RAINFALL AND WATER-SUPPLY.

BY JOHN BIRKINBINE.

[*A Lecture delivered before the FRANKLIN INSTITUTE, Friday, February 4, 1887.*]

THE LECTURER was introduced by the Secretary of the INSTITUTE, and spoke as follows :

LADIES AND GENTLEMEN:—The close relation, or rather, we might say, inseparable connection between rainfall and the procurement of a supply of water for public or domestic uses, while recognized in a general way, is far from being appreciated; and we are apt to forget that all available permanent water-supply is directly traceable to rainfall. Perhaps you will correct me, and advise the use of the terms “directly or indirectly,” but we are probably justified in using the term “directly.” Nature’s laboratory is not a secret one; we can see, if we will, the methods which are employed to accomplish certain ends; and can notice the direct connection between rainfall and all water-supply. We admit that all visible streams or water-courses are immediately traceable to the rain which falls upon their respective drainage areas; and the many unseen or underground streams (the presence of which are determined by various methods which expose the formation of the earth), also owe their existence to certain territories upon which the rain is precipitated, and which are underlaid by certain stratifications of rock or to bodies of water which intercept these strata. The geological structure of a specific district, therefore, naturally affects the water-bearing strata and their position in relation to the surface; but it is generally the disturbed condition of the rocks which causes these subterranean waters to rest in basins or pools, or to find vent as springs. Although where the stratification is regular, and its seams or crevices are continuous, water is often obtained at great depths, apparently beyond the influence of rain, or, as far as can be determined from any connection with other reservoirs, the source from which this water comes, and that which maintains its flow, is the rainfall.

Whether as a gentle shower, or as silently-falling snow, or as a rain-storm, all precipitation of moisture has for its ultimate effect

the production of a proper proportion of water for the growth of vegetation and for the use of mankind, and the quantity of water represented by a given rain- or snow-fall, can be but imperfectly understood or appreciated. Calculations of the volume, weight and power necessary to elevate the water will astonish an investigator, and it is my desire to present, if possible, some conception of the force thus represented.

No attempt will be made to estimate the power which condenses, and holds one volume of oxygen and two volumes of hydrogen into a volume $\frac{1}{1800}$ of the space which they fill as gases ; for it is claimed that to reduce oxygen and hydrogen to the form of water a pressure of 40,000 pounds per square inch is required. And here we may refer to the fact that Faraday demonstrated that to decompose one drop of water required as much electricity as is contained in the thunderbolt. We will, however, consider the power which is apparently more within our comprehension ; namely, that of vaporization, which, while not changing the compound of the two gases, transforms water [which is heavier than air] into vesicles or vapor which is carried to great heights above the earth, and wafted by winds for thousands of miles over the surface of the globe. When we remember that by far the greatest amount of evaporation is near the equator, and that the ocean is the reservoir from which the rains are produced, we may form some idea of the work done, but a very inadequate conception of the power employed.

The presence of water in the atmosphere, which as a great gaseous sea, forms an envelope surrounding the globe, is appreciable in so many ways, that it is remarkable this presence is so often forgotten by us. The dew on the blade of grass, the frost on the window, the brilliant colors of the rainbow, the fog on the ocean, the mist in the valley, the majesty of the cloud bank, the rain, the hail, the snow, all are constant evidences that we exist in an atmosphere in which water is always present in appreciable amount, the quantity of water varying with location, surroundings, temperature, etc. The general composition of the atmosphere is given in *Miller's Elements of Chemistry*, as follows :

	<i>Volumes.</i>
Oxygen, ...	20'61
Nitrogen, ...	77'95
Carbon dioxide, ...	0'04
Aqueous vapor (average), ...	1'40

It contains also traces of nitric acid, ammonia and carburetted hydrogen. The total weight of water in the atmosphere surrounding the earth is estimated to be 54,460,000,000,000 tons; a weight of which we can form no conception, much less realize how it can be held in suspension, as it were; for the air is a mixture and not a chemical compound, or a distinct substance like water. Prof. Cooke, of Harvard, says: "We may regard the globe as surrounded, by at least three separate atmospheres—one of oxygen one of nitrogen, and one of aqueous vapor—all existing simultaneously in the same space, yet each entirely distinct from the other two, and only very slightly influenced by their presence. Oxygen and nitrogen cannot be reduced to liquids even by the intense cold of the poles. The slightest reduction of temperature, however, when the air is saturated with moisture, is sufficient to condense a portion of the vapor to water and to shower it in drops of rain. On the other hand, when the temperature rises, the heat converts more water into vapor, and the aqueous atmosphere is replenished. Thus it is that the atmosphere of aqueous vapor on the earth is liable to very great fluctuations, from which the Creator has protected the great mass of the air by endowing oxygen and nitrogen with the power of retaining the æiriform condition under all circumstances, and the fluctuation in the one case is as important as the stability in the other." *

