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THE SCOTTISH
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IRRIGATION AND AGRICULTURE IN EGYPT.

By Colonel Justin C. Ross, R.E., C.M.G.,
Late Inspector-General of Irrigation in Egypt.

(*Read before the Society in Edinburgh and Glasgow, March* 1893.)

I come before you this evening to explain what irrigation has been in Egypt, and to point out what is the possible future for it. In describing irrigation, I shall attempt to explain the regimen of the Nile, and try to remove many erroneous ideas that have been widely disseminated of late by travellers and guide-books.

My special qualifications for lecturing to-night are that I have been from 1863 to 1883 employed in irrigation in the Gangetic plains, in the North-West Provinces of India, and in the end of 1883 went to Egypt to assist in rectifying the irrigation system there. In Egypt, after a year and a half's experience as Irrigation Inspector in charge of the Eastern Delta, I succeeded to the duties of Inspector-General of Irrigation, of all Egypt,—Colonel Scott Moncrieff, now Sir Colin Scott Moncrieff, who then held the post, becoming Under-Secretary of State for Public Works.

Geology of the Nile Valley.

The Nile is the one river of Egypt proper, and its water supplies the place of the rainfall in other countries in enabling man, by the use of the water in irrigation, to raise crops. Were irrigation to be suspended, all Egypt would remain brown and dry, and produce nothing, save some rank weeds, which would flourish during the winter from the winter's rains.

We have no exact data to show at what period the rainfall ceased in Egypt. Professor Hull has elaborated a theory that there was a "pluviôse" or rainy period about the time of the Glacial period here, but as this is founded on the visible erosion of the ravines bordering the Nile valley, and not on visible traces of a luxuriant vegetation, the matter remains in doubt. The only traces of vegetation in the desert are the silicified tree-trunks which are so often visited by tourists from Cairo. These remains are found at other points in the desert west of the pyramids, and notably near the Salâmah oasis, about 125 miles south-west of Wadi Halfah. This ancient flora is considered to be of the Meiocene period, and has nothing to do with Hull's pluviose period. According to Schweinfurth, traces of marine deposits of the Pleiocene period are found in the western desert at a height of 65 mètres above the present level of the sea.

If there has been no local elevation of the Nile valley since that period, this points to the sea reaching up as far as Girgâ. But as all deltaic deposits at the mouths of rivers have a tendency by their ever-increasing weight to lower the land at the lower part of the Delta, it is more than probable that the same flexure raised the land irregularly higher up the continent, and we may have this Pleiocene deposit of shells raised in proportion.

Not much has been done in the way of deep borings, but what little has been done has shown a very startling series of changes. It was, till recently, thought that the limestone cliffs of the Tertiary period at Cairo represented the sea-front of an extensive sea denudation, and therefore it seemed reasonable to expect that borings conducted at Tanta and Zagazig would show the denuded rock at no great depth. Instead of this, a series of fine clays, gravels, and sands alternating with each other have been found down to a depth of 130 feet, or about 105 feet below the present sea-level, and then 215 feet of coarse pebbles, etc. The known borings made in this century (see Report on a series of specimens of the deposits of the Nile Delta, *Proceedings Royal Society*, No. 240, 1886, by J. W. Judd, F.R.S., Secy. Geol. Society) are as follows :—

1799 . .	French Engineer,	77½	feet at	Asyût.	
1850 (?) .	Linant Pasha,	72	„	apex of Delta.	
1860 (*circa*)	M. Horner,	40-59	„	Delta and Memphis.	
1884-1887	Royal Engineers,	45	„	Kafr el Zayât.	
		73	„	Tanta.	
		84	„	Zagazig.	
1885 . .	Do.,	153	„	Rosetta.	(Of this the lower 10 feet on gravel.)
1888 . .	Do.,	345	„	Zagazig.	(At 121 feet gravels met with.)

Professor Hull supposes a period of great rainfall corresponding to the Glacial period. During this period the Mediterranean was a land-locked sea, and great migrations of large animals—elephants, hippopotami, etc.—took place over three isthmuses corresponding to Suez, Sicily-Tunis, and the Straits of Gibraltar. This, he says, would account for the erosion of valleys much below the present sea-level, as the Fayûm and other hollows, and at the same time allow the Nile to cut through the limestone floor of its valley to the depth shown by the Zagazig boring.

The next notable fact is that of a great submersion of the valley, so that we find the sea-beach at Cairo with borings of the *Pholas* up to a level of 67 mètres above present sea-level. In the present valley this would give sea-water up to about Naga Hamâdi, 375 miles from Cairo up the Nile. It was during this submersion that the gravel and alluvial flats on the sides of the hills bordering the valley were laid down, and that the late marine deposits took place in the Fayûm.

After this the sea appears to have washed the foot of the cliffs at Cairo, at a level of + 22 m., for some time, for during this period there have been formed black deposits of Nile mud, the surfaces of which are practically parallel to the present flood surface, and which have been preserved at the mouths of ravines under a conglomeration of pebbles washed down the ravines, and in the Kom Ombo Lake. These deposits have not been noticed by the various well-known geologists who have visited Egypt. At Kena this deposit is immediately on a bed of pebbles washed across the Nile from the Kena Kus ravine. These pebble deposits are the only instance in which the rocks of the Red Sea ridge have been washed into and across the Nile. In all the other ravines the pebbles are of the ordinary cherts, marls, and limestones of the adjacent desert. The existence of Nile mud lying preserved on these pebbles, and of a similar Nile mud buried under local pebbles in other ravines at the same level relative to the present Nile, would show that the mud deposits were contemporaneous, and that there must have been great erosion in the Kena Kus ravine; but this is evidently much later than Hull's pluvial period, and therefore we are driven to think that there must have been a second period of heavy rain. This imprisoned Nile mud is well seen at Akhmîm, Qâw, Sharawnah, near Isna, and at Tura. It also exists on the plain of Kom Ombo. It is so old that it has lime concretions in it. I have only met with it once under the present Nile deposit, near Kena, where a canal passed through it. The very high-level gravel beds do not contain black mud, but a yellow clay arising from the decomposed limestone and washings from the marl beds. The imprisoning of Nile mud is in full action at the present day: I myself have seen an area of more than one hundred feet in width imprisoned below pebbles which were swept out of a ravine at Kafr Disami and Es Saft, about 40 miles south of Cairo. It will be seen that the geology of Egypt in the most recent times, when man was in a savage state, is very perplexing, and the data we have obtained np to date are not sufficient to pronounce authoritatively regarding it. The recent borings at Zagazig and Rosetta show that down to 120-140 feet (40 mètres, say) successive layers of blown sand and Nile alluvium are found, and below that, gravelly deposits consisting of pebbles and subangular fragments exist for another 200 feet or so. The Zagazig boring has pierced these gravels to a depth of 96 mètres below sea-level.

