PART III.

WATER-WORKS FOR CITIES AND TOWNS.

CHAPTER XIV.

141. Introductory.—A preceding lecture in this course has shown to what an advanced state the public supply of water to large cities was developed in ancient times. The old Romans, Greeks, Egyptians, and other ancient peoples evidently posesssed an adequate appreciation of the value of efficient systems of public water-supply. Very curiously that appreciation diminished so greatly as almost to disappear during the middle ages. The demoralization of public spirit and the decrease of national power which followed the fall of Rome induced, in their turn, among other things, a neglect of the works of the great water system of Rome, entailing their partial destruction. The same retrogression in civilization seemed to affect other ancient nations as well, until probably the lowest state of the use of public waters and the construction of public water systems was reached somewhere between A.D. 1000 and A.D. 1300 or 1400. Without reasonable doubt the terrible epidemics or plagues of the middle ages can be charged to the absence of suitable water-supplies and affiliated consequences. During that middle period of the absence of scientific knowledge and any apparent desire to acquire it, sanitary works and consequently sanitary conditions of life were absolutely neglected. No progress whatever was made toward reaching those conditions so imperative in large centres of population for the well-being of the community. Grossly polluted waters were constantly used for public and private supplies, and no efforts whatever were made among the masses

toward the suitable disposition of refuse matters or, in a word, to attain to sanitary conditions of living.

A few important works were completed, particularly in Spain, but nothing indicative of general relief from the depths of ignorance and sanitary demoralization to which the greater portion of the civilized world had sunk at that time. The city of Paris took all its water from the Seine, except that which was supplied by a small aqueduct built in 1183. So small was the supply, aside from the water obtained from the river, that in 1550 it is estimated that the former amounted to about one quart only per head of population per day. The situation in London was equally bad, for it was only in the first half of the thirteenth century that spring-water was brought to the city by means of lead pipes and masonry conduits. Public water-works began to be constructed in Germany on a small scale in the early part of the fifteenth century. Obviously no pumps were available in those early days of water-supply, so that the small systems which have been mentioned were of the gravity class; that is, the water flowed naturally in open or closed channels from its sources to the points of consumption. Pumps of a simple and crude type first began to be used at a point on the old London Bridge in 1582, and in Hanover in 1527. Subsequently to those dates other pumps were set up on London Bridge, and installations of the same class of machinery were made in Paris in 1608, usually operated by water-power in some simple manner, as by the force of the water-currents. In 1624 the Paris supply received a reinforcement of 200,000 gallons per day by the completion of the aqueduct Arcueil. The New River Company was incorporated in 1619 for the partial supply of the city of London, and it began to lay its pipes at that time. As its name indicates, it took its supply from New River, and the inception of its business is believed to mark the first application of the principle of supplying each house with water. This company is still in existence and furnishes a considerable portion of the present London supply.

142. First Steam-pumps. — The application of steam to the creation or development of power by Watt, near the end of the eighteenth century, stimulated greatly the construction of water-

works, as it offered a very convenient and economical system of pumping. It seems probable that the first steam-pumps were used in London in 1761. Twenty years later a steam-pump was erected in Paris, while another was installed in 1783. The second steam-pump in London was probably constructed in 1787. In all these earlier instances of the use of steam-pumps river supplies were naturally used.

143. Water-supply of Paris and London. — After the early employment of steam pumping-machinery demonstrated its great efficiency for public water-supplies, the extension of the latter became more rapid, and since 1800 the supplies of the two great cities of London and Paris have been greatly increased. As late as 1890 the Paris supply amounted to about 65 gallons per head of population, one fourth of which was used as potable, being drawn from springs, while three fourths, drawn from rivers, was used for street-cleaning or other public purposes. This supply, however, was found inadequate and was re-enforced in 1892 by an addition of 30,000,000 gallons per day of potable water brought to the city by an aqueduct 63 miles long. Another addition of about 15,000,000 gallons has been provided more recently.

Rather curiously the water-supply of London is afforded by eight private companies, one of which is the old New River Company already mentioned. These companies, with one exception, draw their supply mainly from the rivers Thames and Lea, all such water being filtered. The remaining company draws its water from deep wells driven into the chalk. The total population supplied amounts to about 5,500,000, the rate of supply being thus less than 45 gallons per head per day.

144. Early Water-pipes.—Inasmuch as the use of cast iron for pipes was only begun about the year 1800, other materials were used prior to that date. As is well known, the pipes used in ancient water-works were either of lead or earthenware. In the eighteenth century wooden pipes made of logs with their centres bored out were used, sometimes 6 or 7 inches in diameter. As many lines of these log pipes were used as needed to conduct a single line of supply. In the earlier portion of the nineteenth century such log pipes, usually of pine or spruce, were used by

the old Manhattan Company for the supply of New York City. A section of such a wooden pipe, with a bore of about $2\frac{1}{2}$ inches is preserved in the museum of the Department of Civil Engineering of Columbia University. Large quantities of such pipes were formerly used.

145. Earliest Water-supplies in the United States.—The earliest system of public water-supply in this country was completed for the city of Boston in 1652. This was a gravity system. It is believed that the first pumping-machinery for such a supply was set up for the town of Bethlehem, Pa., and put in operation in 1754. Subsequently water-supplies were completed for Providence, R. I., 1772, and for Morristown, N. J., in 1791; the latter has maintained a continuous existence since that date. The first use of steam pumping-machinery in this country was in Philadelphia in 1800. This machinery, curiously enough, was largely of wood, including some portions of the boiler; it was necessarily very crude and would perform with 100 pounds of coal only about one twenty-fifth or one thirtieth of what may be expected from first-class pumping-machinery at the present time. Other cities and towns soon began to follow the lead of these earlier municipalities in the construction of public water-supplies, but the principal development in this class of public works has taken place since about 1850.

It is estimated that the total population supplied in 1880 was about 12,000,000, which rose to about 23,000,000 in 1890, and it is probably not less than 50,000,000 at the present time.

146. Quality and Uses of Public Water-supply.—Advances in the public supplies in this country have been made rather in the line of quantity than quality. Insufficient attention has been given both to the quality of the original supply and to the character of the reservoirs in which it is gathered until within possibly the past decade. A few cities like Boston have scrutinized with care both the quality of the water and the character of the bottom and banks of reservoirs, and have spared neither means nor expense to acquire a high degree of excellence in their potable water. The same observations can be applied to a few other large cities, but to a few only. The realization of the dependence of public health upon the character of water-supply, however,

has been rapidly extending, and it will doubtless be but a short time before the care exercised in collecting and preparing water for public use will be as great in this country as in Europe, where few large cities omit the filtration of public waters.

The distribution of water supplied for public use is not limited to domestic purposes, although that class of consumption controls public health so far as it is affected by the consumption of water. The applications of water to such public purposes as street-cleaning and the extinguishing of fires are of the greatest importance and must receive most careful consideration. Again, the so-called system of water-carriage in the disposal of domestic and manufacturing wastes, constituting the field of sewage-disposal, depends wholly upon the efficiency of the water-supply.

147. Amount of Public Water-supply. — The first question confronting an engineer in the design of public water-supply is the amount which should be provided, usually stated on the basis of an estimated quantity per head of population. This is not in all cases completely rational, but it is by far the best basis available. If the water-supply is designed for a small city or town previously supplied by wells or other individual sources, the first year's consumption will be low per head of population for the reason that many people will retain their own sources instead of taking a share of the public supply. As time elapses that portion of population decreases quite rapidly in numbers, and in a comparatively few years practically the whole population will use the public supply. In communities, therefore, where public systems have long existed and it is desired either to add to the old supply or to install new ones, the only safe basis of estimate is the entire population.

