OBSERVATIONS

ON THE

RELATION WHICH THE FALL OF RAIN BEARS

TO THE

WATER FLOWING FROM THE GROUND.

BY JOHN FREDERIC BATEMAN, M. INST. C. E.

Read 6th of February, 1844.

In the year 1799 Dr. Dalton brought this subject before the notice of the society, in a valuable paper entitled "Experiments and Observations to determine whether the quantity of Rain and Dew is equal to the quantity of water carried off by rivers, and raised by evaporation; with an inquiry into the Origin of Springs."*

In that paper, after observing that "it is scarcely possible to contemplate without admiration the beautiful system of nature, by which the

* Memoirs of the Literary and Philosophical Society of Manchester, Vol. 5.

surface of the earth is continually supplied with water," and after alluding to the importance of the enquiry to agriculture, and to the arts and manufactures, he enters into a very careful investigation of the whole subject, under the several heads of—

"The quantity of Rain and Dew.
"The quantity of water that flows into the sea.
"The quantity of water raised by evaporation. and
"The origin of springs."

Having first determined, from an extensive series of observations, the probable average quantity of rain falling annually throughout the kingdom, which, taking 31 ins. for rain, and 5 ins. for dew, he considers will be 36 ins., and by multiplying this quantity into the area of the country, ascertained the whole amount of rain, he proceeds to estimate how much will be carried down by the rivers to the sea Grounding his calculations upon an estimate made by Dr. Halley, upon the volume of the Thames at Kingston Bridge, and the extent of country from which the supply of water would be drawn, he goes through a consideration of the quantity of water which must be conveyed to the sea by all the various rivers in the country; the result is, that he considers 13 ins. of the annual rain are in that way disposed of, and that 23 ins. remain to be accounted for. This brings him to a consideration of the quantity of water raised by evaporation. To ascertain this point, not finding the observations of others sufficient for his purpose, he made various experiments upon the evaporation from soil. From these it seemed that the evaporation amounted to 25 ins. of rain annually, and if 5 ins. for the dew were added, it would give 30 ins. of water raised annually. As this exceeded the medium reserve of 23 ins., he goes on to enquire "whether the rain is adequate, or whether the earth derives a supply of water from some subterraneous reservoir, according to the opinion of some philosophers." Having accounted for this apparent discrepancy, he finally arrives at the conclusion "that the rain and dew of this country are equivalent to the quantity of water carried off by evaporation, and by the rivers."

He finally examines the various opinions which at that time existed upon the origin of springs, concluding that they must be attributed solely to the rain, their variation depending upon the seasons, and upon the quantity of rain which falls.

Any subject which could command so much of Dr. Dalton's scientific attention, would require nothing being said to prove it worthy of the most careful investigation. Meteorology, generally, has been a favourite pursuit with him through life, and the public are indebted for much of the information, and most of the sound views they possess, to the many papers upon this subject which the doctor has contributed.

It is, however, in the application of the knowledge which is acquired in the pursuit of such enquiries to the wants and purposes of life, that their great practical importance consists.

The intimate connexion between the amount of rain falling, and the supply of water in the country, is obvious. On our knowledge of the relation which one bears to the other, under different circumstances, must we depend for rules to guide us in agricultural and engineering improvements, and in the consideration of all cases in which the application of water, or its multifarious effects, form important points.

In irrigation, for instance; in the supply of water to towns, or in its application as a moving power, for manufacturing or other purposes ; in navigation or in draining ; in estimating its effects upon the country generally, or upon the course and mouths of rivers, and the maintenance of harbours, this knowledge is essential.

It is a matter of surprise therefore, that so little has hitherto been done in the investigation of the subject. Dr. Dalton's paper stands almost alone, and, until recently, no actual observations upon a large scale, appear ever to have been made.

Valuable, however, as the Doctor's reasoning and calculations undoubtedly are, they can only be regarded as mere approximate estimates ; but they are grounded upon the proper data, the best he could at that time command, and are well calculated to account in all respects most rationally, for the manner in which the water of rain is disposed of.

To arrive at accurate conclusions, such as may be depended upon with confidence, in applying the results to the purposes of life, extensive observations upon a large scale, for a long series of years, are necessary, and in districts of various physical and geological character.

