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PROOF.]

THE RELATION OF GROUND WATER TO DISEASE.

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[Read November 19th, 1890.]

The work in which the Fellows of the Royal Meteorological Society are engaged is one of passing importance, having regard to the study of the causation of disease. The words written by John R. Arbuthnot, M.D., F.R.S., over a century and a half ago, are probably as applicable now as when written, when he said that "a history of facts or a journal of diseases "compared with the weather, which, if it should be kept for any great "period of time and in many places I will venture to affirm that mankind "would arrive at more than a conjectural knowledge in this matter. The "ancient physicians seem to have been more attentive to this than the "moderns, and those of the moderns who have attended to it have perhaps "made no inconsiderable figure in their profession."

Various climatic conditions affect disease; and to get at the particular influence of any one condition it is necessary to differentiate between various causes. The variations in climatic condition are extremely diversified, and the study of their influence on disease should not extend over too great an area; for it is only in typical years that their influence is wide-spread.

In studying the relation of the effects of ground water on disease, we

must eliminate those causes which are known to have an influence upon health. The pages of history show that when the ground waters of our own or other countries have arrived at a considerable degree of lowness, as evidenced by the failure of springs and the drying up of rivers, that such periods have always been accompanied or followed by epidemic disease.

I might say, at the outset, that in the study of this subject it will be found, in all probability, that ground water in itself, except under conditions where it is liable to pollution, has no material effect in producing a spreading disease. As a rule it is only in those places in which there has been a considerable amount of impurity stored in the soil that diseases become manifest, and the most common mode by which diseases are, in all probability, disseminated, is by means of the water supplies drawn from the ground, or by the elimination of ground air into the habitations of the people. It will also be found that the periods of low and high water mark those epochs when certain organic changes are taking place in the impurities stored in the ground, which ultimately become the cause and lead to the spread of disease.

For the purpose of illustrating the influences of ground water upon health I propose to deal more especially with the records of Croydon; not that Croydon is an exceptionally unhealthy district, for, on the other hand, it is a district extremely favourable to health by reason of the extension of its population over a maiden soil which has not had time to be polluted by the habitation of man. In fact, if you wish to get the true significance of the bearing of climatic influences on health, you must go into those districts which have been long occupied as the residence of man, in which the ground has received from year to year considerable accessions of pollution, and on this account the observations made at Croydon are unfavourable; but what does occur there is accentuated in other districts not so favourably located. We have, however, in Croydon a comparatively perfect register of Baptisms and Burials going back to the year 1539.

For years past I have been carrying on observations upon the state of the ground water within and around this particular area, with a view of discovering the influences which affect the health of such a place as this, and, in common, all other places. I have had extracted the date, the place, and the cause of every death since registration has taken place, and I have had abstracted from the long register the whole of the burials, separating them to each month of every year. The Croydon Register of Burials shows that the incidence of disease in Croydon three hundred years ago was identical with what it is at the present time.

Croydon is also by no means a favourable place for the study of certain types of disease, owing to the fact that it has been subject at certain periods to various epidemics, the protective influences of which against a second attack of such disease tends to obscure the law that governs their extension.

One of the climatic conditions which affect health is that of temperature. Heat and cold have a marked influence in producing disease. The month of June is the most healthy month of the whole year. As we leave the point of mean temperature, either on one side or the other, the death rate increases, but from a different class of disease.

The following tables show the death rates in Croydon. In this table I have shown the temperature of the months of December, January and February

COLD AND HOT PERIODS WITH DEATHS IN CROYDON.

Year.	Temp. Dec. Jan. Feb.	Death Rate, Jan. Feb. March.	Deaths of Children under 5 years of age, Jan. Feb. March.	Temp. June, July, Aug.	Death Rate, July, Aug. Sept.	Deaths of Children under 5 years of age, July, Aug. Sept.
	°			°		
1837	40·5	39·8[1]	..	60·9	28·5	47
1838	39·1	33·7	51	60·2	31·5	55
1839	39·8	22·3	28	60·3	23·3	35
1840	40·4	23·4	31	59·2	23·9	34
1841	34·6	29·1	41	58·2	18·4	28
1842	38·1	31·0	56	62·8	24·1	35
1843	40·3	25·0	29	59·8	21·1	36
1844	39·4	21·8	33	60·0	16·4	22
1845	34·7	23·5	26	59·2	20·0	26
1846	43·1	20·0	32	64·3	18·8	34
1847	34·7	28·3	47	61·8	28·7	56
1848	40·2	33·5	88	59·9	25·6	32
1849	43·0	31·6	47	61·1	31·8	34
1850	39·0	18·2	33	61·7	19·4	30
1851	41·1	19·3	42	60·9	26·0	40
1852	41·3	20·6	44	61·7	22·2	41
1853	40·6	36·8	73	60·1	22·1	33
1854	37·7	24·3	61	59·4	27·6	62
1855	35·3	26·3	48	61·1	18·4	44
1856	39·2	19·1	51	61·5	17·5	36
1857	38·7	18·8	46	64·0	16·1	49
1858	39·5	18·6	35	63·1	18·6	57
1859	41·7	18·4	34	65·0	25·1	91
1860	36·7	18·7	57	57·4	14·8	33
1861	39·1	19·4	46	62·0	16·0	55
1862	40·9	20·9	66	58·6	14·2	40
1863	42·7	20·7	67	61·3	22·2	78
1864	38·8	29·9	112	60·4	18·5	70
1865	37·4	22·1	82	62·3	21·6	97
1866	42·6	27·5	125	61·1	17·8	78
1867	40·8	22·1	90	60·5	16·8	73
1868	39·6	22·1	105	65·1	25·0	141
1869	44·1	21·7	99	60·2	23·4	135
1870	34·1	20 8	105	62·5	20·2	130
1871	35·8	22·6	133	60·4	22·4	127
1872	41·5	19·5	119	61·7	19·5	126
1873	39·8	17·7	93	61·7	15·7	111
1874	40·3	17·8	101	60·9	15·4	110
1875	37·2	22·1	112	60·3	18·8	125
1876	38·9	21·4	121	62·7	19·9	143
1877	43·7	20·0	130	62·0	15·0	93
1878	41·3	18·0	117	62·0	18·9	164
1879	34·6	21·6	127	58·5	12·9	88
1880	36·0	24·3	130	60·6	24·2	153
1881	37·7	17·7	110	61·2	16·6	149
1882	40·8	21·2	190	59·0	16·3	134
1883	41·5	16·2	117	60·3	12·1	94
1884	42·2	17·7	145	62 1	17·3	171
1885	40·6	19·8	154	60·6	16·3	121
1886	36·3	17·7	126	61·0	15·3	153
1887	36·6	16·0	118	62·8	15·2	143
1888	36·7	16·6	113	58·6	10·8	83
1889	33·3	16·0	126	61·1	13·7	126
1890	38·8	22·2	192	59·6	14·7	142

