UNDERGROUND WATER AND ARTESIAN WATER

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Disposal of Rainfall.

The water which falls from the sky on to the earth's surface is disposed of in a variety of ways. A certain proportion of it runs off rapidly from the surface down slopes and finds its way into creeks and rivers and eventually into the sea. Some of it is immediately or almost immediately evaporated, and returns to the atmosphere whence it came. A third fraction soaks into the soil and, as we shall see, may have quite a complex history. The relative proportions of the rain-water which are disposed of in these different ways vary according to circumstances. For instance, if the rain is in the form of sharp, heavy showers, then much of it will run off, whereas if it is in the form of gentle, steady rain, much will soak in. Again, if the soil is sandy and porous, a greater proportion will soak in than if the soil is clayey and close-textured. And naturally when the temperature is high there will be a greater tendency to evaporation than when it is low.

Of the water that percolates into the soil, some is taken up by the roots of plants, and is thereby brought up again to the surface; this is eventually evaporated into the atmosphere through the medium of the plants. By other means, too, some of it may be brought back to or towards the surface, but a considerable proportion remains in the soil and percolates downwards under the influence of gravity. It may even make its way through the pore-spaces in rocks or along the cracks which are so common in some rocks, especially those which are close to the earth's surface.

Groundwater and the Water-Table.

Of course the quantity of water percolating through the soil at any given place varies from time to time, according to the variation in the rainfall, but it makes its way eventually to a level below which the soil is permanently saturated with water. This level is known as the water-table, and the water contained in the pores of the soil, or in porous rocks, or in the cracks of the non-porous rocks, is known as groundwater or underground water. The position of the upper surface of this body of groundwater is more or less constant, and in general it is below the surface of the land and it is not flat; when the surface of the land is irregular the water-table is irregular also. If, for example, there is a ridge between two parallel river-valleys the water-table will also be in the form of a ridge, but not so marked as the actual surface ridge. The water-table may be for instance 50 feet down at the top of the ridge, while near the valleys it may be only a few feet below the surface. But a curved or ridged surface is not natural for water, and so we find it tending to percolate from higher to lower levels, and at the lower levels it may actually appear at the surface as springs and seepages. The reason why a creek flows even in dry weather is because the water which has soaked into the ground during a previous rainfall has joined the underground water circulation, and is slowly, very slowly, making its way downhill beneath the surface, and making its appearance in the valley. Where the water-table coincides with the surface over a large area, there is a swamp.

It should be emphasised that in general this underground water is not flowing in definite channels. It is able to move or percolate by virtue of the porosity of the soil or rock in which it is contained, or of the presence of cracks and fissures in the solid rock. It is true that underground channels *are* sometimes found, in which the water flows freely; these are usually in limestone, and are due to the fact that limestone is easily dissolved away by ordinary surface waters.

It would appear that the underground waters do not persist to any considerable distance below the surface, because of the fact that the rock-material becomes less porous with depth, and the cracks and fissures tend to close up; hence shafts put down to more than a few hundred feet often show the rocks to be quite dry. Indeed where areas of impervious rocks outcrop at the surface there may be locally no underground water at all.

We have seen that the groundwater is responsible for springs and seepages and permanent flowing water. It is groundwater also that is got when wells are sunk. If a well or a bore is put down, as soon as it reaches the water-table, permanent water appears, and the depth at which the water is struck indicates the depth below the surface of the groundwater level at that particular place. As we have seen that depth will vary from point to point over any area according as there are heights or hollows, but apart from that, the depth of the water-table also depends to a large extent on the rainfall of the region. In an area of high rainfall, the water-table will be close to the surface; in a dry region it may be a long way below the surface. Sometimes there may be local tables perched above the general water-table of the area where the water is unable to percolate downwards very far on account of the presence of a non-porous layer of clay or rock.

Fluctuations of the Water-Table.