It is somewhat rash to pronounce on one or two sections only, but when we find that the Mediterranean currents sweep all the clay of the present flood eastward, and that there is only a sandy foreshore to the Delta, I think we may assume that the above-mentioned gravels and alluvia were not laid down on a sea face, more especially as the sand, according to Professor Judd's microscopic examination, is wind-blown—*i.e.* the grains are round and polished; sea sand is not round or polished. It seems to me that the Delta was much more advanced than now, and that the Nile flowed through extensive hills of drifting sand.

The gravels would appear to support Professor Hull's theory of a shut-in Mediterranean Sea, as the river must have been a torrent descending a much steeper slope than now. Coming now to the present geological period, in which man entered Egypt as a civilised being, capable of undertaking public works for the benefit of the community, we must first examine the conditions of the flow of the Nile before he sought to control it. The great rivers of the world in the sub-tropical regions are characterised by floods which recur at stated times in the year: in other words, they are fed by Equatorial rainfalls which produce floods with great regularity, though they may vary in volume a little.

When these rivers have excavated their beds through the strata of the last geological period, they enter on what is termed a deltaic condition—that is, during long centuries the changes in the height of their floods and in their bed levels are very small. Each ordinary flood as it comes has a tendency to heap up on the river banks loam and sand deposits, but *not* clay. These loamy deposits gradually get so high that, unless there were a compensating arrangement, the river would flow in a hollow ridge of its own making, and the lands right and left would be submerged and probably remain as long marshes full of weeds. The local action of this deltaic ridge is most remarkably shown in the Delta of the Nile, where for at least 50 years the banks of the river have been strengthened by man, so that the whole flood must flow between them. The result of this is that between the two banks there are "Berms" (or, as the Arabs foolishly call them, *Gezâir*, or islands) which have been silted up, and are now 4 feet higher than the natural deltaic ridge. Before these banks were made the flood used to rise 4 feet less and disperse itself into the Delta basins.

The natural remedy for this is provided by the river itself—sooner or later a breach occurs in the deltaic ridge by the river cutting it away as it twists about. The water rushes into the lowlands, and by its velocity tears out a channel for itself. The velocity of the onward current in the main channel is slackened by the loss of water, and coarse sand from the bottom strata collects and forms a bar, thus forcing the river more and more into the diversion. The flood waters rejoin the original stream at some weak point further down, and eventually the original bed may be abandoned, and an immense bank of sand thrown up at the bifurcation. This is then gathered up by the wind, aided by coarse grass and tamarisk, and eventually for more than a mile you may have a sandy plain with drifting tumuli where the river flowed 10 years before. The rest of the deserted channel takes much longer to silt up. First, owing to the feebleness of the current passing through it, its central portion, though flooded by percolation, is at a lower level than the flood in the new channel, and several breaches occur at various points. These breaches project deposits of sand into the reedy channel, through which the descending water filters and comes out clear. Another sand bar is thrown up at the downstream junction with the new channel. In short, we have in this deserted channel three deposits :—

(1) Fine clay deposited in slowly running water, and in which grow water-weeds, turning it into a deep black-blue clay of extreme tenacity.

(2) Loams deposited by a faster-running current.

(3) Sands deposited by the breaches and inrushes of water in very high floods.

So when the river in the course of another century or so comes back and shaves away the old channel, you will see fine clear sand lying on hard clay, and again the same hard clay lying on loam or fine clean sand.

The whole of the Nile valley has without doubt been built up thus, and there is no place where the engineer opens the soil for deep foundations that he does not find these three deposits. Often he is delighted to find a stiff dry clay within 3 feet of the bottom of his foundations. Alas! 2 feet more excavation exposes a fine sand full of water, which gives him infinite trouble. And as often the case is reversed. He has been pumping hard day and night to keep down the water in a foundation pit, when lo! a clay band is reached, and all trouble is at an end. These deposits are not parallel to each other, nor are their thicknesses equal, nor are they necessarily inclined in the same way as the river slope. They are termed fluviatile deposits in geological text-books.

Even when man does not embank the river, confining it to a definite course, he builds towns on the edge, and the stone and hard material from them generally serve to check the river's vagaries, and restrict its changes within narrow limits of probably one mile or so.

We can see that the Romans, when they succeeded the Egyptian Kings, freely used the Temple walls to protect many important sites. They made long river groynes of cut stones from the neighbouring temples, on many of which are Ptolemaic hieroglyphics. I have not seen any Greek temple stones, and conclude therefore that this river-training ceased after the Roman Empire fell. The Mohammedans have done nothing. We have an instance of a Ptolemaic temple at Qâw holding out against the Nile attacks till 1823, when it was seen by an English traveller. It did not exist in 1844. The Roman wall of the Luxor temple has saved the temple during the last ten years, as it has probably done a dozen times since the temple was protected.

But in looking for traces of man in borings, we must be careful to avoid an old error made some time ago by scientific men, who imagined that if they could find in a delta a fragment of stone bearing marks of human work, they could get at the age of the work by calculating from the known rate of accumulation in the delta. The fact is that these great rivers in flood have a far more disturbing effect downwards than laterally. When a serious obstruction is met with, whether a natural bank of clay, or a rocky foreshore, or the ruin of a building, a hole is scooped out which can be three times the average depth of the river. Thus if we take the average depth of the Nile in flood to be 9 mètres, we can find holes 27 mètres deep. At Cairo, where the river has been forced into one channel, and flows past the Kasr en Nil Barracks and the old town of Bulâq, there is a scoured bed of which the level is minus 6 mètres, or 6 mètres below sea-level; and it is 26 mètres deep at flood-time. If we throw a soda-water bottle off the terrace of the barracks, it will lie quite

24 mètres below the present surface, and if by any great slipping of houses and the re-opening of the old channel to the west the Nile were to desert the present channel, this soda-water bottle might in 30 years be covered with 24 mètres of soil, and might be pronounced 24,000 years old!—the Delta rising at the rate of a mètre in 1000 years.

Ancient Irrigation.

We have no definite accounts of irrigation in Pharaonic times, as we have not yet found the mummy of an engineer who was so much attached to his science as to have his *aide mémoire* buried with him. But various inscriptions of provincial governors and of kings record the fact that canals were either well maintained or restored after times of disturbance. Thus in the 12th Dynasty we read in the cave tombs of Beni Hasan: "He determined the waters by what was in the list." This probably alludes to the times of opening the basins.