[1] From Burials.

compared with the number of deaths in January, February and March, and the temperature of the months of June, July and August, and compared with it the deaths in July, August and September.

During the period embraced in this table the population of Croydon has increased from 14,881 in 1837, to 79,615 in 1881, and the population is now estimated by the local authority at over 100,000, a figure which in my judgment is, however, too high.

Although cold is shown to affect health, yet, in all probability, cold is not a natural condition as affecting the health of children under five years of age. This has clearly been demonstrated by the fact that the death rate of children in cold countries, such as Norway, is absolutely less than that of England, while in a warm country like Italy the death rate of children is higher than that of England. This is doubtless due to the influences of high temperature, but in the study of the influence of ground water it is found that the deaths of children rise in a remarkable degree at the period of low ground water, and the death rate fluctuates in a remarkable manner under the variation in the annual amount of ground water, the rate being the lowest with the highest ground water and highest with the lowest ground water, and, consequently, if the ground water is plotted on one side of a diagram and the death rate on the other side, there will be found to be a remarkable parallelism between the lines. We often have the lowest ground waters in the months of the coldest temperatures, and, therefore, it becomes necessary to separate the influence of cold as distinguished from the lowness of the ground water. This country has had the most unhealthy periods when the ground water has been at its lowest. The following table shows the death rates of England and Wales in the first quarters of the years following, which embrace all the known low water periods that have occurred since registration of deaths was established.

DEATH RATES, ENGLAND AND WALES, IN LOW WATER PERIODS.

First Quarter of Year.

Year.	Death Rate.	Temp. Greenwich.	Year.	Death Rate.	Temp. Greenwich.
		°			°
1838	26·2	35·8	1864	27·72	38·1
1845	25·5	33·6	1865	27·00	36·8
1847	28·5	36·8	1866	26·2	42·0
1848	27·9	40·6	1875	27·5	39·6
1853	26·1	37.3	1885	22·0	40·2
1855	29·1	33·9	1888	21·2	36·9
1858	26·3	38·5	1890	23·1	41·4

This table, it will be observed, when compared with the average temperature of the period shows that there are some other influences at work apart from temperature which affect disease and produce death, and it may be said with reference to these observations, that up to the year 1875 the mortality of England and Wales in any quarter of the year (with the exception of the September quarter of 1849, when cholera was rife) was at

these particular periods of low water greater than at any other time. It is well known that heat and cold limit the area of particular diseases, and that the temperature of the ground has also an essential bearing in the causation of disease. Heat has also a tendency to reduce ground water, and, on the other hand, intense cold has a similar effect, as in time of frost the surface waters are frozen and percolation is stopped.

We must also bear in mind in the study of this question that light and darkness have a material effect on disease. The healthiest months of the year are those in which the sun is for the shortest period below the horizon; the unhealthy periods are those in which there is the longest period of darkness. It has been well said that "disease walketh in darkness," and this is true both naturally and literally, for at present we know little of the causation of disease. The period of greatest darkness is also that of the greatest amount of percolation, as it is found that many diseases increase during the percolation period and decline as percolation ceases, so there is a parallelism between the periods of darkness and percolation. It is well known that in malarious countries, malaria is most active at night, and districts which can be traversed with impunity in daylight become dangerous after sunset. We have also the experience furnished by Arctic Expeditions. When H.M.S. *Assistance* was 94 days in winter darkness in the Arctic regions in the Expedition of 1850-51, when the health of its crew is compared with the *Alert* in the last Arctic Expedition which was 142 days in Arctic darkness, it was found that scurvy was very much more rife in the ship the longest exposed to the influence of darkness, although both vessels were on an equality with regard to provisions and other matters.

Dr, Macnamara has observed in India that cholera cases were always most numerous when the sky was overcast, and in this country it has been observed that more deaths take place while the sun is below the horizon than when it is above the horizon. We must, therefore, in studying this question make allowance for the periods of darkness, and must eliminate this as a probable source of error in judging of the influences of ground. When the question of epidemic disease is studied, it will be found that the black death of the 14th century, and the sweating sickness of the 16th century, the plague of the 17th century, in modern times cholera, typhoid fever, scarlet fever, dysentery, diphtheria, all follow the same track, having the same seasonable fluctuations. We may, therefore, look to some common cause which favours the development of these particular diseases.

In studying the question of disease, we must also bear in mind that the conditions which affect mankind also influence the health of cattle. When this is more generally known, probably greater attention will be paid to the study of this question as the means of preventing loss amongst the stock of the country, even if the health of mankind is neglected, but it is curious that in an enlightened country like England, in which sanitary science has had its origin, that a Minister of Agriculture, who looks after the health of the stock, should be appointed before we have a Minister of Public Health.

