CHAPTER XXXI.

SOUTH-WEST LANCASHIRE BASIN.

Garston to Crosby Streams (XLVII., in part).

THIS area of 33 square miles is included by the Ordnance Survey in that of the basin of the *ALT.* It is entirely occupied by Triassic formations, ranging from the Pebble Beds up to the Waterstones of the Keuper. The central ridge, on the western slope of which the city is built, consists of Pebble Beds, cut off to the west by the Everton fault, throwing in the Keuper building stone, well seen in the approach to Lime Street Station from the tunnel. To the east they dip under the Upper Mottled Sandstone, which occupies a belt of country extending from Toxteth Park to Walton-on-the-Hill, east of which another strike-fault brings in the Pebble Beds of Much Woolton, and Childwall.

In 1835, Sir Roderick Murchison* gave the following classification of the Red Rocks overlying the Coal Measures:—

1. Red and Green Marls	*Keuper.*
2. Sandstone and Conglomerate	*Bunter.*
3. Calcareous Marl and Conglomerate ..	*Zechstein.*
4. Lower Red Sandstone	*Roth-todt-liegende.*

In 1837, the Rev. Professor Buckland ascribed the Warwick Sandstones, with their reptilian fauna, to the age of the Keuper of Germany, and compared them with the building stones of Stuttgard and Sinzheim, near Heidelberg. These Warwickshire sandstones consist of either soft, white, or grey sandstones, more or less thin-bedded and interstratified with Marl, with a slightly conglomeratic base, resting indiscriminately on Permian or Coal Measures, and may be considered as the typical English "Waterstones."

In papers read before the British Association in 1842, the Geological Society of London in 1846, and at Manchester

* 'Proc. Geological Society,' London, vol. ii.

at a still earlier date, Mr. Binney, F.R.S., was the first to work out the chief outline of the classification of the Lancashire and Cheshire post-carboniferous red rocks, the sequence being:—

TRIAS (Murchison):—

1. *Red Marl* (Ormerod)	(*a*) Red and Variegated Marls ..	1000	feet.
	(*b*) Gypsum and Saliferous Marls	800	„
	(*c*) Waterstones	440	„
2. *Bunter Series*	Maximum thickness	600	„
PERMIAN. 3.	Red and Variegated Marls and Magnesian Limestone ..	210	„
4.	Lower New Red Sandstone	120	„

In this classification I am inclined to think that the term "Waterstones" does not include the compact Lower Keuper building stone and grit, which was evidently classified with the Bunter Beds beneath in the papers by Mr. Ormerod and others of the period. This restricted use of the term "Waterstones" is one which it is of importance to maintain, as they, probably, and not the building stones beneath it, are the equivalent of the typical Waterstones of Warwickshire.

In 1854, Professor Hull laid a paper before the British Association, showing the Bunter Beds were capable of a triple sub-division, massive sandstone, with pebbles or Pebble Beds, intervening between an Upper and Lower Mottled Sandstone. Occasionally the Pebble Beds are only soft sand with shingle, and the Mottled Sandstone beneath it gradually thins out eastward, its maximum development being in the Shropshire area. In later papers he showed the Lower Keuper moves transgressively over the eroded Bunter Sandstones on to older formations.

LIVERPOOL.—*Acres,* 5211; population, 552,425; rateable value, Urban Sanitary District (Borough), 3,194,299*l.* After deducting three-fourths of the assessments from properties entitled to this deduction for water-rate purposes, the amount is 2,980,391*l.* The works were carried out under the following Local Acts:—10 & 11 Vict. c. 261; 13 & 14 Vict. c. 80; 15 Vict. c. 47; 25 & 26 Vict. c. 107; 29 & 30 Vict. c. 126; 34 & 35 Vict. c. 184. The works cost 2,256,808*l.*, including the cost of works purchased from two private

Companies in 1848; also the cost of the entire system of pipes, &c., for distribution. According to the Corporation authorities, there will be a deficiency of water supply of 7,000,000 gallons a day in the year 1885. To meet this, the Corporation obtained powers from Parliament last year to abstract the head waters of the *SEVERN*.

The present supply is 17,750,000 gallons, the average supply is 15,081,498 gallons, which is used by a population which was 592,063 in 1871, and was estimated in 1879 at 672,000, which is equal to 22·83 gallons per head for all purposes.

The supply is partly derived from Gravitation Works at Rivington, between Wigan and Blackburn, in the basins of the *RIBBLE* and the *DOUGLAS*, and partly from wells in the New Red Sandstone, within the watershed on which the city is built.

The Gravitation Works consist of 7 catchment reservoirs, covering 600 acres, or nearly a square mile, draining the springs off 10,000 acres of moorland. They have a united capacity of 4,059,000,000 gallons.

The following derive their supply from the *Liverpool Corporation Waterworks*:—Allerton, *acres*, 1586; population, 830; rateable value, 17,695*l*. Bootle-cum-Linacre, *acres*, 1580; population, 27,112; rateable value, 116,000*l*. Garston, *acres*, 1625; population, 10,131; rateable value, 54,963*l*. Great Crosby, *acres*, 1768; population, 5100; rateable value, 23,010*l*. Litherland, population, 2426; rateable value, 10,992*l*. Much Woolton, *acres*, 970; population, 4539; rateable value, 20,224*l*. Toxteth Park, population, 10,371; rateable value, 73,458*l*. Walton-on-the-Hill, population, 18,772; rateable value, 47,937*l*. (intermittent supply). Wavertree, *acres*, 1799; population, 11,157; rateable value, 75,034*l*. in 1877. Waterloo with Seaforth, *acres*, 740; population, 9107; rateable value, 51,581*l*.