It cannot be expected that any traces of bridges or regulators should remain, for by their very use they get into a dangerous condition through erosion of the ground on the downstream side. This erosion sooner or later brings the bridge down, unless it is carefully repaired. Thus in times of war or internal troubles the peasantry would soon wreck a bridge by careless regulation. Once a bridge has gone, the ruins are rapidly broken up by the peasantry to mend their villages, and protect them from the waves of the floods. The only old bridge in Egypt is one carrying an old road over a large canal dug by a Jew in the 13th century A.D. The bridge was built in the 14th century, but is not a regulating bridge, and as the Jew's canal has silted up, the bridge stands on dry land, the arches being filled with soil.

Irrigation by Basins.

Up to 1830 the whole of Egypt was irrigated by the Pharaonic system of basins. This system is traditionally referred to the 1st King of Egypt, Mena (Greek Menes). We may suppose that he came into Egypt or conquered the whole of Egypt, and found the Nile in a very untrained state, liable to great floods and irregular movements. The first thing he would do would be to construct a series of banks reaching from the desert on one hand to the high deltaic ridge on the other. The conditions under which he would work must have been much the same as now, save that probably the deltaic ridge was more marked than now, and the people were all living on the ridge or on the desert. To avoid too great a difference of level, he would place his banks at such a distance apart that the difference between the horizontal planes of water would not be more than one mètre. As the slope of the country is $\frac{1}{10000}$, this would give a bank at every 10 kilomètres. At first he would, experimentally, have each basin fed by one or more canals direct from the Nile, and when a basin was brought up to Nile level, *i.e.* when the lower canal ceased to flow, it would be closed; or, as often happens, if the Nile fell in the middle of the flood season, he would also close the canals to keep the water in the basin. When the flood came to an end he would commence to let off the water. But as the canals filled the basins in about 35 days, and had by that time got much silted up, he would have to seek some other method of letting the water flow off. If he took as long to empty his basins as to fill them, he would find that the sowing season had passed, and that there was great risk of the wheat and barley crops being blighted by the hot winds in the end of March.

Considering these things, he would come to the conclusion that he must cut the basins one on to the other, commencing from the south, so that each basin might be brought up to full level for a few days to wet any piece that was dry, and at the end of each chain of basins determined by natural features he would cut the last basin into the Nile. This point would be where the Nile had come fairly near the desert or where a great branch took off.

In some years there would be breaches in the basin banks, and this would cause a great loss of water if the breach occurred when the Nile was falling, in the middle of September, for the whole series of basins of equal area would go, one after the other. To remedy as much as possible the evils of this, the King would see that the last basin of the series should be very much larger than any other, so as to act as a compensating reservoir which could hold a large quantity of water without breaking. This last or tail basin being big, its discharge would also so swell the river that its great mass of water could not pass rapidly into the Nile, as the river would be so swollen by the great inrush of the first waters that it would prevent the remainder of the water flowing out like a torrent. It must be remembered that the sowing of the land under this system is done by throwing the seed on the wet mud, which is soft to a depth of at least 6 inches. The peasants can only sow a certain amount daily. A sudden retreat of the water leaves too much exposed, the land rapidly hardens, and ploughing has to be resorted to. This is difficult, as under this system of agriculture plough oxen are not kept.

This system does not provide for the submersion of the high land near the Nile. In the old days, and I believe up to very recent times, the basin canals ran through the high lands, and the people, in an ordinary Nile, irrigated these lands by lift, sowing autumn crops called *Nabâri*, such as *sorghum*, maize and vegetables. If the Nile fell below good-flood point, they only lifted a little more, and in a high Nile they enjoyed unlimited water for washing the land, etc. In the Pharaonic times so good were the arrangements for clearances, and the *corvée* organisation was so perfect, that I think in the case of a low Nile the canals could be cleared out even during the flood, and the number of men on the lift machines indefinitely increased. From old maps, such as those of the French expedition, I have every reason to believe that this old system of straight delivery canals existed up to, certainly, 1830. There are numerous traces of old silt banks, where such masses of silt have accumulated that even in 50 years they have not been removed for manure. All these are straight delivery canals. There was a considerable failure of the Nile in 1790-1797, and it is not probable that anything was done to improve the canals. Again in 1835 to 1839 the floods were decidedly poor. The

French engineers had arrived in the country, and it is probable that after these years, when such activity was being displayed in the Delta, the canal in the high lands was made. It commenced from the head of the southern basin of a series and passed along the high lands, cutting all the small canals, and feeding them at a higher level than formerly. Also, probably, at this time there were some bridges built in the cross banks in the low lands to admit of the passage of water during the flood from one basin to another; and large canals for a series of low land basins were also made. In ancient times there had been low land canals, but they were really ancient arms of the Nile (and were treated as such), having longitudinal banks with basins and their own deltaic ridges.

The primitive arrangement worked fairly well, so long as there was no great pressure of population or foreign debt, and so long as the peasantry were semi-slaves or serfs. In a bad year, if one-third of the land was unsown in the Nile time, the other two-thirds produced well, and the part unsown could be extensively watered by hand from wells by serf labour.

But when the Khedives of Egypt came into the European market for cash, they found that the old style produced serious deficits in their treasuries, and they gradually began to construct works which should have the effect of utilising the floods throughout the valley.

It will be seen that Upper Egypt down to Asyût is divided naturally into series or chains of basins, which are divided from each other by gravel or rock spurs from the desert. If we have a quantity of water impounded in a series of basins in the end of September, we cannot utilise it if we have not a canal through the desert spur. And if we have no passage under the low land canals, we can only drop it into the low-level canal, even after the desert spur has been pierced by a canal. So that a syphon or ramped culvert under the low-level canal becomes necessary, and by it we are able to pass water at the end of the flood into the next northern high land canal, and from this it is but a step to convert the canal piercing the gravel ridge into the high land canal itself—*i.e.* to transfer its head south of the ridge.

After this we have to deepen all canals to allow of a Bad Nile passing a considerable volume down every canal.

I will here explain what is meant by a Bad, Good, or Flood Nile. The gauge at Aswân, called the Nilometer because its original function was to register the flood of the Nile, is carved on the rock. It was in use in the Ptolemaic period, and it is believed that its cubits are nearly the same as those now in use, which were cut by Mahmûd Pasha el Fellaky, a scientific Turco-Egyptian, who died about six years ago. The cubits now in use are 0·54 of a metre, and the floods of the Nile (or "the Nile," as the Arabs call the flood) varies between 13 cubits and 18 cubits. In a monument in Rome the Nile is represented as a man with sixteen small children climbing about him, showing that 16 cubits was thought a good Nile. At the present day it requires 16¼ cubits to irrigate by flow the greater part of the islands and high lands in the Nile valley, and 17½ cubits flood everything; 17 to 18 cubits continuously for any time, more especially if late in the season, after filling the basins, produces great pressure in the Delta, and the whole population turns out on the banks.