Disease affects every section of the people. It is however, more potent

and strongly marked among the young. Now it would be impossible in the course of such a discourse as this to draw attention to the influences connected with every disease. I, therefore, propose to direct your attention more particularly to what are known as zymotic diseases, the general death rate, and deaths amongst children under 5 years of age.

The question may be asked, What is ground water? The answer is, All water found in the surface soil of the earth's crust, except such as may be in combination with the materials forming the crust of the earth. It is mainly derived from rainfall by percolation; the ground becomes wetted, and when fully saturated in porous soils, water passes through and lodges in the lower portion of the strata and becomes the free water which we measure in wells in order to ascertain its relative height from time to time. Ground water is also produced by condensation: whenever the ground is colder than the air, a certain amount of vapour is condensed within the pores of the surface of the soil, which is partially given off at those times when the soil is warmer than the air, especially at night. In dry countries ground water is principally supplied by the infiltration from rivers, as for example in the Delta of the Nile. In some strata, the whole of the ground water is held by capillarity, as in clay and other soils and rocks of close texture, whilst in others it is held both by capillarity and as free water, which somewhat ordinarily is termed the ground water. The free ground water may be increased by water passing from the superincumbent strata in which it is held by capillarity even without rain, as with the rapid fall of the barometer. The free water of the ground is a very active agent, and may become the direct vehicle of conveying for unlimited distances the active properties of disease. This water rises and falls as a rule every year, forming a wavelike profile, the rise being much more sudden than the fall. It is also always moving in particular directions. As a rule it moves in the direction of natural outlets, which may be either the sea springs or rivers; its greatest amplitude of fluctuation is at the most distant point from its point of escape, while its least range of fluctuation is close to the point of discharge. As a rule, when there is a large quantity of water in the ground a large quantity is discharged, and *vice versa* with small quantities. It should be noted that most of our old cities and towns are located upon porous soils in which usually there has been water in the subsoil, no doubt as a matter of convenience for the purposes of water supply, and in those periods when these underground waters were exclusively relied upon to furnish a supply of water to the inhabitants epidemics and diseases of various kinds were very much more rife and fatal than at the present time, when such sources of water supply in the principal towns of the country have been abolished. The mechanical effect of rain passing into the ground has also an influence in disseminating disease, because all ground contains air, and the rainfall cannot occupy the space previously occupied by this ground air without expelling it. This air more readily escapes into our houses, the passages to which are protected from the influence of rain and are left open, while those outside the house are sealed to the falling rain. On the other hand, all the time that the ground water is diminishing there is a tendency for air to be

drawn in to occupy the space formerly occupied by the ground water. Upon investigation, it will be found that diseases of a certain type are most rife during that period the ground is filling up with water and expelling the ground air, and are least rife when the current of air is inwards instead of outwards from the ground. Of course these conditions are also subject to variation with the changes of barometric pressure. As a rule, the amount of free water in the ground cannot with accuracy be estimated by the quantity of rain, as the quantity entering the ground depends upon the hygrometric condition of the ground ; but in the absence of other information, the state of the ground water may be inferred from rainfall records. In some years it is found that the actual amount of rain which may enter the ground at a particular period as measured by percolation gauges may be considerably less than that flowing off; for if the ground waters are very low, probably more will enter the ground than flow off in the same year. As an example, in the year 1888, after the low waters of 1887, but 7 ins. was known to have flown off the Croydon Drainage area of the River Wandle, while over 13½ ins. percolated through a chalk gauge in the same year. Again, in the same year 1887, only 5 inches of rain passed through the percolating gauges, while in that year nearly 9 inches flowed off, the balance being drawn from the store previously left in the ground. In some years there is no low water, but these are exceptional. However, the records from a well at Hartlip Place, near Sittingbourne, show that in the year 1829 there was no low water, the water rose all through that year to June 1830, and this was a healthy period. In some districts, the fluctuation in the ground water has considerable amplitude. It is not unusual to find wells in which the water line may vary over 100 feet between the highest and lowest waters within a few months. On the other hand, in certain seaside places and towns located near rivers the fluctuation is very small, and as a rule the healthiest districts are those where there is the least vertical rise and fall of the subsoil water, which is the case in nearly all seaside health resorts. There are also examples when an undue elevation of the free ground water beyond what is ordinarily its normal range may produce all the effects which are noticeable after low water periods. Professor Peterkofer, in his observations at Munich and elsewhere, established beyond doubt the coincidence between cholera and typhoid fever with low ground water. If we direct our attention to American experience, we find the Reports of the State Board of Health teeming with information upon this very point, and Dr. Draper says with reference to Massachusetts, that the charts show that enteric fever, cholera, diarrhœa, dysentery, are more prevalent when springs are low than at other periods of the year. Investigations conducted by Dr. Buchanan, F.R.S., and Mr. W. Whittaker, F.R.S., in 1865, on phthisis in this country, show that an excess of water in the soil increases the death rate from that disease. It may be said with regard to all the epidemics of typhoid fever in this country that, without exception, they occur immediately after the periods of the greatest low water, and as a rule typhoid fever occurs at such periods of the year when the waters are usually low, and on the rise of the water, as in the autumn.