148. Increase of Daily Consumption and the Division of that Consumption.—The amount of water required per head of population might naturally be assumed identical with the past consumption, but that would frequently be incorrect. It is one of the most prominent features of the history of public water-supplies in this country that the consumption per head of population has increased with great rapidity from the early years of the installation of the different systems, for reasons both legitimate

and illegitimate. The daily average consumption of water from the Cochituate Works of the Boston supply increased from 42 gallons per head of population in 1850 to 107 gallons in 1893, and in the Mystic Works of the same supply the increase was from 27 gallons in 1865 to 89 gallons in 1894. Again, the daily average consumption in Chicago rose from 43 gallons per head per day in 1860 to 147 gallons in 1893, while in Philadelphia during the same period the increase was from 36 gallons per head per day to 150 gallons. In Cambridge, Mass., the increase in daily average consumption per head of population was from 44 gallons in 1870 to 70 gallons in 1894. These instances are sufficient to show that, under existing conditions, the daily consumption was increased at a rapid rate in the cities named, and they have been selected as fairly representative of the whole field. Civil engineers have made extended studies in connection with this question in a great number of cities, for it bears upon one of the most important lines of public works. It is absolutely essential to the health and business prosperity of every city that the water-supply should be abundant, safe, and adapted to the industrial and commercial pursuits of its population. It is imperative, therefore, that the division of the daily supply should be carefully analyzed. For this purpose the water-supply of a city may be, and frequently is, divided into four parts:

(1) That used for domestic purposes;
(2) That used for commercial and industrial purposes;
(3) That used for public purposes;
(4) That part of the supply which is wasted.

1. That portion of the supply consumed for domestic purposes includes not only the water used in private residences, but in those branches of consumption which may be considered of a household character found in hotels, clubs, stores, markets, laundries, and stables, or for any other residential service. As might be expected, this branch of consumption varies largely from one city to another. The results of one of the most interesting and suggestive studies ever made in connection with this subject are given by Mr. Dexter Brackett, M. Am. Soc. C. E., in

the Transactions of the American Society of Civil Engineers for 1895. In Boston the purely domestic consumption varied in different houses and apartments from 59 gallons per head per day in costly apartments down to 16.6 gallons per head per day in the poorest class of apartment. In Brookline, one of the finest suburbs of Boston, the quantity was 44.3 gallons per day. In some other cities of Massachusetts, as Newton, Fall River, and Worcester, this class of consumption varied from 6.6 gallons to 26.5 gallons per day, the latter quantity being found at Newton in some of the best residences, and the former at houses also in Newton having but one faucet each. In Yonkers, N. Y., where the system was metered, the amount was 21.4 gallons per head of population per day, while in portions of London, England, it varied from 18.6 to 25.5 gallons per head per day. The average of these figures gives a result of 18.2 gallons per head per day, which, in round numbers, may be put at 20 gallons.

2. It is obvious that the rate of consumption for commercial and industrial purposes in any city must vary far more than that for domestic purposes, for the reason that some cities may be essentially residential in character while others may be essentially manufacturing. At the same time, it is to be remembered that many manufacturing establishments may have their own water-supply. The city of Fall River, Mass., is eminently a manufacturing city, yet Mr. Brackett found that the manufacturing demand on the public water-supply amounted to 2 gallons only per inhabitant per day, as the manufacturers draw the most of their supply from the river, but that where the manufacturers depend upon the public supply for all their water the amount rises to a value between 20 and 30 gallons per inhabitant. In Boston in 1892 the water consumed for all manufacturing and industrial purposes, including railroads, gas-works, elevators, breweries, etc., amounted to 9.24 gallons per head of population per day, while in Yonkers in 1897 the total consumption for commercial purposes was 27.4 gallons per head per day. In the city of New York, as nearly as can be estimated, the consumption for commercial purposes is probably not far from 25 gallons

per inhabitant per day. Reviewing all these results, it may be stated that the water consumption for commercial and industrial purposes will generally range from 10 to 30 gallons per inhabitant per day.

3. The consumption of water for public purposes is a smaller amount than either of the two preceding. It covers such uses as public buildings, schools, street-sprinkling, sewer-flushing, fountains, fires, and other miscellaneous objects, more or less similar to those just named. The total use of this character was 3.75 gallons per inhabitant per day for Boston in 1892, and 5.57 gallons per inhabitant per day for Fall River in 1899. A few other cities give the following results: Minneapolis in 1897, 5 gallons; Indianapolis, 3 gallons; Rochester, N. Y., 3 gallons; Newton, Mass., 4 gallons; Madison, Wis., 10 gallons. In Paris it is estimated that not far from 2.5 gallons per head of population per day are used. It is probable, therefore, that an amount of 5 gallons per day per inhabitant will cover this particular line of consumption.

4. A substantial portion of the water-supply of every city fails to serve any useful purpose, for the reason that it runs to waste either by intention or by neglect. The sources of this waste are defective plumbing, including leaky faucets and cocks; deliberate omission to close faucets and cocks, constituting wilful waste; defective or broken mains, including leaky joints; and waste to prevent freezing.

149. Waste of Public Water. — All these wastes except the last are inexcusable. There is no difficulty in detecting defective plumbing, and its existence is generally known to the householder; but if the wasted water is not measured and paid for, it is far too frequently considered more economical to continue the waste than to pay for the plumber's services. In a multitude of cases cocks are left open indefinitely for all sorts of insignificant reasons; in closets, under the erroneous impression that the continuous running of the stream will materially aid in a more effective cleansing of soil- and sewer-pipes, failing completely to appreciate that a far more powerful stream is required for that purpose; sometimes in sinks, for refrigerating purposes, and in many other

flows to waste unobserved from leaky joints and defective or broken pipes.

Inasmuch as cast-iron water-pipes are produced in lengths which net 12 feet as laid, there will be at least 440 joints per mile. Furthermore, as leaky joints and broken pipes are as likely to occur at one place as another, it seems reasonable to estimate leakage through them as proportionate to the length of the pipe-line in a system; and that conventional law is frequently assumed. New pipe-lines have sometimes shown a leakage of 500 to 1200 gallons per mile of line per day. Civil engineers have sometimes specified the maximum permissible leakage of a new pipe-line at 60 to 80 gallons per mile of line per day for each inch in diameter of pipe, thus permitting 600 to 800 gallons to escape from a 10-inch pipe. In 1888 the late Mr. Chas. B. Brush reported a leakage of about 6400 gallons per mile per day from a practically new 24-inch cast-iron main, 11 miles long, of the Hackensack Water Company, the pressure being 110 pounds per square inch. Tests of water-pipes in German and Dutch cities have been reported as showing less waste than 300 gallons per mile per day, but such low results, unless for very low pressures and short lines, may reasonably be doubted. Obviously losses of this character will probably increase with the age of the pipe. By a very ingenious procedure based upon his own experience, Mr. Emil Kuichling of Rochester, N. Y., reaches the conclusion that a reasonable allowance for the waste from leaky joints and defective pipes is 2500 to 3000 gallons per mile of cast-iron pipe-line per day. If, as is frequently the case, the population per mile of pipe ranges from 300 to 1000, the preceding allowance amounts to 3 to 10 gallons per head of population per day. The loss or waste due to running cocks or faucets to prevent freezing cannot be estimated with sufficient accuracy to receive a definite valuation, but it must be considered an element of the total item of waste.

150. Analysis of Reasonable Daily Supply per Head of Population.—It has repeatedly been found that the losses or wastes set forth in the preceding statements amount apparently to quantities varying from 30 to 50 per cent of the total supply; or, to put it a little differently, the water unaccounted for in even the best

systems now constructed apparently may reach one third to one half of the total supply. This is an exceedingly wasteful and unbusinesslike showing. It is probable that the statement is, to some extent at least, an exaggeration. It is practically certain that either the amount supplied or the amounts consumed, or both, are never measured with the greatest accuracy, and that the errors are such as generally swell the apparent quantity wasted. After making judicious use of the data thus afforded by experience, it is probable that the following tabular statement given by Messrs. Turneaure and Russell represents limits within which should be found the daily average supply of water in a well-constructed and well-administered system.

