence of air except as the air and its circulation retards or assists vaporization. The laws of the mixture of gases and vapors are as follows:

First, the weight of vapor that will enter a given space is the same whether the space be empty or filled with gas.

Second, when a space filled with gas is saturated with vapor, the tension or weight of the mixture is the sum of the tension or weight of the gas and vapor separately at the temperature of the mixture.

DIAGRAM 6.

WEIGHT OF AIR AND SATURATED AQUEOUS VAPOR

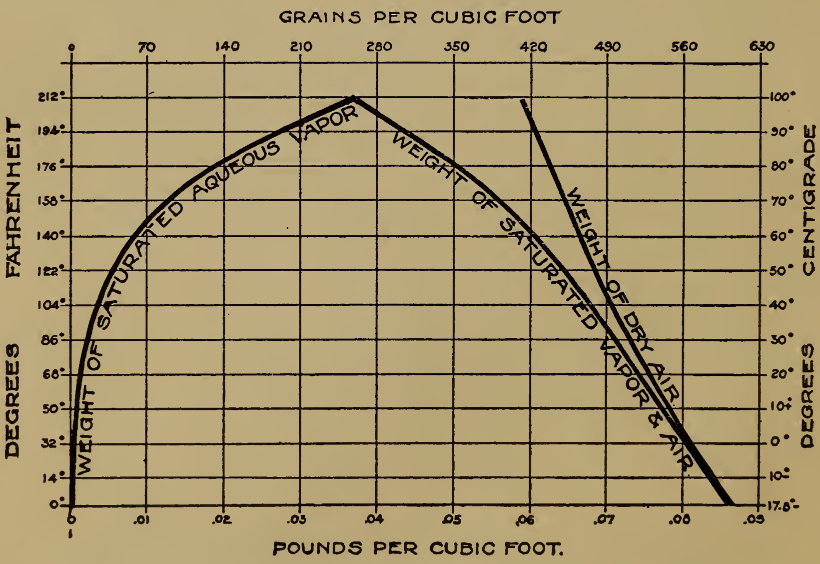


Table 17 shows the tension or weight of saturated aqueous vapor, air, and a mixture of the two at different temperatures. The same relations are also shown graphically on Diagram 6.

TABLE 17.

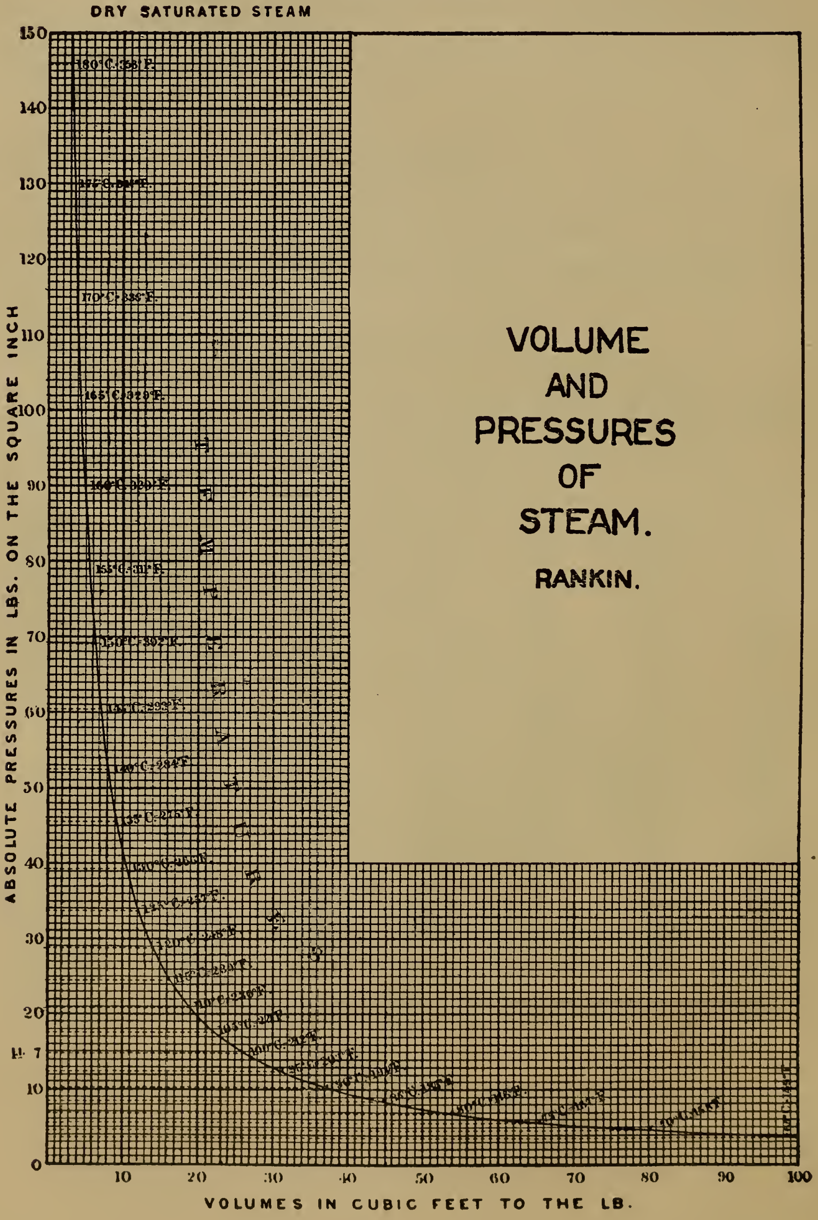
WEIGHTS OF AIR, AQUEOUS VAPOR,

And Saturated Mixtures of Air and Vapor at Different Temperatures, Under the Ordinary Atmospheric Pressure of 29.921 Inches of Mercury.

Temperature Degrees Fahr.	Weight of cubic ft. of Dry Air at Different Temperatures, Lbs.	Elastic Force of Vapor Inches of Mercury	MIXTURES OF AIR SATURATED WITH VAPOR.			
			Elastic Force of the Air in Mixture of Air and Vapor Inches of Mercury	WEIGHT OF CUBIC FOOT OF THE MIXTURE OF AIR AND VAPOR		
				Weight of the Air, Lbs.	Weight of the Vapor, Lbs.	Total Weight of Mixture, Lbs.
0	.0864	.044	29.877	.0863	.000079	.086379
12	.0842	.074	29.849	.0840	.000130	.084130
22	.0824	.118	29.803	.0821	.000202	.082302
32	.0807	.181	29.740	.0802	.000304	.080504
42	.0791	.267	29.654	.0784	.000440	.078840
52	.0776	.388	29.533	.0766	.000627	.077227
62	.0761	.556	29.365	.0747	.000881	.075581
72	.0747	.785	29.136	.0727	.001221	.073921
82	.0733	1,092	28.829	.0706	.001667	.072267
92	.0720	1,501	28.420	.0684	002250	.070717
102	.0707	2,036	27.885	.0659	.002997	.068897
112	.0694	2,731	27.190	.0631	.003946	.067046
122	.0682	3,621	26.300	.0599	.005142	.065042
132	.0671	4,752	25.169	.0564	.006639	.063039
142	.0660	6,165	23.756	.0524	.008473	.060873
152	.0649	7,930	21.991	.0477	.010716	.058416
162	.0638	10,099	19.822	.0423	.013415	.055715
172	.0628	12,758	17.163	.0360	.016682	.052682
182	.0618	15,960	13.961	.0288	.020536	.049336
192	.0609	19,828	10.093	.0205	.025142	.045642
202	.0600	24,450	5.471	.0109	.030545	.041445
212	.0591	29,921	0.000	.0000	.036820	.036820

The relation of pressure, temperature and volume of a pound of confined steam is shown in Diagram 7.

DIAGRAM 7.

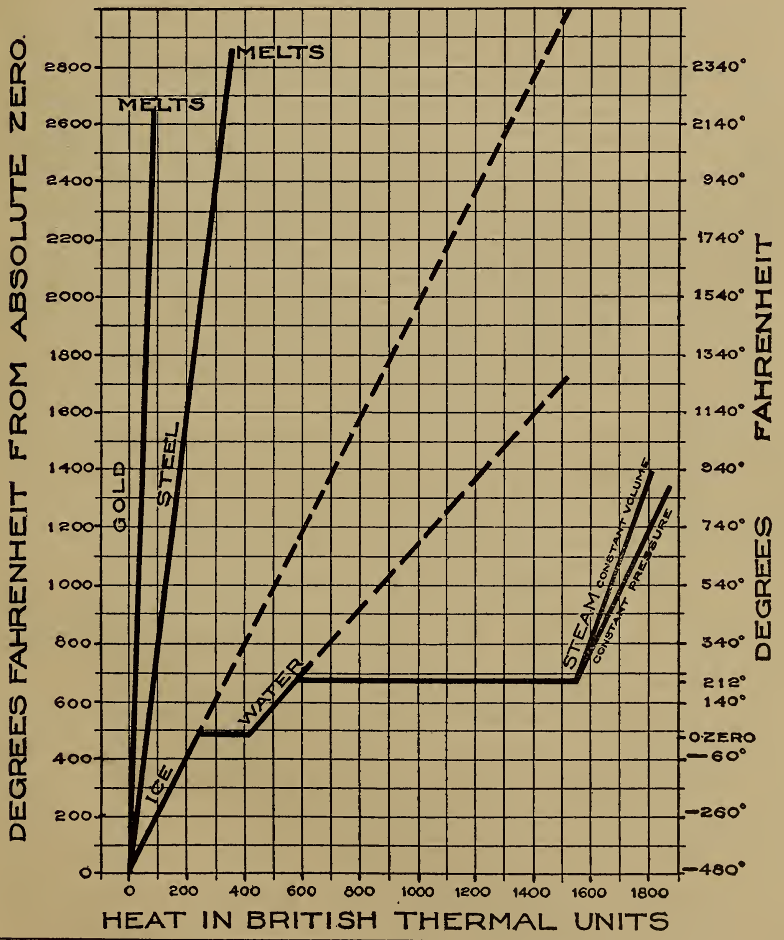


26. **Latent Heat of Water.**—To transform ice, water and vapor or steam from one state to the other, it is only necessary to extract or supply a certain quantity of heat energy. -460° Fah. is the absolute zero of temperature.

A graphical diagram showing the quantity of heat and the resulting temperatures as water changes from solid to liquid, and from liquid to vapor, is shown on Diagram No. 8.*

DIAGRAM 8.

RELATIONS OF HEAT ENERGY IN WATER.



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* See lecture by G. H. Babcock, Scientific American Sup. Nos. 624 and 625, December, 1887.

27. Relation of Water and Energy.—Water of itself possesses no energy, except that which is given to it from outside sources, or from the accident of position. The relation of the mechanical energy of water due to its position and weight are shown in Table 18.

TABLE 18.

EQUIVALENT UNITS OF ENERGY

WORK				HEAT		ELECTRIC	HYDRAULICS			
Foot Pound	Foot Ton 2240 Lbs.	Kilogram Meter	Tonne Meter	B. T. U. Deg. Fah. Pound	Calorie Deg. Cent Kilogram	Volt Columb	Foot Gallon	Foot Cubic	Pound Gallon	Pound Cu. Ft.
1	.000446	1383	.000138	.001285	.000324	.000377	.12	.016	.0519	.0069
2240.	1	309.688	.3097	2.8785	.7262	.8439	268.817	35.906	116.414	15.456
7.233	.00323	1	.001	.0093	.00235	.00272	.8673	.1159	.3755	.0499
7233.18	3.2291	1000	1	9.302	2.3452	2.7241	867.303	115.928	375.516	49.90
778.	.3474	107.562	.1076	1	.2520	.2929	93.28	12.448	40.394	5.368
3085.34	1.3774	426.394	.4264	3.9683	1	1.1623	370.17	49.396	160.29	21.221
2655.4	1.1854	371.123	.3671	3.414	.8603	1	318.39	42.486	137.87	183.23
8.341	.00372	1.1532	.00115	.1072	.0027	.00314	1	.1334	.433	.05754
62.39	.02785	8.6257	.00863	.0803	.00202	.02353	7.48	1	3.245	.4312
19.259	.00859	2.6626	.00266	.0248	.00624	.00726	2.309	.3082	1	.1329
144.92	.0647	20.036	.02004	.1863	.04712	.05457	17.37	2.318	7.524	1

Energy may be acquired by water in the form of heat from outside sources. Under certain conditions the energy so contained in water (as steam) may be utilized for power purposes. The mechanical equivalents of the heat energy of steam under certain condition are shown in Table 19.

28. Water Pressure.—The pressure produced by a column of water is that due to the weight of the column above the surface considered. The comparative pressure in various units of head and area are shown in Table 20.

29. Effects of Atmospheric Pressure.—Normal atmospheric pressure at sea level is about 14.9 lbs. to the square inch. With a weight of 62.425 lbs. per cubic foot, the pressure of water one foot in depth will be equal to .4335 lbs. on each square inch. At sea level, therefore, water will rise to an average height of 33.96 feet in a tube from which the air has been entirely exhausted. On account of atmospheric variations, however, this may reach a maximum height of 34.4 feet,

TABLE 19.

EQUIVALENT UNITS OF ENERGY

Horse Power Hours	1000 Foot Pounds	Heat B. T. U. Per Hour	Steam, One Pound, Working Between Limits Given Below					
			From Water at a Temperature, Fahrenheit, of					
			212°	212°	60°	200°	60°	200°
			To Steam at a Gauge Pressure of					
			0 Lbs.	81 Lbs.	100 Lbs.	100 Lbs.	150 Lbs.	150 Lbs.
1	1980	2544.987	2.65	2.545	2.20	2.5	2.18	2.47
.0005	1	1.285	.00133	.00129	.00111	.00126	.00112	.00125
.0004	788	1	.001035	.001	.00086	.00098	.000859	.000975
.358	751.55	966	1	.996	.87	.95	.855	.94
.394	778	1000	1.035	1	.86	.984	.858	.974
.455	900.15	1157	1.19	1.16	1	1.135	.99	1.122
.401	791.23	1017	1.05	1.02	.88	1	.87	.99
.459	907.15	1166	1.21	1.17	1.01	1.145	1	1.12
.403	797.45	1025	1.06	1.025	.89	1.01	.88	1

TABLE 20.

PRESSURE EQUIVALENTS.

Pounds per Square Inch	Pounds per Square Foot	Pounds per Circular Inch	Kilogramme per Square Centimeter	1000 Dynes per Square Centimeter	Inches of Mercury	Millimeters of Mercury 32° Fah.	Water Pressure Feet Head	Water Pressure Meters Head	Atmosphere
1.	144.	.78540	.0703	69.	2.0376	51.63	2 307	.703	.06793
.00694	1.	.00545	.000488	.00479	.01415	.3585	.01602	.00488	.0004717
1.273	183.3	1.	.08952	87.845	2.594	.6573	2.937	.8954	.08648
14.223	2048.	11.17	1.	981.3	28.98	734.2	32.81	10.	.966
.01449	2.086	.01138	.00101	1.	.02952	7.48	.03343	.01013	.00984
.4912	70.731	.38579	.03453	33.880	1.	25.35	1.1334	.3454	.03336
.01937	2.789	.01521	.001362	1.336	.03947	1.	.04468	.01362	.001316
.4335	62.425	.34128	.03048	29.91	.882	22.38	1.	.30491	.029448
1.422	204.76	1.1169	.1	98.13	2.8975	73.42	3.281	1.	.0966
14.72	2119.68	11.562	1.035	1015.8	29.92	760.	33.96	10.352	1.

or a minimum height of 31.6 feet above sea level. Atmospheric pressure decreases, and may be determined by a modification of the formula proposed by S. G. Ellis* for barometric measurements of heights, which is

$$(1)\quad H = 60000\,(\log B - \log b)\left\{1 + \frac{T+t-60}{900}\right\}$$

H=difference of altitude in feet between two stations.

B and b=the barometric readings in inches of mercury at the two stations

T and t=the temperature of the air at the two stations in degrees Fahrenheit.

In the problem under consideration and for average conditions, B will equal 30 inches, and T and t may be considered constant and equal to 60 degrees Fahr. With these constants substituted the formula (1) becomes

$$(2)\quad \log b = 1.47712 - \frac{H}{64000},\qquad \text{in which}$$

b=average barometer reading in inches of mercury.

H=height of station above sea level in feet.

The average pressure per square inch at various elevations above sea level can be determined directly by the following modification of formula (2):

$$(3)\quad \log P = 1.16801 - \frac{H}{64000}$$

The average height of a column of water which will balance atmospheric pressure can also be determined directly by the following modification of formula (2):

$$(4)\quad \log F = 1.53101 - \frac{H}{64000}$$

In formula (3) and (4)

P=the atmospheric pressure per square inch in pounds.

F=the corresponding height of a column of water in feet.

H=elevation of station above sea level in feet.

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* Proceedings Am. Soc. C. E., Vol. 1.

In Table 21 are given the average annual barometric reading at various points in the United States as determined by the U. S. Weather Bureau for 1890 and 1891, with the height of the location of the barometer above sea level and the calculated pressure, by formula 2.

In Table 22, these formula are applied to determine the conditions at various elevations above sea level. The calculated average barometer reading is given in the second column, the corresponding average atmospheric pressure per square inch in column 3, and the average height of a corresponding column of water in column 4.

30. Physiological Relations of Water.*—About two-thirds of average human food is liquid. The average adult consumes about 4½ lbs. of simple liquid each day, and about 2½ lbs. of solid food, which is nevertheless about half liquid, intimately commingled with actual solid materials.

Water is, therefore, one of the prime necessities of human life, the property of solution being a most important property in physiological processes.

31. Agricultural Relations of Water.—Vegetation is equally dependent on water for the solution of soluble food from the soil and its circulation through the vegetable structure.

For successful agriculture, without an artificial supply of water, about thirty inches of annual rainfall, properly distributed, seems to be essential. About fifteen inches of this is required for vegetation, and the balance is lost in other ways.

Where less than this amount of rainfall is available, irrigation becomes desirable, and with a considerable decrease absolutely essential. Under other conditions, the topography of the country may render certain lands unfit for agriculture, on account of too much water received on the land, either by drainage from higher lands, or by overflow from streams, and successful agriculture may make systems of drainage ditches, or of dykes and levees essential.

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* W. J. McGee, The Potable Waters of Eastern United States; Potable Waters in Human Economy. 14th Annual Report U. S. G. S., Part 2, page 5.

TABLE 21.

Observed and Calculated Barometic Heights

Station.	*Elevation above sea level.	Average annual barometer.	Calculated barometer.	Difference.
Key West, Fla..	22	30.02	29.97	—.05
New Orleans....	54	29.96	29.94	—.02
Philadelphia	117	29.85	29.87	+.02
Memphis, Tenn.	330	29.66	29.65	—.01
St. Louis.......	571	29.36	29.38	+.02
Cincinnati......	628	29.32	29.33	+.01
Detroit, Mich...	724	29.16	29.23	+.05
Chicago........	824	29.06	29.12	+.06
Bismarck, N.Dak.	1681	28.20	28.24	+.04
Ft. Assiniboin..	2690	27.02	27.21	+.19
Salt Lake......	4348	25.58	25.66	+.08
Santa Fe, N. Mex.	7026	23.24	23.30	+.06

TABLE 22.

Relations of Elevation to Barometer and Atmospheric Pressure

Height above sea level.	Average height barometer in inches of mercury.	Average pressure in pounds per square inch.	Average height to which water will rise in an exhausted tube.
0	30.00	14.72	33.96
100	29.89	14.67	33.84
200	29.78	14.62	33.72
300	29.68	14.57	33.60
400	29.57	14.51	33.48
500	29.47	14.46	33.35
600	29.36	14.41	33.23
700	29.25	14.36	33.11
800	29.15	14.30	32.99
900	29.04	14.25	32.87
1000	28.94	14.20	32.76
1250	28.67	14.07	32.47
1500	28.42	13.95	32.19
2000	27.92	13.70	31.61
2500	27.40	13.45	31.04
3000	26.93	13.21	30.49
3500	26.43	12.98	29.94
4000	25.98	12.74	29.41
4500	25.51	12.51	28.89
5000	25.06	12.29	28.37
6000	24.18	11.85	27.37
7000	23.32	11.43	26.40
8000	22.50	11.04	25.47
9000	21.70	10.65	24.57
10000	20.93	10.28	23.70

*Elevations are those of instruments at observatories

32. Commercial Relations of Water.—Water has important relations to commerce in affording a medium for navigation and transportation, especially in foreign and domestic commerce between points along the coast and on the great lakes. Navigation by means of canals and rivers, while still important, has in a degree, lost the relative importance which it attained in the earlier history of commercial development.

The importance of water as a source of power has been largely increased by the rapid developments in the means of electrical transmission. Public water supplies are also largely utilized for various commercial and manufacturing purposes.

33. Sanitary Relations of Water.—The sanitary relations of water are important, not only on account of the necessity of a certain quantity of water to sustain life, but also on account of the effect on health of the impurities commonly found in it. Water, on account of its high solving and transporting qualities, is constantly removing matter from the drainage area on which it falls, and in settled regions receives and transmits much that may be detrimental to health, if the water so polluted is utilized for dietetic purposes. The protection of water for potable purposes, or its purification and delivery free from detrimental impurities, is, therefore, of vital importance. The utilization of water for the removal of waste, and the sanitary disposal or purification of the waters so polluted, is also a matter of the greatest importance.

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CHAPTER III.

GENERAL HYDROGRAPHY AND PHYSIOGRAPHY.

34. **Circulation of Water on the Earth.**—The circulation of water on the earth is due to the following causes:

First. The waters of the ocean, heated at the tropics and cooled at the poles, have a motion towards the poles at the surface, and from the poles in the lower portions of the sea.

Second. The difference in velocity of rotation between equatorial and polar regions effects the flowing waters and gives the warm surface currents an easterly direction against the westerly continental shores. These currents are modified by continents, continental irregularities, islands, and the larger rivers.

Third. The attraction of the moon on the ocean and other large bodies of water produces the tides which follow the lunar revolution until they break on the eastern continental shores, and then flow back, vibrating synchronously with the lunar revolutions.

Fourth. The friction of atmospheric currents on the water produces waves, which, at times of storm, break with great force on exposed portions of the land.

Fifth. A constant evaporation goes on from all water surfaces. This is increased:

A. By increased temperature.
B. By the removal of vapor already formed by atmospheric currents.

The vapor so formed rises into the upper atmospheres, and when cooled below saturation is precipitated as rain.

Sixth. The rainfall and melted snow follow various courses:

A. A portion is re-evaporated and passes into the atmosphere.
B. A portion is utilized in plant growth and transpiration.
C. A portion seeps into the strata, and following their dip, finds its way ultimately into the rivers and seas.
D. A portion flows over the surface into the water courses and thence to the sea.

Seventh. In the polar regions and in high mountain altitudes, precipitation occurs as snow, and the temperatures are so low that melting is comparatively small or does not occur. The resulting vast accumulations of snow exert a pressure sufficient to form ice masses in their lower portions, which, from the super-imposed weight, is pressed outward until its glacial terminations either melt in the lower altitudes, or reach the sea and are melted or broken off as icebergs.

The action of the various factors which control the circulation of water on the earth is modified by the local physical and meterological conditions.

35. **The General Relations of Land and Water.**—In a relative sense the unevenness of the earth's crust is slight, the maximum elevation of the highest land is about 5.5 miles above sea level, and the greatest depth of the ocean is about 6 miles. The maximum variation in elevation, therefore, is only about .14 of one per cent. of the earth's diameter. This elevation is sufficient, however, to raise somewhat more than a quarter of the earth's crust above the ocean.

The exact relations of the area of land and water is not definitely known, as the Polar regions have not yet been fully explored.

The total area of the globe is about 197,000,000 miles. Of this the land occupies somewhat more than 50,000,000 square miles. About 6/7 of the land area occurs in one hemisphere, of which it occupies almost one-half the area, while in the remaining hemisphere only about one-fifteenth of the area is land. (R. S. Tarr.—Physical Geography. Chapter IX. Form and General Characteristics of the Ocean.)

36. Physiographic Features of the Earth.—The physiographic features of the earth may be divided for purposes of study and investigation as follows:

1. Land Forms:
    - A. Continents.
    - B. Islands.
2. Land Features:
    - A. Mountains, Hills, and Cliffs.
    - B. Plains and Plateaus.
    - C. Valleys and Stream Channels.
    - D. Caverns.
    - E. Coast Forms.
3. Water Forms:
    - A. Oceans.
    - B. Lakes.
    - C. Rivers and Streams.
    - D. Swamps and Marshes.
    - E. Phreatic Waters.
4. Water Features:
    - A. Cataracts.
        - a. Gradational.
        - b. Diastropic.
        - c. Vulcanic.
    - B. Springs and Geysers.
    - C. Artesian and Deep Wells.

(J. W. Powell. Nat. Geo. Mon. No. 2, Physiographic Features. Tarr, Physical Georgraphy, Chapter XXI. Land Forms.)

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CHAPTER IV.

HYDRO-METEOROLOGY.

37. **Meteorology.**—Meteorology is the science that treats of atmospheric conditions, the causes which give rise to these conditions and their modifications.

The various phenomena considered in meteorological science are mutually dependent, and must be studied in their broad general relations with each other, in order to be understood.

Hydro-meteorology, while it especially considers those conditions most intimately connected with the water of the atmosphere, its precipitation, evaporation, and general relations, must, nevertheless, also consider as well, general meteorological science, in order to make its more special subjects fully understood. The term "Hydro-meteorology," therefore, may be considered to refer to the general science of meteorology, treated with special reference to the question of aqueous atmospheric circulation.

38. **Atmosphere.**—The earth's atmosphere has most important influences on the evaporation of water, the distribution of aqueous vapor, and the precipitation of rain. While evaporation would take place regardless of the atmosphere, yet the atmosphere being always present, modifies and controls the actual prevailing conditions. (Tarr, Physical Geography, Chapter II; Waldo, Meteorology, Chapter I.)

39. **Atmospheric Temperatures.**—Atmospheric temperatures, which are important factors in the occurrence of rainfall, vary as follows:

First, The atmospheric temperature decreases from the equator to the poles.

Second, The temperature decreases with the altitude above sea level.

Third, The temperature increases with the advent of day and decreases at night.

Fourth, The temperature decreases as the surface of the earth receives the more inclined rays of the sun, due to the revolution of the earth on its solar orbit.

Fifth, Temperature also varies with the variation in the winds, and the variation in relative humidity.

(Tarr, Physical Geography, Chapter 3; Waldo, Meteorology, Chapter 2.)

40. **Atmospheric Pressure.**—Normal atmospheric pressure should be symmetrical and practically the same in all places having a common altitude, for the pressure should be equal to the weight of the column of air above the point under consideration, which should be the same for all places of the same height above sea level.

On account of the disturbing influence of the sun's heat, and the movement of air currents, largely caused thereby, a considerable variation is caused in barometric pressure, and its observation becomes an important matter for meteorological research. (Waldo, Meteorology, Chapter 3.)

41. **Atmospheric Circulation.**—Atmospheric circulation, or the winds, are produced by the following causes:

First, the atmosphere rotates with the earth, of which it forms a part.

Second, the atmosphere, heated at the tropics, rises and flows towards the poles, where, as it is cooled, it settles and produces lower counter currents towards the tropics. The great difference in the relative speed of rotation at the equator and poles gives an easterly direction to the upper warm current, and the lower return current is given a westerly direction for the same reason.

Third. The mixture of aqueous vapor with the atmosphere and the changes of temperature involved in precipitation, produce vertical currents which greatly modify the velocities, altitudes and direction of atmospheric currents.

Fourth. Irregularity in the topographic features of a country creates marked changes in the direction of the lower winds, and produce eddies and irregularities in the lower air currents.

Fifth. Variation in local temperatures of land or water modify the local atmospheric currents sometimes to a considerable extent.

The very great number of possible relations and combinations between these various causes of atmospheric movements make the winds at lower altitudes seem uncertain, while those in the higher altitudes being more free from local influences are more largely governed by the two first great causes.

(See Waldo, Meteorology, Chapter 4; Tarr, Physical Geography, Chapter 4.)

42. Atmospheric Moisture.—The constant circulation of moisture between the air and the surface of the earth and water is the primary phenomenon of hydrology, on which all other phenomena depend.

This circulation passes through three stages, viz.: evaporation, saturation and condensation.

Evaporation takes place whenever the space in contact with the water's surface is not fully saturated. The rapidity of evaporation depends on the humidity of the adjacent space, and the temperature of the air. The movement of dry air currents tending to remove the vapor already formed, is an important factor in increasing evaporations.

The point of saturation depends on the temperature of the surrounding air, and the quantity of vapor which may be contained in a given space increases rapidly with the temperature. A reduction in temperature, in space already saturated, produces super-saturation, and consequent condensation.

Condensation appears in various forms, according to the physical condition with which it is accompanied. The principal phenomena may be classed as dew, frost, fog, haze, mist, clouds, rain, snow and hail. (See Waldo, Meteorology, Chapter 5; Tarr, Physical Geography, Pages 107-116 inclusive.)

43. **Rainfall.**—Rainfall is due directly to the reduction in temperature of atmospheric currents, carrying with them aqueous vapor, to a point where super-saturation and precipitation results.

The general term "Rainfall," as ordinarily used, includes both rain and melted snow.

The causes of condensation are:

First, Cooling by contact with colder bodies.

Second, by Radiation.

Third, by Expansion.

Fourth, by the mechanical mixture of air of different densities and humidities. (See Waldo, Meteorology, Chapter 6; Tarr, Physical Geography, Pages 117-123.)

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CHAPTER V.

HYDRO-GEOLOGY.

44. **Influence of Geological Structure.**—The geological structure, and the resulting topographical conditions of a country modifies to a very great extent its hydrological phenomena. The mountain masses exert a marked influence on the local rainfall. The surface slope of the country is a controlling factor in the character of run off and of river flow. The nature and direction of the strata have a marked influence on the trend of streams, and the effect of flow on the denudation of the strata themselves. The structure and dip of the strata are among the controlling factors which modify the presence and flow of underground waters.

45. **General Classification of Rock Masses.**—For the consideration of this subject the rock masses of the earth may be considered in four principal groups.*

First. The Archean rocks, which constitute the earliest known rock masses, and which, while they may not, and in most cases certainly are not, the primary rocks which constituted the original surface of the globe, yet are the group most closely associated with the primary formations, and are the sources from which the sedimentary rocks are most largely derived.

Second. Volcanic rocks, which have their origin from flows of melted lava, which has issued from the earth's interior, through active volcanoes and volcanic fissures.

Third. The sedimentary rocks which have been formed by the denudating influence of atmospheric and hydrological

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* J. W. Powell, Physiographic Processes, p. 11.

agencies, which continually act with destructive effect on the exposed rock masses. The drainage waters have conveyed the resulting decomposed materials in solution and suspension to the sea, where the material has been deposited in more or less changed forms, and have served to build up new strata, which in their turn, have been lifted up and exposed to like conditions, and served, together with the formations already exposed, to furnish the new material for still later deposits.

These strata are laid down somewhat like the leaves of a book, with upturned edges only accessible at the surface.

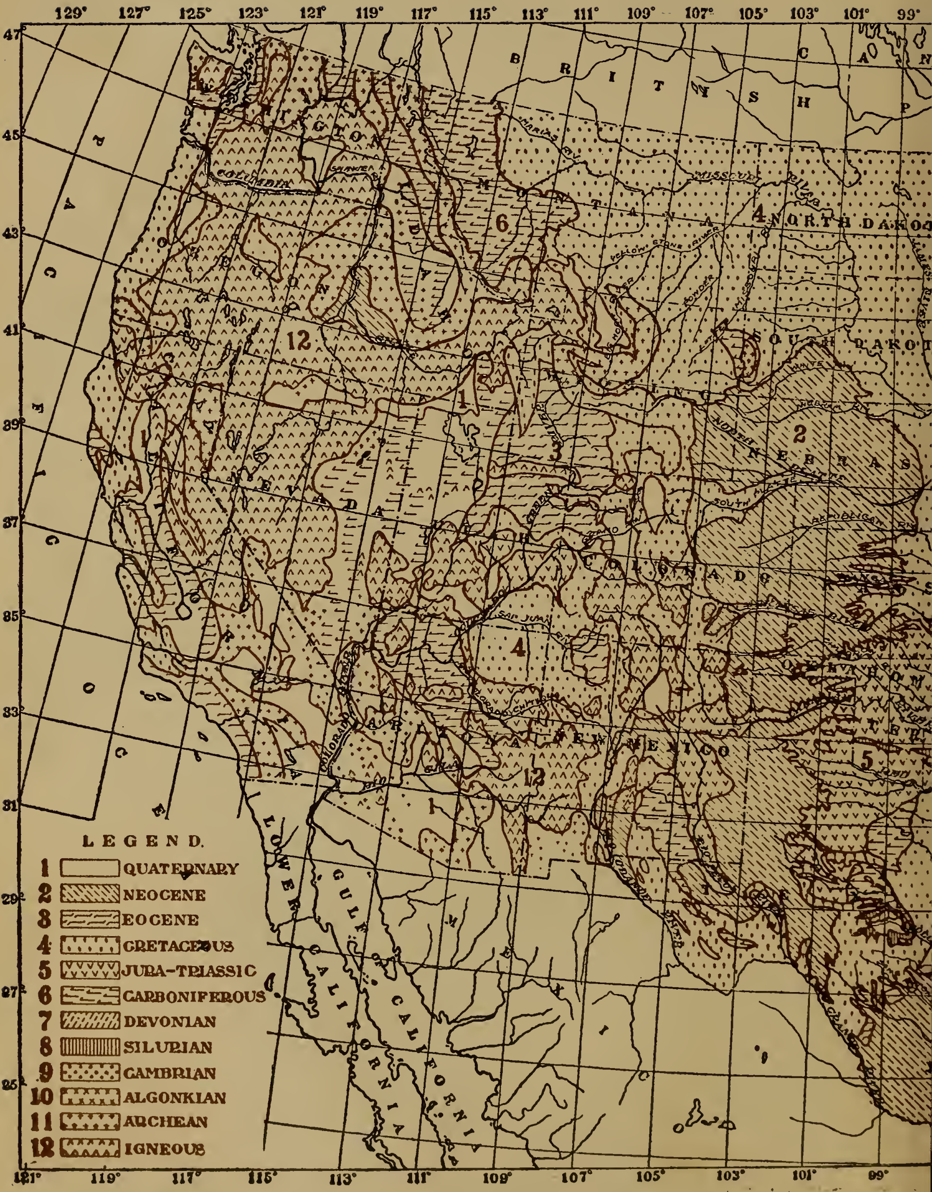
Fourth. The mantle rocks are the superficial deposits consisting of the disintegrated indurated formations produced by the destructive action of the atmosphere, of water and of ice, and which either remain a decomposed mass over the parent rock, or have been transported by various agencies to other localities where they remain a surface deposit of soil and subsoil, comparatively loose and unconsolidated.

46. Chronological Order and Occurrence of Strata.—Table No. 23 gives the geological formation arranged in the relative order of their occurrence, the lowest being the oldest. In no location is the geological section complete, but from the occurrence of these strata at various places in the country the sequence of formation has been determined.

A study of the geological strata, and a knowledge of the probable mode of their formation and occurrence is of great importance in the investigation of hydrological conditions.

Map No. 1 is a general geological map of the United States, showing the formations, as far as they are known to occur at the surface. From these outcroppings the strata dip in general in the direction of the later deposits, sinking beneath the surface, under the more recent formations, and can be reached at points below the surface of more recent strata only by deep excavations, or by the drill. Excavations made on the outcrops of geological deposits will uncover only formations of a still earlier age.

47. Local Study Desirable.—To give a clearer idea of geological growth and of the geological structure of the earth (with the limited time available) a more detailed study of some



129° 127° 125° 123° 121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99°
47° 45° 43° 41° 39° 37° 35° 33° 31° 29° 27° 25°
BRITISH
PACIFIC OCEAN
WASHINGTON
OREGON
IDAHO
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
NEVADA
CALIFORNIA
COLORADO
ARIZONA
NEW MEXICO
LOWER CALIFORNIA
GULF OF CALIFORNIA
MEXICO
COLUMBIA
SNAKE R.
MISSOURI RIVER
YELLOWSTONE RIVER
SAN JUAN
COLORADO
RIO GRANDE
1 2 3 4 5 6 12
LEGEND.
1 QUATERNARY
2 NEOCENE
3 EOCENE
4 CRETACEOUS
5 JURA-TRIASSIC
6 CARBONIFEROUS
7 DEVONIAN
8 SILURIAN
9 CAMBRIAN
10 ALGONKIAN
11 ARCHEAN
12 IGNEOUS
121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99°

Map No. 1

GENERAL GEOLOGICAL MAP OF THE UNITED STATES.

TABLE 23.

Table of Geological Formations of the United States, together with those represented in the Upper Mississippi Valley.

The numbers are those used in Macfarlane's American Geological Railway Guide.

Age.	Group.	U. S. Formations.	Upper Mississippi Valley Formations.	Approximate Thickness.
Cenozoic.	[20] Quaternary.	20 Recent.	[2od] Alluvium. [2oc] Loess. [2ob] Clay and sandy. [2oa] Boulder clay.	Feet. 0 to 400
	[19] Tertiary.	19c Pliocene. 19b Miocene. 19a Eocene.	No representative. " " " "	0 0 0
Mesozoic	[18] Cretacious.	18c Upper Cretacious. 18b Middle " 18a Lower "	No representative. " " " "	0 0 0
	[17] Jurassic.	17 Jurassic.	No representative.	0
	[16] Triassic.	16 Triassic.	No representative.	0
Paleozoic.	[13–15] Carboniferous.	15 Permo-Carboniferous.	No representative.	0
		14B Upper Coal Measures.	Upper Coal Measures.	600 to 1,200
		14A Lower Coal Meas'res.	14Ab Lower Coal Meas'rs. 14Aa Millstone Grit.	
		13 Sub-Carboniferous.	13e Chester Group. 13d St. Louis " 13c Keokuk " 13b Burlington limestone 13a Kinderhook Group.	500 to 800 50 " 200 100 " 150 25 " 200 100 " 150
	[8–12] Devonian.	12 Catskill. 11 Chemung.	No representative. " "	0 0
		10 Hamilton.	10 Black Slate	10 t 70
		9 Corniferous.	9 Devonian limestone.	10 to 120
		8 Oriskany.	8b Oriskany sandstone. Clear Creek limestone.	40 to 60 300 " 500
	[3–7] Silurian.	5–7 Upper Silurian.	7 Lower Helderberg. 5 Niagara limestone.	(?) 50 to 300
		3–4 Lower Silurian.	4b Cincinnati or Hudson River Group. 4a Trenton Group. 3b St. Peter sandstone.	100 to 250 200 " 400 50 " 250
	[2] Cambrian.	2c Calciferous.	2c Lower Magnesian or Oneta limestone.	80 to 825
		2b Potsdam.	2b Potsdam or St. Croix.	100 to 1,800
Azoic.	[1] Archean.	2a Keweenian.	2a Keweenian.	0 to 45,000
		1b Huronian.	1b Huronian or Algoncian.	0 to 13,000
		1a Laurentian,	1a Laurentian.	(?)

particular locality should be made. This will enable the general features of geological structure to be more clearly understood than would be possible with the discussion of the larger area of the United States, where, with the multitude of details, the general principles are likely to be obscured.

For this purpose, the Valley of the Upper Mississippi River has been selected, and in the investigation of the geological history of this territory it should be understood that it is but a representative of conditions, largely similar, which have occurred in all portions of this country and of other lands, all of which have had a corresponding geological history, more or less varied, but in a general way controlled by similar laws, and which have resulted in similar general conditions, more or less modified in detail as the controlling factors have differed in their nature and extent.

At the beginning of the formation of the sedimentary strata, the archean land was probably quite limited in extent in comparison with the present exposed continental areas. Its approximate boundaries, as far as known, and within the present area of North America, are shown in Map No. 2. On this map is also shown the limits of the area of the Upper Mississippi Valley now under discussion.

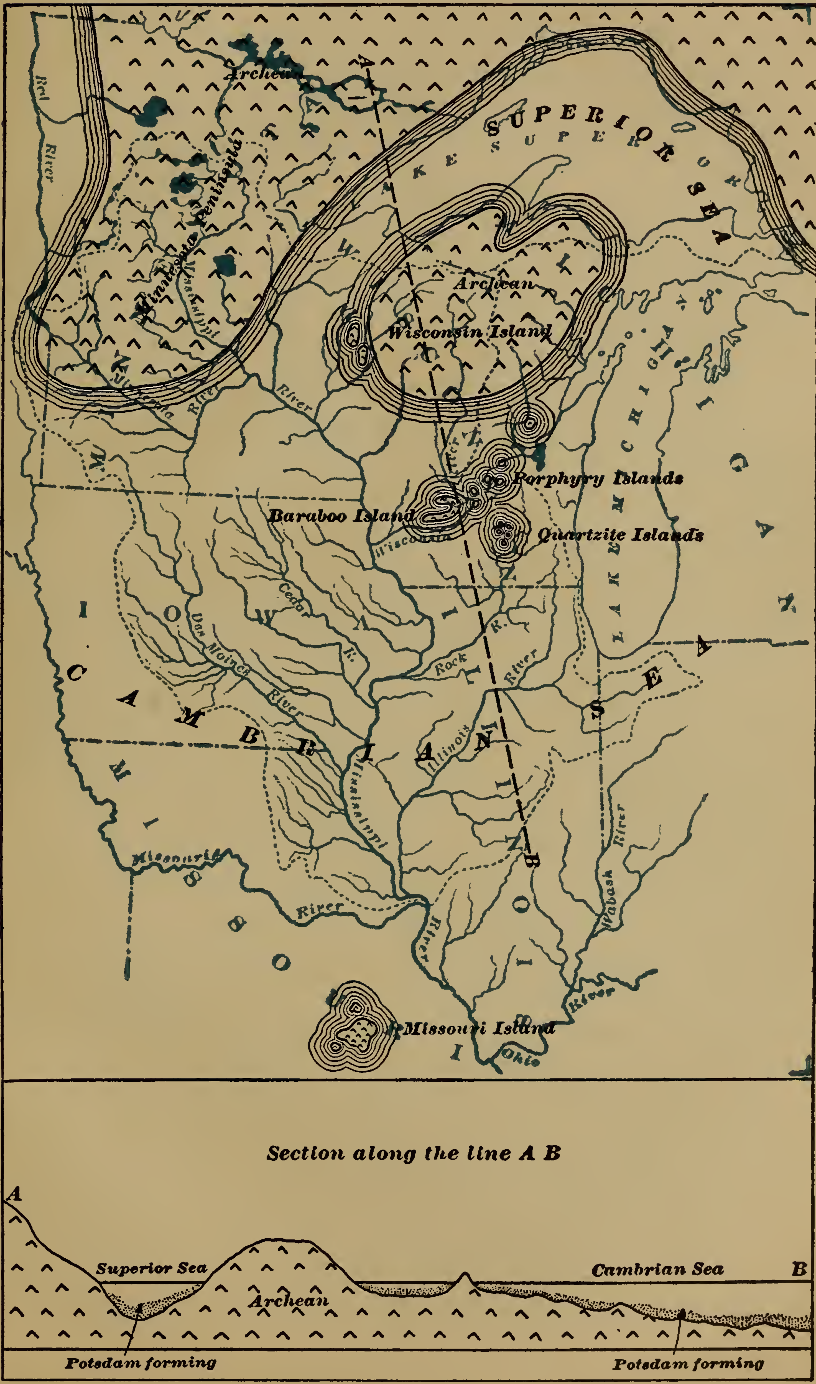
48. The Upper Mississippi Valley.—The Upper Mississippi Valley, together with much adjoining territory, consisting of the Lake Michigan and Lake Superior basins and the valley of the Red River of the north, had a common geological origin and history, and, at a comparatively recent geological period, a common drainage system, all their waters emptying through various channels into the Mississippi River and thence into the Gulf of Mexico, until subsequent geological changes so modified the topography as to produce the present drainage systems.

The territory here considered comprises the greater portion of Illinois, Iowa, Wisconsin and Minnesota, and a small portion of North-eastern Missouri and North-western Indiana, and embraces within its area much of the richest farming country of the United States—a country largely settled, and having numerous thriving and growing communities. In the

MAP No. 2.

APPROXIMATE MAP
OF KNOWN ARCHEAN LAND IN
NORTH AMERICA

MAP No. 3.



CAMBRIAN AGE—Potsdam Deposits forming in Cambrian and Superior Seas.

north are forests of pine, and rich mines of iron and copper, while in the south are valuable deposits of bituminous coal and fire clay. Deposits of valuable building stone are found throughout its extent. It contains all the resources necessary for a rich and populous manufacturing and agricultural development.

49. **Archean Land.**—This territory is shown, on a larger scale, on Map No. 3. On this map is also shown the approximate exposure of the archean deposits during the earlier part of the Cambrian period. This entire region is supposed to be underlain by archean rocks of unknown thickness, which, as far as our knowledge goes, may be regarded as the base rock or foundation on which rests the later sedimentary deposits. The archean rocks of this area may be divided into periods defined by indications of a certain sequence in their origin and method of deposition. The earliest are the Laurentian rocks, consisting of granites, syenites, and allied rocks. Of a later origin are the Huronian or Algonkian deposits, which consist of crystalline magnesium limestone, quartzite, slates and schists, and contain also the iron ores of Minnesota, Wisconsin and Michigan. Next in order came the rocks of the Keweenawan period, consisting of sedimentary rocks, sandstones, conglomerates, and shales, with eruptive rocks containing the copper deposits of the Lake Superior region.

Many of these rocks are flexed, folded, tilted and metamorphosed, showing evidence of upheaval and depression of the earth's crust of great magnitude and extent. With the exception of the eruptive rocks, most of the above show evidence of sedimentary origin, indicating their derivation from a still more remote source, and that they are not themselves a portion of the original crust of the earth.

50. **The Potsdam Formation.**—Since the beginning of geological history, the same agencies that are now wearing away the land surface and filling up the sea, have been at work, aided or hindered by the variations in climate which have marked the passage of time. The rains, with their dissolved gases, soften and wear the surface of the rocks. Taking up the soluble portions, they decompose and disintegrate the

The Rock River at Sterling, Illinois.

most lasting rocks. The sea, working at the coast line, tumbles the rocks into the surf, there to grind them into sand and pebbles, which again aid in the degradation of the adjacent land. Although the amount of this wear from day to day seems small, yet the accumulated work of these agencies, operating through the ages, has sufficed to pull down continents and to build up deposits, which, being elevated by upheavals of the crust, have formed new stretches of land surface, and these in their turn have been disintegrated and destroyed to form new and later deposits. By these agencies the Archean deposits which reared their heads above the Cambrian Sea were worn and disintegrated, and being carried by torrential floods into the sea, formed the vast beds of Potsdam sandstone which underlie all of this area expect that small portion where the Archean rocks still show their outcrop above the surrounding deposits.

During this age the principal part of the area was under the sea, which throughout Wisconsin was comparatively shallow and contained many quartzite islands of the Huronian formation, which yet rear their heads above the Potsdam outcrop. This Potsdam deposit consists mostly of sandstone derived from the broken quartz grains of the decomposed granites and allied rocks. These deposits, close to the Archean land, consist of coarse quartzose sand rock, very open and porous in its nature, and free from the iron, lime and clay, which, in the higher strata, are found associated with it. The Cambrian Sea held in its depths some of the earliest forms of animal life. Myriads of small shellfish, the remains of which may be seen in many of the Potsdam outcrops, inhabited its waters.

Although commonly spoken of as a single geological stratum, the Potsdam is by no means homogeneous in texture throughout. During its formation a vast period of time elapsed, very many disturbances occurred, and the circumstances of deposition of the different portions of the stratum varied greatly. These variations were almost or quite as great as those that marked the changes to subsequent geological ages.

The evidence of this, in portions of Wisconsin, is so marked that Prof. T. C. Chamberlain has classed the Potsdam strata of Central and Eastern Wisconsin in the following sub-divisions:

SUB-DIVISIONS OF POTSDAM DEPOSIT.

	Feet.
Sandstone (Madison)	35
Limestone shale and sandstone (Mendota)	60
Sandstone, calcareous	155
Bluish shale, calcareous	80
Sandstone, slightly calcareous	160
Very coarse sandstone, non-calcareous	280
Total	770

The thicknesses given are subject to wide variation. As a rule they thin out quite rapidly in Wisconsin northward from Madison, and increase in thickness to the southward into Illinois.

Prof. W. H. Winchell notes a somewhat similar classification in Minnesota. In a deep well drilled in East Minneapolis he found the following series of Potsdam rocks. (See Geology of Minnesota, Vol. II, p. 279.)

SECTION OF ARTESIAN WELL, EAST MINNEAPOLIS.

	Feet.
Sand (Drift)	42
Blue limestone, Trenton	28
White sandstone, St. Peter's	164
Red limestone, lower magnesian	102
Gray limestone, lower magnesian	16
Potsdam:	
White limestone, Jordan	116
Blue shale, St. Lawrence limestone	128
White sandstone, Desbach	82
Blue shale	170
Sandy limestone	9
White sandstone	130
Sandy marl, Hinkley	8

White sandstone	79	
Red marl	57	
Red sandstone	290	
		1069
		1421

Although the classification into these sub-divisions is warranted by well-defined beds around Madison, Wis., in eastern Wisconsin and in Minnesota, yet, owing to the thinning out or disappearance of these strata or by the multiplication of sub-divisions, the local variations are so great that in many places it is impossible to classify the strata found, under any general classification except the general name, Potsdam; for the limits of this formation, as a whole, are well and clearly defined. Further examples of the Potsdam stratification will show more clearly its variations. The following section of the Potsdam strata at Hudson, Wis., given by Prof. Chamberlain illustrates this variation. (See Geology of Wisconsin, Vol. IV., p. 113.)

Section of Potsdam Strata at Hudson, Wis.

