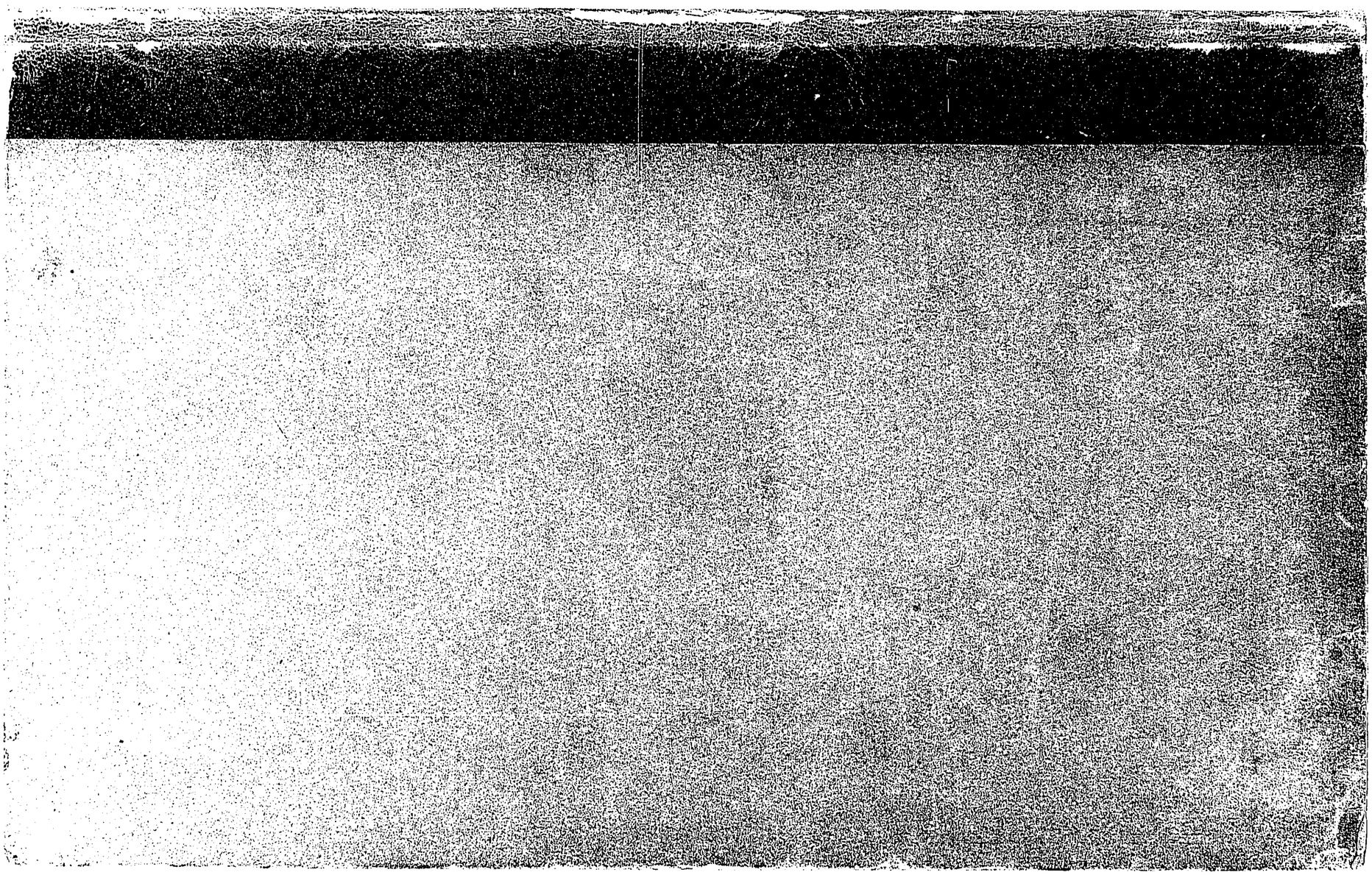

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ROYAL COMMISSION ON WATER SUPPLY.

REPORT

OF

THE COMMISSIONERS.

Presented to both Houses of Parliament by Command of Her Majesty.

LONDON:
PRINTED BY GEORGE EDWARD EYRE AND WILLIAM SPOTTISWOODE,
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.
FOR HER MAJESTY'S STATIONERY OFFICE.

1869.

ORIGINAL COMMISSION.

VICTORIA R.

Victoria, by the grace of God of the United Kingdom of Great Britain and Ireland Queen, Defender of the Faith.

To Our right trusty and right entirely-beloved Cousin and Councillor Charles Henry Duke of Richmond; Our trusty and well-beloved Sir John Thwaites, Knight; Henry Drury Harness, Esquire, Companion of Our most Honourable Order of the Bath, Colonel in Our Corps of Royal Engineers; Benjamin Samuel Phillips, Esquire, one of the Aldermen of Our City of London; Thomas Elliot Harrison, Esquire; and Joseph Prestwich, Esquire; greeting.

Whereas We, taking into Our Royal consideration that an ample supply of wholesome water at all times is of essential importance to the health of the population, especially in large towns:

And whereas the present supply delivered in the Metropolis, as well as in many other large towns, has been found insufficient, and is likely to become more so as the population increases, unless some additional sources of supply can be permanently provided:

And whereas a large portion of the water now supplied to the Metropolis and other large towns is drawn from rivers and open streams which pass through populous districts, and are therefore continually exposed to pollution from various causes:

Now know ye, that We have deemed it expedient that a Commission should forthwith issue for the purpose of ascertaining what supply of unpolluted and wholesome water can be obtained by collecting and storing water in the high grounds of England and Wales, either by the aid of natural lakes or by artificial reservoirs at a sufficient elevation for the supply of the large towns, and to report, firstly, which of such sources are best suited for the supply of the Metropolis and its suburbs; and, secondly, how the supply from the remaining sources may be most beneficially distributed among the principal towns.

And further know ye, that We, reposing great confidence in your zeal and ability, have authorized and appointed, and do by these Presents authorize and appoint, you the said Charles Henry Duke of Richmond, Sir John Thwaites, Henry Drury Harness, Benjamin Samuel Phillips, Thomas Elliot Harrison, and Joseph Prestwich, to be Our Commissioners for the purposes aforesaid.

And for the better enabling you to form a sound judgment on the premises We do hereby authorize and empower you, or any three or more of you, to call before you, or any three or more of you, all such persons as you may judge most competent by reason of their situation, knowledge, and experience, to afford you correct information on the subject of this Inquiry.

And it is Our further will and pleasure that you, or any three or more of you, do, with as little delay as possible, report to Us in writing under your hands and seals your several proceedings by virtue of this Our Commission, together with your opinion on the several matters herein submitted for your consideration.

And We will and command that this Our Commission shall continue in full force and virtue, and that you, Our Commissioners, or any three or more of you, may from time to time proceed in the execution thereof, although the same be not continued from time to time by adjournment.

And for your assistance in the execution of this Our Commission, We do hereby authorize and empower you to appoint a Secretary to the said Commission, whose services and assistance We require you to use from time to time as occasion may require.

Given at Our Court at St. James's, the twenty-fourth day of December 1866, in the thirtieth year of Our Reign.

By Her Majesty's command.

S. H. WALPOLE.

NEW COMMISSION.

VICTORIA R.

Victoria, by the grace of God of the United Kingdom of Great Britain and Ireland Queen, Defender of the Faith.

To Our right trusty and right entirely-beloved Cousin and Councillor Charles Henry Duke of Richmond, Knight of Our Most Noble Order of the Garter; Our trusty and well-beloved Sir John Thwaites, Knight; Henry Drury Harness, Esquire, Companion of Our most Honourable Order of the Bath, Colonel in Our Corps of Royal Engineers; Sir Benjamin Samuel Phillips, Knight, one of the Aldermen of Our City of London; Thomas Elliot Harrison, Esquire; and Joseph Prestwich, Esquire; greeting.

Whereas We, taking into Our Royal consideration that an ample supply of wholesome water at all times is of essential importance to the health of the population, especially in large towns:

And whereas the present supply delivered in the Metropolis, as well as in many other large towns, has been found insufficient, and is likely to become more so as the population increases, unless some additional sources of supply can be permanently provided:

And whereas a large portion of the water now supplied to the Metropolis and other large towns is drawn from rivers and open streams which pass through populous districts, and are therefore continually exposed to pollution from various causes:

And whereas We did, by Warrant under Our Royal Sign Manual bearing date the Twenty-fourth day of December last, appoint you to be Our Commissioners for the purpose of ascertaining what supply of unpolluted and wholesome water can be obtained by collecting and storing water in the high grounds of England and Wales, either by the aid of natural lakes or by artificial reservoirs at a sufficient elevation for the supply of the large towns, and to report, firstly, which of such sources are best suited for the supply of the Metropolis and its suburbs; and, secondly, how the supply from the remaining sources may be most beneficially distributed among the principal towns.

Now know ye, that We have revoked and determined, and do by these Presents revoke and determine, the said Warrant bearing date the Twenty-fourth day of December last, and every matter and thing therein contained.

And further know ye, that We, reposing great confidence in your zeal and ability, have authorized and appointed, and do by these Presents authorize and appoint, you the said Charles Henry Duke of Richmond, Sir John Thwaites, Henry Drury Harness, Sir Benjamin Samuel Phillips, Thomas Elliot Harrison, and Joseph Prestwich, to be Our Commissioners for the purpose of ascertaining what supply of unpolluted and wholesome water can be obtained by collecting and storing water in the high grounds of England and Wales, either by the aid of natural lakes or by artificial reservoirs at a sufficient elevation for the supply of the large towns, and to inquire into the present Water Supply to the Metropolis, and whether there are other districts in addition to the high districts of England and Wales from which a good supply of unpolluted and wholesome water can

be obtained; and to report, firstly, which of such sources are best suited for the supply of the Metropolis and its suburbs; and, secondly, how the supply from the remaining sources may be most beneficially distributed among the principal towns.