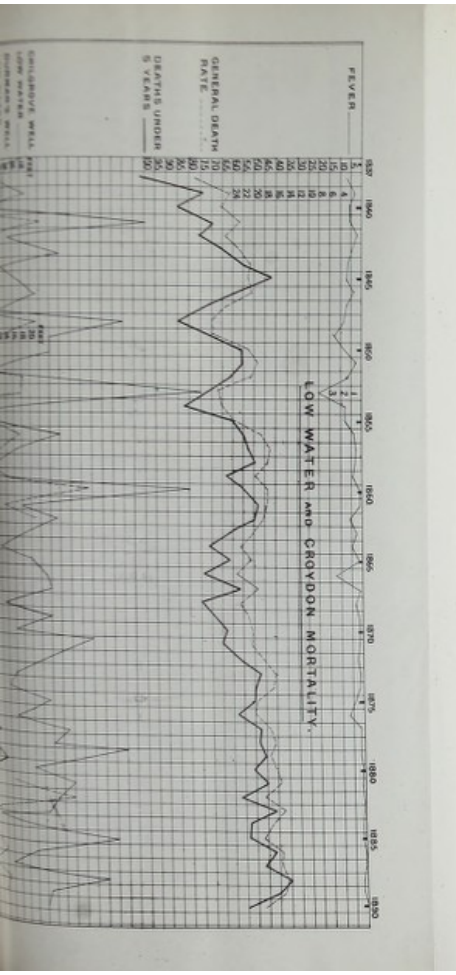
The germs of disease we know can be carried a considerable distance underground through the dark recesses of the soil by the movement of the free ground water, as shown by the exprience at Lausen in 1872. I can also point out a case in my own experience in a chalk district in Yorkshire occurring within the present year, where polluted water has travelled underground a considerably greater distance than in the case of Lausen and has produced typhoid fever.

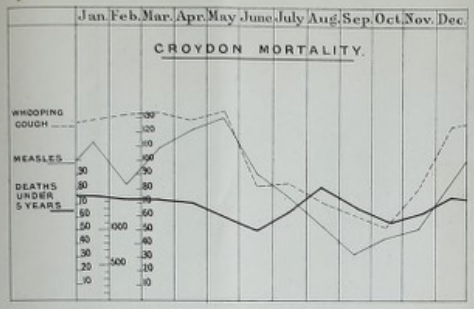
In some districts the number of disturbances or rise and falls in the subsoil have a marked influence upon health; for example, if the health statistics of the City of Chichester are compared with the long record of the well at Chilgrove near that city (the observations in connection with which have been carried on by Mr. Thomas Wood and his father), it is found that the greater number of disturbances which have occurred in the Chilgrove Well mark the most unhealthy years within the City of Chichester. The year 1888 may be taken as a recent example, when there were three distinct rises and falls in the water of this well in this particular year, and the proportional mortality within the City of Chichester was the highest recorded in the last 20 years.

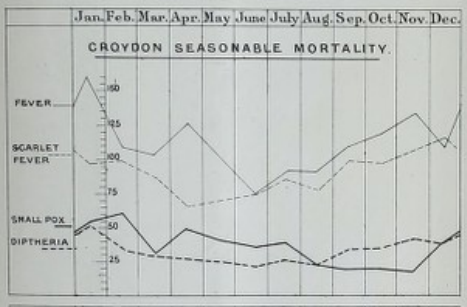
That the earth itself does exercise a baneful influence on health has been well exemplified by the statistics referring to the unhealthiness of cellar dwellings, and which have also established the fact that ground floors, as a rule, are not so healthy as the upper rooms of our habitations.

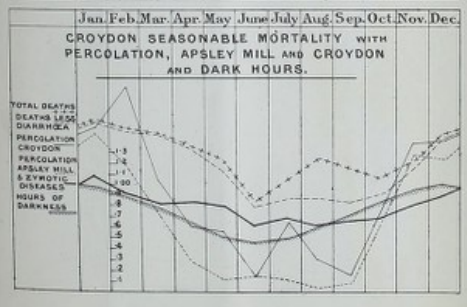
The absence of water passing into the ground for a long period naturally leads to the lowering of the free ground water line, and may lead to the drying of the ground above the water line; and it is curious to note with reference to small pox that the periods marking the epochs of small pox are those in which there has been a long absence of percolation and consequent drying of the ground preceding such epidemics. On the other hand, small pox is unknown at such periods as when the ground has never been allowed to dry, or is receiving moisture by condensation or capillarity.

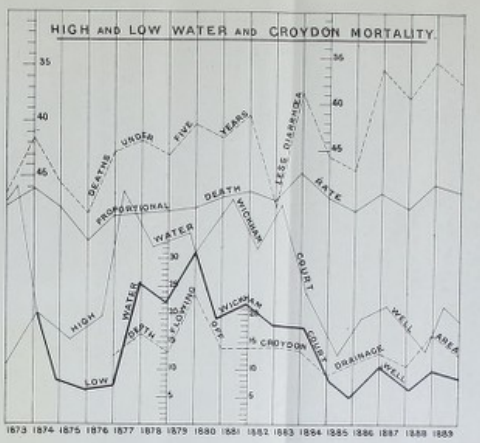
It should also be noted with reference to the effects of ground water upon disease that often these conditions may be artificially produced. It is curious to note that in the first epidemic of typhoid fever in Croydon in 1852, that previous to its outbreak the ground water had been artificially lowered under the town 6 feet by the destruction of a mill dam and the provision of a subsoil drain for the express purpose of lowering the ground water, and it is also curious to note that Dr. Neal Arnott, who reported upon this particular epidemic at Croydon, gave in his report an instance which occurred in the year 1825, where, after the construction of a sewer and the drying of the ground which was marked by the drying up of the ponds in its particular neighbourhood, an outbreak of typhoid fever occurred. It is a matter of common experience that in all old towns formerly ramified with cesspools, often deriving their drinking water from local wells, it is not at all infrequent when works of drainage are first introduced which have a tendency to lower the subsoil water, that typhoid fever occurs which is not unusually ignorantly attributed to the new system of sewerage.