Though in a general way the water-table is constant in position, it is easy to see that actually it may fluctuate. A long period of drought may cause it to sink slowly; a long spell of wet weather will cause it to rise. Hence it is that flowing creeks may cease to flow and springs and wells may gradually dry up during a drought, and on the other hand springs will flow again and dried-up lakes will fill if there is a long spell of rain. This fluctuation of the water-table is well illustrated in the salt lakes of Yorke's Peninsula, S.A. These have no rivers flowing into them. They dry up in the summer and fill in the winter. The reason is that Yorke's Peninsula has a winter rainfall. In the winter, therefore, the water-table rises above the level of the lake-floors and the lakes fill by seepage. In summer the water-table sinks below the level of the floor and the lakes go dry.

But there is another and more permanent change in the water-table, of which the effects are to be seen in many parts of the country here in Australia. It has been proved in various parts of the world that a removal of the natural virgin forest cover tends to increase the run-off of the rivers, and to diminish correspondingly the proportion of the rainfall that soaks into the ground. So in country that has been cleared for grazing or agriculture, when heavy rain comes the creeks run bankers for a short time and then subside, and much of the water that would otherwise have soaked in and joined the groundwater circulation is lost by run-off. This results in a permanent lowering of the water-table; creeks which used to be permanent only flow during rain and for a short time after; lakes and lagoons dry up, and wells have to be deepened, because the water-table has fallen below its original level.

Examples of Groundwater Reservoirs.

There are certain large areas, as for example the Liverpool Plains and other black-soil plains of New South

Wales and parts of the Darling Downs of Queensland, in which little or no solid rock appears at the surface at all. The whole place is covered with a considerable depth of soil, and dry watercourses are to be seen at intervals on the surface. Yet there are windmills dotting the landscape, pumping water from a depth. The reason for this underground supply is that the soil, or most of it, has been laid down in former times as flood-plains in great wide valleys, or even, it may be, on lake-floors, and if a bore is put down far enough through the soil it comes eventually to sand and gravel and then to solid rock. The water is contained in the pore-spaces of the soil, and of the coarser material beneath, and the solid rock acts as a kind of basin, as it were, to hold it up. The covering of soil helps to check evaporation, so that there is in effect a great hidden underground reservoir of water waiting to be tapped.

Another kind of underground reservoir is provided by certain old valleys—fossil valleys one might call them—which are found in this and other States. During what is called the Tertiary era, many millions of years ago, there were river-valleys with considerable depths of shingle and gravel and coarse sand, just like many of our river-beds of the present day. Then came great flows of basalt lava, which filled or partially filled many of these valleys; but water has managed to percolate through from the surface, and the old gravels, etc., may be quite waterlogged. These gravels have been worked in many places, under the name of "deep leads", for alluvial gold, tin, etc., and in some instances the work has been much hampered by the presence of so much water.

Artesian Water and Artesian Basins.