If, on the other hand, the Nile is between 14 and 15 cubits, there is no direct free flow in the high lands, and if it does not rise above 14 cubits, a most disastrous failure of supply takes place in the canals filling the basins.

The lowest Nile that we know of since 1737 was in the year 1877, when the Nile rose for a very short time over 13, and its average for thirty days of flood was only $12\frac{3}{4}$, cubits. The canals were at their worst, and quite out of order, and a real famine was the consequence. The result of that year overthrew Ismail Pasha, and therefore was a blessing in disguise to Egypt. In 1888 also there was a very low Nile, the average being $13\frac{19}{24}$ cubits. Over 250,000 acres were left dry in Upper Egypt, and the financial loss was very great.

In consequence of this bad year, Government resolved to set the canals in order by deepening and extending them, and building all the syphons necessary to ensure water being brought from a sufficient distance from the south to guarantee irrigation in a bad year. The banks were all provided with regulators, and all the necessary escapes were made into the Nile. These works have cost over £600,000, and were very nearly finished when I left Egypt in the summer of 1892. In an ordinary year the new works will ensure a far more equable distribution of the rich red water of the Nile, and thus maintain the whole soil in one uniform richness. The cost will easily be paid back in ten years, and the greater number of the structures will be capable of being utilised in the distant future when perennial irrigation is introduced into the high lands of Upper Egypt.

Summer Irrigation.

To introduce summer crops, such as sugar, cotton, or rice, we have only, in the first instance, to dig wells and lift up the water by machines. This method is suitable to cultivators who have small holdings, and who live in a self-supporting fashion. It is not economical, nor is there a maximum of produce for a minimum of labour expended. For semi-barbaric countries, liable to be upset by war and incursions of semi-savage enemies, it is excellent. There are still many tracts of Upper Egypt cultivated thus, and the well-water is practically inexhaustible, as the Nile-water is never more than 35 feet below the surface even in summer.

But to have summer cultivation on a large scale we must bring the water of the Nile to the surface, either by a canal or a low-grade slope taking off far up the Nile, or by pumping water by steam power up to the field level or into a large canal, or we must make a dam in the Nile to raise its summer level, so that the cost of excavating the canal may not be excessive. The Ibrâhîmîyah canal in Middle Egypt is an example of the first method. The pumps of Khatatbah and Atfah (in Arabic *Atf*), before they were superseded by the Barrage and the numerous pumping machines in Upper Egypt and in the Delta, are examples of the second class. The Barrage at the apex of the Delta is an instance of the third class; and when we extend the summer cultivation (*Sêfi* in Arabic) to Upper Egypt there will be also barrages made for the high land canals.

When summer irrigation was introduced into the Nile valley of Middle Egypt it was only given to the high lands. The low lands are still under basin irrigation. The quality of the water delivered to these basins has been much poorer than it was before the Ibrâhîmîyah canal was dug, as a sufficient number of syphons was not made to pass the fresh water of the Nile under the canal.

The Delta canals have as their main lines various branches of the Nile of the greatest antiquity. On these old canals are situated towns founded in the ancient Empire, probably 3000 B.C., and on others many towns celebrated in the history of the time of Moses.

As long as the Delta remained under basin culture these canals were the supply canals, each on its deltaic ridge. They had deep drainage canals between each pair which carried off the basin water. These canals are called *Masraf* in Arabic. But when Muhammad Ali introduced summer or perennial cultivation, the canals of supply and the Nile had to be embanked, so that the floods might pass down without flooding the fields as before, the water being carried above soil to admit of free-flow irrigation.

Soon after the introduction of perennial irrigation, the village notables in council every year decreed new subsidiary canals, and by 1880 the length and discharging capacity of the distributary canals were about eight times that of the requirements of the land. Dams were made in all directions with the effect of infinitely increasing silt deposits.

The drainage canals (really meant for excess flood-water) were surcharged in the flood by the water in great excess in the numerous subsidiary canals, and the maintenance of their banks was most difficult. Their new function, that of drainage of the water used for soil-washing, was quite disregarded, and they finally became irrigation canals. In a short time they themselves made ridge deposits, and the lands lying near the drainage canal were ruined, as they were surrounded on all sides by high-level water even in summer, the original drainage canal being dammed up in reaches.

We have had the very greatest difficulty in disentangling this complicated series of canals and drains, and in many instances the vested rights have been too much for us, and the expense of making new drains far beyond our budget resources.

This state of affairs is worst in the Eastern Delta, and least in the Western Delta, where, up to 1885, water in summer was very scarce.

In concluding this sketch of irrigation I must give all praise to the legendary King Mena, who introduced the basin system. One never can find out what happened before the time of these extraordinary men whose antiquity is such that all chronologies are modern compared with theirs. They appear before us as masters of engineering, mathematics, agriculture, civil government, and organisation of masses of men on works, whether in the desert or near their strip of fertile land. We now know by the cumulative results of human experience that the only way to keep a deltaic river from being a source of great and frequently recurring calamity is to adopt the basin system of King Mena. As the alluvial deposit rises on the ridge near the river, so does it rise in the low lands off the river, and all through Upper Egypt the highest flood is only 8 to 9 feet deep in the low lands. In Italy the Po is often 24 feet to 36 feet above the land.

In China we read of the horrors of the Yangtse Kiang inundations, where photographs show us breaches in the river and the *bed* of the main stream exposed to view quite dry, the water having rushed out to the side.

America, even from the 200 years of occupation by civilised man, is now beginning to awake to the possibility of the most awful inundations by the Mississippi deserting its course, and a very serious report has been addressed to Congress on this subject.

But the mystery remains, "Where did King Mena get *his* experience?"

Salt in the Soil and its Cure.

The great bugbear of the Egyptian cultivator is the ever-increasing quantity of salt in the soil. Many tourists, even of a scientific type, who travel in Egypt, say without thinking—"Salt! why of course there must be large quantities of salt in the soil of Egypt, as it emerged from the sea in a recent geological period, and all Egypt has been won back from the sea by the Nile depositing its mud in the sea." This error is much more common than one would think in the writings of scientific travellers on the Nile and Euphrates valley.

1. The facts are, that the Nile delta and the Nile valley were not laid down in the sea; that is to say, the surface cultivated near Cairo to-day consists of mud and sand laid down by fresh-water deposits to a depth of at least 50 feet—exactly similar to that laid down at Asyût or Isna, hundreds of miles up the valley.