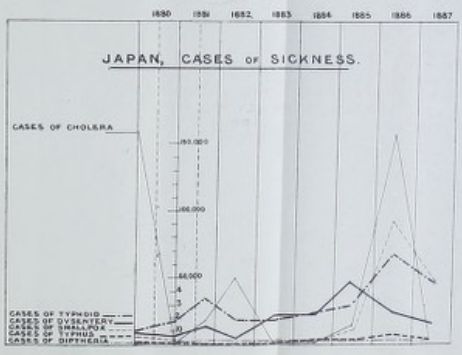

LOW WATER AND CROYDON MORTALITY.
FEVER
GENERAL DEATH RATE
DEATHS UNDER 5 YEARS
1840
1845
1850
1855
1860
1865
1870
1875
1880
1885
1890


Jan. Feb. Mar. Apr. May June July Aug. Sep. Oct. Nov. Dec.
CROYDON MORTALITY.
WHOOPING COUGH
MEASLES
DEATHS UNDER 5 YEARS


Jan. Feb. Mar. Apr. May June July Aug. Sep. Oct. Nov. Dec.
CROYDON SEASONABLE MORTALITY.
FEVER
SCARLET FEVER
SMALL POX
DIPTHERIA


Jan. Feb. Mar. Apr. May June July Aug. Sep. Oct. Nov. Dec.
CROYDON SEASONABLE MORTALITY WITH PERCOLATION, APSLEY MILL AND CROYDON AND DARK HOURS.
TOTAL DEATHS
DEATHS FROM DIARRHOEA
PERCOLATION CROYDON
PERCOLATION APSLEY MILL
ZYMOTIC DISEASES
HOURS OF DARKNESS


HIGH AND LOW WATER AND CROYDON MORTALITY.
DEATHS UNDER FIVE YEARS
PROPORTIONAL DEATH
RATE
LESS DIARRHOEA
HIGH WATER
LOW WATER
DEATH
WICKHAM COURT
WELL
AREA
1873 1874 1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889


JAPAN, CASES OF SICKNESS.
1880 1881 1882 1883 1884 1885 1886 1887
CASES OF CHOLERA
CASES OF TYPHOID
CASES OF DYSENTERY
CASES OF SMALLPOX
CASES OF TYPHUS
CASES OF DIPTHERIA

We possess in this country a number of records with regard to the height of the ground water, and these records are multiplying yearly, and probably, when the importance of this question is more appreciated, we shall get a further increase. The registration of deaths in this country only commenced in July 1837. We have in many parts of the country complete records of the underground water which will carry us back beyond the date when registration of deaths commenced, and by comparing the records which we now possess with the registration of deaths, we are able to show that the relative height of the ground water has a material bearing on health. It would be impossible, in the limits of an address of this kind, to particularise all the various diseases as influenced by underground water. I trust the information about to be given will furnish some useful material to any person desirous of studying the influence of ground water on any specific disease. I may, however, point out to those that are ignorant of the fact, that an investigation of this kind has been made in the case of London and New York by our Fellows, Dr. Buchan, and Sir Arthur Mitchell, M.D., and a published diagram of London mortality shows at a glance the incidence of every class of disease which has occurred during a period of many years, and it will be apparent to any one who will study this document that certain diseases have their allotted seasons and conditions under which they are more or less rife.

The study of underground water will show that certain diseases are more rife when waters are high in the ground, and others when the water is low. The conditions that bring about and accompany low water, however, have by far the most potential influence on health, as all low water years are, without exception, unhealthy. As a rule, the years of high water are usually healthy, except as often happens when high water follows immediately upon marked low water, when on the rise of the water an unhealthy period invariably follows. This has been already referred to and pointed out in the tables, which show the very high death rates that occurred in the first quarters of the year following marked low water periods. The most unhealthy periods are those which indicate the first passage of water through the ground, Periods such as these are indicated by Dr. Arbuthnot, when he wrote "The surface of the earth being by drought first shut up and afterwards opened by rain." He also pointed out what is found to hold good in modern times, that the breaking up of frosts was followed by the commencement of epidemic disease, and he specially mentions the constitution previous to the plague of London as being very singular in breaking out after a hard winter frost, lasting till nearly the end of March, a sudden thaw, the ground covered with water from melted snow and ice and great heat succeeding.

Many epidemics, especially of cholera and typhoid fever, have been traced to particular rainfalls. The majority of the zymotic diseases follow the period of percolation and are most rife in the lowest water year.

Low water years are also equally dangerous to cattle as to man. The year 1714 was a remarkably dry year, when but 11·19 inches o frain were recorded as falling at Upminster. In that year the burials in Croydon were over

double those of the preceding year, and in London the burials rose from 21,057 in the preceding year to 26,569 in this particular year. Another dry year was that of 1742, when 15·7 inches of rain were recorded at Lyndon. In that year the burials in Croydon were almost three times as numerous as in the following year, whilst the burials in London in that year were 32,169 as against 27,483 in the following year. In both these years much cattle died from murrian.

There have even been greater periods of drought recorded than in the years mentioned; but without exception they have exercised a baneful influence, and so, in modern times, the periods of drought mark the periods of disease. On the other hand, wet summers are usually healthy. Those years in which there has been no low water are those in which the health has been invariably good. In the year 1829 the records of the well at Hartlip Place show that there was no low water at the usual period in that year. The waters rose continuously through the year to June 1830, and so, too, with other years in modern times, such as the years 1860 and 1879, and these are all healthy periods.

We must also bear in mind, in studying these questions, that the rates of mortality are by no means so reliable as the rates of sickness. Unfortunately, however, in this country we have not the rates of sickness at present available. In Japan, however, there is every year recorded both the number of cases arising from certain zymotic diseases as well as the number of deaths taking place, and as the seasonable variation of temperature in Japan is almost identical with that of our own country, we can observe in that country the influences of climate upon particular diseases. So, also, in countries in which there is a chronic state of dryness, as in Egypt, it is found that the health is materially influenced by the height of water in the ground. A low Nile marks an unhealthy period, and the most unhealthy periods occur while the ground is filling up with water, as, for example, at Cairo, the average height of the Nile for 6 months, from January to June 1888, was 13·83 metres, when the death rate was 43·1; in the same period in 1889 the average height of the Nile was 13·5 metres, and the death rate was 49·1.