And for the better enabling you to form a sound judgment on the premises We do hereby authorize and empower you, or any three or more of you, to call before you, or any three or more of you, all such persons as you may judge most competent by reason of their situation, knowledge, or experience, to afford you correct information on the subject of this Inquiry.

And Our further will and pleasure is that you, or any three or more of you, do, with as little delay as possible, report to Us in writing under your hands and seals your several proceedings by virtue of this Our Commission, together with your opinion on the several matters herein submitted for your consideration.

And We will and command that this Our Commission shall continue in full force and virtue, and that you, Our said Commissioners, or any three or more of you, may from time to time proceed in the execution thereof, although the same be not continued from time to time by adjournment.

And for your assistance in the execution of this Our Commission, We do hereby authorize and empower you to appoint a Secretary to the said Commission, whose services and assistance We require you to use from time to time as occasion may require.

Given at Our Court at St. James's the Fourth day of April 1867, in the thirtieth year of Our Reign.

By Her Majesty's command.

(Signed) S. H. WALPOLE.

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TO THE QUEEN'S MOST EXCELLENT MAJESTY.

MAY IT PLEASE YOUR MAJESTY,

WE, the Commissioners appointed by Your Majesty for the purpose of inquiring into the means of obtaining additional supplies of unpolluted and wholesome water for the Metropolis and other large towns, humbly report to Your Majesty as follows.

1. The Commission issued by Your Majesty, and dated the 24th of December 1866, commanded us to ascertain "what supply of unpolluted and wholesome water can be "obtained by collecting and storing water in the high grounds of England and Wales, "either by the aid of natural lakes or by artificial reservoirs at a sufficient elevation "for the supply of the large towns, and to report, firstly, which of such sources are "best suited for the supply of the Metropolis and its suburbs; and, secondly, how the "supply from the remaining sources may be most beneficially distributed among the "principal towns."

A second Commission, dated the 4th April 1867, commanded us also "to inquire "into the present water supply to the Metropolis, and whether there are other "districts, in addition to the high districts of England and Wales, from which a good "supply of unpolluted and wholesome water can be obtained."

2. It will be convenient to divide our Report into six parts.

I. On the practicability of obtaining large supplies of water from the mountainous districts of England and Wales.

II. On other available sources of supply.

III. On the present Water Supply of the Metropolis.

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PART I.

ON THE PRACTICABILITY OF OBTAINING LARGE SUPPLIES OF WATER FROM THE MOUNTAINOUS DISTRICTS OF ENGLAND AND WALES.

3. Our attention was first directed to the question of obtaining large supplies of water from the mountainous districts of England and Wales; and five engineering projects, having this object in view, have been laid before us.

Four of these plans have for their object the supply of the Metropolis, viz.:—

Mr. J. F. Bateman's plan, from the sources of the Severn.

Messrs. Hemans and Hassard's plan, from the lakes of Cumberland and Westmoreland.

Mr. Hamilton Fulton's plan, from the sources of the Wye.

Mr. Remington's plan, from the hills of Derbyshire.

The fifth plan, that of Mr. Dale, proposes to supply various towns in Lancashire and Yorkshire.

It will be our duty to describe these plans, and to remark on some of them at considerable length. We have caused the more important of them to be traced on the map of the rivers of England appended to this Report (Appendix B N.) which has been prepared for our use, under the direction of Colonel Sir Henry James, R.E., by the Ordnance Survey Department. From this map, on which the basins drained by the several rivers are distinguished, and many important levels given, a tolerable conception of the general form of the surface of the country can be obtained.

MR. BATEMAN'S PLAN.

4. The first on the list is that of Mr. John Frederick Bateman, F.R.S., civil engineer, who has constructed some of the largest works for Water Supply in the kingdom.

The plan proposed by this gentleman for supplying the metropolis was first published by him in a pamphlet bearing date November 1865, (which we have reprinted in Appendix E. to this Report,) and it has been more fully developed in evidence given by him before us.

App. E.

General Description of the Scheme.

5. Mr. Bateman proposes to collect water by reservoirs to be formed in the mountainous districts of North Wales, and to convey it by an artificial conduit to London.

He urges that the supply for London ought to be sought where the water is purest, softest, and most abundant, and most secure from injury by any operations of manufacture or agriculture. To obtain these conditions he has considered it necessary to go to mountains of hard and impermeable rock, where little cultivation goes on, where only a scanty population is likely to collect, and where reservoirs for storage could be easily provided. He assumes also, as a further condition, that the necessary quantity should be delivered to London at an elevation from which nearly the whole metropolis could be supplied without pumping.

He considers that the nearest high land fulfilling all these conditions is to be found in North Wales, and that the quantity of gathering ground there available is more than sufficient. He has selected, as the best, certain high drainage grounds lying to the south of Snowdon and to the east of Plynlimmon and Cader Idris, and supplying the head waters of the River Severn.

6. The map marked E (2) shows the districts referred to. The Severn rises on the east slope of Plynlimmon, and a few miles down its course it is joined by five other streams, namely, the Tylwch or Dulas, the Clywedog, the Carno, the Ceryst, and the Tarannon. Mr. Bateman proposes to combine the drainage grounds of these various streams into one district, which is tinted green on the map, and which may be distinguished as the *Southern District*. The waters from this district being collected by intercepting conduits, are to be poured into a main reservoir at Trefeglwys, subsidiary reservoirs being added in other parts of the area.

Mr. Bateman also proposes to appropriate the upper drainage grounds of two other rivers lying more to the north, namely, the Vyrnwy and Banw, whose combined waters flow into the Severn between Welshpool and Shrewsbury. This drainage ground is tinted pink on the map, and may be called the *Northern District*. Its waters are proposed to

be stored in several reservoirs constructed on the various streams, and to be collected at a point above Rhyd y Gro.

Both these districts are stated to be generally favourable for water collection. The ground lies high, the rainfall is large, and the conformation of the country admits of the construction of large reservoirs. The geological structure is favourable for the quality of the water, and Mr. Bateman gives an analysis to show that these waters are, in fact, very pure and remarkably free from mineral matter.

7. Mr. Bateman proposes to convey the water from the two districts by separate conduits, converging to a point of junction at Marten Mere, near Montgomery: from this point the joint volume of water would be conducted southwards by a common aqueduct, which, crossing the Severn near Bridgnorth, and passing near the towns of Stourbridge, Bromsgrove, Henley-in-Arden, Warwick, Banbury, Buckingham, Aylesbury, Tring, Berkhampstead, and Watford, would discharge into large reservoirs proposed to be constructed on the high land near Stanmore, about ten miles north-west of London. The total distance the water would have to be brought to London from the delivering point of either of the districts, would be a little above 180 miles. The aqueduct is designed to be capable of conveying 230,000,000 gallons per day.

The direction of the conduit is shown on the plan marked Appendix E (1), and sections of it in various places are given in the Appendices A Q and A R. It would be chiefly an open canal, lined with masonry, but it would be tunnelled where necessary through the hills, and formed by syphon pipes across the deep valleys.

The heads of the conduit, in the Welsh hills, would be at a height of about 450 feet above the mean sea level, and allowing one foot of fall per mile, the water would be delivered into the reservoirs at Stanmore at about 270 feet above the sea.

8. These reservoirs are shown on the plans marked Appendices A N (1 and 2). They are designed to contain 2,000 millions of gallons, equal to twenty days' supply at the present rate of consumption. 6568–70.

9. The plan proposed by Mr. Bateman for the distribution of the water in the metropolis is shown on the map, Appendix A N. He would make use, as much as possible, of the existing store reservoirs of the various companies, to which he would convey the water by large main pipes from the great Stanmore reservoirs. He would, however, re-arrange the distribution, dividing the metropolis into four districts, as shown on the map, conveniently arranged so as to suit the levels of the smaller reservoirs. He would further make such alterations in the service mains as would be necessary to provide for a constant service to all the houses, thus doing away with the present intermittent system. 6570–88.

10. Mr. Bateman states that his aqueduct, in traversing the midland counties, would pass within ten miles of the centre of a very populous country which is probably the most difficult to supply with water of any large manufacturing district in England—namely, Birmingham, Wolverhampton, Dudley, Walsall, and the Staffordshire coal district. He therefore thinks it would be expedient to make provision for supplying these places. 269–75.

There are many important points to be considered in reference to Mr. Bateman's scheme, and on which we have received a considerable amount of evidence.

Evidence as to the Scheme.

11. With regard to the *quantity* of water which can be procured, Mr. Bateman is of opinion that no distant and expensive plan ought to be entertained which would supply less than 200,000,000 gallons a day; and he thinks such a scheme ought to be capable of further extension, so as to provide ultimately for a still larger supply.

The quantity which can be obtained depends on three elements, namely, the area of gathering ground, the rainfall, and the proportion of the latter which can be collected and stored.

12. The *area* of drainage ground marked out by Mr. Bateman is as follows:— 6561.

	Square miles.
Northern District about - - - - -	104
Southern „ „ - - - - -	100
Total - -	204

22–5. 6701. He, however, points out that this area is capable of great extension in the same basin, and that, moreover, it would be easy to add other adjacent districts of a similar character included in the basin of the Wye. The map E (2) shows the additions that may thus be made, and which comprise about 183 square miles.

13. The *rainfall* appears to be open to some doubt, no complete system of rain gauges having been kept in the district for a sufficient length of time. Mr. Bateman, therefore, in making his calculations on this point, relies to a great extent on the physical conformation of the country, and on the facts observed in nearly analogous cases.

App. E. He considers the conformation of the country favourable to a large rainfall. Taking into account the partial results noted by himself, and those obtained in places where like conditions prevail, Mr. Bateman considers that the rainfall here should be as great as in the highlands of Scotland, and as great as in the lake districts of England, with the exception possibly of a particular locality subject, from peculiar local circumstances, to an excessive amount of rain.

23–6.

App. E. 103–8. 119–22. He considers he is justified in estimating the probable *average* rainfall in his district at about 75 inches. But as it does not do to lay out waterworks on an average, he prefers to take the two or three driest consecutive years he can find, and estimates 60 inches for them.