Use.	Gallons per Head per Day.		
	Minimum.	Average.	Maximum.
Domestic	15	25	40
Industrial and commercial	5	20	35
Public	3	5	10
Waste	15	25	30
Total	38	75	115

The values given in the preceding table are reasonable and sufficient to supply the legitimate needs of any community, but, as will be shown in the succeeding table, there are cities in this country whose average consumption is more than twice the maximum rate given above.

151. Actual Daily Consumption in Cities of the United States.— The following table exhibits the average daily consumption of water throughout the entire year for the cities given, as determined for the years indicated in the table.

The city of Buffalo shows a daily consumption of 271 gallons per inhabitant, and Allegheny, Pa., 247 gallons per inhabitant. There are a considerable number showing an average daily consumption per inhabitant of 160 gallons or more. All such high averages exhibit extravagant use of water, or otherwise inefficient administration of the water-supply. The reduction of such high rates of consumption is one of the most difficult problems confronting the administration of public works. The use

TABLE I.

	Population. 1890.	Population per Tap. 1890.	Per Cent of Taps Metered 1890.	Consumption per Inhabitant Daily, Gallons. 1890.	Per Cent of Taps Metered 1895.	Consumption per Inhabitant Daily, Gallons. 1895.	Consumption per Inhabitant Daily, Gallons. 1900.
New York	1,515,301	13.9	20.2	79	27.0	100	115
Chicago	1,099,850	7.1	2.5	140	2.8	139	190
Philadelphia	1,046,964	6.1	0.3	132	0.74	162	229
Brooklyn	838,547	8.7	2.5	72	1.9	89	
St. Louis	451,770	11.8	8.2	72	7.4	98	111
Boston	448,477	6.6	5.0	80	5.2	100	143
Cincinnati	305,891	8.5	4.1	112	6.5	35	121
San Francisco	298,997	9.9	41.4	61	28.0	63	73
Cleveland	270,055	8.7	5.8	103	4.5	142	175
Buffalo	255,664	6.3	0.2	186	0.85	271	262
New Orleans	242,039	54.0	0.4	37	.....	35	48
Washington	230,392	6.5	0.3	158	1.5	200	174
Montreal	216,000	5.3	1.7	67	1.6	83	
Detroit	205,876	5.1	2.1	161	8.2	152	156
Milwaukee	204,468	11.1	31.9	110	51.0	101	84
Toronto	181,000	4.0	4.1	100	3.7	100	
Minneapolis	164,738	16.5	6.3	75	16.0	88	93
Louisville	161,129	11.9	5.9	74	6.6	97	
Rochester	133,896	5.4	11.4	66	18.0	71	83
St. Paul	133,156	12.7	4.2	60	1.7	60	51
Providence	132,146	9.4	62.4	48	74.0	57	54
Indianapolis	105,436	35.6	7.6	71	7.1	74	79
Allegheny	105,287	7.0	0	238	7.1	247	
Columbus	88,150	11.5	6.4	78	9.3	127	183
Worcester	84,655	8.9	89.4	59	90.0	66	67
Toledo	81,434	18.6	9.4	72	35.0	70	59
Lowell	77,696	9.2	22.9	66	33.0	82	83
Nashville	76,168	14.9	0.8	146	24.0	139	140
Fall River	74,398	14.9	74.6	29	82.0	35	35
Atlanta	65,533	20.0	89.6	36	99.0	42	61
Memphis	64,495	11.9	3.7	124	4.6	100	98
Quebec	63,000	10.4	0	160	0	170	
Dayton, O	61,220	20.0	3.8	47	24.0	50	62
Camden, N. J	58,313	.....	.....	131	0	200	185
Des Moines, Ia	50,093	20.0	60.0	55	42.6	43	48
Ottawa, Ont	44,000	4.2	0	130	0	200	
Yonkers, N. Y	32,033	12.0	82.4	68	99.8	100	76
Newton, Mass	24,379	5.5	67.4	40	77.3	65	62
Madison, Wis	13,426	11.0	31.0	40	61.0	52	44
Albany, N. Y	98,000	.....	0.4	162	12.3	.....	192
New Bedford, Mass	55,000	.....	.....	99	15.4	.....	101
Springfield, Mass	49,299	.....	.....	87	31.9	.....	88
Holyoke, Mass	40,000	.....	.....	77	5.82	.....	103*

* Estimated.

of the meter has proved most efficient in preventing wastes or other extravagant consumption, as in that case every consumer pays a prescribed rate for the amount which he takes.

152. Actual Daily Consumption in Foreign Cities.—It has been for a long time a well-recognized fact that the daily use of water in American municipalities is far greater per inhabitant than in European cities. It is difficult to explain the marked

TABLE II.

City.	Estimated Population.	Consumption per Capita Daily, Gallons.
England, 1896–97:*		
London	5,700,000	42
Manchester	849,093	40
Liverpool	790,000	34
Birmingham	680,140	28
Bradford	436,260	31
Leeds	420,000	43
Sheffield	415,000	21
Nottingham	272,781	24
Brighton	165,000	43
Plymouth	98,575	59
Germany, 1890 (Lueger):		
Berlin	1,427,200	18
Breslau	330,000	20
Cologne	281,700	34
Dresden	276,500	21
Düsseldorf	144,600	25
Stuttgart	139,800	26
Dortmund	89,700	78
Wiesbaden	62,000	20
France, 1892 (Bechmann):		
Paris	2,500,000	53
Marseilles	406,919	202
Lyons	401,930	31
Bordeaux	252,654	58
Toulouse	148,220	26
Nantes	125,000	13
Rouen	107,000	32
Brest	70,778	3
Grenoble	60,855	264
Other countries, 1892–96 (Bechmann):		
Naples	481,500	53
Rome	437,419	264
Florence	192,000	21
Venice	130,000	11
Zurich	80,000	60
Geneva	70,000	61
Amsterdam	515,000	20
Rotterdam	240,000	53
Brussels	489,500	20
Vienna	1,365,000	20
St. Petersburg	960,000	40
Bombay	810,000	61
Sidney	423,600	38
Buenos Ayres	680,000	34

* Compiled, except the figures for London, by Hazen. *Engineering News*, 1899, XLI. p. 111.

difference, but it is probably due in large part to the more extravagant general habits of the American people. Examinations in a number of cases have shown that the actual domestic use of water, at least in some of the American cities, is not very different from that found in corresponding foreign cities. Table II exhibits the consumption of water in European cities, as compiled from various sources and given by Turneaure and Russell.

These foreign averages, with three exceptions, represent reasonable quantities of water used, and they have been confirmed as reasonable by many special investigations made in this country.

153. Variations in Rate of Daily Consumption.—The preceding observations are all based upon an average total consumption found by dividing the total annual consumption by the number of days in the year. This is obviously sufficient in a determination of the total supply needed, but it is not sufficient in those matters which involve a rate of supply during the different hours of the day, or the amount of the supply for the summer months as compared with those of the winter. As a general rule the greatest supply will be required during the hot summer months when lawn- and street-sprinkling is most active. It appears from observations made in a considerable number of the large cities of the United States that the maximum monthly average consumption may run from about 110 to nearly 140 per cent of the monthly average throughout the year. As an approximate value only, it may be assumed for ordinary purposes that the maximum monthly demand will be 125 per cent of the average.

The daily rate taken throughout the year is considerably more variable than the monthly. There are days in some portions of the year when consumption by hotels and industrial activities is at a minimum. On the other hand, there are other days when those activities are at a maximum and the total draft will be correspondingly high. Experience has shown that the maximum total draft may vary from about 115 to nearly 200 per cent of the average. It is permissible, therefore, to take approximately for general purposes the maximum total daily consumption as 150 per cent of the average. Manifestly any total

consumption will have an hourly rate which may vary greatly from the early morning hours, when the draft should be almost nothing, to the forenoon hours on certain days of the week, when the draft is a maximum. These variations have frequently been investigated, and it has been shown that the maximum rate per hour of a maximum day may sometimes rise higher than 300 per cent of the average hourly rate for the year. These considerations obviously attain their greatest importance in connection with the capacity of the plant, either power or gravity, from which the city directly draws its supply. The hourly capacity of the pumps or steam-plant furnishing the supply need not necessarily be equal to the maximum, since storage-reservoirs may be and usually are used; but the capacity of the pipe system leading from such storage-reservoirs must be equal to the maximum hourly rate required.