The presence of moisture in the air is made constantly manifest to the sense of sight, particularly by sudden changes of temperature; but often there are circumstances which attract attention where the conditions are in whole or in part produced by artificial means. A very marked instance of this was noticed in starting an iron works in New York State last winter, when the thermometer for a week seldom indicated a temperature above zero, and for days averaged -10° . When doors were opened and the cold dry air rushed into rooms which were warm and moist, clouds of vapor were produced, which filled the apartment as with steam, and such in reality it was. In several instances snow was the result. To prevent freezing, the machinery was kept in motion in advance of the requirements, and the air from the blowing-engine was allowed to escape through a safety vent. When all was in

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* *Religion and Chemistry*, p. 71.

readiness, it was found impossible to close this valve, owing to the ice, one inch in thickness, which had formed on it by the moisture in the air which passed through the blowing-engine, and came from a warm room, being condensed and congealed by the lower temperature of the outside air.

In Mr. Lorin Blodget's work on *Climatology*, he states that, "for much the larger area of the United States, and for all portions east of the Rocky Mountains, the distinguishing feature of the atmospheric precipitation in rain is its *symmetry and uniformity in amount over large areas*. The quantity has rarely or never any positive relation to the configuration of the surface, which would identify it with the distribution of Western Europe and the North Pacific Coast; and, in contrast with these, it has a diminished quantity at the greater altitudes generally, and the greatest amounts in the districts near the sea level. It also differs from these districts, and from large land areas generally, in having a greater amount in the interior than on the coasts for the same latitudes, at least as far north as the forty-second parallel of north latitude."*

We must not interpret this extract too literally, for they are generalizations and we cannot overlook many local influences which affect the rainfall. To a considerable extent, the position of the rain-gauge influences the quantity of precipitation measured, for series of careful records, taken at various localities, and covering considerable periods of time, indicate that the quantity entering the gauge, diminishes irregularly with its height above the ground; probably on account of the greater wind velocity at the higher level. One authority asserts that, at a height of twenty feet, this decrease amounts to as much as ten per cent. of the entire rainfall; and one exceptional case is recorded where the measured precipitation at an elevation of fifty feet, was but forty per cent. of that at the earth's surface. Our water department has attempted to construct a curve showing this decrease from its own observations, as well as from reported experiments; this curve demonstrates that at an elevation of forty feet above the ground eighty-seven per cent. of the actual rainfall enters the gauge. Commenting upon the question, why there is less rainfall caught in gauges high above the ground than in those on the ground, Prof. Cleveland Abbe, in his lecture in December last, upon "Popular Errors

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* *Climatology of the United States*, p. 317.

in Meteorology,"* says: "There is really the same amount of rainfall at 100, or 50 feet altitude as on the ground; the fault is in our rain-gauge which is exposed to stronger winds when set high up, and to almost no wind when flush with the ground. The stronger winds deflected around the gauge carry the drops to one side, and hence the higher gauge catches less than the lower one."

The variations are prominently shown in the annual report of the Philadelphia Water Department for 1885, in which the average recorded precipitations for the years 1883, 1884 and 1885 are given as follows: (The percentages refer to the United States Signal Station as a standard.)

U. S. Signal Station, ...	37'25	inches, percentage	100
Philadelphia Water Department, ...	35'29	" "	95
Pennsylvania Hospital, ...	42'72	" "	115
Germantown, ...	41'25	" "	111
West Chester, ...	50'59	" "	136
Pottstown, ...	44'52	" "	119
Reading, ...	42'91	" "	115

There are other localities mentioned in the report, but I have selected those which are nearest to the city, and we will consider only the first three, which are within the limits of the city, and are taken where it is presumed all possible precautions against error are provided for. These three show a variation in the average, for the three years, of 6.43 inches of rain, and, if we select monthly records, the differences are even greater than the average, as the following will demonstrate: In August, 1885, the U. S. Signal Station reported 6.80 inches, the Water Department 7.90, and the Pennsylvania Hospital 10.08 inches, a difference between extremes of 3.28 inches. In the months where the rainfall is not so heavy as in August, the differences are scarcely less marked. Thus, the following are recorded:

U. S. S. S. W. Dept. P. Hospital.

November, 1884, ...	2'31	2'98	4'01,	a difference of 1'70 inches.
In October, 1885, ...	3'33	3'67	4'85,	" " 1'52 "
In December, 1884, ...	3'28	3'78	4'76,	" " 1'48 "

It is not my purpose to take up the subject of rainfall generally, although the topic for the lecture might possibly have given

* See this JOURNAL, 123, 115.

rise to such expectation. The purpose of the lecture would be better expressed by the more prolix title, "The Water which Falls upon and which is Required by the City of Philadelphia"; and we will now consider the first branch of the subject, which was suggested by the favor with which an article,* entitled "Sun Pumping," prepared for one of our technical journals, was received.

THE WATER WHICH FALLS UPON PHILADELPHIA.