He then comes to the question what proportion of this is available. From long general experience and numerous observations he finds the loss, in such districts, from evaporation and absorption, vary from 9 inches to 16 inches, the smaller loss being where the rocks are the hardest and the declivities the greatest. He takes, as a safe estimate for this district, a mean of 12 inches, which, deducted from 60 inches, leaves 48 inches as the net available produce. But for greater security, he diminishes again this last result by 25 per cent., taking only 36 inches as the estimated available proportion of the rainfall on which to base his calculations. He states that this is only three inches more than he is actually collecting and storing in the Manchester Waterworks, where he supposes the rainfall is probably little more than half what it is on the Welsh hills.

36. 109–14. From the amount of available rainfall is deducted the quantity necessary for affording compensation to the rivers. Mr. Bateman states that the compensation given in the manufacturing districts, (where frequently, in dry weather, every drop of water is impounded in the night and given out in the day,) has usually been about *one-third* of that which can be collected. But for this district he has allowed only *one-fourth*, because it is not a manufacturing district; there are comparatively no mills, and one-fourth would very materially increase the workable volume of the stream.

He remarks that the floods in these districts are enormous, being from 500 to 1,000 times greater than the dry weather flow, and it is from these that the water would be stored for the use of London, and for compensation. By impounding the water the destructive floods would be diminished and the useful volume in dry weather increased, and he adds that this has been the universal result wherever this principle has been applied.

34. On these grounds, Mr. Bateman arrives at the following quantities:

	Northern District.	Southern District.
Amount estimated at a rainfall of 36 inches, about	148,000,000	144,000,000
Deduct one quarter for compensation for rivers -	37,000,000	36,000,000
Leaving for the available supply - - -	111,000,000	108,000,000

giving about 219,000,000 gallons per day as the gross produce of the two districts, having the areas above stated. But from the facility of increase of area, he has not hesitated, in his subsequent calculations, to assume an available quantity of 300 millions of gallons.

14. Other authorities, whom we have examined, think Mr. Bateman's estimate of quantity and rainfall too high.

2465–86. Mr. Hawksley, also a civil engineer of great experience in water supply, judging by analogous districts, considers that the average rainfall would not exceed 45 inches over the whole surface. But he remarks it is known to be impossible, by any system of reservoirs that can be constructed, even with large capital, to deal with more than the average of three consecutive years of minimum fall; the minimum year has about one-

third less than the general average, and in the three consecutive driest years the average fall is almost precisely one-sixth less. Hence, deducting one-sixth from 45 inches, there remains 37½ inches, which Mr. Hawksley considers the quantity due to the three minimum years. Then, secondly, the loss by evaporation, &c. over a district like that, part of which is lowland and part highland, he estimates at about 13½ inches, which leaves 24 inches as the quantity of rainfall available, instead of 36 inches as estimated by Mr. Bateman.

Mr. G. J. Symons, who has for several years recorded annually (in a work published by him entitled "British Rainfall") the fall of rain in various parts of the kingdom, and who has given us elaborate evidence bearing on this and other plans, infers from the facts at his disposal, that the mean fall in three successive dry years would be 44 or 45 inches. 467–506. 526–45. 2729–30.

The Rev. J. C. Clutterbuck doubts Mr. Bateman's estimate of rainfall, and considers the gaugings of the rivers form the only safe criterion of the amount of water obtainable. 1848–66.

Mr. Rawlinson, civil engineer, believes averages in this respect delusive, and considers that a deduction of one-third should be made from the average, to give the minimum fall. 1427–40.

Mr. Hassard, civil engineer, considers that the conclusions which Mr. Bateman has arrived at from the result of gauges kept during the three wettest months of an exceptionally wet year, are not in accordance with the results of gauges in the immediate locality relative to the fall of three dry years. He is of opinion that a greater rainfall than 42 inches could not be reckoned upon over that drainage area in three successive dry years. 965–78.

Mr. Bateman's answers to these objections may be seen in his evidence. 6485. 6524–39.

15. The *storage* is a matter of much importance, as affecting the quantity of water which can be made available to send off the ground. This storage must be sufficient in capacity to collect and impound the flood waters during heavy rains, so as not only to provide sufficient supplies in the dry portions of the year, but also, to a certain extent, to equalize the product of wet and dry years. The storage room must further be calculated not only for the quantity of water intended to be conveyed away, but also for the additional quantity to be sent down the rivers as compensation. 6615.

There being no natural lakes in the district, Mr. Bateman is obliged to have recourse to the formation of reservoirs on a large scale. App. E. 6513–5.

For reasons given by him he considers that a provision for 120 to 140 days' supply would be sufficient, and on this assumption he proposes to make the following reservoirs:— 6560–63. App. E. 37–52. 109–15.

Northern District.	Cubic feet.
Four reservoirs, total capacity about - -	3,494,000,000.
Southern District.	
Three reservoirs - - - - -	3,215,000,000.

The sites of these will be seen on the map E (2), and further particulars will be found in Appendix E., and in Mr. Bateman's evidence. He states that none of the embankments would be more than 80 feet in height, and they would be placed in situations where either hard impervious clay or the solid rock of the Silurian formation would afford the means of making them perfectly safe and water-tight. Two of these reservoirs would be some miles in length, and one, with an embankment of 75 feet high, would hold 50 per cent. more than the available water of Loch Katrine.

16. Some objections have been brought against this portion of Mr. Bateman's plan. Mr. Hawksley considers the proposed storage insufficient, and that the reservoirs, to provide for the three driest years, ought to store about 170 days' supply. 2483. 2489.

Objections have also been made to the amount of property which must be sacrificed to form the reservoirs, and to the danger which might be apprehended in the valley of the Severn from any accident happening to artificial reservoirs, at such an elevation, and containing such an immense storage of water.

17. Another point of great importance in Mr. Bateman's scheme is the *quality* of the water which it will afford.

He has laid before us some analyses procured by him of samples collected in the district; but as we felt that this was a matter on which it was desirable to have the most positive and unexceptionable data, we determined, with the sanction of the Lords of Your Majesty's Treasury, to carry out an independent investigation, by having the district examined, and samples collected and analysed, by competent persons under our own direction.

It was important, in the first place, that the district should be examined, and the samples collected, by a person accustomed to such matters, and this duty we intrusted to Mr. W. Pole, F.R.S., a civil engineer of experience in water supply. He was instructed to go over the ground and select points where samples might be taken, so as to give a fair idea of the waters of the district; to take such samples and forward them to the chemists for analysis; and to note any observations as to the district generally which might appear worthy of our attention. Mr. Pole's report will be found in Appendix B.

Fourteen samples of water were taken, in different parts of the district, and were submitted for analysis to two chemists of eminence, Dr. Frankland, F.R.S., who is employed by the Registrar General to analyse the metropolitan waters, and Dr. Odling, F.R.S., Professor of Chemistry at St. Bartholomew's Hospital. Their report will be found in Appendix D.

18. The quality of water afforded by any particular gathering ground will depend, in the first place, on the geological structure and mineralogical composition of the rocks; in the second place, on the nature of the surface; and thirdly, on the population, cultivation, and on any accidental circumstances that may affect its purity.

To illustrate the geological and physical features of Mr. Bateman's gathering ground we have caused to be prepared the two maps marked Appendices B A, 1 and 2, the former showing the geology of the district, the latter the elevations of the ground expressed by contour lines. The geological and mineralogical features are favourable; the rocks (almost entirely slates of the Silurian series) are such as are best adapted to preserve the purity of the water falling on them, being practically insoluble, and very little liable to disintegration.

The nature of the surface varies in different parts. In the higher portions it is hilly and steep, the slopes are covered with grass used for cattle and sheep pasture, and the population is very scanty. In descending the valleys cultivation begins, trees appear, and the population increases; while in the lower and flatter parts of the district the land is fertile and well tilled. The latter, however, forms only a small portion of the district, and there is no population beyond that of small villages included in the drainage area.

App. D. 6200–6432. 6433–6484. 19. The analysis of the Welsh waters bears out the anticipation of their quality that might be formed *à priori*, and gives the following results: The quantity of solid contents is very small, varying over the district generally from about $2\frac{1}{4}$ to $4\frac{1}{2}$ grains in the gallon. The waters are extremely soft, their hardness, according to Dr. Clark's test, being generally only 1 or 2 degrees. The organic matter is also small, and there are no traces of any noxious pollution; and so far as could be judged by the samples collected, they were of fair appearance, taste, and aëration.

Mr. Bateman asserts that the water will require no filtration, as the storage in such large reservoirs will sufficiently clear it. He bases this opinion on the general clearness of water in natural lakes.

20. We may briefly allude to five objections which have been made to the Welsh waters on the ground of quality.

The first is to the amount of cultivated land in the lower portions of the district, the manuring of which must, it is said, pollute the water flowing over it. But the analyses do not detect any noxious pollution.

App. B. 21. The second objection is the existence of certain manufactories, the refuse of which is calculated to defile the water. This objection has been examined by Mr. Pole on the ground, and shown to be quite insignificant.

App. B. App. D. 8213–4. 22 The third objection is that the district contains metalliferous veins and mineral workings, principally lead, which, it is urged, must contaminate the streams. This is, at first sight, a formidable objection, on account of the well-known powerful effect of many metallic salts upon the human system. On this account we directed Mr. Pole carefully to examine the facts upon the ground, and his full report on the subject, conjoined with the analysis of the samples he brought away for the purpose, disposes we think effectually of this objection. It is true that there are lead workings in the southern district, and that from many of them suspicious-looking refuse is turned into the streams; but it is found that this refuse contains as a rule no metallic salts soluble in water, and consists only of a detritus formed from the earthy matrix of the ore, generally finely divided quartz or slate, which has been separated by the grinding and washing processes, and is held in

mechanical suspension by the water passing away. This, if admitted into the reservoirs, would soon deposit and leave no pollution in the water; Dr. Frankland even suggests that its presence might be useful, by carrying down organic matter in the process of deposit. Mr. Pole points out that it might be easily prevented from fouling the streams.