20	feet coarse, incoherent, red or white quartzose sand.
3	“ buff calcareous layer with shaly layer of green sand.
2	“ compact brown calcareous sandstone.
2	“ brownish-white sandstone.
8	“ incompact white sandstone.
2	“ brownish-white sandstone.
8	“ incompact white sandstone.
12½	“ white to buff sandstone.
8	“ white to buff sandstone, stained with iron.
12½	“ yellowish-brown sandstone, in mottled layers.
3½	“ buff friable sandstone, effervesces slightly.
10	“ incoherent sandstone.
27	“ shaly sandstone, effervesces slightly.
9	“ compact light buff sandstone, effervesces briskly.
5	“ dark brown sandstone.
10	“ dark brown rock, containing much calcareous material.
8	“ shades into strata above and below.
17	“ dark green shale.
10	“ dark buff sandstone.
5	“ buff calcareous sandstone.
5	“ green shale.
5	“ mottled shale.
13	“ light brown to white sandstone.
2	“ friable shale.
10	“ white sandstone.
3	“ green and white sandstone.
15	“ friable light buff and yellowish sandstone.
10	“ white sandstone.
245½	

Other sections encountered in Illinois, are as follows:

AT STREATOR.		FEET
Drift		30
Coal measures		211
Trenton limestone		203
St. Peter sandstone		225
Lower magnesian limestone		90
Potsdam:		
White sandstone	133	
White limestone	211	
White sandstone	37	
Dark gray limestone	50	
Fine reddish sandstone	15	
Dark gray limestone	13	
White and brown sand	1	
Gray limestone	18	
White and brown sandstone	168	
Blue shale	100	
Dark limestone	73	
Variegated sandstone	187	
Soft limestone	60	
Variegated shales	158	
Dark red sandstone	80	
Blue shale	50	
Bluish drab and buff limest.	383	
Totat depth in Potsdam		1737
Total depth		2496

AT ROCKFORD.		FEET
Drift		125
Trenton limestone		30
St. Peter sandstone		225
Lower magnesian limestone		105
Potsdam:		
Green sandstone	5	
Red sandy shale	72	
Gray sandstone	148	
Blue shale	25	
Gray sandstone	40	
Red sandstone	25	
White sandstone	335	
Red shale	2	
White sandstone	13	
Red shale	2	
White sandstone	13	
Red shale	1	
White sandstone	9	
Red shale	20	
White sandstone	80	
Gray sandstone	45	
Yellow sandstone	20	
Red shaly sandstone	105	
White sandstone	90	
Red shale	275	
White sandstone	171	
Total depth in Potsdam		1486
Total depth		198

At Ottawa, Ill.		Feet
Drift		35
St. Peter sandstone		130
Lower magnesian limestone		145
Potsdam:		
Sandstone	110	
Free limestone	175	
Sandstone	260	
Blue shale	120	
Hard sharp sandstone	100	
Sandstone	115	
Shale	360	
Sandstone	290	
Total depth in Potsdam		1530
Total depth		1840

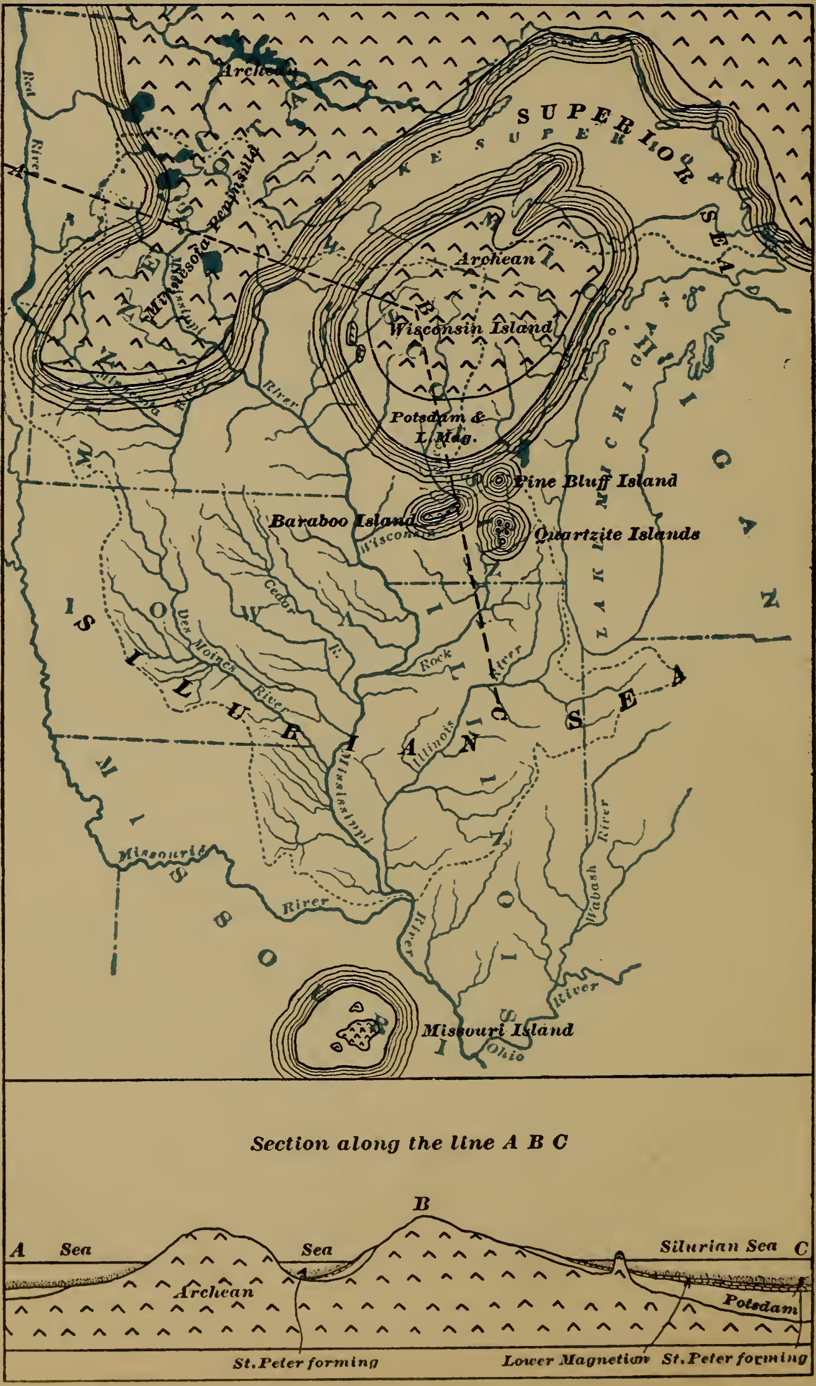
At Joliet, Ill.		Feet
Niagara limestone		230
Hudson River shale		68
Trenton limestone		334
St. Peter sandstone		217
Red shale		40
Lower magnesian limestone		450
Potsdam:		
Sharp sandstone	175	
Blue shale	50	
Sandy limestone	125	
Shale	230	
Sandstone	150	
Total depth in Potsdam		730
Total depth		2066

As indicated in the foregoing tables, the Potsdam varies greatly in its character throughout its extent, not only from shale and limestone to sandstone, but also in the character of the sandstone, which is mostly fine-grained, but becomes coarse-grained in its lower strata, and passes into a conglomerate near its margin, the shore of the ancient Archean land. As may be understood from its physical character, it readily transmits the water which it receives at its outcrop, either from rains or from the numerous streams which flow over its exposed surface, the extent of which may be judged from the maps. The outcrops of the Potsdam occupy about 14,000 square miles in central Wisconsin, extending in a cresent-shaped tract around the Archean outcrop.

51. **The Lower Magnesian or Oneota Limestone.**—While the variation in the circumstances attending its deposition caused considerable differences in the various strata of which the Potsdam deposits are composed, a more radical variation gave rise to a still more remarkable change in the formation, and the lower magnesian limestone resulted. This formation is a dolomitic limestone, coarse, irregular in stratification, often inter-stratified with shale or sandstone layers and limestone breccia, which last, occurring in clusters or heaps, often gives the upper surface a billowy appearance and causes it to vary greatly in thickness. The variation in thickness seems to be more marked in Wisconsin than elsewhere.

Although undoubtedly cracked and fissured to some extent, it seems to be in general free from these disturbances and to offer a quite uniform and homogeneous mass to prevent the upward passage of the waters contained in the Potsdam stratum below it. This stratum is found from 65 to 260 feet thick through Wisconsin and is from 105 feet to 170 feet thick in northern Illinois. It seems to thicken quite rapidly to the southward, and is found to be 490 feet thick at Joliet. 500 feet thick at Streator and 811 feet thick at Rock Island. A flow of water, which may be derived from the underlying Potsdam sandstone, is sometimes found in the softer portions of this stratum.

MAP No. 4.



Beginning of Silurian Age. St. Peter Sandstone forming in the Sea.

52. **The St. Peter Sandstone.**—Above the lower magnesian limestone lies a remarkably uniform quartzose sandstone. It is uniform in material and thickness, and quite covers all the irregularities in the surface of the underlying limestone, except at some points in Wisconsin where it is entirely pinched out; the Trenton limestone lying directly on the lower magnesian limestone. The average thickness of the St. Peter sandstone throughout the territory under discussion is probably about 150 feet, although in Wisconsin Prof. T. C. Chamberlain estimates its average thickness as only about 80 feet. This deposit is supposed to have been formed in a shallow sea by the decomposition of the Archean and Potsdam rocks. The hypothetical condition of the Upper Mississippi Valley during the formation of the deposit is shown in Map No. 4. No fossils have been found in this rock, and its formation marked an epoch probably unfavorable to the existence of life.

This stratum has an outcrop of about 2,000 square miles in Wisconsin, and also crops out at several points in Illinois along a line of upheaval which passes southwesterly from Stephenson County to the vicinity of La Salle, bringing the St. Peter to the surface along the Rock River at Oregon and Grand Detour, and along the Illinois River from La Salle to Ottawa. The lower magnesian limestone is also brought to the surface at Utica by this uplift. The St. Peter sandstone is an important water-bearing stratum, although its outcrop is so low that the pressure of its water is usually much less than the water of the Potsdam.

53. **Trenton Age.**—Although apparently no life existed during the formation of the St. Peter sandstone, yet conditions favorable to the existence of life again returned, accompanied by geographic changes in the relation between the sea and the land, and extensive beds of limestone were again deposited. These constituted the limestones of the Trenton group, which may be divided into various substrata more or less distinct in character. Of these the Galena limestone is, perhaps, the best known, but for the purpose of this paper the Trenton may be considered as a whole, inasmuch as its general character is approximately uniform.

MAP No. 5

Niagara Period. Niagara Deposits forming in Interior Sea.

54. **The Cincinnati or Hudson River Formation.**—Further change in the conditions of deposition gave rise to turbid floods of more or less intermittent and local occurrence. These again altered the character of the deposit, and the Cincinnati or Hudson River shale resulted. This consists of clay shale interbedded with more or less limestone.

55. **The Niagara Formation.**—The Cincinnati formation was followed by the limestone deposits of the Niagara period, which are divisible into strata of more or less local importance. This deposit occurs at surface outcrops at different points in the valley , and embraces the Joliet, Lemont, Naperville, Waukesha and Anamosa limestones. A general idea of the supposed extent of the land in the Upper Mississippi Valley during the formation of the Niagara limestone is shown in Map No. 5, which illustrates also the gradual elevation and extension of the land surface.

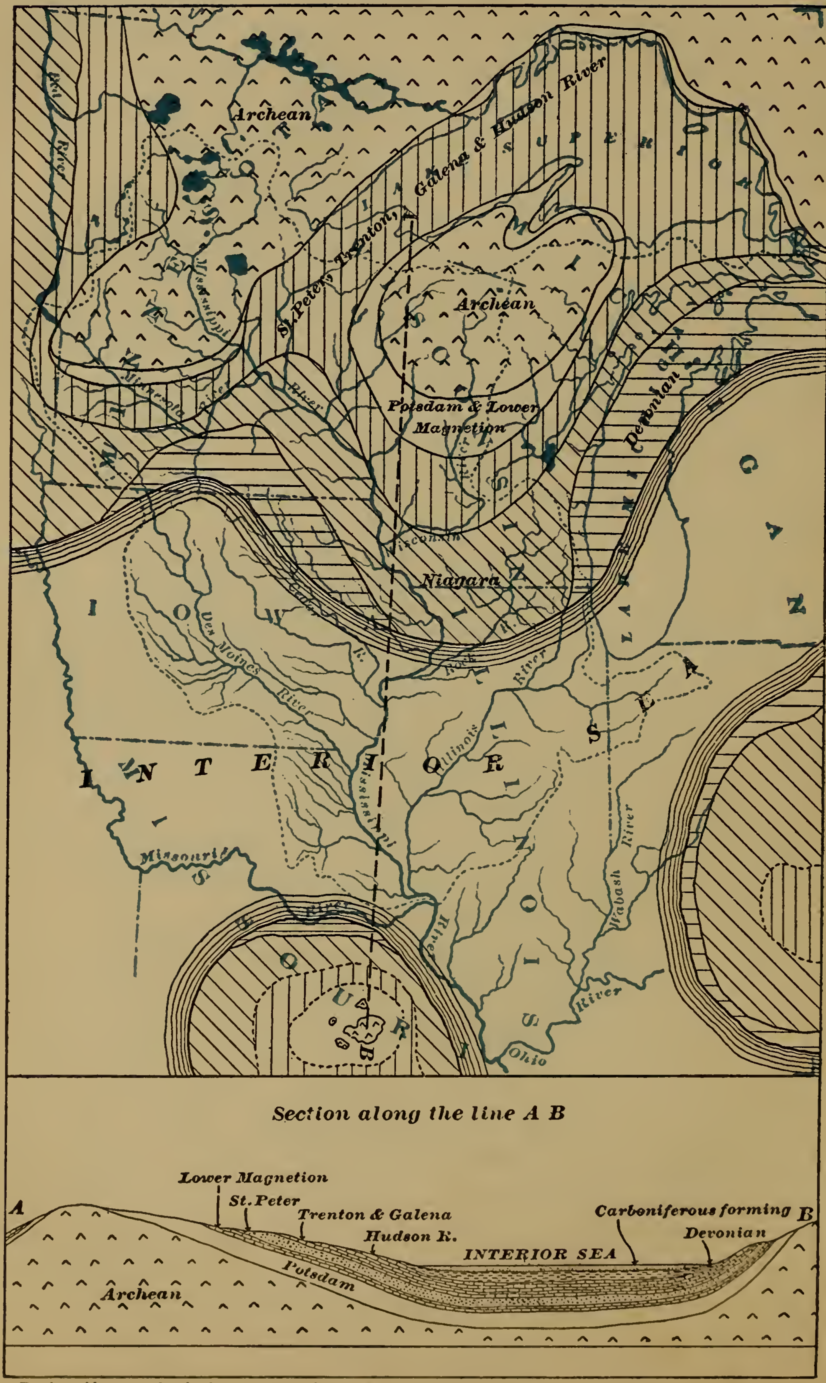
56. **The Devonian Formation.**—Over the Niagara formation were deposited the rocks of the Devonian period, consisting of limestone rocks of no great interest in this discussion.

At this time a large portion of the area under consideration had been elevated above the sea, and the last remaining series of indurated deposits which we shall here consider was in this area more limited in extent than any which preceded it.

57. **The Carboniferous Age.**—The carboniferous age which followed is illustrated by Map No. 6, which shows the further recession of the sea and the consequent limitation of the strata then under process of formation.

This age ushered in an epoch of life very different from any which had preceded it. Its deposits were comparatively local in character, and although they have in a general way been correlated, yet there is a greater variation in these strata than in those of any preceding deposits. Especially is this true in those of the coal measures proper. These deposits seem to have been made in shallow seas, lakes or swamps of limited extent, rather than in a broad and deep sea such as those in which most of the preceding deposits had been formed. Hence, great local variations are observable and the strata have commonly a much more limited geographic extent. This

MAP No. 6.



Carboniferous Period. Carboniferous Deposits forming in the Shallow Interior Sea.

age witnessed the formation of extensive beds of limestone, sandstone, shales and coal.

58. **General Characteristics of the Strata.**—It should be understood that lines of exact demarkation seldom exist between the various strata. One stratum usually passes gradually into another. Changes in the controlling influence which modified the deposition were usually not radical and they only obtained gradually. Thus, in passing from sandstone to limestone, the upper strata of the sandstone will usually be found somewhat calcareous and the lower strata of the limestone somewhat silicious.

A like condition applies to the character of a stratum as varying throughout its geographic extent. The conditions at one point may have been such as to favor the formation of limestone deposits, while those at a point more or less remote may, during the same period, have been favorable to the formation of shale. We thus find widely different strata belonging to the same age. Hence a stratum may within a short distance merge from a sandstone into a limestone, from a limestone into a shale, or the reverse, or from a coarse-grained stone to a fine and more impervious one. Or a stratum may even have been entirely lost by reason of a local elevation which raised the sea bed at that point above the sea level, thus preventing deposits, or by the existence of local ocean currents which might accomplish the same result. The more widespread the conditions controlling deposition, the more uniform is the character of a stratum throughout its extent. The character of the rock deposit which we may encounter in drilling is often highly problematic, and it is only by an extended examination of facts as they have been found to exist, and by their careful correlation, that we may arrive at conclusions as to what we must expect in new and untried localities. The farther the point in question lies from those where the character of the sub-strata is known, the greater is the uncertainty respecting it.

59. **Original Extent of Strata.**—The original extent of the various strata of the district under consideration was much greater than the present geological map of the region would

Map No. 7


LAKE SUPERIOR
MINNESOTA
WISCONSIN
MICHIGAN
LAKE
Red River of the North
Minnesota River
St. Croix River
Chippewa River
Black River
Potsdam
Potsdam or St. Croix
Trenton & Galena
Niagara
Devonian
Cretaceous
This territory deeply covered with drift. Geology uncertain
Duluth
Brainerd
St. Cloud
Minneapolis
Stillwater
Menomonie
Chippewa Falls
Eau Claire
Merrill
Wausau
Faribault
Mankato
Rochester
Winona
La Crosse
Portage
Madison
Watertown
Milwaukee
Racine
Kenosha
Janesville
Beloit
Dubuque
Waterloo
Sioux City
Appleton
Neenah
Oshkosh
Fond du Lac
Sheboygan
Manitowoc
Green Bay
Oconto
Marinette
B

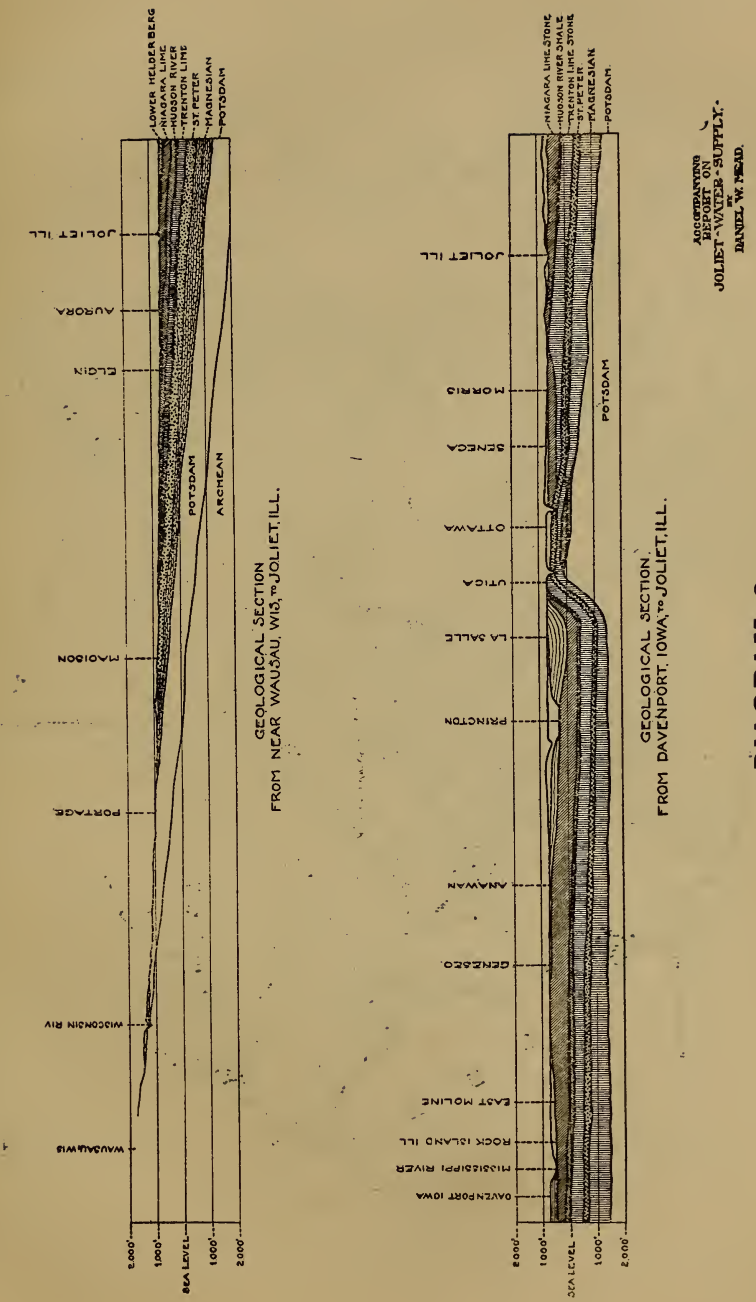
APPROXIMATE GEOLOGICAL MAP OF THE UPPER MISSISSIPPI VALLEY, SHOWING INDURATED FORMATION.

indicate. Hundreds of feet of strata have been disintegrated and eroded by drainage waters. The Hudson River shale, while now encircling Central Wisconsin and Central Northern Illinois as a narrow belt (See Map No. 7), undoubtedly once covered a much greater area, as did the strata of the Niagara group. The section through Elk Mound shows the present geological condition, while the prolongation of the limiting lines of the strata would show their probable original extent.

60. **Deformation.**—It must also be understood that the strata, although originally deposited as more or less uniform sheets, each overlying the strata below, do not exist in this uniform condition at present; for many disturbances, caused by upheavals and depressions in the crust, have opened cracks and fissures and have caused relative displacements of the strata, amounting in some cases to hundreds of feet. The principal axes of disturbance in this area are shown on Map No. 8. The extent of the cracks and fissures caused by these disturbances of the strata may be judged by a visit to any quarry. Their existence largely modifies the hydrological conditions of the various strata, frequently permitting the passage of the waters from one stratum to those below or above, and in the latter case, giving rise to springs.

61. **Slope.**—The underlying Archean rocks slope downward in all directions from their outcrop in the extreme northern portion of this valley, being about 2,000 feet above sea level at their highest outcrop, and perhaps fully as much below sea level at their lowest point. As a rule, the super-incumbent strata follow this general slope. The Potsdam strata, however, thicken rapidly to the southward, as does the lower magnesian above it, so that the higher strata have not as great a rate of inclination as the dip of the Archean rocks would indicate.

The north-and-south section accompanying Map No. 7, and the section shown on Diagram 9, illustrates these remarks, and shows, moreover, that the surface follows the general dip of the strata at present, as it has done through all past geological ages; the outcrops of the older geological deposits being found at the higher elevations. In traveling from the



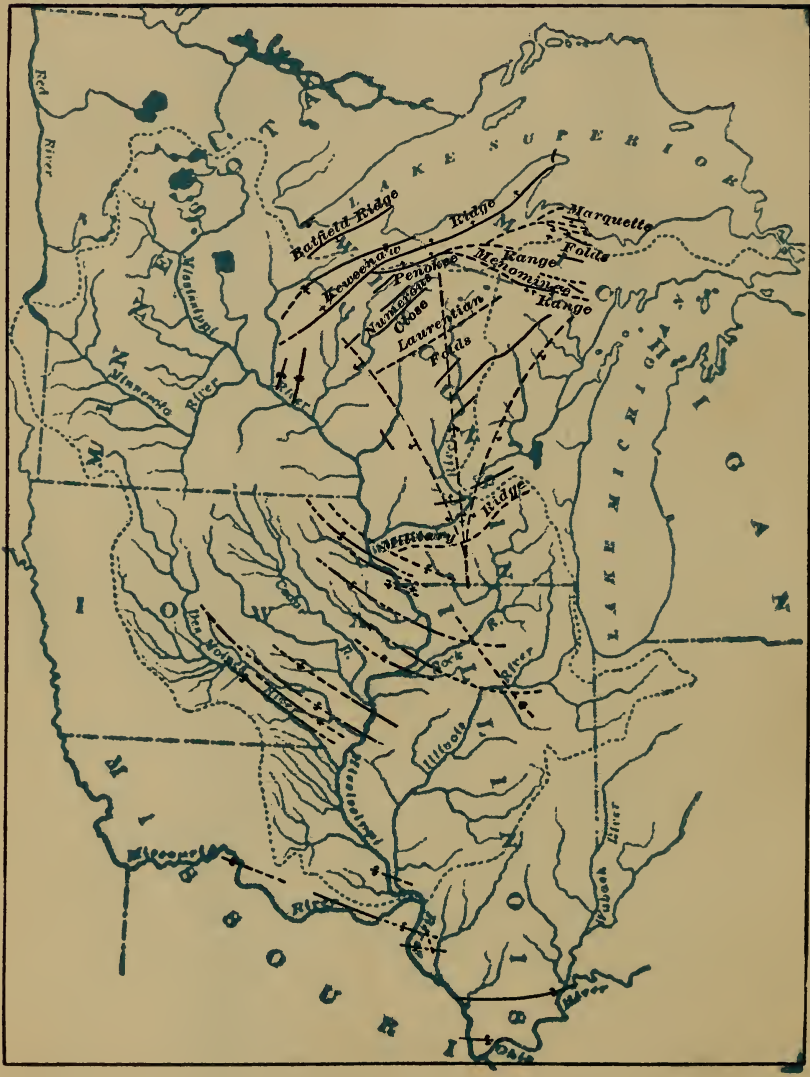
GEOLOGICAL SECTION
FROM NEAR WAUSAU, WIS, TO JOLIET, ILL.

GEOLOGICAL SECTION.
FROM DAVENPORT, IOWA, TO JOLIET, ILL.

ACCOMPANYING
REPORT ON
JOLIET-WATER-SUPPLY.
BY
DANIEL W. MEAD.

DIAGRAM 9

MAP No. 8



Main Axis of Deformation and Dip of Strata.

original Archean nucleus in any direction the traveler will descend in elevation while he ascends in geological succession, passing over each of the deposits already described as he approaches the sea level.

62. **Waters of the Strata.**—The dip of a stratum causes the flow of its waters from its outcrop toward the sea, and from these conditions arise springs and artesian wells where the stratum is intercepted by cracks or fissures or is artificially pierced by the drill.

63. **Upheaval.**—During the ages here briefly reviewed, this territory had gradually arisen from the ocean. The carboniferous deposits mark the last age of submergence in this area, with the exception of certain minor cretaceous areas in the western portion of the Mississippi Valley, areas which are of comparatively little consequence in this discussion.

With the earliest appearance of the strata above the sea the formation of a drainage system began. The atmospheric agencies disintegrated the softer portions of the strata and carved the rocks into various forms as their varying hardness permitted. The drainage waters carried the residuary matter to the sea, thus excavating deep drainage valleys, and forming the later strata by the deposition of the material. The extent of this drainage erosion has already been briefly considered.

64. **Pre-Glacial Drainage.**—The subsequent alteration of these drainage valleys has rendered it almost impossible to conceive of their early character and extent. The hill-tops were higher and bolder than at present. The valleys, deeper, more narrow and more rugged, occupied in many cases locations quite different from those now occupied. The Lake Michigan valley was then occupied by a river which flowed from the north through the present southern extremity of the lake, at an elevation some hundred feet below the present lake level. This river, with a southwesterly course and passing probably not far from the present site of Bloomington, Ill., emptied its waters into the Mississippi near the present mouth of the Illinois River. A light soil covered the valleys and the depressions of the hills, furnishing a scant vegetation for the sustenance of animal life. The mammoth and the

mastodon, whose descendant, the modern elephant, is no longer native of this contient, roamed through these early valleys, probably a co-inhabitant with primitive man.

The Mississippi River occupied to a considerable extent its present course. To this, however, there are local exceptions, notably at St. Paul, La Crosse, Rock Island and Keokuk, where the rock-bottomed rapids testify to a diversion from the ancient bed. The river then probably drained a much larger territory than at present. It also flowed at a level probably from 100 to 250 feet lower than its present one. It is difficult to picture the Upper Mississippi Valley as it then existed, but those who are familiar with the driftless area of Wisconsin, north and west of the Wisconsin River, including the dells and country about Devil's Lake, can form some conception of the early topography of this whole area. This region of Wisconsin has been less altered than any other in the district considered; yet its valleys, which were then much deeper than now, have been more or less completely filled by the fluvial deposits of the drift period.

The principal existing streams of this area, and to some extent their lateral valleys, were features of the topography of the age we are now considering, their appearance has been greatly modified by the subsequent events of the Glacial period.

65. **The Glacial Period.**—From causes not thoroughly understood, the consideration of which is unnecessary for the purpose of this paper, there followed periods of great cold; of long winters and short summers and perhaps of greater average precipitation than at present, which fell as snow over the northern regions and which the heat of the short summer was wholly inadequate to melt. The result was the accumulation of vast snow fields, thousands of feet in thickness, similar to those which now exist in Greenland and Alaska and in the higher altitudes of the Alps, the Himalayas and the Rocky Mountains. The weight of the superincumbent mass, greatest in depth in the north where the summer heat never penetrated, not only compressed its lower layers into ice, but forced them to flow in great glaciers to the southward. Their extent in

MAP No. 9

First Glacial Epoch.

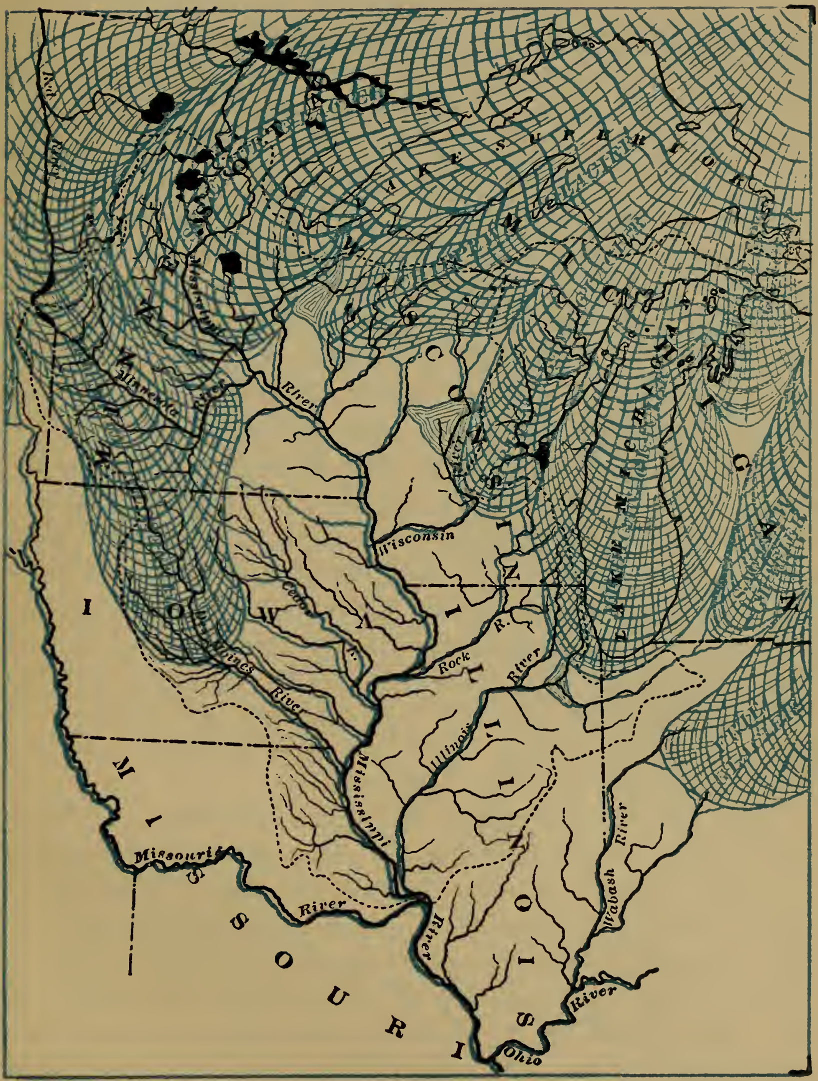
this direction was limited only by the conditions of equilibrium between the melting of the ice mass and its motion. The effects of the flow of these vast ice rivers over the irregular and deeply marked drainage depressions can be easily understood. The rocky hillsides were worn and broken into dust and fragments; huge boulders were torn off and transported hundreds of miles; and the valleys were filled up with the accumulating debris, which was more or less sorted and arranged by the sub-glacial waters. At least two epochs of glaciation, more or less distinct, can be traced in the Upper Mississippi Valley. See Maps Nos. 9 and 10. These have been perhaps the most marked causes in the creation of the present conditions, at least in so far as they are related to civilized life. To this period the agricultural lands of Minnesota, Iowa and Illinois owe their character and fertility, and their ability to maintain the population now within their borders. The drainage system was altered and the topography was greatly changed and re-wrought. Not only were the valleys filled up and the hills cut down, but a new class of topographical features was introduced.

66. Work of Glaciers.—While flowing water can transport only debris of a coarseness depending upon the velocity, moving ice will transport the largest rocks as well as the finest material. On melting the ice deposits its heavier material, most of the finer particles being often lost in the floods which result from the melting of the ice. The material pushed up or deposited in this manner by the ice is termed a "moraine," and when it marks the termination of the ice-flow, a "terminal" moraine. Such is the Kettle Moraine, which extends across the entire territory here considered. When formed on the side of the moving ice capes it is termed a "lateral" moraine, and two of these may be joined into a "medial" moraine.

Upon the melting of detached ice masses covered by extensive deposits of moraine material, this material is deposited about their edges, forming kettle holes, which result in lakes and swamps.

The streams of water resulting from the rains and melting

MAP No. 10.



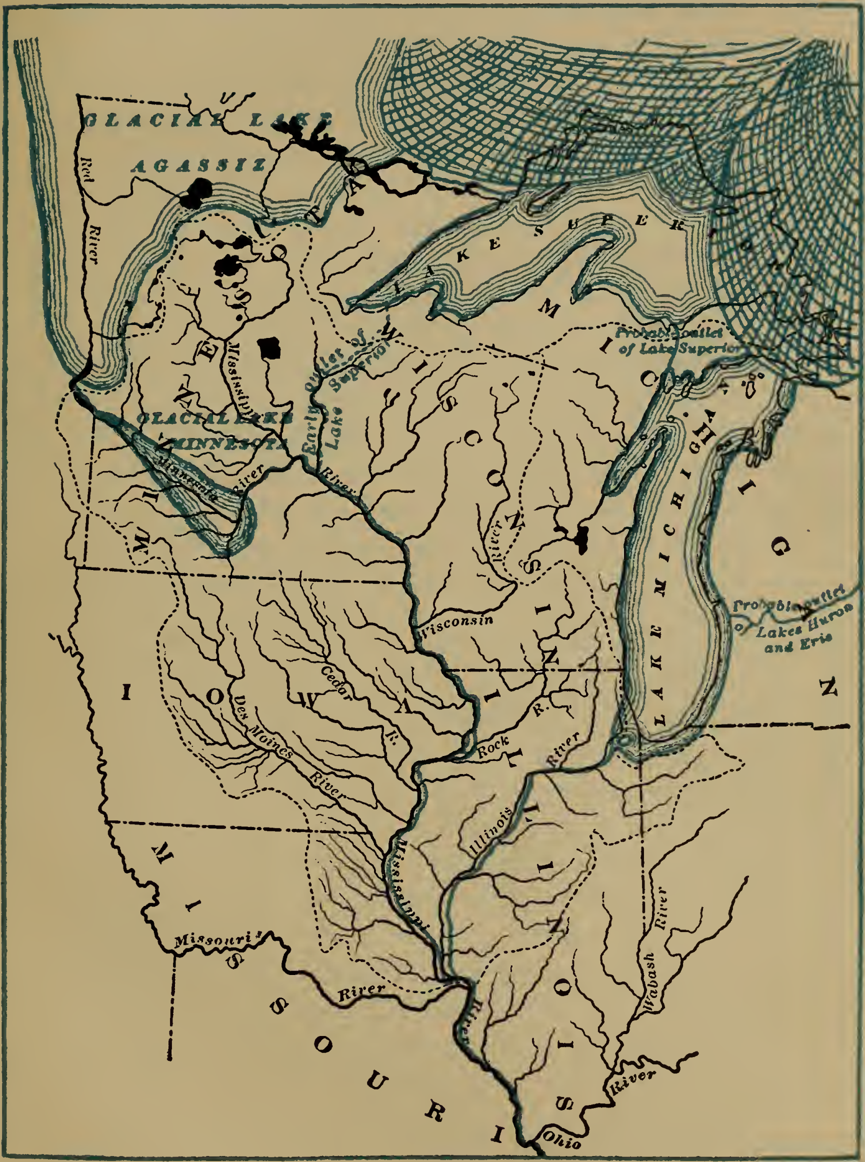
Second Glacial Epoch.

ice, frequently cut open channels in the glaciers and sweep into it vast quantities of material which is there worked over and sorted by the flood, and deposited as a delta at the end of the glacier, or in long lines between the valleys of ice, where it is left, on the melting of the ice, ridge-like deposits called kames.

Map No. 9 is a hypothetical map of the conditions of the Upper Mississippi Valley during what is usually termed the first glacial epoch, or at the time when the ice had reached its greatest southern extension. The limits of the ice are still marked by ranges of hills of morainic material, the nature and character of which offer conclusive evidence of its origin. Many of the topographical features of the first glacial epoch have been greatly modified by subsequent glacial events and by atmospheric and aqueous erosion during the time which has since elapsed. The kettle holes and lakes have been gradually filled and they are now mostly swamps or peat-bogs, and deep lines of drainage have been cut through the glaciated area. This process has been largely aided by the drainage waters of the second glacial epoch. During that epoch the extent of the ice capes was much more limited than in the first, as may be seen by reference to Map No. 10, and, as its period was more recent, its topographical features are more marked. Within the kettle moraine which marks its limits are found the numerous small lakes which form so striking a feature of Wisconsin and Minnesota scenery.

67. **Glacial Recession.**—With the recession of the ice capes began the development of a new drainage topography. The floods which came from the melting ice, inundating great tracts of country, especially along the Mississippi River, gave rise to lacustrine deposits of considerable depth, known as "loess," a deposit consisting mostly of sand with some little clay, and so pervious as to offer little hindrance to the flow of drainage waters. The glacial waters had begun to excavate channels for their flow in their earlier deposits, and this process was continued in the lacustrine districts as the lacustrine conditions ceased to prevail. The old Michigan valley had been filled at the southern extremity of the present lake, and the

MAP No. 11



Recession of the Glaciers.

waters being yet dammed in by the receding glacier from the present outlet of the lake, found a passage through the present valley of the Illinois River. The waters of Lake Agassiz, which was the progenitor of the present Lake Winnebago, with an area equal, at least, to the combined area of Lakes Superior, Michigan and Huron, flowed south through the valley of the Minnesota River, and through the lake which then existed in a portion of that valley, into the Mississippi. The other rivers of this area, while early receiving considerable drainage water from the melting ice, soon lost these waters as the ice receded, and settled down to act as the drains of their present respective drainage areas.

68. Glacial Drainage.—The hpyothetical condition of the country at one period in the recession of the glaciers is shown in Map 11. This map shows the location and outline of the southern extension of the glacial Lake Agassiz, and also the outline of glacial Lake Minnesota. The latter, while shown on the map, was probably either entirely or partially drained at this period. The glacial River Warren occupied the present valley of the Minnesota River, and to its agency the dimensions of the present valley are due. This map also illustrates the main drainage features existing at this period, at which time the glacial River Warren drained Lake Agassiz. The Illinois River drained Lake Michigan, and through the latter probably Lakes Superior, Huron and Erie. At a somewhat earlier date, Lake Superior was drained through the Brule and St. Croix Rivers directly into the Mississippi, as shown by the dotted lines at the western end of the lake; but, as the glacier receded, the outlet from Au Traine Bay to Little Bay de Noquet was uncovered, and at the period illustrated by the map the outlet was probably at this point. Later the discharge probably took place across the peninsula further to the east. Lakes Huron and Erie also probably drained into Lake Michigan at this period. It may, however, be considered doubtful whether all of the features shown on Map No. 11 were contemporary.

At an earlier period in the recession of the ice cape the Chippewa, Black, Wisconsin, Rock and Fox Rivers had received from it a portion of their drainage waters, which had undoubtedly outlined the channels in which they now flow; but at the time illustrated in this map they had lost these waters and they carried only the flow due to the rainfall and drainage of their own watersheds.

The vast floods from the melting ice had greatly changed the earlier glacial deposits in these valleys. The heterogeneous masses of clay, stone and sand were, in many cases, sorted, rewrought and redeposited. As the ice still further receded, the present outlet of Lake Michigan was uncovered, as was also the Hudson Bay outlet to the valley of the Red River of the North. These outlets being at lower elevation than those offered by the Illinois and Mississippi Rivers, these rivers also lost the glacial drainage which hitherto, as the only outlets, they had been receiving from the melting ice capes. In these rivers the results due to the loss of the drainage waters was much more marked and the changes in their conditions were more radical than in the smaller rivers of this area.

69. Post-Glacial Drainage.—As the drainage valleys were deprived of waters from the melting ice, their carrying power decreased and they began to build up their beds, which they had formerly excavated so as to form a valley commensurate in size and inclination with their modern capacities. The local streams, dependent only on local rainfall and drainage area, had also begun to develop as the country was uncovered by the receding ice. These in the main followed such depressions as the ice capes had formed. Rarely, if ever, in the glacial or local drainage streams, were the earlier drainage valleys closely followed throughout their entire extent. The old valleys having been filled, frequently to their tops, it was often as easy and as natural for the modern stream to pass from valley to valley between two hills which formerly separated valleys, as to continue in its ancient course.

As the waters cut through the drift, the rocky hillsides were frequently encountered, and these caused a diminution in the amount of cutting by the stream, while the excavation below still went on. Thus have been formed many falls and rapids both in the Mississippi River and in its tributaries.

The drift itself, as modified by the glacial waters, possesses largely a locally developed stratification, ordinarily somewhat limited in its geographic extent.

The following sections of the drift show its variation in depth and general character, which will be seen to be subject to great local differences.

SECTIONS OF DRIFT.

Bloomington, McLean Co., Ill.

Depth in feet.	Material.
10	Soil and brown clay.
40	Blue clay.
60	Gravel.
13	Black mucky soil.
89	Hardpan.
6	Black soil.
34	Blue clay.
2	Quicksand.

254 feet.

Clinton, DeWitt Co., Ill.

Depth in feet.	Material.
15	Soil and yellow clay.
30	Hard blue clay.
2	Black mould.
8	Drab clay.
8	Black mould and drift wood.
16	Drab clay.
2	Drift wood, etc.
26	Drab clay.
12	Hardpan.
10	Green clay.

133 feet.

Lake City, Minn.

Depth in feet.	Material.
2	Black soil.
40	Yellow clay.
160	Gravel and sand.
5	Fine loam clay.

207 feet.

Bushnell, McDonough Co., Ill.

Depth in feet.	Material.
12	Yellow clay.
8	Yellow clay and sand.
25	Yellow clay.
15	Blue and yellow clay.
18	Blue clay and sand.
29	Blue clay.
3	Blue clay and sand.
4	Sand.

114 feet.

Mt. Carroll, Carroll Co., Ill.

Depth in feet.	Material.
2	Soil.
13	Yellow clay.
2	Blue clay.
15	Reddish clay and gravel.
2	Tough blue clay.
3	Coarse stratified gravel.
11	Pure yellow sand.
5	Black mucky clay.

53 feet.

Minneapolis (Lakewood Cemetery).

Depth in feet.	Material.
135	Gravel and sand.
3	Yellow clay.
74	Blue till.
36	Gravel and sand.
8	Boulders.

256 feet.

Within the driftless areas, the ice floods had filled the lower valleys with detritus brought down by the flood waters, and had thus modified, although to a less extent, the topography of this region.

The major part of the glaciated area, outside of the kettle moraine, is, however, an extended plain, modified by other morainic deposits and by drainage valleys, which have since been somewhat developed. At the close of the glacial ages the ancient topography had been destroyed; while the new was yet in its infancy, and it is still but slightly developed; so slightly, in fact, that imperfect drainage is the rule on the plain between the rivers.

The common law of topographical development in the glacial area is readily understood. The circumstances of glaciation establish the limits of the watersheds; the waters subsequently flowing from the receding ice frequently outlining the location of the streams themselves. The flood waters carve their valleys in proportion to their amount and elevation, and gradually excavate them until their fall from source to mouth is only sufficient to cause a flow of their waters, carrying perhaps more or less of excavated silt in time of flood. The water has then reached its base level, and can go no lower, but works backward and forward across the valley, widening but not deepening it. The depth to which a stream can excavate its valley is then subject to the controlling features of its point of discharge, which in the case of the rivers of this region is formed by the Mississippi River and Lake Michigan. Hence, the nearer these outlets a valley is located, the more marked is its character and depth. Few rivers in this area have reached their base level, for the time since the glacial age has been too short. The Illinois River, in its lower course (as has been already mentioned), is an exception, the glacial waters having reduced it to a lower grade than is suitable for the discharge of its present waters laden with their normal burden of silt. Hence the low lands are flooded and the silt is deposited, gradually raising the bed of the river; and this process if allowed to proceed unobstructed, will finally raise the lower river to its normal base level.

Thus have been formed the surface and underlying rocks of the Upper Mississippi Valley. Volumes have been written descriptive of the ages here so briefly reviewed and of the conditions which we have been obliged to pass with a glance, and to these the reader must turn for further details. Enough has been said, however, to fix the general sequence of events and the general geological condition. For practical purposes, each district should be studied in detail and the whole subject should be examined with reference to the particular questions involved.

70. **Hydrological Conditions.**—As a source of water supply the Potsdam sandstone is one of the most important of the formations embraced in the territory under discussion, and its character has been examined at some length. From this source are derived numerous artesian and deep wells, which have been developed throughout the area shown on the general geological map, No. 7.

As a source of water, the St. Peter sandstone is next in importance in this area. This deposit lies above the Potsdam, being separated from it by the lower magnesium limestone, and is first encountered by the drill. The elevation of its outcrop being less than that of the Potsdam, its waters have not usually as great a head and consequently it does not as often furnish flowing waters.

It has already been stated that the drift sheet which covers a large proportion of this area contains more or less extended deposits of sand and gravel which frequently offer available sources of water. These deposits are sometimes so extended that they may produce many of the phenomena observable in wells from the lower strata, such as artesian flows. Such results were obtained at Belle Plaine, Iowa, and De Kalb., Ill. The irregularity in the deposition of these deposits makes the watershed of any particular supply hard to determine. Its determination may be, however, a matter of considerable importance, especially if its source be from districts from which it may receive organic contamination.

In considering the hydrological conditions of the various strata it should be noted that all are to some extent water-bearing. Even where the ratio of absorption is comparatively insignificant, the cracks and fissures often play an important part. The writer is able to furnish only a limited number of observations on the rocks of the area here considered, and these are given in Table 24, together with data of other and similar rocks from other localities.

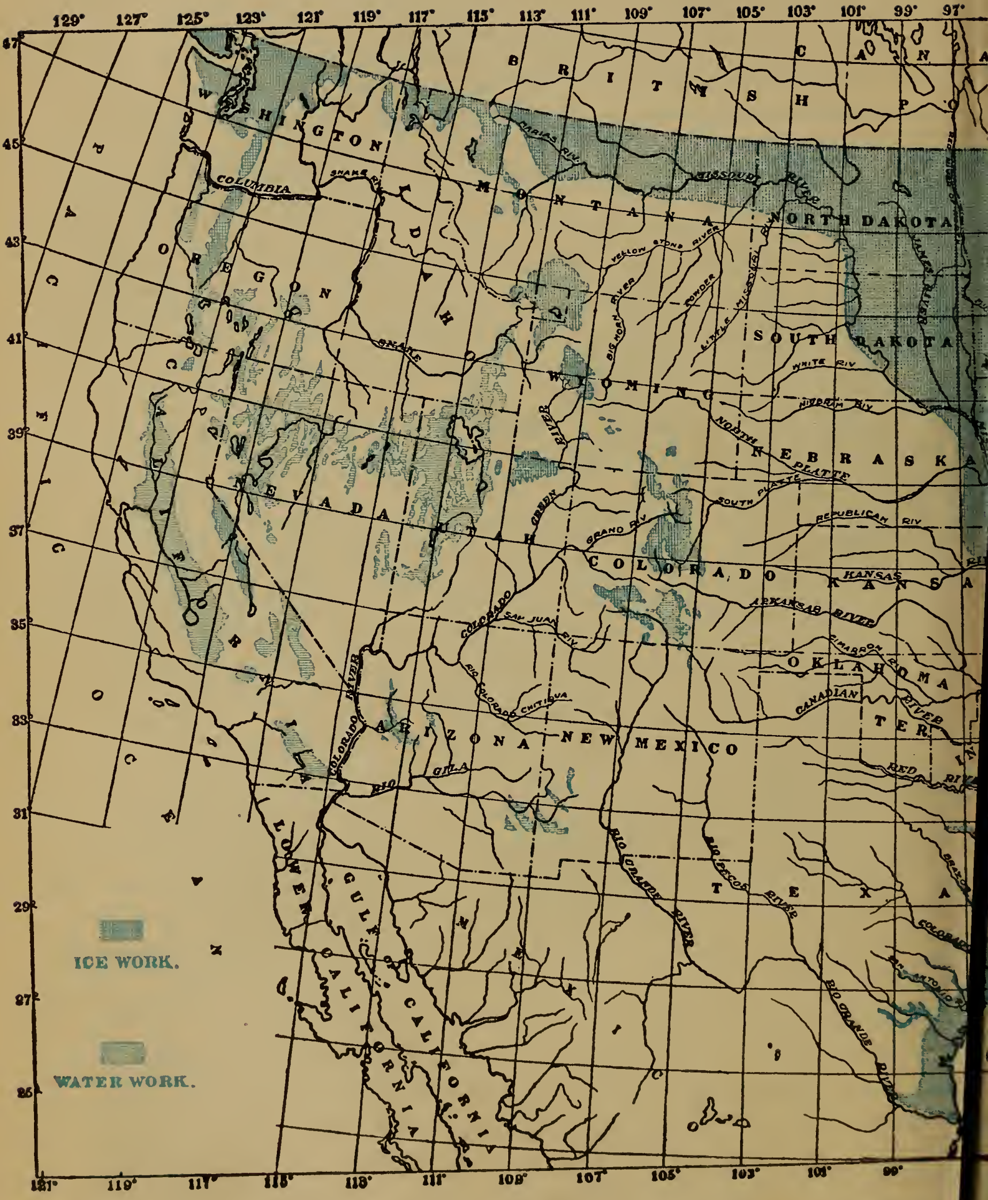
Most of the rocks mentioned in this table are from quarries furnishing building stone. They are, therefore, better and less porous than the average bed rock.

TABLE 24

TABLE SHOWING PERCENTAGE OF ABSORPTION (BY VOLUME) OF VARIOUS GEOLOGICAL STRATA.

Formation.	Location.	Water in 100 parts of rock.	Authority.
Sandstone	Grand Beauchamp, France	13.15	M. Delessee.
Sandstone, another specimen	Grand Beauchamp, France	4.37	M. Delessee.
Calcareous freestone	Grand Beauchamp, France	18.03	M. Delessee.
Lower tertiary, sandstone (pure quartzose)	Grand Beauchamp, France	29.00	M. Delessee.
Upper chalk	Ivry, France	24.10	M. Delessee.
Devonian limestone	Boulogne, France	0.08	M. Delessee.
Oolite sandstone	Cheltenham, England	23.98	E. Wetherel.
Oolite limestone	Cheltenham, England	12.15	E. Wetherel.
Old red sandstone	Gloucestershire, England	11 60	E. Wetherel.
Hornblende granite	East St. Cloud, Minn.	.42	G. P. Merrill.
Gabbro	Duluth, Minn.	.29	G. P. Merrill.
Dolomite	Joliet, Ill.	1 06	G. P. Merrill.
Limestone	Quincy, Ill.	.55	G. P. Merrill.
Limestone	Quincy, Ill.	1.35	G. P. Merrill.
Sandstone	Fond du Lac, Wis.	4.81	G. P. Merrill.
Dolomite	Lemont, Ill.	1.12	G. P. Merrill.
Dolomite	Winona, Minn.	4.76	G P. Merrill.
Dolomite	Red Wing, Minn.	2.5	G. P. Merrill.
Dolomite	Mantorville, Minn.	5.55	G. P. Merrill
Limestone	Big Sturgeons Bay, Wis.	.25	G. P. Merrill.
Sandstone	Ft. Snelling, Minn.	6.25	G. P. Merrill.
Sandstone	Jordan, Minn.	12.5	G. P. Merrill.
Sand and Gravel		33 to 40	R. J. Hinton
Dry clay		12.	R. J. Hinton.
Trenton limestone	Rockford, Ill.	2.10	D. W. Mead.
Galena limestone	Rockford, Ill.	4.2	D. W. Mead.
Berea sandstone	Berea, Ohio	6.6	D. W. Mead.
Bedford limestone	Bedford, Ind.	4.4	D. W. Mead.

From what has been said concerning the variation in the character of a stratum throughout its geographical extent, it will readily be understood that no simple statement of ratio of absorption will furnish a sufficiently reliable indication of the water-bearing qualities of a stratum in all places. We know, however, that the strata are saturated to an unknown depth, the amount of water varying with the porosity of the strata, and with their physical condition as regards cracks and fissures. This area, like many others, is marked by an alternation in the deposition of rocks varying largely in porosity,


129° 127° 125° 123° 121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99° 97°
47° 45° 43° 41° 39° 37° 35° 33° 31° 29° 27° 25°
121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99°
BRITISH CANADA
PACIFIC OCEAN
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA TER.
TEXAS
MEXICO
LOWER CALIFORNIA
GULF OF CALIFORNIA
COLUMBIA
SNAKE RIV
SNAKE
MARIAS RIV
MISSOURI RIVER
YELLOW STONE RIVER
BIG HORN RIVER
POWDER
LITTLE MISSOURI
JAMES RIVER
WHITE RIV
NIOBRARA RIV
NORTH PLATTE
SOUTH PLATTE
REPUBLICAN RIV
KANSAS
ARKANSAS RIVER
CIMARRON
CANADIAN RIVER
RED RIVER
GREEN RIVER
GRAND RIV
COLORADO
SAN JUAN RIV
RIO COLORADO
CHIQUITA
COLORADO RIVER
GILA
RIO
RIO GRANDE RIVER
RIO PECOS RIVER
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BRAZOS
COLORADO
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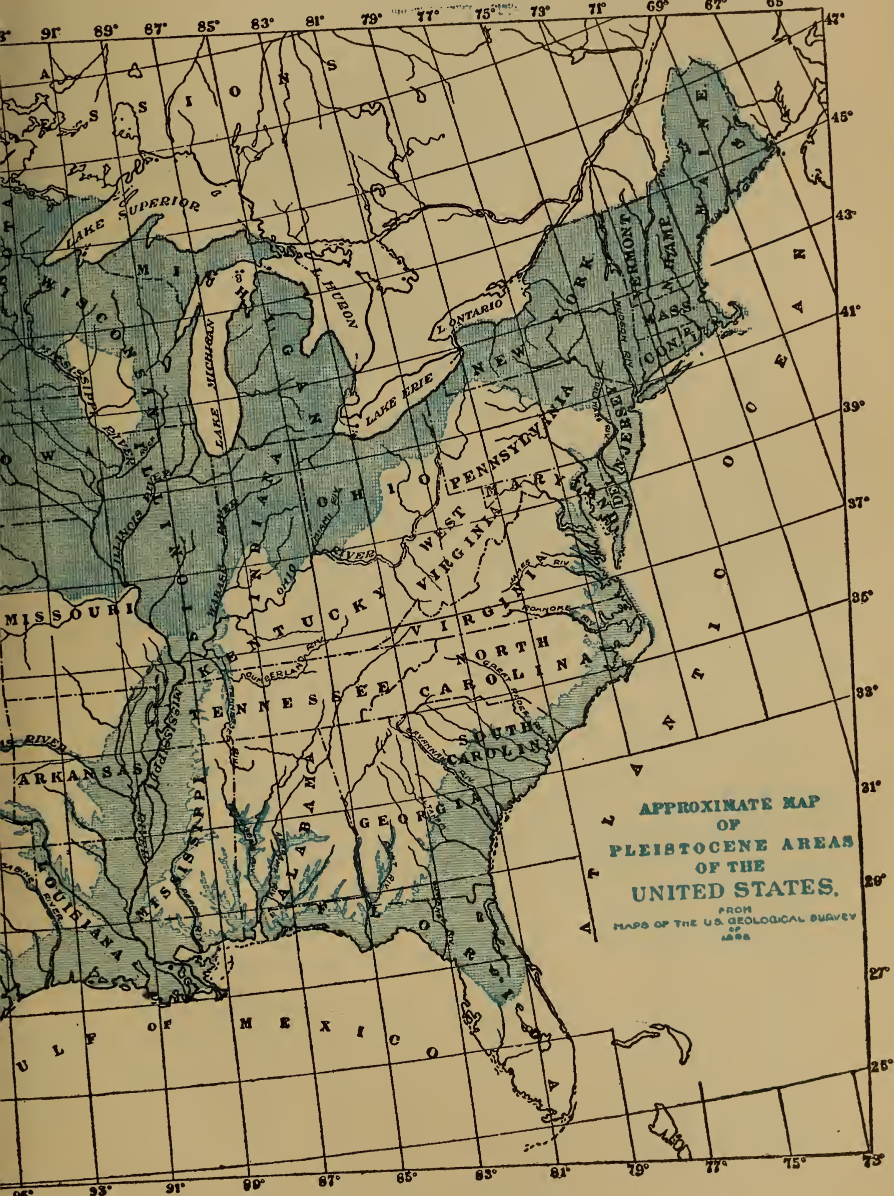
ICE WORK.
WATER WORK.