A portion of the 20 square miles of area supplying the Liverpool private and Corporation wells is built over or covered with impermeable paving in the streets; and, further, only a portion of the eastern area is bare of Drift

Boulder Clay, which throws off the rainfall in surface floods, though a portion of the water is doubtless absorbed in passing through rock-cut valleys. The evaporation off this stiff clay-land, exposed as it is to the influence of the sun and air, is doubtless as high as 12 inches per annum, and the percolation probably not more than 5, though amounting probably to 10 inches in the area bare of drift.

Assuming 1 inch of rain to give 22,427 gallons per acre, or 14,353,280 gallons per square mile, which, spread over a year, gives a daily yield of about 40,000 gallons per square mile, the drainage area with 5 inches of percolation would give a daily volume of 4,000,000 of gallons off 20 square miles, while the yield from public wells alone is 6,250,000, proving the water in the subterranean supply is derived from an area outside the immediate surface drainage district, or else this water flows in from the river, along lines of faults, or that they act as direct ducts from other areas. In the public wells there is no evidence of percolation from the *MERSEY*. In the shallow wells near the Docks, where the natural head of water, derived from the land, is lowered, salt water from the river percolates to a certain distance inland, and fills up the void space. These wells are steadily deteriorating; but so long as the Corporation wells are not overpumped this action will not affect them. The following table shows the average total quantity pumped from the four wells in 1876 somewhat exceeded that pumped in 1868.

AVERAGE DAILY QUANTITY OF WATER PUMPED FROM WELLS, 1868 TO 1876.

Year.	Green Lane.	Bootle.	Windsor.	Dudlow Lane.
1868	2,726,426	1,405,304	969,622	277,626
1869	2,661,314	1,490,745	844,912	328,568
1870	2,770,167	1,475,526	933,515	1,062,405
1871	2,828,032	1,399,049	864,000	1,247,403
1872	2,833,639	1,433,747	869,761	184,184
1873	2,779,059	1,469,293	827,655	810,590
1874	2,517,680	1,291,189	899,379	1,011,260
1875	2,533,050	1,399,791	821,182	1,103,307
1876	2,903,712	1,293,772	830,694	1,169,494

The following particulars of Wells in the New Red Sandstone belonging to the Liverpool Corporation, were furnished to the Underground Water Committee* of the British Association by Mr. G. F. Deacon, the Water Engineer of the Corporation, and by Dr. J. Campbell Brown, the City Analyst, in 1877:—

Bootle Well.—The depth of this well from the surface of the ground is 104 feet. The bottom of the well is 49 feet below Ordnance Datum. In connection with the well there are 15 boreholes, one of which (4 inches in diameter) is sunk to 571 feet below Ordnance Datum, one to 273 feet 5 inches below O.D., and one to 268 feet 5 inches below O.D. The other boreholes are shallow.

Constituents of Water expressed in parts per 100,000, *re-calculated from the Analyses quoted in R. Stephenson's Report of* 1850, *by Dr. Brown.*

No. 2, Bootle, No. 1 Lodgment. January 30, 1850.

Chlorine	2·777
Sodium	1·894
Magnesia	4·714
Lime	7·627
Sulphuric Acid	2·781
Silica	·686
Carbonic Acid	9·649
Organic matter, trace of potash, water of crystallization, and loss	4·014
	34·142
Hardness	25°·3

Dr. Brown states, that the water has undergone a great many variations in composition since 1850, and has now returned to almost the same composition as it had then. After the deep bores were sunk, the hardness was not much more than half as great as it was in 1850, owing to the fact that there are extensive alkali-waste deposits, which yield a large quantity of lime-salts to the water of the upper strata. By continual pumping since the existing bores were sunk,

* Mr. G. H. Morton, F.G.S., and Mr. Mellard Reade, C.E., F.G.S., represented the Committee in South Lancashire; the tabulated comparisons have chiefly been drawn up by the latter.

the hardness had gradually risen, until it is now slightly higher than it was in 1850. The deeper water is still less hard than the upper water. The following, he believes, are reasons for believing that no appreciable quantity of sea-water reaches the well:—If sea-water entered the well, one would expect more chloride of sodium and magnesium salts when the well is hard pumped, and when there is a less strong flow of underground water from the interior towards the sea, that is in dry weather. But

1. The proportion of chloride of sodium is almost exactly the same now as in 1850.

2. The proportion of chloride of sodium does not vary beyond very narrow limits, and is very nearly the same in Bootle well as in wells further inland, such as Dudlow Lane, Windsor, and Green Lane wells.

3. In October, 1875, when the hardness was reduced by the simultaneous stoppage of the pumping and fall of heavy rains, the proportion of magnesium salts was not altered, the change in the hardness having been due almost entirely to an alteration in the proportion of lime-salts.

Bootle Well.

	Hardness.	Level of Water below Ordnance Datum. ft.	in.
	°		
On 5th Dec., 1868, Well	15	37	2½
On 8th Feb., 1870 „	18	38	4
On „ „ „ deep bore	16	—	
On 26th June, 1872, well water	16½	38	0½
On 24th Sept., 1872 „ „	16½	37	3½
On 1st April, 1873 „ „	17½	37	4½
On 28th May, 1875 „ „	22·7	38	0
On 4th June, 1875, east side of well	22·4	40	4
On „ „ „ west „	27·25	—	
On 20th May „ deep bore	22	—	
On 1st Sept., 1876 „	22·28	42	8

In 1876 the hardness varied from 22° to 24½°, and on 7th Dec., 1876, it was 25½°; the mean level was 34 ft. 7 in. below Ordnance Datum.

Dr. Brown does not find that there is any regular difference between the hardness in summer and winter.