23. The fourth objection is in regard to the existence of peat, and its influence on the water. There is a tendency for peat mosses to form and accumulate in mountainous districts, and the brown colour they impart, under certain conditions, to the water issuing from them, is well known. Mr. Pole remarks that in the higher parts of this district patches of peat moss were of frequent occurrence, and that beds of peat of considerable extent were cut and used generally in the neighbourhood for fuel. We believe it is found that in dry weather the streams of such districts, being the produce of springs, remain clear, not taking the peaty tinge; but that in rainy weather, and flood times, when the water permeates and drains through the mosses, an objectionable colouring effect occurs. The majority of the samples collected for the Commission were taken in fine weather, and are reported as clear; but one or two exceptional samples procured during partial floods were highly coloured, being reported as "deep yellow" after standing two days, and leaving a very brown residue on evaporation. App. D. 6203.

Mr. Bateman, from his experience of Loch Katrine, believes that the brown colour of peaty water is lost by exposure to the atmosphere, and argues that the effect of the storage in large reservoirs, and the passage through the long conduit, would have the effect of delivering the water in London perfectly colourless. He has also described to us an ingenious arrangement in the Manchester Waterworks, by which the colourless dry weather discharge of certain streams is separated from the peaty water of floods; but the applicability of this system on so extensive a scale as that necessary for the London supply has been questioned by other witnesses. 134–6. 6657–62. 2510.

Dr. Angus Smith thinks it might be necessary to remove the colour by filtration, but is in doubt how to apply the process. He thinks it cannot always be drunk with impunity, but the only points requiring much attention are the bitter taste and the appearance. 7264. 7214–55.

Dr. Frankland says that the ordinary sand filtration will not remove the colour, and suggests the use of animal charcoal; but he agrees with Mr. Bateman, that by storage in large reservoirs much of the peaty matter would, in all probability, be precipitated. 6203–12.

Dr. Miller thinks peaty water would not be injurious to health, but describes it as at times very disagreeable for drinking purposes. 7059–7124.

Mr. Hawksley is of opinion that in the metropolis it is very necessary that the water should be white water, perfectly clear and colourless, because coloured water would be disagreeable and contrary to the taste of the people. He says soft water is almost necessarily tinted, as it generally comes from moors and from elevated mountain districts, on which there is a large quantity of peat growing, and it is almost impossible to prevent that water acquiring a stain more or less deep. In dry seasons water from these districts may be a good colour, but it is coloured during floods, and these form the great bulk of the supply. 2504–9.

Being asked, If he could choose between the present and soft water for the London supply, which he would prefer? he says, if he could get the water tolerably free from stain he would use the soft water, but if not he would most certainly prefer the white water. He says that peaty water would not be tolerated in London, and instances that its introduction into Liverpool has given rise to much dissatisfaction. Manufacturing towns choose soft water, even if brown, on account of its importance to their trade; but generally, for drinking purposes, the clear, bright, sparkling water is preferred.

Dr. Letheby also states the water from peaty districts would be so frequently tainted and coloured that it would be objectionable, and that Londoners would not drink it. They would prefer a clear, pure, chalk water. 3870–2.

Mr. Simpson objects to the peaty tinge of water brought from certain hilly districts. He says:—"The Severn water at certain seasons is brown as coffee, and it is not a pleasant "water to drink," and he alludes to the colour of the water at Manchester and Liverpool, corroborating Mr. Hawksley, that at the latter place there was a great complaint on this ground. 4685.

24. The fifth objection is one often brought against soft waters, namely, the facility with which they often act on lead.

Drs. Frankland and Odling consider that soft waters do not necessarily act on even bright lead, and that on tarnished lead they seldom act at all. App. D.

1491–8. Professor Way considers that if soft water were used, it would be prudent to guard against its action on lead, by substituting iron for lead pipes.

2671. Dr. Lyon Playfair states that on the intermittent system of supply, with the pipes alternately full and empty, soft water may act upon the lead of the pipes; but if the pipes were always full, as on the constant supply system, there would be very little or almost no risk.

3140–2. Dr. Parkes considers that it would be hazardous if means were not taken to secure the pipes against the action of soft water.

The evidence does not show any instance of injurious effects having resulted from the introduction of soft water into Manchester, Whitehaven, and other towns.

6616. 25. On the important question of cost Mr. Bateman has given us estimates prepared in great detail, having reference to a supply of 230,000,000 gallons per day; but in order to make the outlay gradual, he proposes to divide the execution into four progressive stages, giving—

	Galls. per day.
For the first stage	130,000,000
„ second „	170,000,000
„ third „	200,000,000
„ fourth „	230,000,000

The estimates of outlay on the new works for these several stages, including interest on capital expended during the construction of the works, are as follows:—

For the first stage	£8,685,006
„ second „	10,571,615
„ third „	10,822,474
„ whole ultimate supply of 230,000,000 gallons per day	11,400,023

These sums include the necessary arrangements for conveying the new supplies to the existing reservoirs, with a view to their distribution by the existing mains, but do not include the purchase of existing works or interests. Mr. Bateman, however, estimates that certain property of the companies, to the value of 1,000,000*l.*, may be disposed of as soon as the supply by gravitation is introduced; and he therefore deducts this, reducing each of the above amounts by that sum.

App. E. 6738–44. 26. Mr. Bateman uses arguments to justify the expediency of such a large outlay for the water supply of London as his scheme would involve. He says, "The amount of "the estimate need not startle the public, for it is not more in proportion, either to the "quantity of water to be obtained, or the ability of the inhabitants to pay for it, than "has been expended in Glasgow, Manchester, Liverpool, and many other towns, while "it is far below the cost incurred by many other towns which could be mentioned."

He gives the following comparative statement of the outlay actually incurred in several large towns for bringing improved supplies of water, including compensation to old companies:—

	Cost for each million of gallons per day.
Liverpool	£120,606
Glasgow, for limited supply	59,200
Do., for full supply	33,645
Manchester	60,000
London, estimated outlay for limited supply of 130,000,000 gallons	£165,416
Do., for full supply of 230,000,000 gallons	100,454

But Mr. Bateman considers a fairer test of the ability to pay for water is found in the *assessable value* of respective places, and he gives the following data, calculated in 1865, since which time, however, the rateable value in London has much increased:—

	Total assessable Value.	Assessable Value for Dwelling Houses.
	£	£
Glasgow	1,200,000	600,000
Manchester	1,200,000	600,000
London	15,000,000	10,000,000

From this he reasons that London could bear an outlay for waterworks twelve times as great as Manchester and Glasgow, if measured by the total assessable value, or sixteen times as great if measured by the assessment on dwelling houses alone. And as the outlay in each of the two smaller cities has been something more than 1,500,000*l.*, the proportionate outlay for London would be 19,000,000*l.* on the first principle, and 25,000,000*l.* on the second.

27. Mr. Hawksley doubts the sufficiency of Mr. Bateman's estimate, believing that his reservoirs must be increased in capacity, as before stated.

28. Mr. Bateman developes a financial plan by which he conceives the scheme could be economically carried out, namely, by following the example of the two towns mentioned. App. E.

In each of these towns the waterworks are the property of the corporation, who have the power to levy two rates on account of the water supply, viz.:—

1. A *public rate*, levied in consideration of the protection against fire which "constant supply" and "high pressure" necessarily confer, and in consideration also of the great advantage which all property is supposed to derive from a full supply of water.
2. A *domestic rate*, in respect of the water supplied for domestic purposes.

Both these rates are compulsory rates, levied on all parties, whether they take the water or not. The amounts actually levied at present are:—

	Public Rate.	Domestic Rate.
	In the Pound.	In the Pound.
In Glasgow	1*d.*	1*s.* 0*d.*
In Manchester	3*d.*	9*d.*
In Liverpool	6*d.*	4½*d.*

Mr. Bateman proposes that the water supply of the metropolis should be vested in a public body, who should have power to levy rates of this kind, and who would then proceed to purchase the interests of the several existing water companies, and to introduce the new supply.

29. Mr. Bateman explains that he has been led to the projection of his gigantic scheme by the analogy of the works he has carried out for supplying Glasgow with water from Loch Katrine. For many years the inhabitants of that city, who had previously drawn their supplies from the Clyde, had become uneasy as to the quality of the water, and had anxiously sought for purer sources. In 1853 Mr. Bateman proposed to supply the city by water collected in Loch Katrine, and brought to Glasgow by a conduit 35 miles long. The proposal was at first startling by its magnitude, but after much discussion it was sanctioned and carried out, and the water was delivered from the new source in 1859. Various particulars will be found in the drawing, Appendix A O. 146–58. 176–86.

Emboldened by the success of this work, and acting on the assumption that the metropolis is, or soon will be, in a similar difficulty to Glasgow as regards the supply from its natural river, Mr. Bateman has now brought forward this still bolder scheme. He has sought about, he says, in all directions for a suitable source of supply, and believes that the district he has chosen possesses greater advantages than any other. We may conclude our description with his own words on this point. He says:—

"I may say that I selected this district with a perfect knowledge of what every other part of the country could do. I was aware of the vast quantity of water, and about which there can be no kind of question, in the Lake district, and the elevation of the Lakes; and I knew that those lakes from which water could be obtained were not higher than the sites of reservoirs, which could be formed just as large as lakes, and better than lakes, because you could make them hold more water in the same area in the Welsh hills. Therefore, not only with reference to distance, but with reference to inclination, it was most important to get the water which you wanted at the nearest point. The backbone of England is not only now largely drawn upon by a great many large towns on both sides, in Yorkshire and Lancashire, but it neither possesses the facility for constructing reservoirs, nor the vast amount of rainfall, nor the large area of drainage which for the metropolis is necessary, nor ought it to be tapped, because it is, in fact, the natural resource of all the manufacturing towns in Lancashire and Yorkshire and Cheshire, and therefore the Derbyshire hills and Yorkshire hills were out of the question. The only two districts from which water could be derived were the English lakes and the Welsh hills, without interfering with what might be considered in a national point of view the property 158.

of other districts. But the English lakes, at no greater elevation than the Welsh hills, were at twice the distance, or nearly so.

