WATER

AND

WATER SUPPLY.

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PREFACE

TO

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The first edition of the abstract of these Lectures appeared in Van Nostrand's Engineering Magazine in 1875, and subsequently were incorporated in the Science Series, for the reason that at that time there was a demand for monographs on this special subject, the literature at that period being somewhat scanty.

The original Lectures were delivered at the School of Military Engineering, Chatham, England, in the autumn session of 1873, and were subsequently printed for private circulation, and attracted by their clearness and conciseness in detail, a very wide attention.

The principal point in view by Prof. Corfield was public health, and in this respect he did not enter into engineering matters to any great extent, not more so than the subject absolutely required, but he went very thoroughly over the whole ground, treating it in a practical, common-sense view. For these reasons, and from the fact that a very great many publications bearing upon this subject have appeared since these Lectures were printed, it has been deemed advisable, as the publishers desire to keep the different numbers of this Series available to the public, to reprint this particular one without change or addition, the fact being that comparatively little if any changes or additions could add to the permanent value of the matter presented in these pages. The Lecture form has been preserved throughout. Prof. Corfield's further Lectures on "Sewerage and Sewage Utilization" form No. 18 of this Series.

W. H. F.

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WATER AND WATER SUPPLY.

It will be our purpose to discuss, in the first place, the sources and the kind of water that are required for large communities—the kind in the first place, the quantity in the next, the places to get it in the third, and then the ways to convey it to the community.

It is only one part of the fuel of a community that we have to consider. We shall then consider what are the wastes from a large community, and whether, although useless for the purpose for which the original fuel was supplied, they can be made useful for other purposes, and if so, how? Whether again there is any necessity of getting rid of them, and if so, how this can be done most effectually, and most cheaply, and without prejudice to other communities.

Now then as regards water. Water is required in a large community for a great variety of uses. These uses were divided by the Romans, and they have been divided ever since, into public and private uses. The public uses are such as for cleaning streets, extinguishing fires, for fountains, for public baths, and so on. The private uses are for drinking, washing, cooking, etc. Thus water you see at once from the mere examination of its uses comes to the community to be soiled. It comes in order that the community may be supplied with one of the necessities of life. It comes to wash communities, places, and habitations. It comes, I repeat, to be soiled. It is, therefore, generally, when soiled, useless for the purpose it was originally wanted for. It has either to be purified or got rid of. A community requires pure water for some purposes, and those are especially for drinking and cooking. Pure water

—I do not mean chemically pure, but we shall see directly what is meant hygienically by pure water—is not necessary for every purpose, such as for washing the streets, extinguishing fires, etc. However, practically speaking, only one kind of water can, as a rule, be supplied to a community, and so it becomes necessary for us to know where we can get this sufficient supply of water of a certain quality, viz., sufficiently good for drinking.

Now, roughly speaking, a drinking water should be, in the first place, transparent. In the second place, it should be transparent to white light; that is to say, it should be transparent and without color. It must be without taste and without smell, and it must deposit no sediment on standing, and have no particles suspended in it. Those are the rough qualities of water which anybody can examine for himself; the best way to look at it is to look through about a foot or 18 inches of it in a long glass cylinder, placed on a piece of white paper. It must be aerated to be fit for drinking, and cool. Now, if the water you are examining does not fulfill these conditions, it must be rejected at once, or brought to satisfy them. We have to consider how these conditions are to be fulfilled, and we ought to satisfy them on a large scale. But a water may comply with all these conditions, and yet not be a safe water to drink. It may contain substances which you cannot tell in any of these ways, and, practically speaking, all waters do. Substances whether in solution or suspension may be hurtful, or they may be harmless; and now I want to tell you how, if you have a chemical analysis of a sample of water before you, you can tell whether that water is suitable for your purpose or not. That is a thing you do not generally find in engineering books. It is necessary for you to know it, because if a report is brought up upon a particular water, you ought to be able to know whether that will be a satisfactory water or not.

Natural waters contain dissolved (in

the first place especially) carbonic acid gas. They contain all the constituents of air in solution, but the gases are not in the proportion in which they are in atmospheric air. There is often a great quantity of carbonic acid gas, and oxygen, being more soluble than nitrogen, is generally in larger proportion than in atmospheric air. Now the carbonic acid gas is the one that I am going to speak of first. Water containing carbonic acid in solution has the property of holding in solution quantities of certain salts that it would not dissolve otherwise, or only in much smaller quantities, and the chief of these is carbonate of lime. Natural waters often contain, then, in the first place, salts of lime, especially the carbonate, dissolved in carbonic acid. They contain often the sulphates of lime, soda, magnesia, iron, and so on—in fact, different salts of these and other bases. Phosphates they all contain, and also chlorides and nitrates. All natural waters contain the latter in certain proportions—even rain water. Almost all of them contain salts of ammonia. The question arises which of these may be allowed in water, and which may not, or which, at any rate, may not be allowed above a certain quantity, and what is the quantity? Beyond those simple characters for pure water which I gave you a few minutes ago, there is a property of natural waters which can be easily ascertained by any one, and which constitutes one of the best known differences between various specimens of water, and that is the quality of hardness. What does that mean? Hardness is tested in this way. Pure water dissolves soap, which is a combination of soda with some of the fatty acids. Pure water dissolves soap perfectly and forms a lather at once. Now water containing certain salts in solution, and notably salts of lime, magnesia, and iron, does not do so, because these salts form insoluble precipitates with the soap. That is what is meant by the water being hard. If a water, instead of lathering with soap immediately, takes a great deal of trouble to make a lather, does not do it till after some time, and causes a curdy precipitate, then it is a hard water. That is, of course, a very rough way of putting it; but the amount of soap that is required before a water will lather, gives a test of the amount of salts which cause the hardness of the water, and the chemist takes a standard solution of soap and tries how much of this solution is required before he can get a lather with water, and he says that the water has so many degrees of hardness. What is meant by a degree of hardness? That each gallon of the water contains in solution an amount of salts which will precipitate as much soap as a grain of carbonate of lime would precipitate. What is the importance of this? Hard water is as a general rule less wholesome than soft, and often much less so, it is not so good for household purposes, nor for use in engines, and it entails an enormous waste of soap. It is therefore objectionable, even if the hardness is caused by the presence of harmless salts. The total amount of hardness, the degree of hardness of a water before anything is done to it, is called the "total hardness," and if the total hardness of a water is greater than six degrees on what is called "Clark's Scale" (the value of a degree of which I have already explained) it is called a hard water; if less, it is known as a soft water. Now hard water (supposing you have only got hard water, and cannot get a supply of soft water) is made softer, in the first place, by boiling. That can be done on a small scale. If you boil hard water, of course the carbonic acid is driven off, and the salts held in solution by it, especially carbonate of lime, are precipitated. There is another way of rendering hard water soft, and this can be applied on a large scale; it is known as "Clark's process." The carbonate of lime is held in solution in the water by carbonic acid; you can precipitate it by boiling, or prevent its being held in solution by causing the carbonic acid to combine with something else, as with more lime, and Clark's process, which is now used on an extensive scale (and ought to be used very much more than it is) consists in adding to the hard water milk of lime. This milk of lime combines with the excess of carbonic acid, forming carbonate of lime, which falls down as precipitate together with the carbonate of lime that was previously held in solution, thus leaving the water softer. If you boil water, and then determine the hardness that remains, that is called the "permanent hardness"; an extremely important matter. The importance of it consists in this, that it cannot be removed at any rate on a large scale, and, in the second place, that it is due to salts several of which are injurious, so that a large degree of permanent hardness indicates a bad water. Now this permanent hardness (the hardness that is lost by boiling is called "temporary hardness") is due chiefly to the sulphate of lime and chloride of calcium, and to magnesian salts. These are all objectionable in a water. Let me give you some examples of degrees of hardness of various specimens of water so as to give you a definite idea of hardness.

The hardness of the Thames water above London is 14 degrees of Clark's scale. That is a hard water. The hardness of the New River water is 15½ degrees. That, too, is a hard water. The water of Bala Lake has only ¼ of a degree of hardness, and of course that is an exceedingly soft water. I must tell you before going on that it is now very usual to express hardness in another way. That is to say, instead of saying so many grains per gallon, as is done in Clark's scale, hardness is now very generally expressed by parts in 100,000, and I mention this at once, because the results of most of the analyses that we shall have to refer to during the lectures are given in parts per 100,000. Of course, if you are given the hardness of water in parts per 100,000, you can convert it into degress of hardness in Clark's scale by multiplying by seven and dividing by ten, because Clark's scale gives the resul s in grains per gallon; a grain per gallon is one part in 70,000. On this new scale, as an example, the hardness for the last week of last year of the five Thames companies was about 20 degrees, that is to say, about 14 degrees by Clark's scale.

The hardness, again, of the water supply which is derived from deep borings in the chalk was 29.4 on this scale, or 20.58 of Clark's scale. Of course that is a very hard water indeed. But the hardness of these two waters is quite different, because the permanent hardness of Kent water is very little indeed. The total hardness of that water is almost entirely due to the carbonate of lime, whereas, much of the hardness of the water supply to London by the Thames companies is due to salts other than carbonates, especially to sulphates. Therefore, you get much information about the quality of water by its hardness. If you know water has a high degree of permanent hardness, you know it has a very good chance of being a bad water. It contains probably sulphate of lime and chloride of calcium, and perhaps magnesian salts. The latter are especially objectionable to water, and any water which gives even a small amount of salts of magnesia is to be rejected. Water containing these salts causes diarrhœa when drunk, and it appears to be from the presence of these salts in drinking waters that the swelling of the neck known as *goitre* is produced in Switzerland and other countries.

The next thing to which I wish to draw your attention with regard to substances dissolved in water, is, the amount of chlorides that may be present. I may say broadly, that if you see in a report on the quality of a water that it contains much chlorine, or much common salt (chloride of sodium), you may at once put it down as a suspicious water, and you will see why in a minute. Where do you get chlorides in a water? They may come from an infiltration from the sea. They may come again from strata containing a quantity of common salt.

But another source of chlorides in a water is pollution by sewage. All sewage contains a considerable proportion of common salt. This is one of the necessities of life, it is contained in many of our foods, and in excretal matters, especially in the urine, and so sewage contains it. The average amount in the sewage of water-closeted towns is ten parts of chlorine in the 100,000. Pure natural waters contain less than a grain of chlorine in a gallon, or about 1 part in 100,000. So, if in a sample of water for which you get the analysis sent, you see more than a grain in a gallon of chlorides, you must at once know the reason why. London drinking water contains 2 parts in 100,000. That is not very bad water, and as it is got from the Thames we know that it has been polluted by sewage. The water derived from the chalk—the Kent water—actually contains more than that, but we have a very good reason for not objecting to it on that account, inasmuch as we know that it is not rendered impure by sewage. The well waters of London mostly contain more chlorine than sewage; they are, in fact, a concentrated form of sewage which has gone through certain alterations. I am not here alluding to the Artesian Wells, but only to those which are supplied by the subsoil water above the London clay. The amount of chlorine is a very good test of the purity of a water, except that you must always allow for the possibility of chlorides being present in the soil through which that water has gone.

Nitrates and nitrites are given you in the Registrar General's Reports as the test for what is called "*previous sewage contamination.*" What does that mean? It means that the nitrates, etc., that are dissolved in water come in a great majority of cases (if not in all) from the oxydation of organic matter at some time or other, or in some place. Now to show you how plain it is that water must not be rejected merely because it contains nitrates, I must tell you that there are nitrates and nitrites in all waters, even in small quantities in rain water. What amount of nitrates may be found in water without giving a suspicion of previous contamination? Allowing that they are not injurious in themselves, yet, inasmuch as they at once make you suspect that the water containing them in solution has, at some time or other, been contaminated with organic matters to a large extent, which organic matters have been oxydized, the result being the production of nitrates and nitrites—inasmuch as that is the case, if you get much nitrates, etc., represented in a water, you must at once see if that water is derived from a source where it is likely to get contaminated with refuse matters; because if it is, although the nitrates are harmless, and although it is very desirable that these matters should be oxydized to that state, still you are always liable to its happening some day that the water is contaminated by the solution of these organic matters in their crude unoxydized form, in which case they are very often, if not always, dangerous. Let us see what amount of nitrates is found in various waters. In the drinking water we get in London from the Thames there are about 2 parts in a million (or 0.2 in 100,000). In the New River Water (North London water) a little more than 3 parts; and in the Kent water 4 parts in a million, so that the deep chalk waters (which we know must be very pure) contain more nitrates than the others do, a sufficient proof that the presence of nitrates is not of itself a sufficient reason for rejecting a water. The waters from the Cumberland Lakes contain very much less. To give you an example of a water containing a great deal, I may cite the instance of a well at Liverpool which was found to contain more than 8 parts in 100,000 of nitrates and nitrites, which were all derived (or in all probability derived) from the oxydation of sewage that had traversed the ground round that well. If nitrates be present in large quantities it must be regarded as a suspicious circumstance, unless you have good reason to know that the water comes from a source which is beyond the suspicion of contamination. There are quantities of nitrates in many soils. The presence of nitrates in water got from such soils would not justify you in having the water condemned as a source of supply if there were no other reason.