The quantity of water which may be expected to flow from a flat country well clothed with vegetation, will be very different from that which will pour in torrents down the steep declivities of uncovered mountains ; and again, the water which will pass off from the surface of a limestone district, with its many caverns and perpendicular fissures, will vary considerably from that which will drain off in like manner, from a district, similar perhaps in its external features, but consisting of the dense rock of a primitive formation or the flat beds of the coal measures.—Clay and sand ; morass and cultivated ground ; absorbent chalk and more impervious material, all contribute to produce a varying result.

The rapidity with which rain descends, or the state of saturation in which the ground is found at the commencement of a wet period, will also vary the quantity of water which will flow away in different years as a supply to rivers, although the average or gross amount of rain may be nearly the same.

Perhaps the most serious difficulties which have hitherto existed, consist in the extensive scale on which the observations should be made to be of any real value, and the accuracy required in ascertaining the quantity of water actually discharged from a certain extent of country. The measurement of a single flood may be omitted, and yet that flood may send down as much water in one day as would pass off in two months of ordinary weather.

Of late years works have been constructed in some parts of the country, by using which as a means of observation, these difficulties have been to a great extent removed.

The demand for moving power consequent on the great extension of our manufactures, very early led to the application for that purpose of every important stream in the manufacturing districts. As improvements in the face of the country and in agriculture kept pace with commercial prosperity, the former general regularity of the rivers was found to be considerably disturbed by the effects produced by the making of roads and the better draining and cultivation of the land. The drains and roads form so many conduits by which the rain which falls is rapidly conveyed to the contiguous streams, and the same quantity of water which formerly required several days to make its escape, now passes off in a few hours. Some quiet swamp or bog at the head of a river, which had for centuries contributed to regulate the quantity of water in the stream, by absorbing the superabundance of wet periods and gradually discharging it at other times, becomes allotted off in farms, trenched in all directions and thoroughly drained. The water is then no longer retained to assist the streams in dry periods, but runs off to swell the floods as quickly as the drains can be made to carry it.

This increasing irregularity, combined with a growing demand for further power, has contributed to the construction on many streams, of large reservoirs for the purpose of impounding the surplus water of wet seasons to be applied in supplying the wants of periods of drought, and by such artificial means to regulate the quantity of water in the stream.

Wherever these reservoirs have been constructed of sufficient capacity, opportunities have been created for ascertaining what proportion the water flowing from the ground bears to the rain which falls upon it. The extent of country from the surface of which the water would naturally drain to the reservoir may be easily ascertained, the depth of rain in a given time may be measured by gauges placed in different parts of the drainage ground, and the quantity which is discharged from the reservoir, or which runs to waste in the same period, may, by proper observations, be correctly calculated. Here there is, in a given district, everything which is required, and by a sufficient number of observations, data will be obtained for forming a judgment upon the probable result in a similar locality.

Some of the more important observations, which, under such favourable circumstances, have of late years been made, we will now proceed to notice.

During the construction of the Bann Reservoirs in the north of Ireland, attempts were made to ascertain the quantity of rain which fell in a mountainous district, and how much water could be collected in the basins of the reservoirs.

The Lough Island Reavy Reservoir is situated on the westerly flanks of the Mourne Mountains, at an elevation of about 400 feet above the level of the sea. It derives its supplies from about 3300 statute acres of mountain land, rising in places to abrupt eminences of from two to 3000 feet in height. The direction of the general chain of the mountains is from north-east to south-west, and measuring from Carlingford Bay on the south, to Dundrum Bay at the foot of Slieve Donard, on the north, about 15 miles in length. They form the easterly sea-bord of the island, rising abruptly from the sea, the summit of Slieve Donard 2796 feet in height, the highest in the range, being only one mile and three quarters from the coast. Their average width is about five or six miles, the interior of the country for some distance from their westerly base, being comparatively level, rising to no great elevation above the level of the sea. In these mountains the River Bann and its early tributaries take their rise, within six or seven miles of the sea, from which they run in a westerly direction towards the interior; the river, after passing through Lough Neagh, finally discharges its waters at Coleraine into the North Channel.

The hills are composed of primary and transition strata, many parts uncovered with any kind of earth or vegetation, the declivities for the most part being excessively steep.