Map No. 12



APPROXIMATE MAP
OF
PLEISTOCENE AREAS
OF THE
UNITED STATES.
FROM
MAPS OF THE U.S. GEOLOGICAL SURVEY
OF
[illegible]

TABLE 25

LOCALITIES.	Elevation of top of well above sea level.	Drift (loam, sand, gravel and clay).	Lower coal measures.	Sub-carboniferous.	Devonian.	Niagara.	Hudson River or Cincinnati shale.	TRENTON.		St. Peter's sandstone.	Lower magnesian limestone.	Potsdam sandstone.	Archean.	Total depth.
								Galena.	Trenton.					
Rockford, Ill., well No. 1	713	125							30	225	105	1,035		1,530
Rockford, Ill., well No. 3	724	192								188	105	1,513		1,996
Galena, Ill.	605	65							95	145	170	1,035		1,510
Morrison, Ill.	670	100				75	295	100	200	200	120	180		1,190
Sterling, Ill.		20				30	100	550		300	500	700		2,200
Aurora, Ill.		4				196	130	340		236	160	1,480		2,440
Chicago (stock yards)						254	250	330		155	70			1,105
Joliet, Ill.						230	68	334		257	450	730		2,069
Marseilles, Ill.	478	12	73						4	11				100
Streator, Ill.		30	211					203		225	90	1,737		2,496
Peru, Ill.		60	390	50	100	214	162	376		8				1,360
Ottawa, Ill. (Court House)	486									171	139			310
Ottawa, Ill. (King Catlin and La Chapell)	486	35								130	145	1,530		1,840
Monmouth, Ill.		67	5	220	109	68	85	526		154				1,232
Rock Island, Ill.	558				60	279	180	353	90	145	811	367		2,292
Moline, Ill.		7			113	275	220	320		205	316	161		1,628
Carbon Cliff, Ill.		12			130	338	200	220						900
Warsaw, Ill.		82		183	33	80	184	239		33	10			844

Geological Section of Artesian and Deep Wells in the Upper Mississippi Valley, Showing Strata Encountered and Thickness of Same at Various Localities.

The depths are given in feet.

TABLE 25—Continued

GEOLOGICAL SECTION OF ARTESIAN AND DEEP WELLS IN THE UPPER MISSISSIPPI VALLEY, SHOWING STRATA ENCOUNTERED AND THICKNESS OF SAME AT VARIOUS LOCALITIES.

The depths are given in feet.

LOCALITIES.	Elevation of top of well above sea level.	Drift (loam, sand, gravel and clay).	Lower coal measures.	Sub-carboniferous.	Devonian.	Niagara.	Hudson River or Cincinnati shale.	TRENTON.		St. Peter's sandstone.	Lower magnesian limestone.	Potsdam Sandstone	Archean.	Total depth.
								Galena.	Trenton.					
Ipava, Ill.		23	130	50	215	360	185	270		290				1,570
Palmyra, Wis.		46						130	81	93	62	338		750
Western Union Junction, Wis.		147				233	200	285		100	141	157		1,263
Racine, Wis.		115				305	185	283		48	100	204		1,240
Milwaukee, Wis.		170				267	165	253		193				1,048
Sheboygan, Wis.		92				719	240	213		212				1,475
Janesville, Wis.		350										683		1,033
Oshkosh, Wis.		60						240		(a)		414	248	961
Sparta, Wis.												300		300
Oil City, Wis.		42										448	20	510
Tomah, Wis.		25										427	40	492
La Crosse, Wis.		170										403		573
Prairie du Chien, Wis.		147										812		959
Fond du Lac, Wis.		95						195		135				425
St. Paul, Minn. (Reform School)		36½					24 (?)	114		77½				252
Mankato, Minn.		290									205	1,705		2,200
Owatonna, Minn.		39	59 (*b*)				20 (*b*)	144	28	97				387
Minneapolis, Minn.		42							28	164	102	1,085		1,421
Red Wing, Minn.		40										410		450
Saint Peter, Minn.		15										182		197
Mendota, Minn.		22								60	30	745		857

(*a*) Saint Peter, sandstone wanting. (*b*) Cretaceous.

strata of high porosity frequently lying between those comparatively impervious. This variation is somewhat equalized by cracks and fissures, but the difference is still so marked as to create a great difference in the character of the flow.

The outcrop of these highly pervious strata at the higher elevations in the valley gives rise to hydrostatic pressure within the strata, a pressure which is not wholly equalized by the transfusion of waters due to porosity or to rupture of the strata. Hence, in the lower portions of the valley, these waters often come to the surface with considerable head through natural channels as springs, or through artificial channels as flowing wells.

The existence of water in the strata above renders most efficient aid in confining these low drainage waters. Without this their immense pressures would undoubtedly bring them to the surface. Ordinarily, the difference in elevation between the head of the deeper waters and that of the ground water is very limited. At Ottawa, Ill., however, it amounts to about 180 feet, and at Aurora, Ill., to 90 feet.

Table 25 gives the thickness of the various geological deposits in the Upper Mississippi Valley, encountered in sinking various artesian wells.

Many of the other deposits of this territory may be made available as sources of water supply by driving infiltration tunnels through them of sufficient extent to allow the infiltration of the amount of water needed.

71. **General Geological Conditions.**—Table 23, already referred to, gives the geological formations of the United States, together with those represented in the Upper Mississippi Valley, and their approximate thickness through that territory. In other portions of the United States considerable differences exist in the nature and occurrence of the local geological formations. Their natural history, however, is similar to that of the territory above described, and should be studied in detail when considering hydrological problems which are influenced by the geological structure.

Map No. 1, which shows the occurrence or outcroppings at the surface of the various geological deposits of the United States, has already been referred to.

The glacial sheet, which has been described in some detail with reference to the Upper Mississippi Valley, and which was there developed perhaps to its greatest extent, extended in a broad and irregular belt across North America from the Pacific to the Atlantic, its approximate borders being shown on Map No. 12, which shows the Pleistocene deposits of the United States. This map also shows that in comparatively recent geological times, the Gulf of Mexico extended to and above the mouth of the Ohio River, and that a broad belt of comparatively recent sedimentary deposits has been formed in the old gulf, which, as the land has gradually risen from the sea, has been pushed further and further to the southward, very much in the same manner that the Mississippi River is now forming new land in the Gulf of Mexico. In this way, there has been formed the coastal plain which stretches in a broad band from Texas to Long Island, including the entire area of some of our southern states.

LITERATURE.

A large amount of valuable data in regard to General Geology and Hydro-Geology will be found in the publications of the U. S. Geo. Survey, and of the various State Geological Surveys. The following articles are especially referred to:

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CHAPTER VI.

PHYSIOGRAPHY OF THE UNITED STATES.

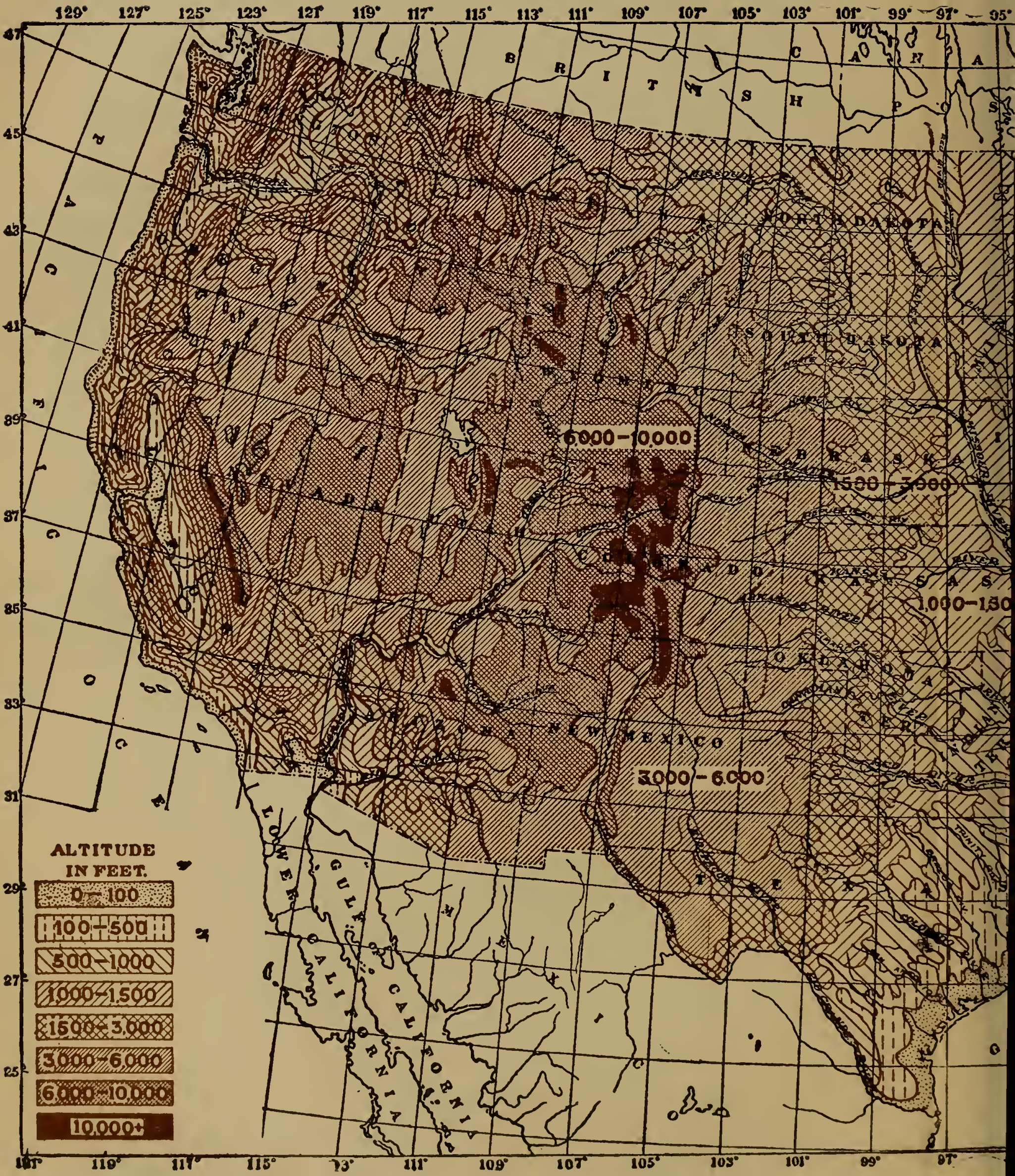
72. **Bearing of Physiography.**—Similarity in Geological, Topographical and Climatic conditions are essential to similarity in Hydrographic conditions. For the purpose of hydrological study and investigation, it is therefore important to determine the geographical limits of regions having similar physical conditions, in order that the limits within which similar hydrological results may be expected, may be understood.

The physiographic regions of a country may be considered with reference to various physical features. Generally the limits of such regions are defined by the leading topographical features common to certain geographical limits.

On this basis the principal physiographic regions of the United States, in accordance with leading topographical features, are as follows:

New England Plateau.
Atlantic Coastal Plain.
Piedmont Plateau.
Appalachian Mountains.
The Allegheny Plateau.
Gulf Plains.
Ozark Mountains.
The Prairies.
Wisconsin Highlands.
The Great Plains.
The Rocky Mountains.
Colorado Plateau.
The Lava Pleateau.
The Great Basin.
Pacific Coast Mountains.

These regions may be still further subdivided in accordance with various local conditions, and for local study and investigation this should be done. (J. W. Powell, Physiographic Regions of the U. S.)


129° 127° 125° 123° 121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99° 97° 95°
47° 45° 43° 41° 39° 37° 35° 33° 31° 29° 27° 25°
BRITISH CANADA
PACIFIC OCEAN
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
NEVADA
COLORADO
NEW MEXICO
MEXICO
LOWER CALIFORNIA
GULF OF CALIFORNIA
6,000–10,000
1,500–3,000
1,000–1,500
3,000–6,000
ALTITUDE IN FEET.
0–100
100–500
500–1,000
1,000–1,500
1,500–3,000
3,000–6,000
6,000–10,000
10,000+
121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99° 97°

Map No. 13


HYPSOMETRIC
MAP
OF THE
UNITED STATES
FROM
GANNETT
0-100
100-500
500-1,000
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
L. HURON
LAKE ERIE
L. ONTARIO
POSSESSIONS
NEW YORK
PENNSYLVANIA
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
FLORIDA
ALABAMA
MISSISSIPPI
TENNESSEE
KENTUCKY
OHIO
INDIANA
ILLINOIS
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
MICHIGAN
MAINE
47°
45°
43°
41°
39°
37°
35°
33°
31°
29°
27°
25°
91°
89°
87°
85°
83°
81°
79°
77°
75°
73°
71°
69°
67°
65°
93°

73. **Climatic Subdivisions.**—Certain subdivisions of these physiographic regions correspond more or less closely with the climatic subdivisions of the United States, which have been adopted by the United States Weather Bureau, as follows:

New England States.
Middle Atlantic States.
South Atlantic States.
Lower Lake Region.
Upper Lake Region.
Ohio Valley and Tennessee.
Eastern Gulf.
Western Gulf.
Upper Mississippi Valley.
Missouri Valley.
Extreme North-west.
Northern Slope.
Middle Slope.
Southern Slope.
Southern Plateau.
Middle Plateau.
Northern Plateau.
Northern Pacific.
Middle Pacific.
Southern Pacific.

(Waldo, Meteorology, pp. 317-363 inclusive.)

See Map No. 13, Showing General Elevation of the United States.

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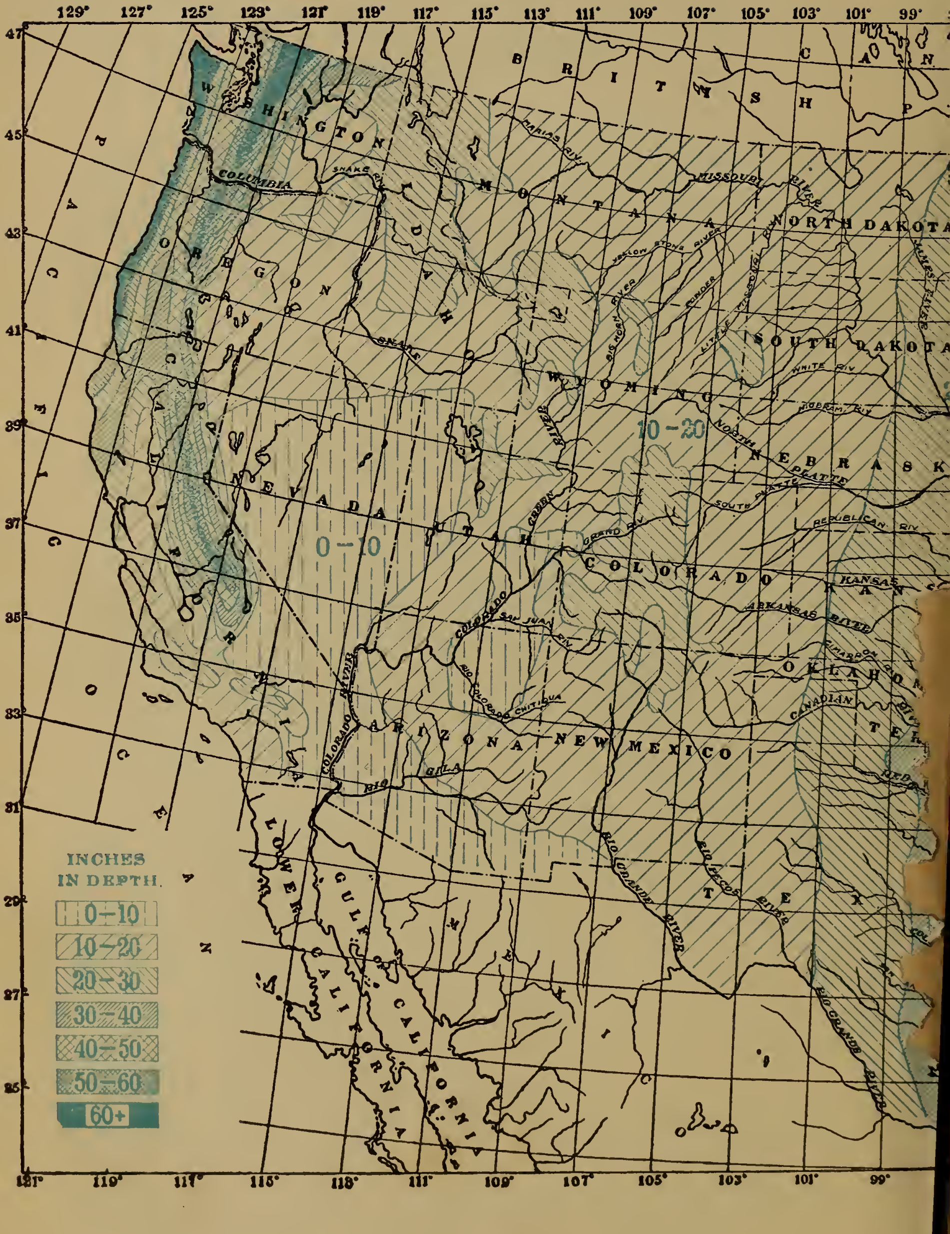
CHAPTER VII.

RAINFALL OF THE UNITED STATES.

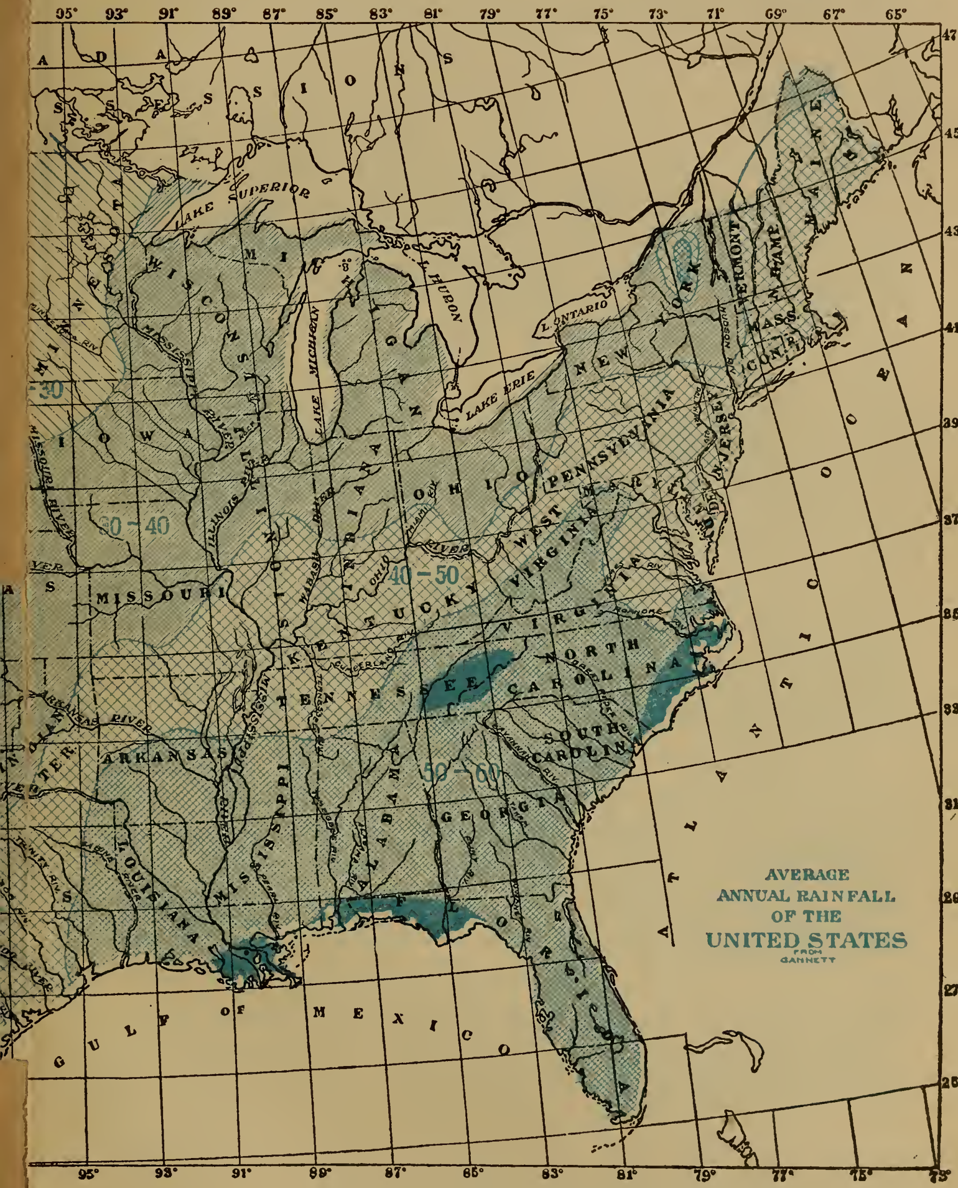
74. **Influence of Rainfall.**—The quantity of water flowing in the streams or strata, and the amount available for navigation, water power, agriculture, water supply, or other uses, depends primarily on the rainfall. The important factors in most cases are:

First, the quantity of rainfall.
Second, its distribution throughout the year, and
Third, its disposal.

75. **Quantity and Distribution of Rainfall.**—The annual quantity of rainfall throughout the United States varies greatly at different points, as will be seen from Map No. 14, which shows the distribution of the average annual rainfall throughout the United States. From this map it will be noted that "from the great plains westward the lines of equal rainfall are, approximately, north and south. In the Southern States, east of Texas, they are approximately parallel to the Gulf coast. In the Eastern States they are approximately parallel to the Atlantic coast. In the Lake region, while they approach parallelism to the parallels of latitude, yet there are some variations, evidently due to the effects of these great bodies of fresh water and their temperature at different seasons of the year. In the vicinity of Cape Hatteras and on the Peninsula of Florida other influences come into play, modifying the direction of the lines of equal rainfall. Cape Hatteras is the point of highest rainfall along the Atlantic coast, due, undoubtedly, to the seasonal winds which pass at sea and reach, more or less, this prominent point. On the Peninsula of Florida we approach the tropical region and approximate the laws of tropical rainfall. East of the ninety-fifth meridian the rainfall decreases as the latitude increases. West of that the general topography of the continent causes the lines to run north and south.


129° 127° 125° 123° 121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99°
47° 45° 43° 41° 39° 37° 35° 33° 31° 29° 27° 25°
121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99°
BRITISH
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
OKLAHOMA
TEXAS
MEXICO
LOWER CALIFORNIA
GULF OF CALIFORNIA
PACIFIC OCEAN
COLUMBIA
SNAKE RIV.
MARIAS RIV.
MISSOURI RIVER
YELLOW STONE RIVER
POWDER
BIG HORN RIVER
LITTLE MISSOURI RIV.
WHITE RIV.
NIOBRARA RIV.
NORTH PLATTE
SOUTH PLATTE
REPUBLICAN RIV.
KANSAS
ARKANSAS RIVER
CIMARRON
CANADIAN
RED RIV.
GREEN RIVER
GRAND RIV.
COLORADO
SAN JUAN RIV.
RIO COLORADO CHIQUITO
COLORADO RIVER
RIO GILA
RIO GRANDE RIVER
RIO PECOS RIVER
RIO GRANDE RIVER
0–10
10–20
INCHES IN DEPTH.
0–10
10–20
20–30
30–40
40–50
50–60
60+

Map No. 14


AVERAGE ANNUAL RAINFALL OF THE UNITED STATES

FROM GANNETT

"In general the rainfall decreases also with the elevation above sea level. This is very noticeable in passing along, for instance, the parallel of latitude 40°. The annual rainfall on the coast in New Jersey ranges from 40 to 50 inches. As we pass westward we come to the area where the rainfall is about 40 inches. This rainfall continues along the parallel until the vicinity of the Mississippi River is reached, when it decreases with the comparatively rapid ascent of the slope to the great plains. By the time Kansas is reached the annual rainfall has fallen to 30 inches; in western Kansas it is only 20 inches, and in passing the boundary of western Kansas we pass the annual rainfall line of 15 inches. On the Pacific slope the phenomena are more complex, because of the prevailing winds and the more rapid ascent from sea level in the region of the Sierra Nevadas."*

Beside the general distribution of rainfall shown on the map, it is important to note the effects of mountain ranges on the rainfall. This is best seen on the Pacific coast, where it will be noted that the western winds, laden with moisture from the Pacific, are cooled by contact with the mountains, which cause a heavy rainfall on the windward side of the range, while the rainfall on the leeward side is much below the average.

76. Variations in Annual Rainfall.—Great variations take place in the annual rainfall of every locality. Sometimes the rainfall of a locality will average considerably below the mean for a term of years, and then will average considerably above the mean for possibly a somewhat similar term. As a general rule, however, there is no great regularity or uniformity in the annual variations, but the rainfall exceeds or falls below the mean in a seemingly lawless manner.

The variation in annual rainfall at various selected stations in the United States is shown on diagram No. 10, on which is also indicated the mean for each station. From this diagram the annual variation and the relation of such variation to the mean are clearly shown.

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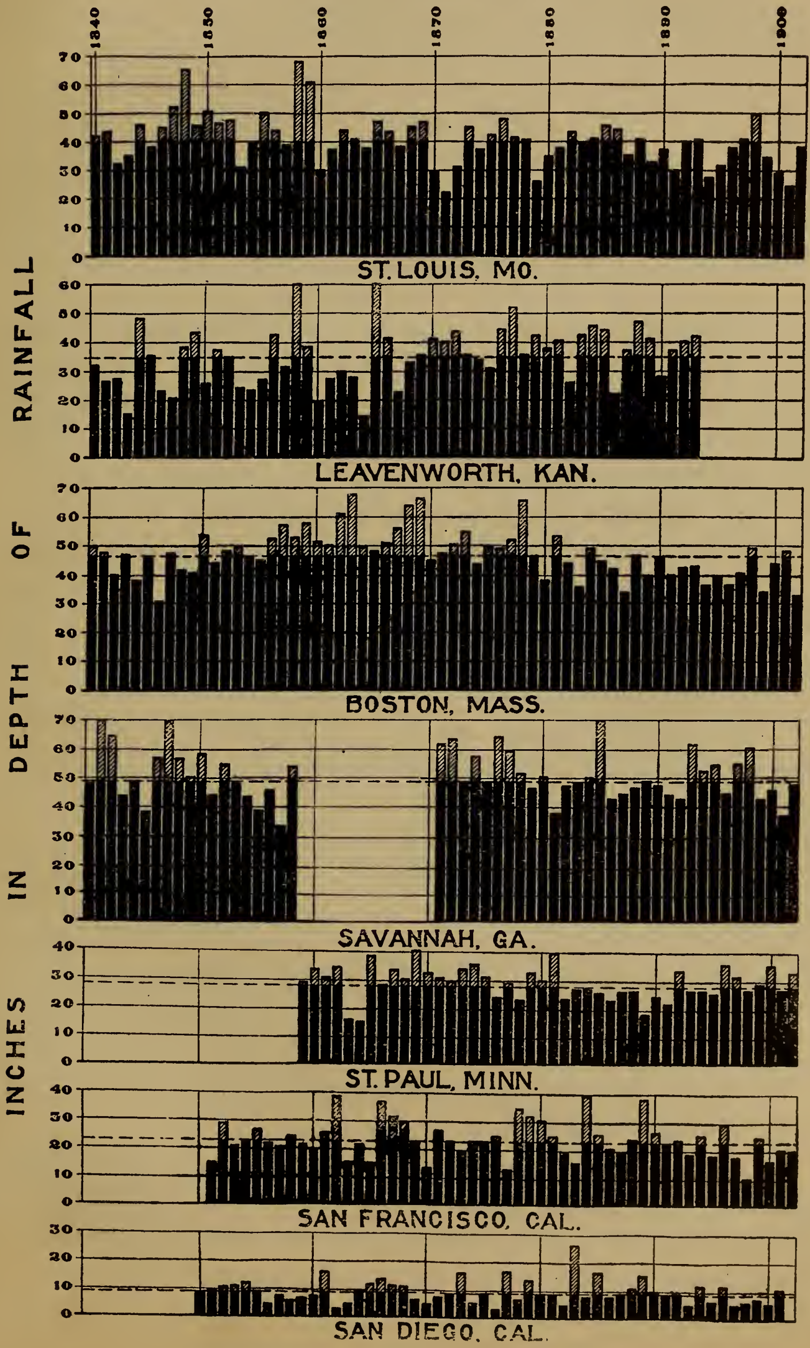
* Bulletin C, Weather Bureau, page 13.

DIAGRAM 10

VARIATION IN ANNUAL RAINFALL AT VARIOUS LOCALITIES. IN THE UNITED STATES.



Some idea of the limiting conditions, and the average relations of extremely dry and extremely wet periods can also be determined from this diagram.

77. **Periodic Variation in Rainfall.**—The maximum and minimum monthly rainfall occurs at each locality at fairly definite periods. The climatic conditions are, in a general way, fairly constant, and as the cycle of seasons change, they produce conditions favorable or unfavorable to the precipitation of rain. These vary largely from year to year, but have, nevertheless, the same general character.

Diagrams 11 and 12 show typical annual fluctuations of the rainfall for various months in the year at a number of places throughout the United States. More extended types of the monthly distribution of precipitation in the United States is shown on Diagram 13.

78. **Relative Importance of Rainfall Data.**—As far as the influence on stream flow, and the engineering problems directly connected therewith is concerned, the periods of winter and spring rains are the most important, while for agricultural purposes the rains of most importance are the rains of the spring and summer.

Averages of rainfall are only of general interest. For the detailed consideration of hydrological study, the actual variation in yearly rainfall, and the actual distribution throughout the various years is of greatest importance.

The question of the frequency of occurrence of periods of extreme rainfall, and the rate of rainfall for such periods are matters of importance in both engineering and agriculture. If rain commonly occurs at times when most needed, and under conditions where it can be best utilized, it becomes of great value; whereas its occurrence at the wrong season, and under unfavorable conditions, may make it of no value, or of positive detriment.

For agricultural purposes, light rains at frequent intervals are much to be preferred to heavy and extended rains, for in the former case much of the moisture will be directly

DIAGRAM 11

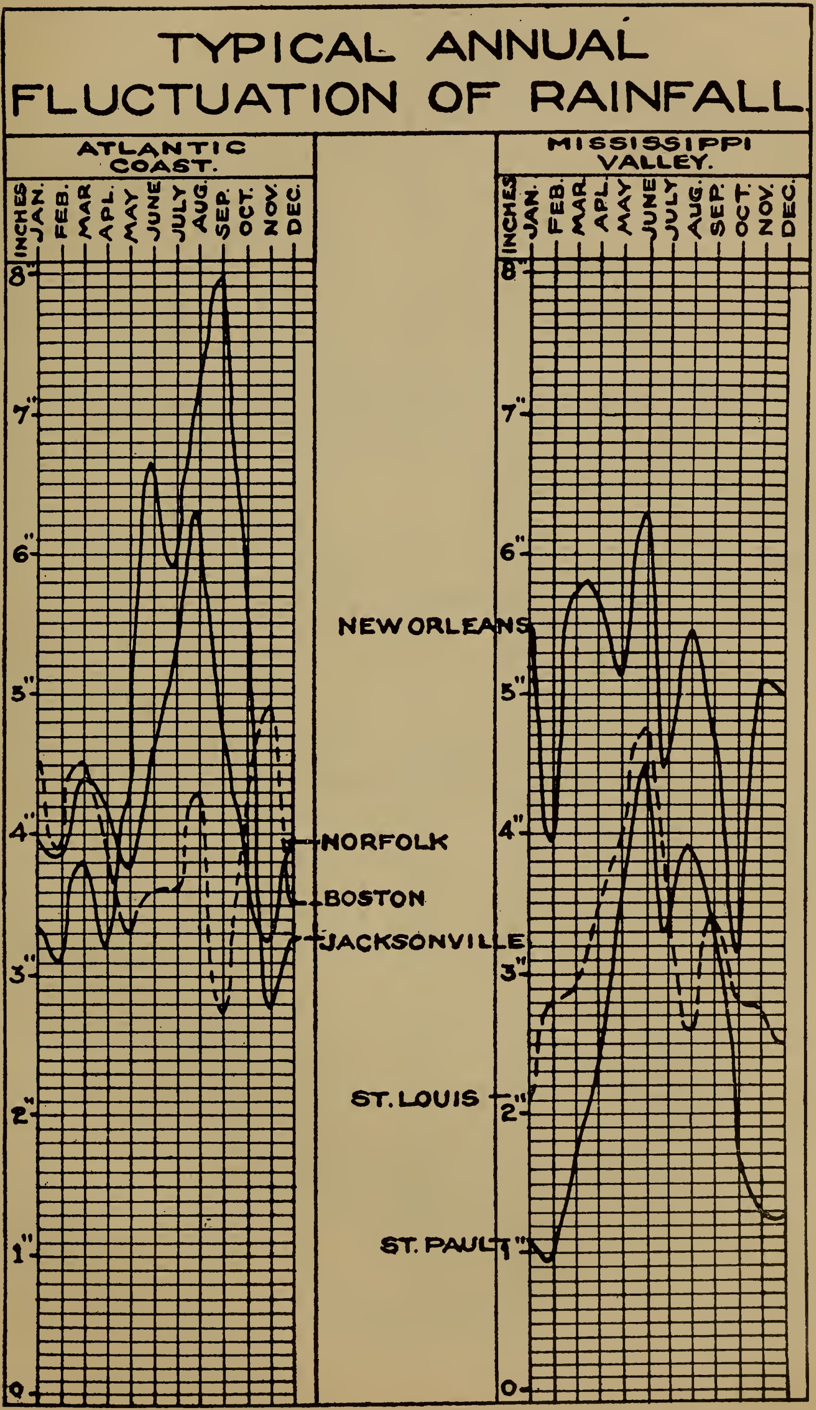

TYPICAL ANNUAL FLUCTUATION OF RAINFALL.
ATLANTIC COAST.
MISSISSIPPI VALLEY.
INCHES
JAN.
FEB.
MAR.
APL.
MAY
JUNE
JULY
AUG.
SEP.
OCT.
NOV.
DEC.
8"
7"
6"
5"
4"
3"
2"
1"
0
NORFOLK
BOSTON
JACKSONVILLE
NEW ORLEANS
ST. LOUIS
ST. PAUL

DIAGRAM 12

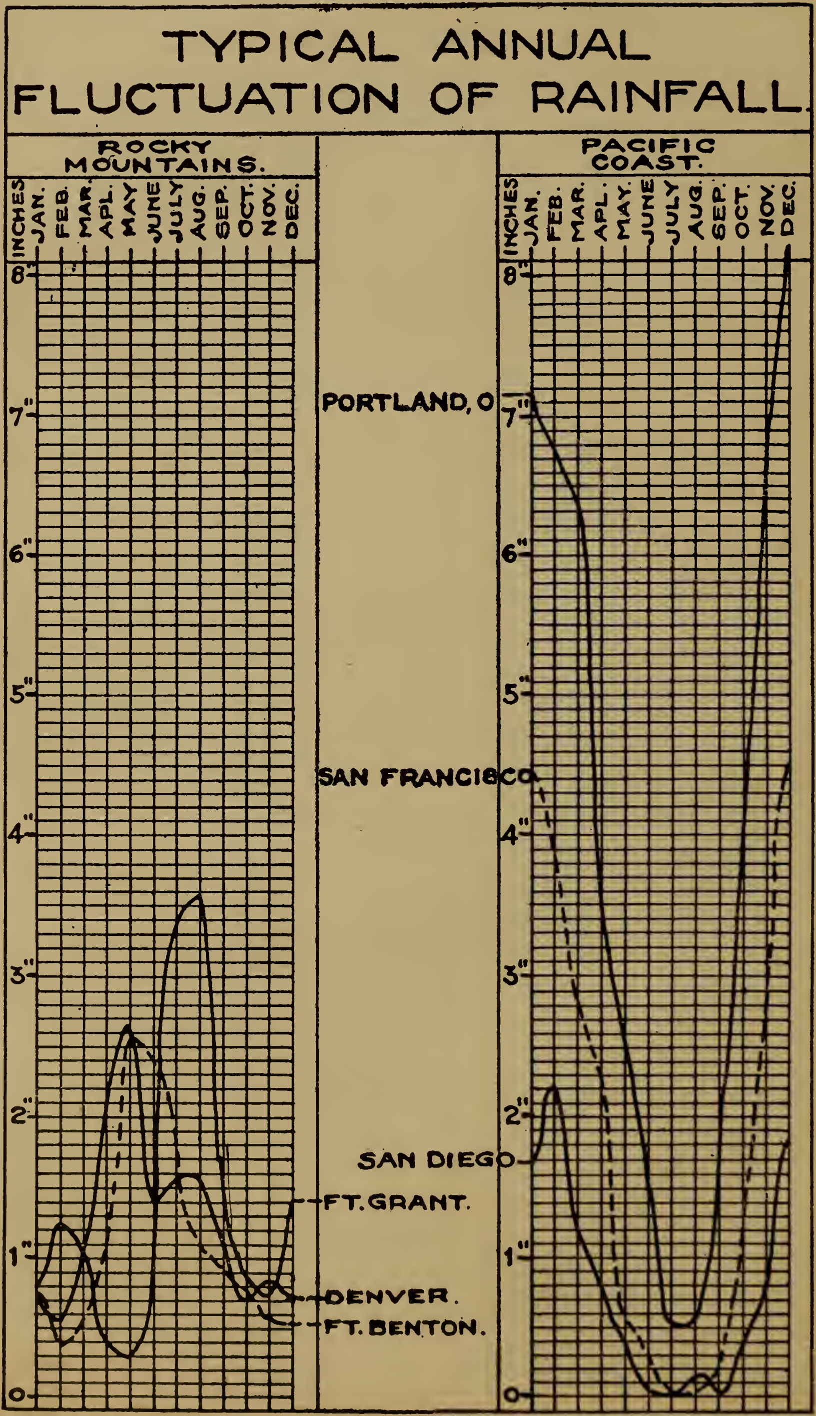
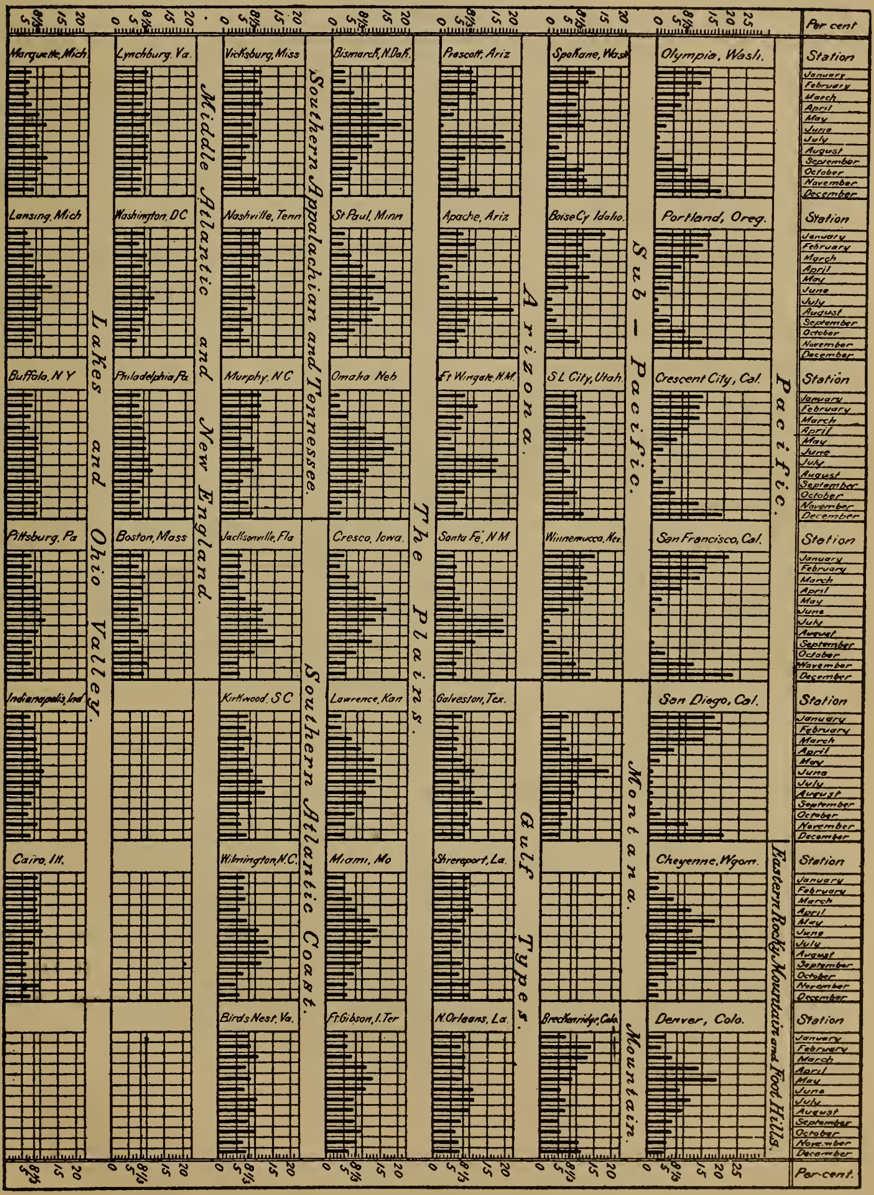

TYPICAL ANNUAL FLUCTUATION OF RAINFALL.
ROCKY MOUNTAINS.
PACIFIC COAST.
INCHES
JAN.
FEB.
MAR.
APL.
MAY
JUNE
JULY
AUG.
SEP.
OCT.
NOV.
DEC.
8"
7"
6"
5"
4"
3"
2"
1"
0
PORTLAND, O
SAN FRANCISCO
SAN DIEGO
FT. GRANT.
DENVER.
FT. BENTON.

DIAGRAM 13.

Types of Monthly Distribution of Precipitation in the United States.

Rainfall Distribution in the U. S. (Percentage of fall in each month represented by heavy lines.)



utilized for plant life, while in the latter, much of it will be lost by passing from the surface and in producing floods in the streams.

79. **Intensity of Rainfall.**—To the engineer, for the purpose of the design of sewerage and drainage works, the question of the maximum rainfall, and the greatest length of time for which such rainfall may extend, becomes important. Rainfalls of great intensity usually occur for only limited periods of time. There is no sufficiently definite relation, however, between intensity and time to admit of a precise expression by a mathematical formula. It is possible, however, by platting the various recorded rainfalls with reference to the rate of fall, to produce a diagram on which may be drawn a curve showing the highest intensity of any individual storm which is likely to occur for the locality for which the data is prepared, and also to construct various other curves which may be regarded as showing the relative probable limits of the reoccurence of similar conditions.

Professor A. N. Talbot has prepared several diagrams (see Diagrams 14, 15, 16 and 17) which show the rates of maximum rainfall in various portions of the United States, on which he has platted curves from a formula he has proposed.* The upper curve he terms "The curve of rare rainfall," and its equation is $Y = \frac{6}{5\,x}$

The lower he terms "The curve of ordinary maximum rainfall," and its equation is $Y = \frac{1.75}{.25\,x}$

In these formulae Y is the rate of rainfall in inches per hour for the time x expressed in hours. The points on the diagram represent the actual records of individual storms. It will be noted that the curve of rare rainfall has been sometimes exceeded.

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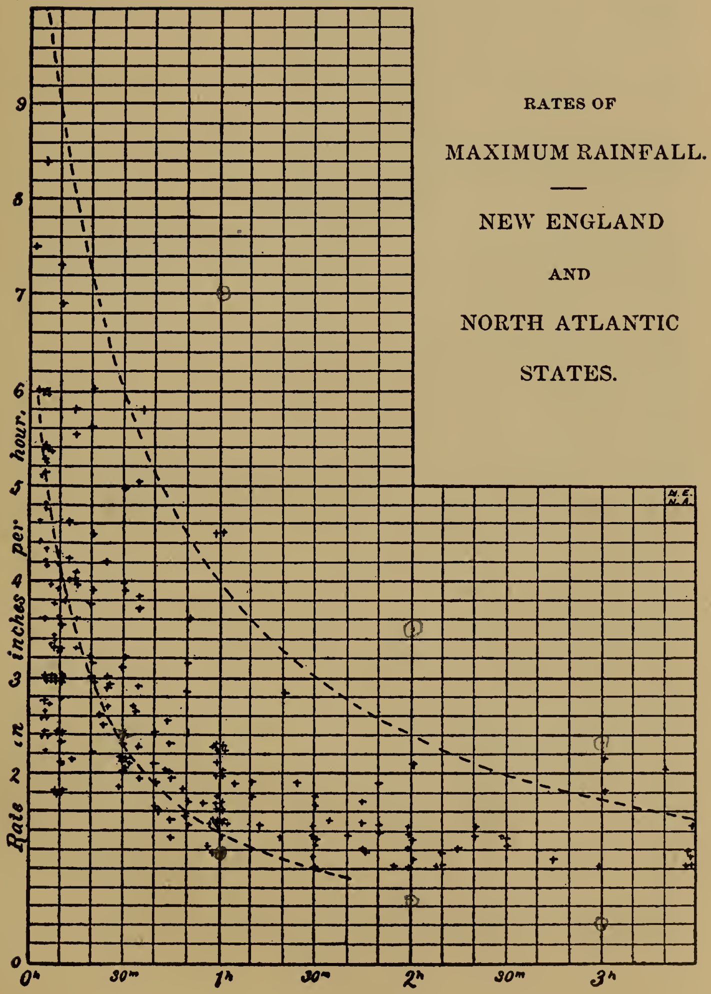
* Prof. A. N. Talbot, Rates of Maximum Rainfall. Technograph, 1891-92.

DIAGRAM 14



RATES OF

MAXIMUM RAINFALL.

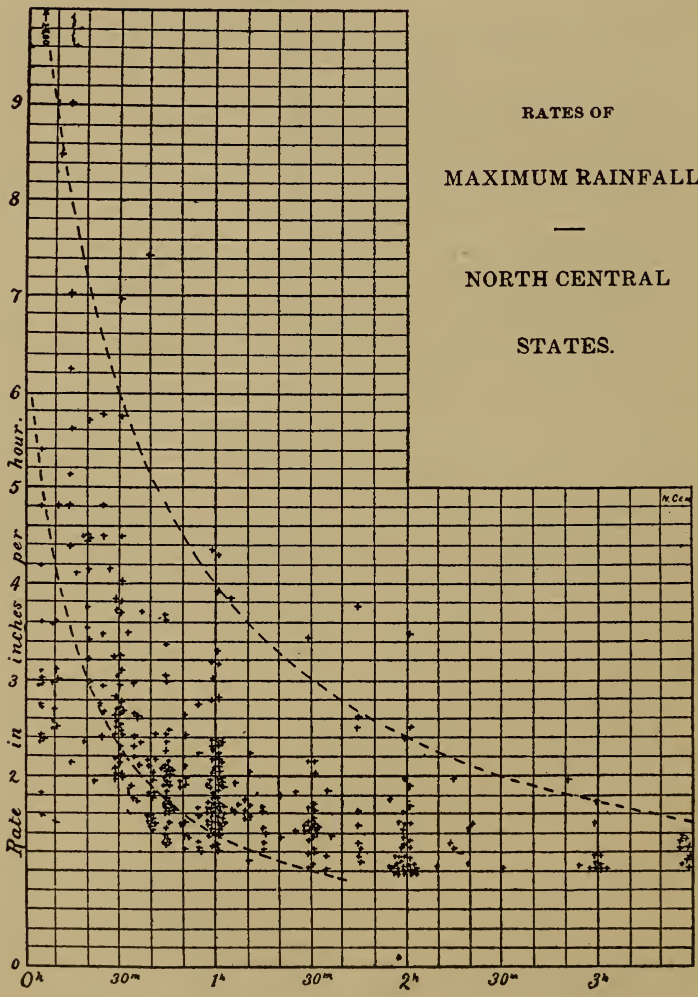
NEW ENGLAND

AND

NORTH ATLANTIC

STATES.

DIAGRAM 15.



RATES OF

MAXIMUM RAINFALL.

—

NORTH CENTRAL

STATES.

DIAGRAM 16

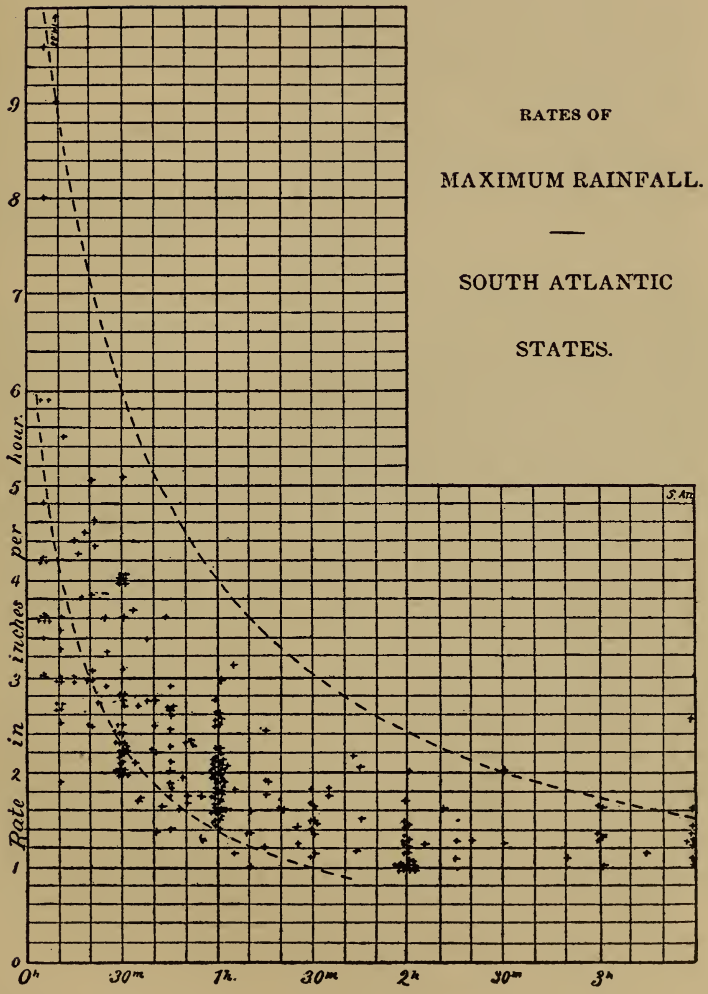
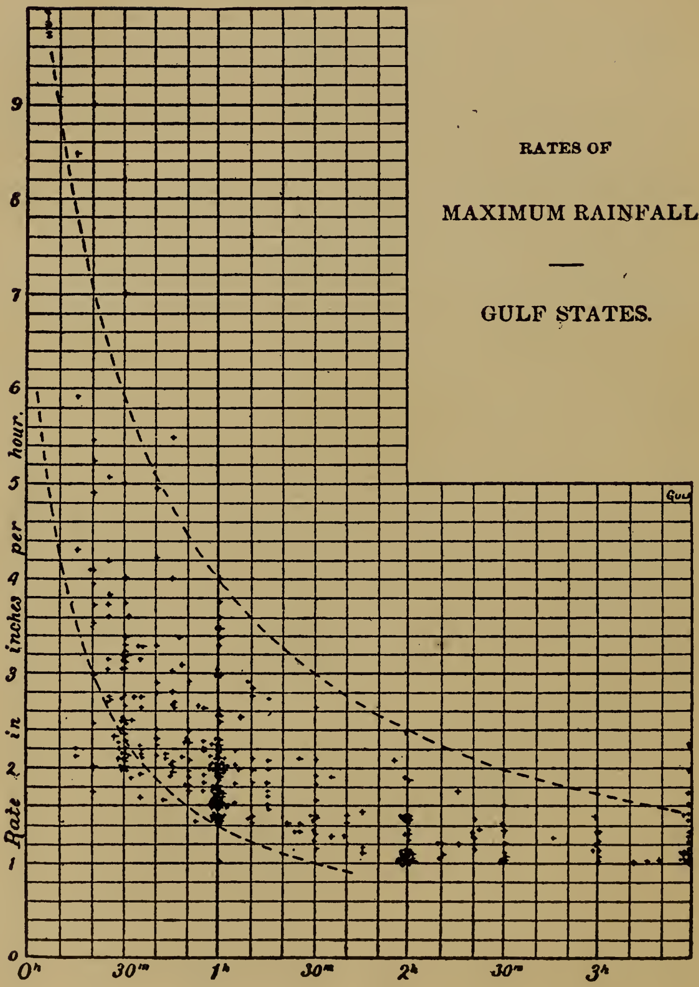

RATES OF
MAXIMUM RAINFALL.
—
SOUTH ATLANTIC
STATES.
S. At.
Rate in inches per hour.
9
8
7
6
5
4
3
2
1
0
0h
30m
1h.
30m
2h
30m
3h

DIAGRAM 17



RATES OF

MAXIMUM RAINFALL.