2. If the sand and gravel, washed and arranged by the sea when it was 40 feet above the present Cairo surface, and which are composed of the detritus of the Eocene cliffs overlooking Cairo, etc., were salt when the sea finally retired from them, they have been practically cleaned of their salt by the heavy, though infrequent, rains forcing the salt down to low levels by percolation. In fact, all soils, whether clays, sands, or gravels, that have emerged from the sea in quite recent periods, are not salt, and it may be laid down generally that, unless we have evaporation greater than the rainfall, we shall not have salt deposits, even in a district that has been recently under the sea. The only exception to this is found in sea-shore lagoons, where there is great solar evaporation going on, and the loss is made up by the sea at each tide.

The analysis of the Blue and White Niles taken at Khartum shows the main source of the salt in the Egyptian water. We find from an analysis taken between 1875 and 1878 that the following were the number of grammes of salt in one cubic mètre of water during summer and at the flood. That is to say, the water passing Khartum was taken at the lowest and flood seasons, and this water would pass Cairo in June and August :—

	Summer. Grammes.	Flood. Grammes.	
White Nile . .	40	130	in one cubic mètre of water.
Blue Nile . . .	21	153	Do.

The other great source of salt in the Nile is from the rains in the desert which fall with great irregularity from December to April on the desert surface, where it is denuded by the wind and the original rocks of the Tertiary and Secondary formations are disintegrated by the action of alternate heat and cold. There is a very considerable amount of salt in veins in these marls and limestones, which weathers out on the surface, often disclosing small pockets of salt. When one of the cyclone-like rain-bursts falls, the surface is scoured and a large quantity of water runs down the Nile, carrying fine mud highly charged with salt. This goes into the Nile direct, or spreads out in the adjacent fields and sinks in, leaving much of its salt in the upper soil. But this is only a local torrent, and occurs only in winter and spring. Part of this rainfall sinks into the desert and comes out in the subsoil of the basin, sometimes as brackish springs. But these springs are often quite sweet, so that this source of salt is not a very constant one. It does, however, have its effect; for the summer low water is undoubtedly fed by these springs, and the proportion of salt in summer at Cairo rises considerably, and is in June double that in August.

It must be noticed that the waters of the White Nile pass through the marsh of the ninth degree of latitude. In the hot weather the evaporation from the marshes must be enormous, and though we have no satisfactory analysis of the Nile water at Fashoda to compare with that of Gondokoro, we can safely assume that the water issuing from the marsh must be more salt than at Fashoda. Also, on the long course of the Nile between Khartum and Cairo (a distance of 2740 kilomètres or about 1700 miles), the evaporation is at the rate of at least 11 mm. a day. The time taken to flow from Khartum to Cairo is at least 60 days, and thus we have an evaporation of nearly $\frac{3}{4}$ of a mètre from the water surface. Taking it in another light we find that the daily loss is about 7 millions of cubic mètres, or not less than 1-6th of the supply. All this evaporation concentrates the water and makes the dissolved matter larger in proportion. When the water impregnated with this very considerable amount of salt is used for irrigation in summer, it is customary to use water every 20 days for cotton and every 15 days for sugar cane. Taking the cotton watering to commence on March 15th, and to go on to August 15th, we have in these 5 months, or 154 days, probably 8 waterings, at least 6 of which are from the heavily charged summer water. Part of this sinks into the subsoil to a point below the sun's action, but a very large part of it either evaporates from the surface or is held in the subsoil and thence evaporated by the sun. I have myself seen this in an irrigated field when a well was being dug. A distinct band of hard, dry earth intervened between the damp surface soil and the lower soil into which the subsoil water was drawn up by capillary attraction. The result of this constant evaporation in the upper soil is that the first 3 feet of the soil get very salt, until they are cleaned by the processes to be described further on. When the soil is thus charged with salt, it loses its natural tendency to crack when dry, and then there is less heat admitted into the soil to carry on the chemical processes of "Nature's decay;" and eventually we come to a point where the soil does not crack at all, and the humus is quite destroyed, the land being rendered barren beyond recovery. When the soil is in this state the beautiful sepia-coloured clay of Egypt is changed into a chocolate-coloured powder, which is blown away by the wind and deposited on neighbouring fields, which are not much injured by it.

M. Matthey, a French chemist, has shown in the Egyptian Institute *Proceedings* that freshly deposited Nile soil contains only a trace of salt; but after 6 years of agriculture the salt appears as 0·332 per cent., or 3 parts in a thousand, notwithstanding the ordinary processes of washing incidental to agriculture.

Of the existence of this salt there can be no doubt even to a passing observer. The ridges in the cotton fields after irrigation have often an appearance of hoar frost, and the Cairo streets, watered copiously twice a day show the salt crystals glittering in the sunlight. You will see from the above details that the Egyptian farmer has not only to face the ordinary deterioration of soil by exhaustive cropping, but has to fear his land getting too salt for agriculture. The *fellâh* (peasant) knows the remedy from childhood, and when he sees the land getting salt he says his land is sick (*ayyânah*), and knows the remedy well—*Plenty of fresh water.* Alas, in many cases this is not obtainable, and in other cases he has nowhere to throw away the salt-laden water after use. In the high lands on the edge of the river in the Nile valley he cannot always command fresh water, for the land is high and the water in the canals is often expended in basin irrigation, and he has to lift it with his *shadûf*, or bucket at the end of a long pole. So, in an ordinary flood, he has to irrigate by the slow *shadûf*, and he cannot throw up water quickly enough to cause a large amount of water to pass down into the subsoil carrying the upper salt with it. So he only makes matters worse. In the Delta, owing to the height of the flood-water above the soil, the farmer can generally command, during the flood, a sufficiency of water, but after he has put it on his land and it has absorbed the salt in the upper or cultivated crust, he cannot discharge the contaminated water on to his neighbours' fields nor into the canal, so he has either to let the water lie on the land and sink into the soil, carrying with it the salt to a level below the cultivated crust, or he tries to find a public drain into which he can discharge the water. This is often not accessible, and then he has to try and join with his neighbours in making a private drain into the nearest public drain, or he and his neighbours return their dirty water into the canal, an act punishable under the new Canal Act.

Now, the Delta, as you know, descends to the sea at a very gentle slope, and the water of both irrigation and washing flows down towards the sea very slowly, commencing at a depth of about 5 mètres below the soil. So long as this water is more than 1 mètre below the surface no harm results. But when, owing to the nearness of the sea or of the great lakes, the water cannot sink any further, it rises close enough to the surface to be evaporated by the sun. A great stratum of salt soil is the result, and irrigation, especially from high-level canals, only brings it up more and more. The soil then loses its power of cracking, and in winter shows a vast sheet of white powdery crust, and in many cases is irretrievably ruined.