Differences can be traced to heavy rainfall and the rate of pumping: *e.g.* the hardness of Bootle Well water was taken weekly for a year; it was generally about 23°, but after heavy rains it fell to 22° and 21°·8, and in very dry weather it rose to 24°. On 1st October, 1875, the hardness was 23°, and on 6th October, when the level of the water was 12 feet 6 inches above the bottom of the well, the pump was stopped for repairs. On the 8th October the water rose to 34 feet, and there was no unusual variation in the hardness; at that time heavy rains began to fall, and on 15th October, the level of the water being 48 feet, its hardness fell to 18°. The hardness due to magnesium salts was almost the same at this time as before the change, the difference being due to calcium salts. Pumping was then resumed on 15th October after the sample was taken, and in 7 days, viz. on 22nd October, the level was reduced to 17 feet, and the hardness rose again to 23°.

	Hardness.
	°
On 31st January, 1877, the water of well was	24·56
„ „ the average water of the deep bore ..	23·44
„ „ the water near the bottom of bore ..	20·56

Dudlow Lane Well.—Depth from surface of ground, 247 feet 3 inches. Bottom of well below Ordnance Datum, 49 feet. Borehole, 18″ diameter, sunk to a depth of 245 feet below Ordnance Datum.

The following is a tabulated statement of the levels of the water in the several wells in relation to the Ordnance Datum on the dates referred to by Dr. J. C. Brown in his report on the hardness of the water:—

	Hardness.	Level of Water below O.D.
	°	ft. in.
On 2nd Dec., 1868	6½	33 7
On 24th Sept., 1872	6	38 11
On 30th Sept., 1872	7½	7 0
On 20th Oct., 1873	7½	3 0 (above)

In 1874, when the pumps were frequently stopped, the average was 5¾°; the highest was 7°.

	Hardness.	Level of Water below O.D.
	°	ft. in.
On 1st June, 1875, the deep bore was ..	7·86	34 9
„ „ „ well itself was ..	8	—
On 4th Sept., 1876, the deep bore was ..	8·88	40 6
„ „ „ well was	8	—
The average in 1877 was	7½	—

The hardness was taken weekly in 1874, and there was no regular difference between the hardness in summer and winter.

Dudlow Lane.—Finished sinking well, 1868. In 1870 a borehole, 18″ diameter, sunk to 196 feet below bottom of well. Pumping stopped during most of year 1872 and part of 1873.

The Green Lane, Bootle, and Dudlow Lane boreholes are provided with plugs, which are occasionally raised or lowered to regulate the depth of water in the wells, according to the speed at which the engines are worked.

Green Lane Well.—The depth of this well from the surface of the ground is 185 feet. The bottom of the well is 49 feet below Ordnance Datum. There are two boreholes; one, of 9″ diameter at the top, and 6″ diameter at the bottom, is sunk to a depth of 248 feet 6 inches below O.D.; the other, of 18″ diameter, is sunk to a depth of 359 feet below O.D.

	Hardness.	Level of Water below O.D.
	°	ft. in.
On 2nd Dec., 1868, the well was	13	38 4
On 26th June, 1872, the deep bore was ..	14½	36 1½
On 28th March, 1873, the well was	13½	35 0
On 25th May, 1875, the deep bore was ..	16	38 6
„ „ the well was	14½	—

In 1875 the percolating water from the upper strata at 40 feet above the bottom of the well was 10°, while the mixed water of the well taken at the same time was from 16° to 16½°.

	°
On 5th Sept., 1876, the water of the deep bore was ..	18·28
„ „ „ „ well itself „ ..	18
In 1876 the average was from 18° to 19½°.	
In 1877, Jan. „ „ „	20°·6.

In 1868 a new well, 12 feet × 9 feet, was sunk 185 feet. In 1869 a borehole, 18″ diameter, sunk in new well to 310 feet below bottom. Engine power not increased.

The following analysis has been re-calculated by Dr. Campbell Brown, in parts per 100,000 :—

No. 11, Green-Lane Well, 50 feet from bottom of well. January 30, 1850.

Chlorine	2·306
Sodium (in combination with chlorine)	1·495
Soda (as sodium sulphate)	1·391
Magnesia	0·000
Lime	4·209
Sulphuric Acid	1·795
Silica	·914
Carbonic Acid	3·302
Organic matter and loss	4·015
	19·427
Hardness	7°·5

The proportion of mineral salts, and especially of the hardening salts, carbonate of lime and sulphate of magnesia, has increased very much since 1850, and is still increasing as the well is pumped to a lower level. The deep water is rather harder than the upper water.

Windsor Well.—Depth from surface of ground, 210 feet. Bottom of well below Ordnance Datum, 24 feet 2 inches. There is one borehole of 6 inches diameter at the top, and 4 inches diameter at the bottom. The total depth of the borehole is 269 feet below O.D.

	Hardness.	Level of Water below O.D.
	°	ft. in.
On 5th Dec., 1868, the well was	15	19 1½
On 26th June, 1872 „	18	17 1
On 30th Sept., 1872 „	17	16 6½
On 20th Oct., 1873 „	16½	—
On 24th May, 1875 „	19¾	17 9
„ „ „ the deep bore was	19	—
On 13th March, 1876, the well was	21½	17 11
On 8th June and Sept. 8th „	23½	20 0
On 7th Dec., 1876, the well was	24½	20 0
On 1st Sept., the deep bore was	21·16	—

Analysis re-calculated by Dr. Campbell Brown, in parts per 100,000 :—

No. 6, Windsor Well, 2 feet from the bottom lodgment. January 29, 1850.