Have you ever thought of the volume, or the weight of the water which is annually precipitated upon the area covered by the city in which we live; or even upon the quantity which falls upon a square mile or a square acre? If not, the amount will be a surprise, and, at the risk of appearing to treat the subject in an elementary manner, I will ask you to follow some calculations which will possibly give an idea of the volume of water, most of which the sewerage system of a great city must care for, the work done by the sun in elevating the weight to the cloud-level (if such a term is admissible), and the relation that the rain falling upon the city bears to the water supplied to it. Let us first consider the precipitation upon an acre and a square mile:

In a square acre there are . . . . . 43,560 square feet.
 " " mile " $(5,280 \times 5,280) = 27,878,400$ " "

Therefore, each foot of rain which falls upon these areas is equivalent in volume to—

43,560 cubic feet, or 325,829 gallons of water per acre; and
 27,878,400 " " " 208,530,432 " " " " square mile.

Now, in round numbers, thirty-two cubic feet of water, under ordinary conditions and temperature, weigh one net ton (2,000 pounds), and thirty-six cubic feet weigh one gross ton (2,240 pounds). On this basis, the weight of water can be readily calculated; however, as the usual method of reporting the rainfall is in inches and not in feet, we may first bring the above figures to this base.

For each inch in depth of rain, the figures per acre and per square mile are as follows :

	<i>Volume.</i>	<i>Weight.</i>
Per acre,	3,630 cubic feet, or 27,152 gallons =	100.8 gross tons. [113.4 net tons]
Per sq. mile,	2,323,200 cu. ft., or 17,377,536 gals. =	64,533 $\frac{1}{3}$ gross tons. [72,600 net tons.]

**Iron Age.*

On the authority of Chief Engineer and Surveyor Mr. S. L. Smedley, the entire area covered by the city, is $129\frac{383}{1000}$ square miles, and if we multiply the volume and weight of water per square mile representing one inch of rainfall, by the area of the city, we have the following :

Volume.

300,582,586 cubic feet, or 2,248,357,740 gallons.

Weight.

8,349,516 gross tons, or 9,393,206 net tons.

This weight is only appreciable by comparing it with the quantities of materials with which we are familiar. During the year 1886, the anthracite coal district of Pennsylvania produced over 33,000,000 gross tons, a larger output than ever before; and, as far as the product is concerned the year was also the greatest in iron production, viz., 5,684,543 gross tons. But four inches of rain on the area within the corporate limits of the city of Philadelphia, weigh as much as all of the anthracite coal mined last year in this state; and one inch of rain upon this area represents a weight nearly fifty per cent. greater than the total output of pig iron in the United States in 1886. The wheat crop of the United States for 1886, estimated by the Department of Agriculture at Washington at 457,000,000 bushels, weighs about the same as one and one-quarter inches of rain on the area of this city.

From the table of the means and extremes of rainfall, as observed at the Pennsylvania Hospital, we find that the annual average for fifty-seven years was 45.19 inches, or 3.766 feet.

TABLE OF THE MEANS AND EXTREMES OF RAINFALL AT THE PENNSYLVANIA HOSPITAL, PHILADELPHIA, COMPILED FROM THE RECORDS FROM 1830 TO 1886, BOTH YEARS INCLUDED.

	<i>Average Rainfall in Inches.</i>	<i>Maximum Rainfall in Inches.</i>	<i>Minimum Rainfall in Inches.</i>
January, ...	3.577	7.837	0.730
February, ...	3.160	6.615	0.551
March, ...	3.551	6.985	1.087
April, ...	3.524	7.750	0.585
May, ...	4.031	8.685	1.070
June, ...	4.142	11.025	0.887
July, ...	4.177	11.805	0.985
August, ...	4.729	15.816	0.620
September, ...	3.645	13.904	0.249

	<i>Average Rainfall in Inches.</i>	<i>Maximum Rainfall in Inches.</i>	<i>Minimum Rainfall in Inches.</i>
October, ...	3'324	10'050	0'447
November, ...	3'566	9'025	1'036
December, ...	3'764	7'378	1'044
Winter, ...	10'500	15'370	4'711
Spring, ...	11'167	17'650	6'594
Summer, ...	13'047	29'228	6'256
Autumn, ...	10'526	18'011	3'359
Year, ...	45'190	61'135 (1867)	33'240 (1834)

We can now estimate the weight and volume of the average amount of rain which annually falls on the city, as follows :

Volume.

For the year, 13,580,327,043 cubic feet, or 101,603,286,282 gallons.

Weight.

377,314,640 gross tons, or 424,478,970 net tons.

In *Stahl und Eisen*, Prof. Ehrenwerth estimates that the total annual coal production of the world approximates 400,000,000 tons (metric).

Therefore, if we accept Prof. Ehrenwerth's figures as correct, the rain, which has fallen annually on the area of Philadelphia, has averaged over ninety-five per cent. of the total coal output, at present, of the world.

Upon the assumption of a uniform distribution of the precipitation throughout the year (a condition which the table shows, and which we know, does not exist), the daily average for the fifty-seven years under consideration, would be :

Volume.