It will also be found in studying this subject that those districts which draw their water supplies direct from the ground are usually most subject to epidemics, and disease is much more marked than in districts in which the water supply is drawn from rivers supplied from more extended areas, or from sources not liable to underground pollution. In the case of Croydon one portion of the district (under three-fourths) is supplied with water taken direct from the ground, whilst the remaining portion is supplied with water from the River Thames. It is curious to note that even so recently as 1885 the zymotic death rate in the districts supplied with underground water was twice as great as in that part of the districts supplied from the Thames, and in this particular year 41 deaths of small pox occurred in the district, not one of which is recorded outside the district supplied by the underground water.

Cholera.

I propose now to deal with the zymotic diseases as affected by ground water, beginning with cholera. Cholera is known to attack with the greatest virulence places of low elevation, the very sinks of impurity. These places have to contend not only with their local impurity, but the impurities which are carried by the movement of the ground water from places at a higher altitude into them. Cholera ordinarily breaks out when there is the least ground water, and a high air and ground temperature is also necessary for its development, and as a rule the low positions are favourable to the production of these high temperatures. Dr. Macnamara says, with regard to cholera, it is more rife in low alluvial soils, and that it advances from east to west, or it advances exactly in the direction from the least to the greater recorded falls of rain, and, as a consequence, just in proportion with the lowness of the ground water, which will be first lowest in the eastern districts and last lowest in the western districts. It has also been observed that cholera follows rainfall. After the drought in India of 1860, followed by rain in 1861, cholera broke out, and it has been observed by Dr. Macnamara and others that rain is connected with the development and dissemination of cholera poison, and that in India no wide-spread epidemic can occur unless during or after rain; but, on the other hand, it has also been noted that excessive rains will remove the disease, probably from rapid percolation and the cleansing of the soil from the germinal matter, or producing a state unfavourable to the development of the germs. It should be noted, with reference to the epidemics of cholera in this country in 1832, 1847, 1854 and 1865, that these periods were all years of low ground waters.

The following table shows the incidence of cholera and small pox in Calcutta for 26 and 29 years respectively:—

TABLE Showing Deaths from Cholera for 26 years, and from Small Pox for 26 years in Calcutta.—Compiled by Dr. Macpherson.

Month.	Cholera, Total Number of Deaths.	Small Pox, Total Number of Deaths.	Rainfall.	Average Temperature.	Range of Temperature.	Prevailing Winds.
			Inches.	°		
January	7150	1425	0·21	63·4	17·9	N NE NW
February	9346	2845	0·42	74·2	17·3	N NE NW
March	14710	4934	1·13	82·9	16·3	W SW S
April	19382	4249	2·4	86·6	14·7	S WSW
May	13335	2261	4·29	89·0	13·3	S S W
June	6325	1054	10·1	86·2	9·0	S S W
July	3979	555	13·9	84·0	6·4	S SE SW
August	3440	223	14·4	82·6	5·2	S SE SW
September.....	3935	188	10·4	83·8	6·6	S SW W NW
October	6211	147	4·72	81·1	8·8	W E S NW
November	8323	132	0·90	75·4	14·2	N NE NW
December	8159	576	0·13	66·9	16·4	N NE NW

It is curious to note the marked parallelism in India between small pox and cholera. But this parallelism between these two diseases is not confined

to that country, nor to small pox only. In Japan, where the seasonable variation of temperature occurs at the same period of the year as with us, but has a greater amplitude, they have for six of the zymotic diseases a registration of sickness; and an examination of these sickness returns shows the same results as in India. The following table shows the rates of sickness in Japan for a period extending from 1879 to 1887, the population of the country being estimated at a little over thirty-nine millions in 1887.

JAPAN.—INFECTIOUS AND CONTAGIOUS DISEASES.

Year.	Cases of Cholera.	Cases of Small Pox.	Cases of Typhoid Fever.	Cases of Diphtheria.	Cases of Dysentery.	Cases of Typhus.
Jan. 1879 to June 1880 ..	162637	4799	10052	1280	8169	2341
July 1880 to June 1881 ..	1580	3415	17140	1838	5047	1527
July to December 1881 (6 months)	9389	342	16999	1107	6827	564
1882.....	51631	1105	19308	2028	4330	629
1883.....	969	1271	18769	2307	21172	412
1884.....	904	1703	23279	2237	22702	3459
1885.....	13824	12759	29504	2798	47377	2302
1886.....	155923	73337	66224	3265	24326	8225
1887.....	1228	39779	47449	2741	16149	2487

It should be noted that cholera, as a rule, has not the same monthly incidence as small pox. The question of high temperature, which materially affects cholrea, would appear to have, if any influence, the contrary effect upon small pox as upon cholera. While the general conditions of ground water which bring about cholera also bring about small pox, the climatic conditions, however, that accompany these diseases are of an opposite character.

Small Pox.

The true significance of small pox must be studied probably not so much in our time as in periods gone by, when it was very much more fatal. It is, therefore, interesting to note that Dr. John Arbuthnot stated with reference to small pox, that he found that it was most fatal during hard frosts and cold North-easterly winds. Small pox is almost always preceded by a long period of the dryness of the ground measured by the absence of percolation. It should be noted that with reference to the year 1871, which was a very fatal year, the smallest amount of percolation recorded occurred. The Register at Apsley Mills shows that but 1·36 inches of water passed into the ground in the whole of that year, and so it has been with other years, for taking the Croydon records it will be found in the autumn of 1870 small pox commenced in Croydon after a very dry period, and continued to the autumn of 1871. In 1876 an outbreak again occurred after a very dry period, and continued till the autumn of 1877, and exactly the same conditions accompanied the outbreaks of 1881 and 1882, 1884 and 1885. It is quite clear that small pox only occurs after intense dryness of the ground. Since September 1885 there have been no deaths from small pox recorded in Croydon, but during the whole of that period (5 years) there has been but one month when no measurable quantity of water percolated through a gravel percolating gauge 1 yard deep, and that was in October 1886, a period when the ground was naturally moist; but in 1884, when small pox last broke out, it was preceded by 7 months in that year when no measurable quantity of water percolated through the same gauge. Having regard to the incidence

which has been shown to exist between small pox and other zymotic diseases which are capable of being transmitted by water and are propagated by unsanitary conditions, it is almost absolutely certain that small pox is propagated and disseminated in the same way as cholera and other diseases under the peculiar climatic conditions to which I have drawn attention.