Rain gauges were placed at Lough Island Reavy, 400 feet above the sea, and on the summit of the Spelga Mountain 1400 feet above the sea. The gauge at Lough Island Reavy was placed within about 9 ins. or a foot of the level of the ground—that on Spelga, within the same distance of the top of a mound raised about four feet above the general level of the ground, with a trench dug round it to prevent the approach of sheep which fed upon the mountains.

From October 1837 to October 1838 there fell at Lough Island Reavy 72 $\frac{3}{4}$ ins., and on Spelga 74 ins. of rain.

This period was below an average in other places where observations were taken, as were also the succeeding years to 1841. It was difficult in that country to find persons to attend properly to the gauges, but the result of our experience, during those years, was to ascertain that of six feet of rain which fell upon the drainage ground, four feet found its way to, and was impounded in the reservoir, besides allowing a quantity to run past it, sufficient to work some small corn and flax mills.

In the year 1839 gauges were placed in suitable positions across the Penine chain of Hills, pretty nearly along the line of the Manchester and Sheffield Road by way of Glossop, for the purpose of ascertaining the fall of rain at different elevations, over a tract of country which would form a fair average of the mountain drainage of the rivers which take their rise in that district. It was intended to have connected these observations with others upon the quantity of water which flowed from the land as a supply to the rivers, but this has hitherto been found impracticable.

The places chosen for fixing the rain gauges, were 1st, the westerly foot of the hills, in the valley of Hurst Brook near Glossop, about 500 feet above the sea. 2ndly, the head of that valley on the westerly edge of a tract of table land on the summit of the hills, probably 1500 feet above the sea. 3rdly, the head of Ashop-dale upon the flank of Kinder Scout, upon the easterly edge of the summit plain, perhaps 1600 feet above the sea, and fourthly, at the easterly foot of the hills in the valley of the Derwent, at Bamford Mills, near Hathersage. This place may be 300 feet above the sea. Mr. John Kershaw, of Hurst, has kindly superintended the taking of the observations at the two first stations, and Mr. W. Moore, of Bamford, undertook the charge and trouble of looking after the proper registering of the others.

The following table contains the result of these observations to the end of 1842 :—

	At the foot of the hills near Glossop. Probable height above level of sea 500 feet.				Near the summit, at the head of the Hurst Brook Valley. 1500 feet.				Near the summit, on the flank of Kinder Scout, at the head of Ashop Dale. 1600 feet.				In the valley of the Derwent, at Bamford, near Hathersage, 300 feet.			
	1839.	1840.	1841.	1842.	1839.	1840.	1841.	1842.	1839.	1840.	1841.	1842.	1839.	1840.	1841.	1842.
	Ins.	Ins.		Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.		Ins.	Ins.	Ins.	
January						2·6	3·0	1·3		9·4	2·4			5·05	2·6	
February						6·6	3·3	2·7		5·3	2·6			3·60	1·4	
March ...						0·5	3·3	5·9		0·6	4·0			0·65	2·7	
April ...	15·75	21·2			30·5	1·6	6·4	4·0		1·6	5·6			1·30	1·3	
May						7·7	4·6	2·3		5·2	5·4			3·20	4·1	
June						6·5	5·9	2·2		7·3	5·2			3·00	3·1	
July.........	5·50		—	3·50	—	6·3	7·2	3·5		13·4	10·3			4·30	4·1	
August	4·25		—	1·70	3·8	9·5	7·3	5·2		7·0	9 5			4·60	3·6	
September.	7·00		—	4·50	8·0	6·7	6·0			9·3	5·4			2·95	3·15	
October ...	3·50	24·00	—	2·90	4·5	6·5	10·5	12·4	3·5	5·7	11·2		3·20	2·15	6·[illegible]5	
November.	3·70		—	6·60	12·3	7·0	9·0	4·3	6·9	8·0	6·4		5·45	7·10	4·4	
December.	4·80		—	3·30	4·9	1·5	6·1	3·3	6·1	2 0	12·1		2·95	0·9	5·5	
	44·50	45·2 to 17 Nov. 10½ Mos.		22·50 6 Mos.	64·0	63·0	72·6	47·1 last 6 Mos. 28·7	16.5 3 Mos.	74·8	80·1		11·60 3 Mos.	38·8	42·9	

The mean annual results are—

	Inches.
At the westerly foot of the hills for $2\frac{1}{2}$ years	45
At the westerly edge of the summit plain, 4 years ...	61.7
Mean of 1840 and 1841............	67.8
Easterly edge of do. 1840 and 1841, 2 yrs.	77.45
Easterly foot, in the Valley of the Derwent............ } 2 years, 1840 & 1841 ...	40.85

The gauges were all exactly alike—all sunk into the ground so as to allow the top of the funnel to be about 12 inches above the surface.