Now in general when all this groundwater which has just been dealt with is encountered in a well or bore, it remains at the level at which it was first found, and this is the level of the water-table at that particular place. But in certain instances the water when struck rises in the well or bore, and this leads us to the consideration of a special type of underground water which is different from that with which we have been dealing, inasmuch as it does not flow under gravity, but is held underground under some sort of natural pressure which forces it upwards when the supply is tapped. This is what is known as artesian water, and it is of very considerable importance in Australia. Strictly speaking, the name should be applied only to water which rises to the surface and flows over it; if it rises, but not to the surface, it is called sub-artesian. The nature of the pressure under which the water is held may be illustrated by a simple experiment. If a glass tube, open at both ends, be taken and bent into the shape of a capital J, with one of the parallel legs shorter than the other, and if water is poured into the tube through the longer leg, it will tend to rise to the same level in both legs of the tube. If the water is poured until it is at the level of the top of the shorter leg, and then you put your thumb or a cork on the top of the shorter limb and pour more water in the longer one, and then open the shorter one again, you know what will happen. The water will pour over the top of the shorter leg and drop in the longer one until the level in the two legs is the same. What was it that caused this flow of water? Surely the pressure caused by the weight of the column of water in the longer leg of the tube above the level of the top of the shorter one. This is what is called hydrostatic pressure, and this is mainly what causes the rise of water in artesian areas. We can go further and describe a model artesian basin, or structure from which artesian water may be derived. Imagine two iron pans or basins of about the same size placed one inside the other but so as not to touch, and that there is a hole in the bottom of the top basin with a fine vertical tube fixed firmly into it, this tube being not more than, say, half the height of the basins. Now if water is poured into the space between the basins so as to keep it filled up to the top, the water will rise in the fine tube and continue to spurt in a jet from the end of it, owing to the pressure of the water in the top part of the space between the basins. If the height of the tube was equal to the height of the rim of the lower basin, then the water would rise to the top and stay there, and if the tube was higher than the basin the water would rise for some distance but not to the top. Imagine now the space between the basins to be packed with coarse sand or shot or something else with considerable pore-space between the particles. The same thing would happen, though of course more slowly, and even if the tube was not actually in the bottom of the basin but somewhere up the side the water would still tend to rise in it. Now that is just exactly the principle of what is known as the closed type of artesian basin. There must first be a porous or pervious layer of rock, either solid rock like coarse sandstone for example, or perhaps loose sands, and this must have impervious rocks underneath, to form the floor, and an impervious or relatively watertight layer of rocks on top; and then the whole must be folded or bent into the form of a basin (for, strange as it may seem, rocks can be folded and bent on a large scale). In the ideal case this would mean that the porous rocks would outcrop at the earth's surface all round the basin, and these are known as the *intake beds*. And, of course, in order that the water should be true artesian it is important that the intake beds should be at a higher level than where it is proposed to bore for water. Then lastly there must be enough water either falling on the intake beds or running over them to provide and maintain the supply. That means that there must be a fairly high rainfall at the margin of the basin. Now we have the conditions described in our second experiment, and in general if bores are put down within the basin so as to penetrate the impervious rocks and tap the porous beds an artesian or sub-artesian supply should be the result. So much for closed basins. But it is known that there can be what are called open artesian basins, in which the lip of the basin is in part broken away, as it were, and indeed in which sometimes only one side of the basin exists, as if the whole structure had been removed by a great vertical cut. It might be thought that in such circumstances water could not rise in bores or wells, inasmuch as it would all tend to seep or drain out at the lowest outcrop of the porous beds, but actually (and the possibility of this has been demonstrated by experiment), owing to the frictional resistance opposed by the particles of the porous beds to the downward passage of the water, the net result is almost the same as if the bed was effectively sealed around its lowest parts, that is to say, the water rises in the bores, though not so high as the outcrop of the intake beds, and of course some of it leaks away out of the basin altogether. Indeed the farther away the bore is put down from the margin of the basin, the lower the level to which the water will tend to rise. Where an open or one-sided basin exists there may be natural outlets for the water at the surface, and these will be in the form of springs or seepages, so that while some springs are gravity springs due to the coming of ordinary groundwater to the surface, others are truly artesian, that is to say, the water rises under natural pressure.

It is, of course, possible that gas-pressure and rock-pressure are factors in forcing the water upwards.

It must not be supposed that artesian water is confined to Australia or that it is a thing of recent discovery. As a matter of fact, artesian borings in China date back to about 2300 years B.C., and there are borings of great age in Asia Minor, Persia, Egypt and the Sahara desert. In France there are many artesian wells—in fact the name is derived from Artesium, the old Roman name for Artois, a province of France. There is much artesian water in the chalk forming what is called the London Basin, and this is utilized in connexion with the water supply of parts of London. In U.S.A. artesian wells are reckoned by thousands. In all these instances the water is used for domestic supplies or for irrigation, and the basins vary considerably in size, while the water may be either artesian or sub-artesian.

Artesian Water in Australia.

In Australia the first bore for artesian water was put down in 1851 in the old Darlinghurst Gaol, but without success, which is not altogether surprising, since the conditions for supplies of artesian water are not fulfilled in the sandstone about Sydney. It was not till nearly 30 years after this that artesian water was actually discovered at Killara Station, between the Darling and Paroo Rivers. It is interesting to note that it was the late Mr. H. C. Russell, then State Government Astronomer and Meteorologist, who first gave a hint that there might be large stores of water underground in western New South Wales. He pointed out that the loss of water suffered by the Darling in its upper reaches was far higher than could be accounted for by ordinary evaporation and far higher than the percentage of loss of the Murray waters, and he accounted for this by supposing that the Darling at some part of its course flowed over unusually porous beds, which soaked it up and conveyed it underground. The truth of this acute surmise has since been abundantly proved. The Darling flows over the intake beds of the Great Artesian Basin, and contributes to its underground supplies.