Typhoid Fever.

The conditions affecting typhoid fever are very marked, and are capable of absolute proof. The disease is most prevalent after a dry time and the first wetting of the ground or percolation from any cause taking place. The quality of the ground water as shown by Professor Petenkoffer does not appear to have any influence upon the disease, yet all authorities agree that it is largely disseminated by well and other waters liable to contamination at low water epochs. Typhoid fever is always more rife while the waters are rising in the ground than when they begin to diminish. In the first great epidemic of fever in Croydon, in the autumn of 1852, which occurred with a very rapid rise of the subsoil water after being remarkably low, and after the artificial lowering of the water to which I have already referred, it is established beyond doubt that the waters in this district in the year 1852 had been remarkably low. In the 20th Volume of the Proceedings of the Institution of Civil Engineers, page 199, attention is drawn to the fact that in this particular year the supply of water in the River Wandle (one branch of which rises at Croydon) was so deficient, that the mills were compelled to be shut down three hours out of every 12 hours, and then there was still a deficiency of water. The low water periods which occurred in 1854 are well authenticated, for this particular year was an universally low water year. In 1858 there was another low water period, not so low as the year 1854. In 1865 and 1866 there was a further epidemic of typhoid. Preceding this epidemic the Croydon branch of the River Wandle was known to have been absolutely dry, and 1875 and 1876 was the last great epidemic, when again it was reported that the Croydon branch of the River Wandle was again dry, and since that period no such degree of lowness of the springs has been experienced at Croydon, and the sanitary works erected since that period have, in my judgment, added much to the sanitary condition of this place.

I must now direct your attention to the distribution of the cases of fever which occurred in the last epidemic at Croydon, and will compare them with the conditions which accompanied the epidemic of typhoid fever in Paris in 1882. Dr. Buchanan, in his report upon the outbreak of typhoid fever in Croydon in 1875, gives the distribution of cases throughout each month of that year. The epidemic, however, continued through 1876. The figures of 1875 show that there were two periods within that year when the disease was at its greatest intensity, namely, in April—a most unusual period—and in October, the disease occurring in the spring of 1875 at a much later period than the ground waters ordinarily commence to rise. The cause of this outburst at this period of the year is clearly shown, as it occurred on the rise of the ground water, which was delayed to the period when the disease eventually occurred, as is shown by the records of the state of the ground water within the higher portions of the Croydon drainage area, and which show that after a very low water period the waters began to rise in November 1874, and were rising up to March 1875, when they fell, rose slightly in June, and fell again and rose again between September and October; there was a fall in November and a rise again in December. The following table shows the height of the water in the well at Caterham Lunatic Asylum, located near the head of the Croydon Drainage Area, at the dates given, together with the number of cases of fever occurring in 1875 and the deaths from fever in the three last months of 1874, through 1875 and the four first months of 1876.

WATER LEVELS IN WELL AT LUNATIC ASYLUM, CATERHAM AND FEVER IN CROYDON.

Year.	Date.	Level of Water Ordance Datum.	Date.	Reported cases of Fever in Months.	Deaths from Fever at Croydon.
1874	23 October	228·03	October	No record.	—
	5 November ..	232·53	November	,,	—
	5 December....	238·53	Dacember	,,	1
1875	2 January .. .	260·53	January.....	15	1
	1 February	287·53	February	53	1
	2 Mtrch	200·03	March	79	4
	1 April.....	295·53	April	186	13
	1 May	276·03	May	39	10
	1 June	280·03	June	30	8
	1 July	268·03	July	18	4
	1 August	264·03	August	32	3
	2 September ..	260·03	September	69	5
	2 October	261·03	October	175	15
	5 November ..	257·03	November.....	92	19
	1 December....	288·03	December	71	6
1876	1 January	290·53	January	No record.	10
	1 February	291·03	February	,,	9
	1 March	294·03	March	,,	8
	1 April.....	312·03	April	,,	2
	2May	304·03	May	,,	—

It should be noted that the water in Croydon itself, which is some miles lower down the valley, would not ordinarily begin to rise until a later period than the waters in this particular well.

In Paris, in 1882, an exactly similar state of things occurred ; the epidemic of fever broke out, as shown by the records published by the late M. Durant Claye, C.E., after a slight rise in the ground water. All the outbreaks of typhoid fever which have been investigated in this country have occurred under similar conditions. As a notable example, the outbreak which occurred at Terling, a village having a population of about 900 persons, in which, between November 1867 and the 13th January 1868, there were 208 cases of typhoid fever. It is mentioned by Dr. Thorne, who inquired into this epidemic, that all the wells in this village had become dry previous to the outbreak of fever, and the disease made its appearance at a time corresponding with the first replenishment of the water in the wells, after being so exceptionally low. Since 1868 numerous recorded epidemics of typhoid fever have occurred, accompanied by exactly the same circumstances as regards the state of the ground water.