One very important fact shown by these observations, is, that a much greater quantity of rain falls on the summit than at the bottom of the hills, and this appears to be uniformly the case, whether taken for a single month or upon the general average.

The years 1839, 1840, and 1841, were all below Dr. Dalton's average of forty-seven years. 1842 only gave three-fourths of that average.

Mr. Thom, of Rothesay, the constructor of the Shaw's water works, near Greenock, and of many other similar works in Scotland, has for many years been an accurate observer, and must have collected a vast amount of information, which it is to be hoped he may some day be induced to bring before the public.

In a communication to the Institution of Civil Engineers some years ago, he gives the particulars of some very important facts, which are the more valuable, as they happen to be from observations made during periods unusually wet and dry, respectively, so that they may be supposed to show extreme results.

The information in his own words, is as follows :—

"*Rain in Bute from* 1*st April*, 1826, *to* 1*st April*, 1827.

	Inches.
Depth of Rain that fell from end of March to October 1st, 1826	12
Of which there found its way to the reservoir......	1.5
Taken up by evaporation, vegetation, &c.	10.5
Depth of Rain that fell from October 1st, 1826, to March, 1827	25.2
Of which there found its way to the reservoir ...	15.3
Taken up by evaporation, absorption, vegetation, &c.	9.9

	Inches.
Depth of Rain that fell in March, 1827......... ..	8.2
of which there found its way to the reservoir...	7.1
Taken up by evaporation, vegetation, &c.	1.1
Depth of Rain from 1st of April, 1826, to April, 1827	45.4
of which there found its way to the reservoir...	23.9
Lost to the reservoir	21.5

Note.—The above was from a drainage of more than 4000 Scots acres.

(Signed,) R. THOM."

" *Rain available for Greenock Reservoirs.*

Square feet of surface draining into Greenock reservoirs	217,700,000
Depth of water which fell thereon, year ending September 30th, 1828	6ft.
Cubic feet of Rain which fell on the drainage	1,088,800,000
Cubic feet of Rain which flowed into the reservoirs	744,594,165
Cubic feet evaporated, absorbed by vegetation, &c.	344,205,835

(Signed,) R. THOM."

Now, the year 1826, was the driest year in this country, of which we have any record. It is reasonable to suppose it must have been a dry year also in Scotland; indeed, the returns during the summer months show it to have been so.

In that year, according to Mr. Thom's return, the available rain, or that which was gathered in the reservoir in Bute, was to the total fall as 239 to 454, little more than one half. During the six summer months from the beginning of April to the end of September, only twelve inches of rain fell, being about one-fourth of the whole year's fall. The quantity which drained off was to that which fell, only in the proportion of 15 to 120, just one-eighth. Any calculation upon an average during this period would have been sorely at fault.

The following five months were still, probably, below an average. The rain in Manchester, according to Dr. Dalton's tables,* being only 13.535 inches, while the mean for twenty-two years, including this period, was 15-951 inches, and the quantity draining off would be effected by the previous drought. The soil must have been far

* Vide Memoirs of Literary and Philosophical Society of Manchester, volume VI., new series, p. 575.

short of its usual saturation. The proportion of the water which flowed off the ground, was to the rain which fell upon it, as 153 to 252—three-fifths of the whole. In the month of March, an excessive quantity of rain seems to have fallen, and seven-eighths of it ran off the ground ; the quantity for that single month was nearly one half as much as had passed off during the preceding five months, although the winter, and about five times the quantity which the six summer months had yielded.

During the remainder of 1827, the rain which fell, was, according to the Manchester Tables, below an average, the whole year including the wet month of March being only one-thirtieth above it.