Chlorine	2·964
Sodium	1·921
Magnesia	5·055
Lime	7·250
Sulphuric Acid	·414
Silica	1·714
Carbonic Acid	11·185
Organic matter, traces of potash, water of crystallization, and loss	2·829
	33·332
Hardness	25°·6

This water has undergone several changes, having deteriorated as the population around it increased; but since the sewering of the district and the paving of the streets were completed it has very much improved, and the composition is now almost the same as it was in 1850. The hardness appears to be less now than it was then; but this may be due to a difference in the test-solution employed, as two experimenters seldom get precisely the same figures for hardness. The same standard soap-solution has been used for several years, and the hardness is found to be slowly increasing. It is less in the deep water than in the upper water.

Rainfall at Sandfield Park, West Derby.—*Observer*, Mr. Biggs.

Rain-Gauge, height above Ground 1 ft. 2 in., above Mean Sea-level 147 ft.

	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.
January	1·94	3·20	1·94	1·90	2·84	2·00	·20	4·30	1·00	2·42
February	2·10	2·90	1·18	1·84	·70	·56	·80	2·70	1·20	1·00
March	·80	1·70	1·08	2·80	1·54	·75	·20	2·80	1·50	1·40
April	·76	1·10	3·26	1·64	2·90	1·50	1·30	2·75	·40	·92
May	3·50	1·46	1·36	·95	4·90	·90	1·10	1·50	1·20	1·80
June	·70	3·90	·95	·42	1·30	1·40	2·80	6·20	1·70	·56
July	3·10	2·51	4·80	·46	1·00	·80	3·70	7·00	3·20	3·50
August	4·40	3·80	1·64	3·62	2·50	2·00	1·30	2·30	3·10	3·75
September	·63	5·50	2 14	2·14	6·54	2·30	4·70	6·30	2·70	2·60
October	3·00	2·10	4·10	4·42	2·94	6·00	5·90	6·42	3·84	3·90
November	2·50	4·50	1·92	2·28	3·70	3·30	1·75	2·94	2·00	5·00
December	1·00	2·23	3·05	6·56	2·16	2·70	2·00	4·36	·80	1·60
Totals	24·43	34·90	27·42	29·03	35·02	24·21	25·75	49·57	22·64	28·45

RIVER ALT (XLVII., in part).

Length, 14 miles; area, according to the Catchment Basin map of the Ordnance Survey, 126 square miles, of which 33 are drained by streams flowing directly into the *MERSEY* estuary at Liverpool. Of the remaining 93 square miles, 7 consist of the Coal Measures, brought to the surface by the Croxteth fault, and the remainder of New Red Sandstones, ranging from the Pebble beds to the Waterstones, which I observed in 1868, in the railway cutting at Orrell, near Litherland. In the higher parts of the ground at Aintree, Little Crosby, and Maghull the rock is more or less overlaid by Upper Boulder Clay. At Sefton the alluvial plain of the river opens out to a wide extent, and forms the level stretch so well known to the lovers of coursing. At the base of the alluvium occurs a bed of peat resting on a greyish-blue silt, which can be traced to the estuary of the river at Hightown, appearing on the beach beneath the Sand Dunes. At the base of the peat occurs a large number of trunks of trees, the roots of some of them being imbedded in the clay beneath. This submarine forest was first described in the 'Gentleman's Magazine' in the last century.

To the north of the *ALT* alluvium is an extensive tract of peat moss, an area of former obstructed and present artificial drainage. The southern portion is drained into the *ALT*, on which are windmills and steam-engines lifting the water to the sea, under the Alt Commissioners Act. The northern mosses are drained into the Crossens Basin, where also are steam-engines lifting the water from Martin Mere, once one of the largest lakes in Lancashire, though never of great depth.

The watershed forming the eastern margin of this basin, separating it from the district drained by *Rainford* Brook, traverses a succession of peat mosses resting on beds of Glacial Drift; in one of them rises *Simonswood* Brook, draining the valley east of Melling and Kirkby, at both of which places the Pebble beds* crop to the surface. In another moss

* The St. Helen's Corporation Waterworks propose to apply for powers to sink two wells in these rocks.

further north rises *Bickerstaffe* Brook, which receives *Knoll* Brook, and drains the valley between Maghull and Town Green, passing the pumping stations at Springfield, near Town Green, of the *Southport Waterworks Company*. There are two shafts here, and a heading at 135 feet from the surface. The total depth is 232 feet; the pumping-level of the water is 125 feet from the surface, and the rest-level is at the surface; 500,000 gallons can be pumped without further lowering. The section consists of 79 feet of Glacial Drift (Sand and Clay), and 153 feet of soft Sandstone of the Upper Mottled Bunter in the well, and a further 20 feet in a boring.

CROSSENS BASIN (XLIV.).

This basin has an area of 55 square miles, all of which are on the Trias, with Sandstones on the eastern margin and Keuper Marls in the western area. These are seen in a few brook sections at Brown Edge and Scarisbrick, but elsewhere are deeply overlaid by Glacial and post-Glacial Drift deposits. In a well at Scarisbrick Park the Marls were penetrated, and beds of Chert, Limestone, and Grit found beneath, which point to the Marls overlapping the Triassic sandstones, as at Charnwood Forest. If this be so, the rocks found were probably referable to the Yoredale rocks. Further on the sea-margin, at Birkdale Park, a boring was carried to a depth of 186 yards without finding the base of the Keuper Marls. At Halsall and Cleve Hill Keuper Sandstone crops to the surface in a range of hills rising from the peat-moss plain, more or less covered with Upper Boulder Clay, and flanked at the base at Shirdley Hill and elsewhere by sands of post-Glacial age, which I have named "Shirdley Hill Sand." They constitute a range of ancient, but post-Glacial Sand Dunes, from which much sand has blown over the interior of the country, and were blown from the sandy shore, which is preserved in the beds underlying the eastern margin of the peat-moss.