154. Supply of Fire-streams.—The draft on a water-supply for fire-extinguishing purposes may have an important influence upon the hourly rate of consumption. These observations are particularly pertinent in connection with the water-supply of small cities where the draft of fire-engines may be considered a large percentage of the total hourly consumption. It is obviously impossible to assign precisely the number of fire-streams which may be required simultaneously in a city having a given population, but experiences of a considerable number of civil engineers furnish reasonable bases on which such estimates may be made. Table III exhibits such estimates as made by the civil engineers indicated. It is given by Mr. Emil Kuichling in the Transactions of the American Society of Civil Engineers for December, 1897. Probably no more reasonable estimate can be now presented.

The discharge of each fire-stream will of course vary with its diameter and the pressure at the fire-engine, but as an average it is reasonable to assume that each stream will discharge 250 gallons per minute. The quantity of water required, therefore, to supply the estimated number of streams given in Table III is found by simply multiplying the number of those streams by 250, to ascertain the total number of gallons consumed per minute. If x is the number of thousand inhabitants in any city, and if y represents the required number of streams, then

TABLE III.

TABLE EXHIBITING ESTIMATED NUMBER OF FIRE-STREAMS REQUIRED SIMULTANEOUSLY IN AMERICAN CITIES OF VARIOUS MAGNITUDES.

Population of Community.	Number of Fire-streams Required Simultaneously.			
	1 Freeman.	2 Shedd	3 Fanning.	4 Kuichling.
1,000	2 to 3	.....	.....	3
4,000	.....	.....	7	6
5,000	4 to 8	5	.....	6
10,000	6 to 12	7	10	9
20,000	8 to 15	10	.....	12
40,000	12 to 18	14	.....	18
50,000	.....	.....	14	20
60,000	15 to 22	17	.....	22
100,000	20 to 30	22	18	23
150,000	.....	.....	25	34
180,000	.....	30	.....	38
200,000	30 to 50	.....	.....	40
250,000	.....	.....	.....	44
300,000	.....	.....	.....	48

Mr. Kuichling deduces the following formulæ for y by the use of the preceding tables, i.e., these formulæ express the results given in the preceding table as nearly as simple forms of formulæ permit.

"For Freeman's data: $\left\{\begin{array}{l} y \text{ min.} = 1.7\sqrt{x} + 0.03x, \\ y \text{ max.} = \dfrac{x}{5} + 10. \end{array}\right\}$ . . . (1)

For Shedd's data: $y = \sqrt{5x} = 2.24\sqrt{x}$. . . . (2)

For Fanning's data: $y = \dfrac{x}{10} + 9$. . . . . (3)

For the author's data: $y = 2.8\sqrt{x}$. . . . . (4)

While for the average ordinary consumption of water, expressed in gallons per head and day, q, Mr. Coffin's formula, as given in his paper previously cited, may be taken

$$q = 40x^{0.14}." \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

By combining equation (5) with equation (4), remembering that the maximum rate of consumption is usually about 1.5 times the average, the total draft in gallons per minute upon

the discharging system at the time of a conflagration will become as follows:

$$Q = 250(2.8\sqrt{x}) + \frac{3}{2}\frac{40 \times 1000}{1440} x^{1.14}$$

$$= 250\left(2.8\sqrt{x} + \frac{x^{1.14}}{6}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

This maximum rate of consumption during a conflagration does not affect the total supply of a large city like New York, Boston, or Chicago, but it may become of relatively great importance in a small city or town. In a large city this draft may and frequently does tax the capacity of a small district of the discharging system. In designing such systems, therefore, even for large cities, it is necessary to insure all districts against a small local supply when a large one may pressingly be needed.

CHAPTER XV.

155. Waste of Water, Particularly in the City of New York.—The quantity of water involved in designing a water-supply for cities and towns is much larger than that which is actually needed. The experience of civil engineers in many cities, both in this country and in Europe, shows conclusively that the portion of water actually wasted or running away without serving any purpose will usually run from 30 to 50 per cent of the total amount brought to the distributing system. In the city of New York there is strong reason to believe that the wastage is not less than two thirds of the total quantity supplied. It is frequently assumed that both the quantities supplied and the quantities uselessly wasted in New York are larger than in other places. As a matter of fact those quantities are actually smaller than in some other large cities. While the supply per inhabitant in New York City is much larger than should be required, the use of water by its citizens is not extravagant when gauged by the criterion of use in other large cities. This question was most carefully and exhaustively investigated in 1899 and the early part of 1900 by Mr. John R. Freeman of Boston, acting for the comptroller of the city of New York.

The usual wastes of a water-supply system may be distributed under six principal heads. First, leaky house-plumbing; second, and "possibly first in order of magnitude," leaky service-pipes connecting the house pipe system with street-mains; third, leaving water-cocks open unnecessarily; fourth, leaky joints in street-mains or pipes; fifth, possibly pervious beds and banks of distributing-reservoirs; sixth, stealing or "unlawful diversion" of water through surreptitious connections.

The sixth item is probably an extremely small one in New

York, although instances of that kind of waste have been found. It is an old wastage known as far back in time as the ancient Roman water-supply. The second and third items probably constitute the bulk of the wastage in this city.

156. Division of Daily Consumption in the City of New York.— In the course of his search for the various sources of consumption, Mr. Freeman concluded from his examinations and from the use of the various means placed at his command for measuring the daily consumption between December 2d and December 5th, 1899, and December 8th and December 15th, 1899, that the average daily consumption could be divided as follows:

	Gallons per Inhabitant per Day.	
Probable average amount really used....	40	
Assumed incurable waste.....	10	75
Curable waste, probably.....	65	
Daily uniform rate of delivery by Croton Aqueduct.....	115	

In his investigations Mr. Freeman had the elevation of water in the Central Park reservoir carefully observed every six minutes throughout the twenty-four hours. At the same time the uniform flow through the new Croton Aqueduct was known as accurately as the flow through such a conduit can be gauged at the present time. Knowing, therefore, the concurrent variation of volume in the Central Park reservoir supplied by the new Croton Aqueduct and the rate of flow in that aqueduct, the consumption of water per twenty-four hours would be known with the same degree of accuracy with which the flow in the aqueduct is measured. It was found by these means that the actual consumption between the hours of 2 and 4 A.M. was at the rate of 94 gallons per inhabitant per day, although the actual use at that time was as near zero as it is possible to approach during the whole twenty-four hours. Nearly all of that rate of consumption represents waste.