Salts of ammonia. These, too, are contained in natural waters in exceedingly small quantities. They do no particular harm in themselves, but they frequently come directly from sewage. The numbers in a drinking water representing salts of ammonia ought to be in the third place of decimals for parts in 100,000, or, if in the second place of decimals, ought to be small. Now the water supply of London, filtered Thames water, contains .001 to .005 parts in 100,000. That is pretty good. The water at Bala Lake contains .001 parts, and rain water contains the same amount; so that we may expect salts of ammonia to be contained in all natural waters. Sewage contains about 6 parts in 100,000. Well water often contains large quantities, four parts, for instance; the pump water in London contains nearly one part in 100,000, and the water of the Thames at London Bridge 0.1 part in 100,000; these are all bad waters, so that when you see ammonia mentioned in an analysis of water in greater quantity than is represented on the second place of decimals in parts per 100,000, you may always safely condemn it, for on looking further you will find what I am now going to speak of, namely, organic matters.

Now the actual organic matters present in a water may be in suspension or solution. If there are organic matters in suspension a water may be safely condemned, because they may even by agitation pass into solution, and so the fact of your trying to separate them may cause more of them to get into solution. Organic matters you will find in analysis represented in two different ways. In one, as, for instance, in the analysis given by the Registrar General, you will find organic matters represented in this way:

so much organic carbon, and so much organic nitrogen in the 100,000, and the Rivers Pollution Commissioners have given this as a standard, not of drinking water, but of a water that shall be considered to pollute any watercourse to which it is turned. Two parts of organic carbon in 100,000 or 3 parts of organic nitrogen in 100,000. What does the London drinking water contain again? From 3 to 4 in 100,000 of organic carbon and about .05 of organic nitrogen. Now we shall see at once the difference between drinking water derived from such a source as the Thames and filtered, and drinking water derived by boring into deep strata—into the chalk. The chalk water only contains .06, that is the fifth of the quantity of organic carbon, and .01, a fifth of the quantity of organic nitrogen that the water supplied by the Thames Companies contains; so that when you come to organic matters, you see the difference at once between a water that is derived from a pure source, and one from an impure. The other method that I have to mention to you, which is used for expressing the amount of organic matters in water, is called "Wanklyn's method,"* from the chemist who discovered it. This method consists in the conversion of the nitrogen contained in the organic matter in the water, or a considerable part of it, into ammonia, and then it is estimated as so much ammonia. I dare say you all know that the test that chemists have for ammonia is perhaps the most delicate test with which we are acquainted. This ammonia you will see mentioned in the records of analysis as "albuminoid ammonia," and to a certain extent it does represent the amount of organic matter in the water. This albuminoid ammonia in a drinking water must not be allowed to be above the third place of decimals. If it appears higher than the third place of decimals in parts of 100,000, if in the second place, or if in the first, it is bad. If in the first place it is decidedly bad water, and con-

* See Wanklyn's Water Analysis.

tains a considerable amount of organic matter in a state of solution. You may consider that the albuminoid ammonia represents about ten times its weight of dry organic matter, and about forty times its weight of moist organic matter. So that .05 of albuminoid ammonia in 100,-000 represents about 2 parts of moist organic matter in the water. You see that, when you have an analysis of water before you, you must consider the different things together. The nitrates help to condemn a water with much organic matter in it. The ammonia does the same, and the chlorides especially so, and chlorides are to be regarded as a suspicious indication in water, if you have not good reason to suppose that they come from some other source than the one I have indicated. The danger of organic matter in drinking water consists in this fact (of course organic matters are necessary to us for our food, and it is not the mere fact of its being organic matter that renders it dangerous,) that it is organic matter in a state of rapid change, in a state of putrefactive change; and then that it may contain and often does contain (especially if it is derived from excremental matter) the poison of specific diseases, which may be distributed in the drinking water to a population and cause an outbreak of cholera, typhoid fever, etc. We know now what sort of water must be got for drinking. The above are its characteristics, and the water supply must either comply with these conditions, or be made to do so artificially.

Now how much of it is wanted? You can look at this in two ways. You can get to know by experience how much bodies of men and towns always have wanted. The amount, of course, varies immensely with the use of baths, whether they are public baths or not, with the amount used for washing the streets, and for manufactures, and also with the amount of waste, because that is a very important item. Now, for washing, drinking, and domestic purposes generally, you may put it down (if there is reasonable amount of bathing) at about ten gallons a head a day, and then you must add nine or ten more for flushing the sewers and washing the streets. Much of this will be added through the water-closets. Thus you may say 20 gallons a day without waste may be taken as a kind of average. For trades you must allow 10 gallons more as a rule. If there are public baths, and where there are many animals, as horses, which require about 12 or 15 gallons a head for washing and drinking, you must make a greater allowance. You will see that about 30 gallons a head a day is the least, even where there is no extra demand, and that is about the amount provided in London, and that is about the least that you should aim at. Professor Rankine tells you that 35 gallons is the greatest amount necessary. However, they don't think so everywhere. New York manages to get through 300 gallons, and does not find it too much. In ancient Rome (to show you that these matters have been thought of a long time ago) they had nine aqueducts to bring water to the city. They thought it of so much importance that several of these aqueducts were from 42 to 49 miles long, and one of them, the Marcian, was 54 miles long. Frontinus, who was the superintendent, and who wrote a most excellent work about them, giving accurate descriptions and measurements of them, tells us the two most recent were made because the seven already in existence "seemed scarcely sufficient for public purposes and private amusements." Now the sectional area of the water supply to Rome by these aqueducts was 1,120 square feet, and it is pretty sure that there were not more than 332,000,000 gallons daily brought to Rome by them. I suppose there were not more than a million people; that gives you about 332 gallons a day that they found necessary.*

Now, let me give you one or two

* Mr. James Parker on the "Water Supply of Rome."

points about the measurement of water that you will find useful. The measurement of water you will often find given in cubic meters. A cubic meter is $35\frac{1}{3}$ cubic feet, or 220 gallons. That is to say, a cubic meter of water is 220 gallons, and as a ton of water contains 224 gallons, a cubic meter of water is almost exactly equal to a ton by weight (or tun by measure). A cubic foot is rather more than 6 gallons, and 100 gallons are just about 16 cubic feet. Let me just give you an example of this. London, during December, 1872, was supplied daily with 100 millions, nine hundred thousand, and something odd, gallons of water. That is to say 458,577 cubic meters, or about the same amount of *tons* by weight or *tuns* by measure; that is, 201.8 gallons to each house, or rather less than a cubic meter to each house, and 28.4 gallons to each person. I told you it was 30. Well, it varies a little. It is a little under 30 very often. Of the total amount of water supplied to a place, you may take it as a general rule that 80 or 82 per cent. is required for domestic purposes, so that during that month of December in London there were about 23⅓ gallons used for domestic purposes. Hence the conclusion about the quantity is, that the least you must endeavor to get is 30 gallons a head a day without any very extra demands. Of this about 80 per cent. will be required for domestic and the rest for public purposes.

So much for the quality of drinking water, and the quantity to be supplied. We have now to go on to consider the places where water of this quality and in sufficient quantity can be procured. The main sources of water are rain, and the sources that are subordinate to rainfall—wells, springs, streams and rivers. Some other sources which are used occasionally, and which are of very little use for a great supply, are such as the dew, ice, snow and distilled water. These latter we may dismiss with a word or two, as only of exceptional utility. Dew has been used in deserts and at sea. Ice and snow furnish enormous quantities of water in certain places where they abound. Ice furnishes an exceptionally pure water, because in freezing the salts are separated out, and the gases too; such water, therefore, requires aeration. Snow and ice if used should not be collected near to dwellings, because of the risk of contamination. Distilled water is an important water supply now, especially at sea. Its chief fault is that it requires aeration. To give it this, Normandy's apparatus may be used, or it may be allowed to fall from one vessel to another like a shower. It has been said that cases of lead poisoning have occurred at sea "partly from the use of *minium* in the apparatus, and partly from the use of *zinc pipes* containing lead in their composition." (Dr. Parkes.) So much for the subordinate sources, which are all of little importance to us.

We now come to rain, which is the original source of all great supplies. Rain, which we are going to consider, is, of course, caused by the fact that, when two air currents come together, both saturated with moisture, one having a lower temperature than another, the mixed air, though it has a mean temperature, has not the mean capacity for water, but a capacity less than the mean, and so some of it falls as rain. Is rain, as it falls, sufficiently pure to be used as a source of drinking water? In the first place it is very soft. In the second place it is well aerated. It dissolves especially carbonic acid and oxygen from the air—the former being about three per cent. of the total dissolved gases and the latter from 30 to 40 per cent. It contains nitrates and nitrites, especially during thunder storms. It contains salts of ammonia, which render it more alkaline when collected in the country. Near towns it contains most of the impurities that are found in the air of towns, and especially it becomes acid instead of alkaline, absorbing a large amount of the sulphuric acid that is in the air. It contains organic matter, and this in increased amount near towns. Rain half a mile from the extreme southwest of Manchester, although the wind was blowing from the west, tasted flat, insipid, oily and nauseous—deposited organic matters, and even organized bodies in considerable quantities, and left a clear water above, containing more than two grains of organic matter in the gallon. Dr. Angus Smith, who examined this water, makes the following remarks: "It becomes clear from the experiments, that rain-water in town districts, even a few miles distant from a town, is not a pure water for drinking; and that if it could be got direct from the clouds in large quantities, we must still resort to collecting it on the ground in order to get it pure. The impurities of rain are completely removed by filtration through the soil; when that is done there is no more nauseous taste of oil or of soot, and it becomes perfectly transparent." He is therefore of opinion that rain collected directly from the air cannot, at any rate near to towns, afford a proper water supply. However, since rain is he source of all the supplies that we get, it becomes necessary, and of great importance in estimating the amount of water that can be got in a district, to measure the rain-fall of that district. Now the depth of the rain-fall of a district has extraordinary varieties, both as to place and time. For instance, as regards time, the tropical rain-fall is almost all at one part of the year. With us it is variable. The rain-fall is measured in England by its depth in inches. The rain-fall is greater in mountainous districts, and on the leeward side of mountains, if they are not high enough to penetrate the clouds; but if they are, it is on the windward side, because the clouds do not get over the tops of the mountains. Now, for the supply of water, the important points to be known about the rain-fall are these: The first is the least amount of rain that has ever been known to fall in a year in a district; the minimum annual fall. Then it is important to know the distribution of the rain throughout the year, and especially the longest drought, because you have got to provide for that time as well as for any other time, and the observations on the rain-fall of a district should extend over not less than 20 years. Of course it is not often that you can get observations at any locality that have been maintained for 20 years, and so we shall have to consider in an instant or two how we are to get over that difficulty.

The machine used for measuring the depth of rain-fall is called a rain gauge. It is essentially a funnel, the area of the top of which is known very accurately. The top of this funnel is provided with a vertical rim to catch the splashings, so that none may be lost. Below the funnel there is a glass vessel placed to receive the water. The height of the water in it may be indicated by a float, or its quantity may be ascertained at given intervals of time by measuring or weighing it, and that is the best plan. Of course the number of cubic inches of water, which is the same as the number of square inches of the area of the funnel, gives you one inch of rain over that area. Suppose the area of your funnel is 20 square inches, 20 cubic inches of water will obviously be the result of one inch of rain-fall over that 20 inches. It is most convenient to measure the water, and the measuring glass is constructed in the following way: At the place where that amount of cubic inches of water stands which is equal to the number of square inches in the area of your funnel a line is drawn, and this represents one inch of rain-fall. If the area of your funnel is 20 square inches, then you take 20 cubic inches of water which you have weighed or measured accurately, place it in your glass vessel and mark *one* at the level where it stands, because that amount is equal to a depth of one inch of water over the area you are observing. One cubic inch of water weighs 252½ grains, almost exactly. That one inch is divided into tenths and hundredths; and with this vessel you are able to measure the amount of rain that has fallen through the funnel in a given time. The top of the gauge must be placed nearly level with the ground; the instrument must, in fact, be sunk. It must be placed in an open situation, and a fence put around it if necessary. One is very frequently placed at a height above the ground, and one on the ground, to show the difference in the amount of rain that falls at the two levels. The amount of rain that falls at the level of the ground (leaving hills out of the question) is always greater than the amount that falls at any height above the ground. If you have got records of the rain-fall of a district for a considerable number of years your work is to a great extent done, because then you have merely to take out the facts that you want. If you have not, the only way to do it (with a limited time) is to place rain gauges at convenient situations, and as many as possible all over the district you are examining, and if there are any hills in or near the district some of them ought to be placed on their tops, and each of these rain gauges ought to be carefully and regularly examined at certain fixed times. Then you must compare the records of all these gauges with the results given by the nearest rain gauge that has been observed for a considerable number of years, to get a kind of relation between the rain that falls at these different stations on your district, and the rain that falls at the nearest place from which you can get any reliable data, and from this comparison you must calculate what will probably be the longest drought in your district, and what is probably the least annual rain-fall. Now, the average in different parts of England is from 22 inches to 100, or even 120 per annum; in some countries, as Burmah, 180 to 220, and it is even said to be as much as 600 inches in one place. This useful rule was given by Mr. Hawkesley (and certainly the tables show that it is a very accurate rule) that if you take the average rain-fall of a place for 20 years, and subtract a sixth from it, that will give you the average annual rain-fall of the three driest years during that period. If you take the average annual rain-fall for 20 years, and take a third part from it, that will give you the amount of rain in the driest year of these 20 almost exactly, and if you take the average of 20 years, and add a third to it, then that will give you pretty nearly the amount of rain in the wettest year.