The year 1828, Mr. Thom has not given in similar detail, but looking at the Manchester Tables, the excess in the year, (for it is the wettest which those Tables show), appears to have been principally occasioned by extraordinarily heavy rain in July ; the remaining months being very near the general average ; so that the year might not have been generally so wet, as the gross amount of rain would appear to indicate.

Considering it, however, as a *wet* year, Mr. Thom's return would show, that for such a season, the water flowing from the district above the Greenock reservoirs, would be about two-thirds of the rain which fell. The proportion is as 744 to 1088.

The land draining into the Greenock reservoirs is high and mountainous, principally moorland, having a good deal of similarity to the moorland districts of Lancashire and Yorkshire, but of different geological character. Its formation is principally basaltic. It lies near the sea, on the east of the Firth of Clyde.

Bute is an island, on the west of the Firth of Clyde, about sixteen miles in length, by four and a half in breadth. Where Mr. Thom's experiments were made, it is comparatively a *low country*. It is, I believe, an undulating pastoral district, having no *great elevations*. The average rain for forty years, Mr. Thom states to be forty-eight inches. From its proximity to the sea and high land, it may be a favourable situation for a great fall of rain.

Some useful information may be obtained from observations, which have been made upon the quantity of water discharged from the Turton and Entwistle reservoir, near Bolton. This is a large reservoir, containing about one hundred millions cubic feet of water, constructed about the years 1835 and 6, for the purpose of regulating the supply of water on Bradshaw brook and the river Irwell, by impounding the flood waters.

Mr. Thomas Ashworth, was the engineer employed to construct it. Having fixed an iron gauge below the outlet from the reservoir, all the water discharged was for sometime regularly measured, none being permitted to flow away, otherwise than through the gauge.

In his printed report to the commissioners of the reservoir, dated Sepember 12th, 1836, he states, that the quantity discharged during the first year, amounted to 250,865,600 cubic feet, and that there was then in the reservoir a depth of water of seventy-two feet, which, according to his estimate of the capacity, may be taken at about 50,000,000 cubic feet.

The drainage ground, carefully measured from a map, furnished by the Ordnance office, is 2036 statute acres. On this area, 250,865,600 cubic feet would be equal to a depth of water gathered to the reservoir of thirty-four inches in the year, besides that required for evaporation from the surface of the water. If the fifty millions feet in the reservoir were added to the quantity actually discharged, the depth would be about forty-one inches.

These observations were apparently taken from the summer of 1835, to the summer of 1836, the quantity of rain falling during that period, being rather under a general average. At Bolton, it was three inches less than Mr. Watson's ten years' average of 49.2 inches.*

In a report, dated June 30th, 1837, Mr. Ashworth states, that during the preceding year of 365 days, (probably to midsummer of 1837,) 289,404,000 cubic feet of water had been discharged. This quantity would be equal to a depth of thirty-nine inches, collected in the reservoir.

* Memoirs of the Literary and Philosophical Society of Manchester, volume VI., new series, p. 586.

The rain at Bolton for this year was one inch, or 1-49th below the mean, the mean rain being as stated above to the end of 1840—$49\frac{1}{5}$th inches.

No observations having been taken upon the depth of rain falling upon the drainage ground of the reservoir, the information furnished does not enable us to ascertain what proportion of the whole was impounded. Of course the rain must have exceeded the water actually collected and discharged.

During the past year, many observations have been taken upon an extensive tract of land, adjoining the drainage ground of the Turton and Entwistle reservoir, for the express purpose of ascertaining many of the points now under consideration. The facts there observed will probably supply the deficiency, in the information afforded by that reservoir.

On the 13th January last year (1843) a rain gauge was placed on land contiguous to a reservoir of the Bolton Water Works Company, for supplying the town with water. The reservoir is called the Spring Water Lodge, and is situated upon Hampson's pastures, near Belmont. The gauge is placed at an elevation of about 800 feet above the level of the sea, being about 500 feet above the town of Bolton, and perhaps 700 or 800 feet below the highest land in the district. It is sunk in the ground, in an exposed situation on the westerly slope of the valley of the river Eagley, the top of the funnel being about a foot above the level of the ground. The quantity of rain which has fallen during the last twelve months, from the 13th January last year, to the 13th of January this year, is given in the following table, in which I am enabled, by the kindness of Mr. H. H. Watson, of Bolton, to give the fall of rain there, during the same period. The two accounts, and Mr. Watson's average for ten years, as published in the 6th volume, new series, of the Society's Memoirs, are placed together for the facility of comparison.