—

GULF STATES.

A similar curve is shown by Diagram 18, which is reduced from the Report of the Chief of the Weather Bureau for the year 1896-7. On this plate, Curve A shows the curve of probable maximum intensity for Washington, and B, for Savannah, Ga. These curves are constructed by selecting the rainfalls of maximum intensity for certain consecutive periods of time. The full line shown on the plate was constructed from the combined records of excessive rainfalls in the cities of Boston, Providence, New York, Philadelphia, and Washington, representing the observations for an aggregate of about seventy years, and was the curve adopted by the engineers making the Report on the Sewerage of the District of Columbia in 1890.

DIAGRAM 18

Curves of Probable Maximum Intensity of Rainfall.

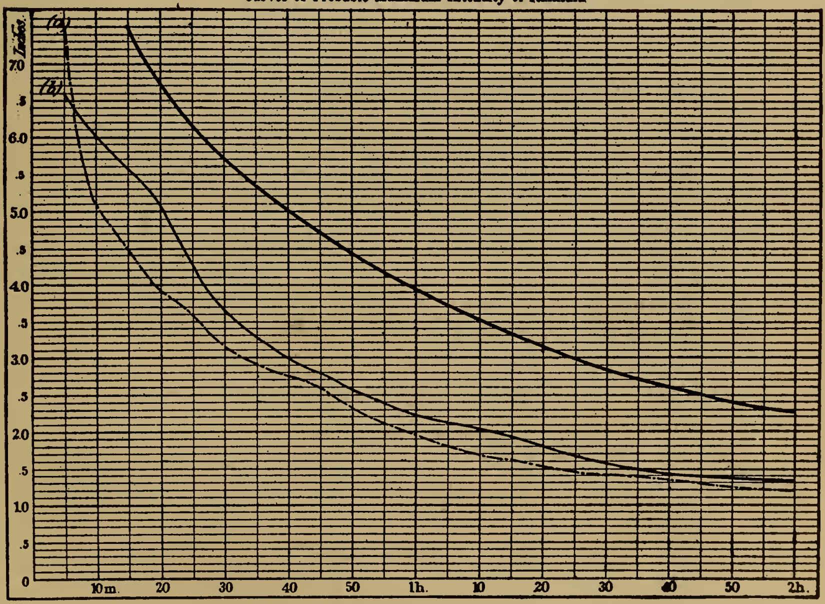


Table 26, from Bulletin C of the United States Weather Bureau, shows the heaviest rainfalls on record at selected representative stations throughout the United States, and Table 27 from the same source shows the annual and seasonal averages, seasonal variations, and quantity of rainfall for each state of the United States.

TABLE 26

Maximum Rainfalls at Selected Stations in the United States.

Station.	No. of years.	Year.	Month.	72 hours.	48 hours.	24 hours.	Station.	No. of years.	Year.	Month.	72 hours.	48 hours.	24 hours.
Albany, N.Y	18	49.3	8.9	5.1	4.3	3.2	Memphis, Tenn	21	73.4	18.2	13.6	13.4	8.9
Alpena, Mich	19	45.5	13.2	6.0	5.2	3.9	Mobile, Ala	21	90.9	15.2	12.9	10.8	7.3
Assinniboine, Fort, Mont	11	25.5	9.7	4.3	4.3	3.3	Montgomery, Ala	19	64.1	11.6	8.4	8.1	6.0
Atlanta, Ga	21	65.0	15.8	10.1	9.6	7.4	Nashville, Tenn	21	67.3	14.5	8.0	5.6	5.2
Augusta, Ga	22	57.1	11.9	6.7	6.1	4.9	New Orleans, La	21	85.6	22.7	11.4	9.8	8.9
Bismarck, N. Dak	17	31.0	6.6	3.5	3.4	2.4	Norfolk, Va	22	70.9	11.9	7.2	6.1	4.6
Boston, Mass	22	65.6	11.0	6.4	6.2	4.4	North Platte, Nebr	17	30.1	8.5	3.3	3.3	3.2
Buffalo, N.Y	22	60.3	10.6	4.4	3.5	3.2	Omaha, Nebr	22	48.8	12.7	5.5	5.4	5.0
Buford Fort, N. Dak	24	23.3	7.1	3.7	3.6	3.2	Oswego, N.Y	22	55.9	10.5	4.5	4.0	3.6
Brownsville, Tex	15	60.3	30.6	....	....	....	Palestine, Tex	10	59.6	17.2	7.5	6.7	4.4
Cairo, Ill	20	61.5	15.0	5.7	5.2	4.2	Philadelphia, Pa	66	61.2	16.8	10.1	8.4	5.2
Charleston, S.C	64	78.4	19.2	11.6	9.6	8.3	Pittsburg, Pa	21	50.6	9.5	4.5	4.2	3.6
Cheyenne, Wyo	22	19.3	4.8	2.4	2.2	1.9	Port Huron, Mich	17	41.0	7.4	3.8	3.8	3.3
Chicago, Ill	22	45.8	11.3	4.2	6.4	5.6	Portland, Oreg	22	67.2	20.1	10.8	10.8	6.7
Cincinnati, Ohio	21	54.8	11.7	4.6	3.2	3.0	Prescott, Ariz	20	26.7	8.0	4.9	4.3	5.0
Cleveland, Ohio	22	53.6	10.2	5.1	5.0	3.6	Red Bluff, Cal	20	49.1	20.7	6.3	5.9	3.0
Deadwood, S. Dak	9	33.9	10.3	....	....	....	St. Louis, Mo	52	68.8	17.1	6.7	6.7	4.5
Denver, Colo	22	21.5	8.6	3.8	6.7	6.5	St. Paul, Minn	22	39.2	11.7	5.1	4.6	3.7
Dodge City, Kans	17	33.7	12.8	5.9	4.1	3.2	St. Vincent, Minn	20	33.9	9.8	4.6	4.6	4.5
Dubuque, Iowa	32	55.4	10.5	5.8	5.4	4.5	Sacramento, Cal	42	34.8	15.0	8.7	8.4	5.3
Duluth, Minn	21	45.3	11.5	4.2	4.0	3.0	Salt Lake City, Utah	24	38.0	10.0	2.6	2.4	2.0
Eastport, Me	18	64.6	13.2	7.1	6.3	5.5	San Antonio, Tex	21	42.0	11.4	6.9	5.8	4.5
El Paso, Tex	28	21.9	8.2	2.2	2.1	2.0	San Diego, Cal	42	27.5	9.0	4.2	3.0	2.8
Fort Smith, Ark	17	61.0	14.3	8.5	6.3	5.1	San Francisco, Cal	42	38.7	24.4	6.8	5.9	4.7
Galveston, Tex	20	67.0	26.0	12.7	10.1	7.9	Santa Fe, N. Mex	33	24.9	7.9	3.6	2.5	1.5
Helena, Mont	10	20.1	4.7	3.2	2.7	2.2	Shreveport, La	20	66.5	15.6	8.8	8.0	6.9
Huron, S. Dak	10	28.1	8.1	3.3	3.2	2.1	Spokane, Wash	10	25.7	5.1	2.4	2.3	2.2
Indianapolis, Ind	22	57.5	13.1	6.4	6.0	4.3	Toledo, Ohio	21	45.8	8.5	3.5	3.5	3.2
Jacksonville, Fla	22	82.1	21.1	10.3	8.6	6.2	Vicksburg, Miss	20	84.3	22.2	8.1	7.0	5.4
Keokuk, Iowa	20	51.5	12.7	5.5	5.3	4.8	Walla Walla, Wash	23	40.6	12.8	2.1	1.9	1.6
Key West, Fla	21	58.4	19.8	11.8	11.0	8.2	Washington, D.C	22	61.3	12.9	5.3	4.7	4.2
Knoxville, Tenn	21	73.8	17.3	7.8	6.5	5.6	Winnemucca, Nev	20	18.2	5.2	1.9	1.8	1.1
Leavenworth, Kans	55	59.8	15.8	4.4	5.1	3.6	Yuma, Ariz	16	5.9	2.5	2.4	2.4	1.7
Lynchburg, Va	20	60.5	11.8	6.2	5.5	4.7							

TABLE 27.

Annual and Seasonal Average of Rainfall for each State

	Area in square miles.	Spring.	Summer.	Autumn.	Winter.	Annual.	Seasonal variation.
		Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Alabama	52,250	14.9	13.8	10.0	14.9	53.6	1.5
Arizona	113,020	1.8	4.3	2.2	3.1	10.9	3.3
Arkansas	53,850	14.3	12.5	11.0	12.8	50.6	3.9
California	158,360	6.2	0.3	3.5	11.9	21.9	40.0
Colorado	103,925	4.2	5.5	2.8	2.3	14.8	2.4
Connecticut	4,990	11.1	12.5	11.7	11.5	46.8	1.1
Delaware	2,050	10.2	11.0	10.0	9.6	40.8	1.1
District of Columbia	70	11.0	12.4	9.4	9.0	41.8	1.4
Florida	58,680	10.2	21.4	14.2	9.1	54.9	2.4
Georgia	59,475	12.4	15.6	10.7	12.7	51.4	1.5
Idaho	84,800	4.4	2.1	3.6	7.0	17.1	3.3
Illinois	56,650	10.2	11.2	9.0	7.7	38.1	1.5
Indiana	36,350	11.0	11.7	9.7	10.3	42.7	1.2
Indian Territory	31,400	10.6	11.0	8.9	5.7	36.2	1.9
Iowa	56,025	8.3	12.4	8.1	4.1	32.9	3.0
Kansas	82,080	8.9	11.9	6.7	3.5	31.0	3.4
Kentucky	40,400	12.4	12.5	9.7	11.8	46.4	1.3
Louisiana	48,720	13.7	15.0	10.8	14.4	53.9	1.4
Maine	33,040	11.1	10.5	12.3	11.1	45.0	1.2
Maryland	12,210	11.4	12.4	10.7	9.5	44.0	1.3
Massachusetts	8,315	11.6	11.4	11.9	11.7	46.6	1.0
Michigan	58,915	7.9	9.7	9.2	7.0	33.8	1.4
Minnesota	83,365	6.5	10.8	5.8	3.1	26.2	3.5
Mississippi	46,810	14.9	12.6	10.1	15.4	53.0	1.5
Missouri	69,415	10.0	12.4	9.1	6.5	38.0	1.9
Montana	146,080	4.2	4.9	2.6	2.3	14.0	2.1
Nebraska	77,510	8.9	10.9	4.9	2.2	26.9	5.0
Nevada	110,700	2.3	0.8	1.3	3.2	7.6	4.0
New Hampshire	9,305	9.8	12.2	11.4	10.7	44.1	1.2
New Jersey	7,815	11.7	13.3	11.2	11.1	47.3	1.2
New Mexico	122,580	1.4	5.8	3.5	2.0	12.7	4.1
New York	49,170	8.5	10.4	9.7	7.9	36.5	1.3
North Carolina	52,250	12.9	16.6	12.0	12.2	53.7	1.4
North Dakota	70,795	4.6	8.0	2.8	1.7	17.1	4.7
Ohio	41,060	10.0	11.9	9.0	9.1	40.0	1.3
Oregon	96,030	9.8	2.7	10.5	21.0	44.0	7.8
Pennsylvania	45,215	10.3	12.7	10.0	9.5	42.5	1.3
Rhode Island	1,250	11.9	10.7	11.7	12.4	46.7	1.2
South Carolina	30,570	9.8	16.2	9.7	9.7	45.4	1.7
South Dakota	77,650	7.2	9.7	3.5	2.5	22.9	3.9
Tennessee	42,050	13.5	12.5	10.2	14.5	50.7	1.4
Texas	265,780	8.1	8.6	7.6	6.0	30.3	1.4
Utah	84,970	3.4	1.5	2.2	3.5	10.6	2.3
Vermont	9,565	9.2	12.2	11.4	9.3	42.1	1.3
Virginia	42,450	10.9	12.5	9.5	9.7	42.6	1.3
Washington	69,180	8.6	3.9	10.5	16.8	39.8	4.3
West Virginia	24,780	10.9	12.9	9.0	10.0	42.8	1.4
Wisconsin	56,040	7.8	11.6	7.8	5.2	32.5	2.2
Wyoming	97,890	4.3	3.5	2.2	1.6	11.6	2.7
Total	2,985,850						
Average		9.2	10.3	8.3	8.6	36.3	3.0

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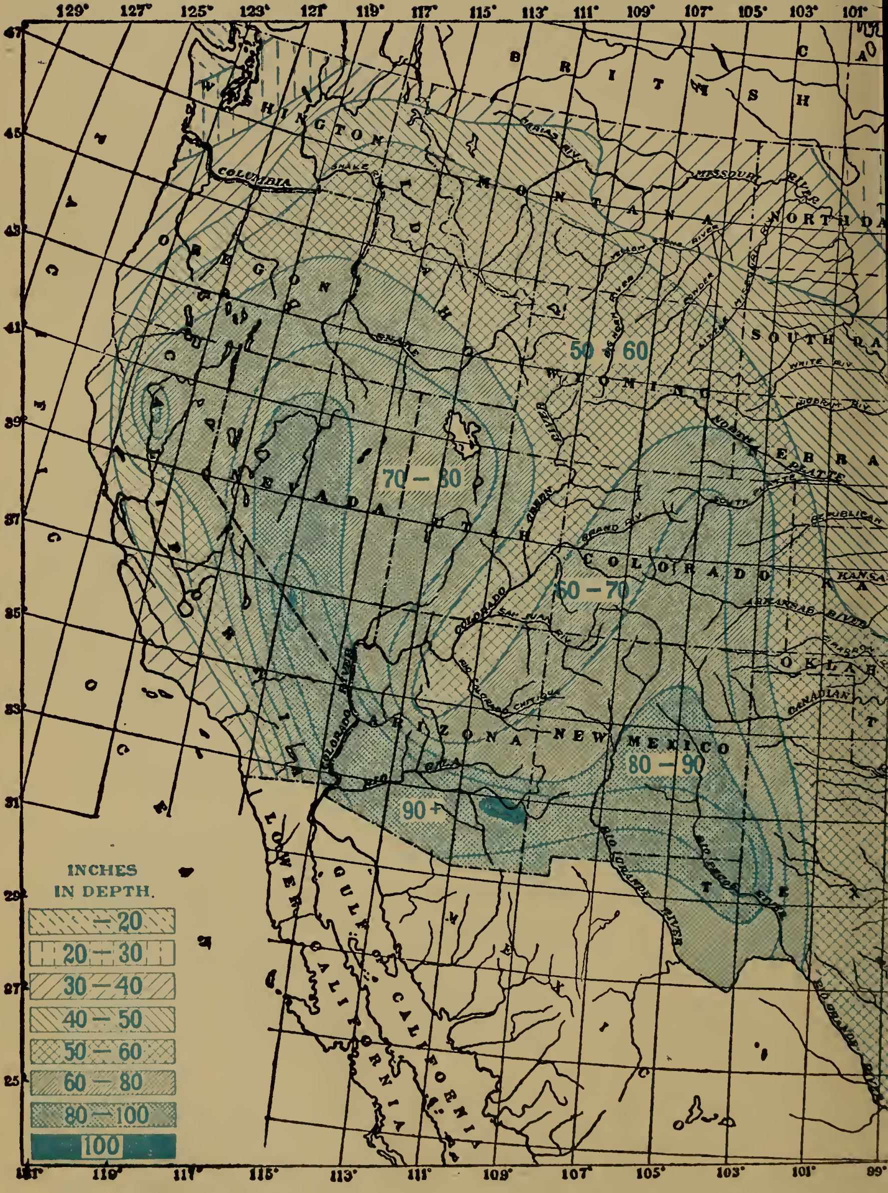
CHAPTER VIII.

THE DISPOSAL OF THE RAINFALL.

80. **Manner of Disposal**—The ultimate disposal of the rainfall depends on the rate of rainfall and the condition of the surface receiving it. If the receiving surface is highly pervious the water may pass into the strata as rapidly as it falls. A heavy rainfall occurring when the ground is frozen, or on an impervious stratum, will flow at once into the streams, with a velocity regulated by the surface gradient. A comparatively small rainfall may produce, under these circumstances, flood conditions. A similar rainfall during the summer will be largely lost by evaporation, taken up by the growing crops, or may rapidly sink into pervious ground, giving little or no run off. Subject to these variations, the annual rainfall is partially lost in evaporation, partially taken up by the strata, a limited portion is used by vegetable growth, and the balance forms the flood flow of streams. The importance of each manner of disposal depends entirely on the controlling surface conditions.

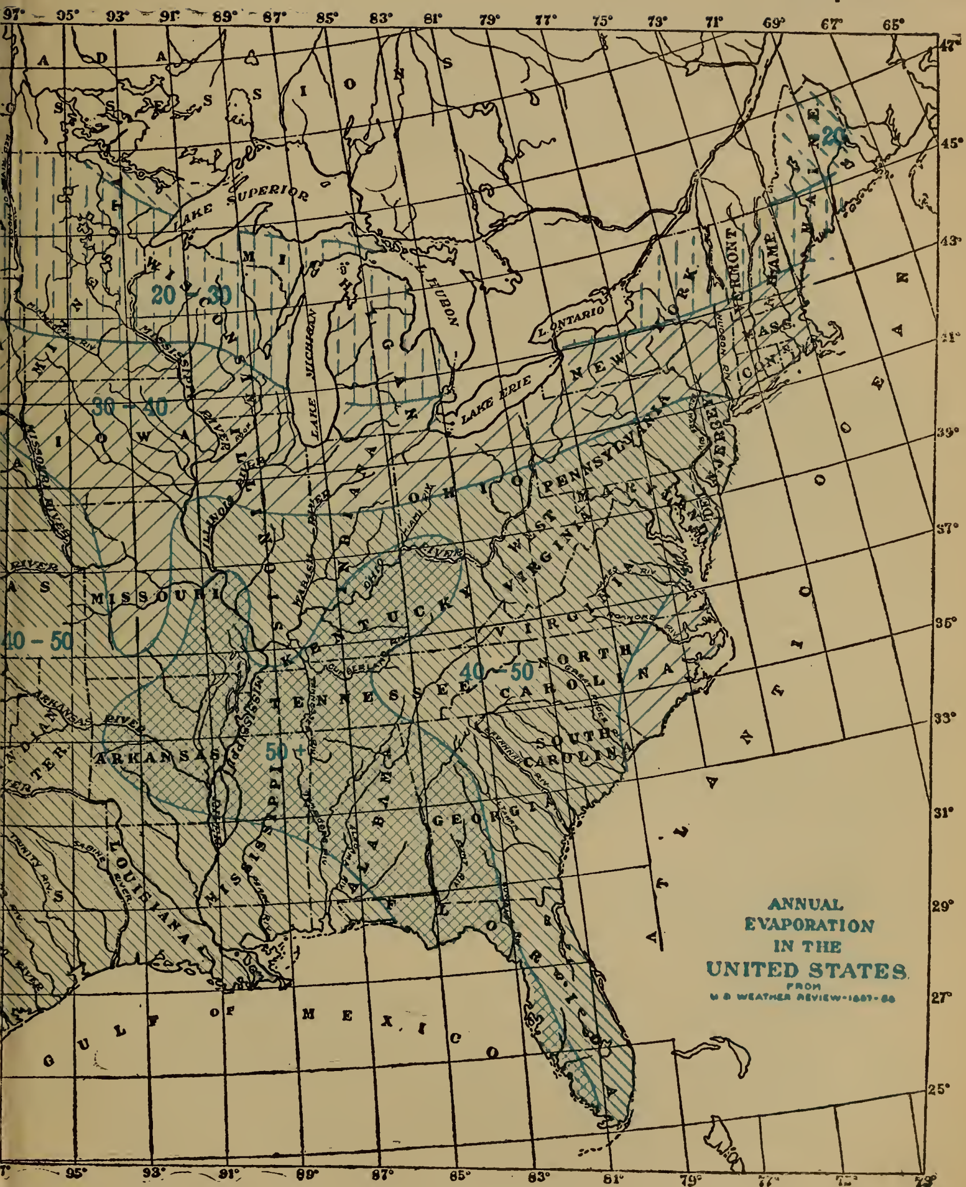
81. **Percolation.**—A portion of the rainfall on pervious strata sinks below the surface until it reaches a relatively impervious stratum. The water then follows the dip until it fills the stratum, thus causing it to become impervious to further percolation, or until it finds an outlet in springs and rivers, or flows to more distant and unknown outlets, sometimes below the surface of the sea.

A portion of the underground water is absorbed by the roots of plants, and on this water vegetation must depend for its supply during dry periods. Water drawn from the earth by plants, after performing its functions in vegetation, is transpired from the vegetable surfaces.



129° 127° 125° 123° 121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101°
47° 45° 43° 41° 39° 37° 35° 33° 31° 29° 27° 25°
121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101° 99°
BRITISH
WASHINGTON
COLUMBIA
SNAKE R.
MONTANA
MISSOURI RIVER
MARIAS RIV.
NORTH DA
OREGON
IDAHO
SNAKE
YELLOWSTONE RIVER
BIG HORN RIVER
POWDER
LITTLE MISSOURI
SOUTH DA
WHITE RIV.
CHEYENNE RIV.
WYOMING
GREEN RIVER
NEBRASKA
NORTH PLATTE
SOUTH PLATTE
REPUBLICAN
PACIFIC OCEAN
CALIFORNIA
NEVADA
UTAH
COLORADO
GRAND RIV.
KANSAS
ARKANSAS RIVER
CIMARRON
OKLA
CANADIAN
COLORADO
SAN JUAN RIV.
LITTLE COLORADO
COLORADO RIVER
ARIZONA
NEW MEXICO
GILA
RIO GRANDE RIVER
RIO PECOS RIVER
TEXAS
LOWER CALIFORNIA
GULF OF CALIFORNIA
MEXICO
50 – 60
70 – 80
60 – 70
80 – 90
90 +
INCHES IN DEPTH.
– 20
20 – 30
30 – 40
40 – 50
50 – 60
60 – 80
80 – 100
100

Map No. 15



ANNUAL
EVAPORATION
IN THE
UNITED STATES
FROM
U S WEATHER REVIEW-1887-88

The dry weather flow of streams also depends on percolating water. Streams derived from areas where porous strata are largely developed are the more constant, and are less subject to fluctuations either from floods or drought. From this source is also derived all phreatic waters—ground water, the underflow of streams, deep and artesian waters, and the waters of springs.

82. **Evaporation.**—Whenever water is in contact with unsaturated atmosphere evaporation occurs. Evaporation takes place from damp earth surfaces and from the water surface of swamps, lakes, streams, and oceans. The percolation of water into the strata limits the amount actually evaporated from a given area by reducing the amount of water in contact with the atmosphere and thus confining the evaporation largely to exposed water surfaces. If such were not the case the evaporation, over much of the area of the United States, would greatly exceed the annual rainfall, and no water would be available for other uses. (See Map No. 15, showing the annual evaporation in the United States.)

Evaporation depends upon the temperature of the water, and on the temperature and humidity of the atmosphere adjacent to it. It is greatly promoted by atmospheric currents, which remove the vapor already formed, and bring dry air into contact with the water surface. (Turneaure & Russell. Water Supply, Chapter V. Rafter, Relation of Rainfall to Run Off, p. 38.)

83. **Water Used by Growing Crops.**—The quantity of water used by growing crops is very large, as already noted in Section 31.

The water serves to convey the soluble foods of the soil to the various fibres of the plant, and is then transpired from the vegetable surfaces. The amount actually retained as a part of vegetable growth is very small. This is shown in Table 28, which shows the amount of water required to produce a pound of dry matter, including, however, transpiration and evaporation from the cultivated surface.*

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* Eighth Annual Report Wisconsin Agric. Exp. Station, p. 126.

TABLE 28.

The Amount of Water Required to Produce a Pound of Dry Matter in Wisconsin for Oats, Barley and Corn.

		Lbs. of water used.	Lbs. of dry matter produced.	Lbs. of water per lb. of dry matter.		Computed yield per acre.	Computed amount of water.	
					Mean.	Lbs.	In tons per acre.	In inches.
Barley .	1	158.3	.3966	399.14	401.74			
Barley .	2	141.03	.3488	404.33		7,441	1,494.67	13.19
Oats . .	1	224.25	.4405	509.31	501.47			
Oats . .	2	220.7	.4471	493.63		8,861	2,221.76	19.60
Corn . .	1	300.45	1.0152	295.95	301.49			
Corn .	2	298.65	.9727	307.03		19,845	2,991.53	26.39

The actual amount of water used in irrigation is not always a criterion of the amount actually needed for plant growth. The amount used varies greatly in different localities, as would be expected from the great difference in local conditions. In most cases the quantity of water used is in excess of the amount actually needed for the crops. Table 29 shows the result of actual measurements of water used for irrigation purposes.*

84. **Run Off.**—The water which passes directly into the streams by surface flow is the principal cause of floods In addition to the surface flow, the streams ultimately receive the larger proportion of the ground waters, and from this source the ordinary dry weather flow of streams is maintained.

The entire stream flow constitutes the run off, which varies greatly in different streams, and also in the same stream in different years. In a general way, however, the run off is approximately constant and its amount is shown in Map No. 16.

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*Bul. 86, U. S. Dept. Agric. Irrigation Investigation.

TABLE 29

Tabular summary of season's measurements of precipitation, evaporation, and duty of water.

Station.	Period during which water was used.	Rainfall.	Evaporation.	General duty.		Special measurements of duty.			Remarks.
				Depth of irrigation.	Depth of irrigation and rainfall.	Location.	Depth of irrigation.	Depth of irrigation and rainfall.	
		Feet.	*Feet.*	*Feet.*	*Feet.*		*Feet.*	*Feet.*	
Carlsbad, N. Mex.: Pecos Canal.	Entire year	[1] 10.31	4.55	6.26	6.57	Hagerman farm	15.44	15.75	Measurements carried on from April to October.
Mesa, Ariz., Mesa Canal:									
1896	do	.78	...	5.91	6.69				
1897	do	1.04	...	5.55	6.59				
1898	do	.57	...	5.01	5.58				
1899	do	.39	...	3.81	4.20				
Riverside, Cal.: Gage Canal	do	.47	...	2.24	2.71	District No. 1	2.32	2.79	
						District No. 2	2.23	2.70	
Salt Lake City, Utah:						District No. 3	1.78	2.26	
Butler Ditch	April–September	.49	...	6.24	6.73				
Brown & Sanford Ditch	do	.49	...	5.32	5.81				
Upper Canal	do	.49	...	6.30	6.79				
Green Ditch	do	.49	...	4.52	5.01				
Lower Canal	do	.49	...	2.83	3.32				
Big Ditch	do	.49	...	3.09	3.58				
Logan, Utah: Logan and Richmond Canal.	June–September	.27	3.27	3.59	3.86	Cronquist farm.	2.60	2.87	
Lamar, Colo.: Amity Canal	March–September	.91	...	4.92	5.83	Biles lateral	1.82	2.50	Water used under Biles lateral April to September. Rainfall, Holly, Colo., 0.68 feet.
Gothenburg, Nebr.: Gothenburg Canal.	June 7–Sept. 30	1.26	...	2.57	3.83	Daggett farm	4.24	5.50	Rainfall April to September. Water used after harvest.
Wheatland, Wyo.: Canal No. 2.	June–August	.37	[2] 1.26	2.53	2.90	J lateral:			
						Oats	1.55	1.92	
						Corn	.70	1.07	
Boise, Idaho: Boise and Nampa Canal.	May–September	.22	...	...	...	Rust lateral	5.06	5.28	
						A. F. Long farm	2.40	2.62	Rainfall at Boise.
						Wilson orchard	1.48	1.70	Do.
Bozeman, Mont.: Middle Creek Ditch.	June 16–Sept. 16	.42	[3] 1.74	2.10	2.52	Station farm:			
						Clover	1.02	1.46	Rainfall, 0.44 foot.
						Peas	1.10	1.51	Rainfall, 0.41 foot.
						Grain	1.98	2.40	Rainfall, 0.42 foot.
						Barley	.98	1.39	Rainfall, 0.41 foot.
						Oats	1.53	1.91	Rainfall, 0.38 foot.
						Do	1.34	1.70	Rainfall, 0.36 foot.
						Do	2.16	2.52	Rainfall, 0.36 foot.
						Do	1.28	1.72	Rainfall, 0.44 foot.

[1] May 1 to November 11, 1899.

[2] Evaporation at Laramie, Wyo.

Evaporation from July 6 to September 30.

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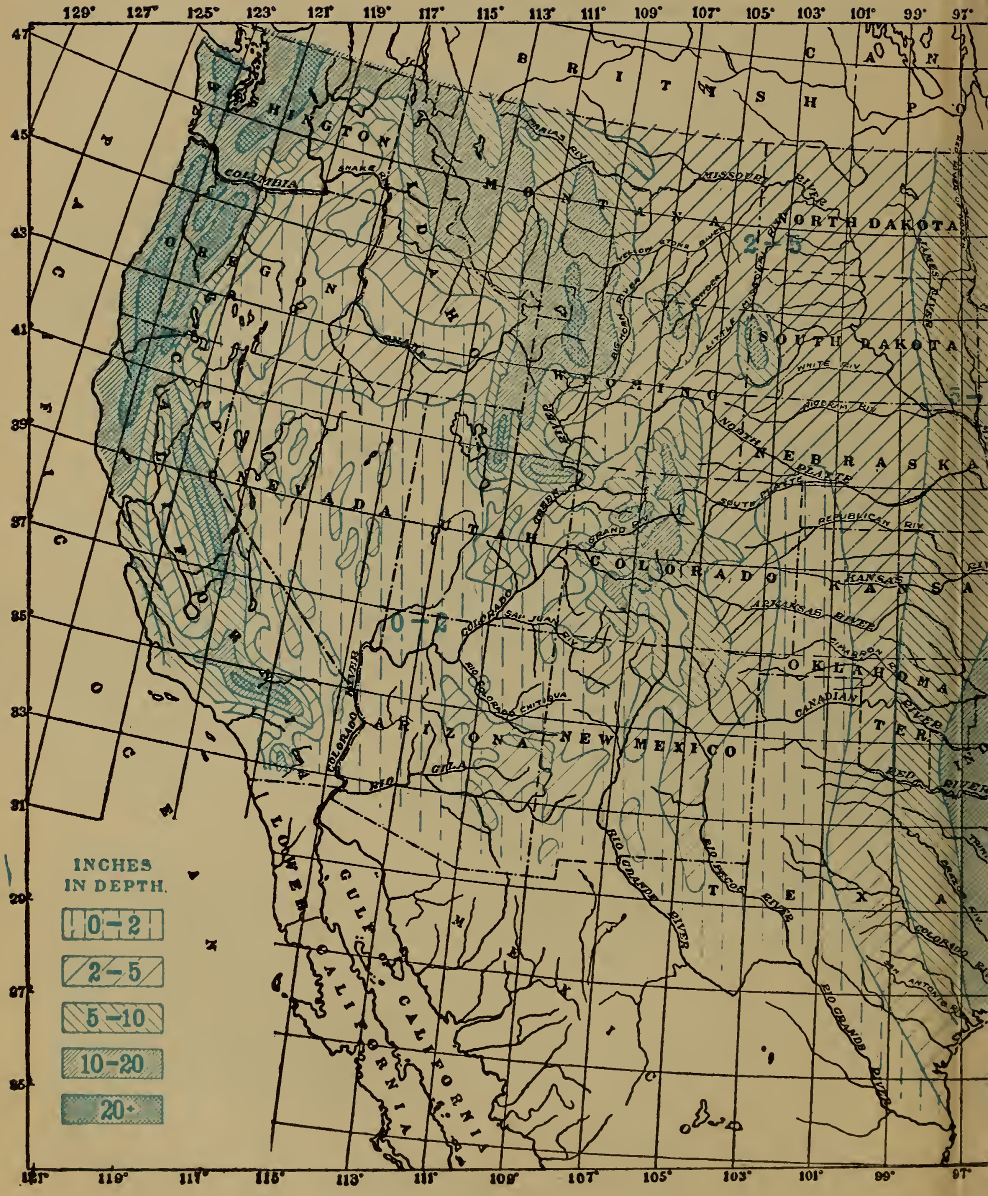
INCHES IN DEPTH.
0–2
2–5
5–10
10–20
20+
BRITISH POSSESSIONS
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
IND. TER.
TEXAS
MEXICO
LOWER CALIFORNIA
GULF OF CALIFORNIA
PACIFIC OCEAN
COLUMBIA
SNAKE R.
MISSOURI RIVER
YELLOWSTONE RIVER
BIG HORN RIVER
LITTLE MISSOURI RIV.
JAMES RIVER
WHITE RIV.
NORTH PLATTE
SOUTH PLATTE
REPUBLICAN RIV.
KANSAS
ARKANSAS RIVER
CIMARRON
CANADIAN
RED RIVER
GREEN RIVER
GRAND RIV.
COLORADO RIVER
SAN JUAN RIV.
RIO COLORADO CHIQUITA
RIO GILA
RIO GRANDE RIVER
RIO PECOS RIVER
COLORADO R.
SAN ANTONIO R.
47°
45°
43°
41°
39°
37°
35°
33°
31°
29°
27°
25°
129°
127°
125°
123°
121°
119°
117°
115°
113°
111°
109°
107°
105°
103°
101°
99°
97°

Map No. 16

APPROXIMATE
MEAN ANNUAL RUNOFF
OF THE RIVERS
OF THE
UNITED STATES
FROM NEWELL

CHAPTER IX.

STREAM FLOW.

85. Laws of Stream Flow.—While the flow of a stream is directly dependent on the rainfall, yet it is impossible, simply from the known rainfall on a watershed, to closely estimate stream flow and its constant and great variations.

Stream flow depends not only on rainfall, but also on temperature, atmospheric pressure, and on the geology and topography of the watershed. The presence or absence of pervious strata, of swamps and forests, of the various classes of vegetation and agricultural improvements, each and all modify the regime of a stream. Being so largely pre-determined by climatic conditions, the flow will vary from month to month and from year to year as these conditions likewise vary. (Rafter, Relation of Rainfall to Run Off, W. S. & I. Paper No. 80, also Physiographic Processes, p. 6.)

86. Daily Variation in Flow.—Diagrams 19 to 24 show graphically the actual daily variation in the flow of streams in various portions of the United States, and under widely different conditions.* The figures on the left indicate the scale of total discharge in cubic feet per second, while those on the right, which have been added to the original diagrams, indicate the scale of discharge in cubic feet per second per square mile, which is of more particular value for comparative study.

Diagram 25 shows the daily flow of the Passaic River in cubic feet per second per square mile for a still longer period of years.† These diagrams illustrate the fact that the average monthly flow of a stream may be made up of considerable variation in daily flow; also that single determinations of flow afford absolutely no criterion on which to base an intelligent estimate of the regime of a stream.

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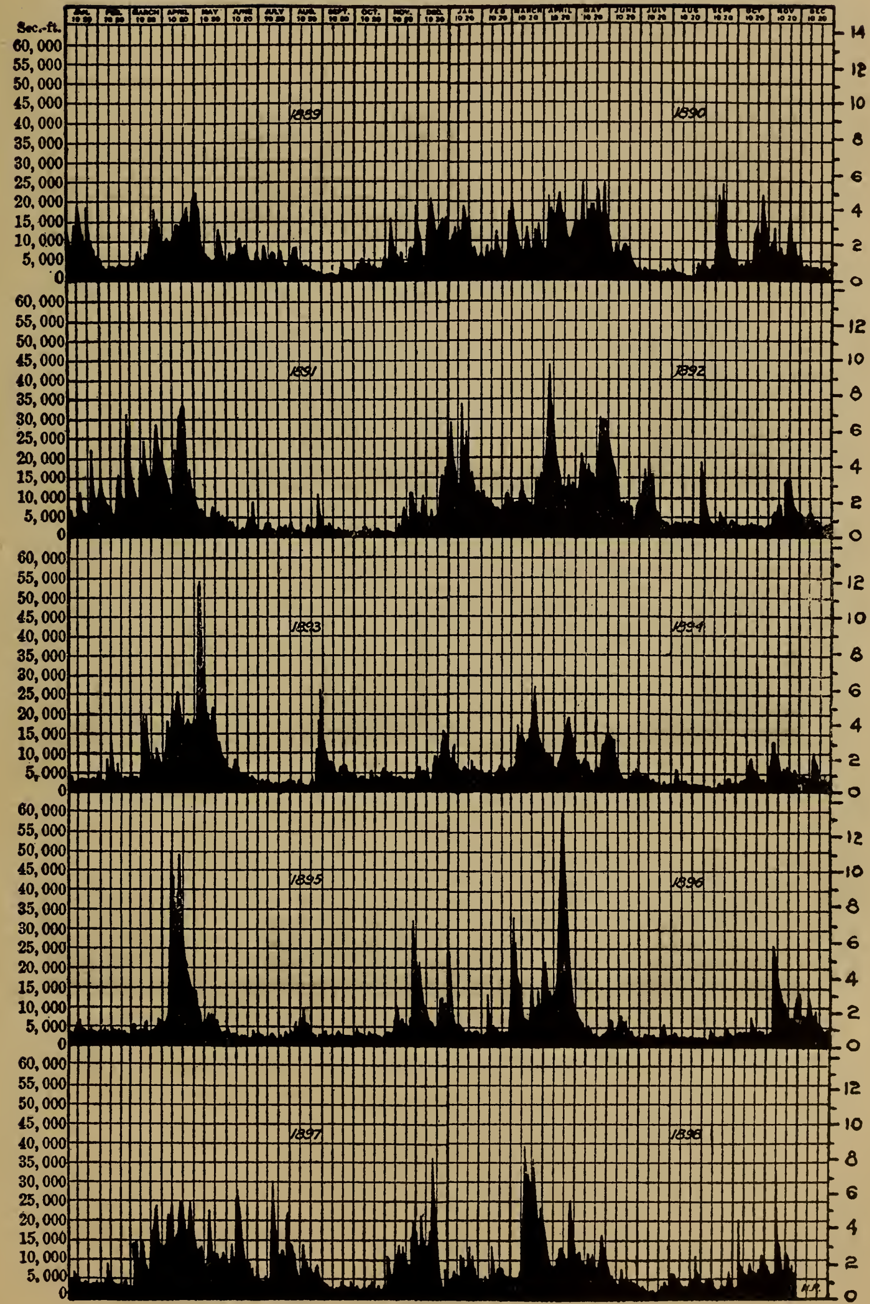
* 20th An. Rep. U. S. G. S., Part II.

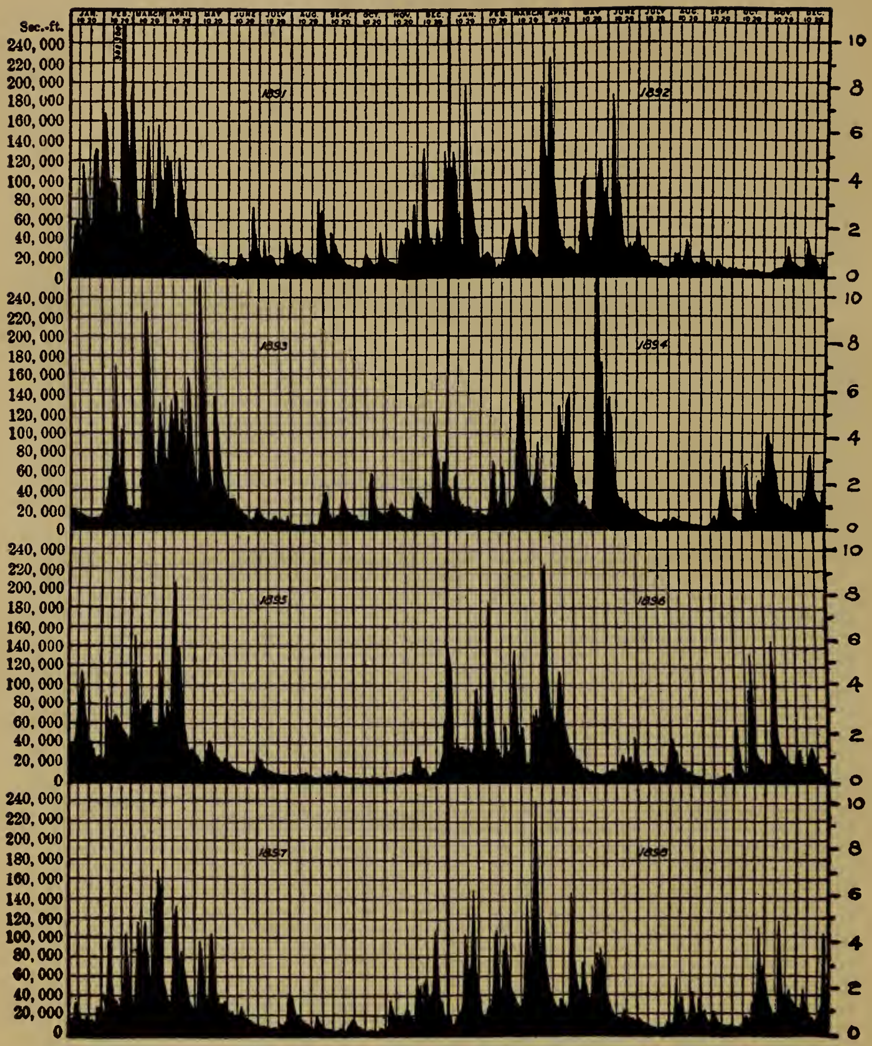
† Final Rep. New Jersey Geo. Survey, Vol. III.

DIAGRAM 19.



Discharge of Hudson River at Mechanicsville, New York, 1889–1898.

DIAGRAM 20

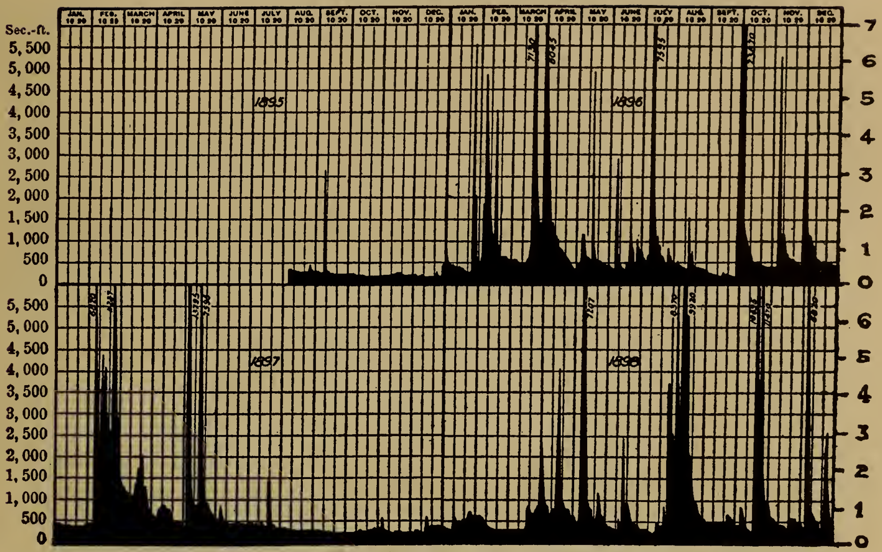


—Discharge of Susquehanna River at Harrisburg, Pennsylvania, 1891-1898.

Diagram 25, on which the monthly rainfall has been given, also affords an interesting illustration of the relation of monthly rainfall and stream flow.

Diagram 26, which shows the variation in mean monthly run off from the great lakes for each year from 1860 to 1892, illustrates the influence of storage on maintaining uniformity of flow. While a considerable seasonable variation in flow

DIAGRAM 21.



—Discharge of North River at Port Republic, Virginia, 1895–1898.

is shown in the run-off, such variation is small compared with the volume of discharge, and does not exhibit the rapid fluctuation in flow, caused by rainstorms, as in the case of smaller streams.

87. **Extreme Variation.**—In many hydraulic problems the extreme variations in stream flow, either maximum or minimum, are the most important factors. Various formula have been suggested for flood flows, none of which, however, should be used without a knowledge of the conditions under which they are applicable. The known ratio of actual maximum and minimum flow on watersheds, where such flow has been determined, is of importance. Such data serves as the best guide for all such calculations, where the area considered is subject to similar conditions. The maximum and minimum flow of various American and foreign streams is contained in Table 30, which gives the drainage area, mean annual rainfall, and maximum and minimum discharge in cubic feet per second per square mile of various streams in the United States and foreign countries.*

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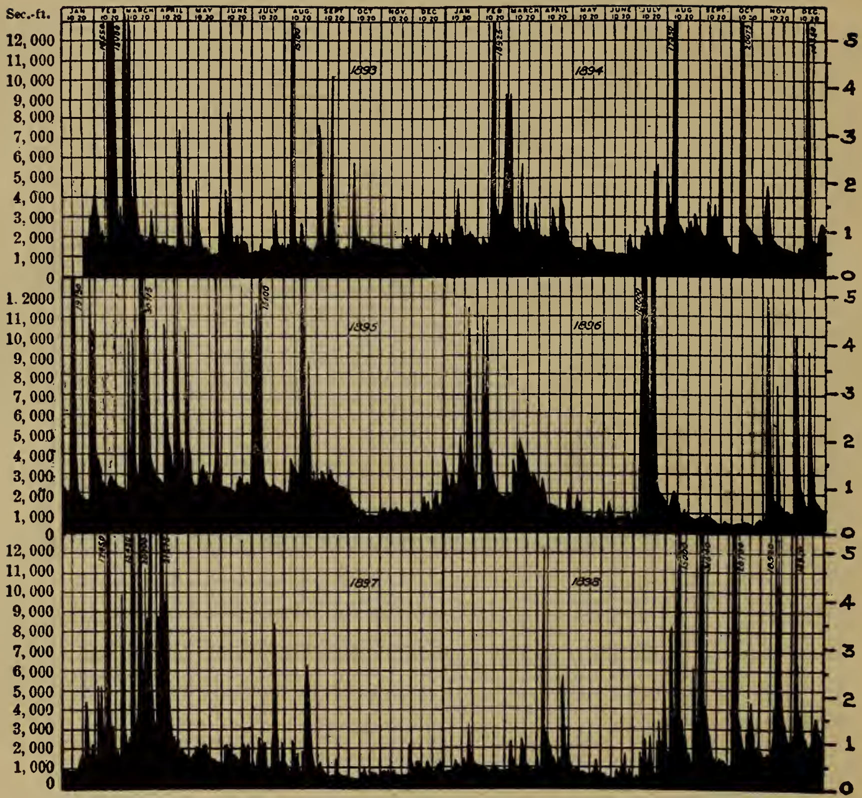
*Report of State Engineer of New York on Barge Canal, 1901.

DIAGRAM 22.



Discharge of Ocmulgee River at Macon, Georgia, 1893-1898.

Diagram 27 also shows the rate of maximum flood discharge of certain American and European rivers.*

(See Turneaure & Russell, Water Supply, Chapter VI.)

88. Monthly Average Flow.—For the purpose of certain calculations, the average monthly stream flow is the most convenient basis.

The average monthly discharge, in cubic feet per second per square mile of drainage area, of a few eastern rivers of the United States, is given in Table 31. From this table it will be seen that the minimum average monthly flow of a stream does not always occur during the same month, and

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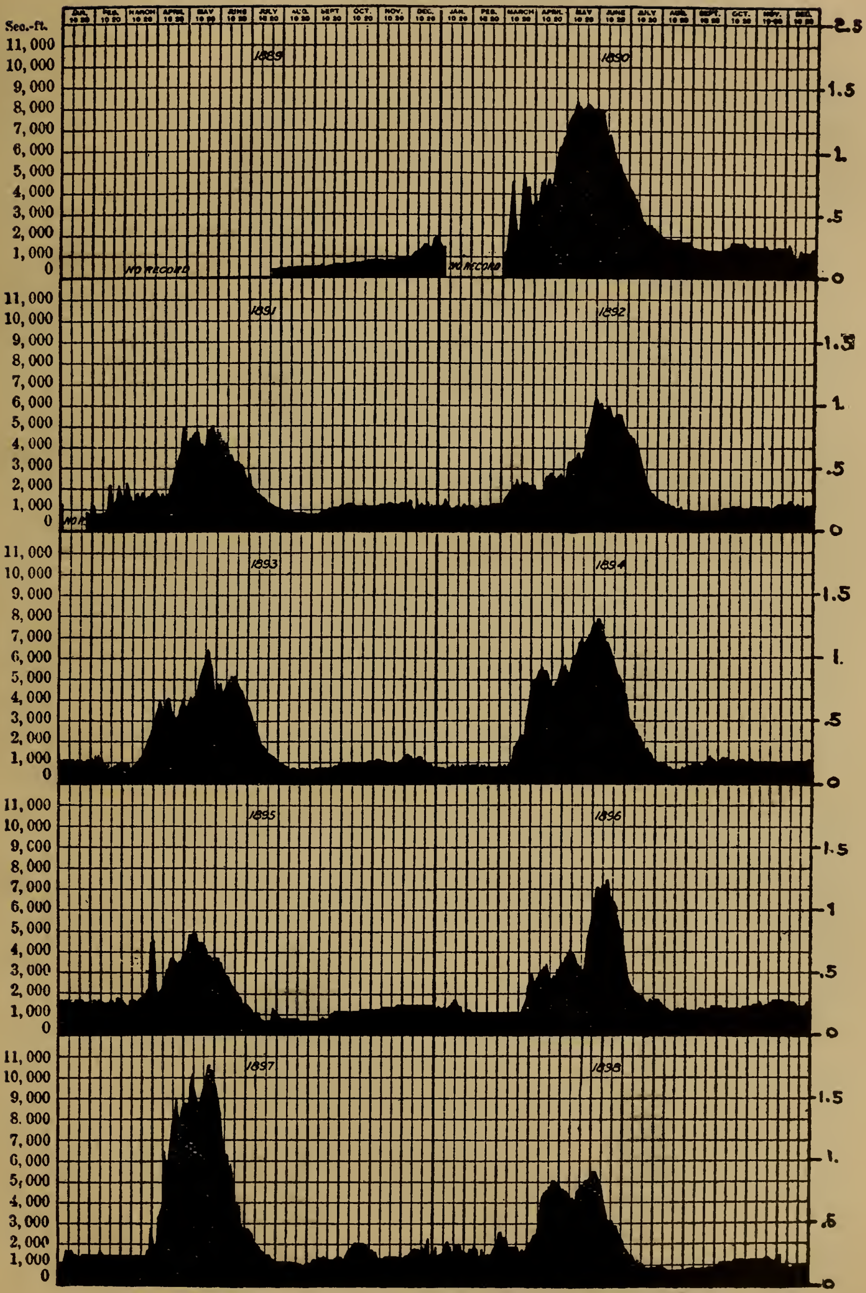
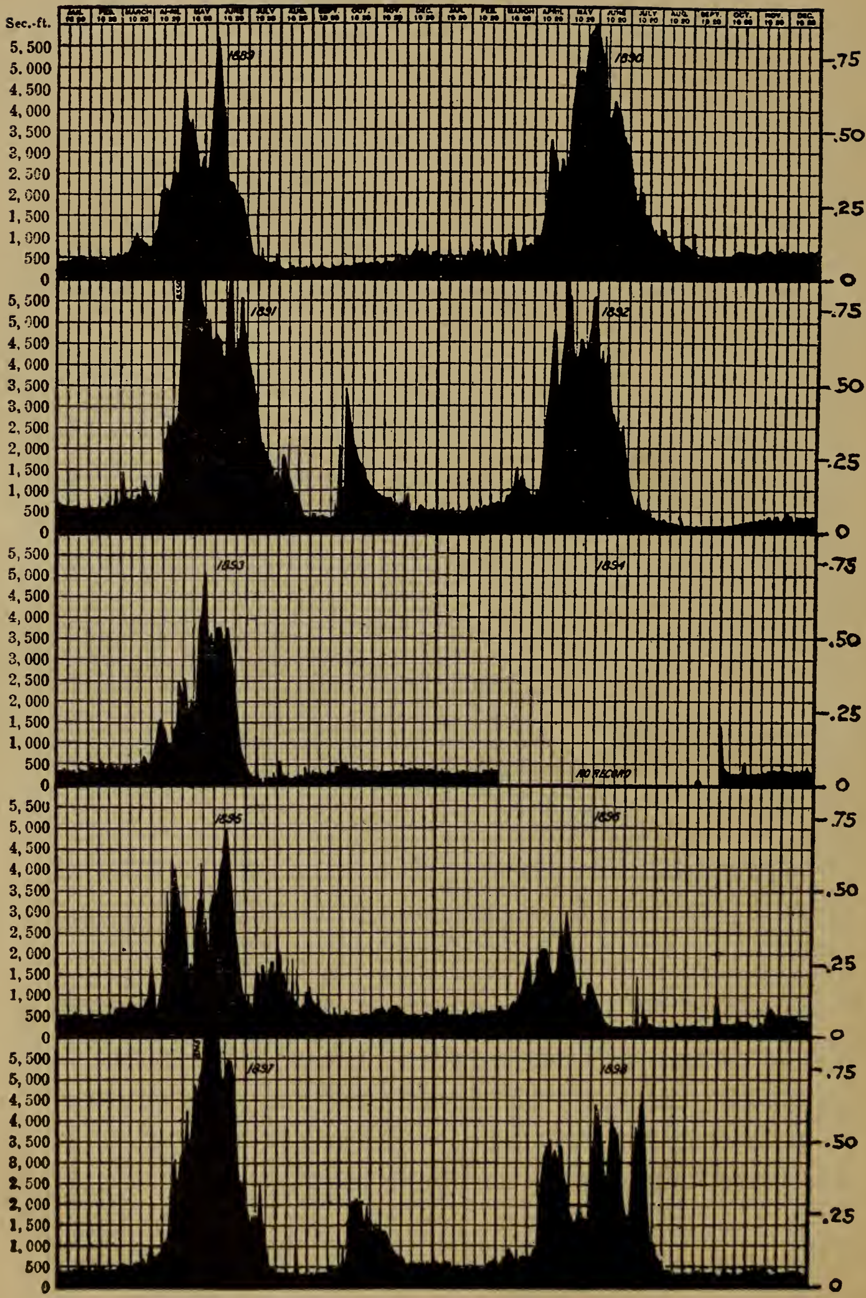
*Report of State Engineer of New York on Barge Canal, 1901.