The *Southport Waterworks Company* have three wells in this basin, one at Scarisbrick in the hard upper beds

of the Upper Mottled Sandstone, 124 feet deep, with no borehole; the water rises to the surface and drains away into an adjacent quarry. It is not used or pumped. North of Aughton, west of Ormskirk, are two wells known as the Pilot shaft and the Parliament shaft, 180 feet in depth, with boreholes to 222 feet from the surface. At 144 feet from the surface are two adit levels; the water is only pumped down to 110 feet from the surface, with two engines. The Glacial Drift is only 40½ feet thick, and contains numerous shells of mollusca; the remainder is in soft Red Sandstone of the Upper Bunter.

SOUTHPORT.—*Acres*, 3,665; population, 32,191; rateable value, 188,007*l.* Is in district of supply of *Southport Waterworks Company*, who deliver 600,000 to 1,000,000 gallons to this Urban Sanitary Authority from a reservoir 9 miles distant, filled by pumping wells in the New Red Sandstone; Works under Southport Waterworks Acts, 1854, 1856, 1867, 1870, and 1878.

BIRKDALE PARK.—*Acres*, 2214; population, 8706; rateable value, 43,797*l.*; supplied by *Southport Waterworks Company*.

ORMSKIRK.—*Acres*, 573; population, 6651; rateable value, 14,711*l.*; supply, 250,000 gallons, from well in the Upper Mottled Sandstone, constant during the day. The well is 129 feet above Ordnance Datum, is 60 feet deep, and 7 feet diameter; there is no borehole. Before pumping the water stands at the surface, after pumping it is reduced to 2 feet from the bottom of the well, or 71 feet above Ordnance Datum; its level is restored by two hours' rest, and is affected by rain within 24 hours. It contains 6·68 grains of salts (chiefly common salt) to the gallon.

RIVER DOUGLAS (XLVI.).

Length, 21 miles; area, 168 square miles, according to the Catchment Basin Map of the Ordnance Survey, but this requires some modification. In it is included 12 square miles of Coal Measures, drained by the *Croal*, a tributary

of the *Irwell*, and therefore belonging to the *MERSEY* Basin. On the other hand, the remarkable valley lying at the foot of Anglezark Moors, in which are constructed the reservoirs of the *Liverpool Corporation Waterworks*, occupying 16 square miles of Millstone Grit and Lower Coal Measures, is represented as belonging to the basin of the *RIBBLE*, instead of which it was formerly drained by the *DOUGLAS*, which is impounded in it, as well as water brought from the *Roddlesworth* in an aqueduct crossing the watershed, crossing the *Col*, between the basins of the *RIBBLE* and the *DOUGLAS*. These alterations give an additional 4 miles of area to the *DOUGLAS*, bringing it up to 172 square miles, of which 130 consist of Millstone Grit and Coal Measures, 1 of Permian, and 41 of Trias.

Between the margin of the peat-moss formerly covered by Martin Mere and the *DOUGLAS* between Rufford and Hesketh Bank, a tract of Upper Boulder Clay intervenes, the top of which forms the *DOUGLAS* watershed, running from Hesketh Bank by Tarleton and Sollom to Rufford. From this point, Burscough Junction, the watershed traverses a peat-moss, the surface of which is at or about high-water mark, and were the peat removed the *DOUGLAS* would flow over Martin Mere to Crossens, instead of through the valley between Tarleton and Bretherton. The formation of the estuarine deposits at Crossens probably caused the obstruction of drainage, which led to the growth of peat and the formation of Martin Mere. The waters of the *DOUGLAS*, thus deflected northwards from their previous persistent north-west direction by Wigan, Parbold, Horscar, and Crossens, flowed over the three miles of low ground intervening between Horscar and Sollom, joined the waters of the *Yarrow*, and fell into the *RIBBLE*, through the valley cut in the Boulder Clay by the *Yarrow* and its tributary the *Lostock*. The rainfall at Rufford, 38 feet above the sea, was in—

1876.	1877.	1878.	1879.	1880.
36·57	49·68	34·63	32·82	35·14

Average rainfall for the last 10 years, 37·18 inches.

Following the watershed of the *DOUGLAS*, it runs along the Upper Boulder ridge, on which is situated the village of Burscough, to near Ormskirk, where it trends south-east and ascends Scarf Hill, formed by an outlier of Keuper Sandstone, thrown in by a north-north-west fault, and attaining a height of 250 feet, the underground water-level here being 100 feet below the surface. East of this point it crosses the great boundary fault of the Coal Measures, with a throw equal to the thickness of the whole of the Sandstones of the Trias, but no trace is left on the ground. The whole has been planed perfectly flat, and the Glacial Drift overlies alike Trias and Coal Measures; the fault is not even visible.

The watershed gradually rises to 272 feet near the source of the *Tawd* to Billinge Beacon, from which it descends to 102 feet at Bryn Moss, at the point indicated as the probable pre-Glacial course of the *Plank Lane* stream (and possibly of the *Irwell*) into the valley of the *DOUGLAS*. From Bryn Moss it rises to 155 feet at Amberswood Common, and ascends, by Aspull Moor, to 500 feet between Haigh and Blackrod, from which it descends into the Col Valley at Horwich, to 367 feet at Red Moss, thence ascending to 1150 feet at Horwich Moor to its culminating point at 1450 feet on Winter Hill.

Following the left bank of the *DOUGLAS*, the first important tributary is *Eller* Brook, rising on the northern slope of the Scarf Hill ridge, and draining Burscough, and the western slope of Lathom Park, which lies on the upper beds of the Gannister series. A short distance south of the infall of this stream is that of *Whain* Brook, draining Horscar Moss.

River Tawd.

At Wanes Blades Bridge is the infall of the River *Tawd*, rising near Pimbo Lane Station, draining the Lower Mottled Sandstone inlier of Digmoor Green, the Middle Coal Measures of Skelmersdale, and the Gannister beds of the east side of Lathom Park.