There has been a considerable amount of evidence collected in Paris, and also in this country, that outbreaks of typhoid fever can be traced to particular dates of heavy rainfall, clearly establishing the fact that rainfall is associated with these epidemics, and, consequently, we are not surprised to find that often there exists a parallelism between rainfall and typhoid fever. In judging, however, of the effects of rain upon the subsoil, the direct measurement of a well will not give, as a rule, the first indication of the commencement of water percolating through the ground, for the simple reason that if the quantity passing through is very small, it has no appreciable effect upon the height of the water in the ground itself, for the ground water is like a reservoir that at certain periods receives water, but it is also flowing out of it and no increase will be visible in the store until the rate of supply exceeds the rate of exhaustion. When, however, we do perceive there is a check in the rise of the waters, or they become stationary, we may conclude that percolation

has commenced. It may also be a matter of considerable importance to note that in all the epidemics of fever which have occurred in Croydon the universal testimony has been that women and children and teetotalers suffer the most, and in Dr. Buchanan's report on the last epidemic of fever it is shown that out of every 1,000 houses in that part of the district supplied with water taken direct from the ground, 104 were invaded by the disease, but in the district outside this area, containing at least a fourth of the whole population of the place, only 7 per 1,000 were attacked. The significance of these facts ought not to be without its warning to all who are answerable for the public water supplies of our country.

Diphtheria.

Diphtheria, according to a communication made at the last International Conference on Hygiene at Berlin, like typhoid fever, is propagated by excremental poisoning of the ground, and we know it is disseminated almost in the same way as typhoid fever. We know that it follows typhoid fever in parallel lines, but it requires the very opposite conditions which are necessary for its development that occur in typhoid fever and small pox. A damp state of the ground marked by extreme sensitiveness to percolation of rain is the condition which is essential to the development of diphtheria. With typhoid, a dry ground is essential to development, as we approach one or other or both these conditions, so typhoid or diphtheria supervene. It follows in its incidence typhoid, and occurs in the percolation periods. In this country, diphtheria has not been separately registered until recent periods, for some years it was registered as a type of scarlet fever; we have no record in Croydon of its existence before 1849. In 1858, however, it became to be recorded with some degree of regularity. During the whole of the last 5 years the ground at Croydon has been in a continual state of dampness, as indicated by the records of the percolation gauges, and during the whole of that period diphtheria has been more or less rife, and generally increasing throughout the country.

Scorlet Fever.

Scarlet Fever follows the state of the dryness of the ground, which is essential for its development, and it occurs in the percolation period. The conditions that precede small pox are those favourable for the development of this disease. Hence it is most rife in the years preceding small pox. Like small pox the dampness of the ground for any considerable period in any particular locality may check its development, or render it less virulent, and it is most rife in low water years.

Measles.

It is curious to note with reference to this disease that in Croydon it apparently follows the opposite law to that of typhoid fever in the years in which there have been epidemics of typhoid fever, as in 1852, 1864, and in 1875; when the conditions were favourable to the development of typhoid, there were no deaths, or very few, from measles. This disorder is least prevalent at the low water periods, and is mostly rife at and near high water periods. In this respect it follows the same course as small pox, and as a rule measles is most rife in a year following a low water year, especially when it happens to be also a low water year.

Whooping Cough.

Dampness of the ground is an essential condition to the development of whooping cough. It is a disease which causes a large number of deaths, and has been particularly rife during the past five years, during which time there has been a marked dampness of the ground. It destroys, in Croydon, three times as many persons as small pox, and it is most rife and fatal in all those years when small pox is absent. It follows the percolation period in

its incidence, increasing with percolation and diminishing as the waters in the ground subside.

Diarrhœa.

It is generally supposed that diarrhœa is almost entirely influenced by high temperature. There is no doubt whatever that high temperature has a marked influence in the development and spread of this disease, but by comparing the records of any particular years with the temperature, it must be observed that there are other influences also at work, and it is found that diarrhœa is generally more prevalent in a low water year than in other years, that is with a very much colder temperature in a low water year we get a very much higher death rate from this disease. For example, in Croydon in 1854, which is a very marked low water period throughout the country, the average temperature for June, July and August was 59°·4. In the following year, the temperature of the same months was 61°·1. In 1854, the deaths were over five times as numerous from this disease as those which occurred in the warmer year, very clearly establishing the fact that diarrhœa, influcened as it is by high temperature, is also amenable to the conditions which produce low ground water, and that the organic changes which take place at such periods in the ground affect all sources of water supply, the temperature of which, rather than the season, governs the course of diarrhœa.

Deaths of Children.

Whatever errors may exist as to the cause of death amongst children, there can be no doubt as to the ages at which children die. In comparing the deaths of children under 5 years of age with the state of the ground water, it is found that there is in Croydon an exact parallelism between the state of the ground water and the death rate of such children.

General Death Rate.

It should also be noted that the general death rate of a district is amenable to the state of the ground water, being influenced like the deaths of children, but in a less marked degree, yet, nevertheless, years of drought and low water are always found to be the most unhealthy.

In concluding this subject, I desire to impress upon you that the health of communities is influenced by the sanitary condition under which they live, and diseases of a virulent type are producible by very opposite climatic conditions, but are always most rife and most fatal in those districts in which there is the greatest chance of the ground being polluted. It is essential for the conditions of a healthy life that the soil upon which we reside should be freed from every chance of pollution, and every step should be taken with this view. It is also important in studying the causation of disease, that very much more attention should be paid to matters referring to the hydrometry of the soil. I should like to see a considerable extension made in the establishment of percolating gauges, and that all Meteorological Observatories should possess such an instrument.

It is also essential in the study of the cause of disease that the registers of sickness, which are now required to be taken in many of our towns, should be published in ample form every year by the same authority, and should be available for the use of all investigators. I trust that what I have said may be of some interest, and will be the means of getting enlisted into our ranks a larger number of observers, particularly those who can devote their time to the elucidation of the various meteorological conditions which affect the health of the people.