The irrigation of rainless countries is not studied much in Europe, nor does our Indian experience throw much light on the subject, as our Indian plains are visited by very heavy rain once a year, which washes away the salt. In America, however, we have rainless regions which have been irrigated for the last thirty years, and the scientific agriculturist has had some experience. The literature on this subject is increasing, and many remarkable facts are being discovered. The Professor of Agriculture in the University of California, Mr. E. W. Hilgard, has written, in 1890, some very interesting accounts of experiments in this direction, and has collected a large amount of facts about alkali lands. These lands are afflicted not only with salt as in Egypt, but with carbonate of soda, which is much more difficult to get rid of. Professor Wallace of the Edinburgh University has these pamphlets.

The question of providing drains at a lower level than the surface of the soil is forced on the Government as a work of general utility, since village communities cannot combine sufficiently to dig and maintain the large side and main drains.

The process of drainage in Egypt is nothing like what is understood by drainage in Scotland. Here we lay down pipes or loose stone drains in the subsoil, so that the rain water may not lie stagnating on the fields. But in Egypt, where, properly arranged, the drainage system is the exact converse of a canal system, a drainage channel is a wide canal dug in the soil of a width varying from 4 to 15 metres (13 to 49 feet). As we have main canals of supply, distributary canals, and minor distributaries, we have also minor drains discharging into large side drains, which discharge into the main drains. These last discharge into the great lakes in the Delta, and in Upper and Middle Egypt into the Nile when it is low, and into the adjacent basins when the Nile is high.

The Egyptian Government, between 1850 and 1883, allowed matters to drift sadly as regards upkeep of drains. In Middle Egypt it did nothing, and the sugarcane lands on the Ibrâhîmîyah canal in 20 years became seriously deteriorated by salt, more especially the lands lying next the basins where the lands lay lower than the level of the water in the adjacent basin. These fields, however, received at the same time, much of the washings from the higher fields nearer to the river. The great boundary drain (the Muhêt) was choked up with weeds, and was even used as an irrigating channel at many points.

Again, in Lower Egypt, though the upper part of the Delta between the level of + 18 M and + 6 M was naturally kept in good heart by the process of washing into the subsoil, the whole of the rest of the land was deprived of drainage facilities by the practical abandonment of the large trench drains, which were either choked up with weeds or dammed up by fishermen who were in collusion with the local engineer. And on the slightest failure of canal supply the people used to irrigate from the drains, using the water which had done its duty once at a higher level in cleaning the rice fields. Nay, more, they had erected permanent machines (*Sâqiyah*) which brought with them rights and vested interests, and, when we came to set the drains in order, they wanted compensation and even threatened civil action against Government for disturbance. Many properties lying near the drains deteriorated very rapidly, though their land level was as high as 4 mètres above the lakes. The drains were so much choked up by weeds and fishers' dams that the water in them used to stand above the soil, and banks had to be made along the drains to keep the water from drowning the crops! If the drains had been clear there would have been a fall of at least 1 mètre into them.

In 1884 and 1885, before we obtained money for repairs of drains and canals, the *corvée* (or forced labour) could not overtake the task of drain-clearance after the canals had been cleared. The village agricultural councils of course voted the canal clearance first. The methods of washing the soil are three in number, exclusive of the great basin system in force in Upper Egypt.

First, By flooding the fields to a depth of 6 to 9 inches by a general flush of water, and then letting the water partly sink into the soil and partly go back to the Nile or canal. This is generally done at the end of the flood, when there is great command of water and the whole country is flooded, but many landowners practise it with small quantities of water, trusting entirely to the absorption into the soil.

The *second* method is by washing the fields with a large amount of water, let on continuously for 10 to 14 days, and discharged constantly at the lower end of the enclosure made to contain the water.

These enclosures embrace many fields and have banks of such a height that about 1 foot of water will lie on the surface of the ground. This method is generally adopted during Nile flood, as the water, rich in fertilising mud, is run on and the mud settles down on the field in a film. In Middle Egypt, however, it must be practised in the winter, as there is no proper outlet for drainage water when the Nile is high. The operation is termed *colmatage* in French and "warping" in English. The enclosures are most economically made to embrace 1000 acres, but these large operations require much plant, and therefore the enclosures (termed *Hoshah* in Arabic) are more often 200 to 250 acres in extent. This method can only be practised when there is a large drain close at hand, and where the canal system is more than sufficient for the ordinary irrigation of the surrounding estates.

The *third* method is by a close reticulation of small drains running into a larger drain parallel to the canal supplying the water. The parallel drain is 150 mètres from the canal, and the cross drains are 50 mètres apart. The ground is thus cut up into little blocks of 150 by 50 mètres, or about $1\frac{1}{2}$ acres each plot. This is the size adopted by the Abukîr Drainage Company. Other landed proprietors make smaller ones, even to half an acre. Generally speaking the filtration system is used, no surface water being turned into the drains. Owing to the instability of the banks of salt soil, a depth of 6 inches is the safest to use over the fields.

According to the Abukîr Company's engineer, the cost is about £1, 10s. per acre for the year's washing. The second year's operations cost also £1, 10s., so that an acre of land which is not absolutely salt-stricken may be reclaimed for £3. (See note at the end of this paper, giving statistics of this Company's arrangements.)

The Fayûm.

The Fayûm is a depression apart from the Nile valley. It is shut in on all sides by the desert, save one narrow passage through the hills bordering the Nile valley. It slopes gradually away from the east, or Nile, side, and terminates in a wide shallow lake with an area of about 78 square miles.

The lake water is brackish and undrinkable, but the fish are of the fresh-water type. Though the Fayûm is always talked of as a depression, it does not appear such to a casual observer. The water of the lake, the Birket el Qurân, is now 42 mètres below sea-level and about 68 mètres below the Nile in flood. The surrounding low hills and desert are, however, sufficient to render the climate more equable than that of the Nile valley and Delta, affording protection from the high winds of the one and the fogs and cloudy weather of the other.

The fig and grape grow well in the Fayûm, and have a good flavour.

Where the soil is deep and well washed, the yield is good, and there appears to be less risk of worm in the cotton and of rust, etc., in the cereals. The *sorghum*, or large millet, grows very well, and I have myself measured it $14\frac{3}{4}$ feet high.

But unfortunately the black soil of the Fayûm is not deep, save where the old Nile deposits have settled on the flat portions; and the supply of water is decidedly brackish, as it comes from the Bahr Yûsif—originally, no doubt, a depression carrying off the Nile floods under the western hills, and which has, since the creation of the basin system, been employed as a basin feeder and a basin drain. The land between the Nile and the Bahr Yûsif drains into the latter when it is not in flood, and the percolation water of the basins returns from the hill side throughout the year. Even before the opening of the Ibrâhîmîyah canal, the Bahr Yûsif was a perennial stream fed by this drainage water and must have been very brackish indeed. About 250,000 cubic mètres *per diem* are obtained from this source at present. This natural supply is not capable of irrigating more than one-fifth of the cultivated area in summer. The Ibrâhîmîyah canal furnishes the remainder of the summer supply at the head of the Bahr Yûsif at Dêrût.