Summing up the whole matter in the light of his investigations, Mr. Freeman made the following as his nearest estimate

to the actual consumption of the daily supply of water of New York City:

	Gallons per Inhabitant per Day.
ACTUAL USE:	
Domestic (average)	12 –20
Manufacturing and commercial	20 –30
City buildings, etc	2 – 4
Fires, street flushing and sprinkling	0.4– 0.7
Total	34 –55
INCURABLE WASTE (probabilities):	
Leaks in mains	1– 2
Leaks in old and abandoned service-pipes	1– 2
Poor plumbing, all taps metered and closely inspected	2– 3
Careless and wilful wastes	1– 2
Under-registry of meters	1– 1
Total incurable waste and under-registry	6–10
Minimum use and waste	40–65
NEEDLESS WASTE:	
Leaks in street-mains (a guess)	15–10
Leaks in service-pipes between houses and street-mains (a guess)	15–10
Defective plumbing (a guess)	25–15
Careless and wilful opening of cocks (a guess)	17–14
To prevent freezing in winter and for cooling in summer	3– 1
Total needless waste	75–50
Total consumption	115–115

157. Daily Domestic Consumption. — The quantity assigned in the preceding statement to domestic use is confirmed by the abundant experience in other cities where services are carefully metered, as in Fall River, Lawrence, and Worcester, Mass., and in Woonsocket, R. I., where measurements by meters show that the domestic consumption has varied from 11.2 to 16.3 gallons per inhabitant per day. Furthermore, annual reports of the former Department of Public Works and the present Department of Water-supply for the City of New York show that during the years 1890 to 1898 such meters as have been used in the territory supplied by the Croton and the Bronx aqueducts indicate a daily consumption varying from 13.8 to 24.2 gallons per inhabitant per day. The same character of confirmatory evidence can be applied to the quantities assigned to manufacturing and commercial uses, city buildings and fires, street flushing and sprinkling.

depending upon local considerations. In 1893, when it was desired to estimate the future population of London for as much as forty years, it was found that the increase for the ten years from 1881 to 1891 was 18.2 per cent, with an average of about 20 per cent for several previous decades. It could, therefore, be reasonably estimated for the city of London that its population at the end of any ten-year period would be 18.2 per cent greater than its population at the beginning of that period. In Appendix 1 of the report of the Massachusetts State Board of Health upon the Metropolitan water-supply for the city of Boston made in 1895, the increases for the two ten-year periods 1870–1880 and 1880–1890 were 6 per cent and 9.6 per cent respectively for the city proper, but for the population within a ten-mile radius from the centre of the city they were 28.7 per cent and 33.7 per cent respectively. The corresponding percentages for the cities of New York, Philadelphia, and Chicago for the same periods are as shown in the following tabular statement:

	Population.			Percentages of Increase.	
	1870.	1880.	1890.	1870–80.	1880–90.
New York.....	1,626,119	2,131,051	2,821,802	31	32
Philadelphia.....	726,247	921,458	1,162,577	27	26
Chicago.....	310,996	550,618	1,075,158	77	95*

* Includes added territory.

Obviously every estimate of this kind must be made upon the merits of the case under consideration. The probable increase of population for any particular city is sometimes estimated by considering the circumstances of growth of some other city of practically the same size, and if possible with the same commercial industries or residential environment, or making suitable allowances for variations in these respects. Since it is imperative to secure as accurate estimates as practicable, both methods or other suitable methods should be employed, in order that the results may be confirmed or modified by comparison. In every case the supply system should be designed to meet reasonable estimated requirements for the longest practicable future period, preferably not less than twenty years.

161. Sources of Public Water-supplies.—One of the most important features of a proposed water-supply is its source, since not only the potable qualities are largely affected by it, but frequently the amount also. The two general classes into which potable waters are divided in respect to their sources are surface-waters and ground-waters. Surface-waters include rain-water collected as it falls, water from rivers or smaller streams, and water from natural lakes; they are collected in reservoirs and lakes or impounding reservoirs. Ground-waters are those collected from springs, from ordinary or shallow wells, from deep or artesian wells, and from horizontal galleries, like those sometimes constructed near and parallel to subsurface streams or in subsurface bodies of water, affording opportunity for filtration from the latter through sand or other open materials to them.

The quality of water will obviously be affected by the kind of material through which it percolates or flows. Surface-waters, flowing over the surface of the ground or percolating but a short distance below the surface, naturally have contact with vegetable matter, unless they are collected in a country where the soil is sandy and where the vegetation is scarce. If such waters flow through swamps or over beds of peat or other similar vegetable mould or soil, they may become so impregnated with organic matter or so deeply colored by it that they are not available for potable purposes. Ground-waters, on the other hand, possess the advantage of having flowed through comparatively great depths of sand or other earthy material essentially free of organic matter. They may, however, in some locations, carry prejudicial amounts of objectionable salts in solution, rendering them unfit for use. As a rule, ground-waters are apt to be of better quality than surface-waters, but they do not generally stand storage in reservoirs as well as surface potable waters. It is advisable to store them in covered reservoirs from which the light is excluded, rather than in open reservoirs. They are sometimes impregnated with salts of iron to such an extent as to make it necessary to resort to suitable processes for their removal, and they are also occasionally found so hard as to require the employment of methods of softening them.

Both sources of supply are much used in the United States.

Table IV shows the percentages of the various classes of supplies as found in this country during the year 1897; the total number of supplies having been at that time nearly 4000.

TABLE IV.

WATER-SUPPLIES OF THE UNITED STATES.

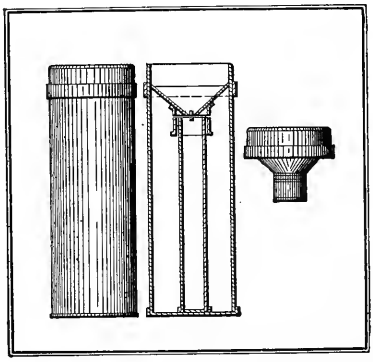
	Source.	Per Cent of Total.	
Surface-waters:	Rivers	25	
	Lakes	7	
	Impounding reservoirs	6	
	Combinations	·5	
			38·5
Ground-waters:	Shallow wells	26	
	Artesian wells	10	
	Springs	15	
	Galleries and tunnels	1	
	Combinations	2	
			54
Surface- and ground-waters:	Rivers and ground-waters	6	
	Lakes and ground-waters	1	
	Impounding-reservoirs and ground-waters	·5	
			7·5
	Total		100.0

It will be observed that a little more than one half of the supplies are from ground-waters. The practice in connection with European public water-supplies is different in that a considerably larger percentage of the total is taken from ground-waters.

The original source of essentially all the water available for public water-supplies is the rainfall. It becomes of the greatest necessity, therefore, to secure all possible information regarding rainfall wherever it may be necessary to construct a public water-supply. Civil engineers and other observers have for many years maintained continuous records of rainfall observations at various points throughout the country, but it is within only a comparatively short time that the number of those points has been large. Through the extension of the work of the Weather Bureau, points of rainfall observation are now scattered quite generally throughout all States of the Union. The oldest observations are naturally found in connection with stations located in the Eastern States, where the rainfall is more uniformly distributed than in many other portions of the country. Obviously

rainfall records become of the greatest importance in those localities like the semiarid regions of the far West where long periods of no rain occur.

162. Rain-gauges and their Records. — The instrument used for the collection of rain in order to determine the amount falling in a given time is the rain-gauge, which may be fitted with such appliances as to give a continuous record of the rate of rainfall. It has been found that the location of the rain-gauge



Ordinary Rain-gauge.

has a very important influence upon the amount of rain which it collects. It should be placed where wind currents around high structures in its vicinity cannot affect its record. The top of a large flat-roofed building is a good location in a city, although the elevation above the surface of the ground, as is well known, affects the quantity of water collected by the gauge. The collection will be greater at a low elevation than at a high one, in consequence of the greater wind currents at the higher point, it being well known that less rain will be collected where there is the most wind, other things being equal.

163. Elements of Annual and Monthly Rainfall. — In consequence of the great variations in the rate of rainfall, not only for different portions of the country, but at different times during the same storm, it becomes necessary to determine various quantities such as the maximum, minimum, and mean annual rainfall, the actual monthly rainfall for different months of the year, and

the maximum and minimum monthly rainfall for as long a period as possible. The minimum monthly rainfall and the minimum annual rainfall are of special importance in connection with public water-supply and water-power questions, since those minima will, in connection with the area of a given watershed, determine the greatest amount of water which can be made available for use.