So you get with a considerable amount of accuracy the quantity of rain; the least amount of rain you are likely to get, and the greatest as well. Then, of course, you want to know the area of the district, and besides the actual amount of the rain-fall, you must also know the amount which is available. In the first place, a great deal of the rain-fall is lost by evaporation and absorption. Evaporation from the surface, and absorption by plants, etc. Then, if the ground is very porous to a great depth, a considerable amount will be absorbed so fast that you cannot collect it. Most of the rain-fall is at once available from or near the surface in steep countries, and especially those which are formed of primitive and metamorphic rocks, as granite, clay-slate, etc., and generally from impervious rocks that are steep-sided. Almost all the rain-fall in these cases is available at once. It runs off the surface and collects in lakes, and is available directly. And then, on hilly pasture lands in limestone and sandstone regions, something like two-thirds of the rain may be considered available, and on flat pasture countries something like one-half. For instance, on the green sand, Mr. Prestwich estimated that from 36 to 60 per cent. is available. On chalk and loose sand there is very little indeed available.

Now one of the most important things, if *not* the most important thing to know, is the geological character of the rocks of the district you are examining, because that will tell you a very great deal about the amount of available water, and about the way to get it. We are told that in chalk countries the rivers and streams carry off at once about a fifth of the rain-fall; that the evaporation and absorption by vegetables and animals amounts to as much as a third, and that the remainder (*i. e.*, the greater part of the total rain-fall) sinks into the ground. In less absorbent strata you may put down that it is about equally divided—that one-third is carried off by the streams, etc.; another third absorbed by plants and animals, or lost by evaporation, while a third sinks into the ground.

Well now, let us consider what means have been taken to get at this water that sinks into the ground. Of course it is got at by digging down, and now we must consider in what strata we are likely to be successful in digging wells or making borings to get underground water. In the first place, wells in sands lying over impervious strata, over clays especially, if they are not deep, do not, as a rule, afford much water. They may, however, afford a fair supply as to quantity, but very often afford a bad supply as to quality. For instance, the wells sunk into the sands and gravels over the London clays afford a very impure water. If water of this description has come directly from the surface, and especially in the neighborhood of towns, it is contaminated in all sorts of ways. The water in these wells never overflows or spouts up. Wells, on the other hand, sunk through impervious strata to pervious ones below, generally, though not always, supply excellent water. At any rate, they have much greater chance of supplying excellent water, because they supply the water that has come from the high grounds at a considerable distance. For instance, the borings that are made through the London clay down to the chalk, supply some of the best water in London. The Kent water is still better, and is supplied in large quantities by borings which pass through the chalk, through the upper green sand, and through the gault (an inpervious stratum) into the lower green-sand. These wells are known as Artesian wells. The water rises up a considerable height in them, and may overflow. It is often thought that Artesian wells always overflow, but they don't. The water rises up to a certain height, which height is of course determined by several considerations—for instance, by the height it came from originally. Of course the water that you get from under Kent is the water that has fallen upon the outcrop of the green-sand at a very considerable distance round the London basin.

Mr. Prestwich, who has paid the greatest attention to the water supply of London, and to the arrangement of the strata around London, has calculated that, from the lower green-sand underneath the London basin, there is to be got an enormous supply of water for the metropolis, that is to say, on the presumption that this lower green-sand is continuous underneath London. It would not be fair if I did not tell you here that the lower green-sand does not appear to be continuous underneath the London basin. Some of the older strata are brought into contact with the chalk, so that the lower green-sand is missing, probably, underneath a great part of the district. This we know from deep borings which have been made at several places. Of course the chalk and also the green sand are merely instances. You want to know the alternation of the strata right away down the whole geological series, so as to be able to say, if you go into a country and study the maps and sections for a short time, "If we make a well here and bore down, we shall probably go through a band of clay into a pervious stratum, and get a supply of water." You want for this purpose to study the geological maps, and to have ample time to do it. If we go below the chalk into the oolitic series, we have similar alternations of pervious and impervious strata. When we go below this we come to the new red sandstone, and I mention this, because there is an important point connected with it. The new red sandstone is (to a great extent) a pervious stratum. It contains enormous quantities of water, but the caution about it is, that in many countries it holds immense salt deposits. It is in the new red sandstone of Worcestershire (for instance) that the salt deposits of Droitwich are found; so that borings in the new red sandstone (although it is true that some towns are supplied from that stratum), are frequently found to give a brackish water. Below this come the Permian strata, in which you have the magnesian rocks, that I mentioned last time, and it is a mischievous thing to bore into these strata, because you may get water containing large amounts of magnesian salts. Towns which are placed upon these strata are best supplied (like Manchester) from older formations, such as mountain limestone, and so on, which generally afford excellent water. The best supplies are obtained from them, not by boring or by wells, but from springs. There is one thing I must mention, before I leave the wells, and that is, that the sinking of deep wells may lower the level of the water in the country above considerably, and that is a point that has often to be taken into consideration. For instance, Mr. Clutterbuck showed that wells at a considerable distance from London have been seriously affected by the pumping of the green-sand water below London. He showed that the level of the water in these wells was affected so much, that you could tell by the levels of the well waters at a considerable distance from London, whether the pumping had been going on in London on the previous day or not. There is another thing that requires to be known, especially about borings in the chalk, and that is, that some of the borings will give an inexhaustible supply of water, practically speaking, while borings close by will give you next to none. This Mr. Prestwich accounts for, by stating that the water in chalk runs chiefly through crevices, and does not infiltrate through the mass of rock. Before I say a few words to you about the construction of wells, I have something to say about springs, and the amount of water they supply. Now springs occur where you have an impervious stratum cropping out from beneath a pervious one, and this may happen in various ways.

The water in springs, and also that in wells, varies very much in quality according to the place that it is taken from. Spring water differs from rain water in that it has passed through certain rocks, and dissolved more or less considerable quantities of substances on its way. Spring water resembles rain water in containing a considerable amount of carbonic acid in solution. This has the property of dissolving many substances, one of the chief of which is the carbonate of lime. The water then passing through the rocks dissolves carbonate and sulphate of lime, salts of iron, etc. It is important to know this for many reasons. In the first place, some of these waters dissolve, in mountain limestone districts for instance, so much carbonate of lime as to become what is known as petrifying springs. Of course if you take a petrifying spring and bring it along an aqueduct, under certain conditions your supply is stopped up; and one of the aqueducts at Rome is to be seen to this day perfectly closed for a considerable length with a deposit of carbonate of lime and other salts, because the contractor took in a spring that he was not told to tap—a mineral spring. Now the purest spring water you can get comes from the igneous, the metamorphic, and the older stratified rocks. Many of these hard rocks yield a very pure water without a great deal of salts in solution. The mountain limestone, the oolitic limestones, and the chalk rocks also yield a good supply, and these waters are fit for drinking so long as they do not contain any quantity of magnesian salts. Water from sandstones, especially the new red sandstone, I have told you, often contains common salt. Waters in clay countries very often contain considerable quantities of the sulphate of lime. The waters of the London and Oxford clays do, as also the water of the lower lias clay. These are bad waters. They are permanently hard and unwholesome. Well waters have partly the same qualities, unless they contain additional impurities from the causes I have mentioned before. River water is often purer than spring water; that is to say, it often contains less total solids in solution. The permanent hardness is generally greater. It contains less substances in solution, because much of the carbonic acid has escaped, and the substances it held in solution have been deposited. River water very often contains much more organic matter, especially near towns.

Wells sunk in hard rocks may require no lining at all; if they pass through sandy strata they require a lining of brickwork, and sometimes part or the whole of it must be set in cement. For an artesian well, an ordinary well is dug first of a tolerable breadth and depth, and then a boring is made which varies from twenty down to three or four inches in depth. As soon as an impervious layer is bored through, and a pervious stratum reached, the water rises through the boring into the well (which acts as a sort of cistern), and has to be pumped up, or it may rise so high as to overflow.

The ordinary atmospheric lifting pump is seldom used, but a kind of lifting pump with a solid piston and metallic valves is often used. In fact, the cylinder in which the solid piston slides is connected with the space between the valves above the piston instead of below it. So that when the piston is raised the water is lifted through the upper valve, and when it is depressed water is drawn from the well into the body of the pump through the lower valve. Forcing pumps are also used. They are driven by engines, and the water is pumped into air vessels, by which the pressure on the mains is equalized so that it does not come in jerks. Let me mention one or two examples of artesian wells, and the amounts of water got from them in different strata. From the well of Grenelle, near Paris, in 1860, there were about 200,000 gallons daily. This well when first sunk yielded 800,000 gallons daily, so that you see the supply has considerably diminished with time, which is an important thing to take note of. The boring of this well of Grenelle began at twenty inches in width, and ends at about eight or somewhat less. It is 1,800 feet deep (being one of the deepest borings ever made), and more than 1,700 feet of it is lined with copper tubing, which was placed there instead of some wrought-iron tubing, with which it was originally lined. The copper tubing begins at 12 inches in diameter and goes down to 6½. The temperature of the water in this well at about 1,800 feet is as much as 82 F., and you may put it down that as a rule, the temperature of the water increases 1° F. for every 50 feet below the surface. Of course there are certain places where it increases very much more (about Bath for instance), but these are exceptional cases. The boring in the well at Trafalgar square is sunk 384 feet from the surface into the chalk, and it yields 65 cubic feet in a minute, or more than 580,000 gallons in the 24 hours. There is a well in Woolwich in the chalk 580 feet deep, which yields 1,400,000 gallons in 24 hours, and the last I am going to mention in the chalk is a well near London—the Amwell hill well—close by the source of the New River. That is only 171 feet deep, and it is said to yield very nearly 2½ million gallons in the 24 hours.* As all this water underneath the London basin comes originally from districts at some distance from London, it is not to be wondered at that the pumping at London lowers the level of the water in the wells in those districts. These are examples of successful borings. Now, a word with regard to the new red sandstone wells of Liverpool. These wells you will find described in the twelfth volume of the proceedings of the Institution of Civil Engineers. One of them, called the "Bootle Well," has many points of interest about it. Its maximum yield was,

*Hughes' "Water-works."

in 1853, about 1,100,000 gallons in the 24 hours. A curious point about it is that at the bottom of the well instead of there being one boring there are 16 or 17. These 16 or 17 borings are of very different depths, and it became very interesting to know whether the whole of them were of any use, and Mr Stephenson thought of blocking them up, all but one. He did so, and found that one yielded very nearly as much water as the 16, so that a very considerable amount of capital had been wasted in the boring of these holes. That is worth knowing. There are six other public wells at Liverpool in this new red sandstone, and the ordinary yield was about 4½ million gallons daily from them all. This was in 1850. Eighteen years afterwards, evidence was given before the Commissioners on the Water Supply for the Metropolis of a falling off in the water supply of these wells. In fact, the continual pumping had diminished the supply. In 1854, these wells in the new red sandstone at Liverpool were pronounced failures by Mr. Rawlinson, as also were others in England and America, and Mr. Piggott Smith, in a report on the water supply of Birmingham, confirmed this, and it is a fact that they have had to be supplemented by a supply of much superior water from a distance. Mr. Stevenson estimated the cost of a pumping station for one of those Liverpool wells, including shafts and steam engines, at £20,000, and the annual cost per million gallons a day at £1,324, this being without interest or compensation, but including depreciation. Generally, well waters are liable to vary in amount from month to month, and from year to year, as witnessed by the amounts pumped from these Liverpool wells, and by the amounts pumped year after year from the Cornish mines.

After wells, the next thing we have to consider is the way in which water can be collected from springs and streams over a large area, called a drainage area. That is one method of supply, and the other method, of course, is pumping from rivers. We tell the amount of water that can be got from a large surface of land, in the first place, by a way I spoke to you about before, viz.:—by estimating the amount of available rainfall on it. Then we can tell it in another way, by correctly measuring the amount of water that is brought down by streams and springs; so that we have to consider the methods used for gauging springs, streams, etc. The gauge most commonly in use is the one known as the Weir gauge. Weir gauges are made by damming up the stream, and making it all pass over a sharp ledge or through an orifice or notch, or row of notches, on a vertical board. Then from formula you can, by means of tables, calculate the amount of water that passes through the notch, or over the orifice of the weir in a given time. You determine the height of the still water by means of a scale, the zero of which is level with the base of the notch, and you do it in this way. A stick is planted in the bed of the stream, its top at some little distance from the weir, and so that its top is level with the base of the notch, or row of notches, in the weir, and then you measure by the scale from the top of this stick to the level of the water from the orifice. That is one way. The next plan is by calculating from the declivity. This is only applicable to regular channels, like the New River for instance, and if the stream is small you can make the whole of it pass through a trough, and then calculate the velocity from the declivity. Another way is by measuring the maximum surface velocity, which is done by means of floats of any sort, or by means of fan wheels, and various little instruments for measuring the surface velocity of streams. You take the maximum surface velocity, and about three-fourths of this will represent the mean velocity of the section. The discharge of springs is estimated by the time taken to fill a vessel of known capacity. A word about the permanence of springs and streams, which is an extremely important point. In the first place you must try and get evidence from maps and trustworthy sources generally. At the bases of hills springs are usually permanent. In flat countries you may put it down that the reverse is generally the case. Springs in limestone countries are very permanent. Springs in very permeable strata are very generally variable, unless they are tapped at a considerable distance from the surface, and then they often give an enormous yield.