LATHOM.—*Acres*, 8694; population, 4161; rateable value, 31,137*l.* 7*s.*; wells.

SKELMERSDALE.—*Acres*, 1941; population, 5707; constant supply of 700 gallons from Ormskirk Local Board of Health, brought by tank waggon—brought daily by rail to Skelmersdale, and contents sold to inhabitants; supply supplemented by wells and ditches.

The eastern margin of the *Tawd* drainage area is the Ashurst Beacon ridge, which, once continuous with that of Harrock Edge, was cut through in pre-Glacial times. The valley afterwards was filled in with Glacial deposits, and since to some extent re-excavated. Terraces of Upper Boulder Clay, Middle Sand, and Lower Boulder Clay flank the hill-side, through Dalton, Waltham Green, and Upholland, where they are cut through by the gorge of *Dean* Brook, Orrell, Lamberhead Green, and Pemberton.

ORRELL.—Population, 4299; rateable value, 10,000*l.*; supply from Pemberton Local Board preparing.

PEMBERTON.—*Acres*, 2894*l.*; population, 13,763; rateable value (district), 37,000*l.* Waterworks scheme was sanctioned by Pemberton Local Board Water Act, 1875, to supply 15 gallons per head, from a reservoir to hold 21,000,000 gallons, of surface-water flowing off cultivated land. The reservoir was made on porous strata, overlying old coal workings. In opposing the Bill, I stated it would not be made watertight, which has proved to be the case. After exhausting their borrowing powers the Board has had again to seek assistance from the Local Government Board.

UPHOLLAND.—*Acres*, 4685; population, 4435; rateable value, 21,268*l.*; wells and springs.

The last feeder of importance is that draining Bryn Moss and Worsley Mains, flowing north along the line taken by the Leigh and Hindley Canal, excavated entirely on Glacial Drift.

A little south of Wigan the river *DOUGLAS*, following it up stream, turns eastward and northward; flowing through a gorge in the Glacial Drift, at the curve it receives *Clarendon*

Brook, rising above Kirkless Hall, the site of the large iron-works of the Wigan Coal and Iron Company.

INCE-IN-MAKERFIELD.—*Acres*, 2320; population, 16,017; rateable value, 52,715*l.*; constant supply of 143,000 gallons from two wells, 150 feet in Pebble Beds at Golborne, 5 miles distant; service reservoir constructing, water softened by Clark's process; Ince Water Act, 1872. In 1871 the *South Lancashire Water Company* promoted a Bill in Parliament for the supply of Ince, West Houghton, Aspull, Blackrod, Haigh, Adlington, Horwich, Lostock, portions of Halliwell, Heaton, Leigh, and Hindley. Ince opposed, having their Golborne Bill pending. Hindley opposed, wanting to be supplied in bulk, and both townships were left out of the Bill. On Ince refusing to supply Hindley, the latter obtained powers in their Gas Act of 1872 to obtain water from the Red Sandstone at Lowton, but the works were not carried out, and the Board united with Hindley in 1876 to obtain an Act to acquire the lapsing powers of the *South Lancashire Waterworks Company*, and, whilst the works are being carried out, to obtain water from Bolton Corporation, at 6*d.* per 1000 gallons, for 7 years from 1876.

ASPULL.—*Acres*, 1905; population, 8111; rateable value, 27,901*l.* 13*s.*; scheme of supply now before Local Government Board.

The gorge of the *DOUGLAS* at Wigan cuts the town into two parts, that on the left bank being called Hardybutts. Good sections of the Middle Drift are seen in sand-pits, at the back of the main street. The sand is generally current-bedded to the south-south-east, and contains fragments of marine shells. A little below the level at which the Leeds and Liverpool Canal contours the district, the sands are overlaid by Upper Boulder Clay, and both thinning out, the Coal Measures come to the surface, which continue by Haigh Hall and Fir-Tree House, at an elevation of about 500 feet. Above this, both on the watershed, and on the other side of it, at Aspull Moor, a cold clay comes in, probably of Upper

Glacial age. Near Worthington Hall, north-east of Standish Railway Station, the *DOUGLAS* commences to describe another curve of the "S" to which its course may be compared, trending north-east with the strike of the Middle Coal Measures over which it flows, the north-north-east strikes from Wigan to Worthington being changed by the action of the Haigh fault to north-east. Other faults again change the strike, between Huyton Bleach Works, near Adlington and Blackrod, to south-east, and the direction of the *DOUGLAS* changes with it, and continues to the Blackrod fault, east of which its present course is governed by the occurrence of Drift, Glacial and post-Glacial. East of the fault, which is a downthrow west, the strike-direction of the stream is maintained by a feeder draining the *DOUGLAS* basin side of Red Moss, but the *DOUGLAS* trends from the north-east by Anderton Hall, and before the formation of the Rivington reservoirs turned at right angles, and flowed again from the north-west for the third time.