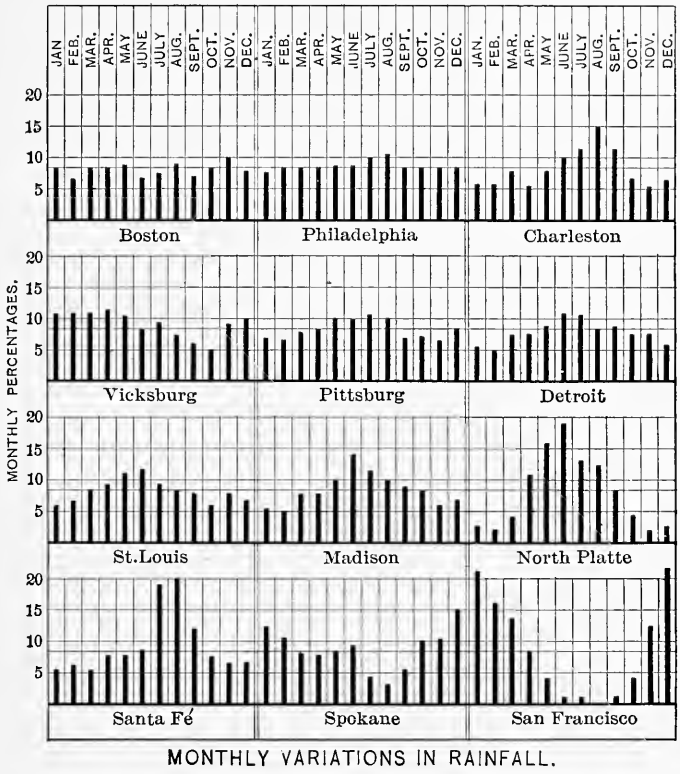


FIG. 1.

In entering upon the consideration of such questions, therefore, civil engineers must inform themselves with the greatest detail as to the characteristics of the monthly and the annual rainfall of the locality in which their works are to be located.

The diagram Fig. 1 and Table V are constructed from data given in the bulletins of the Weather Bureau and exhibit some

TABLE V.

GENERAL RAINFALL STATISTICS FOR THE UNITED STATES.

Station.	Mean Yearly Rainfall.	Per Cent of Summer and Autumn Rain to Mean Yearly.	Per Cent Driest Year to Mean Year.	Per Cent Two Driest Years.	Per Cent Three Driest Years.	Number of Years' Record.
North Atlantic:						
Boston	45.4	50	60	70	80	79
New York	44.7	52	62	77	80	61
Philadelphia	42.3	52	70	75	80	72
Washington	42.9	51	69	71	74	45
South Atlantic:						
Wilmington	53.7	61	75	80	81	26
Charleston	49.1	61	48	55	62	89
Augusta	48.0	50	81	88	87	27
Jacksonville	54.1	65	74	77	83	27
Key West	38.2	70	54	61	73	49
Gulf and Lower Mississippi:						
Montgomery	52.5	42	76	80	83	24
Mobile	62.6	51	68	75	78	26
New Orleans	60.3	52	64	75	77	26
Galveston	47.7	58	50	65	72	26
Nashville	50.2	46	67	73	83	32
Ohio Valley:						
Pittsburg	36.6	53	70	78	85	54
Cincinnati	42.1	50	60	72	71	62
Indianapolis	42.2	51	59	76	82	27
Cairo	42.6	47	62	75	81	25
Louisville	47.2	48	74	81	85	25
Lake Region:						
Detroit	32.5	56	65	72	79	46
Cleveland	36.6	54	71	74	81	41
Duluth	30.7	63	65	81	88	26
Upper Mississippi Valley:						
St. Louis	40.8	52	55	65	75	60
Chicago	34.0	54	66	80	86	30
Milwaukee	31.0	55	66	74	73	53
Madison	33.2	58	39	58	68	28
St. Paul	28.2	63	53	54	75	39
The Plains:						
Omaha	31.4	63	57	63	70	27
North Platte	18.1	61	56	67	72	22
Denver	14.3	48	59	71	77	27
Cheyenne	12.7	55	39	62	75	27
The Plateau:						
Tucson	11.7	65	44	79	80	19
Santa Fé	14.6	69	53	63	66	37
Salt Lake City	18.8	39	55	64	74	29
Walla Walla	15.4	38	46	81	86	27
Pacific Coast:						
Astoria	77.0	33	64	68	77	34
Portland	46.2	31	67	76	79	27
Sacramento	19.9	16	42	67	84	47
San Francisco	23.4	17	51	73	78	47
Los Angeles	17.2	15	33	48	59	24
San Diego	9 7	18	30	54	61	47

of the general features of the rainfall for different points throughout this country. The heavy lines of the diagram show the average monthly precipitation at the points indicated, for periods of a considerable number of years, as shown in the table. It will be observed that the rainfall is comparatively uniform in the North Atlantic States but quite variable on the Pacific coast, as well as in the Mississippi and Missouri valleys and west of those valleys.

164. Hourly or Less Rates of Rainfall.—Although not often of great importance in connection with public water-supply systems, it is sometimes necessary to possess data regarding maximum hourly (or less) rates of precipitation in connection with sewer or drainage work. The earlier records give exaggerated reports of maximum rates of rainfall, although that rate varies rapidly with the time. Throughout a rain-storm the rate of precipitation is constantly varying and the maximum rate seldom if ever extends over a period equal to a half-hour; usually it lasts but a few minutes only. In this country an average rate of 1 inch per hour, extending throughout one hour, is phenomenal, although that rare amount is sometimes exceeded. A maximum rate of about 4 inches per hour, lasting 15 to 30 minutes, is, roughly speaking, about as high as any precipitation of which we have reliable records. The wasteways or other provisions for the discharge of surplus or flood waters of the Metropolitan Water-supply of Boston are designed to afford relief for a total precipitation of 6 inches in twenty-four hours. It is safe to state that an excess of that accommodation will probably never be required.

165. Extent of Heavy Rain-storms.—In all engineering questions necessitating the consideration of these great rain-storms it is necessary to remember that their extent is frequently much greater than the areas of watersheds usually contemplated in connection with water-supply work. The late Mr. James B. Francis found in the great storm of October, 1869, which had its maximum intensity in Connecticut, that the area over which 6 inches or more of rain fell exceeded 24,000 square miles, and that the area over which a depth of 10 inches or more fell was 519 miles. Again, in the New England storm of February,

1886, 6 inches or more of rain fell over an area of at least 3000 square miles. Storm records show that as much as 8 or 10 inches in depth have fallen over areas ranging from 1800 to 500 square miles, respectively, in a single storm.

166. Provision for Low Rainfall Years.—The capacity of any public water-supply must evidently be sufficient to meet not only the general exigencies of the year of lowest rainfall, but also the conditions resulting from the driest periods of that year. It is customary among civil engineers to consider months as the smaller units of a dry year. It is necessary, therefore, to examine not only the annual rainfalls but the monthly rates of precipitation during critical years, i.e., usually during dry years.

It is impossible to determine absolutely the year of least rainfall which may be expected, but evidently the longer the period over which observations have extended the nearer that end will be attained. It is sometimes assumed that the lowest annual rainfall likely to be expected in a long period of years is 80 per cent of the average annual rainfall for the same period. Or, it is sometimes assumed that the average rainfall for the lowest two or three consecutive years will be 80 per cent of the average for the entire period, and that the year of minimum rainfall may be expected to yield two thirds of the annual average precipitation. Such features will necessarily vary with the location

TABLE VI.

	Mean Monthly Rainfall, Inches.		Respective Ratios.		Probable Depth in Inches of Actual Rainfall.
January	4	×	1.65	=	6.6
February	4	×	1.50	=	6.0
March	4	×	1.65	=	6.6
April	4	×	1.45	=	5.8
May	4	×	.85	=	3.4
June	4	×	.75	=	3.0
July	4	×	.35	=	1.4
August	4	×	.25	=	1.0
September	4	×	.30	=	1.2
October	4	×	.45	=	1.8
November	4	×	1.20	=	4.8
December	4	×	1.60	=	6.4

of the district considered. Conclusions which may be true for the New England or northern Atlantic States probably will not hold for the south Atlantic and Gulf States. Data for such conclusions must be obtained from the rainfall of the locality considered. Table VI exhibits the comparative monthly rainfall which J. T. Fanning suggests may be used approximately for the average Atlantic coast districts.