The Great Artesian Basin.

Since the time of the first bore at Killara Station there has been a tremendous exploitation of the waters of this Great Artesian Basin, and its boundaries are now fairly accurately known. This is by far the largest in

Australia and probably in the whole world, covering as it does an area of more than 600,000 square miles. Over 60% of this is in Queensland and the remainder in the N.E. part of South Australia, eastern part of Northern Territory and the northern part of inland New South Wales. The area covered by the basin is shaped roughly like a water-carafe, with its neck (a rather crooked one) extending north to the Gulf of Carpentaria and Cape York Pensinula, and the widest part extending east and west for nearly 1,200 miles from about Toowoomba and Warwick in Queensland to beyond Charlotte Waters on the borders of South Australia and Northern Territory. North and south the extent is 1,500 miles from Cape York in Queensland to Dubbo in N.S.W. Dubbo is about the most southerly point on the eastern side; the western side just comes down to the Transcontinental railway line about Coondambo, north of Lake Gairdner, and the southern boundary—the bottom of the carafe—is rather irregular between these extreme points. The intake beds are for the most part all along the eastern margin of the Basin forming a belt averaging about 65 miles wide at the surface, and about 60,000 square miles in area, over 80% being in Queensland. This belt of intake beds outcrops right in the highlands of the main divide on its western side, so that it is crossed by many streams flowing west and south-west, belonging chiefly to the Murray-Darling system. All this area receives an average of more than 20 inches of rainfall per annum, and a goodly percentage of the run-off of this rainfall soaks into the porous beds and eventually joins the artesian circulation. There is another much smaller intake on the S.W. margin in South Australia, from the Transcontinental railway line north into the Northern Territory, but the waters of the rivers which feed this intake are very salty; other intake beds are found in W. and N.W. Queensland. The water-bearing strata slope downward from the margins of the basin and attain depths of more than 5,000 feet in places. Observation shows that this immense basin is not of the closed type; there are natural outlets for the water, first in the shape of submarine springs in the Gulf of Carpentaria, which are very probably connected with the Great Artesian Basin, and secondly in the form of natural springs known as mound-springs, which occur in a number of places within the area of the basin. They are found, for example, about Hungerford on the N.S.W.-

Queensland border, at and north of Blackall in Queensland, and especially to the west and south of Lake Eyre in South Australia. These springs have evidently been in existence for a very long time, and they have built up mounds of sand and clay ranging from 10′ to 130′ in height and several miles in circumference; the water in some instances comes up so fast that it is in a state of agitation in the cup-like lakelet on top of the mound. In an open basin it has been shown that the height above sea-level to which the water in the bores tends to rise decreases from intake to outlet. From a consideration of bore-pressures in the Great Artesian Basin it has been proved that there are falls in the level towards the north at Gulf of Carpentaria and towards the S.W. about Lake Eyre, so that on these grounds one would be justified in assuming that the basin has natural outlets. Of course, in these open basins the water is in a state of movement, whereas in a completely closed basin it is stagnant.

Geological History of the Great Artesian Basin.

We may now consider the geological history of the Great Artesian Basin. Away back in what is called the Jurassic Period, some 150 million years ago, Australia stretched northwards so as to join on to New Guinea and perhaps Asia, and an immense series of freshwater lakes extended roughly from about Cape York to Dubbo and then across to Lake Gairdner in South Australia. The land around this area was high, and rapid flowing rivers brought down loads of coarse sand and gravel into the lake, so as to deposit in places some thousands of feet of sediment on its slowly sinking floor. Eventually the sea broke in, and not merely occupied most of the site of the old lake, but also spread to the S.W. across to what is now the Nullarbor Plain, dividing Australia into two separate portions, an eastern and a western. Into this sea there was borne much sediment from the land, but finer in texture, mud and fine sand, because the highlands had been worn down and the rivers had not such carrying power as before. After the deposition of a great thickness of fine sediment on the sinking bed of this ocean the sinking movement gave place to a rising one, the sea was pushed out and the area became a land area once more; partly covered with large lakes. Later on some elevation of the land, especially on the eastern margin, brought the old coarse lake-sediments well above the level of the later deposits. These coarse beds are the chief intake beds of the Great Artesian Basin, and it is their superior height that provides the head which causes the water to rise in the bores, and it is the fine-grained old marine muds and sands on top that provide the covering that keeps the water down.