Before 1865, when there was no Ibrâhîmîyah canal, the people in the Fayûm used to collect water in small reservoirs called *Khazzân*. These reservoirs held up at their lower end about 20 feet of water. In the winter they were partially emptied by a sluice and the higher parts were cultivated, and at the end of winter they were filled up again. Some of the more important ones were filled in September and retained full during the winter. As the Fayûm has no wells in it, the importance of these reservoirs must have been very great. The last one was abandoned in 1885 and its cultivable area sold.

On the eastern edge of the Birket el Qurûn there is a wide flat foreshore—the result of many centuries of erosion from the lands by the irrigation canals, etc. Owing to the large amount of waste water from the Bahr Yûsif and to the existence of an old basin, called the Hod et Tuyûr, the level of the lake rose at least 17 feet between 1870 and 1883, and about 10,000 acres of cultivable land were submerged. The measures adopted to remedy this state of affairs were to abolish the basin irrigation of the Hod et Tuyûr, making it *sêfi*—that is, cultivating cotton, etc., in summer, and secondly, to prevent an undue amount of water passing into the Fayûm at seasons when it was only required for the corn mills in the ravines. These measures have been very successful; the lake has been lowered 3½ mètres since 1885, and cultivation has begun on the submerged flat, though not so rapidly as could be desired, owing to a lack of summer water, which renders rice cultivation impracticable.

The water that reaches the Fayûm in flood-time is not so red—*i.e.* highly charged with deposits—as the Nile itself, but still a very large amount of good mud is put on the Fayûm fields, and there is not so much sand in the soil on the banks of the Bahr Yûsif.

The salt, however, is greatly in excess of that in the Delta, notwithstanding the very great facilities for washing enjoyed by the Fayûm cultivators. I think the reason is that they have a dread of surface washing, as they lose an appreciable amount of soil on each occasion owing to their carelessly discharging the water down the steep slopes of the Fayûm. And again, washing by percolation is not so advantageous as in the Delta, for in many places the rock is found at 4 feet below the surface, and in other places a hard impermeable pan of marl occurs.

I have not in this lecture made any reference to the most interesting of all questions, the antiquities of Egypt, as there would be no time to do so; but in the case of the Fayûm I will make an exception, for its great archæological interest turns on an irrigation work, and the irrigation engineer until quite recently has not been consulted by the archæologists, who as a rule are not engineers, and have in the last forty years been grievously misled by the only engineer whom they did consult, viz., Linant de Bellefonds Pasha.

The great problem of ancient irrigation is, Where was Lake Mœris? We are told by Herodotus, B.C. 450, and Strabo and Diodorus, B.C. 25, that the Lake Mœris was a great sea-lake sheet of water between the Nomes of Arsinoë and Memphis. Into this lake the Nile ran during and after the flood, and when the river had sunk, the waters of Lake Mœris returned gradually to the Nile and thus maintained a good summer supply at Memphis and in the seven branches of the Nile.

Now, a line joining Memphis and the Medinet el Fayûm (Arsinoë) passes through the northern half of the Fayûm, and traces of a bank and colossal statues are in existence at the present day. Herodotus says the

Labyrinth, or great temple, was on the shore of Lake Mœris, and he also saw "in" the water (or more probably across the water flooding the fields of the dry part of the Fayûm) the two pyramids with colossal statues on them. The water of the lake would be seen at the back of these statues stretching to the distant horizon.

Dr. Petrie had the good fortune to find the nose of one of the statues in the ruins of their pedestals, and a figure of one of the Nomes, or provinces, into which Egypt was divided. He also dug down on the side of the Labyrinth, and found that the great temple was now represented by 7 feet and more of chips, made by the masons of Roman and Ptolemaic times when they broke up the Labyrinth to beautify the temple at Arsinoë, which was embellished and restored by Ptolemy Philadelphos in honour of his sister-wife Arsinoë. There are many traces of the founder of the temple and Labyrinth, the great Twelfth Dynasty King, Amenemha III., whose hieratic name is Maat-en-Ra. Herodotus appears to have listened to his dragoman as credulously as the present race of tourists, when he told him the lake was dug out by a king called Mœris in the time of the twelve kings of Egypt, about 250 years before. This was a time of great national decay and intestinal trouble, and therefore very unlikely to be one in which so great a public work could have been executed. We now know from inscriptions that Amenemha built a city and temple at Shad (the Arsinoë of Ptolemy), and if he did not actually commence the reclamation he perfected it. We also find from the sarcophagus of a high official buried close to the Labyrinth in Ptolemaic times that he bore the titles of overseer of the gate of the great lake and overseer of the cutting of the mouth or head of the lake.

The province in ancient times was called Tâ-sha, the land of the lake; and in Coptic times *πιομ*, the sea, from which the word Fayûm is derived. The word Mœris is a Greek form of Mar-ur, softened by Egyptian speech into Mi-ur, the great reservoir.

The Egyptological world, between the time of Lepsius in 1844 and that of Mariette in 1860-76, imagined that Lake Mœris was a small, high-level, shallow reservoir made out of the upper part of the Fayûm. This basin was supposed by Linant Pasha, the great consulting engineer of Muhammad Ali and his successors, to be fed by a high-level desert canal starting from near the town of Asyût. The water was thus about 20 feet above the Nile valley, and was let off into the river by sluice gates. Linant Pasha supposed the existing bank of Edwah and the wall of Minya el Hêt to be boundaries of this lake, as his levels showed their present height to be sufficient for this purpose. Thus the remainder of the Fayûm was cultivated. Recent levels have shown Linant Pasha's levelling to be 38 feet out (11·8 mètres), and it is, of course, an impossibility that the Fayûm land should be higher than the Nile valley, as the Nile valley was first deposited, and then the Fayûm.

Recent levels have shown that the old bank, the site of the colossi at Biahmu, the original soil of the temple of Arsinoë, and the marks across the lake on the west face are all about 22 mètres above sea-level, and though the southern bank has been probably levelled (having been made with earth and not sand as the northern bank), we can suppose that the circuit of bank was closed parallel to the Bahr Yûsif.

We can thus suppose without any difficulty the greater part of the Fayûm flooded to 22 mètres above sea-level, and as its shores would be the desert, we can see what Strabo means by saying that the shores are similar to sea-beaches—*i.e.* sandy.