Springs in primary strata and in granite countries are very often very permanent indeed, and it is in these countries you have some of the large lakes which are used for supplies of water. In clay basins the water supply is variable as a rule, being very great in the winter, when there are often floods, and very small in summer. In chalk countries the springs are more permanent, for the reason that they draw from considerably beyond the actual basin. Intermittent springs sometimes occur, especially in the chalk; they are due to the gradual collection of water in subterranean hollows, which, when filled above a certain level, empty themselves by means of a syphon-shaped outlet; it is obvious that they must not be relied on as sources of a supply of water. This will end our consideration of the merits of different localities from the water supply point of view.

Having found a sufficient supply of good water, or a sufficient supply of water that can be purified on a large scale by filtration—a subject which we shall consider further on—or by means of Clark's process, which I have described to you, or by both combined, we come to the modes of collection and distribution, which vary very much as to the site, sources, etc. One of the oldest plans, and for all that one of the best, is the eastern or Roman plan, if you like so to call it, which is that of tapping natural springs at their sources, or lakes, above the places to be supplied, and conducting the water by channels or aqueducts above or below ground, or alternately above and below, as occasion may require; collecting it in large cisterns, allowing the sediment to settle, and then distributing by means of gravitation.

In later times we can adopt the same plan, and distribute either by gravitation or by steam power, as we choose. Permanent springs at a distance may be conveyed by the Roman plan through channels across the country, covered the whole way right up to the distributing reservoirs or tanks. The conduits may be built of masonry and cement, like the Roman aqueducts, embedded in puddle, or they may be earthenware pipes, in which case they must be laid in watertight trenches, and jointed securely, or the water may be contaminated in various ways, and much of it may be lost, or the pipes may be of cast-iron, and this should be the case where deep valleys have to be crossed by means of inverted syphons.

Earthenware pipes are not strong enough to be used as inverted syphons. The rule is, that if the fall is greater than 1 in 300, then cast-iron pipes should be used. The fall of these conduits should be 5 feet in a mile, if they are of something like 2 feet in diameter, which is of a small size. If larger, it may be less, down to 1 in 10,000, or 6 inches in the mile. That is the fall of the New River conduit that supplies part of the north of London with water.

The velocity of the water should not be less than one foot in the second, so that it may move at a sufficient rate, nor greater than four feet in a second, for fear it should wear away the course by carrying down stones, etc. As an opinion about this plan, which I am going to describe to you at greater length, I may mention that Mr. Rawlinson stated, in a discussion on the water supply of Melbourne, which you will find reported in Vol. 18 of the proceedings of the Institution of Civil Engineers, that "he thought the plan of gathering spring water in Great Britain, by means of earthenware pipes to some common storage reservoir, was one that might be favorably looked at; the modern means of making earthenware pipes offered many facilities; and where springs were at a sufficient elevation and tolerably permanent, the water might be collected and brought into a covered reservoir on the Eastern plan. There were situations where that plan might be preferable to making an impounding reservoir."

Now, I should like to give you a short account of some of the points which are to be observed in the Roman aqueducts at Rome; and afterwards I propose to give you an account of some extremely remarkable Roman aqueducts which are very little known, and which have been very seldom described, to wit, the aqueducts with which the town of Lugudunum, now called Lyons, was supplied, which aqueducts have some very interesting and instructive points about them, as you will see directly.

As I think I told you before, Rome was supplied by nine aqueducts. The first two were built entirely underground for their whole length, because the water supply might otherwise have been cut off in case of invasion. The more ancient of these two, the oldest of all the nine aqueducts, ran for a distance of about 11 miles. I need not say anything more about that one. When the Romans built the third aqueduct they were, it appears, no longer afraid of its being destroyed by enemies, and so they built it partly above ground, and partly underneath the ground. By the direct road to the place from which they took the water was 39 miles from Rome. Three thousand men were set to work at it under the Prætor Marcius, and so it has been called the Marcian aqueduct. This aqueduct was made so strong that the two succeeding ones were built on the top of it, so that you have the three channels one above another. The size of the channel of the Marcian aqueduct was about 5 Roman feet high by 2½ wide.* The thickness of each of the sides was a foot. You can see this aque-

* The Roman foot was equal to about 11.65 English inches.

duct outside one of the gates of Rome at the present day.

On these aqueducts there were ventilating shafts. There were also what are known as piscinæ, or small settling reservoirs. These piscinæ I shall describe to you a little further on. Then the base of the channel was broken up by inequalities, partly to help to break the very considerable fall, and likewise to aërate the water by agitation.

I may now say a word or two about the water supply of the Roman town of Lugudunum, in Gaul. In the first place, I must remind you that those aqueducts which supplied Rome with water were carried across no deep valleys; they had, it is true, often to be supported on high arches,because they pass over low ground, and the Romans have over and over again been blamed for not using syphons ; it has been said that the Romans were not acquainted with the properties of water, in that they did not use syphons in these aqueducts. We shall see directly whether that is true or not.

The town of Lugudunum (Lyons) was supplied by water by means of three aqueducts. The first of them was built in the first century before Christ, and here is the description of it in a few words. It had two branches, which united at a particular place. It passed over a large plateau in a straight line; then went underground. Emerging from beneath the ground, it descended, by means of inverted syphons, into a deep valley, and was received at the bottom of that valley on a supporting bridge of arches. It was thus carried across the valley, and ascended the other side into a reservoir. So you see in the course of this aqueduct, which was built in the first century before Christ, there was a large and deep valley crossed by means of inverted syphons, by the very method which we employ now; and this shows you that the Romans then certainly understood and perfectly well appreciated the properties of the syphon.

I will now give you a description of the second aqueduct by means of which

Lugudunum was supplied with water.

It was underground the whole way, and it carried the water to a greater height than the other. The reason that it was constructed at all was, because the water was required to be carried to a greater height than the former aqueduct brought it. It was very nearly the size of the Marcian aqueduct. It was built of cubical stones placed together, as I may tell you a great many of these aqueducts were built. The stones were placed together without cement, and they fitted so accurately that some aqueducts built in this way are not even lined with cement. This aqueduct is in all probability intact at the present day for three-fourths of its length. Now we come to the third, which is the most important of the three, and which is, perhaps, the most remarkable Roman aqueduct of which we have the remains anywhere. The two former ones did not bring the water to a sufficient height. There is at Lyons an abrupt hill (Fourvières), on which several Roman palaces were built, and it was necessary to bring water to these. The Emperor Claudius, who was born at Lugudunum, and who lived there, determined to bring water onto this hill. He had already made an aqueduct for Rome (the Claudiun aqueduct), and so he knew something about it. He had not used inverted syphons, however, in his aqueduct at Rome, and for the simple reason, as you will presently see, that it was practically impossible; but he comes and orders a new aqueduct to be built for the city of Lugudunum, and it is that one which we are now going to consider, as briefly as possible.

This aqueduct descended in the first place into three or four valleys on its way. The aqueduct was 52 kilometers long, including the syphons. It had 17 or 18 bridges of arches to carry it over low grounds, and four bridges to carry the syphons across the valleys.

And now I may tell you the size of the two more important of these valleys. The valley of the river Garon, which is the second one it had to cross, is 120 meters deep, and 800 meters broad. The valley of Bonan ——, which is the next, and which is the place at which I examined the aqueduct very carefully some time ago ———, is 139 meters deep, and 1,060 meters across, between the two reservoirs, which are placed one on each side of the valley. So you see these are two very considerable valleys that had to be crossed.

And now, how did the Romans manage to effect their purpose? Bridges were out of the question, although we know that they built splendid aqueduct bridges, where possible, in such situations, as witness the well-known Pont du Gard, near Nismes, which had three rows of arches one above another, supporting the channel, and which is even now so perfect that it is about to be utilized for the purpose for which it was originally built.

They used inverted syphons. I told you that earthenware pipes will not do for syphons. Cast iron pipes need to be employed for large syphons. The Romans could only work iron on a small scale, and so used leaden syphons. One thing they did, and which it is important to note in this: the water was brought up along the single channel of the aqueduct—the *specus*, as it was called—which in this particular one is about 2 Roman feet broad by 6 high, into a reservoir. This reservoir had some such dimensions as 5 yards by nearly 2, and the walls were about a yard thick; there was an opening in the roof for the purpose of cleansing, and on the front side of the reservoir (the one facing down the valley), there were several holes into which the leaden pipes were fixed. Now one of these valleys had 8 leaden syphons, another 9, and another 10; and the object, of course, of dividing the water in this way was that they might get pipes that would resist the enormous pressure, and if a pipe burst the rest might remain sound, so that only part of the water would be lost. Delorme, I should tell you, has calculated that this single aqueduct brought 11 millions of gallons of water into the place in 24 hours. It is hardly likely that it brought so much as that, but it certainly brought a considerable amount.

The interior of the channels was usually constructed of very small stones carefully placed, and generally laid in cement. There was in this particular one —and probably it was so generally—a layer of cement along the walls of the watercourse, and another layer, a considerably thicker one, along the base of the channel. The arches of the bridges were built of enormous rectangular blocks of stones, and the pillars broken at certain intervals by layers of brickwork buried in cement. The whole of the exterior of this was covered over with the work known to engineers as the "opus reticulatum," which is made of cubical pieces of stone, fitted carefully together.

There is another curious thing to observe, and that is that the syphons were provided with little tubes, or valves, to let out any air that might be carried down from the height by the water, and which might otherwise break the pipes. In the smaller valleys there were small leaden tubes, which rose up from the lowest part higher than the reservoirs, and in the larger ones weighted valves were used for the same purpose. But what I want you to see in this is, that by the time the Romans constructed even the earliest of these aqueducts at Lugudunum, they knew perfectly well the properties of water. They knew perfectly well they could make it travel up to the top of a hill if it had come down a slightly higher hill on the other side of a valley. Now I just wish to give you the height of the reservoir on the one side of the valley of Bonan, the deepest of them all. The height of that reservoir above the level of the Saone at Lyons, is 151 meters, or something over that. At the other side of the valley into which the water was received the reservoir was 143 meters above same level, that is to say, the difference in height between those two reservoirs was only eight meters. In another case, it was 9 meters. Not only then did they understand these matters so well as that, but they actually lessened this amount by causing the syphons to enter nearest reservoir—the one nearest the place to be supplied—high up close to its roof, so that they actually thus diminished the pressure by at least a meter. I have given you this description at such length, because it shows how much we have to learn from what has been done a very long time before our own age, and also because there are so few descriptions of these splendid aqueducts.

We now come to the next plan, that of having a large drainage area, and of collecting the water from that area into an impounding reservoir. Before I begin to describe this, I will give you a brief account of one or two important impounding reservoirs. The first one will be that of the Rivington Pike reservoir, which now supplies the town of

Liverpool with most of its water. This Rivington Pike reservoir is calculated to supply 21 millions of gallons of water per day to Liverpool, and it has 481 million cubic feet of contents, with a drainage area of 16¼ square miles; its embankment is 20 feet high. You will see from that, that it is calculated to contain 150 days' supply.

Then there is a reservoir which was made to supply Melbourne with water, the particulars of which are given in the volume from which I quoted to you before, namely, Vol. 18 of the Proceedings of the Institution of Civil Engineers, in a paper by Mr. Bullock Jackson. It is called the Yan Yean reservoir. The description runs thus:

"The Yan Yean reservoir was formed by throwing an embankment across a valley between two spurs of hills; thus retaining the rain-water which falls on the natural basin, as well as the flood-water which is led into it in winter from the Upper Plenty River; the river itself and the artificial watercourse forming, in the latter case, a vehicle for its conduction. The area of this reservoir, when full, is 1,303 acres; the greatest depth is 25 feet 6 inches, and the average depth not less than 18 feet. Its contents measure nearly 38,000,000 cubic yards, or upwards of 6,400,000,000 gallons. The area of the natural catchwater basin, independent of the reservoir, is 4,650 acres; so that, including the area of 600 acres drained by the watercourse, there is a direct drainage into the reservoir of 5,250 acres. . . . The original surface of the ground at the site of the Yan Yean reservoir consisted of a stiff retentive clay; the site was, therefore, admirably adapted for a reservoir. Prior to the commencement of the works, about two-thirds of the whole area were densely timbered with large specimens of eucalyptus, which were taken up and burnt. The sides of the reservoir, excepting in two parts, rise in a steep slope. The embankment is 1,053 yards in length at the top, and 30 feet 9 inches in height at the deepest part; the width at the top is 20 feet; the inner slope is 3 to 1, and the outer slope 2 to 1. The inner slope is pitched with rough stones from 15 to 20 inches deep. Along the center is a puddle bank and puddle trench, with an inner apron and check trench. The puddle trench and bank are unusually thick, because, in the first place, almost the whole of the material used in the construction of the bank was clay, so that it entailed little extra expense; but principally, because previous to the works being commenced, the site of the embankment was occupied by trees of a gigantic size, with long straggling roots, which were all grubbed up, and which it was feared might leave clefts in the soil."