DIAGRAM 23



Discharge of Bear River at Collinston, Utah, 1889-1898.

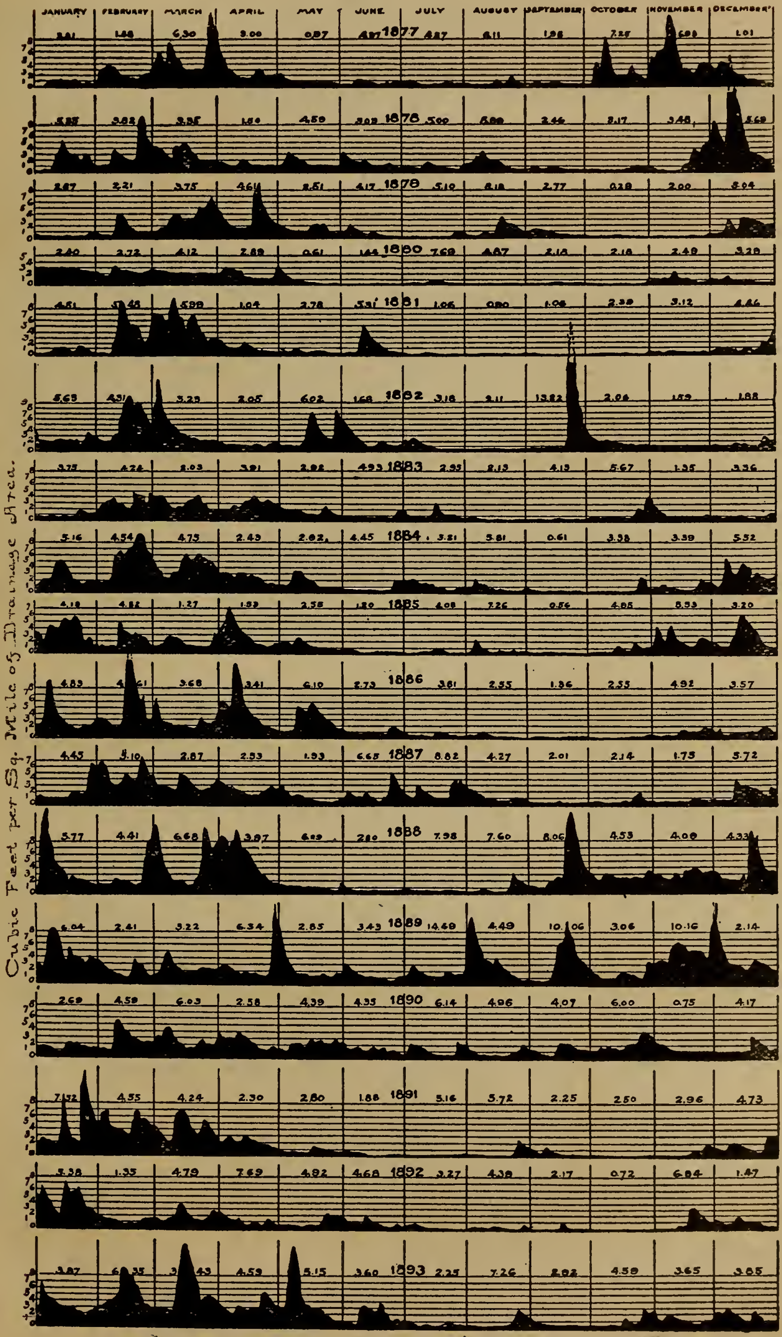
DIAGRAM 24.



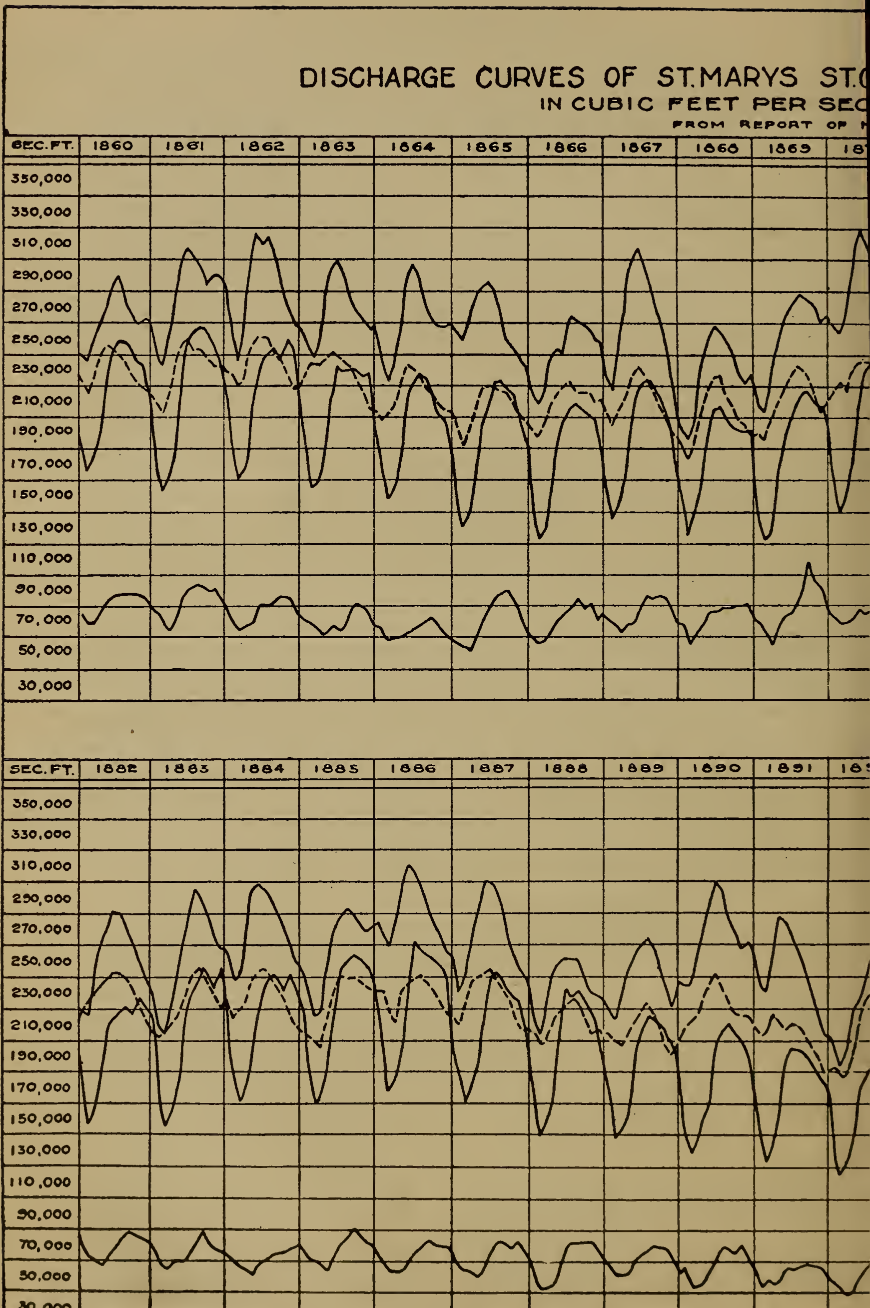
—Discharge of the Rio Grande at Embudo, New Mexico, 1889–1898.

DIAGRAM 25.

DAILY FLOW OF PASSAIC RIVER LITTLE FALLS, N.J.



NOTE.
HORIZONTAL DIVISIONS DENOTE CUBIC FEET PER SECOND PER SQUARE MILE OF DRAINAGE AREA



DISCHARGE CURVES OF ST.MARYS ST.

IN CUBIC FEET PER SEC

FROM REPORT OF

DIAGRAM 26

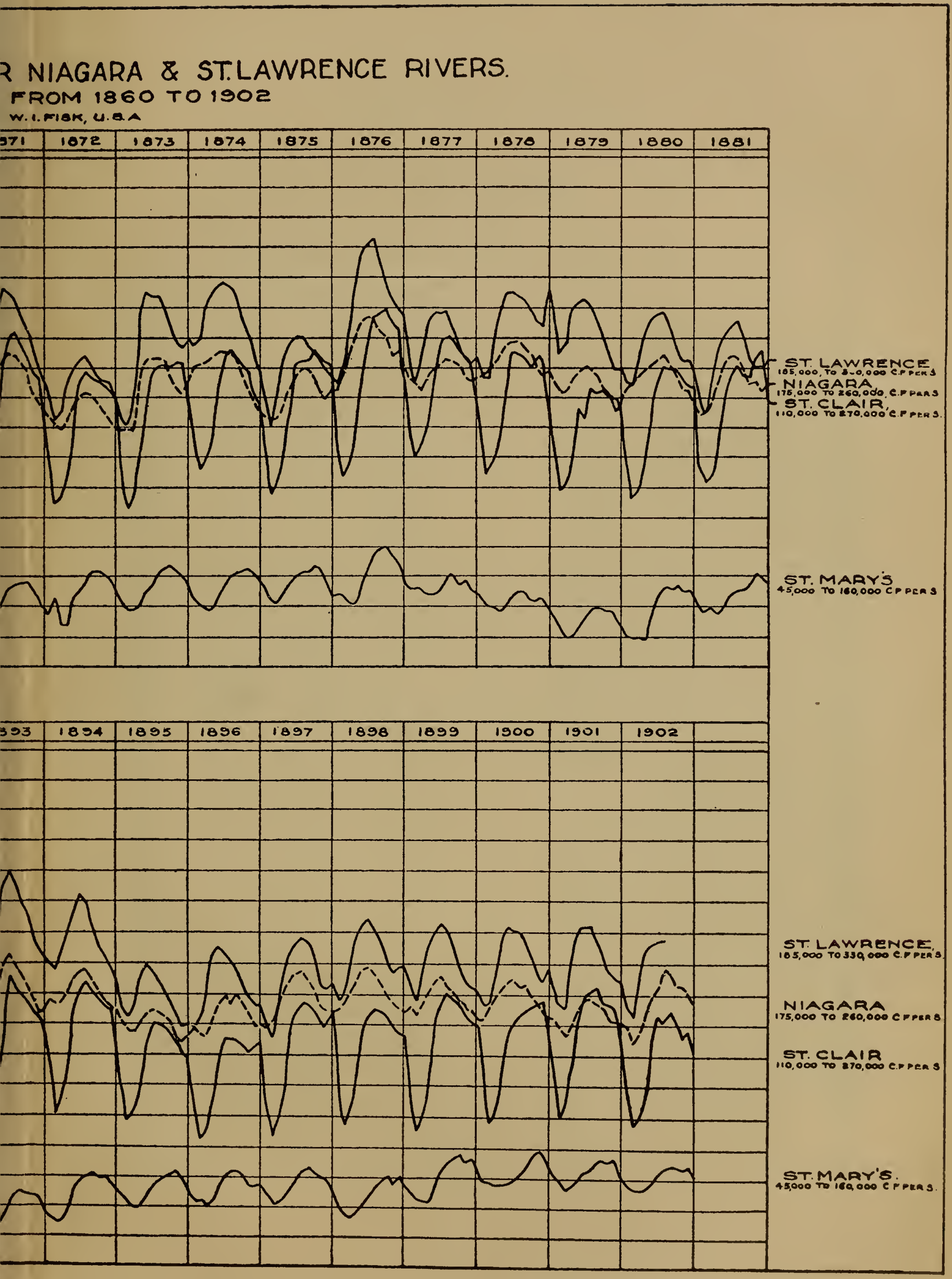

NIAGARA & ST. LAWRENCE RIVERS.
FROM 1860 TO 1902
W. I. FISK, U.S.A
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
ST. LAWRENCE
185,000, TO 330,000 C.F PER S
NIAGARA
175,000 TO 260,000 C.F PER S
ST. CLAIR,
110,000 TO 270,000 C.F PER S.
ST. MARY'S
45,000 TO 160,000 C.F PER S
1894
1895
1896
1897
1898
1899
1900
1901
1902
ST. LAWRENCE,
185,000 TO 330,000 C.F PER S.
NIAGARA
175,000 TO 260,000 C.F PER S
ST. CLAIR
110,000 TO 270,000 C.F PER S
ST. MARY'S.
45,000 TO 160,000 C.F PER S.

TABLE 30.

DRAINAGE AREA, 500 TO 1,000 SQUARE MILES

STREAM AND LOCALITY.	Drainage Area, Sq. Miles	Mean Annual Rainfall, Inches	Discharge Cu. Ft. per Sec. per Sq. Mile	
			MAX.	MIN.
I. AMERICAN STREAMS.				
Broad river at Carlton, Ga	762	47.73	22.21	.394
Coosawattee river at Carters, Ga	532	52.73	15.17	.588
Des Plaines river at Riverside, Ill	630	29.75	14.23	.000
Etowah river at Canton, Ga	604	52.73	31.50	.405
Flint river at Molina, Ga	892	52.73	7.37	.062
French Broad river at Asheville, N. C	987		7.88	.660
Greenbriar river, mouth Howard's cr., W. Va.	810	40.70		.120
Housatonic river, Massachusetts	790			.165
Little Tennessee river at Judson, N. C.	675		56.40	.408
Mahoning river at Warren, O	596			.017
Mahoning river	967			.028
Monocacy river at Frederick, Md	665	38.77	16.98	.116
North river at Port Republic, Va	804	38.77	29.78	.220
North river at Glasgow, Va	831	38.77	44.80	.180
Olentangy river at Columbus, O	523			.014
Passaic river at Paterson, N. J	791	45.00		.190
Potomac river, no. branch at Cumberland, Md.	891	38.77	22.82	.045
Potomac river at Cumberland, Md	920	38.77	19.46	.022
Raritan river at Bound Brook, N. J.	879	45.94	59.30	.140
Schoharie creek at Fort Hunter, N. Y.	948	39.25	44.00	
Shenandoah river at Fort Republic, Va	770	38.77		.167
Tuckasagee river at Bryson, N. C	662		45.30	.603
II. FRENCH STREAMS.				
Armancon river at Aisy	575		49.20	.011
Armancon river at Tonnerre	853			.034
Marne river at St. Dizier	915	30.70	7.73	.101
Meuse river at Pagny-la-Blanchecote	573			.039
Meuse river at Chalaines	607	31.51		.041
Meuse river at Pagny-sur-Meuse	734			.056
Meuse river at Vignot	817			.085
Meuse river at Mt. Mihiel	914			.078
III. GERMAN STREAMS.				
Ihna river at Stargard	672	26.60	15.50	.137
Jagst river at its mouth	708	29.50		.200
Kocher river at its mouth	768	29.50		.221
Lippe river at Hamm	965		9.75	.235
Malapane river at Czarnowanz	773	25.04	14 35	.274
Oppa river at Strebowitz	805	24.40	21.95	.256
Stober river at its mouth	620	22.70	3.65	

TABLE 30—Continued

DRAINAGE AREA, 1,000 TO 2,500 SQUARE MILES.

STREAM AND LOCALITY.	Drainage Area, Sq. Mile.	Mean Annual Rainfall, Inches.	Discharge Cu. Ft. per Sec. per Sq. Mile.	
			MAX.	MIN.
I. AMERICAN STREAMS.				
Androscoggin river at Rumford Falls, Me.	2,220	40.39	25.00	.475
Broad river at Gaffney, S. C.	1,435	47.73	13.05	.550
Catawba river at Catawba, N. C.	1,535		34.30	.553
Chattahoochee river at Oakdale, Ga.	1,560	48.91	21.75	.432
Genesee river at Mt. Morris, N. Y.	1,070	38.09	39.20	.094
Greenbriar river at Aederson, W. Va.	1,344	44.86	41.55	.041
James river at Buchanan, Va.	2,058	40.83	15 56	.146
Neuse river at Raleigh, N C.	1,000			.193
Neuse river at Selma, N. C.	1,175		6.70	.064
Ocmulgee river at Macon, Ga.	2,425	49.23	14.92	.157
Oconee river at Carey, Ga.	1,346	49.31	7.44	.283
Oostannala river at Resaca, Ga.	1,527	52.47	14.50	.389
Potomac river at Cumberland, Md	1,364	35.28		.018
Saluda river at Waterloo, S. C.	1,056		12.08	.275
Schuylkill river at Philadelphia, Pa.	1,800			.170
Schuylkill river at Fairmount, Pa.	1,915		12.17	.013
Scioto river at Columbus, O.	1,070			.004
Scioto river at Shadeville, O.	1,670			.015
Tar river at Tarboro, N. C.	2,290		6.38	.074
Youghiogheny river at Ohio Pyle, Pa	1,775			.060
II. FRENCH STREAMS.				
Aisne river at Biermes	1,341			.085
Aisne river at Berry-au-Bac	2,120			.092
Aisne river at Berry-au-Bac	2,120		7.58	
Loing river at its junction with the Seine	1,785	28.40		.046
Lys river	1,420		1.74	.099
Marne river at La Chaussee	2,297			.010
Marne river at Chalons	2,497			.010
Meuse river at Verdun	1,219	28.33		.110
Oise river at Chauny	1,575			.104
Seine river at Troyes	1,314			.051
III. GERMAN STREAMS.				
Bober river at Sagan	1,638	39.20	17.40	.389
Drage river at its mouth	1,234		2.11	.356
Ill river at Strasburg	1,294		9.15	.327
Kuddow river at Usch	1,830	18.90	19.30	.405
Lahn river at Diez	2,008	25.60	12 80	.123
Lippe river at Wesel	1,890		11.62	.198
Main river above mouth of the Regnitz river	1,725	27.44		.224
Netze river at Antonsdorf	1,086			.063
Netze river above Eichhorst.	1,130			.046
Oder river at Hoschialkowitz	1,440	21.60		.155
Oder river at Annaberg	1,800	24.60	27.00	.219
Oder river at Olsau	2,250	24.60	43.90	.274
Obra river at Moschin	1,325			.101
Ruhu river at Mulheim	1,728		33.80	.176
Saale river at its junction with the Main	1,070	27.76		.081
Welna river at Kowanowko, near mouth	1,013		3.14	.077

TABLE 30—Continued

DRAINAGE AREA, 2,500 TO 5,000 SQUARE MILES.

STREAM AND LOCALITY.	Drainage Area, Sq. Miles.	Mean Annual Rainfall, Inches.	Discharge Cu. Ft. per Sec. per Sq. Mile.	
I. American Streams.			Max.	Min.
Black Warrior river at Tuscaloosa, Ala.	4,900		38.80	.018
Broad river at Alston, S. C.	4,609		10.26	.394
Cape Fear river at Fayetteville, W. Va.	4,493		1.17	.076
Catawba river at Rock Hill, S. C.	2,987		21.96	.445
Chattahoochee river at West Point, Ga.	3,300	52.92	17.87	.252
Connecticut river at Dartmouth, N. H.	3,287			.306
Coosa river at Rome, Ga.	4,001	52.73	11.42	.225
Crow Wing river, Minnesota	3,576	30.84	2.84	.250
Dan river at Clarksville, Va.	3,749	38.28	8.80	.107
Hudson river at Mechanicsville, N. Y.	4,500	41.61	15.50	.189
Kennebec river at Waterville, Me.	4,410		25.20	.006
Merrimac river at Lowell, Mass.	4,085		19.83	.310
*Merrimac river at Lawrence, Mass.	4,551		20.00	.27
Mohawk river at Rexford Flats, N. Y.	3,384		23.10	
Mohawk river at Cohoes, N. Y.	3,444	38.65		.232
Ocanee river at Dublin, Ga.	4,182	49.31	6.69	.021
Potomac river at Dam No. 5, Md.	4,640	38.77	22.15	.078
Savannah river at Calhoun Falls, Ga	2,712	47.73	.96	.518
Shenandoah river at Millville, W. Va	2,995	39.56	11.44	.203
Staunton river at Clarksville, Va.	3,546	38.28	10.30	.157
Susquehanna river, w. br., Williamsport, Pa.	4,500		11.60	.178
Tallapoosa river at Milstead, Ala.	3,840		9.50	.091
Yadkin river at Salisbury, N. C.	3,399		23.55	.225
Yadkin river at Norwood, N. C.	4,614		13.70	.284
II. French Streams.				
Aisne river at Soissons	3,040		6.43	.081
Aisne river, above junction with the Oise river	3,285	23.50	5.95	.096
Eure river at its mouth	2,980	22.30	2.72	.076
Isere river at its mouth	4,360		21.00	.780
Marne river at Chateau Thierry	3,332			.127
Meuse river at Sedan	2,560	28.33	8.05	.194
Meuse river at Fumay	3,700	28.33	4.04	.191
Seine river at Bray	3,750		4.05	.003
Seine river at Nogent-sur-Seine.	3,594			.103
Yonne river at Sens	4,270		9.09	.106
Yonne river at Nogent-sur-Seine	4,300	30.80	6.37	.140
III. German Streams.				
Main river, below mouth of the Regnitz river	4,650	27.44		.186
Moselle river at Metz	3,550	29.48	14.92	.199
Mur river at Graz	2,959		12.98	.243
Neckar river at Heilbronn	3,155			.146
Neckar river at Offenau.	4,770		33.35	.167
Oder river at Ratibor	2,580	24.60	21.20	.306
Oder river at Kosel	3,520	24.60	14.10	.128
Oder river at Krappitz	4,150	24.60	3.86	.187
Regnitz river at its junc. with the Main river	2,920	25.60		.164

*Figures supplied by Mr. Rich. A. Hale, Lawrence. Mass.

TABLE 30—Continued

DRAINAGE AREA, 5,000 AND OVER SQUARE MILES.

STREAM AND LOCALITY.	Drainage Area, Sq. Miles.	Mean Annual Rainfall, Inches.	Discharge Cu. Ft. per Sec. per Sq. Mile. MAX.	MIN.
I. AMERICAN STREAMS.				
Connecticut river at Holyoke, Mass	8,660		13.26	.029
Connecticut river at Hartford, Conn	10,234	44.53		.310
Connecticut river at Hartford, Conn	10,234	44.53	20.27	.510
Coosa river at Riverside, Ala	6,850	48.08	10.53	.197
Delaware river, New Jersey	6,750		50.00	.300
Delaware river at Stockton, N. J	6,790	45.29	37.50	.170
Delaware river at Lambertsville, N. J	6,855	45.29	9.71	.364
James river at Richmond, Va.	6,800	40.83		.191
Kanawha river at Charleston, W. Va	8,900	40.70	13.49	.123
Mississippi river	7,283	32.64	1.49	.261
Mississippi river above St. Paul	36,085	25.75	19.73	.045
Mississippi river	164,534			.190
Mississippi river	526,500			.050
Mississippi river	1,214,000			.210
Missouri river	17,615	15.70		.100
New river at Fayette, W. Va	6,200	40.70	13.49	.189
Ohio river at Pittsburg, Pa	19,990			.114
Ohio river	200,000	41.50		.270
Oswego river at Oswego, N. Y	5,013	37.69		.230
Potomac river at Point of Rocks, Md	9,654	39.35	19.40	.083
Potomac river	11,043	38.77	42.60	.170
Potomac river at Georgetown, D. C	11,124	38.77	15.70	
Potomac river at Great Falls, Md	11,427	45.36	41.15	.215
Potomac river at Great Falls, Md	11,476	45.36	15.25	.093
Potomac river at Chain Bridge, D. C	11,545	38.77	17.16	.165
Red river, Arkansas	97,000	39.00	2.32	
Roanoke river at Neal, N. C	8,717	38.21	7.38	.229
St. Croix river, Minnesota	5,950	32.58	6.00	.424
Savannah river at Augusta, Ga	7,294	47.73	42.50	.272
Susquehanna, w. branch, at Northumberland	6,800		17.53	.074
Susquehanna river at Harrisburg, Pa	24,030		18.88	.092
Tennessee river at Chattanooga, Tenn	21,418		20.78	.199
II. FRENCH STREAMS.				
Loire river at Nevers	6,560		23.10	.070
Loire river, between Maine and Vienne rivers	9,950			.255
Marne river at Charenton	5,657			.016
Marne river at its junction with the Seine	5,295	30.70	4.67	.080
Meuse river at Maestricht	8,240	42.50	5.51	.146
Meuse river at Maeseyck	8,480	42.50	7.36	.244
Meuse river above Ruremond	8,750		3.01	.317
Oise river at Creil	5,622		3.14	.194
Rhone river at Lyons	18,000	36.32	11.83	.333
Seine river at Port a l'Anglais	17,624			.046
Seine river at Paris	20,000	21.27	5.80	.085
Seine river at Mantes	25,135		3.09	.091
Seine river at mouth of the Eure river	28,583		3.09	
III. GERMAN STREAMS.				
Elbe river at Torgau	22,000	27.09	2.89	.144
Main river above mouth of Saale river	5,820			.182
Main river below mouth of Saale river	6,900			.166
Main river above mouth of Tauber river	7,290			.167
Main river below mouth of Tauber river	8,000			.167
Main river at Frankfort	9,610		12.50	.121
Memel river at Tilsit	38,600		4.02	.813
Moselle river at Kochem	10,253		8.52	.174
Moselle river at Coblenz	10,840	24.76	13.04	.166

DIAGRAM SHOWING THE RA

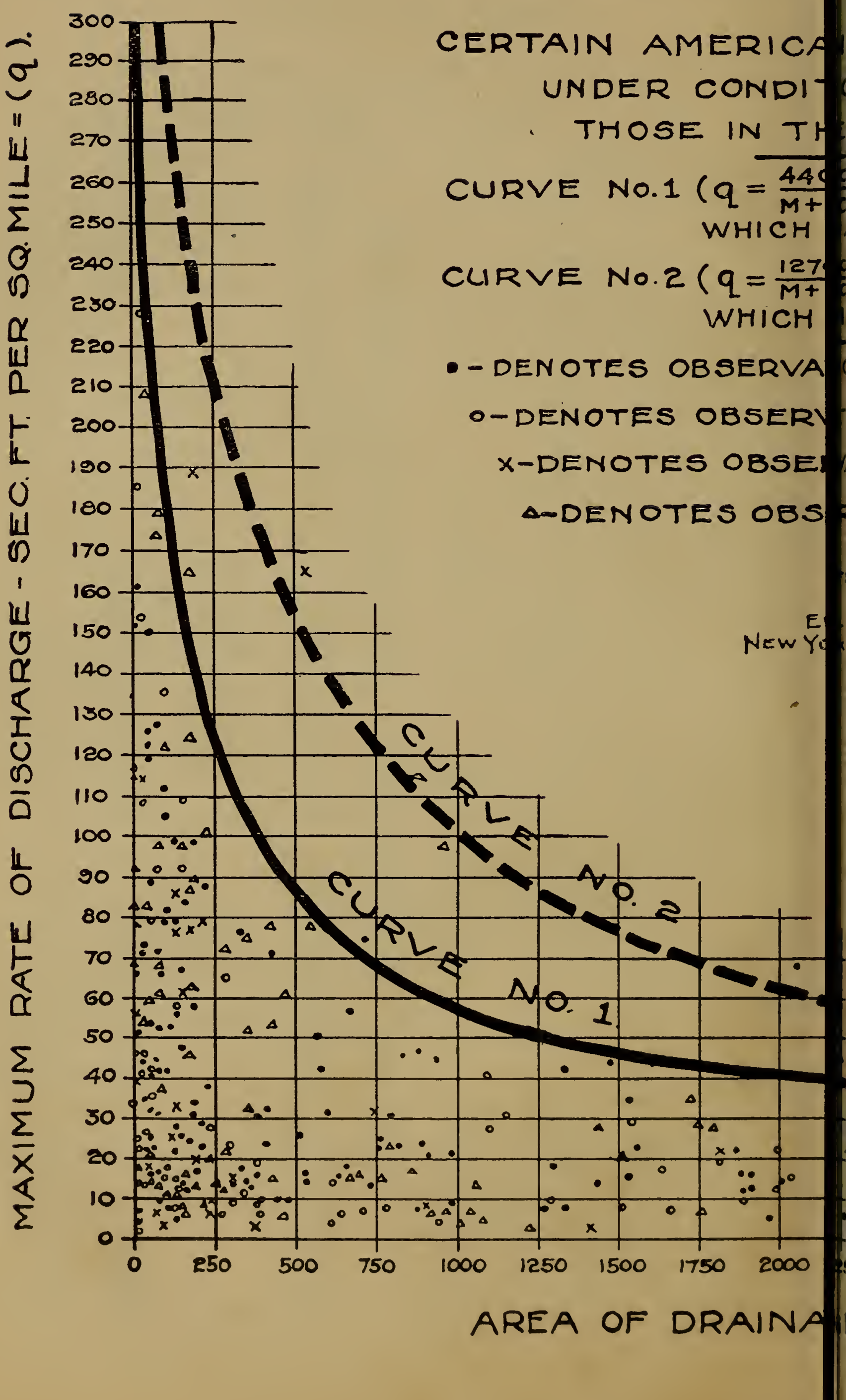


DIAGRAM 27.

E OF MAXIMUM FLOOD DISCHARGE.
OF
AND EUROPEAN RIVERS,
NS COMPARABLE TO
MOHAWK VALLEY.

+20) CORRESPONDS TO FLOODS
AY OCCUR OCCASIONALLY.

+7.4) CORRESPONDS TO FLOODS
AY OCCUR RARELY.

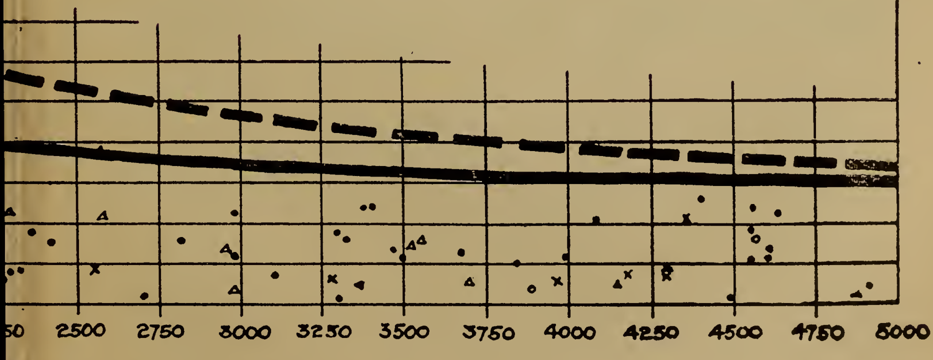
NS ON AMERICAN RIVERS.

TIONS ON ENGLISH RIVERS.

ATIONS ON FRENCH & BELGIAN RIV.

VATIONS ON GERMAN & AUSTRIAN RIV.

OM REPORT
OF
KUICHLING, C.E.
STATE CANAL SURVEY.



E BASIN - SQ. MILES - (M.)

for the consideration of these streams, for practical purposes, the better arrangement of the recorded flows is not by monthly periods, but in the relative order of the flows.

In Table 32, this data has been rearranged so that the least flow for any month in the given year is shown on the first line, and the flows of other months are arranged below

TABLE 31.

AVERAGE DISCHARGE IN CUBIC FEET PER SECOND PER SQUARE MILE OF DRAINAGE AREA OF VARIOUS RIVERS OF THE UNITED STATES, FROM 1888 TO 1901.

	HUDSON RIVER AT MECHANICSVILLE, N.Y. DRAINAGE AREA 4500 SQ. MILES															SHENANDOAH R. MILLVILLE, W.VA. 2895 SQ.M.				POTOMAC R. POINT OF ROCK, MD. 9654 SQ.M.			DELAWARE R. LAMBERTVILLE, N.J. 6855 SQ.M.
YEAR	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	AV.	'97	'98	'99	AV	'98	'99	AV.	'99
JANUARY	1.41	2.44	2.50	1.84	4.19	.71	1.50	.86	1.51	.89	1.72	1.49	1.30	.69	1.65	.40	.53	1.66	.86	2.46	1.97	2.22	3.13
FEBRUARY	.82	.84	1.74	2.59	2.06	1.02	1.07	.79	1.04	.87	1.50	1.17	2.77	.54	1.34	3.37	.33	1.23	1.64	.92	3.01	1.97	3.67
MARCH	1.52	1.84	2.47	3.94	2.41	1.97	3.28	.93	3.02	2.71	4.49	2.14	1.72	1.80	2.45	1.53	.51	2.29	1.44	1.65	3.73	2.69	5.78
APRIL	4.73	3.04	3.35	4.45	4.79	3.98	2.47	5.29	5.55	4.24	3.05	5.25	5.02	6.28	4.39	.79	1.05	1.10	.98	1.73	1.25	1.49	5.08
MAY	4.76	1.97	3.98	1.25	4.37	4.95	1.68	1.52	1.02	2.70	2.46	2.17	2.00	2.60	2.67	1.86	1.42	.85	1.38	1.96	1.19	1.58	1.19
JUNE	1.09	1.32	1.64	.71	2.80	1.07	1.38	.63	1.05	2.63	1.17	.38	.91	1.73	1.37	.46	.33	.55	.45	.45	.57	.51	.57
JULY	.34	1.28	.43	.32	2.06	.56	.70	.57	.62	2.47	.37	.54	.52	.79	.86	.42	.28	.31	.34	.26	.27	.27	.99
AUGUST	.38	.95	.45	.39	1.22	1.11	.55	.87	.54	1.83	1.14	.31	.60	1.03	.83	.30	2.73	.36	1.13	2.41	.25	1.33	.77
SEPTEMBER	.63	.44	1.97	.45	.89	1.53	.42	.58	.64	.61	.86	.46	.42	.89	.78	.22	.40	.34	.32	.27	.25	.26	1.35
OCTOBER	1.02	.83	2.05	.33	.63	.86	.81	.58	.91	.56	1.75	.58	.47	.94	.88	.23	1.66	.27	.72	1.49	.18	.84	.93
NOVEMBER	2.36	1.77	2.03	.91	1.69	.81	1.42	1.87	2.52	2.22	2.05	1.42	1.11	.83	1.64	.26	.85	.51	.54	.95	.34	.65	1.50
DECEMBER	2.22	2.93	.72	1.81	.93	1.60	.97	2.42	1.54	3.20	1.25	1.02	1.13	1.88	1.69	.47	1.38	.47	.77	1.66	.44	1.05	1.86
AVERAGE	1.77	1.65	1.94	1.62	2.34	1.68	1.37	1.41	1.66	2.08	1.83	1.43	1.50	1.67		.86	.96	.83		1.35	1.12		2.23

	GENESEE RIVER N.Y. 1070 SQ.M. DR.A. RUN OFF IN SEC-FEET PER SQ.M.					OSWEGO R N.Y. 5000 SQ. MILES						BLACK R N.Y. 1889 SQ. MILES						LAKE CHAMPLAIN 7750 SQ.M.				MOHAWK R LITTLE FALLS 1308 SQ.M.					HUDSON R. FT. EDWARDS 2800 SQ.M.			
YEAR	'93	'94	'95	'96	AV.	'97	'98	'99	'00	'01	AV.	'97	'98	'99	'00	'01	AV	'99	'00	'01	AV.	'98	'99	'00	'01	AV.	'99	'00	'01	AV.
JANUARY		1.40	.66	.47	.84		.98	.85	.61	1.07	.88		1.16	2.49	1.30	1.50	1.67	1.37	1.41	1.53	1.44		2.11	4.25	1.33	2.56	1.26	1.15	.65	1.02
FEBRUARY		.86	.22	.91	.66		1.24	.49	.93	.37	.76	1.14	2.01	1.23	3.09	1.28	1.74	1.25	1.87	1.28	1.47		1.15	2.96	.86	1.66	.68	2.55	.55	1.26
MARCH		3.31	1.94	3.00	2.75		1.99	.97	.99	1.45	1.35	3.34	5.08	2.67	1.57	3.18	3.17	1.63	2.09	1.33	1.67		2.88	1.09	3.50	2.76	1.79	1.40	1.23	1.47
APRIL		3.38	2.01	3.38	2.93	2.00	1.51	1.53	2.80	3.39	2.25	5.02	2.46	7.35	7.37	7.60	5.96	2.80	2.86	3.95	3.20		6.20	6.23	5.41	5.95	6.00	6.04	7.55	6.53
MAY		4.43	.19	.17	1.60	1.25	1.63	1.35	1.53	2.00	1.55	2.26	1.62	2.97	3.02	2.65	2.52	3.17	2.32	3.66	3.05		2.03	1.38	2.20	1.94	3.41	2.27	3.00	2.89
JUNE		1.10	.13	.39	.54	.76	1.66	.40	.62	1.63	1.01	1.44	.87	.81	.86	2.81	1.36	1.79	2.42	2.70	2.30		.78	.61	2.52	1.30	.58	1.01	2.23	1.27
JULY		.14	.11	.24	.16	.43	.36	.15	.19	.75	.38	.47	.60	.64	.70	.86	.65	1.23	1.54	1.32	1.37		.61	.72	.86	.73	.41	.45	.76	.35
AUGUST		.22	.12	.20	.18	.47	.18	.12	.13	.39	.26	1.21	.79	.47	.60	1.13	.84	.89	1.20	1.70	1.26		.17	.53	.89	.53	.26	.59	.90	.58
SEPTEMBER	.33	.93	.10	.16	.38	.25	.27	.12	.13	.37	.23		.78	.52	.54	1.63	.87	.67	.92	.98	.86	1.84	.25	.48	.90	.86	.48	.40	.88	.58
OCTOBER	.38	.44	.11	1.74	.67	.21	.40	.11	.17	.43	.26	.50	1.66	.34	.64	2.28	1.12	.58	.85	.82	.75	1.91	.39	.69	1.13	1.37	.37	.44	.96	.59
NOVEMBER	.54	.82	.47	.82	.66	.36	.89	.22	.40	.58	.51	2.20	2.08	.87	2.65	1.43	1.85	1.15	1.04	.78	.99	2.21	1.36	2.95	1.23	1.94	1.02	1.13	.76	1.26
DECEMBER	2.34	.61	1.32		1.42	.83	.78	.32	1.80	1.36	1.02	2.50	1.44	1.85	2.24		2.01	1.47	1.72	1.35	1.51	1.36	2.57	2.48	3.02	2.41	1.84	1.18	1.06	1.36
AVERAGE		1.47	.62	1.04			.99	.55	.87	1.15		2.01	1.72	1.87	2.06			1.50	1.67	1.78			1.70	2.11	1.95		1.58	1.55	1.71	

	KENNEBEC RIVER WATERVILLE ME. 4410 SQ. MILES								ANDROSCOGGIN R. RUMFORD FALLS, ME. 2220 SQ.M.					MERRIMAC RIVER LAWRENCE, MASS. 4553 SQ. M											CONNECTICUT R. HOLYOKE, MASS. 8660 SQ.M.			
YEAR	'93	'94	'85	'96	'97	'98	'99	AV.	'96	'97	'98	'99	AV.	'90	'91	'92	'83	'94	'95	'96	'97	'98	'99	AV.	'96	'97	'98	AV.
JANUARY	.60	.37	.46	.98	.81	.73	.53	.64	1.49	.82	.88	.98	1.04	1.53	2.92	1.87	.65	.66	.63	1.44	.75	1.62	1.73	1.38	1.26	.58	1.19	1.01
FEBRUARY	.33	.40	.41	.64	.84	.77	.54	.60	.78	.76	.77	.80	.78	1.70	2.96	.94	1.10	.94	.51	2.00	1.01	1.71	1.07	1.40	1.05	.67	1.00	.91
MARCH	.95	.91	.45	2.98	.86	2.56	.73	1.35	2.45	.81	2.32	.80	1.60	3.44	5.19	1.61	2.36	3.16	1.28	4.62	2.32	4.09	2.62	3.07	3.14	1.67	4.09	2.97
APRIL	2.64	3.33	5.43	6.21	5.75	6.74	5.31	5.06	3.61	3.56	4.19	3.79	4.29	3.79	4.73	1.79	3.42	2.43	4.35	4.00	3.87	3.34	5.81	3.75	4.89	4.10	3.38	4.12
MAY	6.92	2.17	2.17	3.87	6.10	3.70	4.81	4.53	3.39	5.23	4.21	4.40	4.31	3.14	1.61	2.25	4.28	1.54	1.37	.98	2.22	2.42	2.09	2.19	1.12	2.60	2.19	1.97
JUNE	3.47	1.77	1.46	1.25	2.94	2.26	2.00	2.16	1.40	3.15	2.14	1.41	2.03	1.73	1.00	1.28	.97	1.33	.67	.77	2.79	1.42	.65	1.26	.62	2.58	1.31	1.30
JULY	1.31	1.30	.80	1.21	2.96	.89	1.14	1.37	.90	2.98	.84	.79	1.38	.69	.64	1.05	.52	.50	.57	.45	2.37	.58	.54	.79	.42	2.71	.45	1.19
AUGUST	.51	.67	.61	.71	1.65	.71	.73	.80	.77	1.06	.79	.62	.81	.75	.54	1.06	.57	.57	.48	.44	1.12	.83	.44	.60	.34	1.25	.57	.72
SEPTEMBER	.46	.62	.40	.77	1.04	.59	.43	.62	.87	.72	.88	.69	.80	1.84	.56	.87	.61	.40	.37	.67	.61	.64	.44	.72	.55	.50	.63	.56
OCTOBER	.33	.83	.20	.83	.60	.92	.28	.61	.93	.72	1.27	.70	.91	2.70	.47	.47	.73	.50	.88	1.14	.48	1.41	.39	.85	1.27	.42	1.40	1.03
NOVEMBER	.51	.85	1.27	2.07	1.29	1.77	.46	1.17	1.38	1.03	1.27	.75	1.11	1.95	.54	1.43	.74	.78	2.10	1.46	1.28	2.17	.61	1.20	1.63	1.72	1.82	1.72
DECEMBER	.36	.44	1.37	.62	1.21	.59	.51	.73	.90	1.17	.98	.70	.94	1.44	.90	.86	1.17	.67	2.06	.96	2.28	1.93	.61	1.31	.88	2.51	1.12	1.50
AVERAGE	1.65	1.12	1.27	1.84	2.17	1.97	1.46		1.74	1.83	1.71	1.36		2.06	1.84	1.29	1.43	1.11	1.27	1.58	1.76	1.83	1.42	1.48	1.43	1.76	1.60	1.60

progressively from minimum to maximum. The average monthly flow thus arranged for each watershed will give a much better criterion of the stream flow to be expected on each watershed during the year than the average monthly flow as shown in Table 31.

From Table 32 it will be seen that the average minimum monthly flow of the Hudson River at Mechanicsville, N. Y.,

TABLE 32

AVERAGE DISCHARGE IN CUBIC FEET PER SECOND PER SQUARE MILE OF DRAINAGE AREA. MONTHLY DISCHARGE OF EACH RIVER ARRANGED IN ORDER OF MINIMUM FLOW.

	HUDSON RIVER AT MECHANICSVILLE, N.Y. DRAINAGE AREA 4500 SQ. MILES															SHENANDOAH R. MILLVILLE, W.VA. 2995 SQ. M				POTOMAC R. POINT OF ROCK, MD 9654 SQ. M.			DELAWARE R. LAMBERTVILLE, N.J. 6855 SQ. M.
YEAR	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	AV.	'97	'98	'99	AV.	'85	'99	AV	'99
MINIMUM	.34	.44	.43	.33	.63	.56	.42	.57	54	.56	.57	.31	42	.54	48	.22	.28	.27	.26	26	19	22	.57
	.38	.83	.45	.45	93	.71	.55	.58	.62	.61	.86	.46	.47	.69	61	23	.33	.31	39	27	25	.26	77
	.63	84	72	.52	.99	81	.70	.58	.64	.87	1.14	.54	.52	.79	.74	.26	33	.34	.31	.45	.25	.35	93
	.82	.95	1.64	.59	1.22	.86	.81	79	.91	.89	1.17	.58	.60	83	.90	.30	.40	.36	.35	.92	.27	.60	99
	1.02	1.28	1 74	71	1.69	1.02	.97	.86	1.02	1.83	1.25	.58	.91	.89	1.13	.40	.51	.47	.46	.95	.34	.65	1 19
	1.08	1.52	1.97	.91	2.06	1 07	1.07	.87	1.04	2.22	1.50	1.02	1.11	94	1.31	.42	.53	.51	.48	1.16	.44	.80	1.33
	1.41	1.77	2.03	1 23	2.06	1.11	1.42	.93	1.05	2.47	1.72	1.17	1.13	1.03	1.47	.46	.85	.55	62	1.49	.57	1.03	1 50
	1.52	1.84	2.09	1.84	2.41	1.53	1.50	1.52	1.51	2.63	1.75	1.42	1.30	1.73	1.75	.47	1.05	.85	79	1.65	1.19	1.42	1.86
	2.22	1.97	2.47	1.91	2.80	1.60	1.58	1.54	1.54	2.70	2.05	1.49	1.72	1.80	1.96	.79	1.38	1.10	1.09	1.73	1.25	1.49	3 13
	2.36	2.44	2.50	2.59	4.19	1.97	1.68	1.87	2.52	2.71	2.46	2.14	2.00	1.88	2.38	1.53	1.42	1.23	1.39	1.96	1.97	1.97	3.67
	4.73	2.93	3.35	3.94	4.37	3.98	2.47	2.42	3.02	3.20	3.05	2.17	2.77	2.60	3.21	1.86	1.66	1.66	1.73	2.41	3.01	2.71	5 08
MAXIMUM	4.76	3.04	3.98	4.45	4.79	4.95	3.28	5.29	5.55	4.24	4.49	5.25	5.02	628	4.67	3.37	2.73	2.29	2.80	2.46	3.75	3.20	5.78

	GENESEE RIVER, N.Y 1070 SQ. M. DR. A					OSWEGO, R. AT OSWEGO, N.Y. 5000 SQ. MILES						BLACK R N.Y. 1889 SQ. MILES						LAKE CHAMPLAIN 7750 SQ. M.				MOHAWK R. N.Y LITTLE FALLS 1308 SQ. M.					HUDSON R FT. EDWARDS 2800 SQ. M			
YEAR	'94	'95	'96	'97	AV	'98	'99	'00	'01	'02	AV	'97	'98	'99	'00	'01	AV	'99	'00	'01	AV.	'99	'00	'01	'02	AV	'99	'00	'01	AV.
MINIMUM	14	.10	.16		.15	.18	.11	13	.37		20		.60	.47	.54	.86	.62	.58	.85	.78	74	.17	.48	.86	.	.50	.26	.40	.55	.40
	.22	.17	.17	.	.19	.27	.12	.13	.37		22		.78	.52	.60	1.13	.76	.67	.92	.82	.80	.23	.53	.86	.	.54	.37	.44	.65	.49
	.44	.11	.20		25	.36	.12	.17	.39		26		.79	.54	.64	1.28	.81	.89	1.04	.98	.97	.39	.61	.69		63	.41	.45	.76	.54
	61	.12	24	.	.32	.40	.15	.19	.43		29		.87	.64	.70	1.45	.91	1.15	1.20	1.28	1.21	.61	.69	.90	.	73	.48	.59	.78	.62
	.82	.13	.39		.45	.78	.22	.48	.38		.52		1 18	.81	.86	1.50	1.09	1.25	1.41	1.32	1.33	.78	.72	1.13	.	.88	.58	1.01	.88	.82
	.86	.19	.47	.	.51	.89	.32	.61	75		64		1.44	.87	1.50	1.63	1.41	1.25	1.54	1.33	1.37	1.15	1.58	1.25	.	1.32	.68	1.13	.90	.90
	.95	.22	.82		.66	.98	.40	.62	1.07		77		1.66	1.23	1.57	2.28	1.69	1.37	1.72	1.35	1.48	1.30	1.89	1.33	.	1.51	1.26	1.15	.96	1.12
	1.10	.47	.91	.	.83	1.24	.49	.93	1.36		1.01	.	1.68	1.85	2.24	2.65	2.11	1.47	1.87	1.53	1.62	2.03	2.48	2.20	.	2.24	1.79	1.18	1.06	1.34
	1.40	.66		.	1.03	1.51	.85	.99	1.45	.	1.20		2.01	2.49	2.65	.	2.38	1.63	2.06	1.70	1.80	2.11	2.95	2.52	.	2.53	1.82	1.40	1.23	1.48
	3.31	1.32	1.74	.	2.12	1.63	.97	1.53	1.63		1.92		2.06	2.67	3.02	2.81	2.65	1.79	2.32	2.70	2.27	2.57	2.96	3.02	.	2.85	1.84	2.27	2.23	2.11
	3.39	1.94	3.00	.	2.78	1.66	1.35	1.80	2.00	.	1.70	.	2.46	2.97	3.04	3.16	2.91	2.80	2.42	3.66	2.96	2.88	4.23	3.50	.	3.54	3.41	2.55	3.00	2.99
MAXIMUM	4.43	2.01	3.38		3.27	1.99	1.53	2.80	3.39		2.43	.	5.08	7.35	7.37	7.60	6.85	3.17	2.86	3.95	3.33	6.20	6.23	5.41	.	5.95	6.00	6.04	7.55	6.53

	KENNEBEC RIVER, WATERVILLE, ME 4410 SQ. MILES.								ANDROSCOGGIN R RUMFORD FALLS, 2220 SQ. M.					MERRIMAC RIVER LAWRENCE MASS 4553 SQ. M.											CONNECTICUT R. HOLYOKE, MASS 8660 SQ M			
YEAR	'93	'94	'95	'96	'97	'98	'99	AV.	'96	'97	'98	'99	AV.	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	AV.	'96	'97	'98	AV
MINIMUM	.56	.37	.28	.62	.60	.28	.59	.44	.77	.72	.77	.	.75	.69	.47	.47	.52	.37	.37	.44	.48	.58	.39	.48	.34	.42	.45	40
	.46	.40	.40	.64	.81	.43	.59	.53	.78	.72	.79		.76	.75	.54	.86	.57	.40	.48	.45	.61	.64	.44	.57	.42	.50	.57	50
	.51	.42	.41	.71	84	.46	.71	.58	.87	.76	.84	.	.82	1.44	.54	.87	61	.44	.37	.67	.75	.83	.46	.71	.55	.58	.63	.59
	.51	.62	.45	.77	.86	.51	.73	.64	.90	.81	.88		.86	1.53	.56	.94	.65	.50	.37	.77	1.01	1.41	.54	.85	.62	.67	1.00	.76
	.53	.67	.46	.83	1.04	.53	.77	.69	.90	.82	.88	.	.87	1.70	.64	1.05	74	.50	.63	.96	1.12	1.42	.61	.94	.88	1.25	1.12	1.08
	.53	.85	.61	.98	1.21	.54	.89	.80	.93	1.03	.98	.	.98	1.73	.90	1.06	.79	.66	.67	.98	1.28	1.62	.61	1.15	1.05	1.67	1.19	1.30
	.60	.85	.80	1.21	1.29	.73	.92	.91	1.38	1.06	1.27	.	1.24	1.84	1.00	1 28	.97	.67	.88	1.14	2.22	1.71	.65	1.24	1.12	1.74	1.31	1.39
	.95	.91	1.27	1.25	1.65	.73	1.17	1.13	1.40	1.17	1.27	.	1.28	1.95	1.61	1.43	1.10	.78	1.28	1.44	2.28	1.93	1.07	1.49	1.26	2.51	1.40	1.72
	1.31	1.30	1.37	2.07	2.94	1.14	2.26	1.77	1.49	2.98	2.14	.	2.20	2.70	2.92	1.61	1.17	.94	1.37	1.46	2.32	2.17	1.73	1.84	1.27	2.58	1.82	1.89
	1.64	1.77	1.46	2.98	2.96	2.00	2.56	2.20	2.45	3.15	2.52	.	2.64	3.14	2.96	1.79	2.36	1.33	2.06	2.00	2.37	2.42	2.09	2.25	1.63	2.60	2.19	2.14
	3.47	2.17	2.17	3.87	5.75	4.81	5.70	3.99	3.39	3.56	4.19	.	3.71	3.44	4.72	1.87	3.42	2.43	2.10	4.00	2.79	3.34	2.62	3.08	3.14	2.71	3.38	3.08
MAXIMUM	6.92	3.53	5.43	6.21	6.10	5.31	6.76	5.72	5.61	5.23	4.21	.	5.02	3.79	3.19	2.25	4.28	3.16	4.35	4.62	3.87	4.09	5.81	4.14	4.89	4.10	4.09	4.36

is 0.48 cubic feet per second per square mile, the minimum for any year during the period of observations being 0.31, and the maximum 0.63.