* * * * * * * * * *

A consideration of all these circumstances (and I gave the whole subject full consideration) determined me in going to the Welsh hills. I saw that there you could get everything nearer, and at an elevation which would enable you to make the works cheaper than in any other part of the kingdom."

Remarks by the Commission on Mr. Bateman's Plan.

30. Having now described the main features of Mr. Bateman's scheme, as presented to us, we proceed to offer some remarks upon it.

31. We are of opinion that Mr. Bateman's plan is practicable in an engineering point of view. The construction of large reservoirs, and the formation of a long conduit, present no problems beyond the ordinary resources of engineering skill, and there are no local or other difficulties to be contended with but such as must be expected to attend works on such a large scale, and such as may with ordinary prudence be surmounted.

32. With reference to the estimates of the cost of these works, as laid before us by Mr. Bateman, we must remark that although he has taken great pains to ascertain the main features of the scheme, sufficiently to establish its practicability, and in some cases by actual survey, yet that detailed surveys and sections of the greater part of the works (the cost of which surveys would probably be not less than 10,000*l.*) have not yet been made. In the absence of such detailed surveys of a scheme involving works of great magnitude, and to some extent novel, and subject to large contingencies and elements of uncertainty, we do not consider that it is possible to arrive at any reliable estimate of the cost which could safely be taken as the basis for recommendation of the scheme.

33. Mr. Bateman, in answer to question No. 6740, has given a calculation of the expected annual income and expenditure, but we are satisfied that there are many points in this calculation which are open to objection or doubt, and we are not able to adopt it.

34. He has also, in answer to question No. 6632, given, in a tabular form, "comparative "estimates of obtaining additional supplies of water from the existing sources and North "Wales," but on examination of the details of these calculations we are of opinion that these estimates are equally open to objections, and Mr. Bateman has not convinced us of the superior economy of the Welsh scheme. He contemplates considerable saving from the consolidation of the management, and from the levying of compulsory rates; but these measures would be equally applicable, and the benefits arising from them equally available, if the present sources of supply were retained.

35. It must be recollected that Mr. Bateman, if his gravitation scheme were introduced, could not entirely dispense with pumping. The high-water level of his Stanmore reservoirs, though 270 feet above ordnance datum, would be less than 200 feet above the ground level of many populous parts of London. And considering the depths to which both the Stanmore and the district reservoirs must of necessity occasionally be drawn down, and the large pressure necessary to force the water through the main and distributory pipes, we doubt whether the head would be sufficient to supply the upper stories of the houses in many parts of London, particularly under the unequal drafts resulting from the system of constant supply. In all these places, therefore, pumping would be required, and this would diminish the advantage assumed for the gravitation scheme.

36. The quality of the water, which appears very similar to that supplied to Glasgow from Loch Katrine, is satisfactory as regards its softness and purity. On other points we consider there are objections.

In the first place it is liable to be coloured by peat. The evidence shows the large presence of peaty matter in the flood samples, and as the great body of the water collected would be in floods and rainy seasons, there seems reason to believe that the coloured condition would be a common one. We agree with the witnesses that coloured water would not be acceptable to the inhabitants of London, for a taint in the water which is visible to every drinker is more likely to be objected to than one which might perhaps be less harmless but less easily seen. We think the question of how far the colour would be lost by storage and in the conduit requires determination by more extended experience;

and it is obvious that the adoption of any system of filtration, if applicable in such a case, would add largely to the original outlay, as well as to the annual cost of the supply.

There is another point requiring serious consideration, namely, the action of soft water on lead, which is often energetic. Of the sixteen samples of Welsh waters collected for the Commission by Mr. Pole, nine were found to act more or less on bright lead, and five to have no action; while on tarnished lead two had considerable action and fourteen had no action. It is true that the introduction of soft water into towns has in this respect often been effected with apparent impunity. The pipes and cisterns soon become coated in a way that, if they are kept full, is thought to preserve them from chemical action. We are, however, told by a very competent witness, that in Manchester "there have been 7268.
"several instances where medical men have believed injurious effects to have been caused "by the lead, and in several cases where there have been lead cisterns the effect has been "very decided indeed; but there have been also several where it has been believed that "the lead poisoning had its origin from the pipes alone,—enough at least to render great "caution necessary." We have had it also stated "that soft waters do not *necessarily* "act on lead." Although, therefore, under a perfectly efficient system of management, or by the substitution of iron for lead, there may be little danger to be apprehended from the use of soft water, still, under the innumerable accidental conditions which must occur in the distribution of a large town supply, arising from repairs of pipes, leakages, carelessness, peculiar states of the water resulting from local causes, and so on, there is no doubt that whilst in hard water the risk of danger is reduced to a minimum, in soft water, on the contrary, the risk must be a maximum one, and one which must always exist.

The circumstance that generally no ill effects have been found to result from the introduction of soft water, is inconclusive against the instance in which it has been affirmed; and unless a very clear and serious case were to occur, many minor cases of slight injury might take place without the cause being suspected.

We shall make some further remarks on the comparative advantages and disadvantages of hard and soft water in a subsequent part of our Report.

37. There is at present an insufficiency of data as to the amount of rainfall in the district, but we are of opinion that the evidence before us tends to show that Mr. Bateman's estimate of it is too high. The rainfall in all districts varies very much in different years, as well as in different parts of the same district, and hence it is only by a long continued and widely extended series of observations on the ground itself that any exact results can be obtained.

Although Mr. Bateman's anticipations on this point may not be fully realized, it must 6701–2.
be borne in mind that he states such a deficiency may be met by taking in a larger area of gathering ground. This appears feasible, the drawback being that it would increase the outlay necessary to be expended.

38. There is every reason to believe that if Mr. Bateman's scheme were ever brought forward in Parliament, it would be subject to a most powerful and determined opposition from interests of various kinds connected with the river and estuary of the Severn.

The Commission has received little or no evidence on this head; for the reason, no doubt, that until the scheme assumes a more practical shape, there is not sufficient inducement to the various parties to come forward.

Mr. Hawksley alludes to some of the points that would be likely to come into dispute, 2460–4.
stating that there are very large interests down the River Severn, from its head to the foot of the estuary, which will be interfered with.

Mr. Simpson corroborates this, and adds that the abstraction of water would be a serious evil, and that considering the great trade and the sums of money that have been spent on the river, it is questionable whether it ought to be interfered with.

It has also been objected that the appropriation of the streams and the loss of the floods would destroy or injure valuable fisheries, particularly of salmon; but on this point we have had no evidence, no one interested in these fisheries having appeared before us.

39. A serious objection has been raised to this as well as to other large schemes for supplying the metropolis from a distance, namely, the danger of having so large a population as that of London and the suburbs dependent solely on one supply of water, which might so easily be stopped by any one of several causes, such as wilful damage, frost, or the failure of any work along the line.

In regard to the first of these causes, we believe anxiety has been felt in other analogous
2527–8. cases. Mr. Hawksley says that this objection has been practically raised by foreign Governments to schemes of his own under similar circumstances.

2422–8. Mr. Duncan testifies to the anxiety lately felt on this point at Liverpool, and the precautions taken there to prevent interference with the works.

2527–43. Mr. Hawksley also attaches much importance to the difficulties likely to arise in long-continued cold weather, from frost and snow impeding the current through the long
3990–8. open conduits; and Mr. Muir, the engineer to the New River Company, states that it requires labour and considerable expense in severe frost to keep the New River in efficient flow.

6570. Mr. Bateman, in reply to these objections, says he has provided for ordinary cases of
6643–4. interruption by reservoirs of so large a size near London, that within 10 miles there would
240–43. be three weeks' storage to cover any interruption from accident or repair. He admits that no provision could be made against the possibility of the water being cut off during hostile occupation or by wilful damage; but this objection is, Mr. Bateman considers, applicable to many large cities; and is a contingency so remote as not to weigh against the many advantages of the plan.

6669–79. His experience of Loch Katrine aqueduct leads him to attach no great weight to the objection as to freezing, as in a very severe winter, when the temperature fell to 12 and 14 degrees below zero in the open air in the district along which the conduit was carried, the temperature of the Loch Katrine water never fell lower than 39 degrees, and there was not a particle of ice in any shallow or bay in Loch Katrine.

We do not, however, consider the two cases analogous. The great depth of Loch Katrine may maintain a minimum temperature of 39°, but in smaller reservoirs the temperature would necessarily be liable to fall lower. Further, the water after leaving Loch Katrine, having to pass through a tunnel 2,325 yards in length and in places 523 feet below the surface of the ground, and again just before reaching Glasgow passing through another tunnel of 2,640 yards long and 246 feet below the surface, would necessarily have its temperature raised in winter in consequence of the permanent greater heat of the ground at those depths. In the Welsh scheme, on the contrary, there are no deep tunnels; and whereas in the Glasgow works the whole distance of 26 miles was tunnelling or "cut and cover," here there would be nearly 100 miles of open cutting In a river like the Thames the temperature in winter is kept up by the springs which feed it, an advantage an aqueduct does not possess.

The freezing of canals and rivers, even of considerable capacity, in this climate, is a matter of frequent occurrence; and it must be borne in mind that, although the channel may not actually be stopped, the presence of ice and congealed snow in it would seriously diminish the velocity of flow and consequently reduce the quantity of water conveyed.

Then in a conduit of such vast length, and involving engineering works of such great variety and magnitude, it is only reasonable to contemplate the possibility that by some unavoidable mischance, such as a landslip or otherwise, failure or accident might happen to some of the works, which might have the result of stopping the flow for perhaps a considerable time; and in case of repairs being necessary it must be remembered that a large river 180 miles long, with a considerable fall and velocity, would be a difficult thing to deal with.