According to Mr. Hawkesley, the considerations that you have to take into account in constructing impounding reservoirs are these: In the first place you have to consider the extent of the drainage area. In the second place, the amount of rainfall. And in the third place the quantity of rainfall which can be collected into any reservoir which it is practical to make in the district. The size of these reservoirs must be proportioned to the population to be supplied, their area often requiring to be $\frac{1}{20}$ of the area of the water-shed. Mr. Hawkesley stated in a discussion, that he considered on an average of years that 30 inches of rainfall out of a rainfall of 48 inches, could be collected in an impounding reservoir. It is usually considered that one-sixth part of the total rainfall must be put down as lost every year by floods that you cannot store. The water that you cannot collect is, of course, lost by evaporation from the surface of the ground, absorption by plants, and so on.

Now as to the site of the reservoir. In the first place steep-sided valleys are the best situations. In the next place, it is necessary, of course, that the place for collecting and storing water should be sufficiently high above the place to be supplied, so as to enable you to supply water by gravitation, and necessary also, that it shall not be too high above it, so that you may not have too great a rush of water.

Then besides the situation, the incline of the rocks must be considered. It is especially important in limestone that the dip of the strata shall be in the direction in which the water is running, because if the dip is against it you very often have immense quantities of water lost, disappearing between the strata and running away in another direction. Stiff impervious clay or compact rock affords the best situation. Trial shafts or borings require to be made at various places, it being better to make shafts than borings, to see if you have a sufficiently impervious material for the bed of the reservoir, and a sufficient depth of it. It is only with small reservoirs, as a rule, that you can safely puddle the whole of the bottom, or that it is done, and for this reason in small reservoirs the site is of less importance, as you can puddle the whole of the bottom, and carry it under the embankment of the puddle wall.

The embankment should have constructed what is called a puddle wall down the center of it. I shall do well to give you some rules about this. Mr. Rawlinson lays it down, that the puddle wall is to be a foot thick at the surface of the ground for every three feet in height of the embankment, that is to say, that in an embankment 100 feet high, the puddle wall should be about 33⅓ feet thick at the base. Then it slopes up to the top so as to be about four feet broad at the top. Having decided the thickness that you are going to make the puddle wall by the height that you are going to make the embankment, according to that rule, you have then to dig what is called a puddle trench. This is dug down to a considerable depth into the impervious bed that will be the bottom of the reservoir. The trench is usually sunk with sides sloping towards one another, though this is considered by some authorities to be an insecure plan. It would involve a considerable amount of extra work, which would to a great extent be unnecessary, to sink the puddle trench with sides diverging from one another, as you would expect it ought to be, and so it is sometimes recommended to sink the puddle trench with perpendicular sides. If it is very wet at the bottom of a puddle trench, it is usual to begin filling it with Portland cement concrete, and then to go on with the puddling. For puddling only the stiffer kinds of clay are used. On each side of the puddle wall a masonry wall is built, about equal to it in thickness. The example I gave you was one in which the embankment slope on each side of this puddle wall was pretty correct, namely, three to one inside, and two to one outside. This embankment is made of such materials as can be obtained in the neighborhood, and the whole embankment must be made in very thin layers, and should be trampled in as much as possible. The inner slope of the embankment is shingled up to a little short of the water-mark, and from that point it is pitched with blocks of stones. It is sometimes necessary to make minor embankments across valleys that may join with the one you are going to make into a reservoir. Now a reservoir requires a waste weir for the storm waters. This is generally made round the end of the embankment, or cut into the hillside. The water is carried from this point down to the old stream-course, and the channel is puddled until you are well clear of the embankment.

I have one or two words to say about the reason for the existence of these impounding reservoirs, and also about the size which it is necessary to make them, and the rules that are laid down for the amount of water that they should hold. In the first place, they are necessary where a sufficiently copious and permanent supply cannot be got from a river or large stream, or from artesian wells, in order to secure a constant supply of water throughout the year, and they do this by storing the extra supply of water during floods, so that it may be saved for use in times of drought; secondly, they allow a settling to take place; and, in third place, they are necessary to prevent damage to the lower lands by floods, for great damage is occasionally done by the floods, even of such rivers as the Thames and the Severn, and, of course, great quantities of water are wasted.

The size must depend upon the amount of water required, and upon the permanence of the supply; we have reckoned the requisite supply at thirty gallons per head per day. Impounding reservoirs should, according to the opinion of many engineers, hold a six months demand. You can tell how much that is, if you will lay down the amount of gallons which you intend to supply per head, and the population to be supplied. If possible, the gathering-ground that supplies these reservoirs should be so large that the least available annual rainfall is sufficient for the supply; and then the reservoir should contain an excess of six months demand over six months least possible supply; that is to say, supposing the least possible supply at any time during the year is zero, then the reservoir must contain six months demand. The reservoir must be (to put it in Mr. Hawkesley's words) "sufficiently large to equalize all the droughts and floods to which the country was subject. Occasionally, but not very frequently, there might be a great excess of downfall, resulting in floods as large as three or four hundred times the minimum volume." Now the minimum volume is only about an 18th or 20th part of the mean volume, so it follows, that the floods are only 15 or 20 times the mean volume.

Now with regard to compensation. It is necessary in many instances to compensate owners, mill-owners, and others, people who are interested in the streams that you are going to impound, and, on an average, it is found that in England one-third of the amount of water requires to be given as compensation to these people, and, therefore, two-thirds remain for the use of the town. This compensation, of course, must be considered in determining the size of the reservoir. Sometimes it has been arranged that the amount given to the owners on the banks should be the average summer discharge, minus the floods, and sometimes special compensation reservoirs have been built to collect the water from a certain portion of the drainage area, these compensation reservoirs being entirely under the control of the persons who are to be compensated. However, you may take it as an average, that about one-third in England generally goes to them.

The culverts have been commonly built through the embankment in the made earth. This is stated to be a bad plan. Mr. Rawlinson says they should always be built in the rock or in the solid ground, and not in the made earth. The water tower is generally built just inside of the embankment, and the discharge or outlet pipes open into it with valves, which valves ought to be inside the embankment, and not outside of it. What are called "separating weirs" have been constructed in some reservoirs. They are ingenious contrivances by which the water, when at its ordinary height, flows over the weir into the culvert to be taken away to the town. When it is in flood, the force with which it comes enables it to pass over the opening leading to the culvert, and to get away into the old watercourse. "Feeders" for diverting streams into the reservoir are also sometimes necessary. It is often found to be necessary to cut a new course for the stream that runs down the valley, especially if it be a very large stream, or if it be a stream that is liable to floods.

I see that I forgot to mention one point, which I should have stated at the beginning of the lecture, with regard to the situation of these reservoirs. The site must not be too low, for if it is, the reservoir is necessarily too shallow, and shallow reservoirs are very bad, in that the water cannot possibly be kept pure, it being perfectly impossible to store it and keep it pure in shallow reservoirs. If the ground is too high, and no other suitable place can be got, then it is necessary to make what are called "balancing reservoirs," so that the force of the water may be broken by its being kept in a series of reservoirs at different levels.

I do not profess to have given you the engineering details, as you will plainly see. All I have tried to do is to give you some of the most important points, according to the best authorities that I have been able to find.

The channels are generally made of masonry or brickwork. The water-way is, according to Rankine, best semi-circular, or a half square, or a half hexagon. These channels are usually made cylindrical; they require ventilating shafts after the custom of the Romans. Occasionally they are made with an egg-shaped section, like large sewers.

Channels require to be curved at their junctions, or at any rate they require to be joined at very acute angles.

With regard to aqueducts, Mr. Rawlinson tells us that "aqueducts of iron will probably be cheaper than masonry or brickwork constructions." They have been made self-supporting by Mr. Simpson, by constructing them in the form of tubular iron girders.

Now, with regard to the fall of these channels, I gave you one or two points before, when considering the pipes conveying the streams. In the discussion on the water supply of Paris, in the 25th Volume of the Proceedings of the Institute of Civil Engineers, Mr. Bateman gave the following example with reference to the Loch Katrine aqueduct of the Glasgow Water Works: "The fall was 10 inches to the mile throughout, except where the water was carried by syphon pipes across deep valleys, which, in one instance of a hollow of 250 feet, was done for a distance of 3½ miles, and in these cases there was a fall of 5 feet per mile, to economize the size of the pipes."

This aqueduct, I believe, is about the

largest that has been constructed. The channel is cylindrical, and about 8 feet in diameter. Mr. Rawlinson said in the same discussion, that "the fall of an aqueduct must be in proportion to the depth and volume of water which it had to deliver. The fall of the New River in London was 1 in 10,000, or 6 inches to the mile, but with so large a volume, and an unpaved channel, it was necessary to form a weir, and give the water a vertical fall of a few inches at certain points of its course. He found that plan was adopted in the East. In laying out a line of aqueduct two principles were involved. If it were graded, as the Romans graded some of theirs, from 5 to 15 feet per mile, there would be difficulty in stopping the water at any point. It was practicable, however, to grade an aqueduct having a fall of 15 feet or 20 feet per mile, if vertical falls were introduced at intervals, alternately with level or nearly level lengths. This mode enabled an engineer to fix the velocity, so as to prevent undue washing. The vertical falls tended to aërate the water, and this in itself constituted an additional advantage. All covered aqueduct conduits should be abundantly ventilated, and there should be side entrances, stop gates, overflows and washout valves." Sometimes in aqueduct bridges the sectional area of the channel is diminished, and the gradient made steeper. This, of course, gives greater velocity to the water, and a smaller amount of material is required, and so less expense incurred in constructing the bridges. So much as to the masonry.

Now as to pipes. Earthenware pipes are made up to about 3 feet in diameter. If they are of compact glazed earthenware, they are very tough and strong, but they will not bear shocks, either the shocks of water or anything else, and they cannot be jointed so as to resist a great pressure, and so are not suitable for syphons. We will not say anything more about lead pipes, because they are not now used for this purpose. Cast iron pipes, Rankine says, should be of a uniform thickness; and he lays down the following rule for the *minimum* thickness: "The thickness of a cast iron pipe is never to be less than a mean proportioned between its internal diameter and one forty-eighth of an inch." But, he adds, "it is very seldom indeed that a less thickness than $\frac{3}{8}$ of an inch is used for any pipe, how small soever." Large cast iron pipes are liable to burst, and there are some instances on record of it; one in the water-works for the supply of Melbourne, which I have already mentioned once or twice, in which case the pipe was 33 inches in width, was laid through the embankment of the reservoir and burst. Now this is what Mr. Hawkesley said in a discussion on the subject at the Institution of Civil Engineers, about the bursting of cast iron pipes: "Cast iron in the shape of a pipe would stand little unequal pressure externally, although such a pipe would bear an enormous pressure when equally distributed, whether applied externally or internally, and most in the former case, as the metal then would be under compression," and he went on to say that, at "the Rivington Pike reservoir of the Liverpool water-works, two lines of pipes were carried through an embankment 20 feet high, at a distance of 16 feet from the top of it. They were cast iron pipes, each pipe being made in 10 or 12 pieces, and they are the largest pipes that have been laid, each pipe being 44 inches in diameter. Now, out of these two lines of pipes, fully one-third of the pipes so placed, which were excellent castings, were broken, although they had borne a pressure of 300 feet internally. The fractures invariably occurred at the top and bottom, and not at the two sides, as might have been expected. The pipes being flattened and distorted by the pressure of the earth, were subjected to a strain at the top and bottom greater than at the sides, and were undoubtedly broken by compression. This fact convinced him that pipes in that position were very insecure. Commonly, in similar cases, there was a pressure of water on the inside, and a pressure of earth on the outside; and it was a usual arrangement for the valve which shut off the water to be placed under the embankment" (that is a point I have referred to as one of considerable importance), "so that if a pipe became ruptured when in use the water would escape into the embankment, and if it found its way to the back of the puddle, the embankment would be torn down, and the whole of the water in the reservoir set free. It was not, therefore, desirable that large pipes should be laid under an embankment, where they would be subject to a considerable pressure of earth."

When a pipe of that magnitude breaks it usually does great damage. In one of these pipes that I have just mentioned to you, sixteen million gallons of water were capable of being discharged daily, and if an accident occurred there would be a column of 44 inches in diameter, acting with perhaps 200 or 300 feet of pressure to be dealt with. Another thing about these large pipes is, that there is a considerable difficulty in repairing them. One length of these weighs about 4 tons, so that they cannot easily be dragged about or taken up. Now, cast iron pipes are said often to break from the pressure of the air. Whenever air gets driven in along with the water, and especially so in syphons where valleys are crossed, these pipes are broken (it is said) by the collection of compressed air.

Mr. Hawkesley tells us that he considers that they are broken when the air is let out; that it is the shock caused by the running together of the two separated parts of the water that causes the breakage of these pipes, when the compressed air that is collected in them is let out too suddenly; and he recommends, and has practiced in the case of those large mains at the Liverpool water-works, the adoption of valves with an aperture of only $\frac{3}{4}$ of an inch; through these the air rushes out, but they do not permit the columns of water to come together very suddenly; there should be one of these at each place throughout the channel where the pipe is higher than the theoretical line, or than the line of the fall. At each one of these places air is liable to accumulate and to become compressed, and, perhaps, to burst the pipe. At each one of these places, therefore, there should be means of letting out the compressed air, and even with regard to this precaution we were, as I showed you before, forestalled in the aqueducts of the ancients.