Utilization of the Artesian Water.

There are well over 5,000 bores in this Great Artesian Basin. In Queensland alone there are 4,700, some flowing, some sub-artesian, the flowing bores yielding about 290 million gallons of water daily. The deepest bore in New South Wales is over 4,300′ deep; in Queensland there is one 7,009′, but in this the lowest water-bearing bed is at about 6,000′. Most of the bores are shallower. The temperature of the water varies roughly with depth; in the case of the deepest bores the water comes to the surface at or very near boiling point. Some of the flowing bores have yielded up to 3,000,000 gallons a day, though most give much less than that. But there has been for a number of years a gradual decline in the yield in many of the bores, amounting on the whole to about 3% per annum. Some of the flowing wells have become sub-artesian and some have even gone dry. This and other circumstances suggested to the late Professor Gregory that the water of this Great Artesian Basin was not originally rain-water at all, but had been introduced from great depths in connexion with large-scale injections of molten lava. It is now, however, generally agreed that the water comes entirely or almost entirely from the surface.

The water of this basin unfortunately contains much in the way of dissolved mineral salts, chiefly carbonate of soda, so that it is quite unfit for irrigation. Its principal use is for watering stock, and the availability of this water has not merely enabled stock-routes to be opened up, but has also much increased the carrying capacity of holdings. Some of it is also used for domestic purposes and for town supplies, and at Moree the bore baths are used medicinally.

Other Artesian Basins of Australia.

Apart from very small and local structures in New South Wales, there are no less than 12 other artesian basins in Australia, certainly of much less area and importance than the Great Artesian Basin, but all useful to a greater or less extent. The most important at present is the Murray basin, about 190,000 square miles, in western and southern New South Wales, north-west Victoria and eastern South Australia. It gets its water from the River Murray and its tributaries, and it is largely in flat or undulating country. The deepest water-bearing strata are about 1,500′ below the surface. Most of this basin is sub-artesian, and its supplies have proved very useful in helping to develop some of the rather dry country of N.W. Victoria.

Another large basin is the Desert Basin around and south-east of Broome, in Western Australia, which is 130,000 square miles in extent. Then there is a small one about Port Phillip of about 300 square miles, one in the Adelaide Plains, and one under Perth. There is a big basin, mostly sub-artesian, underlying the Nullarbor Plain.

All these basins are of the open one-sided type, and some or all of them outlet under the sea. They are all of generally similar structure and mode of origin to the Great Artesian Basin, but except for the Desert Basin are of much more recent formation. In some of them the water is very saline, but in most it is useful for domestic and stock purposes and even for irrigation. None of the basins, however, is as yet fully exploited.

In the whole of Australia there are over 6,300 artesian and sub-artesian bores. From all the flowing bores nearly 460 million gallons of water are poured out every day, and this takes no account of the quantities pumped from the sub-artesian wells.

Conclusion.

We are indeed fortunate in having these vast underground reservoirs of water in the parts of the continent that need it most (for over 90% of the area covered by the artesian basins receive less than 20″ of annual rainfall). Yet there have been unmistakable signs that the supply is not inexhaustible, for the annual diminution in the natural flow from the Great Artesian Basin, though partly resulting from the multiplication of bores, is also doubtless due to the withdrawal of water from the basin at a greater rate than it is being renewed. We are, in fact, in danger of overdrawing our account in the Artesian Bank, and everyone concerned should recognize the grave necessity of conserving to the utmost this most precious and important of our country's natural resources.