40. The objection as to the danger of the collection of such vast bodies of water in artificial reservoirs at the head of so important and populous a valley as that of the Severn, derives its principal force from the accidents that have been known to arise, and the destruction of life and property that has ensued from the rupture of reservoirs. And, considering that several large towns and populous and flourishing districts, would all be at the mercy of a flood from one of these gigantic stores of water, and that any failure would be most likely to happen when the store was at the largest, there is no doubt that an accident of the kind would be a great national disaster. In the hands of competent engineers and contractors, with ample funds and time at their disposal, the works may be so substantially constructed as to reduce the risk of such accidents to a remote chance, but we think that, although such an objection ought not to weigh against the plan if it were necessary, it may form an element in the choice between this and other sources of supply.

THE CUMBERLAND LAKE SCHEME.

41. Another plan, somewhat similar to that last described, is brought forward by Messrs. Hemans and Hassard, who propose to supply the metropolis with water from the lakes of Cumberland and Westmoreland.

This plan is described in a pamphlet published by the promoters in July 1866, which we have reprinted in Appendix F., and we have had explanations given by both these gentlemen in their examinations before us.

42. They remark, "It is felt that these suggestions appear somewhat at a disadvantage, App. F.
"particularly as the sources of water supply recommended would seem at first sight to
"demand works in length and extent of greater and more startling magnitude than even
"the already sufficiently bold project of Mr. Bateman, for bringing water to London from
"the Welsh hills at a distance of 183 miles. The sources herein recommended lie at a
"distance of 240 miles from London, but, notwithstanding this increase of distance, we
"believe that when the subject is fully investigated it will appear that our project—
"although involving an apparently larger outlay in the first instance—will, from the
"absolute certainty of the rainfall, the extraordinary purity of the water, the facilities
"afforded by the existing lakes for the construction of the immense reservoirs, and from
"the revenue which may fairly be expected from the sale of water in the districts
"traversed by the aqueduct, be found the best and cheapest which has yet been proposed,
"and that ultimate economy will arise from its selection."

43. The scheme is somewhat complicated in its arrangement, but it will be easily understood from the map, Appendix F (1).

It will be seen that to the north of the great dividing range of hills running east and west between Scaw and Shap fells lie three large lakes, Thirlmere, Ullswater, and Haweswater. These are at a considerable altitude, the level of the water above the sea in each lake being as follows:—

	Feet.
Thirlmere	533
Ullswater	480
Haweswater	694

It is proposed to dam up the outlets of the two higher lakes, so as to raise their levels still further, namely, Thirlmere by 64 feet, and Haweswater by 42 feet.

It is also intended to increase the quantity of water running into them by adding the drainage from the sides of neighbouring hills, to be collected and brought into the lakes by intercepting conduits at proper levels.

The waters from these two lakes would then be conducted by conduits and tunnels into the centre or lower lake, Ullswater, which would be treated as a great distributing reservoir from which the supply would be drawn off as required. This lake has a large drainage of its own, and it is proposed to increase it by a small additional district in the same way as the others.

The natural outlet of the Ullswater lake is at the north end, by the River Eamont, flowing into the Eden, and so by Carlisle into the sea. It is proposed, however, in the present scheme, to tap the lake at its southern end, and to run the water off from it by a tunnel to be formed under Kirkstone Pass, opening out on the slopes of the hills above Windermere, from whence the water would flow by gravitation through a conduit to London.

44. *Area of the Districts.*—The area of the district proposed to be made available as App. F. 1.
collecting ground is as follows:—

	Square Miles.
Thirlmere drainage	44
Haweswater ,,	38
Ullswater ,,	95
Total	177
To this may be hereafter added—	
Drainage on the southern slopes of the main range	53

App. F. 45. *Rainfall and Quantity of Water.*—The lake district having been long noted for its large rainfall, the promoters consider that on this point no difference of opinion can arise.

In the pamphlet (Appendix F.) the promoters state that the observations of the late Dr. Miller, from 1847 to 1853 inclusive, give an average annual fall of 100·56 inches, but 1864 and 1865 being dry years gave only 80·38 inches. They therefore, to avoid question, took the smaller figure 80 inches as the rainfall to be depended on.

606–23. Mr. Hassard, however, in his evidence gives a revised estimate. He says that the three years 1853, 1854, and 1855 were consecutive years of very great drought, the quantity being only about 83 per cent. of the average. These three years give a mean of 64 inches, which therefore he takes as his standard of estimation.

App. F. From the rainfall has to be deducted the loss by evaporation and absorption, which, in a precipitous and rocky district, the promoters assume will be not more than 12 inches. They, however, take it as 14 inches.

The following therefore appears to be their estimate of the quantity to be yielded by the district:—

Area of collecting ground	177	sq. miles.
Mean rainfall of three consecutive dry years	64	inches.
612. Deduct loss by evaporation and absorption	14	„
Available	50	„
This from a drainage area of 177 square miles will give per day about	350,000,000	gallons.
706. Deduct for compensation to rivers a quantity equal to 9 inches of rain over the collecting area	63,000,000	„
Available for supply to metropolis and other towns	287,000,000	„

Mr. G. J. Symons has given us an elaborate report on the rainfall. He considers the evidence in regard to the lake district unusually complete; and he infers from the whole that the true mean rainfall for it may be taken at 77 inches, and the mean of three dry years at 80 per cent. of this, or 61·6 inches. In the driest years he would take something like 66 or 68 per cent. of the average, which would give about 53 inches. During the ten years ending 1859 there was only one drought of more than 40 days' duration, and more than one inch of rain fell during its continuance.

46. *Storage.*—The storage would be obtained principally in Ullswater, Thirlmere, and Haweswater lakes, but partly also from auxiliary reservoirs formed in other places; the raising of Thirlmere and Haweswater, as already described, would allow of a large amount of storage room in them. It is also proposed to raise Ullswater 5 feet, and to draw it down 20 feet when absolutely necessary. It is explained, however, that this would only be required when the maximum quantity was taken, and even then only in very rare cases of extreme drought.

The whole available storage would be about 5,563,000,000 cubic feet, which is equal to 120 days' supply at 250 millions of gallons, or to 157 days' supply at 200,000,000 gallons per day, after giving credit for the average minimum summer yield, and allowing for compensation.

App. F. 47. *Conduit.*—The water would be conveyed from Ullswater to London over a length of 270 miles by conduits, tunnels, and iron pipes.

The work of greatest magnitude connected with the scheme would be the tunnel under Kirkstone Pass, to bring the water southwards from Ullswater. It would be 7¼ miles in length. From the south end of this tunnel the conduit would pass by Ambleside and Kendal, and down the eastern side of Lancashire (avoiding the Wigan coalfield), to the east of Manchester and of the Potteries district, and to the east of the Staffordshire coalfield and of Birmingham, and onwards towards London, following a route
301–2. nearly parallel with that of the London and North-western Railway. The conduit would be in effect equivalent to a river 30 feet wide and 10 feet deep. The inclination taken has
428. been small, viz., 6 inches, and in some cases 4 inches per mile, and for pipes 20 to 24 inches per mile. Probably in some part wrought-iron pipes of 8 feet diameter, lined with cement,

might be used with advantage. Detailed descriptions of these works, and of the nature of the districts over which they are taken, will be found in Mr. Hassard's evidence. The 733. 743.
conduit would terminate in a large regulating reservoir to be constructed near Edgeware, at a distance of about 12 miles from Cumberland Gate, Hyde Park. The height of 730–57. 765–7.
this would be 232½ feet above Ordnance datum, which the promoters consider would 778–817.
ensure an ample pressure for ordinary domestic supply and in case of fire, and would allow 823–38.
of the use of the existing appliances of distribution, which they assume would be destroyed 818–22.
by the use of a much higher pressure and by the adoption of a different system of service. Elevated districts must still be supplied by pumping. The reservoirs are proposed to be in duplicate, containing in the aggregate 15 days' supply at 250,000,000 gallons per day.

48. *Other Towns on the Way.*—The promoters state that the conduit, in passing through the heart of England, Lancashire, the Potteries, and the midland counties, would be capable of affording *in transitú* a practically unlimited supply of water to the large manufacturing districts and population on the line of its route. They estimate that more than 50,000,000 gallons per day might thus be disposed of.

49. *Additional Supply from Bala Lake.*—The promoters contemplate taking in 589–604.
water from Bala lake, in order to replace water which might be sold to manufacturing 884–98.
towns in the north. This would require an additional aqueduct 70 miles in length, which would join the main conduit at Stoke; and at the point of junction they propose to form an additional reservoir capable of holding about 21 days' supply; they estimate the cost of this addition at 1,500,000*l.*, and the extra quantity obtained at from 50,000,000 to 60,000,000 gallons.

50. *Estimate.*—The promoters estimated in their pamphlet that the cost of the project App. F.
complete, for 250,000,000 gallons a day, would be 12,200,000*l.* But in Mr. Hassard's 1060.
evidence he gives an amended estimate as follows:—

Reservoirs, conduits, and works of collection	£1,013,000
Tunnel under Kirkstone Pass	360,000
Aqueduct to London	9,806,260
Regulating reservoirs near London	500,000
	£11,679,260
Interest during construction, and other expenses	1,820,740
	£13,500,000

Mr. Hassard compares this estimate with that for Mr. Bateman's plan, and also with 681.
the cost expended for a like purpose in Liverpool, Manchester, and Glasgow, and gives 693–9. 718–28.
the result as follows, being the cost for each million gallons per day:— 839–51. 1059. 1060.

In Liverpool	£115,115
In Manchester	60,000
In Glasgow, present	59,260
„ ultimate	33,645
In London, from Wales	95,454
„ from lakes	88,000

Formidable objections have been raised to these estimates, as will be seen in the 6703–36.
evidence.

51. *Financial Scheme.*—Messrs. Hemans and Hassard agree with Mr. Bateman that App. E.
the water consumers should be the proprietors of the new works; that a compulsory 910–12.
rate should be levied for water supply on all property within the area benefited; and that the existing waterworks should be purchased and incorporated with the new project, and the companies secured in their present incomes.

They give in their pamphlet a statement of estimated income and expenditure, and Mr. Hassard gives amended figures in his evidence.