Pipes are also sometimes burst by the pressure of the water when a valve on the main is closed; this difficulty has been overcome by a plan mentioned by Mr. H. Maudslay at the Institute of Civil Engineers: "In some instances there had been a small valve and pipe, so placed at the side of the large main as to join the main both before and beyond the large valve, in order that the whole body of water might not act like a water-ram on the closing of the large valve. This plan has been adopted in the Neptune fountain at Versailles, and also, he believed, in the mains supplying the fountains at the Crystal Palace. On shutting the large valve, the main flow was stopped, but the small pipe permitted a continuous flow of the smaller quantity, and thus the danger of bursting was avoided. The second valve was afterwards closed gradually. He thought that this was the most simple plan that could be adopted, and perhaps the least costly, while it was certainly very effective." Another plan is that described by Mr. Hawkesley, as follows: "The valve upon the main at Liverpool was divided into three openings, each of which was provided with a separate screen, so that by raising or lowering each of these slowly in succession the water was either admitted or turned off very gradually. The object of dividing the valve into three apertures was to enable a workman to operate with facility on any one of the screws. In large pipes, where the pressure was great, it was necessary, in order that the brass pieces, upon which the valve acted, might not be abraded, that only a certain amount of pressure should be put upon them, and that the friction under that pressure should not be greater than a man could overcome, by simply turning a handle, without stripping the thread of the screw. As a further provision the center valve was made very narrow; the side valves were first closed and then the center one, so that concussion was prevented. In addition there were branches at various points, upon which equilibrium valves, with a piston underneath, were placed, and others had double beat valves. But as these valves required to be heavily weighted, the inertia of the weight would, if other means were not taken, prevent the valve from rising so rapidly as was desirable. Therefore, between the weight and the valve there was a spring, the action of which was independent either of the valve or of the weight, so that, instead of the valve waiting for the large weight to rise, the spring immediately yielded under it and the water was discharged instantaneously. When these valves were used not the slightest shock was experienced. If there had been, the pipe would undoubtedly have been ruptured, for the length of the column, and the velocity, upon which the force of concussion was dependent, were both very great. That was another reason he preferred a smaller pipe. There were still, however, other precautions. Powerful disk-valves, made by Sir W. Armstrong & Co., and which acted in a similar way to the cataract apparatus of a small power steam engine were placed upon the main. They were made to close slowly, being let go by a trigger. As a hundred million gallons might pass through the main in twenty-four hours, if a pipe burst, without any provision being made to stop the flow, a great deal of mischief would ensue. Supposing, however, a fracture to occur when the disk-valve was open, then the valve would gently close in about two minutes, and arrest the discharge. These valves cost £300 each. He had found them to act, on various occasions, extremely well, and but for them the country would have been flooded on several occasions."

Now, we have considered the Roman plan and also the plan of collecting water by drainage areas into large impounding reservoirs and conveying it by channels to the place that wants it, the place where it is to be distributed. When it comes there, it is collected in what are called service reservoirs. The most ancient examples of these service reservoirs are those very piscinæ, upon the Roman aqueducts, which I have spoken of, and you can see examples of them in Rome at the present day. The best I ever saw was at a place called Bona in Algeria, where is to be seen a set of the most magnificent service reservoirs. The plan was to have four compartments. The water was first let into one of the two upper ones; it then fell from that into one below, possibly over a waste-pipe. The water then passed, possibly through strainers, into another compartment on the same level, and it then rose through the roof of that compartment into a third at the level of the first one, out of which it went onwards, and considerable settling took place. Now, there were means of scouring out these two lower compartments, which could be shut off from the upper ones so that the mud might be got out of them. The water, when it is brought to these reservoirs by either of these two methods, or when it is got into them, as it very often is now for the supply of large towns, directly out of the river, very often requires to be filtered, as mere settling is not enough for it. We have then to consider what materials are used for filtering the water, what size the filter beds require to be, and what effect is produced on water by filtration.

Now, in the first place, the materials that are commonly used for filtration are sand and gravel. The different merits of sand and gravel and also of charcoal I shall have to consider in the next lecture, but I must conclude this lecture by telling you that the effect of filtration of water, even by sand and gravel, is not merely the mechanical effect of removing the suspended substances that the water may contain, but that, at the same time, there is a chemical action going on. This is on account of the air that is contained between the little particles of sand, which air is so brought into contact with the finely divided water that any substances in the water that are capable of oxydation do become oxydized, and a considerable amount of the organic matters in the water are thus oxydized, and transformed into innocuous matters. That is the first important point to understand about filters, whether in filtering water for drinking purposes, or with regard to a filter about which we shall have to say more after a while—a filter to purify sewer water.

I have shown you that it was a fallacy to suppose that the Romans did not understand the principle of the syphon, but that they constructed most admirable ones on the aqueducts that brought water to Lyons. It so happens, by a curious chance, that I have recently seen some plans and sections of the Roman aqueducts which supplied Jerusalem with water, and on one of those I find a syphon, not made with lead pipes, but a syphon made of stone. It is made of blocks of stone with a hole through each; the blocks are put together so as to form a continuous pipe. Each piece is cut at the end so that around the pipe itself, the aperture in the stone, there is a ring left projecting on the face of the stone, and that ring fits into a groove on the next stone. That made a sufficiently tight syphon to convey the water, without any great amount of leakage, to a considerable vertical depth and up again. The depth, as far as I can judge from the plans, is about 100 feet from the highest point to the lowest. Well, now, we get up to the point where the water has reached the town, and there I told you it is almost necessary, certainly usual, to construct a service reservoir.

The Romans constructed them under the name of piscinæ; and I told you, I think, in two words, how those were made; I now want to give you a rather longer account of their construction. The water that was brought by one of the aqueducts to Rome was taken direct from the river Anio, and the result of taking the water direct from the river was that after the heavy rains it was charged with mud, and though large cisterns were provided, in which, by an ingenious arrangement, much of the sediment was caught, still it was not considered satisfactory by Frontinus, who was the engineer, and who, therefore, under his patron the Emperor Nerva, altered the source. Still the water that came to Rome required to have settling tanks, as described by Mr. Parker in a paper I quoted before, and from which I again quote:

"The building consisted of four chambers—two beneath and two above. Supposing, for the sake of illustration and in the absence of a diagram, the letters

A B
C D represent the four chambers. The channel of the aqueduct coming from the east, at a tolerably high level enters the chamber B. Thence the water passed (possibly over a large waste pipe) into the chamber beneath, D. Between D and C there were communications through the wall (possibly provided with fine grating). Through the roof of C there was a hole, and the water passed upwards, of course, finding the same level in A as in B, whence it was carried off into another stream. By the aid of sluice gates the water could be transferred direct from chamber B to chamber A, and access was obtained by an opening to the chambers beneath, and the mud was from time to time cleared out."

Just the same thing was the case at Lugudunum (Lyons). Large settling tanks have been found on the hill of Fourvières, consisting of two reservoirs with vaulted roofs, thus described: One of them was 48 feet long by 44 feet broad, and 20 feet high, with two conduits to admit the water, and several round holes in the roof from which it could be drawn. The walls were 3 feet thick, lined with very hard cement. A second was 100 feet long, 12 feet broad, and 15 feet high, divided by a wall into two chambers. A third was a large one, of which five of the supporting arches remain, and the discharge conduit, 1½ feet broad, which distributed the water, by means of leaden pipes (of which a specimen has been found) to the palaces, gardens, etc. In some cases similar constructions formed public reservoirs from which the people drew the water. In Rome "there were 591 open reservoirs (lacus) for the service of all comers. * * * These reservoirs were what we usually speak of as fountains; and some hundreds are in use to this day, many probably on the site of the older ones. There were very stringent laws respecting their use. Heavy penalties were inflicted upon any one dipping a dirty bucket or vessel into the reservoir. There were also laws respecting the 'overflow,' as the fountains, of course, were constantly running; these were the most important to keep in order, as all the poorer classes depended entirely upon them for their supply of water."

Now let us consider the Service Reservoirs as they are made now. Service reservoirs must either be placed at a low level, so that the water has to be pumped from them, or high up, which is better, so that the water, if not brought to them at that level, is pumped into them, as at Lyons, on the Rhone, where the water is brought to them at the highest point. They are made to contain a few days' supply. In the first place, they must always be covered; even the Roman ones were. The reason of their being covered is that, if not covered, the water becomes impure, for the impurities of the air dissolve in the water, and the growth of confervæ is also, of course, very much aided by light. If they are at the level of the ground, they are built of masonry.

Mr. Rawlinson says, "The ground excavated for the foundation of a tank should be made perfectly water-tight. The bottom may be covered with clay puddle and the side walls be backed or lined with clay puddle. The thickness of the puddle should not be less than 12 inches. If the site selected for a tank is sand, gravel, or open jointed rock, great care must be taken to give the puddle a full and even bearing over the whole surface area; open joints in rock must be cleaned out and then filled up with concrete. In gravel, large stones must be removed and the entire surface brought to a level, smooth, and even plain. Clay puddle will only resist the pressure of water when it rests solidly on an even bed, so as to prevent the water forcing holes through it, which will be the case if there is a rough, uneven surface and open space beneath." *

The roof is supported on piers with arches between them, and across some-

* Suggestions as to the preparation of plans as to Main Sewerage and Drainage and as to Water Supply.

times iron columns are placed in rows supporting the girders which carry the arches. The supply pipe has one or more exits, a waste and a wash-out, which may be connected by valves so that the supply can be directly connected with the exit independently of the tank.

The water is received in a sort of well or tower through which it passes into the tank, and after settling has taken place it passes out through a valve into the exit pipe. When the supply is too great it is carried off by an overflow to which the wash-out pipe may be jointed.

Well now I should like to give you a more detailed description of such reservoirs, and I take as an instance, and that for several reasons, the description of some reservoirs with supply tanks:

"The reservoir of Passy is intended to receive the waters pumped from the Seine at Chaillot, and those furnished by the Artesian well of Passy when disposable; it is composed of three compartments, two of which are covered by a second range of arches, the third, intended as a reserve in case of fire, being deeper than the rest, and only of one story; the two upper ranges of arches, also, are to be made to hold a supply of water, one of them being covered and the other not. The united capacity of these various compartments is 9,227,097 gallons, and their levels above the Seine are respectively arranged at 150 feet, and 163 feet, above zero of the scale of the bridge of la Tournelle. The capacity of the separate reservoirs is, for those nearest to the ground, respectively 2,232,800 and 2,344,984 gallons; these are covered with reservoirs of the capacity of 1,282,792 and 1,495,729 gallons; and the uncovered side portions of the reservoir are devoted to the remaining 870,792 gallons. These buildings are formed on the 'tuf du calcaire lacustre,' which afforded a hard, resisting foundation, and did not require any particular precautions to prevent the subsidence of the piers, or to secure the water tightness, or the impermeability of the bottom. The external walls have been in consequence carried down to the depth of 8 ft. 4 in. and have a width of 8 ft. 8 in. all around. The floors are of masonry, 1 foot thick in meuliere and cement, covered with a rendering coat of 1¼ inches of the same cement worked to a fine face. This is covered with a range of cylindrical vaults of 10 feet opening, springing from pillars 2 ft. 8 in. square upon the top, gradually enlarging to 5 ft. at the bottom. It is calculated that in no case does the weight brought upon a square inch of this masonry exceed 152 lbs. The thickness of the arch forming the roof of the first tier, and the floor of the second division, is about 1 ft. 2 in. on the crown; that of the roof of the upper division is only 4½ inches, executed in two courses of tiles bedded in cement, and 'rendered' with a coating of that material and covered with concrete.

"The reservoirs of Menilmontant are considerably larger than those of Passy, and being founded upon the upper members of the Paris Basin, special precautions were required to insure that the ground should not yield under the combined pressure of the masonry, and the $29\frac{1}{4}$ million gallons of water intended to be stored. The marls covering the gypsum of which the mountain of Menilmontant is composed, were not considered to be able to withstand that weight. The foundations of the piers were therefore carried lower down, and thence built in a description of rough rubble of menliere set in hydraulic lime. The bottom floor of the reservoir is arched over these piers, and the upper tier of arches rests upon this floor."

It is only fair to tell you that some engineers, and among others, Mr. Rawlinson, considered the plan of building two-storied reservoirs as a bad one, and not to be imitated; but it is necessary to know that there is such a plan, and the description applies, to a great extent, to all reservoirs.