37,214,595 cubic feet, or 278,365,171 gallons.

Weight.

1,033,739 gross tons, or 1,162,956 net tons.

But the table demonstrates that in the year 1867 as much as 61.135 inches of rain fell, which would increase the above amounts over thirty-five per cent., and that in the year 1834 but 33.24 inches of rain are reported, which is about seventy-three per cent. of the average precipitation, and the figures, as above, for that year would be but seventy-three per cent. of those given. It will be noted that the average rainfall occupies a point very nearly midway between the two extremes above given ; this mean between the extremes is 47.188 inches.

Similarly the maximum and minimum monthly precipitations

indicate variations from these figures, but, for the present, we will consider only the minimum monthly rainfall to estimate a possible daily average from it, leaving the maximum to actually recorded severe rain-storms; for the rainfall has ranged from *nil* to 7·323 inches in a day. Taking the minimum monthly rainfall from the table, viz., September, 0·249 inches, the daily average on the assumption of uniform distribution throughout the month is 0·0083 inches, which indicates that for any one month the minimum amount of water falling per day on the city of Philadelphia was :

Volume.

2,494,835 cubic feet, or 18,661,369 gallons.

Weight.

69,301 gross tons, or 77,963·5 net tons.

(or probably less than the evaporation from the area of the city in the same time.)

To consider the maximum rainfall, we look up the records of severe rain-storms, and by reference to the Pennsylvania Hospital reports, we find that from and including the year 1840, there were twenty-seven days on which over three inches of rain fell. The greatest amount being 7·323 inches, which are reported as falling during the twenty-four hours in August, 1873; the next in August, 1867, with a record of 6·680 inches, and in August, 1860, 6·005 inches. On two consecutive days (the 22d and 23d) of September, 1882, 5·566 and 4·260 inches, respectively, fell, a total for the two days of 9·826 inches. Of the twenty-seven days, on which over three inches of rain fell, eleven were in August, four in June, three in October and September, two in April and November, and one each in January and July; the heaviest of these last two being a fall of four inches in January, 1875.

Most of the large precipitations above mentioned, continued but for a portion of a day; in fact, many of the records mentioned are for precipitations lasting but part of a day. Some of these will be noted later.

If, for the purpose of forming an appreciation of the enormous quantity of water represented by one of these heavy down-pours, we take the latest recorded one for a day, viz., August 4, 1885, 4·46 inches, we find that it was equivalent (for the area of Philadelphia) to a

Volume

of 1,340,598,334 cubic feet, or 10,027,675,520 gallons, and

Weight

of 37,238,843 gross tons, or 41,893,678 net tons.

Or, to make the amount appreciable, such a storm as that mentioned, when less than four and one-half inches of rain fell in a day, deposited on the area of Philadelphia, a weight of water greater by over twelve per cent. than the total amount of anthracite coal mined in 1886; and this weight of water represented more than half of the weight of the total crop in 1886 of corn, wheat and oats.

The volume would be over one-fourth of that of the great storage dam proposed for the Croton Aqueduct at Quaker Bridge, to cost the City of New York, \$7,000,000.

The automatic recording water-gauge, connected with the office of the Water Department, at Thirteenth and Spring Garden Streets, shows that on the morning of November 18th last, 0.52 inches of rain fell in nine minutes; and a similar gauge, located at Doylestown, indicated, on August 3, 1885, a fall of one and one-half inches of rain in twenty minutes. It is unnecessary to follow calculations further to form a conception of the amount of water represented by such precipitation; but it will be interesting to note that a rainfall, over the area of Philadelphia, such as that recorded last November, is equivalent to a flow of 290,000 cubic feet per second; which is 15,000 feet per second more than the reported average flow of water over the falls of Niagara.

If time permitted, we could follow the subject of the weight and volume of water which falls upon nearly 2,000 square miles of drainage area of the Schuylkill River, of which but about forty per cent. passes Fairmount Dam, giving an average daily flow for the river, at ordinary stages, of less than three times the average daily precipitation on the area of Philadelphia above determined.

It has been the desire to draw our minds to an appreciation of quantity and weight, and I would now ask that you follow me to a conception of the *power* represented by the rainfall upon the area of our city, or, if I may use the term the "Horse-power employed in Sun Pumping," for as Guyot says, in *Earth and Man*: * * * "The Sun, the great awakener of life, the king of Nature, shoots his burning rays every day athwart the waters. He causes the invisible vapors to rise, which, lighter than the air itself, unceasingly tend to soar into the atmosphere, filling it, and constituting within it another atmosphere. In their ascending movement, they encounter the colder layers of the higher regions of the atmos-

phere, which perform the part of coolers. They are condensed in vesicles, that become visible under the form of clouds and fogs. Then borne along by the winds whether invisible still, or in the state of clouds, they spread themselves over the continents and fall in abundant rains upon the ground which they fertilize. * * * To study the distribution of the rains and of the moisture on the surface of the globe, is to study the course of the winds which are their carriers"*