Mr. Robert Stephenson, in his report on Liverpool water supply in 1850, stated "that a uniform supply of 12,000,000 or 13,000,000 gallons per day may, in my judgment, be reckoned on with absolute certainty." The average rainfall was originally taken at 48 inches, of which 36 inches was assumed to be available, and one-third of this, or 12 inches, was allowed for millowners' compensations, leaving 24 inches for Liverpool. The actual rainfall (average of 17 years) was only 45·71 inches, and the average 11 years delivery to Liverpool only 14½ inches, and in 1865 only 9¾ inches, instead of the 24 inches depth originally anticipated. With an additional storage reservoir then constructing, holding 1,200,000,000 gallons of water, a total storage of 68,500 cubic feet to the acre was afforded, which in a run of dry years had little chance of being filled, and which the engineers only calculate to yield 10,500,000 gallons a day in average years, and 9,000,000 gallons in cycles of three dry years. This quantity in 1861 was supplemented by 7,500,000 gallons per day from wells at Liverpool. The gravitation

works have never supplied more than 17,000,000 gallons per day, after deducting 8,300,000 gallons per day compensation to mills; in 1864–65–66, the average supplied to Liverpool was less than 8,000,000 gallons, in 1865 only 6,177,000 gallons per day. In September, 1867, the compensation water was reduced to 6,500,000 gallons a day, by the purchase of 1,850,000 gallons, which was available in the 1868 drought. The full store of water at Rivington was reduced by the drought from 3100 million gallons to 700 million gallons, or (including compensation) to 50 days' supply of seven hours' service.

YIELD of the RIVINGTON RESERVOIR, derived from information afforded by THOMAS DUNCAN, Esq., OCTOBER, 1865.

YEARS.	Rainfall by Daily Gauge.	Quantity Collected.	Equal to Proportion of Rainfall.		Given to Compensation to Mills per Day.	Delivered in Liverpool.
		Gallons per day.	Per Cent.	Inches.		
1861	46·38	22,173,493	77·13	=35·77	8,300,000	10,403,818
1862	48·51	24,844,597	82·63	=40·08	8,300,000	10,790,414
1863	51·01	25,243,003	79·84	=40·72	8,300,000	11,195,044
1864	39·035	17,125,406	71·37	=27·85	8,300,000	11,046,339
Mean	46·233	22,346,624	77·74	=36·10	8,300,000	10,841,403

LIVERPOOL WATERWORKS DISTRICT.

Minimum rainfall of 14 years .. .. .. 34·78
Mean „ „ .. .. .. 45·14
Min. 77 per cent. of Mean.

Year.	Rainfall.	Collected.
1861	$46\frac{1}{3}$	$35\frac{3}{4}$
1862	$48\frac{1}{2}$	40
1863	51	$40\frac{3}{4}$
1864	39	28

Mr. T. Duncan* stated that the *Rivington Waterworks* were based on the calculations of Mr. Hawksley; that the daily yield would be 16,000,000 gallons a day. Mr. Hawksley assumed a mean rainfall of 48 inches, and allowed 25 per cent. for absorption and evaporation, and a third off this quantity for compensation in bulk, the resultant available has fallen far below the quantity expected.

The right bank of the *DOUGLAS*, below the reservoir, drains the district of Anderton, the south side of Adlington, Worthington, and Standish. At the latter place the Coal Measures crop to the surface, but generally they are deeply overlaid by Upper Boulder overlying Middle Sands, the latter cropping in the valley of the *DOUGLAS* and its deeper tributary valleys drained by small streams; these have short courses, a minor watershed running parallel to the river through Standish and Wigan Lane to Wigan, which is built on Glacial Sand or Middle Drift, resting on Coal Measures, from which the coal has been largely worked, causing a certain amount of subsidence.

BLACKROD.—Population, 4234; rateable value, 21,360*l.*; Waterworks constructing, under Blackrod Local Board Act, 1876, impounding springs at Wilder's Wood, in the township of Horwich.

ADLINGTON.—Population, 3258; rateable value, 8390*l.*; no public water supply; insufficient supply from wells and lodges.

STANDISH with LANGTREE.—*Acres*, 3698; population, 4261; rateable value, 19,747*l.*; no public supply.

WIGAN.—*Acres*, 2188; population, 48,196; rateable value, 128,000; constant supply under Wigan Waterworks Act, 1853, of 1,800,000 gallons, including compensation water from gravitation works storing surface waters; the water is filtered at the storage reservoir, and then pumped into the high-service reservoir.

* 'Royal Rivers Commission,' p. 120.

Rainfall at Wigan Waterworks, 225 feet above the sea, taken by Mr. W. Bolton.

1858	36·18	1862	49·01	1866	43·61	1870	34·35	1874	41·26	1878	38·66
1859	37·35	1863	44·70	1867	33·51	1871	36·53	1875	37·70	1879	35·36
1860	46·01	1861	34·79	1868	37·58	1872	54·84	1876	40·37	1880	36·98
1861	47·63	1865	33·48	1869	40·52	1873	34·28	1877	51·10	1881	..

Average of the 21 years, 1858–1878 inclusive, 40·64 inches; average of the three wettest years of that period 50·49, or 9·85 above the average; average of the three driest years, 33·78 inches, or 6·86 inches below the average. 1858–59, 1864–65, 1870–71, were examples of dry years following each other; 1860, 1861, 1862, of three wet years following each other. In 1858 rain only fell on 117 days.

Between Wigan and Shevington the only important feeder falling into the right bank of the *DOUGLAS* is *Wrightington* Brook, impounded in Wrightington Park, and draining entirely Drift-covered Coal Measures. Another feeder comes in east of Parbold Hill, which drains a curious valley running east and west, parallel to the watershed, between Adlington and Harrock Hill. The sides of the valley are the sands of the Middle Drift, and at the bottom rises the *Hic-bibi* Brook. At Bispham a fault brings in the New Red Sandstone with a small exposure running east and west, parallel and close to the exposure on the upthrow side of Permian Marls with a thin band of Magnesian Limestone, described by Professor Hull, resting on the Lower Coal Measures uncomformably. Further north, at Black Moor, a feeder draining the soft Red Sandstone of Maudsley comes in, and between Hanging and Red Bridges it receives an important tributary, the River *Yarrow*.

River Yarrow.