To take an example nearer us, there is Mr. Simpson's elevated reservoir on Putney Heath; that contains ten millions of gallons altogether. There is there a double covered reservoir to contain filtered water for domestic use, and a smaller open one to contain unfiltered water for the streets, and to supply the Serpentine, and so on. So that you see it is usual in these cases to build several reservoirs together. This covered reservoir that has to contain water for domestic purposes, is double, or constructed in two halves. Each part has an area of 310 feet by 160 feet, and a depth of 20 feet. The sides all round have a slope of one to one. This gives a mean area of 290 feet by 140 feet, and a capacity of about 5,075,000 gallons for each reservoir, exclusive of the space occupied by the piers. "Hence the whole capacity may be taken" as stated by Mr. Simpson in his evidence, "at 10,000,000 gallons. The sides of the reservoir are cut out in the form of steps, which are filled up with concrete to a uniform slope of one to one; and a bed of concrete one foot in thickness is also laid over the whole bottom; each half of the reservoir is covered with eight brick arches, averaging rather less than 20 feet span, the arches being each 20 feet span, and the others 18 ft. 8 in. Two piers supporting these arches are built lengthways, and are each 310 feet long at the top, and 270 feet at the base. The arches are each one brick in thickness, and are covered over with a layer of puddle, the haunches being filled up with concrete. The piers are carried out 14 inches thick; but the division wall between the two parts of the reservoir is rather more than four feet thick, with a concrete slope of one and a half to one on each side. The 14-inch piers supporting the arch are built with large circular hollows 17½ feet diameter. The centers of these circular hollows are 40 feet apart, so that solid brickwork 23 feet long is left between the circular hollows, supposing a horizontal section taken through the centers of the hollows. Each of the 23 feet spaces has a 14-inch counterfort carried out at right angles.

These counterforts occur at intervals of 26 feet and 13 feet alternately, and project 6 feet wide at the base, on each side of the pier, and run out to nothing at the top, or springing of the arches." "The versed sine or rise of the arches is 5 ft. 3 in., or rather more than one-fifth of the span. Each arch is provided with two openings in the center, communicating with a line of 12 inch earthenware tubular pipe, which passes through the spandrels and communicates with perforated iron tops in the division wall between the two parts of the reservoir. By this contrivance the space above the water in the covered reservoirs is effectually ventilated. The supply pipe from Thames Ditton is 30 in. in diameter and comes into each part of the reservoir at the level of top-water, which is a few inches below the springing of the arches. At this level a waste weir, or overflow, is fixed to prevent the reservoir being filled too full. The exit mains to London consist of two 24-inch pipes, and they pass from the bottom of the reservoir, which has an inclination in one direction of 1 in 20, and a fall across of six inches." *

Now a great reason for the existence of these service reservoirs is, that the hourly demand during the day varies very much from the mean. It is sometimes so much as three times the mean demand, during certain hours, so that by this means it is not necessary for the mains to be made inordinately large. But otherwise the mains would have to be made large enough to give the greatest demand, instead of being only sufficient for the mean demand. And this is the case if the reservoir is only large enough to contain half the daily demand. In that case the distributing pipes need only to be calculated to give the greatest hourly demand. These you will recollect are underground tanks. Elevated tanks are sometimes made of cast iron, or wrought iron plates bolted together, and tied by wrought iron rods at the bottom, to one another. The supply, exit, and overflow pipes ought to be together

(*Hughes' "Water-works.")

in a corner of the reservoir, in a small separate compartment. This separate compartment is connected with the main reservoir by a valve, so that the main reservoir can be cleaned out and the supply go on independently of it. Thus you can shut out the supply, stop pumping, open a valve, and let out all the water from the large reservoir by the supply pipe to the town. Then you can close the valve and let the supply go on through this little separate reservoir, while the other is being mended or cleaned out.

The overflow pipe, or waste pipe, or whatever you like to call it, ought to open into an open channel, and not be connected, as is very frequently the case, with the nearest drain or sewer. It ought to open above ground, because as the reservoir is covered, if it does not do so, the foul air from the drain will come up that waste pipe, and be dissolved by the water in the cistern, and so you will render the water that you have taken so much trouble to get pure, you will render it impure, and that is what is continually done in all towns, and in houses, as I shall tell you presently when speaking of sewerage.

For distributing basins or tanks, Rankine says that "the most efficient protection against heat and frost is that given by a vaulted roof of masonry, or brick, covered with asphaltic-concrete, to exclude surface water, and with two or three feet of soil, and a layer of turf." Mr. Rawlinson says that "brick and masonry tanks, if arched, may be covered in with sand, or fine earth, to the depth of 18 inches, which will preserve the water cool."

Up to the present time we have been describing works connected with impounding reservoirs; now, with regard to river works. With river works you still more certainly require settling reservoirs into which water may either flow directly through culverts from the river, as it does at Chelsea, or into which it may be pumped. When the water flows in from culverts, you require almost invariably to have filter beds, which we shall describe a little further on. Sometimes for river works it is necessary to construct a weir right across the river, in order to keep the water as near as may be at constant level. The engine power employed ought to be considerably greater than that which is actually wanted, one-third greater at any rate, and, of course, there ought always to be a reserve engine. At the Chelsea works, to which I have before referred, the depositing reservoirs are made in London clay, and the bottom and sides are merely lined with cement placed upon this clay. From this the water passes direct to the filter beds.

With regard to those cases in which the water is taken from rivers, there are certain things I want to tell you. I want to tell you something about the purification of river water. We know that into rivers, especially in thickly populated countries, an enormous amount of refuse matter of all sorts is thrown, and it is necessary to know whether this refuse matter is destroyed in its passage along the rivers, that is to say, whether the water, after running a certain distance, becomes sufficiently pure to be used for drinking. And now I must quote to you from a book from which I shall have occasion to quote a great many times during the course of the remaining lectures, a book entitled "A Digest of Facts relating to the Treatment and Utilization of Sewage."

"The evidence collected on this head by the Royal Commission on Water Supply was very various. Dr. Frankland says:

'There is no process practicable on a large scale by which that noxious material (sewage matter) can be removed from water once so contaminated, and therefore I am of opinion that water which has been once contaminated by sewage or manure matter is henceforth unsuitable for domestic use.'"

Now the results of experiments are found to give the following facts:—In the first place it appears that in rivers that are well known to be polluted, and the water of which has a temperature not exceeding 64° Fahrenheit, a flow of between eleven and thirteen miles "produces but little effect upon the organic matter dissolved in the water." To remove all uncertainty from the "variability of the composition of the river waters at different times of the day," experiments were made by mixing filtered London sewage with water; "it was then well agitated and freely exposed to the air and light every day, by being syphoned in a slender stream from one vessel to another, falling each time through three feet of air." The mixture which originally contained in 100,000 parts .267 of organic carbon and .081 of organic nitrogen was found to contain, after 96 hours, .250 of organic carbon and .058 of organic nitrogen; and after 192 hours, .2 of organic carbon and .054 of organic nitrogen. The temperature of the air during this experiment was about 20 deg. Cent. (68° Fahrenheit). "These results indicate approximately the effect which would be produced by the flow of a stream containing 10 per cent. of sewage for 96 and 192 miles respectively, at the rate of one mile per hour." They show, then, that at the above temperature, during a flow of 96 miles, at the rate of one mile an hour, the amount of organic carbon was reduced 6.4 per cent., that of organic nitrogen 28.4 per cent.; while during the flow of 192 miles, at the same rate, the amounts of these two substances were only reduced 25.1 and 33.3 per cent. respectively. It is shown that the oxydation of this organic matter is chiefly affected by the amount of atmospheric oxygen dissolved in the water, "such dissolved oxygen being well known to be chemically much more active than the gaseous oxygen of the air."

It was found, however, that the action of this dissolved oxygen was not really anything like so quick or so perfect as generally supposed, and that 62 per cent. of the sewage was the maximum quantity that would be oxydized during 168 hours, even supposing that the oxydation took place during the whole time at the maximum rate observed, which was certainly not the case.

"It is thus evident, that so for from sewage mixed with 20 times its volume of water being oxydized during a flow of 10 or 12 miles, scarcely two-thirds of it would be so destroyed in a flow of 168 miles at the rate of one mile per hour, or after the lapse of a week. . . . . . Thus, whether we examine the organic pollution of a river at different points of its flow, or the rate of disappearance of the organic matter of sewage when the latter is mixed with fresh water and violently agitated in contact with air, or finally the rate at which dissolved oxygen disappears in water polluted with 5 per cent. of sewage, we are led in each case to the inevitable conclusion that the oxydation of the organic matter in sewage proceeds with extreme slowness, even when the sewage is mixed with a large volume of unpolluted water, and that it is impossible to say how far such water must flow before the sewage matter becomes thoroughly oxydized. It will be safe to infer, however, from the above results, that there is no river in the United Kingdom long enough to effect the destruction of sewage by oxydation.

Now there were several scientific men who gave evidence of another sort, and who declared that practically speaking water was sufficiently pure after even a short flow. The answer to that statement is found if we just go into a few of the public health facts. Here is one. This is gathered from Mr. Simon's report on the cholera epidemics of London in 1848-49 and 1853-54. "When the Lambeth Company took its water from the Thames near Hungerford Bridge, the people who drank that water died at the rate of 12.5 per thousand. When the source of supply was moved to the Thames at Thames Ditton, the mortality was only 3.7 per thousand, while at the same time, and in the same districts, the mortality among the people who were supplied with water by the Southwark Company from the Thames at Battersea was at the rate of 13 per thousand."

I could give you any number of facts of that sort to show you that water that has been polluted is dangerous to drink. I may just mention to you the opinion which Sir Benjamin Brodie, the late Professor of Chemistry at Oxford, has given; he said in his evidence before the Rivers' Pollution Commissioners:—"I believe that an infinitesimally small quantity of decayed matter is able to produce an injurious effect upon health. Therefore if a large proportion of organic matter was removed by the process of oxydation the quantity left might be quite sufficient to be injurious to health. With regard to the oxydation we know that to destroy organic matter the most powerful oxydizing agents are required; we must boil it with nitric acid and chloric acid, and the most perfect chemical agents. To think to get rid of organic matter by exposure to the air for a short time is absurd."

I give you those statements in order to bring you to the conclusion to which I wish you to come, namely, that we should not take water for the supply of villages and towns from a river that has been contaminated at all, if it can possibly be helped; that it has never been proved that such water gets really pure again; and that at certain times therefore very considerable danger may arise from drinking such water; in fact, as Mr. Simon said when examined before the Royal Commission on Water Supply, "it ought to be made an absolute condition for a public water supply that it should be uncontaminable by drainage."

The water when taken from the river, or even if it is taken from the gentle slopes of cultivated lands, and also in some other instances, requires to be filtered as well as allowed to settle; deposition is not sufficient of itself. It is important, also, to keep out inferior waters, that is when there are several sources; and with this condition you may prevent the necessity of the water all requiring to be filtered.

Mr. Parker says:—"At last it may be interesting to know what Frontinus did, or rather, what he says with becoming modesty, his patron, the Emperor Nerva, accomplished on this score: 'But the water of the Anio Novus often spoilt the rest, for since it was the highest as to level, and held the first rank as to abundance, it was most often made use of to help the others when they failed. The stupidity, however, of the Aquarü was such that they had introduced this water into the channels of several others where there was no need, and spoilt water which was flowing in abundance without it. This was the case especially as regards the Claudian, which came all the way for many miles in its own channel perfectly pure, but when it reached Rome and was mixed with the Anio it lost all its purity. And thus it happened that many were not in fact helped at all by the addition of the extra water, through the want of care on the part of those who distributed it. For instance, we found even the Marcian, the most pleasant *to drink* on account of its brightness and freshness, in use in the baths, and by the cloth-fullers, and according to all accounts employed for the most base services. It pleased, therefore, the Emperor to have all these separated, and for each to be so arranged that first of all the Marcian should be assigned *to its own use*, so that the Anio Vetus, which from various reasons was found to be less wholesome, as well as being at a low level, should be employed for the watering of the gardens in the suburbs, and in the city itself, for viler purposes.'"

So you see they had, even then, found out that one water was more wholesome than another, and when they had got supplies from two or three sources they knew it was better to keep them separate, and so use the best one for drinking purposes and the inferior ones for other purposes.

Now when water containing substances

in suspension is passed through a medium provided with fine pores, it is, of course, at least the purer by virtue of the removal of all such matters as are unable to pass through the pores. If that were all that filtration accomplished, it would be only a fine straining process. But that is not all. If you take a large quantity of porous material, for instance, a large mass of sand, or gravel, or especially charcoal—almost any porous material—and pass water through it, water containing certain substances in solution, and certain substances in suspension, those in suspension will remain unless they are fine enough to pass through the pores of the material. But all these porous substances contain an immense amount of air between their pores, and the water by being passed through them is divided into an infinite number of exceedingly small rivulets, exceedingly small streams, and so the substances in solution in the water are brought into the closest possible contact with the oxygen of the air between the pores of the filtering material, and so when you have passed the water through a filter, a chemical action takes place, and not merely a mechanical action. You have a mechanical action first, and then you have also a chemical action. That chemical action consists in the oxydation of the substances held in solution in the water—that is, such substances as are capable of oxydation, and these are the ammonia and the putrescible organic matters which are so dangerous when left in drinking waters.

One of the best filtering substances, that is, one which alters the substances contained in water most in its passage through it, is animal charcoal, and you will find in the 26th and 27th vols. of the *Proceedings of the Institution of Civil Engineers*, a most important and interesting discussion on this property of animal charcoal, and other substances—sand, and so on—upon the power of these materials to cause the oxydation of substances in water. I should tell you that the paper itself to which I refer in that 26th vol. is not worth reading, but the discussion afterwards is very well worth careful study. The paper is worthless, because it came to an entirely erroneous conclusion on account of the experiments being performed by a process which is practically worthless.