The power that is required to convert the water into vapor and lift it far above us, can be but imperfectly understood; but to form a conception, let us consider merely the elevation of the water to the cloud level. Prof. Loomis, in his text book on *Meteorology*, gives the average height of the clouds as two miles; we know that some of the clouds which drop their rain upon the earth are much lower than this, but we do not know how high the water was raised, nor how far it was carried before intercepted by the cooler stratum that made the vapor visible as cloud. Let us then assume the average height to which the water, (which as rain falls on Philadelphia) is elevated, to be 10,000 feet; and, using the figures with which we have become somewhat familiar, attempt to estimate this power. If our estimate of height is excessive, it is capable of reduction by the decimal system to any amount required.

Hann is given as the authority for the statement that five-tenths of the aqueous vapor is found within the stratum between the sea level and 6,500 feet above it, and that nine-tenths of the vapor is below 20,000 feet. It is asserted that from a series of balloon and mountain observations, he formulated the following general table:

Altitude above Sea Level.	Proportionate Quan- tity of Aqueous Vapor.
1,000 feet,	1.00
2,000 "	0.87
3,000 "	0.73
4,000 "	0.64
5,000 "	0.56
6,000 "	0.50
7,000 "	0.48
8,000 "	0.42
10,000 "	0.34
12,000 "	0.27
14,000 "	0.23
16,000 "	0.18
18,000 "	0.16
20,000 "	0.13
22,000 "	0.07

* *Earth and Man*, p. 130.

This is referred to, that you may note a possible error in the assumption, but as we know that many of the lower strata of clouds are evanescent, and are dissipated by the sun's rays, while most of our rains come from clouds at a greater elevation, we will make the estimates on the assumption that all of the vapor which falls as rain has been raised to an average height of 10,000 feet; for the object of these estimates is rather to form a conception of these forces of nature, than to give absolutely exact figures.

To make the estimates of power, let us use the familiar standard of 33,000 pounds raised one foot high per minute as one horse-power, and apply the formula :

$$\frac{\text{Net tons per day} \times 2,000 \text{ lbs.} \times 10,000 \text{ feet}}{33,000 \text{ foot-pounds} \times 1,440 \text{ minutes}} \text{ equals the HP. developed.}$$

It is only the developed horse-power which we shall consider, and no allowances will be made for losses of any kind.

We, therefore, have the following figures to represent the horse-power to be developed in raising to a height of 10,000 feet the quantities of water represented by the precipitation of—

	<i>Horse-power.</i>
One inch of rain on one acre, ...	47'7
" " " " " square mile, ...	30,555
" " " " " 129'383 square miles (the area of Philadelphia), ...	3,953,370
The average daily precipitation of the month of minimum rainfall (0'249 inches) on the area of Philadelphia, ...	32,812'9
The average daily rainfall, calculated from the annual average (45'19 inches) on the area of Philadelphia, ...	489,460
The maximum rainfall recorded in twenty-four hours in fifty-seven years (7'323 inches) on the area of Philadelphia, ...	28,950,524

To understand what these powers represent, we can best refer to the volume of the last census on manufactures, in which the total amount of steam- and water-power employed in 85,923 establishments reporting was 3,410,837 horse-power, of which 2,185,458 horse-power was steam-power, and 1,225,379 horse-power was water power. Therefore, if the census returns are considered to represent developed power, the entire manufacturing industry of the United States, as given by the census returns, has not sufficient

power connected with it, to raise in one day the water represented by one inch of rain on the area of Philadelphia and the entire steam- and water-power, as reported in the census, could not, in working together for twenty-four hours, develop more than twelve per cent. of what we have estimated as necessary to raise the 7·323 inches of rain which fell in one day over the area of Philadelphia to a height of 10,000 feet. To form an idea of the "sun-pumping" represented by a severe rain, such as above mentioned, when 0·52 inches of rain fell in nine minutes; we find that to raise an equal amount in the same time to a height of 10,000 feet would require the development of 329,000,000 horse-power. Now, if we apply Fairbairn's formula of "one cubic foot falling twelve feet per second equal to one horse-power" to Niagara Falls, where 275,000 cubic feet per second fall 230 feet, we find that the entire power which this immense cataract could produce in nine hours, would be scarcely sufficient to elevate to cloud-level the water which fell in the city of Philadelphia in the nine minutes above mentioned. In these general estimates, no allowances of any kind are made. I would offer one more comparison; at the western extreme of Lake Superior, close to the City of Duluth, the St. Louis River, a stream about double the volume of the Schuylkill River, falls in a distance equal to that from Manayunk to the Fairmount dam, from a height 100 feet higher than the Roxborough hill to tide level. And yet, upon the basis of one cubic foot falling twelve feet per second, this magnificent, but as yet undeveloped stream would supply but one-fourth the power to raise the average daily rainfall on the area of the city.