On the Oswego River in the same state, with no very great difference in total annual rainfall, the average minimum monthly flow is 0.20, the minimum for any year being 0.11, and the maximum 0.37. These figures, it must be remembered, are averages for each month, and the actual minimum flow for the period is often a much less quantity. (See diagrams 19 to 25.)

89. **Depth of Rainfall and Run-Off.**—Kuichling has prepared several diagrams showing the relations between the depth of rainfall and run-off in certain eastern rivers for each month. These diagrams are reproduced in Diagram 28. On these diagrams the figures not enclosed are numbers of observations from drainage basins Nos. 1 to 8 inclusive, of the following list. The figures enclosed in circles are the numbers of observations from drainage basins Nos. 1 to 28 inclusive.

WATERSHEDS FROM WHICH OBSERVATIONS WERE PLATTED ON DIAGRAM 28.

No.	Name of Basin.	Area in Sq. Miles.	No. of Years Record.
1.	Croton River, N. Y.	338.0	30
2.	Perkiomen Creek, Pa.	152.0	13
3.	Neshaminy Creek, Pa.	139.3	13
4.	Tohickon Creek, Pa.	102.2	14
5.	Sudbury River, Mass.	75.2	25
6.	Hemlock Lake, N. Y.	43.1	12
7.	Mystic Lake, Mass.	27.7	18
8.	Cochituate Lake, Mass.	19.0	33
9.	Cayadutta Creek, N. Y.	40.0	2
10.	Saquoit Creek, N. Y.	51.5	2
11.	Oneida Creek, N. Y.	59.0	2
12.	Nine-Mile Creek, N. Y.	63.0	1
13.	Garoga Creek, N. Y.	80.8	1
14.	E. Branch Fish Creek, N. Y.	104.0	1

15.	Oriskany Creek, N. Y.	144.0	2
16.	Mohawk River, N. Y., at Ridge Mills	153.0	2
17.	W. Branch Fish Creek, N. Y.	187.0	3
18.	Salmon River, N. Y.	191.0	1
19.	East Canada Creek, N. Y.	256.0	2
20.	West Canada Creek, N. Y.	518.0	2
21.	Schroon River, N. Y.	563.0	4
22.	Passaic River, N. J.	822.0	17
23.	Raritan River, N. J.	879.0	3
24.	Genesee River, N. Y.	1070.0	7
25.	Mohawk River, N. Y., at Little Falls	1306.0	2
26.	Black River, N. Y.	1889.0	4
27.	Hudson River, N. Y., at Mechanicsville, N. Y.	4500.0	12
28.	Muskingum River, O.	5828.0	8

Diagram 29 shows the relation of monthly rainfall to run-off on the Rock River watershed in Illinois.* (See Rafter, The Relation of Rain Fall to Run-Off; also diagrams 30, 31 and 32.)

90. **The Water Year.**—The water year naturally divides itself into periods beginning, approximately, with December, and ending, approximately, with the following November. The period from December to and including May is usually termed the "storage" period; June, July and August constitute the "growing" period, and September, October and November the "replenishing" period. These periods vary somewhat each year, and are not necessarily limited by our artificial division of months. During the storage period the winter snows and the spring rains saturate the ground to a great depth, and a large amount of water is held in storage, both in lakes, swamps, and forests, and in the soils, gravels, and other pervious strata. That portion of the stored water within the boundaries of a watershed that lie above the level of the bed of the stream is, or may become, available to supply the stream. Portions of this stored water are used by growing vegetation, and portions are evaporated from the soil. The remaining portions will supply a stream to a certain extent, regardless of the amount

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* Water Power of the Rock River. Mead.

RELATIONS BETWEEN DEP

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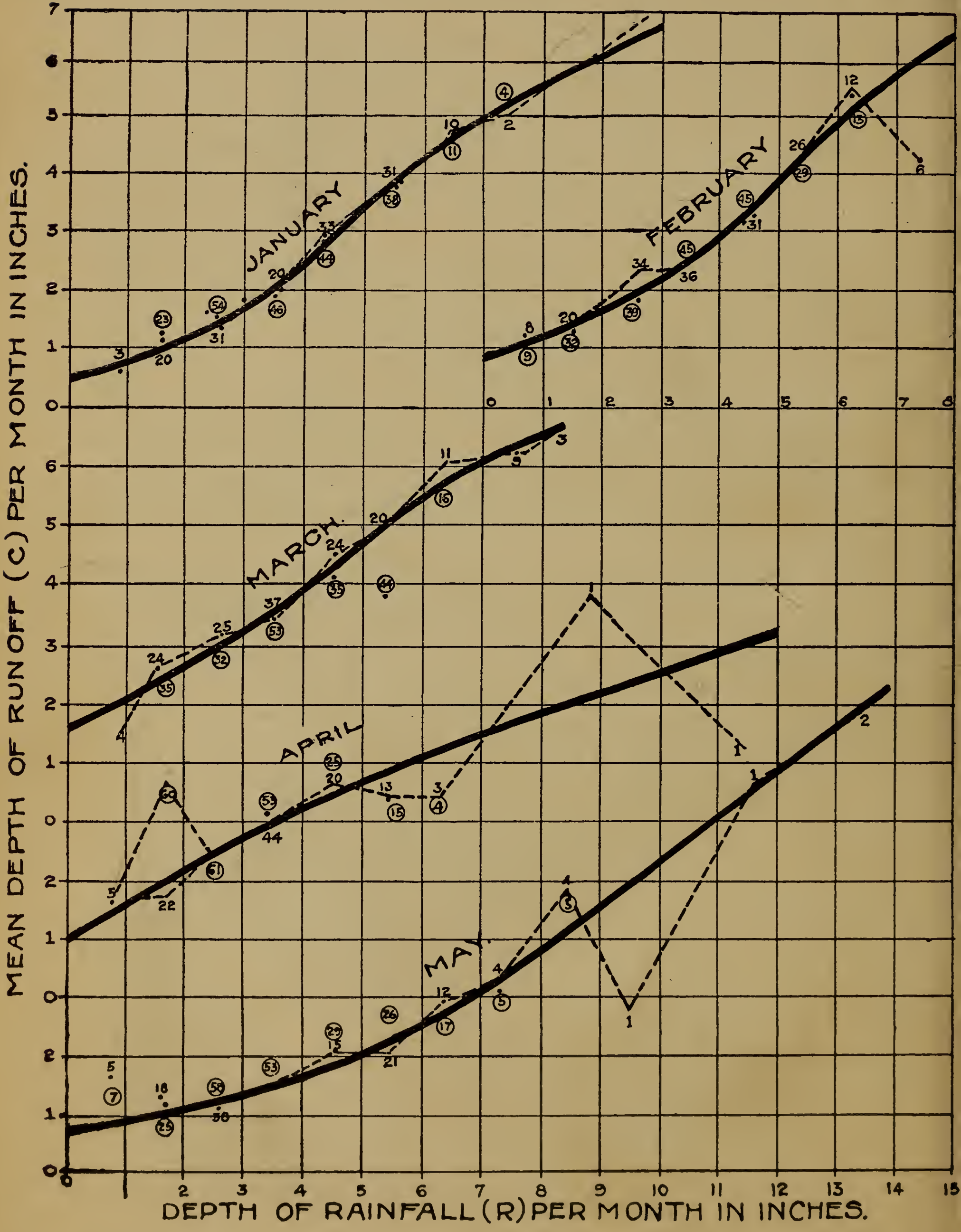

DIAGRAM 28

HS OF RAINFALL AND RUNOFF.

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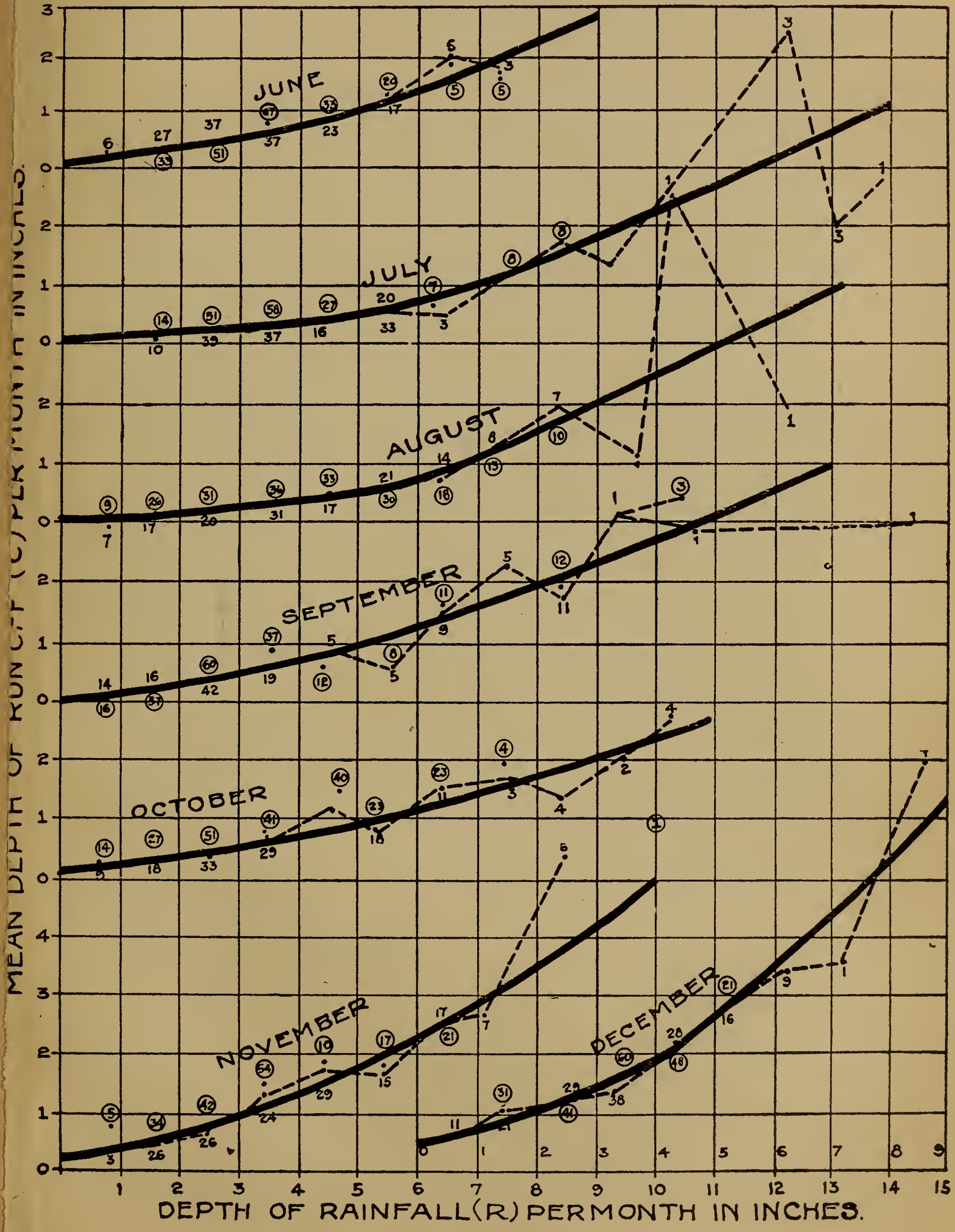
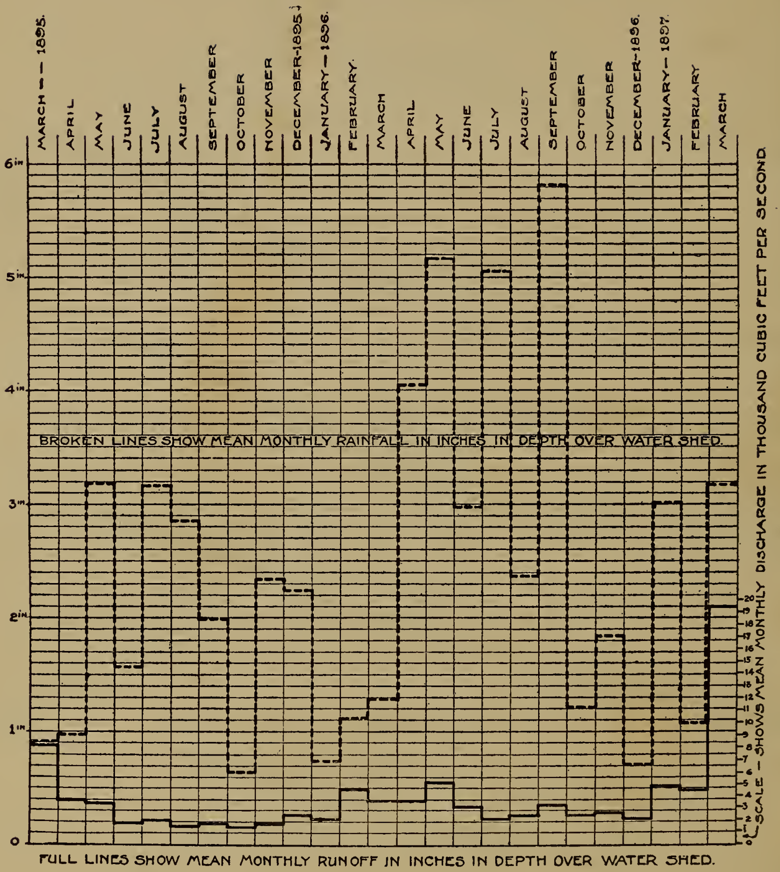


DIAGRAM 29



Showing Relation of Mean Monthly Stream Flow to Mean Monthly Rainfall on Rock River Watershed.

of monthly rainfall, and will produce a stream flow for several months even without rain.

The ground water is called upon to furnish more or less of the stream flow sometimes early in May, and seldom later than the beginning of June, and during June, July and August the rainfall is rarely sufficient to take care of the evaporation and plant growth without something of a draft on the ground water. The stream flow for this period is usually entirely dependent on the ground water, except during exceptional rain storms. By the end of the growing period the ground water is often so depleted as to be capable of storing five or six inches or more of rainfall.

During the replenishing period the ground again begins to receive its store of water, and with favorable rainfalls, becomes full during the storage period of the winter and spring.

The relation of Rainfall to Run-Off and Evaporation (which is, in this case, intended to include all other methods of disposal except run-off), for various periods of the water year, and for various eastern rivers, are illustrated in Tables 33, 34, 35 and 36. These relations are also graphically shown on Diagrams 30, 31 and 32.

These tables and diagrams have been reproduced from Rafter, The Relation of Rainfall to Run-Off, to which reference is given for further discussion.

91. **Stream Losses from Percolation.**—While the seepage or ground water ordinarily furnishes the dry weather flow of streams, yet in some cases the river water may again partially seep into their banks at other portions of their courses, if the condition of the ground water level so permits. This condition seldom exists, however, except in the flood stages of a stream where the rapid rise in the waters of the stream is greater than that of the ground water and reverses the ground water slope in the immediate vicinity of the river. (See Table 37.)

In some cases in the arid regions, the waters of streams entirely disappear, their waters, aside from those portions lost by evaporation, being entirely lost in the strata. Such streams usually originate in humid regions, or in the mountain snows, and steadily decrease in size as they flow, constantly losing their waters by evaporation and percolation until they terminate in a sink. Such waters either form a morass of sufficient extent so that the surface evaporation disposes of the remaining stream flow, or the waters continue as an underflow in the pervious strata.*

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* See Slichter, The Motions of Underground Waters, p. 38.

TABLE 33.

Connecticut River, 1872-1885, inclusive.

[Catchment area = 10,234 square miles.]

Period.	1872.			1873.[a]			1874.[a]		
	Rain-fall.	Run-off.	Evapo-ration.	Rain-fall.	Run-fall.	Evapo-ration.	Rain-fall.	Run-off.	Evapo-ration.
Storage	14.92	13.30	1.62	18.16	21.80	3.64	23.08	23.04	0.04
Growing	18.96	6.29	12.67	10.11	2.71	7.40	14.37	6.62	7.75
Replenishing	12.42	6.64	5.78	15.04	5.22	9.82	7.76	2.15	5.61
Year	46.30	26.23	20.07	43.31	29.73	13.58	45.21	31.81	13.40

Period	1875.			1876.[a]			1877.		
Storage	17.51	15.47	2.04	22.50	24.74	− 2.24	18.09	12.68	5.41
Growing	14.55	3.80	10.75	12.51	3.35	9.16	14.00	2.91	11.09
Replenishing	11.36	3.60	7.76	10.57	2.28	8.29	13.08	5.27	7.81
Year	43.42	22.87	20.55	45.58	30.37	15.21	45.17	20.86	24.31

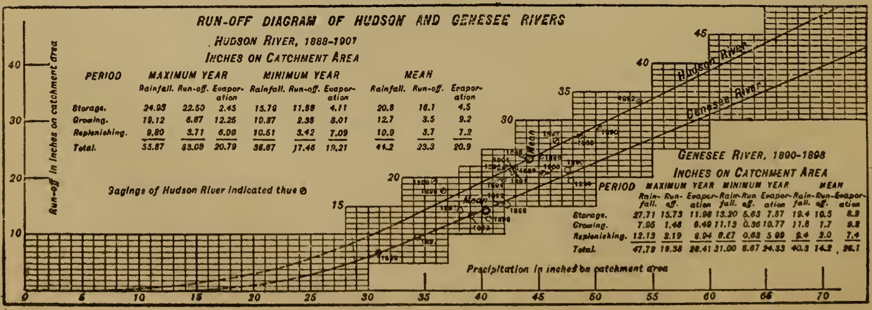
Period.	1878.			1879.			1880.		
Storage	21.88	18.02	3.86	23.19	21.49	1.70	18.29	14.78	3.51
Growing	13.59	3.45	10.14	16.07	2.92	13.15	11.82	2.45	9.37
Replenishing	10.56	3.06	7.50	9.48	2.93	6.55	11.58	2.62	8.96
Year	46.03	24.53	21.50	48.74	27.34	21.40	41.69	19.85	21.84

Period.	1881.			1882.			1883.		
Storage	20.83	16.02	4.81	[b]20.50	12.14	8.36	[b]12.85	8.73	4.12
Growing	11.30	2.93	8.37	[b]11.45	3.35	8.10	[b]13.50	2.51	10.99
Replenishing	11.38	3.39	7.99	[b]6.50	2.17	4.33	[b]6.20	1.37	4.83
Year	43.51	22.34	21.17	38.45	17.66	20.79	32.55	12.61	19.94

Period.	1884.			1885.		
Storage	21.42	20.20	1.22	18.58	13.63	4.95
Growing	12.14	2.79	9.35	14.82	3.20	11.62
Replenishing	8.51	2.61	5.90	11.76	5.61	6.15
Year	42.07	25.60	16.47	45.16	22.44	22.72

[a] Not included in mean. [b] Rainfall computed, approximate.

DIAGRAM 30.



HUDSON RIVER, 1888-1901

INCHES ON CATCHMENT AREA

PERIOD	MAXIMUM YEAR			MINIMUM YEAR			MEAN		
	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation
Storage.	24.95	22.50	2.45	15.79	11.68	4.11	20.8	16.1	4.5
Growing.	19.12	6.87	12.25	10.37	2.36	8.01	12.7	3.5	9.2
Replenishing.	9.80	3.71	6.09	10.51	3.42	7.09	10.9	3.7	7.2
Total.	53.87	33.08	20.79	36.67	17.46	19.21	44.2	23.3	20.9

GENESEE RIVER, 1890-1898

INCHES ON CATCHMENT AREA

PERIOD	MAXIMUM YEAR			MINIMUM YEAR			MEAN		
	Rain-fall.	Run-off.	Evaporation	Rain-fall.	Run off.	Evaporation	Rain-fall.	Run-off.	Evaporation
Storage.	27.71	15.73	11.98	13.20	5.63	7.57	19.4	10.5	8.9
Growing.	7.95	1.46	6.49	11.13	0.36	10.77	11.8	1.7	9.8
Replenishing.	12.13	2.19	9.94	6.67	0.68	5.99	9.4	2.0	7.4
Total.	47.79	19.38	28.41	31.00	6.67	24.33	40.3	14.2	26.1

—Run-off diagram of Hudson and Genesee rivers.

TABLE 34.

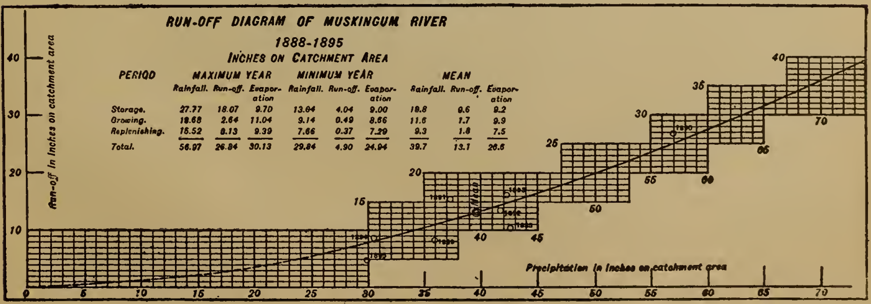
—Hudson River, 1888–1901, inclusive.

[Catchment area=4,500 square miles.]

Period.	1888.			1889.			1890.		
	Rain-fall.	Run-off.	Evapo-ration.	Rain-fall.	Run-off.	Evapo-ration.	Rain-fall.	Run-off.	Evapo-ration.
Storage	20.40	17.06	3.34	17.10	14.04	3.06	24.75	19.28	5.47
Growing	10.25	2.05	8.20	15.05	4.26	10.79	13.50	2.85	10.65
Replenishing	13.27	4.53	8.74	10.81	3.41	7.40	12.10	6.81	5.29
Year	43.92	a 23.64	20.28	a 42.96	21.71	21.25	a 50.35	28.94	21.41
	1891.			1892.			1893.		
Storage	20.69	16.59	4.10	24.95	22.50	2.45	19.83	15.20	4.63
Growing	13.49	2.07	11.42	19.12	6.87	12.25	13.37	3.12	10.25
Replenishing	8.78	1.90	6.88	9.80	3.71	6.09	8.98	3.59	5.39
Year	42.96	20.56	22.40	53.87	33.08	20.79	42.18	21.91	20.27
	1894.			1895.			1896.		
Storage	21.37	13.18	8.19	15.79	11.68	4.11	22.17	16.52	5.65
Growing	8.73	3.20	5.53	10.37	2.36	8.01	10.25	2.53	7.72
Replenishing	11.87	2.99	8.88	10.51	3.42	7.09	12.79	4.58	8.21
Year	41.97	19.37	22.60	36.67	17.46	19.21	45.21	23.62	21.58
	1897			1898.			1899.		
Storage	19.77	14.60	5.17	22.80	18.61	4.19	19.48	15.15	4.33
Growing	15.80	7.79	8.01	13.52	3.24	10.28	7.40	1.63	5.77
Replenishing	10.94	3.80	7.14	12.19	5.27	6.92	8.91	2.76	6.15
Year	46.51	26.19	20.32	48.51	27.12	21.39	35.79	19.54	16.25
				1900.			1901.		
Storage				21.13	16.12	5.01	18.47	14.84	3.63
Growing				12.11	2.30	9.81	15.09	4.02	11.07
Replenishing				12.17	2.25	9.92	9.02	3	6.02
Year				45.41	20.67	24.74	42.58	21.86	20.72

a Approximate.

DIAGRAM 31.



RUN-OFF DIAGRAM OF MUSKINGUM RIVER

1888-1895

INCHES ON CATCHMENT AREA

PERIOD	MAXIMUM YEAR			MINIMUM YEAR			MEAN		
	Rainfall.	Run-off.	Evapor-ation	Rainfall.	Run-off.	Evapor-ation	Rainfall.	Run-off.	Evapor-ation
Storage.	27.77	18.07	9.70	13.04	4.04	9.00	18.8	9.6	9.2
Growing.	18.68	2.64	11.04	9.14	0.49	8.66	11.6	1.7	9.9
Replenishing.	10.52	6.13	9.39	7.66	0.37	7.29	9.3	1.8	7.5
Total.	56.97	26.84	30.13	29.84	4.90	24.94	39.7	13.1	26.6

-Run-off diagram of Muskingum River.

TABLE 35.

Genesee River, 1890–1898, inclusive.

[Catchment area = 1,070 square miles.]

Period.	1890.			1891.			1892.		
	Rain-fall.	Run-off.	Evapo-ration.	Rain-fall.	Run-off.	Evapo-ration.	Rain-fall.	Run-off.	Evapo-ration.
Storage	[a]23.01	[b]12.96	[b]10.05	18.22	11.88	6.34	19.84	9.38	10.46
Growing	[a]10.52	2.51	8.01	12.78	1.06	11.72	15.30	4.90	10.40
Replenishing	[a]14.01	5.75	8.26	7.12	1.11	6.01	6.55	1.14	5.41
Year	[a]47.54	[b]21.22	[a]26.32	38.12	14.05	24.07	41.69	15.42	26.27
	1893.			1894.			1895.		
Storage	20.65	[b]11.10	[b]9.55	27.71	15.73	11.98	13.20	5.63	7.57
Growing	9.55	[b]1.00	[b]8.55	7.95	1.46	6.49	11.13	.36	10.77
Replenishing	9.10	1.25	7.85	12.13	2.19	9.94	6.67	.68	5.99
Year	39.30	[b]13.35	[b]25.95	47.79	19.38	28.41	31.00	6.67	24.33
	1896.			1897.			1898.		
Storage	17.84	9.25	8.59	15.68	7.31	8.37	18.66	10.40	8.26
Growing	10.28	.83	9.45	11.92	1.34	10.58	14.15	2.05	12.10
Replenishing	12.56	2.72	9.84	6.79	.73	6.06	9.69	2.68	7.01
Year	40.68	12.80	27.88	34.39	9.38	25.01	42.50	15.13	27.37

[a] For years 1890-1892 the run-off is that of Oatka Creek, a tributary of Genesee River, and the rainfall of Oatka Creek catchment area has been taken rather than that of entire upper Genesee area.

[b] Approximate.

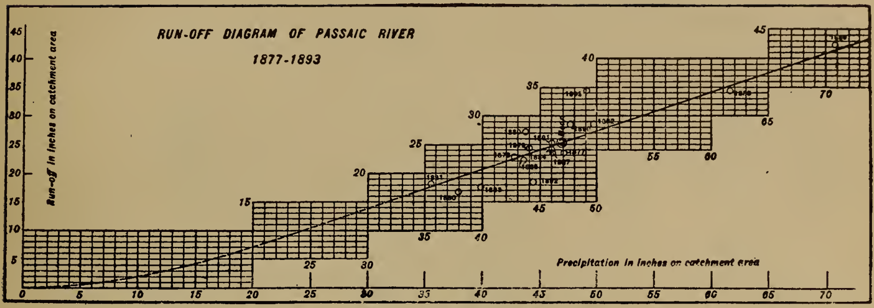
TABLE 36.

Muskingum River, 1888–1895, inclusive.

[Catchment area=5,828 square miles.]

Period.	1888.			1889.			1890.		
	Rain-fall.	Run-off.	Evapo-ration.	Rain-fall.	Run-off.	Evapo-ration.	Rain-fall.	Run-off.	Evapo-ration.
Storage	17.16	5.17	11.99	13.52	6.02	7.50	27.77	18.07	9.70
Growing	14.31	1.77	12.54	12.12	1.24	10.88	13.68	2.64	11.04
Replenishing	11.14	3.39	7.75	10.24	.96	9.28	15.52	6.13	9.39
Year	42.61	10.33	32.28	35.88	8.22	27.66	56.97	26.84	30.13
	1891.			1892.			1893.		
Storage	16.72	12.42	4.30	20.39	9.06	11.33	25.04	14.13	10.91
Growing	13.56	1.77	11.79	16.54	3.65	12.89	8.31	1.22	7.09
Replenishing	7.08	1.37	5.71	4.81	.67	4.14	9.01	.85	8.16
Year	37.36	15.56	21.80	41.74	13.38	28.36	42.36	16.20	26.16
				1894.			1895.		
Storage				16.93	7.63	9.30	13.04	4.04	9.00
Growing				4.56	.66	3.90	9.14	.49	8.65
Replenishing				9.02	.41	8.61	7.66	.37	7.29
Year				30.51	8.70	21.81	29.84	4.90	24.94

DIAGRAM 32



-Run-off diagram of Passaic River.

92. Seepage from Artificial Channels.—In artificial channels the loss from seepage or percolation is often considerable, a large portion of the supply being sometimes needed to maintain the flow. Seepage losses in such cases are so closely related to losses by evaporation that it is seldom possible to distinguish the exact relation between the two.

On the proposed enlargement of the Erie Canal, the loss from seepage, evaporation, etc., has been calculated at from 4.5 to 5.5 inches on the total area of the canal each day.*

In some measured sections of American canals this loss has reached as high as 17 inches or more. The majority of French and German canals of the better class are so constructed that the loss is not more than 2 inches per day.

In many irrigation ditches in the west, where the embankments are carried above the general ground level, and are made of pervious material, the loss from this source becomes an important and often very serious matter, as the loss in many cases fully equals the amount of water actually utilized in irrigation.

93. Basis of Estimates of Stream Flow.—No exact law for determining the relation of rainfall and stream flow has been, or, from the nature of the case, ever can be found, for such relations are, of necessity, peculiar to the watershed, and subject both to the local conditions of the watershed and to the variation in annual climatic conditions.

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* Report on Water Supply for the New York Barge Canal, by E. Kuichling.

TABLE 37.

Table of Measurements of Seepage Water in the South Platte River, Col., October 23d to November 5th, 1891.

From Sixth Biennial Report, State Engineer of Colorado.—In Feet per Second.

Names of Streams and Ditches where measurements were taken.	Amount of water in river.	Amount of water diverted from river by irrigation ditches and canals. From last station.	Amount of inflow from natural tributaries.	Amount of water in river at points measured, plus that diverted by canals and minus the inflow from natural tributaries.	Amount of increase in volume of river between points measured.	Decrease in volume of river between points measured.	Miles between points measured.	Amount of increase per mile between points measured.	Remarks.
South Platte River	204.35								Above dam of High Line Canal.
" "	46.16	185.76		231.92	27.57		6	4.93	Below City Ditch.
Plum Creek			2.98						
South Platte River	84.86	16.89		284.53	53.61		6	8.93	At Littleton.
Bear Creek			7.26						
Cherry Creek			5.59						
South Platte River	90.05	23.86		300.73	16.20		10	1.62	At foot Sixteenth Street, Denver.
Clear Creek			1.04						
South Platte River	79.58	53.98		343.20	42.47		11	3.86	Below Fulton Ditch.
" "	73.96	41.96		379.54	36.34		7	5.19	Below Brighton Ditch.
" "	90.28	27.18		423.04	43.50		9	4.83	Below Evans No. 2 Ditch.
" "	11.09	87.43		431.23	8.14		7	1.16	Below Farm's Ind. Ditch.
" "	17.48			437.67	6.39		5	1.29	Above St. Vrain Creek.
St. Vrain Creek			28.94						
Big Thompson Creek			12.85						
South Platte River	87.68	37.48		503.56	65.89		11.5	5.73	Below Latham Ditch.
" "	114.60			530.48	26.92		6	4.49	Above Cache la Poudre River.
Cache la Poudre River			61.11						
South Platte River	244.33			607.01	76.53		9	8.50	Below Harding Ditch.
" "	211.69	49.25		623.21	16.20		11	1.47	Below Putnam Ditch.
" "	106.69	120.28		638.40	15.29		14	1.09	Below Ft. Morgan Canal.
" "	134.81	10.14		676.76	38.36		9	4.37	Below Platte and Beaver Ditch.
" "	186.79	46.21		774.95	98.19		14.5	6.77	Above Smith Ditch at Snyder.
" "	46.68	119.84		754.68		20.27	17.5	Loss 1.16	Above Merino.
" "	66.73	13.31		788.04	33.36		13	2.59	At Sterling.
" "	52.72	42.08		816.11	28.07		9	3.12	At Iliff.
" "	39.65			803.04		13.07	15	Loss 0.87	Two miles above Crook.
" "	47.70			811.09	8.05		20	0.42	Below Sedgwick.
" "	42.96			806.35		4.74	16	Loss 0.29	At Julesburg. Average increase per mile = 3.24.

A study of the distribution of the monthly rainfall, the probable evaporation and deep seepage, together with a detailed consideration of the physical conditions of the watershed, and limited observations of the actual flow, if considered in the light of the large amount of stream flow data which is now being yearly recorded, will give an intelligent basis on which such flows and their probable variations can be fairly estimated.

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1894. Sixteenth Annual Report, Part II, Bulletin No. 131.
1895. Seventeenth Annual Report, Part II, Bulletin No. 140.
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CHAPTER X.

GROUND WATER.

94. **General Principles.**—That portion of the rainfall, on any watershed, which sinks into the ground, fills the pervious stratum until a gradient is established sufficient to maintain a flow, and then slowly moves towards the stream. The gradient established usually rises quite rapidly from the surface of the stream, into which the water flows, toward the divide. The slope depends principally on the quantity of the ground water and the relative porosity of the stratum through which it moves.

When the stream flows through pervious material the ground water plain enters the river coincident with the river surface. When the stream has cut its channel into impervious material, the ground water appears as springs along its banks, at the junction of the impervious stratum with the overlying pervious deposit.

95. **Occurrence of Ground Water.**—Water occurs in all geological strata and probably to a depth of about six miles below the surface. It is found in quantities sufficient for practical purposes only in the upper portion of these deposits, and under conditions which may be classified as follows:

First. In the granites, traps, igneous, metamorphic rocks, and other impervious strata only in cracks and fissures.

Second. Occasionally in channels and waterways of limestone rock, which channels have been created by the action of the drainage waters themselves.

Third. In the pervious deposits of the glacial drift. These deposits consist of clays, sands and gravels, which cover the country to a depth of from a few inches to, in some cases, several hundred feet, over the areas formerly occupied by the ice of the glacial invasion. (See Area marked "Ice Work," Map 12.)

Fourth. In the pervious mantle rocks which cover to a greater or less extent all of the indurated deposits outside of the Glaciated Area.

Fifth. In the lacustrian and fluvial deposits of ancient and modern lakes and rivers, which deposits are often laid down in stratified form, but are generally less in extent than the earlier sedimentary formations.

Sixth. In the pervious beds of the sedimentary deposits which frequently occur under extensive areas. (See Turneaure & Russell, Water Supply, Chapter 7; Slichter, The Motion of Underground Waters. W. S. & I. Paper No. 67, Chapter 2.)

96. **Laws of Flow.**—The flows of ground water are due to gravity. With the exception of those waters which occur in cavernous limestone, or in coarse gravel, the flow is very slow, and seldom amounts to more than a few feet each day. (Turneaure & Russell, Water Supply, Chapter 7; Slichter, The Motion of Underground Waters, Chapter 1; Rafter, The Relation of Rainfall to Run-Off, p. 43.)

97. **Artesian Waters.**—Most of the stratified deposits are at least slightly tilted and when composed of pervious deposits lying between impervious strata, may give rise to important artesian conditions. Artesian areas of great importance are found at numerous places in the United States. The principal areas are shown on Map No. 17. Of these areas the upper Mississippi Valley, which is one of the most important, has been described in some detail in Chapter 5. The Dakota basin is also of much importance.* In this area the water bearing stratum is the Dakota sandstone belonging to the cretaceous period. The outcrop occurs on the slope of the Black Hills and the Rocky Mountains, at an elevation of 3,000 ft. or more above sea level, and the resulting wells are noted for their high pressure.

The wells of the Red River Valley derive their supply from the lacustrian deposits of the extinct Glacial Lake Agassiz. This basin is of smaller extent than the preceding, but is of considerable local importance.**

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* Report U. S. G. S., 1895-96, VII. Artesian Waters of the Dakotas. N. H. Darton.

** Monograph XXV, U. S. G. S. Glacial Lake Agassiz. Warren Upham.

The Atlantic Coastal system occupies essentially the Atlantic and Gulf Coastal Plains. The water in this area is obtained from cretaceous deposits, which are spread like a mantle on the eastern and southern slopes of the Alleghenies, and give rise to the artesian conditions which are developed to a considerable extent along the Atlantic Coast, through New Jersey, Delaware and Virginia, the Carolinas, Georgia, Alabama, and Western Tennessee.* Such wells are the source of the water supplies of many communities in this belt, among which may be mentioned Asbury Park, N. J., Charleston, S. C., Savannah, Ga., and Memphis, Tenn.

The same Cretaceous deposits afford the artesian conditions through Texas. In the north-eastern portion of this state a large number of artesian wells are developed in the Trinity and Puluxy sands. Wells are also obtained in the southern portions of the state in the more recent deposits immediately along the coast.§ There is also a small artesian basin of some local importance along the Pecos River in western Texas.

Numerous minor artesian basins exist in the valleys of the Rocky Mountains. Among these are the Denver basin and the artesian basin in San Luis Park.†

A number of basins where favorable artesian conditions are found have been reported by Mr. W. C. Knight, of the Wyoming Experimental Station.** Some favorable developments have been made at Boise, Idaho, and favorable artesian conditions also exist in other portions of south-western Idaho and in south-eastern Oregon.***

Numerous artesian areas have also been developed in California, among which may be mentioned those in the vicinity of San Jose, at the southern end of San Francisco Bay;

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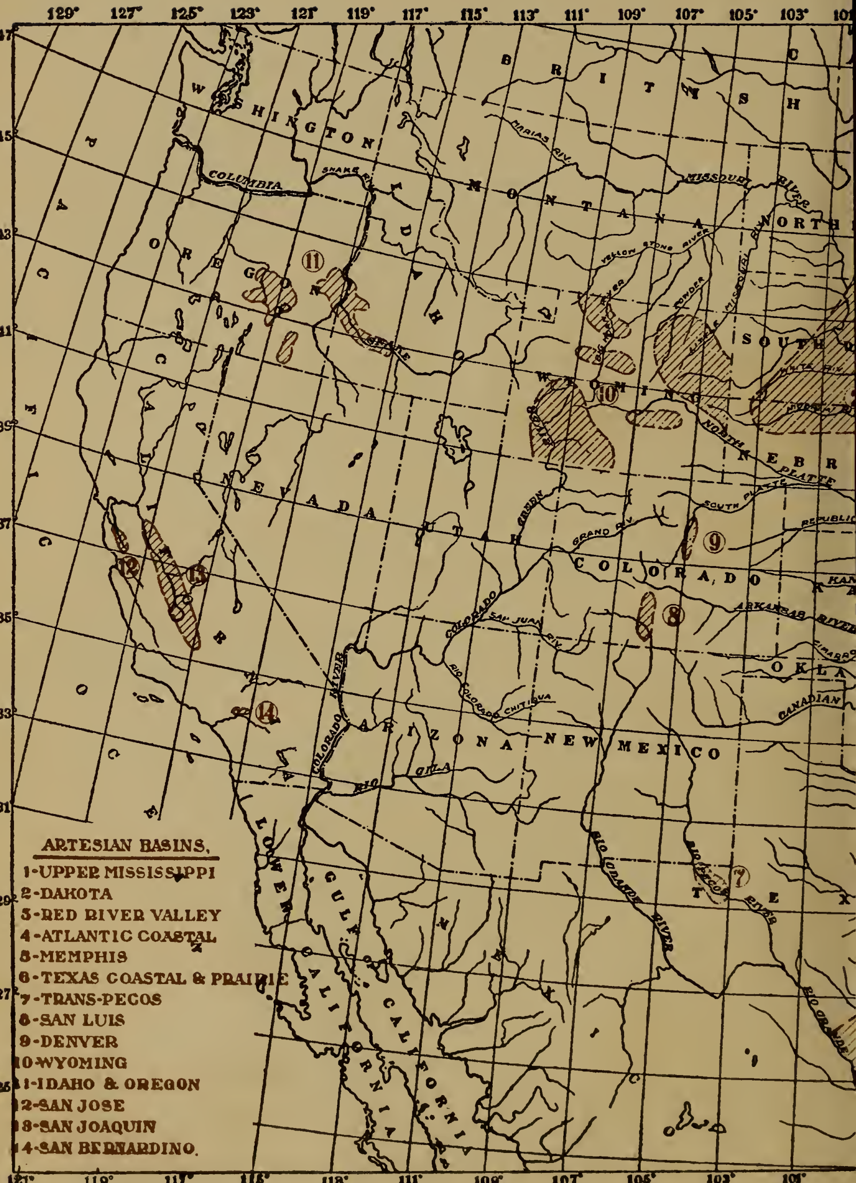
* Bul. 138, U. S. G. S. Artesian Well Prospects in the Atlantic Coastal Plain Region. N. H. Darton.

§ Annual Report U. S. G. S., 1899-1900, Pt. VII. Geology of the Black and Grand Prairies of Texas. R. T. Hill.

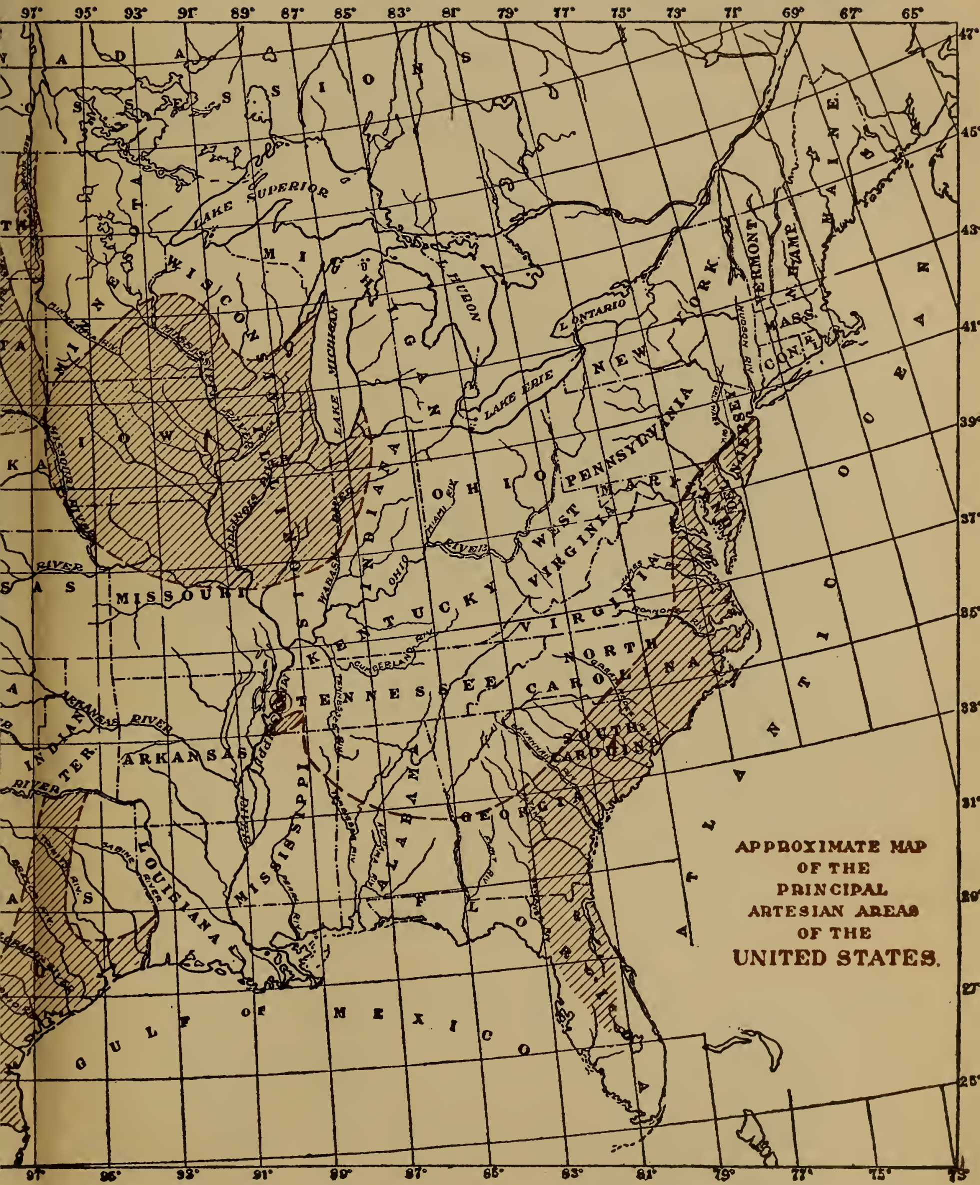
† Bul. 16, Agric. College of Colorado. Artesian Wells of Colorado. L. G. Carpenter.

** Bul. 45, Wyoming Experimental Sta. Artesian Basins of Wyoming. W. C. Knight.

*** Bul. 217, U. S. G. S. Notes on the Geology of S. W. Idaho and S. E. Oregon. I. C. Russell.


ARTESIAN BASINS.
1-UPPER MISSISSIPPI
2-DAKOTA
3-RED RIVER VALLEY
4-ATLANTIC COASTAL
5-MEMPHIS
6-TEXAS COASTAL & PRAIRIE
7-TRANS-PECOS
8-SAN LUIS
9-DENVER
10-WYOMING
11-IDAHO & OREGON
12-SAN JOSE
13-SAN JOAQUIN
14-SAN BERNARDINO.
129° 127° 125° 123° 121° 119° 117° 115° 113° 111° 109° 107° 105° 103°
47° 45° 43° 41° 39° 37° 35° 33° 31° 29° 27° 25°
121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101°
BRITISH
WASHINGTON
MONTANA
IDAHO
OREGON
WYOMING
NEVADA
UTAH
COLORADO
CALIFORNIA
ARIZONA
NEW MEXICO
TEXAS
NEBR
SOUTH
NORTH
OKLA
MEXICO
PACIFIC OCEAN
LOWER CALIFORNIA
GULF OF CALIFORNIA
COLUMBIA
SNAKE RIV.
MARIAS RIV.
MISSOURI RIVER
YELLOW STONE RIVER
POWDER
LITTLE MISSOURI
GREEN
GRAND RIV.
NORTH PLATTE
SOUTH PLATTE
REPUBLICAN
ARKANSAS RIVER
CIMARRON
CANADIAN
COLORADO
SAN JUAN RIV.
RIO COLORADO CHIQUITO
COLORADO RIVER
RIO GILA
RIO GRANDE RIVER
RIO PECOS RIVER
RIO GRANDE
7 8 9 10 11 12 13 14

Map No. 17



APPROXIMATE MAP OF THE PRINCIPAL ARTESIAN AREAS OF THE UNITED STATES.

also extensive developments in the San Joaquin valley,[1] and in Southern California, at San Bernardino and Pasadena.[2]

There are also numerous other localities where artesian conditions of local importance have been developed in the glacial drift and in other geological deposits. Some of the areas shown on the map are not greatly developed, but are considered of sufficient importance for at least passing mention. (Turneaure & Russell, Water Supply, Sections 95-103; Slichter, The Motion of Underground Water, Chapter 3.)

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[1] Eng. Record, February 17th, 1894. Artesian Wells in the San Joaquin Valley.

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No. 7. Seepage Waters of Northern Utah, by Samuel Fortier. 1897.

No. 12. Underground Waters of Southeastern Nebraska, by N. H. Darton. 1898.

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CHAPTER XI.

HYDROGRAPHY OF SURFACE WATERS.

98. **Growth of Rivers.**—The drainage waters which ultimately become the stream flow, are the active geological agents which have been and are largely instrumental in the disintegration of the strata, and are still more largely instrumental in the transportation of the disintegrated material and its deposition at other points.

Geological and topographical conditions modify the possible extension of a drainage system, but within the limits established by these conditions, the drainage waters are the direct agent in the formation and modification of their own drainage area.

The laws of river development and growth are important and must be known and appreciated in all engineering questions involving the improvement of rivers and the protection of areas subject to river overflow. (Tarr, Physical Geography, Chapters XV. and XVI.)

The principal drainage areas of the United States are shown on Map No. 18.

99. **Growth of Lakes.**—Lakes are of various origins, and are classified by Powell, according to such origin, into Diastrophic, Coulee, Crater, Bayou, and Glacial Lakes.* Examples of each of these types are found within the U. S.

The Great Lakes are Diastrophic in origin, although glacial action had much to do with the present form. These lakes are of great importance in commerce and transportation, and their drainage waters are also utilized to a considerable extent for power purposes.

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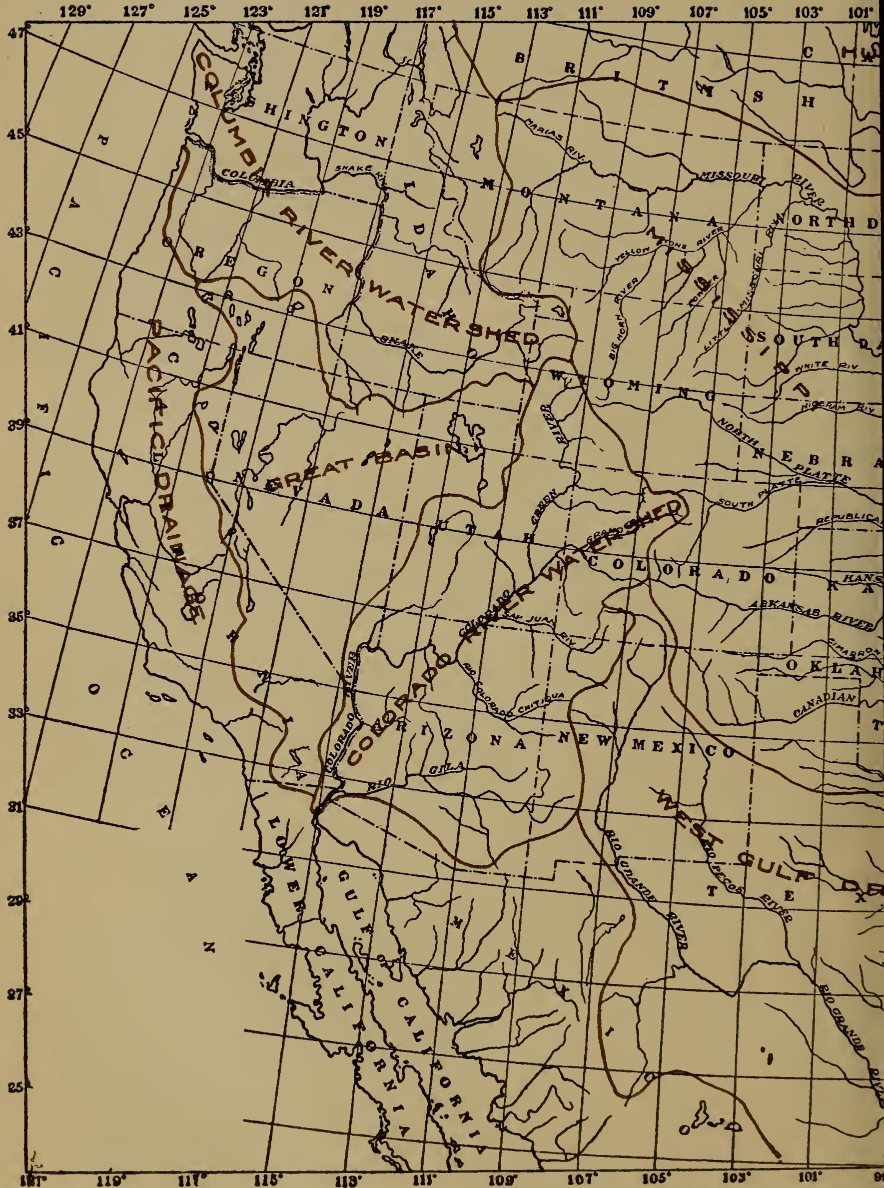
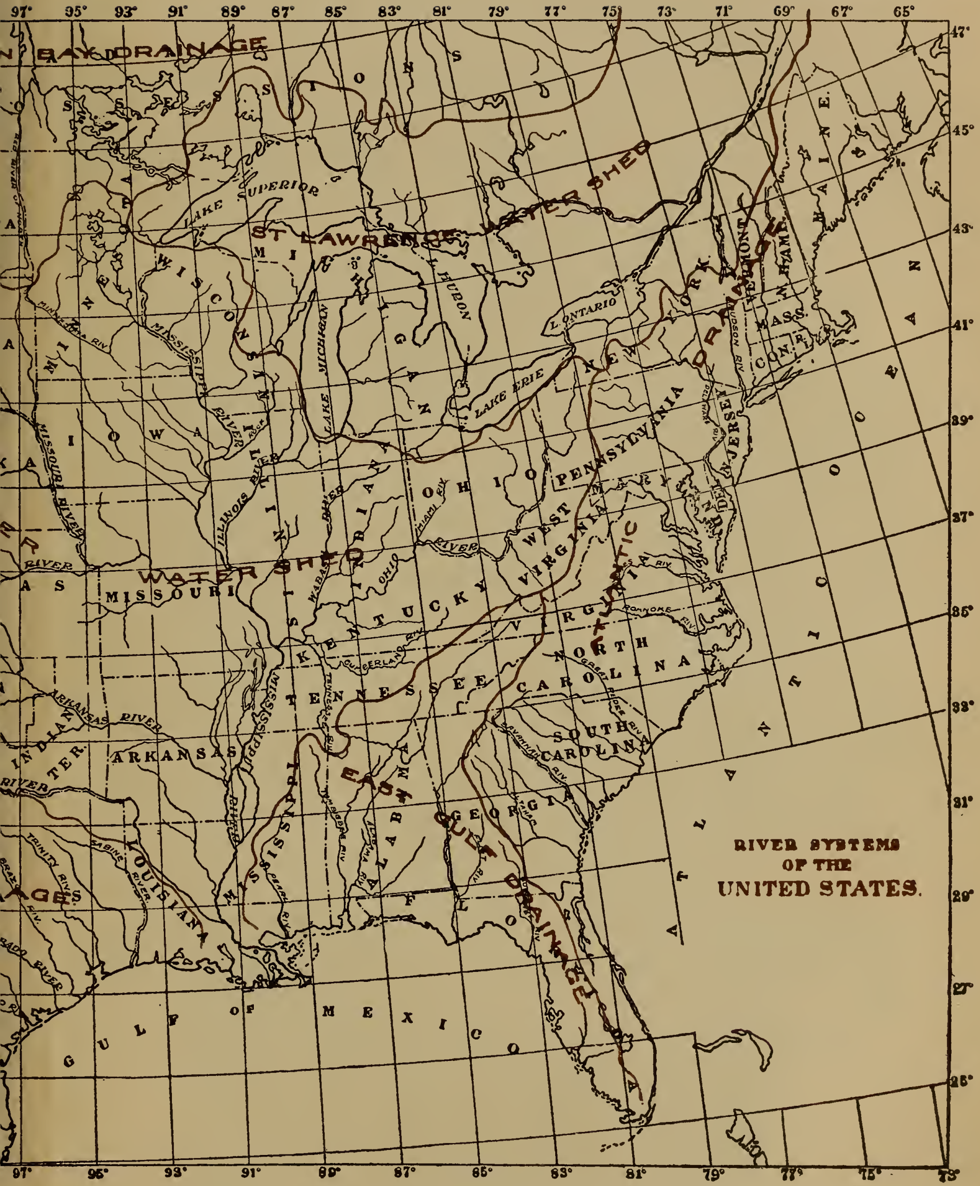
* Powell, Physiographic Features.