52. *Quality of the Water.*—The topographical and geological character of the gathering ground is generally similar to that of the Welsh hills, but is in some respects more

favourable, inasmuch as the hills are higher and steeper and less covered with vegetation, and the area contains less population and less cultivated land. Some portions of the district are less favourable than others, but they might, if it were necessary, be excluded.

The two maps, marked Appendices AZ, 1 and 2, have been prepared to show the geological features of the ground, and its elevation at various points above the mean sea level.

There are extensive lead workings in some parts of the district, but the evidence shows that they need not form any objection to the scheme.

We have made an independent investigation of the quality of the water from this district, in the same manner as that from North Wales; the samples were, as in the former case, collected by Mr. Pole and analysed by Drs. Frankland and Odling, and the reports of these gentlemen will be found in Appendices A and D.

The results of the analyses are very similar to those of the Welsh waters as regards softness and purity, and freedom from mineral contents and organic contamination. But the waters are open to the objection mentioned in the former case as regards the probability of their being coloured by peat. The samples generally were taken in fine weather, but many of these were slightly coloured, and two samples that were taken when the streams were in flood were reported to be "yellowish brown, leaving a nearly black residue on evaporation." It is suggested that these waters might be excluded from the collection and used for compensation, but it is probable that they only represent the state that the streams generally would assume in heavy rains, when the water storage would principally take place. The water taken from the lakes was "clear and colourless, leaving a "slightly brown residue on evaporation."

Remarks by the Commission on Messrs. Hemans and Hassard's Plan.

53. This plan has so many points of resemblance to that of Mr. Bateman, that many of the remarks we have made on the Welsh project will be applicable to this also.

The plan is practicable, and has the advantage of the existence of the natural lakes at a high level, but the estimates of cost are more uncertain than in the former case, on account of the less detail in which the promoters have prepared their plans, the greater length of the conduit, (about 90 miles longer than Mr. Bateman's,) and the greater uncertainty as to its exact route and nature.

The quantity of water obtainable is abundant, as the rainfall, whatever may be its exact amount, is admitted on all hands to be very large.

The quality of the water is satisfactory, subject to the same objections that we have mentioned in the Welsh case.

6916–78. 7149–82. There would probably be less formidable opposition to this scheme than to Mr. Bateman's, on account of the less magnitude and importance of the rivers flowing from the district. But the objections from the possible stoppage of the flow in the conduit would be increased in proportion to its greater length.

The remark we have made as to the necessity for pumping to some extent in the Welsh scheme applies with much greater force to this plan, as the promoters propose to deliver the water into the store reservoirs near London at a level 37½ feet lower than Mr. Bateman. This level we believe would be insufficient to supply any but the lower districts, so that pumping would be required over a large portion of the metropolitan area.

There is no doubt that the lake district is a very fine gathering ground for soft water; but it is deserving of consideration that this district is not unlikely to be claimed as the most natural source of supply for large and increasing manufacturing populations in the north of England, for whom soft water would be particularly valuable; and we hold it to be erroneous in principle that any one town or district should take possession of a gathering ground geographically belonging to another, unless it can be clearly shown that circumstances render such a step justifiable.

MR. HAMILTON FULTON'S PLAN.

3446–3571. 4078–4171. **54.** The plan proposed by Mr. Fulton is explained in his evidence, and in the two plans in the Appendix marked A A (1 and 2).

He proposes to take water from the upper sources of the River Wye in Mid-Wales. The reasons alleged for the selection of this district are—

3450. "That it is very thinly inhabited, the water at present is scarcely used at all, either for manufacturing, domestic, or navigation purposes; the fisheries which exist can be protected from injury; there are no manufacturing towns in the watershed; and the only application of water for mechanical purposes is for flour mills, of which there are very few."

He also adds—

3174. "The reason why I have chosen the Wye district in preference to any other is, that the importance of the navigation of the Wye is very small, and consequently the abstraction of its water would be no injury as far as the navigation is concerned. Indeed from the sea up to Hereford, which is the largest town in the district, and which has a population of between 15,000 and 16,000 inhabitants only, I believe the trade is nearly extinguished on the river, that is to say, it is nearly superseded by the railway; and the only trade by navigation which exists now is by the canal from the Severn, which runs up to Hereford."

Mr. Fulton has selected four districts on the Wye and its head tributaries: App. AA.

	Square miles.
No. 1 containing - - - -	146
2 „ - - - -	125
3 „ - - - -	102
4 „ - - - -	67
Total area	440

3454–67. Reasoning by analogy with the lake district he assumes a rainfall of 60 inches per annum, and that the net quantity after deducting for evaporation and absorption will be 30 inches.

Taking then the highest district, No. 1, with which he proposes to commence, this would give a yield of 175,000,000 gallons. From this he deducts 44,000,000 gallons for compensation to the rivers, which leaves a net quantity of 130,000,000 gallons fro m this district alone. The four districts together are estimated to yield a net average daily 3500. supply of 393,000,000 gallons. Six reservoirs are proposed in the first district as shown in the map, the lowest of them being near Rhyader and at a height of 590 feet above the sea.

3519–25. From this point there would be a conduit to London 180 miles long. It would be laid first along the valley of the Wye, so as to take in the water of the other and lower districts when required, and passing Glasbury and Hay; and thence it would pass near Kington, Ludlow, Tenbury, Bewdley, Stourport, Bromsgrove, Henley-in-Arden, Warwick, Banbury, Tring, and Watford, to a point near Barnet, eight miles from Hyde Park, where it is proposed to construct a service reservoir at 276 feet above mean sea level. The aqueduct would be 15 feet wide and 14 ft. 6 in. deep with a fall of from 6 to 24 inches per mile, and it is estimated to deliver 230,000,000 gallons per day.

3531–46. 4093–4102. Mr. Fulton has made an approximate estimate of the cost of the first portion of the scheme, viz., to bring 130,000,000 gallons, which amounts to 7,000,000*l.* For 100,000,000 gallons more the cost would be 2,000,000*l.* in addition.

55. We have had no evidence on this scheme, except from the promoter himself. We consider, however, that from its general similarity to Mr. Bateman's plan it might be further investigated, if any scheme of the kind for the supply of the metropolis should be deemed necessary.

MR. REMINGTON'S PLAN.

4321–4442. **56.** Mr. George Remington proposes to bring water from the hills of Derbyshire, collecting it at a point above Mill Dale on the River Dove, 586 feet above the sea, and bringing it by a conduit 135 miles long to a reservoir on Barnet Hill, 300 feet above Ordnance datum.

He proposes to appropriate an area of 262 square miles, and the following extract from his evidence will show his estimate of the quantity of water obtainable—

4335. What quantity of water do you propose to supply per day at Barnet Hill?—About 100,000,000 gallons. I have put it down in the paper which I sent in to the Commission as 83,000,000 gallons, or one-sixth of the rainfall on the 262 square miles, but in round numbers I would take it at 100,000,000 gallons per day.

4337. The rainfall has been gauged at Uttoxeter, which is on the Dove, but Uttoxeter is very low, and there the rainfall is about 30 inches, and I have assumed the quantity falling on the high district to be 48 inches.

He estimates that his scheme would cost 5,000,000*l.*

In the absence of more complete data we cannot regard this scheme further than in the light of a suggestion, and we need not remark on it more particularly, except to say that this in any case could only form an auxiliary source; while from the proximity of a number of important manufacturing towns we consider such a source should be reserved for their supply, for which it seems well fitted.

MR. DALE'S PLAN.

1061 *et seq.* **57.** The last plan for obtaining water from mountainous districts is that of Mr. Thomas Dale, engineer to the Corporation Waterworks of Hull. This plan is described in his evidence before us, and in a pamphlet published by him in 1866.

He proposes to take water from the same sources as Messrs. Hemans and Hassard, namely, from the Cumberland and Westmoreland lakes; but instead of bringing it by an aqueduct to London, he contemplates conveying it by pipes to supply various towns in Yorkshire and Lancashire.

The plans, Appendices Q (1) and Q (2), will give an idea of Mr. Dale's project. It will be seen that he would convey water from Ullswater and Haweswater first to Leeds and various towns in Yorkshire, and then, by a continuation of the conduit, to Liverpool and other towns in Lancashire.

The following is a list of these towns, and the quantities which Mr. Dale's scheme proposes to supply:—

	Gallons per day.
Lancaster	2 millions.
Preston	8 ,,
Wigan	¼ ,,
Dewsbury	3 ,,
Wakefield	3 ,,
Liverpool	40 ,,
Leeds	15 ,,
Bingley	1 ,,
Kendal	2 ,,
Bolton	8 ,,
Blackburn	6 ,,
Keighley	2 ,,
Bradford	10 ,,
Huddersfield	¼ ,,
Burnley	¼ ,,
Rochdale	4 ,,
Halifax	¼ ,,
Colne	1 ,,
Bury	8 ,,
St. Helen's	2 ,,
	131 ,,

We have already stated, in speaking of Messrs. Hemans and Hassard's scheme, that this is a favourable district for affording water supply to manufacturing districts in the north; but we believe Mr. Dale's proposal to take the water across the backbone of England to the Yorkshire towns a mistake, as they can be well supplied from districts nearer to them. It would, we conceive, be more advantageous to confine the supply from the lakes to the towns and districts lying to the west of the main chain of hills, and to carry the water more directly to them.

REMARKS ON GRAVITATION SCHEMES GENERALLY.

58. The experience with plans for supplying large towns with water by gravitation, from catchment reservoirs formed in hilly districts, has not yet been so extensive as to enable engineers to make accurate calculations, in all cases, as to their sufficiency.

Liverpool, for example, was originally supplied by pumping from the red sandstone strata under the town; but some years ago, this source proving insufficient, large works were established for bringing water by gravitation from the Rivington Hills. The supply however proved much less than was expected, the sandstone had again to be resorted to, and now additional sources are required. It was anticipated, on good authority, that a supply of 12 or 13 million gallons per day from the new works might be reckoned on; but our evidence says— App. BB.

> The Rivington Works are practically a failure as gravitation works; three dry years in succession reduce the available water to six millions of gallons per day, and four successive years of drought, which may very probably occur in future, would reduce it still further; and unless enormous reservoirs or lakes could be made, capable of storing the surplus waters of three or four years; these works must prove insufficient.