We can form another idea as to what the rainfall upon the area of the city of Philadelphia amounts to, which will probably be even more satisfactory than the calculations as to horse-power. The usual method of rating pumping-engines, is by the duty in pounds of water raised one foot high by the consumption of 100 pounds of coal; and although some tests have shown duties in excess of 100,000,000 foot-pounds, we shall consider that a sufficiently high basis for estimation, for it is much above the average work performed by the pumping-engines in the United States. If, therefore, we assume a duty of 100,000,000 foot-pounds, we will have for each gross ton of coal consumed 2,240,000,000 pounds of water raised one foot high. To elevate the water, (which fell as rain,) to

the cloud-level, say 10,000 feet, the following amounts of coal would be consumed :

	Gross Tons.
One inch of rain on one acre, ...	1'008
" " " " " one square mile, ...	645'33
" " " " " area of Philadelphia, ...	83,495'
45'19 inches of rainfall on the area of Philadelphia (that is, the average for fifty-seven years), ...	3,773,146'

That is, to raise the average amount of water, which has fallen annually upon the areas of the city of Philadelphia for the past fifty-seven years, would require the yearly consumption of 11·4 per cent. of all the anthracite coal mined in 1886, using the most improved pumping machinery.

Or, on the assumption of the same rainfall in the anthracite region as at Philadelphia, one-half of the total production of coal at the present mine development, would be consumed in raising the water, which falls as rain upon the 470 square miles of the anthracite region.

I recognize that in all of the calculations presented, there are many possible sources of error, and would therefore again remind you that they are intended as comparative and not as absolute estimates; their object being solely to present a conception, imperfect though it be, of the forces which are continually at work about us.

THE WATER WHICH IS SUPPLIED TO PHILADELPHIA.

No subject is of greater interest to each of us than the character and quantity of our water-supply, for on these depend largely our comfort, safety and health. It is not essential that we should enlarge upon this, nor will I consider it necessary at the present time to refer to the chemical analyses which have from time to time been published. That it is not all that we desire, is too well recognized to need mention; the presence of mud discoloring it, or the shortage in certain districts when heavy demands for fires, etc., have been made, are convincing proofs that an improvement is necessary; but that it is as unsatisfactory as some have asserted need, on the other hand, scarcely be noticed. However, a subject of so much importance cannot be too thoroughly discussed; but while we should look at it in all candor for the weak points, we should be equally frank in admitting the merits of the supply

upon which we depend. Those of our citizens, whose business calls them to various parts of our own country, or to foreign lands, and who have opportunities for observing the peculiarities of their own and foreign cities, cannot but agree that an absence of local pride seems to be pre-eminent among our citizens, and that we seldom or never "put our best foot forward." We are too apt to display our disadvantages, and to make light of our advantages, and in no one thing is this more pronounced than in some of the statements concerning our water-supply, which have obtained publicity. Several years ago, our deficiencies in this line were heralded throughout the country to our disadvantage, until, as one, familiar with water-supplies, facetiously remarked: "We were drinking poison, and our pipes had so *shrunk* in diameter that the supply was both unhealthy and inefficient." That the case is not as bad as this is evident from the fact that, although the year just past was one of unusually large water consumption, and that during the season of the greatest demand, there was a severe drought, few complaints of either the quality or quantity of water were heard. It is not my desire to be understood as asserting that we should not have a better water supply; on the contrary, it should command the most earnest and immediate attention of our city authorities; but the wholesale condemnation of what we now have, and the dire predictions as to the future which are published, are beyond the truth, and some of them are apparently instigated in the interest of special schemes.

Familiarity with the Schuylkill and Delaware Rivers, from which our supply of water is obtained, encourages one to appreciate their disadvantages; but the knowledge of their drainage areas, gained by tracing many of the various tributaries from their sources to their confluences with the rivers, and an intimate acquaintance with the industrial development of the region, permit me also to recognize their merits. No more reliable source of water-supply is obtainable than from a stream of considerable size, particularly if the water passes over rapids, or by falling over dams, etc., is exposed to aëration. But the otherwise available character of river water may, and in our case is, offset by deleterious drainage. This is particularly true of the Schuylkill River, from which over ninety per cent. of our supply is obtained; but some of the deleterious drainage which enters into it, fortunately for us, neutralizes other objectionable features.