Here I must give you an example. Dr. Frankland tells us that he filtered New River water through animal charcoal; that before filtration it contained in solution about 18 grains in a gallon of solid matters, that after filtration it contained 11.6. Of course you are prepared for a less amount of impurity after filtration. Now the organic and other volatile matters contained in the water before filtration amounted to .37 of a grain in a gallon, and after filtration the amount was 15; that is to say that more than one-half of these matters were removed by filtration through animal charcoal. After a month this charcoal removed still more organic matter, and some mineral matters as well, and even a few months afterwards one-half of the organic and volatile matters only remained after filtration. These experiments show a very important thing, which is perfectly true of a sand filter as it is of an animal charcoal filter, and that is, it is not by storing up these matters that a filter works, or else it would be of no use whatever to make a filter. You would have it choked up in a very short time, and it would continually have to be renewed, whether made of sand, of gravel, of charcoal, or what not. It is by oxydizing the substances that the advantage is obtained, and the results of oxydation you can find in the water afterwards, and these results of the oxydation are nitrates and nitrites, and carbonates. Of course these are harmless matters, and that is the important action which a filter has. Dr. Frankland stated that he had passed the water supplied to London by the Grand Junction Company through a thickness of three feet of animal charcoal, at the rate of 41,000 gallons per square foot per day of twenty-four hours, under a head of water of thirty feet, the charcoal being in granules like coarse sand, and that at that rate—a tremendous rate—more than one-half of the organic matter was removed. He thought from these experiments on animal charcoal that persons who had to supply water to towns ought to use it, as at any rate one of the media in the filter beds. I must not pass from charcoal without mentioning that vegetable charcoal is agreed on nearly all hands to be almost entirely useless for purposes of filtration. In the first place it contains enormous amounts of salts which are soluble in water, so that the water becomes very much harder in passing through it than before, and then it does not purify water in the way that animal charcoal does.

Well, now some of the effects of sand filters, as employed by the Water Companies, Wanklyn points out. He says that the Thames water at Hampton contains fifteen parts of albuminoid ammonia, or ammonia derivable from organic matter, in one hundred millions, that is to say, .15 in 100,000, which is the way we have generally reckoned it, and that after filtration by the company it only contains 5 or 6; so that you see water is capable of being purified—that is, the matters in solution are capable of being altered in drinking water on an immense scale.

Now what sort of things are these filter beds, as they are made? because laboratory experiments are all very well, but you have practically to do it on a large scale. Mr. Hawkesley has made some large water-works, as you are most of you probably aware, at Leicester, and there, there is a reservoir of forty acres in extent. There are also four filter beds, each ninety nine feet long, and sixty-six feet wide, and eight feet eight inches deep from the ground. The water comes in separate channels to these filter beds, and it is passed downwards through the following filtering materials:—Two feet six inches of sand, and then two feet six inches of layers of gravel of various sizes (from the size of beans up to eggs) to the drains below, and thence by pipes into an octagonal pure water tank. This tank, eight feet eight inches deep, holds seven feet eight inches of water, and is sixty-six feet from side to side. That is the general plan.

The supply comes to the filter beds from the reservoir at various points; it passes through two feet six inches of coarse sand—for, it must be observed, fine sand will not do, as it gets choked up by the suspended matters in the water—and then through two feet six inches of gravel. The filtering beds have sloping sides and are made of sand, fine gravel, coarse gravel, then very coarse gravel, with a drain at the bottom. The filtered water is delivered into an upright pipe in the tank, which comes within two feet of the top, so that the pressure of the water on the beds from above can never be greater than that due to a height of two feet. It is essential that the pressure on the surface of the beds should not be too great.

Well now from these filters six hundred or seven hundred gallons per day per square yard flow, and the proper rate of vertical descent for the water, as it is generally considered, is six inches per hour, not more, or seventy-five gallons per square foot in twenty-four hours, and that you see is about the rate at which it passes through these last named works; now the effect at this particular place is that the water is clarified, and a considerable proportion of the organic matters in solution are removed from it. The sand of the surface of the filter beds requires scraping from time to time, and also renewing.

At the Gorbals Filtration Works near Glasgow, the filtering materials are placed in vertical compartments with passages between them, in each of which the water rises to nearly its original level and then flows over into the next compartment and down through the filtering material in it. There are two other plans I must mention; at Blackburn, for instance, there is no filtration.

There they have a surface reservoir, and they take the water out of it from the top by a sort of process of decantation. They let it settle, and then take only the water from the top. Another plan is in practice at St. Petersburg. There the water is made to fall down a series of steps, and then through wire gauze, and lastly through sand filters, and by these means the water which is generally very impure is rendered tolerably pure and a considerable amount of putrescible organic matters is collected from this wire gauze.

Now we have to consider briefly the ways in which water may be distributed in towns. In the first place, as to the mains: their size must be calculated according to the supply required.

Mains are often made in towns on both sides of the streets, in order that the supply may not be entirely cut off during repairs. There must be means provided by which the water may be stopped in a main in order that it may be repaired. The bends and junctions should always be curved. There should be no junctions made at right angles, and there should be no angular junctions if it can be helped. Mains should be made of cast iron. They should be greater than 3 inches in diameter. The best service pipes for houses are $\frac{3}{4}$ in., or 1 inch wrought iron service pipes that screw together. They are better than lead, and they are likewise cheaper than lead. Wrought iron pipes are better than lead for this reason, that certain kinds of water act upon lead. Soft water is apt to act upon lead. Fortunately, hard waters, containing a considerable amount of carbonic acid, act very little on leaden pipes, and so it is the practice very frequently to have leaden pipes and cisterns made of lead, and practically very little harm results. If you refer to the 25th vol. of the "Proceedings of the Institution of Civil Engineers," you will find a discussion on water supply, and there you will see that Mr. Bateman gave it as his opinion that even soft water acted very little indeed on leaden pipes, after a time. It acts on them at first, but the leaden pipe or cistern soon gets covered inside with an insoluble coat of subcarbonate of lead, and the result is that afterwards the water acts very little on it. The water of Loch Katrine, which is supplied to Glasgow, acts very little on the leaden pipes and cisterns used. However, there is no reason for having lead if danger be apprehended as likely to result; wrought iron will do just as well, and is cheaper.

A town may be supplied in one of two ways. These two ways are known as the Constant and Intermittent systems. First, there is the *Constant system*, in which, of course, the mains are always full, and the water is brought into the houses by pipes from the mains, no cisterns being needed, as the water is always in the pipes, and you have only to turn a tap in order to get it. Secondly, there is the *Intermittent system*, in which the water is only supplied for a short time during the day, and in this

Intermittent system it is therefore necessary to have cisterns in the houses. Now as to the relative advantages and disadvantages. Professor Rankine says: "The system called that of *Constant service* according to which all distributing pipes are kept charged with water at all times, is the best, not only for the convenience of the inhabitants, but also for the durability of the pipes and for the purity of the water; for pipes when alternately wet and dry tend to rust, and when emptied of water they are liable to collect rust, dust, coal-gas and the effluvia of neighboring sewers, which are absorbed by the water on its re-admission. In order, however, that the system of Constant service may be carried out with efficiency and economy, it is necessary that the diameters of the pipes should be carefully adapted to their discharge, and to the elevation of the district which they are to supply, and that the town should be sufficiently provided with town reservoirs. When these conditions are not fulfilled, it may be indispensable to practice the system of *Intermittent service*, especially as regards elevated districts, that is to say, to supply certain districts in succession during certain hours of the day." You see, therefore, that Professor Rankine emphatically condemns the system of Intermittent service as compared with that of Constant service.

Now the great objection to the system of Intermittent service is the necessity of having cisterns, whatever they are made of. Water becomes impure in cisterns, dust collects in them, and the cisterns require frequently to be cleansed. If this is not done the water may even become dangerous to drink. Where cisterns are necessary, slate cisterns are the best. They require to be made with good cement, or they are apt to leak, and then you are liable to get red lead or something of that sort used to fill up the joints, and so you get the water tainted. Iron rusts, and for that reason cast iron mains require to be varnished inside and out. Zinc has been used for cisterns and also for pipes, but zinc often contains lead, and cases have been known of lead-poisoning having resulted from the use of zinc pipes or cisterns. There have been plenty of ways proposed for coating lead pipes so that the water may not act upon them. Several of them are absolutely objectionable; one of the methods, for instance, was the use of a varnish containing arsenic; and even other varnishes, which do not seem to be objectionable, are not now practically used.

If you look in vols. 12 and 25 of the *Proceedings of the Institution of Civil Engineers*, you will see a great many arguments for and against both the "Constant" and "Intermittent" systems, and one argument against the "Intermittent" system is always that the amount of waste is enormous. It is stated, as you will there find, that at that time the amount of water wasted in London was something like half the supply. You find it alleged that there is great waste also on the Constant system, because, it is said, the mains are always full and the taps are apt to be left running. But this may be provided against by having the taps placed inside the houses, and then you will be quite sure there is not much waste. Then, the waste that has been observed with the Constant system has been mostly caused where the Intermittent system has been changed for the Constant system, and in that case you do sustain a loss of water; a loss on account chiefly of faulty pipes, and leaky fittings, for such as may do very well under the Intermittent system are not good enough to be employed for the Constant system. In Liverpool, at a particular date, there were used 33,000,000 gallons of water a week, in the supply of which only 1,000,000 gallons were supplied on the Constant service, and the whole of the remaining 32,000,000 gallons were on the Intermittent service. For some weeks, as an experiment, three-sevenths of the town were put on the Constant service, and then the amount of water used rose from

33,000,000 to 41,000,000 gallons per week. But where there has originally been sufficient attention to the fittings, and where they are strong enough it is otherwise. For instance, in the case of Wolverhampton, at the same period, it is stated that in that town there was a saving effected by changing from the Intermittent to the Constant system, a saving of no less than 20 gallons per head per day. (Vol. xii., p. 503.)

A disadvantage of the Constant system is that the water supply sometimes runs short in the higher parts of the town, while in the lower parts there is a sufficient supply; so that cisterns would sometimes need to be provided, even under the Constant system, in these higher parts of the town.

As a summary: With the Constant system the waste of water is certainly less than with the other if the fittings are properly attended to, and if the fittings, pipes, etc., have been originally arranged for the Constant system. The water in the case of the Constant service is purer and fresher, and at a lower temperature in summer, and less subject to frost in winter. The water is purer because it escapes the impurities which I have already pointed out, as collecting in pipes, and it also escapes those impurities which the water gets by being stored in cisterns.

The inconvenience from interruption to the supply during repairs is never actually experienced, as the interruption need only be for a few hours. On the other hand, the interruptions and the waste caused by neglect of turn-cocks, by the limitation of the quantity of water, by leaky taps and cisterns, and in other ways—these inconveniences are absent. Then the leakage from pipes is less. In the Constant service the pipes are made stronger, and practically there is much less bursting. Mr. Hawkesley states that the difference between the systems is a question of pipes and fittings, and that when the supply is well managed the waste under the Constant system is less.

Then the water supply should always be to the top of the house, and, if possible, to each story of the house. If cisterns are necessary, those used for drinking water should always be separate from any other cistern in the house. If, for instance, there is a cistern for the water-closet, it should be entirely separate from the cistern used for the storage of drinking water; there should be two separate cisterns. Then a chief point to attend to with regard to the drinking water system is that it should be covered. Secondly—That it should be easily accessible, so as to be readily cleaned out: and thirdly—and this is a most important point—that the waste pipe from it should empty out into the open air either over the surface of the yard or over a roof or into a rain-water pipe, which itself does not go down into a drain. The waste pipe should on no consideration be connected with any water-closet appa ratus or with drains. This is almost invariably done, and that is why I insist so much on the importance of this point.

I may tell you that one of the most frequent causes of typhoid fever in London at this moment—of this I have not the slightest doubt—is that the waste pipes from the drinking water cisterns are connected with some part of the sewerage apparatus, and very often directly with the sewers. The house drain, more frequently than not, being unventilated, the waste pipe of the drinking water cistern becomes the ventilator of the house drain, and the foul air of the house drain goes up into the space between the surface of the water and the lid of the cistern, and is absorbed, and the result, in many cases, as I have frequently observed, has been a severe attack of diarrhea through the whole household, or else of typhoid fever, and I have no doubt in some cases of cholera also.

The overflow pipes from other cisterns we need not be so particular about, because we do not require to drink the water; but it is just as well that they should empty in a similar way if possible. If not, they may be made to end in what is called the D trap of the water-closet. I shall explain that, however, more fully further on.

Now we have brought the water into the house—either into the cisterns, or it may be merely into the pipes, which are kept constantly full, and which have taps at various levels inside the house. When inside the house, it may be purified still further, if necessary, by household charcoal filters, or by boiling and then being left to stand in stone vessels. That is an excellent plan, and I must tell you here that impure water may be purified to a very considerable extent by making an infusion in it; for instance, an infusion of tea. This is very important for you to know when you may have to drink water in marshy countries. A great deal of mischief is sometimes done by drinking water in marshy countries, and this mischief may be prevented by merely boiling it. That is a very good thing, but still it is better, on the whole, to make a weak infusion of something like tea, in it, and that is the system which has been practiced for a thousand years in China.