This stream is 15 miles in length, rising near the source of the *DOUGLAS;* its drainage area forms the northern part of that basin. Following its left bank, up stream, it traverses

the New Red Sandstone by Croston and Eccleston, and crosses the fault bringing in the Lancashire Coalfield, which is well seen in *Lyd* Brook at Eccleston Green, where Pebble-bearing Sandstone is thrown against Lower Coal Measures at about 125 feet above the mean sea-level. The stream flows past Gillibrand Hall, where it trends south through a deep valley in the Glacial Drift to Duxbury Park, where it turns north-eastward with the strike of the Middle Coal Measures, over which it flows, and which forms the floor of the Drift-cut valley; crossing the Chorley fault, the stream trends eastward to its source above the Rivington reservoir, which intercepts its upper waters. The village of Rivington, on the eastern bank of the reservoir, is in the part of the basin thus intercepted.

Croston.—*Acres*, 2361; population, 1791; rateable value, 9143*l.*; private wells.

Following the right bank of the *Yarrow*, down stream, after leaving the Rivington reservoirs, an important feeder comes in, known as *Black* Brook, rising at Green Hill, 1170 feet above the sea, and flows through the valley of Kinderscout Grit, separating Anglezark from Wheelton Moors, to the Liverpool Water Supply Conduit, thence, crossing the fault throwing in the Newer Millstone Grits and Lower Coal Measures, it flows past Heapey Print Works, and through a deep valley between Grey Heights and Chorley, and falls into the *Yarrow* at the northern end of Duxbury Park. From the infall of this stream to Euxton, the Drift-covered country around Chorley, rising to 313 feet at Hastwood Green, and 364 feet on the watershed, is drained by streams which do not expose the rock surface, and are chiefly cut through the sands of the Middle Drift.

Chorley.—*Acres*, 3613; population, 19,472; rateable value, 55,000*l.*; supplied, under Chorley Waterworks Act, with a constant daily quantity of 400,000 to 500,000 gallons, including trade supply, from reservoir storing springs and streams on the Anglezark Moor. The reservoir is on the eastern margin of the upper Rivington reservoir. The top

water is about 520 feet above the mean sea-level. The reservoir is constructed on shales underlying the Second Grit, and is embanked at both ends; the bye-wash is at the northern end, and the waste water flows into the reservoir.

Northward, the watershed limit of the *Lostock* tributary to the *Yarrow* trends north-north-west over the tops of the Millstone Grit of the Anglezark Moors, descending to 1215 feet at Bromley Pastures, 1028 at Withnell Moor, and to 555 in the Withnell Col Valley, between the valleys of the *DOUGLAS* and *MERSEY*. Thence, ascending Withnell Hill, it attains 675 feet near the Church on the Millstone Grit Rough Rock. Leaving this formation, it crosses a synclinal, bringing in Lower Coal Measures, traversed by the Leeds and Liverpool Canal, which is crossed at 360 feet. On the opposite side of this synclinal is the long escarpment formed by the Rough Rock of Brindle and Hoghton Towers, traversed for a short distance by the watershed at an elevation of 425 feet.

A north-west fault at Brindle brings in the Shales under the Rough Rock, which are traversed by the watershed to Thorpe Green, after which it crosses the third Millstone Grit and underlying Shales, and the termination and summit-level of the branch canal, carried from the Leeds and Liverpool Canal at Heapey. This branch canal was formerly connected by a tramroad, laid on stone sleepers, with the Lancaster Canal at Preston, crossing the *RIBBLE* by a wooden bridge still standing, and the alluvial flat of that river by a long embankment now utilized as a public promenade.

The Walton-le Dale water supply is now derived from a well sunk to a depth of 500 feet in the Millstone (*third*) Grit, at a point near the summit station, 320 feet above the sea, chosen by myself. Between the Walton Summit Station and Bamber Bridge, the fault throwing in the New Red Sandstone is crossed by the watershed, which descends to 150 feet at Bamber Bridge; the rock is deeply covered with Glacial Drift, and is probably not less than 125 feet below the surface. Westward the watershed runs nearly parallel to the *Lostock*,

descending to 114 feet at Farrington, where it passes on to the extensive tract of peat moss, forming Longton, Farrington, and Hoole Mosses, which rest on the Upper Boulder Clay, thence passing west to the mouth of the *DOUGLAS*, at Marsh Houses.

River Lostock.

West of Croston the *Yarrow* receives this stream; it is 13 miles in length, rising on the western slope of the Rough Rock of Withnell, which rises to 675 feet above the sea. It follows the strike of the Lower Coal Measures, between Heapey and Brindle, to Whittle-le-Woods, where it flanks the Millstone Grits of Brindle and Clayton Green, crossing the fault bringing in the Trias at Cuerden Park, it describes an S-like curve, and flows by Bamber Bridge, Farrington, Ulnes-Walton, and Bretherton. Feeders on the left bank drain the district of Leyland. A feeder on the right bank drains the valley between Hough Moor and the Clayton Green ridge. At the head of the valley is the boring for the water supply of Walton-le-Dale.

Rainfall at Crooke Hall, Whittle-le-Woods, 265 feet above the sea (Mr. T. J. Hare) :—

1876.	1877.	1878.	1879.	1880.
38·43	53·64	36·96	36·48	36·73

Giving an average for the 5 years of 40·44 inches.

Leyland.—*Acres*, 3741; population, 4161; rateable value, 22,800*l.*; at present supplied by wells in the sands of the Middle Drift; a pumping scheme is in preparation, from a well and boring.

The *DOUGLAS*, from the infall of the *Yarrow*, flows through a low tract of country, covered with Glacial Drift, which has been cut into by streams, as *Bretherton Carr* and *Much Hoole* Brooks. There is no natural division north of the *DOUGLAS* watershed at Marsh Lane, further than these small streams drain in the one case into the tidal *DOUGLAS*, and in the other into the estuary of the *RIBBLE*.