Without entering into details of the drainage of the Schuylkill River, we may follow it from its source, in the anthracite coal regions, where it becomes so strongly impregnated with acid from the mines as to interfere with the life of fish, etc.; but this same acid destroys the organic matter emanating from a populous district probably as far as Reading. In the neighborhood of Reading, large tributaries draining a limestone formation enter the river, and so neutralize this acid that at Pottstown, forty miles above Philadelphia, the water which is supplied to that city from the river is comparatively unobjectionable. Below this point, Phoenixville, Norristown and Conshohocken likewise, obtain their water supply from the river; but they also add to its impurities a considerable amount, which would be greater still had they efficient sewage systems. The discoloration of the Schuylkill water (outside of the mill refuse, which could and should be largely prevented), comes principally from the streams which enter the river between Norristown and Pottstown, and which, while objectionable, is not positively injurious. The large volume of purer water brought to the river from tributaries below Norristown, and possibly the limestone streams in that vicinity, have a marked effect in the improvement of our water-supply as to potability. Our present water-supply is objectionable more from its mechanical than from its chemical impurities, and with proper methods for the prevention of objectionable matters entering the river, with ample settling capacity provided, with possibly aëration by mechanical means, our water-supply will continue to be above the average of that furnished to large cities. To-day, there is much that is objectionable to our senses, as well as to investigation, which can be removed. But as the city grows, the surrounding country will be more densely populated; the pollution of the stream being increased by the augmented population and industries, and it is probable that it would be much cheaper to construct a system of supply obtained from sources which can be more readily controlled from contamination, than to attempt to maintain the purity of the river in the distant future. It is here that a study of the rainfall is essential to the determination of a suitable water-supply, and it will be necessary in providing for the future to select a source whose purity can be maintained, or to adopt a system which will prevent objectionable products from entering the water which is furnished to our citizens.

Those who heard, or who have read, the lecture delivered in this room by Dr. Leeds, will remember that he laid great stress upon aëration of the water supplied to cities, and recommended the use of air-compressors to deliver the air under pressure so as to take advantage of the solubility of oxygen.

He instances results which apparently sustain the statements as to the value of such oxidation, and the advantages of introducing the air under pressure, but if we admit all that is claimed, it is hardly probable that the method can be generally employed, particularly in works already established. He gives as a reason for the compressors which were purchased for the purpose, not being employed at our various Philadelphia pumping-stations, that "At only one of them, * * * has the process been applied, namely, at Belmont, the other mains being too leaky to permit of its being used." It would rather seem that the contours, followed by the lines of pumping-mains from the other works, were of necessity such as would not keep them free from traps in which the air can accumulate, and thus produce jars to destroy the pipes. One of the first rules of good pipe-laying is, wherever possible, to obviate air-traps, and the efforts of an engineer are to prevent the accumulation of air in the pipes, after they are laid. We can, therefore, not expect that with our water-supply as at present arranged, aëration, by means of compressors in connection with the pumping mains will be successful, their use would rather be attended with considerable risk to the pipe system. If the beneficial results from aëration can be maintained, and they are sufficient to command attention if but a portion of the organic matter is thus oxidized, it would appear that better and less risky methods of reaching the desired results would lie—

(1.) In the direction of raising the water above the surface of the reservoirs, and allowing it to fall in cascades, thus exposing it to the air, and, at the same time, adding ornaments to the reservoirs.

(2.) The idle compressors could be utilized by placing them near to, or upon, floats in the reservoirs and forcing the air under pressure into the water near the bottom; or,

(3.) As the lift would be but a few feet, rotary pumps, similar to wrecking pumps, could be placed on floats and large volumes of

water be quickly raised so as to fall in thin cascades and permit of aëration.

Either of these suggestions would appear to be applicable to our existing system of water-supply, and free from the serious objection of air in the pipe system; the disturbance of the water might, however, interfere with the settlement of matter held in suspension; but as our reservoir capacity is insufficient to accomplish any real clarification, of which we have evidence to-day in the color of the water, this would at present be a minor objection. For large storage reservoirs, in which the development of organisms cause unpleasant tastes, or odors, these methods may also be found efficacious.

The total amount of water supplied to the city of Philadelphia in the year 1885, as given in the published report of the Water Department, was 25,165,020,072 gallons, a daily average of 68,945,260 gallons. This amount was raised to an average elevation of 156.2 feet, and the work done was therefore 89,746,351,338 foot-pounds per day; or, on the assumption of continuous work, 62,323,855 foot-pounds per minute, equal to 1,889 horse-power continuously exerted.

Mr. John L. Ogden, Chief Engineer of the Water Department, states that, during the year 1886, the minimum daily pumpage was 49,187,598 gallons, and the maximum 102,202,857 gallons, the average being 78,432,289 gallons per day. If the average height to which this was pumped, was the same as in 1885, the increase would be 13.8 per cent., requiring the continuous development throughout the year of 2,150 horse-power.

Our calculations show that the average precipitation on the area of Philadelphia was equal to a volume of 278,365,171 gallons daily, or about four times the average daily pumpage of last year. Therefore, if we could collect twenty-eight per cent. of the water falling on the area of the city and store it, we would have an ample supply for our present requirements. But the collection of water, without storage, would not avail us, for we must provide for dry seasons, such as that which occurred last year, when from August 8th to October 26th, inclusive (eighty days), the Water Department gauge showed that but 1.578 inches of rain fell, which is equivalent to a deposition on the area of the city of 44,348,856 gallons per day, or fifty-six and one-half per cent. of the average

daily pumpage for the year, and probably less than the evaporation for eighty days.