TABLE.

1843.	Bolton Water Works, Spring Water Reservoir 850 feet above the sea.	Bolton 320 feet above the sea.	Mean at Bolton for 10 years, ending 1840.
	Inches.	Inches.	Inches.
January .... (At the Water Works Reservoir, from the 13th to the 31st.)	3.0	5.28	7.33
February................	1.9	1.47	
March	2.7	2.31	3.27
April	12.0	7.58	2.50
May.......................	4.4	3.51	2.26
June	5.0	2.81	4.54
July.......................	8.0	5.17	5.59
August	4.5	4.19	4.41
September	1.0	1.05	4.24
October	11.1	8.50	5.05
November	7.4	6.36	5.84
December	2.0	1.17	4.17
	63.0		
1844. January to the 13th, to complete the 12 months	3.2		
	66.2	49.40	49.20
For eleven complete months, omitting January, 1843....	60.0	44.12	

Here, again, the important fact of the greatest fall of rain being upon the high ground is clearly proved.

As to the full quantity of water which has through this period reached the valley, no observations have been taken, but some very careful measurements at particular times, throw a good deal of light upon the rapidity and extent to which the water of heavy rain flows off the ground.*

The months of February and March were dry months, the rain being much below the average. The month of April was remarkably wet, a greater quantity of rain falling in that month than in any other previous April for many years. May was a little above the average. In June the rain for the entire month was below the average, but it all fell in the first ten days; it was nearly continuous rain during eight of them. During this period of the month the following observations were made.

The ground was perfectly saturated at the commencement of the month, the river being

* In the course of the present year some works will be completed for gauging every drop of water flowing from an extensive portion of the district, and from the daily register which will be kept, means will be afforded for ascertaining the results under all circumstances. These observations will extend over a period of five years.

then in a swollen state from the rain at the end of May, and it was therefore to be expected that a large proportion of the water would run off the ground. The fall of rain during the time was five inches. The quantity of water flowing down the river at Dunscar weir, below the Egerton works, from a drainage ground of about 5400 statute acres was measured daily ; the rain ceased on the 10th, on which day the stream was flowing at the rate of 157 cubic feet per second ; on the day preceding it had been 250 feet per second ; on the 11th it was 27 feet per second, and on the 12th it had shrunk to its usual volume, which, with the assistance of the Belmont reservoir, is from 12 to 15 feet per second.

The quantity of rain which had fallen was equal to 99,099,000 cubic feet of water—that which ran off, including one day after the rain had ceased, was upwards of 90,000,000 cubic feet, better than 9-10ths of the whole.

During no part of this period was there a *heavy* flood. It is not at all unusual to have a flood equal to two, three, or four times the quantity which was passing down at that time at its greatest height. The rain was continuous rather than heavy. Half the quantity which then fell in ten days has not unfrequently fallen in one. The greatest volume of the water was about 250 cubic feet per second, the mean $98\frac{2}{3}$.

On the 17th, 22nd, and 27th of the same month, no rain having fallen since the 10th, the river was again carefully measured, as well as every separate stream which flowed into it. There was but little difference in the results. The quantity gradually decreased, but not considerably. The natural stream at Dunscar weir, unassisted by artificial means, was about three cubic feet per second.

The district from which these streams derive their source adjoins the land which supplies the Turton and Entwistle reservoir. It lies to the westward of the valley in which that reservoir is situated, and forms the first trough of any importance in the range of hills, which, commencing at Rivington Pike, and extending inland, is the first to break the clouds borne by the westerly winds, surcharged with moisture, from the Irish Sea. The external features and geological character of both districts are the same. Both are situated on the lower portion of the coal measure formation, which there lies tolerably level bedded. The elevation above the sea is similar, and the declivity of the land and the nature of cultivation very much alike. Both consist of moorland and pasture, the latter forming a somewhat greater proportion of the whole in the Turton and Entwistle district, than in that at Belmont. The Belmont district may be rather more favourable for the deposition or precipitation of rain, as the clouds, after dragging over the first high ground, will rest awhile in the first trough, formed by the Belmont valley, before they are carried over the second summit to the Turton and Entwistle valley.