If the average monthly rainfall throughout the year were one inch, the values of the ratios would show the actual monthly precipitation. In general the table would be used by dividing the total yearly rainfall by 12, and then multiplying that monthly average by the proper ratio taken from the table opposite the month required. Such tables should only be used for approximate purposes and when actual rainfall records are not available for the district considered.

167. Available Portion of Rainfall or Run-off of Watersheds. —If the public water-supply is to be drawn from a stream where the desired rainfall records exist, it is necessary to know what portion of the rainfall, either in the driest or in other years, may be available. This is one of the departments of the hydraulics of streams for which much data yet remain to be secured. The watersheds or areas drained by some streams, like the Sudbury River of the Boston, and the Croton of the New York water-supply, have, however, been studied with sufficient care to give reliable data. The amount of water flowing in a stream from any watershed for a given period, as a year, is called the annual "run-off" of the watershed, and it is usually expressed as a certain percentage of the total rainfall on the area drained. For certain purposes it is sometimes more convenient to express the run-off from the watershed as the number of cubic feet of water per second per square mile of area. Table VII, taken from Turneaure and Russell, exhibits run-off data for a considerable number of streams in connection with both average and minimum rainfalls.

The information to be drawn from this table is sufficient to give clear and general relations between the recorded precipitation and run-off. The percentage of run-off is seen to vary quite widely, but as a rule it is materially less for the year of minimum

TABLE VII.

STATISTICS OF THE FLOW OF STREAMS.

Stream.	Area Drained, Square Miles.	Years.	Average Yearly.			Year of Minimum Flow.		
			Rain, Inches.	Flow, Inches.	Per Cent.	Rain, Inches.	Flow, Inches.	Per Cent.
Sudbury	75.2	1875–97	45.77	22.22	48.6	32.78	11.19	34.1
Cochituate	18.87	1863–96	47.08	20.33	43.2	31.20	9.76	31.3
Mystic	26.9	1878–96	43.79	19.96	45.6	31.22	9.32	29.8
Connecticut	10,234	1871–85	44.69	25.25	56.5	40.02	18.25	45.6
Croton	338	1870–94	48.38	24.57	50.8	38.52	14.54	37.8
Upper Hudson	4,500	1888–96	39.70	23.36	59.0	33.49	17.46	52.2
Genesee	1,060	1894–96	39.82	12.95	32.5	31.00	6.67	21.5
Passaic	822	1877–93	47.08	25.44	54.0	35.64	15.23	42.7
Upper Mississippi	3,265	1885–99	26.57	4.90	18.4	22.86	1.62	7.1

Stream.	Area Drained, Square Miles.	Years.	Average for December to May.			Average for June to November.		
			Rain, Inches.	Flow, Inches.	Per Cent.	Rain, Inches.	Flow, Inches.	Per Cent.
Sudbury	75.2	1875–97	22.98	17.52	76.0	22.61	4.70	20.8
Cochituate	18.87	1863–96	22.97	14.87	64.7	24.10	5.46	22.7
Mystic	26.9	1878–96	22.11	15.12	68.4	21.66	4.84	22.4
Connecticut	10,234	1871–85	20.13	17.95	89.1	24.56	7.30	29.7
Croton	338	1870–94	23.39	17.81	76.1	24.99	6.76	27.0
Upper Hudson	4,500	1888–96	18.20	16.23	89.0	21.50	7.13	33.0
Genesee	1,060	1894–96	19.58	10.20	52.2	20.24	2.75	13.6
Passaic	822	1877–93	22.47	18.22	81.1	24.39	7.19	29.5

flow than for the average year. That feature of the table is an expression of the general law, other things being equal, that the smaller the precipitation the less will be the percentage of run-off. A number of influences act to produce that result. During a year of great precipitation the earth is more nearly saturated the greater part of the time, and hence when rain falls less of it will percolate into the ground and more of it will run off. Again, if the ground is absolutely dry, a certain amount of rain would have to fall before any run-off would take place. The area and shape of a watershed will also affect to some extent the flow of the stream which drains it. A larger run-off would reasonably be expected from a long narrow watershed than from one more nearly circular in outline. The greater the massing of the water-

shed, so to speak, the more opportunity there is for the water to be held by the ground and the less would be the run-off.

TABLE VIII.

AVERAGE YIELD OF SUDBURY WATERSHED, 1875–1899, INCLUSIVE, VARIOUSLY EXPRESSED.

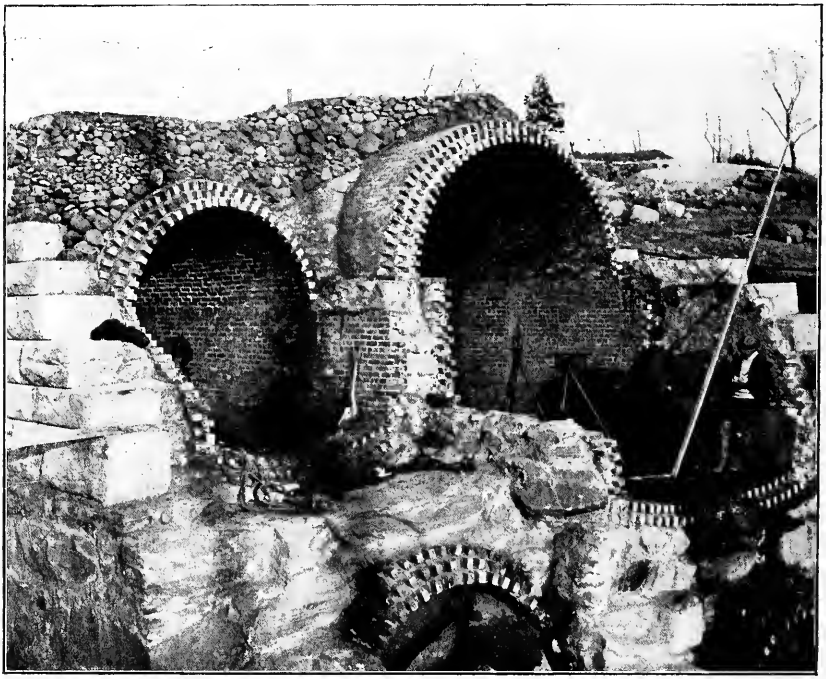
(Area of watershed, 75.2 square miles.)

Month.	A Square Mile.		Rainfall.		
	Cubic Feet per Second.	Million Gallons per Day.	Collected, Inches.	Per Cent Collected.	Total, Inches.
January	1.937	1.252	2.233	51.6	4.33
February	2.904	1.877	3.050	71.7	4.26
March	4.489	2.901	5.175	117.4	4.41
April	3.124	2.019	3.485	107.5	3.24
May	1.680	1.086	1.936	58.1	3.33
June	.735	.475	.821	28.0	2.93
July	.305	.197	.352	9.3	3.77
August	.478	.309	.551	13.3	4.16
September	.376	.243	.419	13.0	3.23
October	.829	.536	.956	21.9	4.37
November	1.474	.953	1.645	39.0	4.22
December	1.612	1.042	1.859	51.9	3.58
Year	1.655	1.070	22.482	49.1	45.83

168. Run-off of Sudbury Watershed.—Table VIII has been given by Mr. Charles W. Sherman, as representing the average yield of the Sudbury watershed for the period 1875 to 1899, inclusive, expressed in several different ways. The average rainfall was 45.83 inches, and the percentage which represents the run-off is 49.1 per cent of the total. The average monthly run-off varies from .305 cubic foot (for July) to 4.489 cubic feet (for March) per second per square mile. As a general rule it may be stated that the average run-off from the drainage areas of New England streams amounts very closely to 1,000,000 gallons per square mile per day. The area of the Sudbury watershed is 75.2 square miles, with 6.5 per cent of that total area occupied by the surface of lakes or reservoirs. As will presently be seen, the amount of exposed water surface in any watershed has an appreciable influence upon its run-off.