At Newcastle-on-Tyne gravitation works were constructed in 1848, but in 1850 the supply failed, and the former establishments for pumping from the Tyne had to be again resorted to. Enlargements of the gravitation works were carried out, but still with insufficient results, and a permanent pumping establishment is now in course of erection.

Bristol was supplied in 1851 by gravitation from the Mendip Hills; in 1864 the supply failed, and after enlarging the works, recourse was had to permanent pumping works from springs nearer the town.

59. During the sittings of this Commission the gravitation plans throughout the country have been subjected to a severe test by the occurrence of an unusually long drought in 1868. Although the rainfall of the whole year was above the average, yet it was very unequally distributed, as from the end of April to the end of September, a period of five months, there was scarcely any rain. Hence the capacities of the catchment reservoirs were severely tested, the towns having to depend entirely on the stores in them, without any feeding supply except that of perennial springs.

We have had evidence on this point from Mr. Bateman, Mr. Hawkesley, and Mr. John Taylor, chief assistant to the late Mr. James Simpson, who has given us, in Appendix B C., the result of inquiries made as to the effects of the drought in several towns.

60. In Manchester it appears that after official notices had been published cautioning the inhabitants against waste, and urging them to economize their supplies, the corporation, on the 3rd of August, limited the supply to the city to 12 hours of the day, stopped the street watering, and diminished the trade supplies by one half. They also made an arrangement with the millowners for reducing by one half the quantity given to the mills on the line of the river, and made compensation in money for the deficiency. In the middle of September the general supply to the town was further limited to eight hours per day, and the quantity for trades also diminished. Many persons were prosecuted for waste or undue use of water. The eight hours' supply lasted seven days, and the 12 hours' supply 76 days.

The following are extracts from Mr. Bateman's evidence in regard to this case:—

> With regard to the quantity of water supplied to Manchester during the drought of 1868, you stated that the balance left in store on the 25th of September, after 150 days drought, was 435,000,000 gallons, but that during 45 days there was a diminished quantity supplied to the mills, and further that during 52 days the water was shut off at night. Supposing the supplies to the mills and to the town to have been continued to their full amount during this period, have you calculated what would have been the quantity in store?—We should have exhausted our store, and we should have been, perhaps, something like 200,000,000 or 300,000,000 gallons deficient. 7427.
>
> You are preparing larger storage, are you not?—Yes. Our works are now very far from being complete, but we are constructing two new large reservoirs; and we have a third reservoir which we have never been able to fill owing to the bad foundation, which, as soon as the two others are completed, we shall restore, and that will nearly double our storage at once. It is a mere question of storage in Manchester. We have abundance of water, but we are two years behindhand in our works, and we are two years beforehand in the calculated supply. We have been extending the supplies to the outlying districts so much that, while we have been falling behind in our engineering operations, we have been going too fast in the supply of water to the district, and therefore the two causes together put us into this position this year. 7428.
>
> In our Manchester Waterworks we are at present incomplete. We are behindhand in several of our reservoirs which we are now constructing, and we are beforehand with the quantity of water which we are supplying, so that we are not quite equal to what we should be in storage, and therefore we were not able to give the full supply of water which we could have desired during the last drought. Our available storage in Manchester is equal at present to only 24,000 cubic feet of water per acre of collecting ground. In Liverpool the storage is equal to 48,500; in Dublin it is equal to 25,500; at Loch Katrine it is equal to 30,000; and at Gorbals it is equal to 52,000.

At Rochdale, as early as the 25th June, the supply was limited to four hours per day for 15 weeks; but with this precaution, during the second week in October the store became entirely exhausted, and the town would have been almost without water but that recourse was had to pumping from a colliery in the neighbourhood.

At Bury the store ran so low towards the end of August that it was reserved entirely for compensation to the mills, and the company obtained a supply of seven gallons per head from neighbouring works; for baths and for the numerous manufacturing and trade uses in the town there was none. This continued for five weeks.

At Preston the reservoir became practically dry at the end of August, and costly pumping works were hastily established, which were required for 58 days.

At Kendal the reservoirs were exhausted earlier, and measures of the same kind were adopted.

At Newcastle the gravitation works would have failed for many weeks had they not been supplemented by the pumping from the Tyne.

At Bradford 60,000 of the inhabitants were limited to one day's supply per week for 16 weeks, and 90,000 had their supply gradually reduced during five or six weeks to six hours per day. The want of water for manufactures was here seriously felt.

At Halifax the reduction began on the 11th of May; the domestic supply was limited to 14 hours per day for 66 days, to 10 hours for 10 days, and to six hours per day for 86 days; the supply to large consumers being gradually reduced from 30,000 to 1,000 gallons per day.

At Sheffield the supplies were first reduced in June, and further in July, August, and September, the last reduction being to four hours per day.

The towns of Stockport, Bolton, Ashton, Stalybridge, Oldham, Dewsbury, Warrington, Blackburn, and others suffered more or less, and Mr. Taylor concludes his report with the following remark:—

> The general result has been that nearly all gravitation supplies of water, obtained from drainage grounds, have failed in a manner hitherto unprecedented within the known experience of such works, proving that the data on which they have been based have been fallacious, and that the storage reservoirs and gathering grounds of such works must be greatly increased to meet the demands of years like the present.

61. The causes of this difficulty may lie either in an over-estimate of the available rainfall or in an insufficient provision of storage. The sufficiency of water-collecting plans in these respects must be tested both by the concurrence of several consecutive dry years and by occasional droughts of long duration; and to obtain the necessary data on these points, for any particular district, must require special observations on that district extended over a considerable time.

62. In so variable a climate, and with a rainfall in different parts of the kingdom ranging in round numbers from 20 to 100 inches, it is of primary importance to have the most complete information as to the rainfall, and, as the annual variation is also great, the average fall for a term of years cannot be determined without observations extended over a long period. Less than 20 years would probably not suffice. But the question, with reference to a water supply, has to deal not with the average rainfall of a long term of years, but with a short term depending on the capacity of the storage. In no case yet contemplated would it be prudent to rely on more than the average of three years, and under certain conditions it is doubtful whether two years would not be a safer term.

The Rev. W. Jenyns, in his "Observations on Meteorology," gives an instance in which, even with a term of 10 years, the average varied $7\frac{1}{2}$ inches, the mean quantity in one case being $18\frac{1}{2}$ and in the other 26 inches. In two other terms of 10 years the difference was 2·331 inches.

The experience, however, of half a century would seem necessary to determine the minimum fall for a short term of years. We may take the annual rainfall recorded at the Greenwich Observatory from 1815 to 1868, to average 24 inches. From these observations it appears that during this period of 54 years there were three years in which the rainfall was under 17 inches, or only about two-thirds of the average, viz., in 1832, 1840, and 1864; that during the same period there was one term, and one term only, of three years, 1832–4, in which the average amount of rainfall was a quarter short of the average annual fall; that there were four terms of that length in which the annual rainfall was from a quarter to a sixth short; while once in the 54 years there was a term of five years, the rainfall of which averaged nearly a sixth short. These variations are shown in the following table:

Length of Term.		Average annual Rainfall.	Quantity short of general Average of 24 Inches.
		Inches.	
1 year	1832 (doubtful)	16·1	—7·9
	1840	16·6	—7·4
	1864	16·4	—7·6
2 years	1832–3	18·5	—5·5
	1834–5	20·2	—3·8
	1857–8	19·6	—4·4
	1863–4	18·05	—5·95
3 years	1832–4	18·3	—5·2
	1856–8	20·4	—3·5
5 years	1854–8	20·8	—3·2

The short three-years terms occurred at intervals of 22 years; for the short five years the limits of recurrence are not yet reached.

In the mountainous districts of England the irregularity of the rainfall is still greater. Mr. Symons has given evidence showing that in a period of 22 years at Windermere it has reached as high as 116·26, and fallen as low as 47·54 (1861 and 1855), whilst once in that time the mean of three years (1855–57) did not exceed 52·71. The mean of the 22 years was 79·85.

It is evident, therefore, that a very long series of observations is necessary to be made before any authoritative opinion can be expressed, not only as what may be the true average annual rainfall, but what (for this inquiry is still more important) may be the mean of the three driest years, and at what interval they may occur. In the case of a large city like London, when such a source of supply is proposed, an exact determination seems to us imperative. Of course it will be understood that not only should the observations extend over a long term of years, but also that they should be made in many places so as to get at the average rainfall of the district, which Mr. Symons has well shown to have very different values in immediately adjacent places; as it varied in the same year in fourteen areas in the Lake district, from 45 to 100 inches. When the rainfall has been determined with exactness, the proportion which can be delivered in a hard rock district may be estimated with considerable accuracy.

The system of collecting grounds utilizes, no doubt, the rainfall to the greatest extent. But the great disadvantage is, that the springs to fall back upon in time of drought are insignificant in comparison with the great quantities stored in permeable strata; the very circumstance of a large immediate delivery of the rainfall precludes the possibility of that subterranean storage of a large portion of it, which forms so valuable a resource during severe and long-continued droughts.

63. The question of storage room involves complicated considerations, which have been especially dwelt upon by Mr. Hawkesley. On account of the irregularity of the rainfall, particularly in mountainous districts, it is impracticable to construct reservoirs large enough to store the entire quantity received, so that all large floods occurring when the reservoirs are full must pass away and be lost. Hence the available average obtainable from reservoirs must fall much short of that deduced simply from the fall of rain. We cannot here enter further into this question; but the experience we have above mentioned suffices to show the difficulty of making reliable calculations on this head, even when tolerably complete data are at hand.

64. It is worthy of remark that during the exceptionally long drought of 1868 the Thames and the Lee seem not to have been diminished in volume below the ordinary flow of dry years, a result entirely due to the equalizing effect of the great subterranean stores contributing to their flow.

We shall hereafter go more fully into the advantages of these rivers as sources of supply, which cause them to contrast so favourably with gravitation schemes.