The problem to be solved by our city authorities in securing a source of future water-supply, is fortunately not a difficult one, for there are several available drainage areas from which a supply of potable water can be obtained; either of which are more than ample for the present requirements of the city. The problem is, rather, how far into the future shall we look, and for how much of posterity shall provision be made? Upon the solution of this will depend also the character of the works constructed, and their number.

The available sources are:

(1.) The Schuylkill River, from which the water must be raised into the reservoirs by pumping, with the attendant constant expense of operating the machinery. To continue the use of this source, persistent precautions against pollution must be taken and provision for storage must be made.

(2.) The Delaware River, by pumping from a point or points away from the influence of the city's sewage. This will require the continual expense of maintaining machinery, increased storage and demand watchfulness against future pollution.

(3.) Gravity supplies from one or more of the tributaries of the Schuylkill or Delaware Rivers, or from the upper waters of the latter stream. Such supply will be dependent upon the rainfall upon the areas drained, the percentage of the precipitation lost by evaporation, infiltration and absorption, and the storage capacity provided. While gravity supplies are generally more costly to construct than pumping works, they are less expensive to maintain, and the territory drained can be more readily controlled.

(4.) Publicity has been given to a project (which will probably never mature) to construct an immense dam across the valley of the Schuylkill, above Manayunk, to act in the double capacity of a store reservoir for a supply of water, and for power. This plan would remove much of the objectionable drainage, by *wiping out of existence* a large proportion of the manufacturing industries, and a considerable part of the town-sites along the river; and bring close to us the possible risk of the failure of the dam. If the damage to industries, to private dwellings, the losses to business centring about the city, and the changes of railroad lines which

this necessitates, are considered in connection with the fact that much of the objectionable drainage would still exist, it will hardly meet popular favor.

When the arrangements for this lecture were made, it was expected that the recommendations of the Chief Engineer of the Water Department as to a future water-supply would have been made public. Such, however, is not the case, but I understand that they will shortly appear and it would be discourteous to anticipate these recommendations; for those to whom have been entrusted the duty of determining what is best to be done, are entitled to a careful consideration on our part of the problems which they have studied out with so much care. But having from boyhood taken a lively and continuous interest in the water-supply of our city, I will be pardoned for expressing the conviction, based upon a careful study of the subject, that Philadelphia will obtain the best and most reliable water-supply by gravitation from one or more of the tributaries of the Schuylkill and Delaware Rivers, and in view of possible social or political disturbances, it would appear that for the future, a supply which did not make the city dependent on one source only would be advisable. To have a proper control of the areas drained, they should be the property of the city, and such purchase would, in view of the rapid reduction of our forest area, be likely to prove a profitable investment. Much of the area drained by these tributaries is imperfectly adapted for agriculture, but, if properly cared for, could sustain valuable forests, which would assist in securing the collection of the water falling as rain, by making the springs perennial, and at the same time grow timber of value. Philadelphia should not only control her water-supply, but also the sources from which it is obtained. A great city maintaining a magnificent forest preserve, wherein tree culture could be carried on both practically and technically, having the double purpose of maintaining the purity of the water-supply and the growth of timber for profit would do much to popularize a much neglected feature of state and national administration.

For whatever knowledge I may possess concerning the present or the future water-supply of the city, I am indebted to him, to whom I also owe the credit of any educational facilities or personal advantages, and it was in assisting my father in the study of the requirements of the city, that my interest in the subject originated.

It is, therefore, a great gratification to find that the results of the examinations, surveys and estimates, made at a large outlay during late years, are so close to those made by him twenty years ago, at an expense of about \$5,000. I regret that his life was not spared to allow him to appreciate this, or to have others recognize the fact that his conception of what Philadelphia needed, was but a quarter of a century ahead of what the city must now have.

You may properly credit these statements to loyalty to the memory of my father, and I am proud to admit such fealty as influencing me. But I will ask those of you who may be interested in the subject to compare the results of reconnoissances on foot of the streams convenient to the city, the surveys, calculations and estimates published by him in 1865,* with similar data published as the results of examinations made, at a cost of \$80,000, with the most approved instruments, with the help of a large corps of assistants, and with the advantage of twenty years of progress to confirm the above statement.

Either of the subjects embraced in the topic of this lecture are sufficient for an entire evening, and they have been but imperfectly treated. But if the data presented will assist us to recognize how immensely beyond our conception are the forces of Nature, which are constantly about us, if what has been said helps any one to appreciate the omnipotence of the Creator, at whose bidding "there went up a mist from the earth and watered the whole face of the ground," if any thought expressed may aid in securing for Philadelphia of to-day, and the Philadelphia of the future, such a water-supply as a great city deserves; or if any suggestion made will assist in securing your support to any honest endeavor to advance our city, your patience in listening to me will have been rewarded.

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* *Report upon Future Water-Supply of Philadelphia.* By Henry P. M. Birkinbine, Chief Engineer, 1865.