169. Run-off of Croton Watershed.—The total area of the Croton watershed, from which New York City draws its supply,

i.e., the area up-stream from the new Croton Dam, is 360.4 square miles, of which 16.1 square miles, or 4.47 per cent, of its total area is water surface. Mr. John R. Freeman found in the investigations covered by his report to the comptroller of the city of New York in 1900 that the average annual rainfall on that area for the thirty-two years beginning 1868 and ending 1899 was 48.07 inches, and that the average run-off for the same period was 47.7 per cent of the total average rainfall, equivalent to a depth of 22.93 inches.



Aqueducts near Jerome Park Reservoir, New York City.

Table IX gives the main elements of the rainfall and run-off for the Croton watershed during the thirty-two year period, for the averages just given.

The table shows that the least annual rainfall was 36.92 inches for 1880, and that the run-off represented a depth of 12.63 inches only, or 34.21 per cent of the total annual precipitation.

TABLE IX.

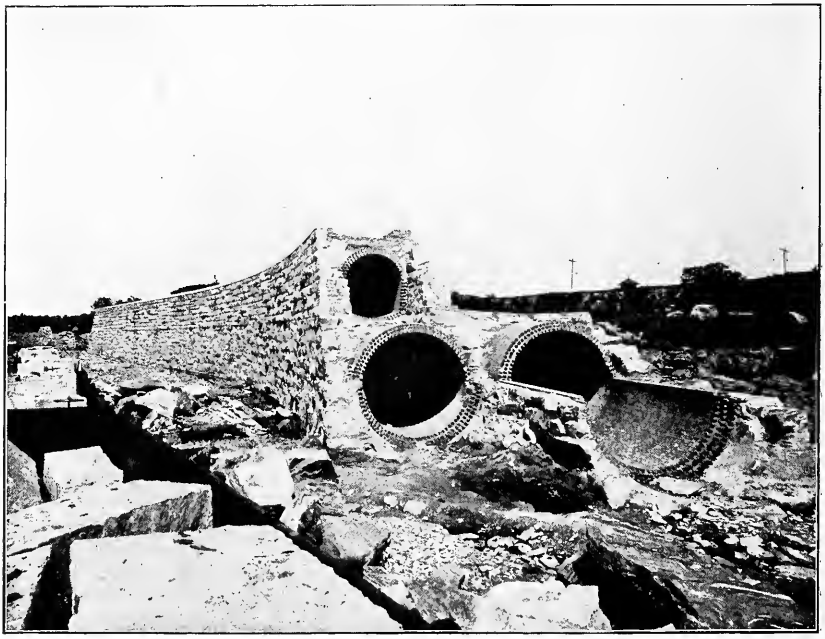
RAINFALL ON CROTON WATERSHED IN TOTAL INCHES—1868-1898. NATURAL FLOW OF CROTON RIVER AT OLD CROTON DAM, IN EQUIVALENT INCHES. PERCENTAGE OF RUN-OFF TO RAINFALL FOR EACH YEAR.

Year.	Total Rainfall.	Total Run-off.	Per Cent.	Year.	Total Rainfall.	Total Run-off.	Per Cent.
1868	50.33	33.33	66.22	1885	43.67	17.71	40.55
1869	48.36	23.61	48.82	1886	47.74	20.10	42.10
1870	44.63	19.20	43.02	1887	57.29	26.61	46.45
1871	48.94	19.46	39.76	1888	60.69	35.27	58.12
1872	40.74	16.92	41.53	1889	55.70	31.39	56.36
1873	43.87	25.02	57.03	1890	54.05	25.95	48.01
1874	42.37	25.10	59.24	1891	47.20	23.48	49.75
1875	43.66	24.77	56.73	1892	44.28	17.68	39.93
1876	40.68	21.09	51.84	1893	54.87	29.05	52.94
1877	48.23	20.22	41.92	1894	47.33	20.56	43.44
1878	55.70	27.17	48.78	1895	40.58	15.95	39.31
1879	47.04	19.65	41.77	1896	45.85	23.26	50.73
1880	36.92	12.63	34.21	1897	53.12	25.59	48.17
1881	46.69	19.25	41.23	1898	57.40	29.72	51.77
1882	52.35	24.28	46.38	1899	44.67	22.28	49.88
1883	42.70	13.33	31.22	Average for 32 years.	48.07	22.93	47.70
1884	51.28	24.08	46.96				

As a rule the same feature of a low percentage of run-off will be found belonging to the years of low rainfall, although there are many irregularities in the results. On the other hand, the high percentages of run-off are for the years 1868, 1888, and 1889, and they will generally be found belonging to years of relatively great precipitation. A low percentage of run-off will also be lower if the year to which it belongs follows a dry year or a dry cycle of two or three years. Similarly the high percentages of run-off will, as a rule, be higher if they follow years of high precipitation; that is, if they belong to a cycle of relatively great rainfall.

170. Evaporation from Reservoirs.—If it is contemplated to build reservoirs on a watershed the capacity of which is being estimated on the basis of either the driest year or the driest two- or three-year cycle, it is necessary to make a deduction from the rainfall for the evaporation which will take place from the surface of the proposed reservoir. In order that that deduction may be made as a proper allowance for added water surface in a drainage area, it is necessary that the amount of evaporation be determined for the district considered. The rate of evaporation is dependent upon the area of water surface, upon the wind, and upon the temperature both of the water and air above it. Numerous

evaporation observations have been made both in this and other countries, and extensive evaporation tables have been prepared by the Weather Bureau, from which a reasonable estimate of the monthly evaporation for all months in the year may be made for almost any point in the United States. Particularly available



Aqueduct Division Wall of Jerome Park Reservoir, New York City.

observations have been made by Mr. Desmond Fitzgerald of Boston on the Chestnut Hill reservoirs of the Boston Water-supply, and by Mr. Emil Kuichling, engineer of the Rochester Water-works, on the Mount Hope reservoir of the Rochester supply. Table X exhibits the results of the observations of both these civil engineers.

As would be anticipated, the period from May to September, both inclusive, shows by far the greatest evaporation of the whole year, while December, January, and February are the months of least evaporation. The total annual evaporation at Boston was 39.2 inches and 34.54 inches at Rochester.

TABLE X.

MEAN MONTHLY EVAPORATIONS.

Month.	Chestnut Hill Reservoir, Boston, Mass.		Mount Hope Reservoir, Rochester, N. Y.	
	Evaporation, Inches.	Per Cent of Yearly Evaporation.	Evaporation, Inches.	Per Cent of Yearly Evaporation.
January	0.96	2.4	0.52	1.5
February	1.05	2.7	0.54	1.6
March	1.70	4.3	1.33	3.9
April	2.97	7.6	2.62	7.6
May	4.46	11.4	3.93	11.4
June	5.54	14.2	4.94	14.3
July	5.98	15.2	5.47	15.8
August	5.50	14.0	5.30	15.4
September	4.12	10.4	4.15	12.0
October	3.16	8.1	3.16	9.1
November	2.25	5.7	1.45	4.2
December	1.51	3.9	1.13	3.2
Total for year	39.20		34.54	
Mean temperature	48°.6		47°.8	

A reference to data of the Weather Bureau will show that annual evaporation as high as 100 inches, or even more, may be expected on the plateaux of Arizona and New Mexico. Other portions of the arid country in the western part of the United States will indicate annual evaporations running anywhere from 50 to 90 inches per year, while on the north Pacific coast it will fall as low as 18 to 40 inches.

171. Evaporation from the Earth's Surface.—Data are lacking for anything like a reasonably accurate estimate of evaporation from the earth's surface. It is well known that the loss of water from that source is considerable in soils like those of swamps, particularly when exposed to the warm sun, but no reliable estimate can be obtained for the exact amount. Nor is this necessary for the usual water-supply problems, since it is included in the difference between the total rainfall of any district and the observed run-off in the streams. Indeed evaporation from reservoirs is similarly included for reservoirs existing when the run-off observations are made.