129° 127° 125° 123° 121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101°
47° 45° 43° 41° 39° 37° 35° 33° 31° 29° 27° 25°
121° 119° 117° 115° 113° 111° 109° 107° 105° 103° 101°
BRITISH
WASHINGTON
COLUMBIA RIVER WATERSHED
COLUMBIA
SNAKE RIV.
MARIAS RIV.
MONTANA
MISSOURI RIVER
NORTH D
IDAHO
OREGON
SNAKE
YELLOW STONE RIVER
BIG HORN RIVER
LITTLE MISSOURI RIV.
SOUTH DA
WHITE RIV.
NIOBRARA RIV.
WYOMING
GREEN RIVER
NORTH PLATTE
NEBRA
SOUTH PLATTE
REPUBLICAN
PACIFIC DRAINAGE
CALIFORNIA
GREAT BASIN
NEVADA
UTAH
GREEN
GRAND
COLORADO RIVER WATERSHED
COLORADO
KANS
ARKANSAS RIVER
CIMARRON
OKLAH
CANADIAN
SAN JUAN RIV.
COLORADO
RIO COLORADO CHIQUITA
ARIZONA
NEW MEXICO
GILA
RIO
COLORADO RIVER
WEST GULF DRA
RIO GRANDE RIVER
RIO PECOS RIVER
TEX
LOWER CALIFORNIA
GULF OF CALIFORNIA
MEXICO
RIO GRANDE RIVER
PACIFIC OCEAN

Map No. 18


RIVER SYSTEMS OF THE UNITED STATES.
BAY DRAINAGE
ST LAWRENCE WATER SHED
WATER SHED
ATLANTIC DRAINAGE
EAST GULF DRAINAGE
LAKE SUPERIOR
LAKE MICHIGAN
L. HURON
L. ONTARIO
LAKE ERIE
MINNESOTA
WISCONSIN
MICHIGAN
IOWA
ILLINOIS
INDIANA
OHIO
MISSOURI
KENTUCKY
TENNESSEE
ARKANSAS
INDIAN TER.
LOUISIANA
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
PENNSYLVANIA
NEW YORK
NEW JERSEY
DEL.
MARYLAND
VERMONT
N. HAMP.
MAINE
MASS.
CON.
R.I.
MISSISSIPPI RIVER
MISSOURI RIVER
ILLINOIS RIVER
OHIO RIVER
ARKANSAS RIVER
RED RIVER
HUDSON RIV
ROANOKE RIV
CUMBERLAND RIV
PEE DEE RIV
SAVANNAH RIV
GULF OF MEXICO
ATLANTIC OCEAN
97° 95° 93° 91° 89° 87° 85° 83° 81° 79° 77° 75° 73° 71° 69° 67° 65°
47° 45° 43° 41° 39° 37° 35° 33° 31° 29° 27° 25°
97° 95° 93° 91° 89° 87° 85° 83° 81° 79° 77° 75° 73°

The U. S. Government annually expends large sums in the maintenance and improvement of navigation on these lakes, and extended observations are made to determine their hydrological factors. Many of these observations are of much interest, as they afford perhaps the largest available measure of change in hydrological conditions.

100. **Hydrography of the Great Lakes.**—The surfaces of these lakes are subject to seasonal and annual fluctuations. Seasonal fluctuations are caused largely by the variation of the rainfall and run off from month to month, by the effects of temperature and by the variation in barometric pressure.

The annual variations and the variations between different years are largely due to the variations in annual rainfall on the watersheds, although its distribution through the seasons, and the factors which also control stream flow, likewise modify these results.

The mean annual variation in the surface elevation of the Great Lakes is shown on Diagram 33. The variation in the annual means is shown in Diagram 34, and the variation in lake levels from 1860 to 1902 is shown on Diagram 35.

In connection with these diagrams, diagram 26, showing the flows of the rivers connecting and draining the Great Lakes should be examined. Table 38 gives the principal physical data of these lakes.

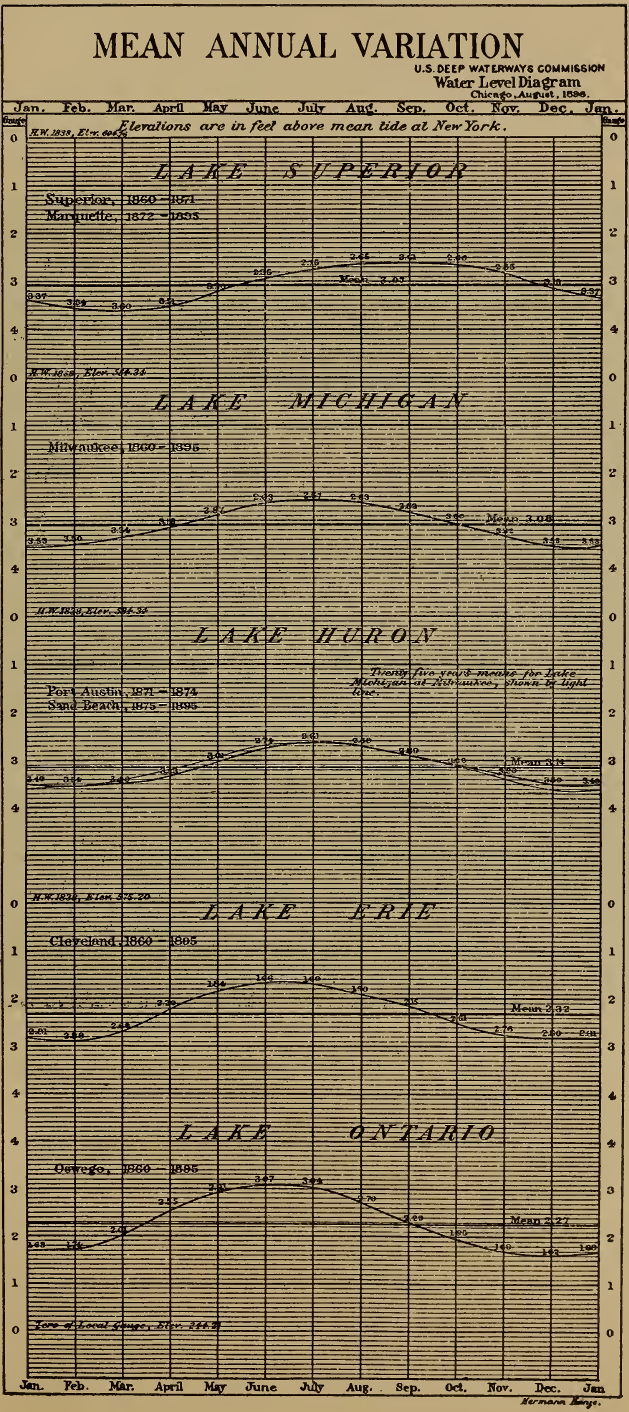
101. **The Ocean.**—The ocean is of the greatest interest to the engineer as a highway of commerce. Its influences are encountered by the engineer in the improvement of harbors, the construction of navigable channels, and the improvement of tidal rivers. Its currents have an important influence on the temperature and humidity of the lands near which they flow.

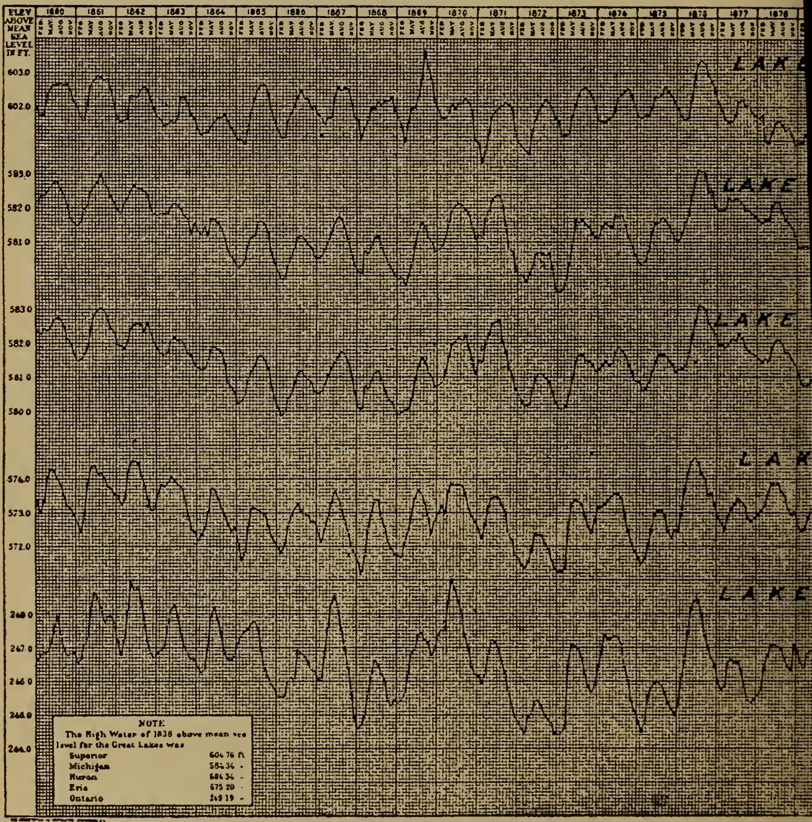
The important features of the ocean are:

First, Its Currents,
Second, Its Tides,
Third, Its Waves,
Fourth, Its Temperatures,
Fifth, Its Form and Depth.

(Tarr, Physical Geography, Chapters 9, 10 and 11.)

DIAGRAM 33.


MEAN ANNUAL VARIATION
U.S. DEEP WATERWAYS COMMISSION
Water Level Diagram
Chicago, August, 1896.
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sep.
Oct.
Nov.
Dec.
Jan.
Gauge
Elevations are in feet above mean tide at New York.
LAKE SUPERIOR
Superior, 1860 – 1871
Marquette, 1872 – 1895
3.37
3.60
2.56
3.66
2.96
2.65
3.37
Mean 3.07
LAKE MICHIGAN
Milwaukee, 1860 – 1895
3.53
3.50
3.34
2.63
2.63
Mean 3.08
3.53
LAKE HURON
Port Austin, 1871 – 1874
Sand Beach, 1875 – 1895
Twenty five years means for Lake Michigan at Milwaukee, shown by light line.
3.40
3.40
2.80
Mean 3.14
3.40
LAKE ERIE
Cleveland, 1860 – 1895
2.81
3.20
2.76
2.80
2.81
Mean 2.32
LAKE ONTARIO
Oswego, 1860 – 1895
3.07
2.55
2.70
1.95
Mean 2.27
Zero of Local Gauge, Elev. 244.21
0
1
2
3
4
Hermann Kenze.



NOTE
The High Water of 1838 above mean sea level for the Great Lakes was

Superior	604.76 ft.
Michigan	584.34 "
Huron	584.34 "
Erie	575.20 "
Ontario	249.19 "

DIAGRAM 35.

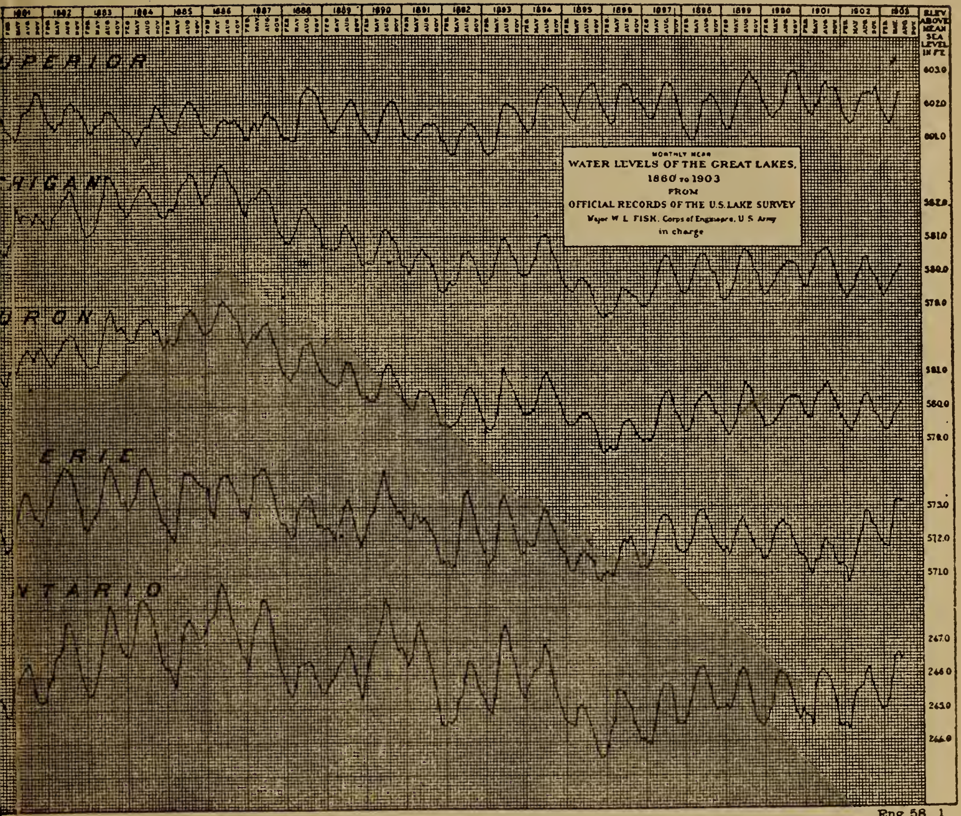


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DIAGRAM 34.

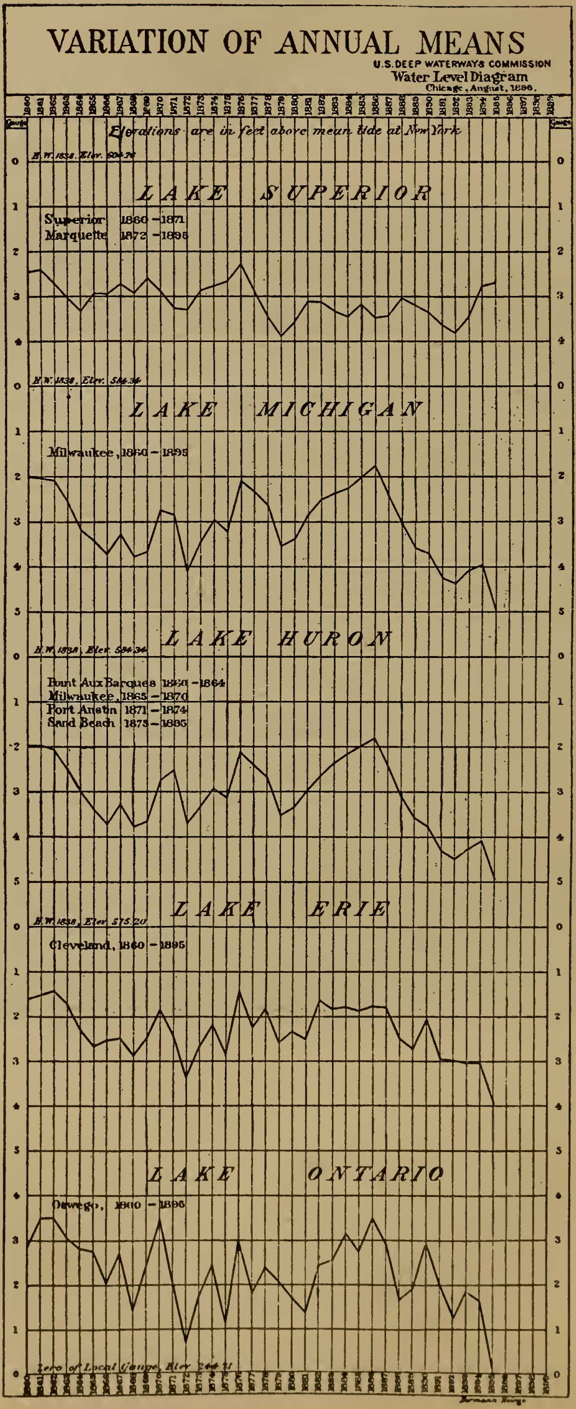
VARIATION OF ANNUAL MEANS
U.S. DEEP WATERWAYS COMMISSION
Water Level Diagram
Chicago, August, 1896.
1860 1861 1862 1863 1864 1865 1866 1867 1868 1869 1870 1871 1872 1873 1874 1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899
Gauge
Elevations are in feet above mean tide at New York
H.W. 1838. Elev. 604.76
LAKE SUPERIOR
Superior 1860 – 1871
Marquette 1872 – 1895
H.W. 1838. Elev. 584.34
LAKE MICHIGAN
Milwaukee, 1860 – 1895
LAKE HURON
H.W. 1838. Elev. 584.34
Point Aux Barques 1860 – 1864
Milwaukee, 1865 – 1870
Port Austin 1871 – 1874
Sand Beach 1875 – 1895
LAKE ERIE
H.W. 1838. Elev. 575.20
Cleveland, 1860 – 1895
LAKE ONTARIO
Oswego, 1860 – 1896
Zero of Local Gauge, Elev. 244.31
0 1 2 3 4
0 1 2 3 4 5
0 1 2 3 4 5
0 1 2 3 4 5
4 3 2 1 0
Hermann Berge

TABLE 38.

PHYSICAL DATA OF THE GREAT LAKES.*

Superior Basin.

Area of drainage basin	square miles	76,100
Area of Lake Superior	do	32,100
Discharge St. Mary's River (mean 1882-1898)	s-f	69,954
Discharge St. Mary's River (mean 1860-1903)	s-f	77,345
Annual Rainfall (mean 1882-1898)	s-f	147,164
Annual Rainfall (mean 1882-1898)	inches	26.27
Annual Evaporation (mean 1882-1898)	do	13.75
Temperature (mean 1882-1898)		35.95°F.
Wind, velocity per hour (mean 1882-1898)	miles	9.7
Humidity, percentage of saturation (mean 1882-1898)	per cent.	76.5

Huron and Michigan Basins.

Area of drainage basin	square miles	137,800
Area of Lakes Huron and Michigan	do	45,500
Discharge St. Clair River (mean 1882-1898)	s-f	191,980
Discharge St. Clair River (mean 1860-1902)	s-f	197,820
Annual Rainfall (mean 1882-1898)	s-f	325,857
Annual Rainfall (mean 1882-1898)	inches	32.12
Annual Evaporation (mean 1882-1898)	do	20.56
Temperature (mean 1882-1898)		42.08°F.
Wind, velocity per hour (mean 1882-1898)	miles	10.3
Humidity, percentage of saturation (mean 1882-1898)	per cent.	76.5

St. Clair and Erie Basins.

Area of drainage basin	square miles	40,800
Area of Lakes St. Clair and Erie	do	10,600
Discharge Niagara River (mean 1882-1898)	s-f	207,468
Discharge Niagara River (mean 1860-1902)	s-f	219,843
Annual Rainfall (mean 1882-1898)	s-f	102,308
Annual Rainfall (mean 1882-1898)	inches	34.08
Annual Evaporation (mean 1882-1898)	do	26.10
Temperature (mean 1882-1898)		48.01°F.
Wind, velocity per hour (mean 1882-1898)	miles	10.4
Humidity, percentage of saturation (mean 1882-1898)	per cent.	73.6

Ontario Basin.

Area of drainage basin	square miles	33,000
Area of Lake Ontario	do	7,400
Discharge of St. Lawrence River (mean 1882-1898)	s-f	248,518
Discharge of St. Lawrence River (mean 1860-1902)	s-f	251,930
Annual Rainfall (mean 1882-1898)	s-f	89,557
Annual Rainfall (mean 1882-1898)	inches	36.87
Annual Evaporation (mean 1882-1898)	do	23.82
Temperature (mean 1882-1898)		44.10°F.
Wind, velocity per hour	miles	10.6
Humidity, percentage of saturation (mean 1882-1898)	per cent.	74.9

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* Annual Report Chief of Engineers U. S. A., 1903. Appendix F. F. F., p. 2861.

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CHAPTER XII.

HYDROMETRY.

102. Of Flowing Water.—The measurement of flowing water is by no means a simple operation, especially in channels of varying sections. In channels of uniform section there is a regular increase in velocity from the sides to the center of the stream, and from the bottom of the channel to the surface, which in each case is fairly uniform and constant.

In natural river channels, where the cross-section is different at each station, and where the banks and bottom of the stream differ in form and direction from point to point, the river flow, which in general varies in the same manner as the current in uniform channels, is also affected by cross and counter-currents and other irregularities in the flow, which are caused by the inequalities in the banks and bed of the stream.

103. Vertical Velocity Curves.—Diagrams 36 and 37, which are reproduced from the report of the State Engineer of New York, show various mean vertical velocity curves. These diagrams show comparisons between the mean vertical velocities of streams with different classes of beds, and also comparative velocity curves for open and ice covered sections.*

For some time, the Corps of Engineers, U. S. A., have been engaged on hydrographic surveys of the rivers connecting and draining the Great Lakes, and some of the graphical records of their observations are of great interest and value in showing the actual variations encountered in stream measurements, which must be known and appreciated in order that the engineer may understand the limitations of hydrometry,

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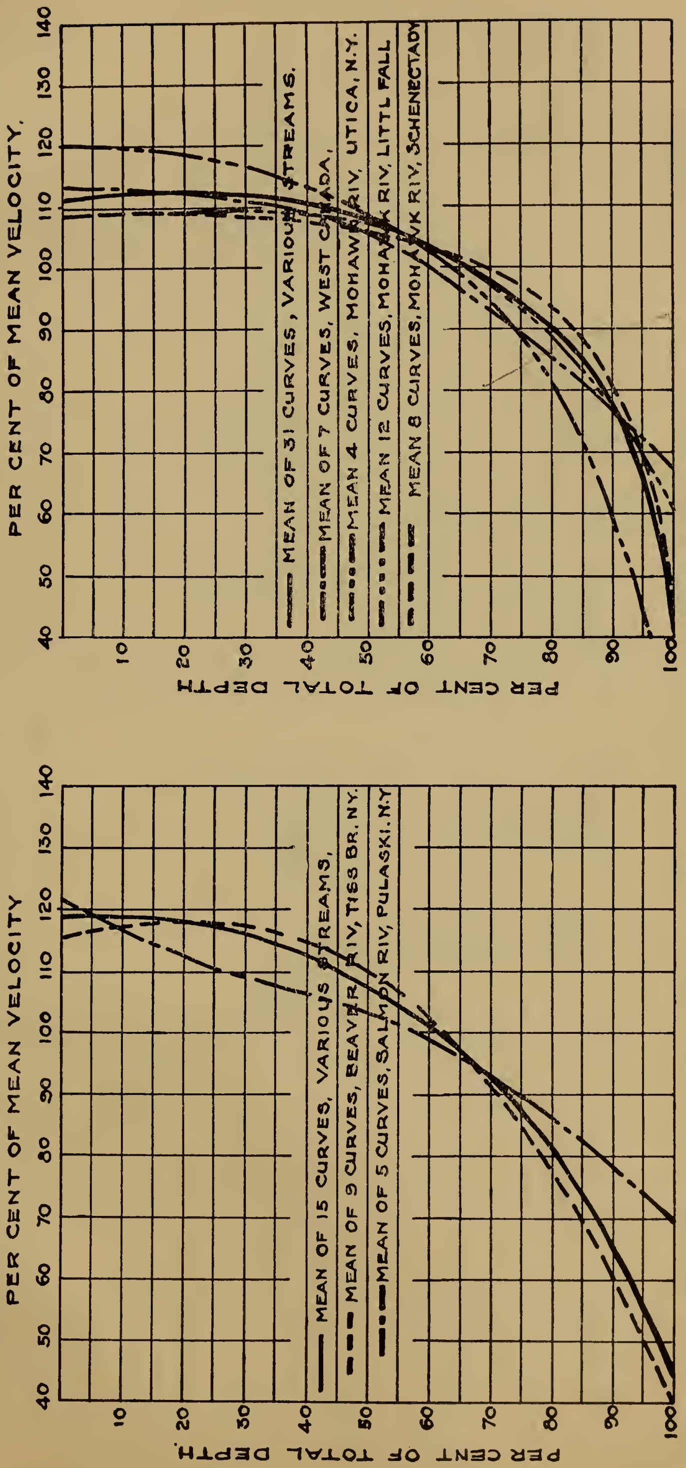
* Report State Engineer, N. Y. Supplement, 1902.

DIAGRAM 36.

COMPARISON OF MEAN VERTICAL VELOCITY CURVES.

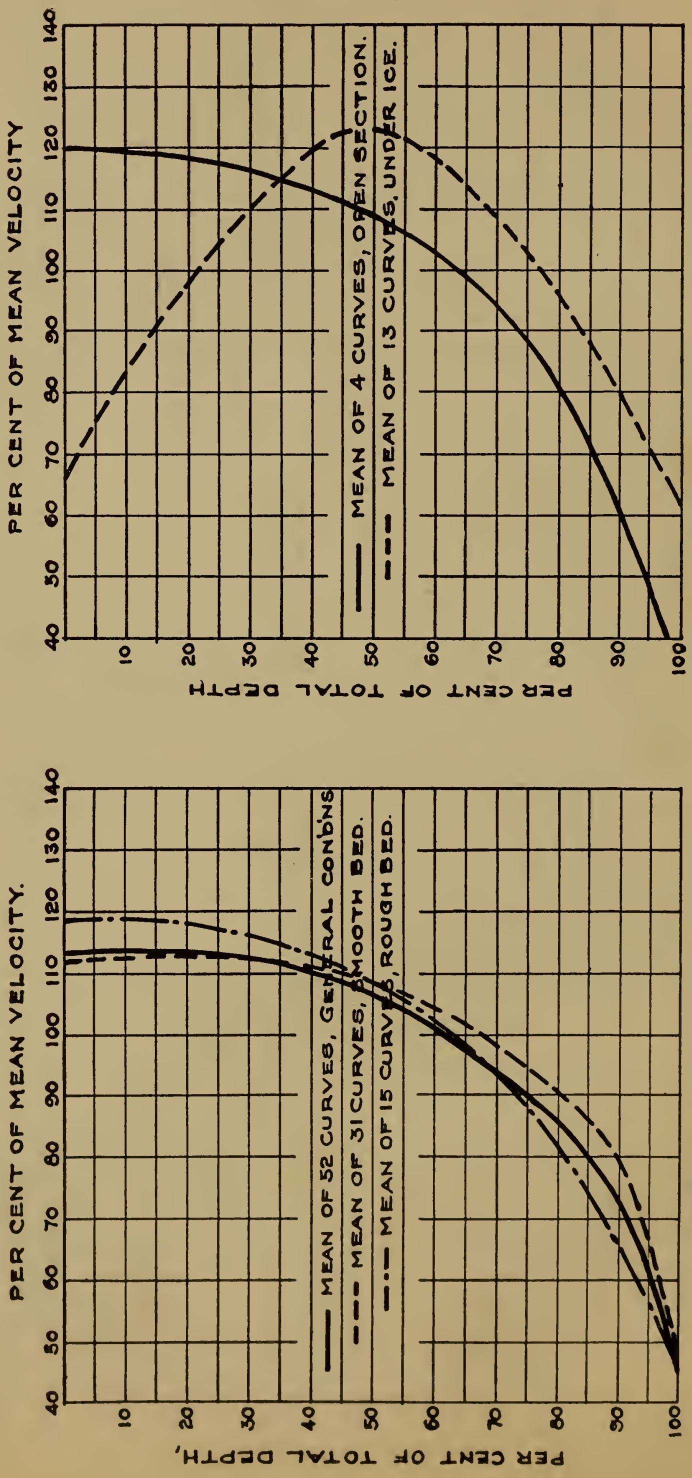


STREAMS WITH DEEP, SMOOTH CURRENTS AND EARTH BEDS.

STREAMS WITH ROUGH CURRENTS AND STONY OR ROCK BEDS

DIAGRAM 37.

COMPARISON OF MEAN VERTICAL VELOCITY CURVES



MOHAWK RIVER, UTICA, N.Y. FOR OPEN AND ICE COVERED SECTIONS

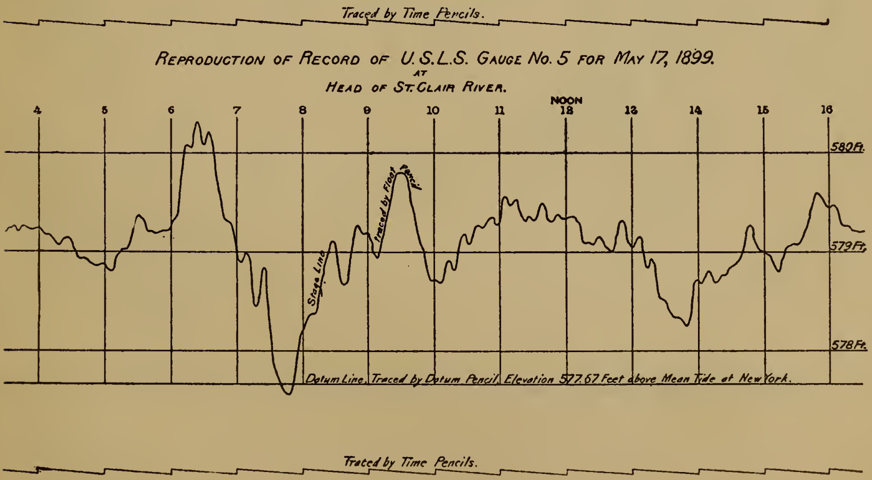
VARIOUS STREAMS WITH SMOOTH AND ROUGH BEDS.

and the errors which are liable to arise in hydrometric operations.

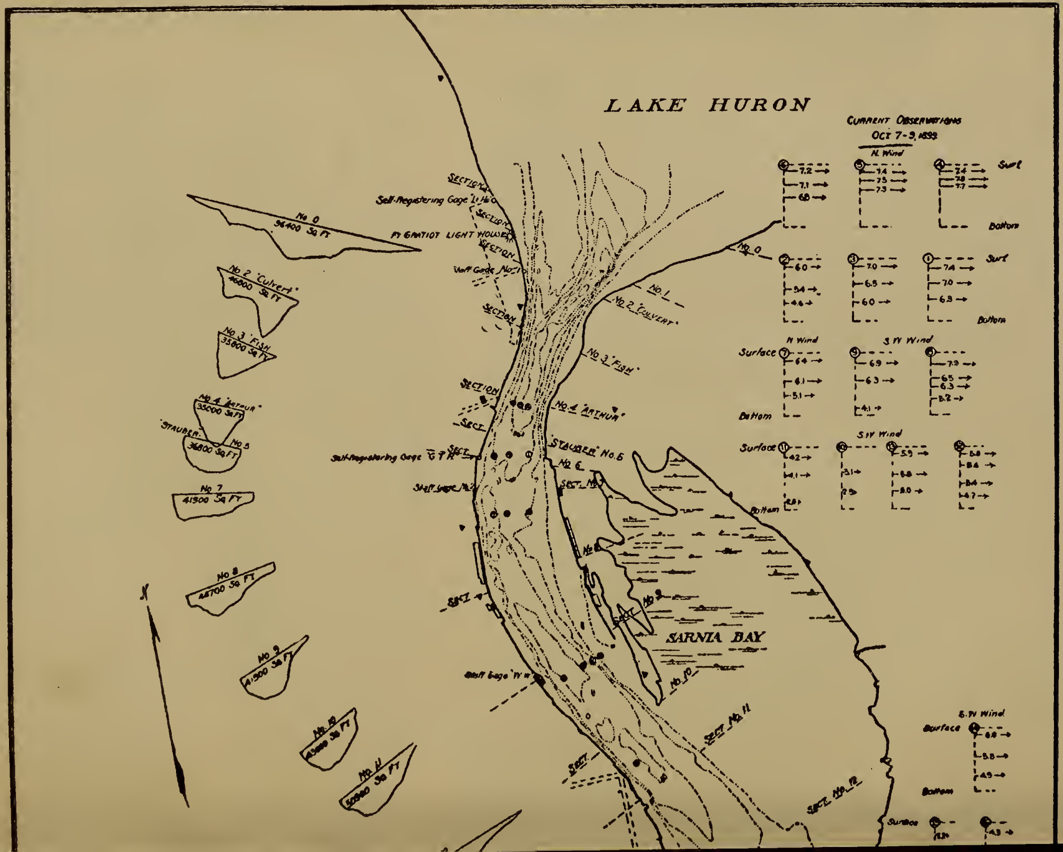
Several diagrams and maps have been reproduced from the report of the Engineers of the Northern and North-western lake survey. Those selected illustrate the hydrographic conditions at the head of the St. Clair River.

104. **Vertical Surface Fluctuation.**—Diagram 38 is a reproduction of the graphical record of the U. S. L. S., Gauge No. 5, for May 17th, 1899. This gauge is located at the head of the St. Clair River, and the diagram shows both the nature of the graphical record which can be obtained from such a gauge, and also the fact, not ordinarily fully appreciated, that the surface of the moving water in a river channel has a constant vertical motion, not only from hour to hour, but literally from minute to minute. With the facts shown by this diagram fully in mind, it will be readily understood that a single set of observations of river flow is of little or no value as a basis for drawing conclusions as to maximum or minimum discharge, or for establishing, in any sense, the regime of the stream.

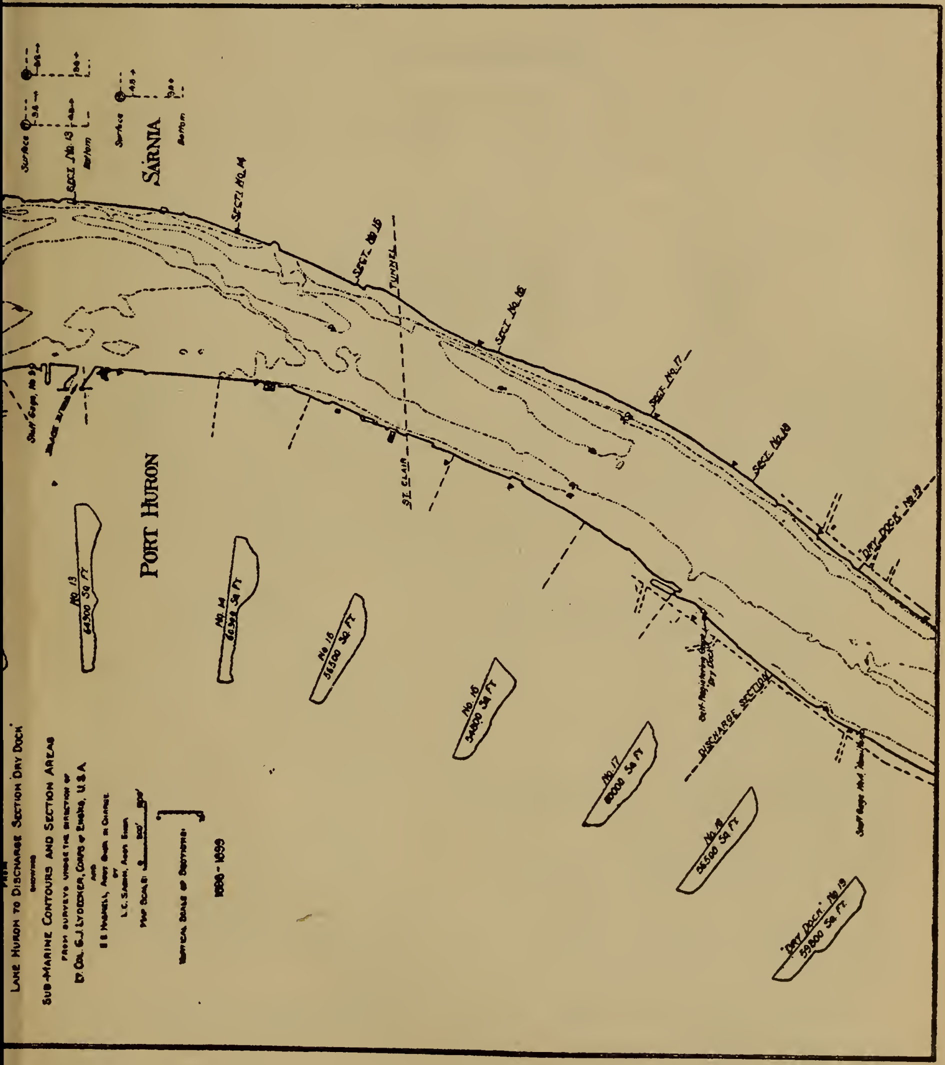
DIAGRAM 38.



105. **Physical Data of the St. Clair River.**—Map No. 19 is a hydrographic map of the St. Clair River, and shows the


LAKE HURON
CURRENT OBSERVATIONS
OCT 7-9, 1899
N. Wind
Surf
Bottom
7.2
7.1
6.8
7.4
7.5
7.3
7.4
7.8
7.7
6.0
5.4
4.6
7.0
6.5
6.0
7.4
7.0
6.3
N Wind
S W Wind
Surface
Bottom
6.4
6.1
5.1
6.9
6.3
4.1
7.9
6.5
6.3
5.2
S W Wind
4.2
4.1
3.1
5.9
5.0
5.8
8.4
8.4
4.7
S.W Wind
6.8
5.8
4.9
4.3
No 0
No 1
No 2 "Culvert"
No 3 "Fish"
No 4 "Arthur"
"Stauber" No 5
No 6
SECTION
Self-Registering Gage "Lt Ho"
FT GRATIOT LIGHT HOUSE
Staff Gage No 1
SECT
Self-Registering Gage "G T R"
Staff Gage No 2
SECT. No
No 8
No 9
SECT
SARNIA BAY
No 10
Staff Gage "W W"
SECT No 11
SECT No 12
No 0
36400 Sq FT
No 2 "Culvert"
46800 Sq FT
No 3 "Fish"
35800 Sq FT
No 4 "Arthur"
35200 Sq FT
"Stauber"
No 5
36800 Sq FT
No 7
41300 Sq FT
No 8
46700 Sq FT
No 9
41300 Sq FT
No 10
43000 Sq FT
No 11
50000 Sq FT
N

MAP No. 19.



MAP
LAKE HURON TO DISCHARGE SECTION "DRY DOCK"
SHOWING
SUB-MARINE CONTOURS AND SECTION AREAS
FROM SURVEYS UNDER THE DIRECTION OF
Bt. Col. G. J. Lydecker, Corps of Engrs. U.S.A.
AND
E. E. Haskell, Asst. Engr. in Charge
BY
L. C. Sabin, Asst. Engr.
Map Scale: 0 500' 1000'
Vertical Scale of Sections:
1898-1899
SARNIA
PORT HURON
Surface
Bottom
Sect. No. 13
Sect. No. 14
Sect. No. 15
Tunnel
Sect. No. 16
Sect. No. 17
Sect. No. 18
"Dry Dock" No. 19
St. Clair
Black River
Self Regr. Gage No. 9
Self Registering Gage "Dry Dock"
Discharge Section
Staff Gage Mich. Cen. R.R.
No. 13 64500 Sq. Ft.
No. 14 60300 Sq. Ft.
No. 15 58500 Sq. Ft.
No. 16 34800 Sq. Ft.
No. 17 60000 Sq. Ft.
No. 18 58500 Sq. Ft.
"Dry Dock" No. 19 59800 Sq. Ft.

conditions from Lake Huron to a point some five miles south. The cross-sections at various intervals are shown, and the contours of the stream bed are given.

DIAGRAM 39.

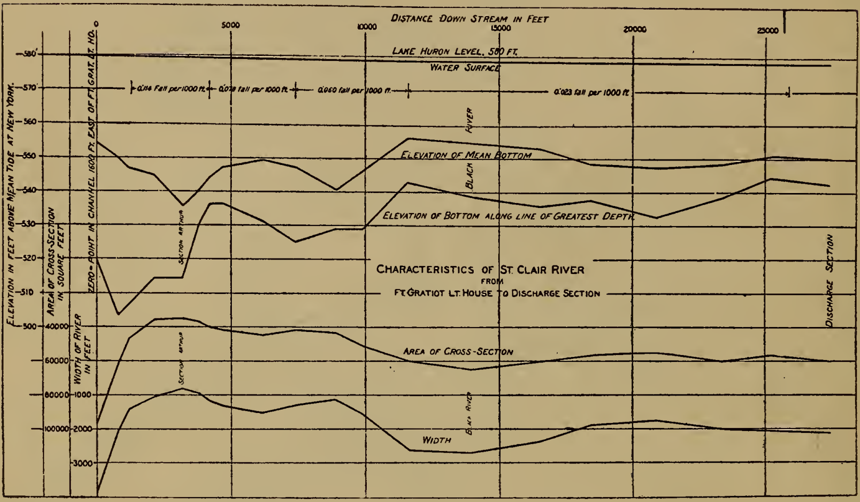
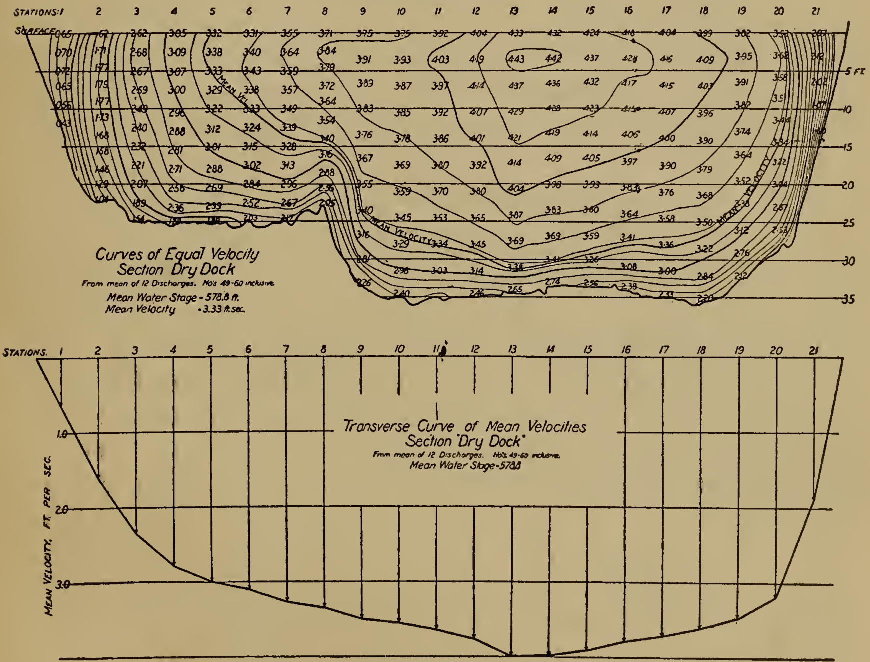


Diagram 39 shows the characteristics of the St. Clair River from St. Clair to the discharge section. The variations in the elevation of the river bottom, in the area of cross-section and in the width of the stream, are shown. From this diagram and from Map 19, an understanding of the constant change in conditions of flow may be gained. In considering the data of this river, it should be understood that it is a river of considerable magnitude, and that the conditions encountered in it are much more uniform and constant than in most of the smaller streams with the measurement of which the engineer will ordinarily be concerned.

The discharge section for the measurement of this river is shown near the bottom of the map. Mr. L. C. Sabin, Assistant Engineer in charge, describes this section as follows:

"The location seeming to present the most favorable condition for discharge measurement is the reach of the river, about two miles in length, beginning just above the mouth of the Black River. This portion of the river is comparatively straight and uniform, and after a survey of the location the discharge section, called "dry dock," was selected, at a point near the foot of the reach, where the river was a trifle wider and shallower than above or below. The general direction of the river at this place is north-east to south-west, the section is a little over 2,100 feet in width, and as the observations for discharge were to be taken 100 ft. apart, the section was divided into 21 partial areas, with a discharge section at the centre of each (except in case of two end areas, the width of which varied with the water stage)." This section is No. 19 on Map 19, and is also shown on Diagram 40.

DIAGRAM 40.



Several recording water gauges were located on this river, one about 1,500 ft. above the discharge section is called Gauge "Dry Dock." Another self-recording gauge was located on the Grand Trunk Railway property, near the head of the river: just below section No. 4, and is called, "G. T. R." Gauge. A third recording gauge was established on the lake shore, 600 ft. above Fort Gratiot lighthouse, and is called "Lighthouse" Gauge.

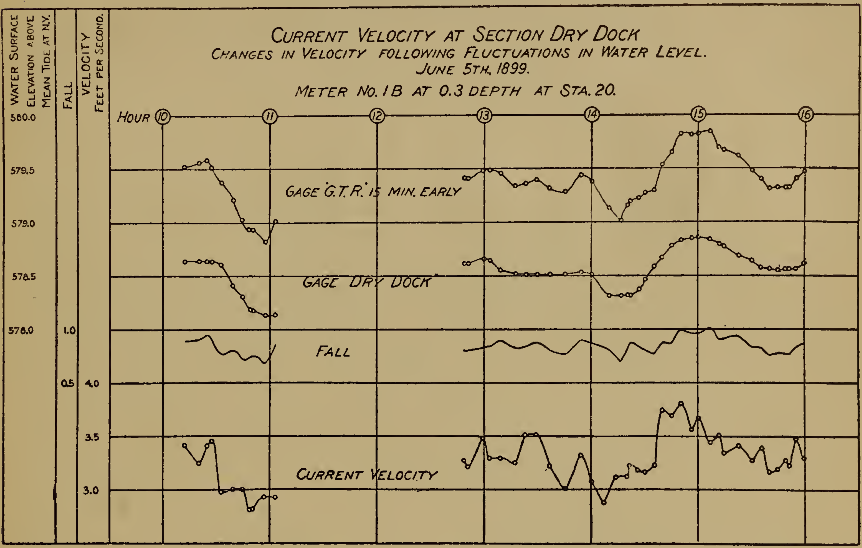
106. Propagation of Waves.—Concerning the fluctuations in water level, Mr. Sabin says:

"Among many examples of extreme fluctuations collected by the self-registering gauges, we have selected one to show the propagation of a wave from the lake through the outlet. The record of the four gauges on December 7th, 1899, are reproduced on Diagram 41, all drawn to the same vertical and time scale. * * * This particular wave was caused by both wind and barometer. In the morning a storm of some intensity was centered over Duluth, and during the forenoon of the 7th, the water level at the foot of Lake Huron had been abnormally depressed by a stiff south wind, and the effect of the barometer gradient. The low passed the meridian of Port Huron about 3 p. m., causing a rearrangement of the iso bars over Lake Michigan, and a shift of wind from the south to the west. This removed the cause of the low water and in the reaction the water rose to about as far above normal as it had been below.

DIAGRAM 41.

"The rate of travel of the wave down stream is the point to which attention is called. It seems that the maximum is reached at G. T. R. very soon after it occurred at lighthouse, but the maximum at dry dock occurred about fifteen minutes later, while nearly an hour is required for it to reach Roberts' Landing. A study of this and other similar records leads to the conclusion that the time required for a certain fluctuation in stage at G. T. R. to be felt at dry dock is fifteen minutes. This corresponds to a velocity of wave of 24 feet per second. The theoretical velocity $V = \sqrt{gD}$, where D represents mean depth, would be about 31 ft. per second."

DIAGRAM 42



107. Fluctuation in Current Velocity.—On Diagram 42 is shown the fluctuations in current velocity at section Dry Dock on the St. Clair River from ten o'clock to eleven o'clock in the forenoon, and from one o'clock to four o'clock in the afternoon of June 5th, 1899. There is also platted on this diagram the records of the water gauges at G. T. R. and at Dry Dock.

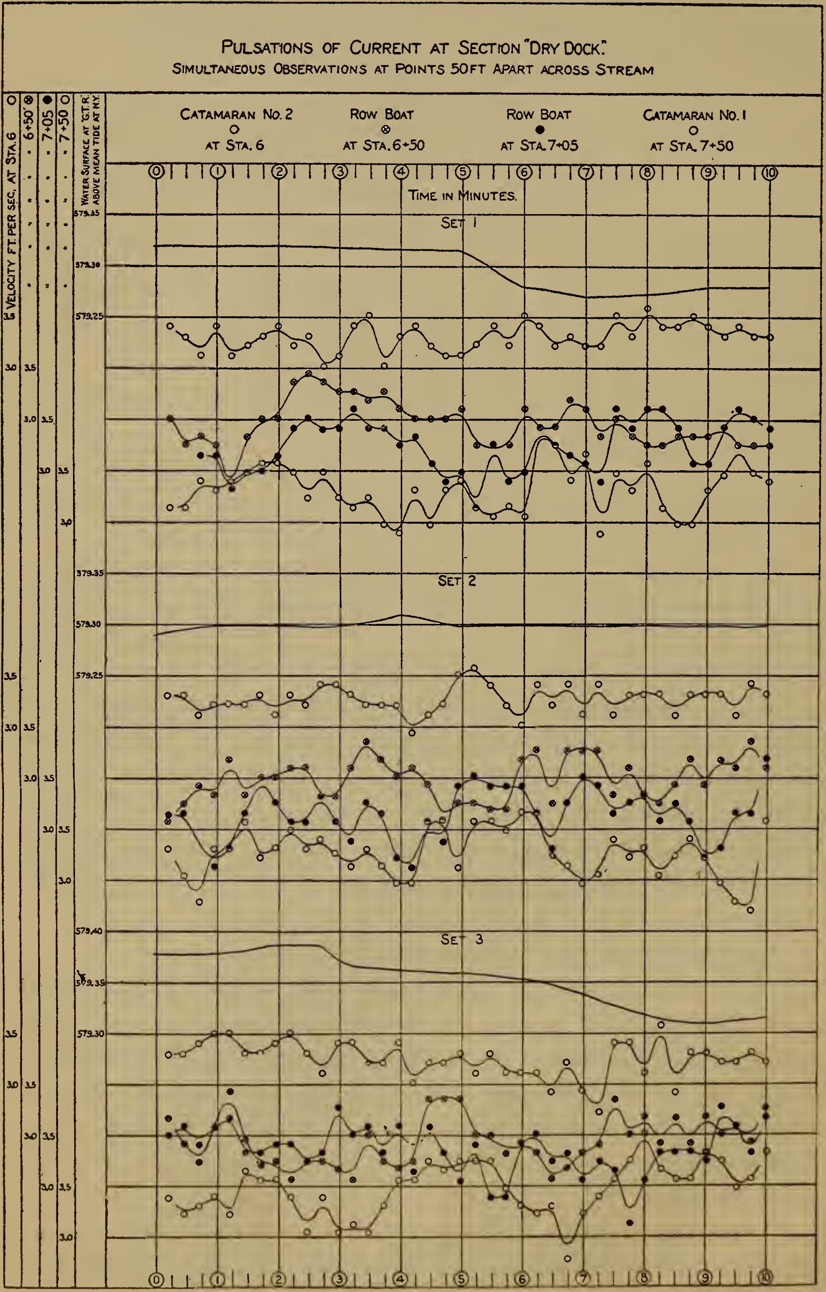
Concerning these fluctuations, Mr. Sabin says:

"The velocity of the stream filaments passing a fixed point in the cross-section seems to be ever changing. These variations may be divided into at least two classes: first class to include those fluctuations having a short period but considerable aptitude, and the second class, covering the more permanent changes, which may be traced to the change in stage.