The general results, however, may be expected to be pretty much the same, and it will therefore be useful, until further observations are made, to connect the different kinds of information which the two valleys now furnish.

We find that in an average year, the water collected and discharged from the Turton and Entwistle reservoir, is equal to nearly forty inches of water upon the whole drainage ground ; and during last year, which was very little more than an average one, the depth of rain at Belmont exceeded sixty inches. Now supposing the same depth of rain to have fallen above the Turton and Entwistle reservoir, during the year in which the forty inches were there collected, that quantity would be nearly two-thirds of that which fell. This agrees with the experience of the Bann reservoirs in average years, and with the observations of Mr. Thom, at the Greenock reservoirs in 1828.

This result is twice as much as the proportion Dr. Dalton assumes by his approximate calculations, even with the addition to the depth of rain of five inches for dew. In those, however, there may be two principal sources of error : first, in the quantity of water which flows into the sea, and secondly, in the means of supply.

First, as to the quantity of water flowing into the sea.—

Dr. Dalton grounds his calculations on an assumption of Dr. Halley's, as to the volume of the Thames, at Kingston ; and, imagining that

Dr. Halley has overrated the quantity, takes only two-thirds of his result. Now we have seen that the ordinary measure of a river is very far from affording any criterion by which to judge of the volume of the floods, when much the greatest quantity of water which flows from the ground passes down the rivers; therefore the ordinary volume of the river Thames, whether right, as assumed by Dr. Halley, or as corrected to suit the impressions of Dr. Dalton, cannot be taken as a sufficiently accurate basis of calculation. There can be little doubt that the results would be far below the truth, and that the thirteen inches Dr. Dalton assumes as the depth of rain flowing into the sea, would require to be considerably increased.

Secondly, as to the means of supply.—

In endeavouring to ascertain the average quantity of rain, Dr. Dalton takes a mean of the observations which had at that time been kept throughout England. This, no doubt, gives a very correct idea of the rain falling in the generally inhabited parts of the country; but it may be questioned if it forms a correct measure of the rain which forms the principal supply of rivers.

Most of the rivers, in this country, take their rise in mountainous or hilly districts. From the much greater quantity of rain which falls there, and the rapidity with which it flows from the steep declivities of the hills, it is evident that the principal supply to the rivers is there to be looked for.

Dr. Dalton's estimate, therefore, is probably much below the truth.

If, then, both the depth of rain falling as a supply to rivers, and the quantity of water borne to the sea be taken at a higher rate than he has assumed, his calculations upon the evaporation from soil, &c. which must make up the difference, might still be probably correct, but on these, the Doctor himself places no dependance.

It is clear that the best mode of ascertaining the real quantity of water evaporated from land, required for purposes of vegetation or absorbed by the ground, consists in observations similar in magnitude to those which have been attempted to be described. Garden experiments, upon a square box of a few inches, although they may be sufficient to illustrate the operations of nature to a philosophic mind, are not to be depended upon as rules to guide us in the application of our knowledge to the purposes of life.

In the consideration of this question, it is important also, to observe the position of the gauges by which the depth of rain is measured. It is now sufficiently notorious from the number of experiments which have been made, that gauges placed at different elevations, abruptly raised from the ground, indicate a less fall of rain the higher the gauge is placed. For instance, a gauge placed on the top of a house, shows less rain than one placed on the ground immediately below, and another situated at the top of a contiguous steeple, indicates less than that on the top of the house.

From this fact, which seems clearly established, it has been contended, that less rain will fall on *elevated* than on *low* land. The observations which have been detailed in this paper, clearly show that this is not the case, and most other observations within the region of the clouds, where the proper position of the gauge has been attended to, show the same result, although local circumstances vary the depth of rain in particular places amongst the hills themselves.

The material question is, to ascertain the quantity of water which reaches the ground, and though the singular phenomenon of the decrease in a direct line upwards, has given rise to much philosophical speculation, it does not form an important element in the practical consideration of the subject, if it can be proved, that, apart from local influences, the same effect is not produced by different elevations of the land.