* * *

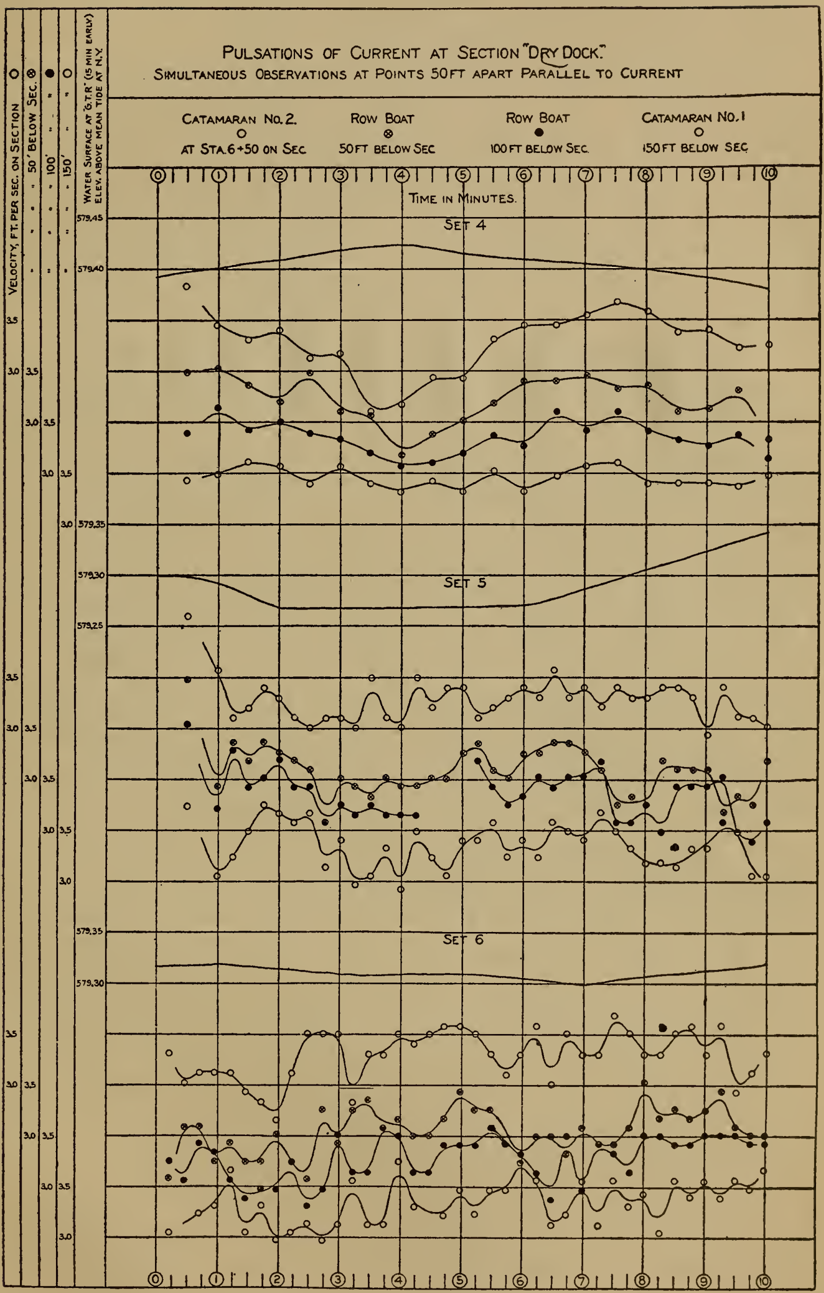
"The fluctuations in stage, with an aptitude of over one foot, is shown in discharge curve by an extreme variation of

DIAGRAM 43.



PULSATIONS OF CURRENT AT SECTION "DRY DOCK."
SIMULTANEOUS OBSERVATIONS AT POINTS 50 FT APART ACROSS STREAM

DIAGRAM 44.


PULSATIONS OF CURRENT AT SECTION "DRY DOCK."
SIMULTANEOUS OBSERVATIONS AT POINTS 50 FT APART PARALLEL TO CURRENT
CATAMARAN NO. 2. ○ AT STA. 6+50 ON SEC.
ROW BOAT ⊗ 50 FT BELOW SEC.
ROW BOAT ● 100 FT BELOW SEC.
CATAMARAN NO. 1 ○ 150 FT BELOW SEC.
TIME IN MINUTES.
0 1 2 3 4 5 6 7 8 9 10
SET 4
SET 5
SET 6
VELOCITY, FT. PER SEC. ON SECTION ○
50' BELOW SEC. ⊗
100' ●
150' ○
WATER SURFACE AT "G.T.R" (15 MIN EARLY) ELEV. ABOVE MEAN TIDE AT N.Y.
579.45
579.40
579.35
579.30
579.25
3.5
3.0

velocity of nearly a foot per second. This represents the second class fluctuation in current velocity, with the cause traced directly to variation in stage.

"The first class of fluctuation does not admit of such simple treatment. The most variable observations were those made on Sept. 23rd, when two catamarans, held 150 ft. apart, and two small boats were placed between them 50 ft. apart, each boat and catamaran had a meter running at the same depth and taking simultaneous readings at 15 sec. intervals. Some of the results of this work are shown on diagrams 43 and 44.

"In the first three sets (Diagram 43) the meters were in a line across the stream, and 50 ft. apart. In the second three sets (Diagram 44), the line of meters extended in the direction of the current. In the first sets it is seen that two adjacent meters may follow each other for a time, but will soon depart, when another pair will act together. This serves to bring out the fact that the minor fluctuations do not affect the entire cross-sectional line, and, in fact, that there is no synchronism over any large portion of it, neither can the fluctuations be traced with accuracy to the four positions, as would be the case if a wave of great extent passed across the stream diagonally. In the remaining curves taken with the meters in line of current, the similarity of the four curves seem to be plain, although a certain wave, if we may so speak of it, in the curve of the upper stream meter, may die out or change its form before reaching the last meter in the line. There are so many crests and troughs that may be followed through the series that little doubt can remain that these fluctuations travel down stream for some distance without much diminution in energy. The time required to travel 150 ft. appears to be one minute, giving a velocity of only about 2½ ft. per second. As this is less than 1-10 of the velocity of the fluctuations of the second class, it points to the conclusion that the two classes are quite distinct, both in immediate cause and in character."

Diagram 40, which shows a cross-section of the river at section Dry Dock, also shows the curves of equal velocity at that section. A transverse curve of mean velocities is also shown. This diagram is an interesting study of the effect of the shape of cross-section on the velocity of flow, and illustrates how irregularities in flow may be produced by rapid variations in cross-section.

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THE ICE SEASON.

BASIN OF THE GREAT LAKES AND SURROUNDING TERRITORY.

LONGITUDE 70° TO 109° WEST.
LATITUDE 37° TO 59° NORTH.

SHOWING BY YEARS AND AVERAGES THE RECORD FOR CHARACTERISTIC ROUTES AND REGIONS.

EXPLANATIONS:

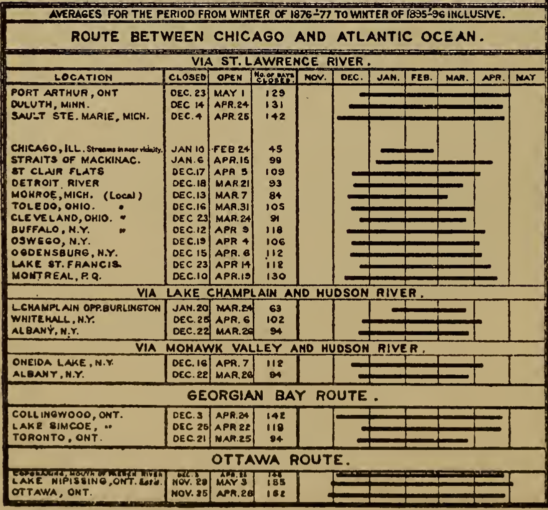
SCALE
HORIZONTAL:— DAYS
NOV. DEC. JAN. FEB. MAR. APR. MAY

SIGNS

ACTUAL ICE .... ▬
LAST AND FIRST VESSEL .... ▭
OFFICIAL CLOSING AND OPENING ... ▬
OPEN SEASON .... ┅
EQUIVALENT PERIOD .... ▬

AUTHORITY

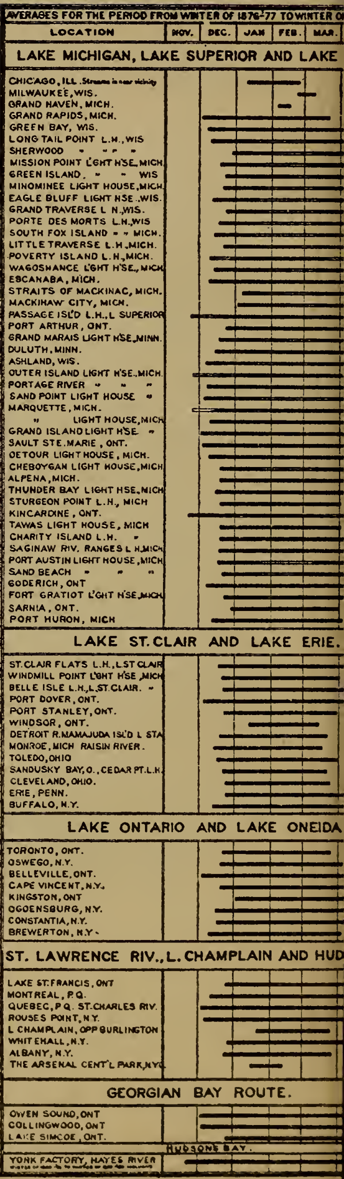
Compiled by Assistant Charles Poore, under direction of L. E. Cooley, C.E., from Records of the Meteorological Office, Department of Public Works, Department of Marine and Fisheries, and Department of Railways and Canals, Dominion of Canada, and of the Weather Bureau, Engineer Corps U.S.A., Light House Establishment, and Collectors of Customs of the United States, from Harbor Commissioners, Hudson Bay Company, various documents, and private records, obtained largely by special correspondence, and originally compiled for the Commission.



AVERAGES FOR THE PERIOD FROM WINTER OF 1876-77 TO WINTER OF 1895-96 INCLUSIVE.

ROUTE BETWEEN CHICAGO AND ATLANTIC OCEAN.

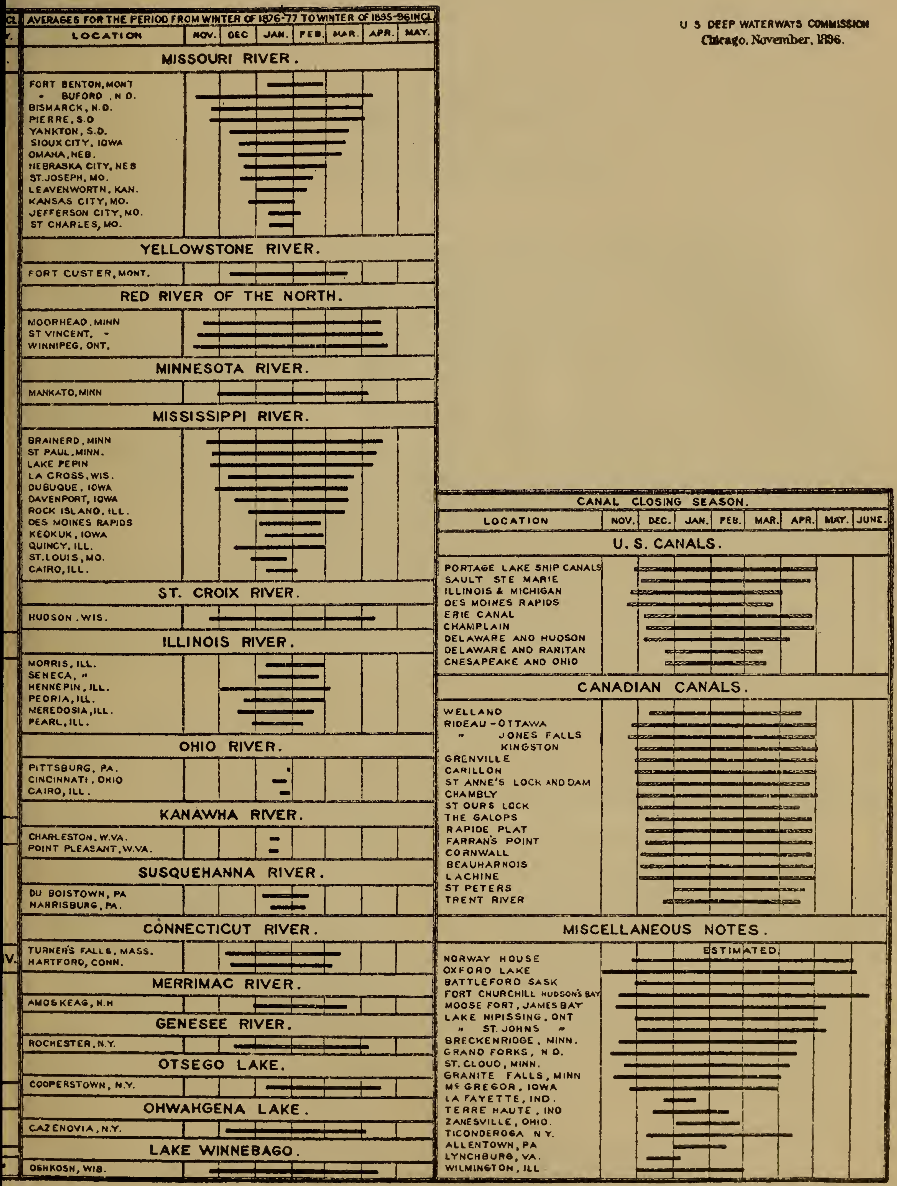
LOCATION	CLOSED	OPEN	No. OF DAYS CLOSED.
VIA ST. LAWRENCE RIVER.			
PORT ARTHUR, ONT	DEC. 23	MAY 1	129
DULUTH, MINN.	DEC 14	APR. 24	131
SAULT STE. MARIE, MICH.	DEC. 4	APR. 25	142
CHICAGO, ILL. Streams in near vicinity.	JAN 10	FEB 24	45
STRAITS OF MACKINAC.	JAN. 6	APR. 15	99
ST CLAIR FLATS	DEC. 17	APR 5	109
DETROIT RIVER	DEC. 18	MAR 21	93
MONROE, MICH. (Local)	DEC. 13	MAR 7	84
TOLEDO, OHIO. "	DEC. 16	MAR. 31	105
CLEVELAND, OHIO. "	DEC 23	MAR. 24	91
BUFFALO, N.Y. "	DEC. 12	APR 9	118
OSWEGO, N.Y.	DEC. 19	APR 4	106
OGDENSBURG, N.Y.	DEC 15	APR. 6	112
LAKE ST. FRANCIS.	DEC 23	APR 14	112
MONTREAL, P.Q.	DEC. 10	APR. 19	130
VIA LAKE CHAMPLAIN AND HUDSON RIVER.			
L. CHAMPLAIN OPP. BURLINGTON	JAN. 20	MAR. 24	63
WHITEHALL, N.Y.	DEC. 25	APR. 6	102
ALBANY, N.Y.	DEC. 22	MAR. 26	94
VIA MOHAWK VALLEY AND HUDSON RIVER.			
ONEIDA LAKE, N.Y.	DEC. 16	APR. 7	112
ALBANY, N.Y.	DEC. 22	MAR. 26	94
GEORGIAN BAY ROUTE.			
COLLINGWOOD, ONT.	DEC. 3	APR. 24	142
LAKE SIMCOE, "	DEC 25	APR 22	118
TORONTO, ONT.	DEC. 21	MAR. 25	94
OTTAWA ROUTE.			
[illegible]	[illegible]	[illegible]	[illegible]
LAKE NIPISSING, ONT. [illegible]	NOV. 29	MAY 3	155
OTTAWA, ONT.	NOV. 25	APR. 28	152



AVERAGES FOR THE PERIOD FROM WINTER OF 1876-77 TO WINTER O

DIAGRAM 45

U S DEEP WATERWAYS COMMISSION
Chicago, November, 1896.



Drawn by Hermann Krause

CHAPTER XIII.

ICE INFLUENCES.

108. **Formation of Ice.**—Ice is formed in natural waters at temperatures ranging from 32° to 28° F., depending on the amount of mineral matter held in solution.

In streams and fresh water lakes where the waters are comparatively free from mineral matter, the waters become heavier as they become colder until a temperature of about 39.2° F. is reached, beyond which the cooling of the surface water results in expansion and the retention of the cool water at the surface, after which freezing rapidly follows.

The formation of ice, at least when the ice reaches a thickness of one foot or more, offers a serious impediment to navigation. The ice season in the basin of the Great Lakes is shown by Diagram 45, and the local variations of the season at selected localities are shown on Diagram 46.*

109. **Effects of Ice.**—Ice in forming expands with great force, and structures built in northern waters must be designed to avoid injurious effects from this cause.

Engineering constructions in streams must also be built to resist the movements of ice in the spring, when it is sometimes carried out by floods, which give it considerable velocity, and consequently great force. Free water ways should also be provided for all streams subject to spring runs of ice; otherwise the ice may lodge on obstructions, damming back the waters and resulting in the destruction of much property by the overflow and by the sudden release of the impounded waters.

110. **Anchor Ice.**—While solid ice is light enough to float, and remains at the water surfaces, it often happens that thin flakes and needles of ice, which are formed in the running

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* Report of U. S. Deep Waterway Commission, Doc. 192, 54th Congress.

water, have nearly the specific gravity of the water. In this condition the ice is readily carried below the surface by even slight currents, and frequently causes considerable trouble, both to waterworks intakes and to water power plants, often causing inlets to be completely choked up, and the plants to be shut down until the ice can be removed. Such conditions only arise in open bodies of water and cease when the surface is frozen over.

111. **Effect on River Flow.**—The presence of a layer of ice greatly modifies the river flow. The friction of flow on the ice sheet is approximately the same as the friction on the river bed. This will be seen from the vertical curve shown on Diagram 37.

LITERATURE.

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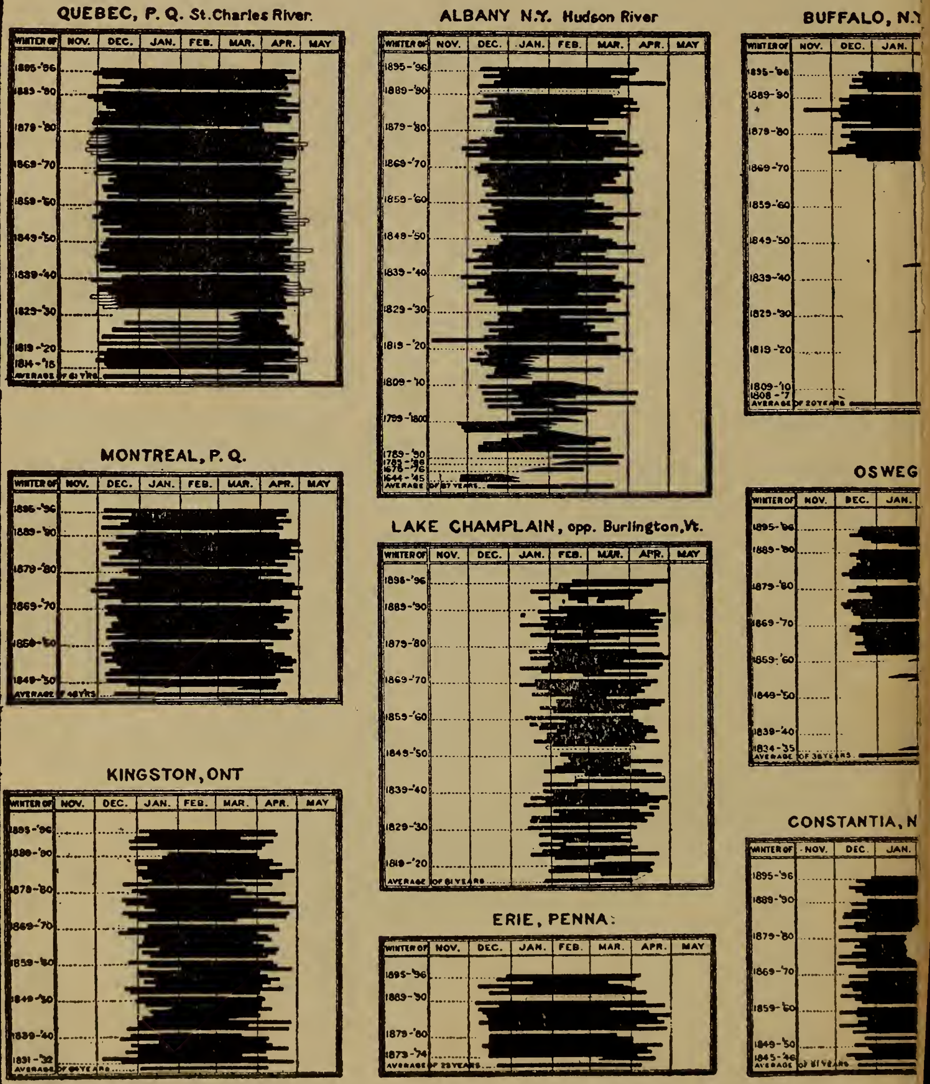
LOCAL VARIATIONS I

FROM REPORT OF U.S. DEEP W
189



QUEBEC, P. Q. St.Charles River.

ALBANY N.Y. Hudson River

BUFFALO, N.Y

MONTREAL, P. Q.

LAKE CHAMPLAIN, opp. Burlington,Vt.

OSWEG

KINGSTON, ONT

ERIE, PENNA.

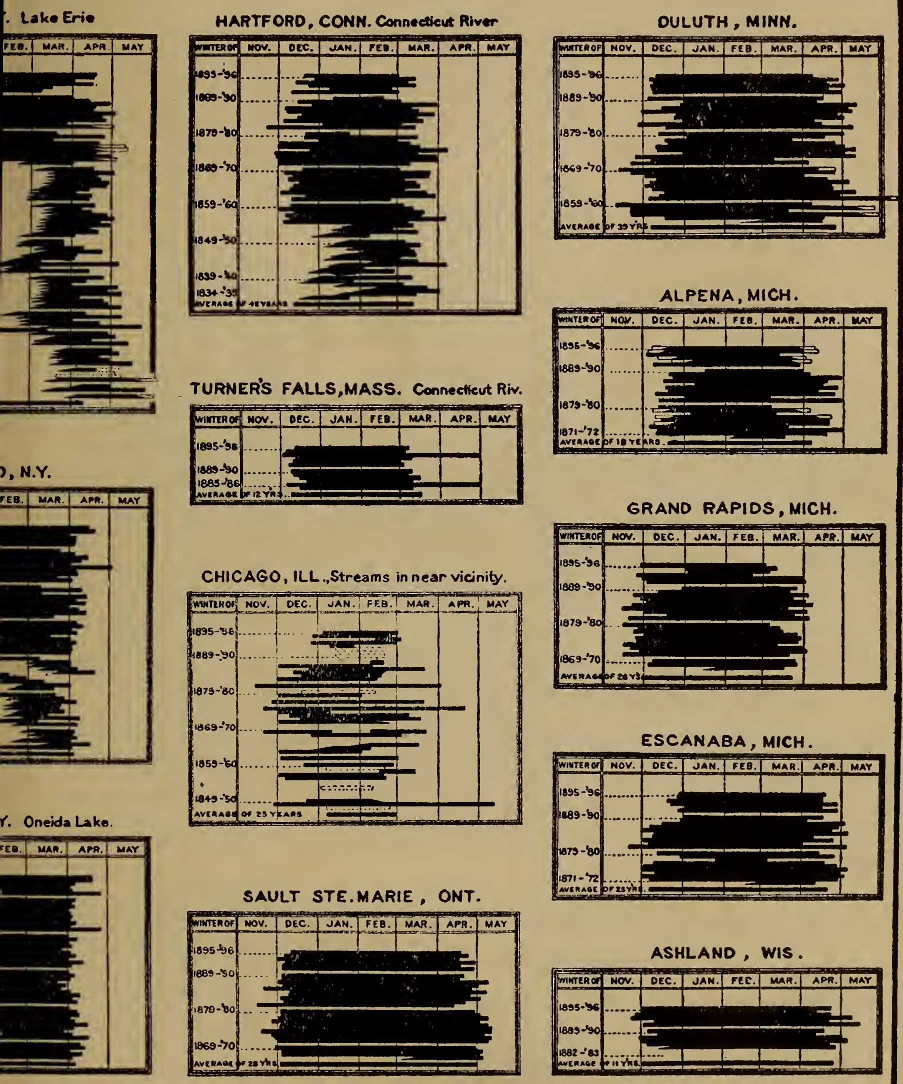
CONSTANTIA, N

DIAGRAM 46.

N THE ICE SEASON

ATER-WAY COMMISSION.

6.



CHAPTER XIV.

CHEMISTRY OF NATURAL WATERS.

112. **General Relations.**—The high solving qualities of water, especially when charged with carbonic acid gas, has made water an active agent in the gradation of the strata. The removal of the soluble salts from the rocks, with which the water comes in contact, destroys their integrity and results in their disintegration.

As a result of solution and disintegration, all waters are charged with soluble or suspended matter, derived from the material which they have met in their course from the clouds to the sea. Soluble matter is acquired by water, not in the proportion that it exists in the strata, but more nearly in proportion to the solubility of the salts. The matter carried in suspension by moving water varies in its character with its relative specific gravity, and the velocity of the current. (See Section 21.)

113. **Analyses of Rocks and Rock Waters.**—The analyses of various rock formations of the upper Mississippi Valley are shown in Table 39, and from these analyses can be inferred the nature of at least some of the salts which must be contained in the water flowing through or from such strata.

The analyses of some of the rock waters, obtained from various Geological Strata in the upper Mississippi Valley, are shown in Tables 40 to 43. A comparison of these analyses with those of Table 39 will render the relations between the strata and the strata water apparent.

TABLE 39.

Analyses of Geological Deposits in Upper Mississippi Valley Showing the Sources of the Mineral Matter Contained in Water from Different Sources.

In Grains per United States Gallon of 231 Cubic Inches.

	Calcium Carbonate.	Magnesium Carbonate.	Silica.	Alumina.	Ferric Oxide.	Water.	Lime.	Magnesia.	Soda.	Potassa.	Organic matter.	Miscellaneous.	Total.
Peaty soil, Wisconsin	.	. .	64.49	4.80	5.74	.	1.62	.72	.51	.14	21.40	.58	100.00
Prairie loam, South Wisconsin	.	. .	79.59	4.17	8 16	. .	1.30	1.04	.49	.19	4.24	.79	100.00
Red marley clay, Kewanee County, Wis.	.	. .	60.26	13.44	4.39	. .	5.03	3.48	.15	. .	5.84	7.41	100.00
Marl, Kewanee County, Wis.	86.06	7.18	1.48	.19		1.67	. .	. .	. .	. .	2.95	.44	100.00
Locustine clay, Ashland, Wis.	4.31	4.01	58.09	25.32	4.44	4.09	. .	. .	. .	. .	. .	. .	100.26
Kaolin from Wisconsin	. .	. .	70.82	18.98	1.24	5.45	.24	.02	10	2.49	. .	.02	99.36
Drift clay, Bloomington, Ill.	3.90	5.32	67.80	11.55	4.31	2.00	. .	. .	2.42		. .	. .	97.30
Carboniferous shale, Rock Island, Ill.	.24	.75	60.64	22.84	6,10	5.00	. .	. .	. .	. .	. .	3.85	99.42
Carboniferous shale, Galesburg, Ill.	. .	. .	68.69	17.95	7.25	. .	.76	1.47	2.83	2.83	. .	1,05	100.00
Subcarboniferous limestone, Quincy, Ill.	94.68	4.31	.05	.20		.76	. .	. .	. .	. .	. .	. .	100.00
Devonian (Lower Helderberg), Milwaukee, Wis.	54.57	43.41	1.49	.21		.32	. .	. .	. .	. .	. .	. .	100.00
Niagara limestone, Racine, Wis.	52.16	45.50	. .	.82		.67	. .	. .	. .	. .	. .	.28	99.65
Niagara limestone, Chicago, Ill.	46.90	14.19	26.08	. .	6.57	6.26	. .	. .	. .	. .	. .	. .	100.00
Hudson River shale, Clinton, Ia.	. .	. .	75.50	13.04	4.00	3.00	.50	. .	. .	4.50	. .	. .	100.90
Trenton limestone, Beloit, Wis.	52.63	36.40	1,96	3.27		.	. .	. .	. .	. .	. .	5.74	100.00
Trenton (Galena limestone), Watertown, Wis.	54.05	44.14	1.57	.07	.17	. .	. .	. .	. .	. .	. .	. .	100.00
St. Peter's sandstone, Mineral Point, Wis.	. .	. .	96.74	.71	1.45	. .	.63	.08	. .	. .	. .	. .	99.61
Lower magnesium limestone, Ripon, Wis.	51.68	40.93	3.16	3.09	.60	.70	. .	. .	. .	. .	. .	. .	100.16
Lower magnesium limestone, Utica, Ill.	43.50	30.07	1.00	20.00	2.00	3.00	. .	. .	. .	.18	. .	. .	99.75
Lake Superior sandstone, Bass Island, Wis.	. .	. .	87.02	7.17	3.91	. .	.11	1.06	.22	1.43	. .	. .	99.92
Potsdam (Mendote limestone), Greenbush, Wis.	55.68	36.52	4.18	2.17	1.45	.52	. .	. .	. .	. .	. .	. .	100.58
Potsdam (Quartzite), Minnesota	. .	. .	84.52	12.33	2.12	2.31	.31	. .	1.34	1.11	. .	. .	102.04
Potsdam sandstone, Minnesota	. .	. .	78.24	10.88	3.83	. .	.95	1.60	.06	1.67	. .	. .	97.23
Archean (Quartz diorite), Wisconsin	. .	. .	46.31	11.14	21.69	4.44	9.68	. .	6.91	. .	. .	. .	100,77
Archean (Serpentine), Wisconsin	. .	. .	38.24	1.48	. .	9.53	1.42	14.83	. .	. .	. .	34.50(*a*)	100.00
Archean (Syenite), Minnesota	. .	. .	65.12	16,96	4.69	. .	4.17	1.99	3.07	2.18	. .	. .	98.73
Archean (Labradorite), Minnesota	. .	. .	48.32	35.95	. .	. .	12.05	.25	2.98	.19	. .	. .	98.74

(*a*) Oxide of iron with a little soda.

TABLE 40

Analyses of Mineral Residue of Various Surface and Drift Waters in the Upper Mississippi Valley.

In Grains per United States Gallon of 231 Cubic Inches.

Compound.	Symbol.	Chicago, Ill. Lake Michigan.	Woodstock, Ill. Well in Drift.	Rockford, Ill. Driven Well in Drift.	Lincoln, Ill. Filter Gallery in Drift.	Galesburg, Ill. Old Water Works Well Drift.	De Kalb, Ill. Corkin's Well in Drift.	Heron Lake, Minn.	Rock River, Minn.	Minneapolis, Minn. Mississippi River.
Potassium sulphate	K_2SO_4	.283	.308	.157	1.026	. .	4.68	.467	.192	.102
Sodium sulphate	Na_2So_4	.2.5	4.4.3	.216	. .	. .		1.079	1.493	.175
Potassium chloride	KCl	. .	. .	. .	.735	K_2CO_3 .432	2.33	. .	. .	. .
Sodium chloride	$NaCl$	. .	5.060	.111	2.31	.122	. .	.297	.117	.164
Sodium phosphate	Na_3PO_4	Trace	. .	Trace	. .	. .	. .	. .	. .	. .
Sodium bicarbonate	$NaO_2CO_2H_2O$	. .	5.295	4.66	. .	Na_2CO_3 1.505	. .	. .	. .	. .
Magnesium bicarbonate	$MgO_2CO_2H_2O$	. .	5.196	11.433	. .	. .	12.25	. .	. .	. .
Magnesium carbonate	$MgCO_3$	2.202	. .	. .	4.735	5.062	6.29	4.451	4.106	3.163
Calcium bicarbonate	$CaO_2CO_2H_2O$	. .	16.592	16.032	. .	. .	. .	$Ca2NO_3$ .292	. .	. .
Calcium carbonate	$CaCO_3$	4.465	. .	. .	7.307	9.692	16.66	5.990	7.933	6.395
Calcium sulphate	$CaSO_4$	.319	. .	. .	6.76	.332	7.39	2.792	.373	. .
Ferrous bicarbonate	$FeO_2CO_2H_2O$	. .	.926	.396	. .	. .	. .	. .	. .	. .
Ferrous carbonate	$FeCO_3$	.029	. .	. .	6.59	3.791	.12	.099	Fe_2O_3 .513	.055
Alumina	Al_2O_3	Trace	.184	.081					.058	
Silica	SiO_2	.306	.863	1.049	.710	1.125	.87	.414	1.225	.783
Total		(1) 7.829	(2)	(3) 29.941	(1) 16.079	(1) 22.061	. .	(4) 15.881	(4) 16.010	(5) 10.837

(1) Analyzed by J. H. Long.
(2) " " W. Haines.
(3) Analyzed by E. G. Smith.
(4) " " W. A. Noyes.
(5) Analyzed by J. A. Dodge.

TABLE 41

ANALYSES OF MINERAL RESIDUE OF WATERS FROM THE POTSDAM STRATA AT VARIOUS PLACES IN THE UPPER MISSISSIPPI VALLEY.

In Grains per United States Gallon of 231 Cubic Inches.

Compound.	Symbol.	Rockford, Ill., Water Works Well.	Dixon, Ill., Condensed Milk Co.'s Well.	Sterling, Ill., Water Works Co.'s Well.	Galena, Ill., Water Works Well.	Oak Park, Ill., Water Works Well.	Clinton, Iowa, Water Works Well.	Kenosha, Wis., Water Works Well.	St. Louis, Mo., Asylum Well.	Turner, Ill., R. R. Co.'s Well.	Janesville, Wis., Water Works Well.	Madison, Wis., Water Works Well.	Prairie du Chien, Wis., Water Works Well.	Sparta, Wis., Private Well.	Watertown, Wis., Water Works Well.
Potassium sulphate	K_2SO_4	.501	.07	.46	.06	6.79	. .	Trace	KBr 3.0582	4.49	.116	.24	. .	. .	.14
Sodium sulphate	Na_2SO_4	.355	.75	.54	. .		6.626	5.48	. .		.408	.29	12.798	. .	. .
Potassium chloride	K Cl	. .	. .	. .	. .	30.54	. .	. .	.8680	1.48	. .	. .	3.806	$CaCl_2$ .583	. .
Sodium chloride	Na Cl	.274	.27	.69	.10		6.662	.86	401.5730		.489	.29	90.201	.583	.86
Sodium phosphate	Na_3PO_4	Trace	Trace	Trace	. .	. .	. .	Trace	. .	. .	Trace	Trace	Trace	. .	Trace
Sodium bicarbonate	$Na_2O_2CO_2H_2O$	.816	. .	. .	. .	Na_2CO_3 8.70	6.282	. .	. .	. .	. .	1.09	NaBr .123	. .	. .
Magnesium chloride	$Mg Cl_2$	. .	. .	. .	. .	. .	. .	. .	46.0840	. .	. .	. .	. .	$MgSO_4$ 2.333	.45
Magnesium bicarbonate	$MgO_2CO_2H_2O$	12.798	12.16	13.35	8.50	. .	7.426	8.06	. .	. .	12.664	12.89	. .	.583	11.58
Magnesium carbonate	$MgCO_3$	. .	. .	. .	. .	2.33	. . .	. .	.	4.08			10.974		
Calcium bicarbonate	$CaO_2CO_2H_2O$	13.173	14.04	14.85	3.70	. .	11.220	15.03	$CaCl_2$ 47.4911	. .	12.045	15.24	. .	4.086	14.57
Calcium carbonate	$Ca CO_3$	. .	. .	. .	. .	8.46	. .	. .	. .	6.67	. .	. .	6.22	. .	. .
Calcium sulphate	$Ca SO_4$	. .	.17	. .	. .	Trace	. .	6.02	50.1847	.11	.314	. .	15.370	. .	.53
Ferrous bicarbonate	$FeO_2CO_2H_2O$	.079	.07	.06	.01	Trace	.017	.09	Fe_2O_3 .0584	.12	.087	.21	.232	.583	.16
Alumina	Al_2O_3	.139	.09	.06	.06	.		.03	. .		.093	Trace	.061	. .	.04
Silica	$Si O_2$	.583	.77	.61	.06	.40	6.12	.45	.9346	.56	.536		2,843	.583	.47
Total		(1) 28,718	(1) 28.39	(1) 30.64	(2)	(3) 56.89	(1) 38.854	(1) 36.02	(4) 550.2551	18.22	(1) 26.752	(5) 30.76	(6) 137.035	(6) 9.311	(1) 28.80
Depth of well in feet		1530	1500	1450	1509	2180	1674	1365	2199	2087		1015	1044	300	957

(1) Analyzed by E. G. Smith.
(2) " " W. Simpson.
(3) Analyzed by G. M. Davidson.
(4) " " Prof. P. Schweitzer.
(5) Analyzed by W. W. Daniels.
(6) " " G. Bode.

TABLE 42

ANALYSES OF MINERAL RESIDUE OF WATERS FROM THE ST. PETER SANDSTONE AT VARIOUS PLACES IN THE UPPER MISSISSIPPI VALLEY.

In Grains per United States Gallon of 231 Cubic Inches.

Compound.	Symbol.	Whitewater, Wis. Blackman's Well.	Davenport, Iowa. Glucose Well.	Jerseyville, Ill. Water Works Well.	Monmouth, Ill. Water Works Well.	De Kalb, Ill. Water Works Well.	Rockford, Ill. Water Works Well.	Peru, Ill. Zinc Works Well.	Rock Island, Ill. Wagner's Brewery Well.	Burlington, Wis. Water Works Well.	Milwaukee, Wis. W. A. Jacobs' Well.	Fond du Lac, Wis. Wild's Well.	Broadhead, Wis. Gomber's Well.	Sheboygan, Wis. Public Well.	Moline, Ill. Wheelock's Well.
Potassium sulphate	K_2SO_4	.13		10.30	4 86	1.13	.233	. .	. .	.56	. . . .	. . .	. .	. . . .	. . .
Sodium sulphate	Na_2SO_4	.16	16.096	5.05	23 45		.349	7 25	15 60	1.08	8.8572	4.086	.17	. . . .	20.848
Potassium chloride	KCl	. .	. . .	. .	. .	.11	. .	. .	. .	. .	.2745	. . .	. .	14 4822	. .
Sodium chloride	$NaCl$	.11	28.080	85.93	9.61		.110	16 00	32.00	.46	.6405	4 086	.32	306.9436	27.854
Sodium phosphate	Na_3PO_4	Trace	. . .	Trace	. .	. .	.072	Trace	. .	Trace	. .	. .	.	. . .	. . .
Sodium carbonate	$NaO_2CO_2H_2O$	.73	. .	. .	. .	. .	. .	7.02	Na_2CO_3 4.00	. .	. . . . .	. .	.03	. . . .	. . .
Magnesium bicarbonate	$MgO_2CO_2H_2O$	11.97	4.770	15.53	14.07	6 47	12.286	7.16	. .	8.89	6.6307	4.670	4.86	.1742	. . .
Magnesium carbonate	$MgCO_3$	. .	. .	. .	.	.	.	. .	6 30	. .	. . .	. .	.	$MgCl_2$ 54.9139	5.849
Calcium carbonate	$CaCO_3$	. .	. . .	.	. .	. .	. . .	. .	10.00	. .	. . . . .	. .	. .	$CaCl_2$ 27.8225	8.765
Calcium bicarbonate	$CaO_2CO_2H_2O$	15 92	5.132	6.84	15 82	8 39	13.837	12 65	. .	12.10	8.6925	6.421	6.66	13,6585	. . .
Calcium sulphate	$CaSO_4$	. .	5 540	16.91	4.70	. .	.195	. .	.	2 46	14.5485	.584	. .	169.8277	. . .
Ferrous bicarbonate	$FeO_2CO_2H_2O$	.29	. . .	.11	.24	.69	.151	.07	. .	.03	.1342	. .	.23	.5044	. . .
Alumina	Al_2O_3	13	.361	.06	.10		.069	.04	.	.03	.1891	. . .	13	.1283	. . .
Silica	SiO_2	.59	.216	.78	1 04	. .	.548	.79	. .	.40	2 3790	. . .	.69	.4665	.355
. . . .	. . . .	. .	. . .	. .	. .	organic	. .	. .	.	. .	. . . . .	organic	organic	(a)	$FeCO_3$
. . . .	. . . .	. .	. .	. .	. .	.70	. .	. .	. .	. .	. . . . .	.584	.18	.3318	.221
Total	. . . .	(1) 30.04	. . . 60.196	(1) 141.51	(1) 73.89	(2) 17.49	(1) 27.856	(1) 50.98	(3) 67.30	(1) 26.01	(4) 42.3462	(4) 20 431	. . 13.27	(5) 589 2536	(6) 63.892
Depth of well in feet	. . . .	315	2101	2003	1227	800	370	1360	1068	1108	1200	. . .	30	1475	. . .

(1) Analyzed by E. G. Smith.
(2) " " G. M. Davidson.
(3) " " Wahl & Hennsoch.

(4) Analyzed by G. Bode.
(5) " " C. F. Chandler.
(6) " " W. Haines.

(a) Composed of chloride of lithium, bromide of sodium, and phosphate of lime, with traces of iodide of soda, sulphate of baryta and biborate of soda.

TABLE 43.

ANALYSES OF MINERAL RESIDUES OF ARTESIAN AND OTHER WELL WATERS OF THE UPPER MISSISSIPPI VALLEY.

(Geological Source Uncertain.)

In Grains per United States Gallon of 231 Cubic Inches.

Compound.	Symbol	Waterloo, Wis., Well.	Chicago Artesian Wells.				Galesville, Wis., Jordan's Well.	Watertown, Wis., Magnetic Well.	Manitowoc, Wis., Rahr's Well.	Sparta, Wis., Magnetic Well.	Humboldt, Minn., Artesian Well.	Bell Plaine, Ia., Artesian Well.	Story City, Ia., Watkin's Well.	Knox City, Mo., Landreth's Well.	La Grange, Mo., Wyaconda Artesian Well.	Hannibal, Mo., Oakwood Artesian Well.	Palmyra, Wis., Artesian Well.	Du Pere, Wis., Artesian Well.	Middle Grove, Mo., Harris' Well.	Fond du Lac, Wis., Hunter's Well.	Geneseo, Ill.
			W. H. Boup & Co.	Munger's Laundry.	Auditorium.	Leland Hotel.															
Potassium sulphate	K_2SO_4		.10	Trace.	1.58	.129		. .	. .	.64	. .	.		.4721	KCO_3 8.173	.	. . .	. .	. .	1.90	. .
Potassium chloride	KCl	7.348	. .	.				.	.584	$CaCl_2$ .61	15.655	. .	. .	. . .	. .	. .	. . .	2.140	2.4500	.57	. .
Sodium sulphate	Na_2SO_4	.	. .	.47	36.75		1.97	1.17	37.358	2.21	. .	5.207	6.745	30.8562	9.223	77.26	. . .	1.193	9.0200	2.47	11.034
Sodium chloride	$NaCl$	24.319	1.88	1.82	2.33	2.514	.18	.	$CaCl_2$ 22.182	.14	276.499	.512	—	1.1721	320.607	712.28	527.0307	2.088	.7700	2.66	90.403
Sodium phosphate	Na_3PO_4	. .	Trace.	.28	Trace.	.		. .	. .	.06		.		.	. .	.	. . .	Trace.	. . .	K_2CO_3 .76	. .
Sodium bicarbonate	$NaO_2CO_2H_3O$	37.498	8.36	7.03	.	. .	.89	.	. .	. .		. .	. .	.	.209	.	. . .	. .	. . .	. .	. .
Sodium carbonate	Na_2CO_3	. .	. .	. .	. .	6.324	. .	. .	. .	.21		. .		. . .	. .	. .	. .	. .	. . .	.76	. .
Magnesium sulphate	$MgSO_4$	11.955	. .	. .	. .	. .	. .	.	48.449	.	7.112	32.716	.	23.5369	. .	72.21	. . .	. .	28.3100	3.23	. .
Magnesium bicarbonate	$MgO_2CO_2H_2O$	16.387	3.47	7.45	. .	. .	8.16	7.58	. .	. .	. .	. .	. .	. . .	31.287	. .	. . .	9.540	. . .	. .	. .
Magnesium carbonate	$MgCO_3$	. .	. .	.	.	.249	. .	. .	. .	4.03	7.860	10.922	7.279	. .	. .	. .	. . .	. .	. . .	1.14	10.231
Magnesium chloride	$MgCl_2$	. .	. .	. .	11.90	. .	. .	. .	. .	.	9.144	. .	. .	. . .	. .	. .	53.4778	. .	. . .	. .	. .
Calcium bicarbonate	$CaO_2CO_2H_2O$	13.996	4.94	5.63	21.33	.	6.50	11.08	25.100	.	. .	.	. .	32.6502	51.604	.		5.915	79.4289	. .	4.503
Calcium carbonate	$CaCO_3$	$CaCl_2$ 29.976	. .	. .	. .	5.692	. .	. .	. .	.40	$CaCl_2$ 4.226	. .	11.624	. . .	. .	. .	$CaCl_2$ 28.3920		. . .	.95	24.105
Calcium sulphate	$CaSO_4$	. .	.	. .	16.31	. .	. .	.58	57.788	.18	11.608	83.266	. .	18.4061	. .	125.89	67.4325	5.856	24.2800	2.28	. .
Ferrous bicarbonate	$FeO_2CO_2H_2O$	. .	.15	.04	.13	.	2.67	Trace.	. .	. .	. .	.612	. .	2.3919	. .	. .	. . .	.124	3.3913	. .	2.80
Ferrous carbonate	$FeCO_3$	. .	.	.		.374	. . .	. .	. .	14.31	.108	.	.348	. . .	.	. .	. . .	. .	. .	. .	1.806
Alumina	Al_2O_3	. .	.10	.03	.07	. .	.68		. .	. .	.238	.		.6697	.093	. .	. . .	.055	.	.	8.550
Silica	SiO	1.190	.75	.49	.84	1.337	.29	1.17	1.167	.28	1.215	.093	1.461	.9508	2.851	. .	1.1098	.426	1.9976	.95	. .
Organic		(i) 1.283	. .	. .	. .	.441	.48	. .	. .	(a) .12		. .	.053	(b) 7.5586	. .	. .	(e) .6189	. .	. . .	. .	. .
Total		. .	(2) 18.99	(2) 23.23	(2) 91.24	(3) 16.990	(4) 21.82	(4) 21.58	(4) 192.628	(5) 23.223	(6) 33.665	(8) 133.227	(7) 27.510	(9) 118.6649	424.057	(10) 987.64	(9) 676.0617	(13) 27.357	(11) 149.6478	19.00	(1) 157.409
Depth		. .	800	. .	. .	. .	65 ft.	. .	(g) 150	.	. .	. .	. .	. . .	(d) 840	. .	(c) 1683	. .	(f) 20 ft.	(h) 187	. .

(1) Analysis by D. M. Stanner.
(2) " E. G. Smith.
(3) " C. G. Wheeler.
(4) " G. Bode.
(5) " J. M. Hirsh.
(6) " G. A. Marnier.
(7) " F. W. Clarke.
(8) Analysis by Prof. Andrews.
(9) " Paul Schweitzer.
(10) " R. Chauvert & Bro.
(11) " Woodward & Robertson.
(12) " E. J. Gillett.
(13) " W. W. Daniels.

(a) Said to consist of barium, strontium and lithium carbonates.
(b) Free carbonic acid gas.
(c) Flow said to have begun at 700 feet (St. Peter's); lower flow probably from Potsdam.
(d) Flow probably from St. Peter's sandstone.
(e) About equal parts of sodium bromide and lithium chloride.
(f) In sand rock.
(g) Water from Niagara limestone, in which well is sunk 90 feet; there is 60 feet of drift over the rock.
(h) Water is from the Galena limestone.
(i) Chloride of lithium.

114. Seasonal Variation.—Surface waters, derived partially from surface flows and partially from ground water which has flowed perhaps only a short distance through the strata, are usually more free from mineral matter than the deep ground waters. In the springtime the flow of streams is derived more largely from melted snows and surface flows, and is at such times more free from mineral matter than during times of low water. During low water the flow is derived entirely from the ground water.

All surface waters have also a seasonal variation in the organic matter which they contain. This variation is as marked as that of the mineral matter contained in them.

115. Deep Waters.—Deep and artesian waters are usually charged more highly with mineral matter than those obtained from the more superficial deposits. The distance a water flows through the strata, which is also a measure of the length of time which it has been in contact with the salts of the strata, will also indicate in a general way the relative amounts of salts which will be found in the water. In this connection note the increase in the amounts of mineral matter, in waters obtained from the potsdam strata, as the distance from the outcrop increases. This is shown by the analyses of the waters at Rockford, Monmouth, and Jerseyville, Illinois, as shown in Table 42.

116. Organic Matter.—River waters, which have fallen on populous districts and on fertilized agricultural land, or which have received the sewage of municipalities, are sometimes highly charged with organic matter, and its accompanying bacterial life. Such waters sometimes contain the specific germs of certain forms of disease, and if used, without purification, for dietetic purposes, may reproduce similar diseases in those using it.

When water is to be used for the purpose of a public water supply, or for manufacturing purposes, it is often necessary to have examinations made to determine the nature and amount of the matter it may contain. The extent of these analyses depends on the use to which the water is to be put, and, to some extent, on its natural history. These analyses usually include one or more of the following:

First. An analysis of the mineral residue, showing the amounts and character of the mineral matter contained in the water.

Second. A sanitary or organic analysis showing the amounts of certain products or accompaniments of organic matter.

Third. A bacterial examination, to determine the relative number of bacteria present and often to determine their character.

Fourth. A microscopic examination to identify the microscopic organisms present.

The results of sanitary analyses and bacterial counts are indicative only and must always be interpreted in the light of the natural history of the water itself.

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CHAPTER XV.

APPLIED HYDROLOGY.

117. **Application.**—In the application of the principles of hydrology to practical purposes, the nature and extent of the data needed and consequently of the investigations which it is necessary to undertake, varies in accordance with the purpose in view. In the following outlines, the principal factors to be considered are shown and the hydrological data on which they depend are briefly indicated.

118. **Water Supply.**—

- A. Investigation of Sources (Physiography and Hydrogeology).
  - a. Quantity; sufficient with or without pondage. (Rainfall, run off, evaporation and seepage.)
  - b. Quality; suitable with or without treatment. (Sanitary protection, softening, filtration, storage.)
- B. Methods of Development.
  - a. Surface Water (sanitary protection).
    - Dams and Reservoirs (geology, seepage, evaporation).
    - Inlets (floods, ice).
  - b. Subsurface Water (sanitary protection).
    - Open wells, drive wells, infiltration galleries, storage (geology).
  - c. Deep Water (geology).
    - Springs and artesian flows.
    - Deep wells and pumping.

        - Shaft, tunnels and wells.
        - Storage.
    - C. Head for Distribution (relation of energy).
        - a. Gravity (conduits).
        - b. Direct pumping (machinery).
        - c. Pumping to reservoir.
    - D. Distribution. (Hydraulic.)
        - a. Pipe system.
        - b. Valves, hydrants and services.
        - c. Control of delivery meters.

119. **Water Power.**
    - A. Source (hydrography).
        - a. Great Lakes.
        - b. Streams.
        - c. Springs and artesian wells (rare).
    - B. Quantity (rainfall, run off, evaporation).
        - a. Average flow and variations.
        - b. Minimum flow.
        - c. Maximum flow.
    - C. Head; amount of head and influence of maximum flow on head.
    - E. Development.
        - a. Dams and spillways (geology and run off).
        - b. Head and tail races.
        - c. Power plant and auxiliaries.
        - d. Transmission.

120. **Irrigation.**
    - A. Source of supply (hydro-geology).
        - a. Quantity; sufficient with or without pondage.
        - b. Quality; suitable for agricultural purposes.
    - B. Methods of Development.
      (See Water Supply.)
    - C. Head for Distribution.
        - a. Gravity.
        - b. Pumping (machinery).
    - D. Distribution (evaporation, seepage).
        - a. Canals, flumes and ditches.
        - b. Modules or measuring devices.

121. Agricultural Drainage (Rainfall, run-off).

- A. Subsoil drainage.
    - Drains, ditches, outlets.
- B. Surface drainage.
    - a. Extent of drainage area.
    - b. Rainfall and run off.
    - c. Outlet, gravity, pumping.
    - d. Canals and ditches.

122. Flood Protection (Run-off).

- A. Height and nature of floods.
- B. Dikes and levees.
- C. Interior drainage.

123. Municipal Sewerage and Drainage.

- A. Systems; combined, separate, mixed.
- B. Extent of area and population.
- C. Topography; grades.
- D. Quantity.
    - a. Storm water (rainfall and run off).
    - b. Sewage.
- E. Disposal.
    - a. Directly to streams; gravity, pumping.
    - b. Treatment.
- F. Conduits and appurtenances.

124. Transportation and Navigation.

- A. Canals.
    - a. Route (geology and topography).
    - b. Water supply.
        - Source (rainfall, run-off and evaporation).
        - Quantity needed (lockage, seepage, evaporation and waste).
    - c. Works.
        - Excavation and embankments.
        - Aqueducts and culverts.
        - Dams and waste weirs.
        - Locks, gates and valves.
- B. River Improvements.
    - a. Stream flow (rainfall, run off, variations).
    - b. Reservoirs.

- c. Dredging.
- d. Dams; fixed and movable.
- e. Locks; gates and controlling works.

C. Harbors (currents, tides and waves).

- a. Breakwater.
- b. Dredging.
- c. Docks.

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