To show how discontented Egyptologists were with Linant's small Lake Mœris, I quote from the translation of M. Maspéro by Miss Edwards. M. Maspéro is so worried by the defects in Linant's solution that he says:—"Recent explorations have proved that the dykes by which this pretended reservoir was bounded are modern works created probably within the last 200 years. *I no longer believe that Lake Mœris ever existed.*"

But M. Maspéro, through the whole of the thirtieth page of his *Egyptian Archæology*, shows himself very badly informed about existing irrigation in Egypt. This shows how a man can live ten years in the country and travel all over it many times, without becoming acquainted with the facts of irrigation, if he is not an agriculturist or an engineer. Brugsch Pasha, the great modern German Egyptologist, as recently as April 1892, declared in a paper read before the Egyptian Institute—"Dépuis Linant et Lepsius aucun savant sérieux du nombre des géographes et des Egyptologues ne s'est opposé à l'opinion émise par ces deux illustres auteurs," thus sustaining the Linant theory in the teeth of the facts known to Schweinfurth and Petrie, both *savants sérieux.*

Those who wish to thoroughly get up the facts and data collected in the last eight years, should consult *The Fayûm and Lake Mœris*, by Major Brown, R.E. (Edward Stanford, Charing Cross.) In this well-got-up little work they will find much to interest them and set them thinking.

As to tourists visiting the Fayûm, I regret to say that modern progress has halted there somewhat; with the exception of a few roads made in the last three years, and a branch railway taken out from the old central line, no progress in civilisation or in providing necessaries and comforts for travellers has been effected. Save one small Greek hotel in the chief town of the Fayûm, there is no accommodation whatever for a stranger.

When one takes into consideration the great range of temperature at Cairo (and its smells!), and the chilly winds of the Helwân desert, and the very short winter season at Luxor, one is struck by the possible future of the Fayûm as a really quiet, healthy resort. If a hotel were established on the low-level plateau about 30 feet above the lake, and a few rowing and sailing boats put on the lake, I feel sure a delicate person would enjoy the long quiet winter of the Fayûm, and avoid the noise and smells of Cairo, etc. The Copts of this out-of-the-way region would be an interesting study, and to others of a scientific turn of mind the archæology and geology would be interesting, but, above all, the delicate ones would have quiet and delicious air.

Reservoirs and Water Storage.

Although in 1884 much water ran to the sea in summer, it was soon found that, after we had raised the Barrage and given a largely increased summer supply to the eastern and central provinces, the people were not slow in availing themselves of the privilege. In fact, owing to the fall of one-third in the price of cereals, the Egyptian cultivator soon saw that, if he was to pay his rent at all, it must be by cotton. I regret to say that the statistics of the years 1873 to 1883 are most deficient, save in the amount of cotton actually exported. But it is a matter of common notoriety that the yield per acre previous to 1880 was as much as 40 per cent. more than now, save where agriculture had been most carefully carried on; and if we take into consideration the large increase of vegetable cultivation among the peasantry, we find that the summer cultivation of the Delta must have increased in area by at least one-third. People, certainly, do not use more water on a field than in the old days. It used to be a quite common rule to irrigate every 10 or 12 days. Now, with the rotations of water delivery, they cannot well give more than one watering in 20 days. The scarcity of water began to be felt in 1885 and in that year we had to throw an earthen dam across the mouth of the Rosetta branch in order to prevent the salt water coming up to the Atfah pumps, which supplied Alexandria. In 1886 the supply passing into the Damietta branch was so small, owing to the greatly increased discharges of the central Delta canal and of the canals for the eastern Delta near Cairo, that a rough stone dam was thrown across the Damietta branch in summer to feed the Bahr Mues, which irrigates down to and past Zagazig, and the next year another dam was thrown across the river below Mit Ghamr to raise the supply in the canal feeding the Bahr Saghîr and the riparian canal to Damietta. This diminution of supply brought the salt water up to Damietta, and we had to dam the river at the Damietta mouth with earth. In 1890, when the Barrage repairs were practically completed, and the new Rayyâh Taufîqi, or eastern riparian canal, had been opened, there was no need of any dam at the mouth of the Damietta branch, and it was not made in the summer of 1890. Owing, however, to the differences of levels in the newly enlarged riparian canals, on both banks there was great irregularity of delivery of water, and, in some cases, the owners of engines on the Nile itself had to take to their engines, and for a few weeks they threw water so salt that the cultivation sickened. Since then, great efforts have been made to force the water down to the furthest limit of cultivation; and, though they have been successful, the proprietors of the numerous large stationary engines on the Nile banks look back with regret to the time when *they* had as much water as they liked to pump, and the rest of the water, now used with great effect, used to flow out to sea, and keep the salt water away from their doors.

We have now arrived at a stage in the summer irrigation of Egypt where the available natural supply has been completely exhausted, and there still remains more land to grow cotton, irrespective of the vast areas in the northern parts that stand in need of amelioration by a fairly cheap process. The Nile flood rice (called *Sabêini* from its ripening in 70 days) is now no longer remunerative, and thus amelioration can only be done cheaply by growing summer rice. For this there is no water whatever available. Every year sees more and more cotton sown, and, save in localities favoured with very large water-supply, rice steadily diminishes. The sanitary authorities also complain that the water in summer gets more stagnant than before, owing to the great ponding up above the Barrage. The desert reclamations also want water, and, in addition to this, there is a growing desire to extend sugarcane cultivation in Upper Egypt; so that, at least, it may be put under the same *régime* as Middle Egypt in summer. There are also very good desert reclamations to be effected in the Fayûm. All these demands for increased summer irrigation point to the necessity of increasing by artificial means the water-supply. Now, you are familiar with the means of getting a water-supply for towns in this country. Your engineers throw dams across valleys in the mountainous regions, and submerge the land which is not valuable, and sometimes even submerge villages. The rain fills the reservoirs, and the small quantity of water necessary for a town is obtained with some difficulty, often by several reservoirs. For the Nile it is different.

The discharge required to improve the irrigation of Egypt is at least 20 millions of cubic mètres a day, and this amount of water is quite inconceivable by any European standard. It is equal to a quarter more than the discharge of the Ganges canal, familiar to many of you who have been in India.

This water can be got in only three ways:—

(1) By damming up the great Equatorial lakes, and letting their surplus water down in time to reach Egypt through May, June, and July.

(2) By damming the Nile itself in favourable places where the country is desert, and, therefore, where no great damage can be done to existing rights.

(3) By filling in flood-time any great desert depression, and then letting the water back to the Nile in summer.

The first plan, that of impounding water in the great lakes Victoria and Albert Nyanza on the Equator is too large a subject to consider in any great detail. The area of Victoria Nyanza is 65,000 square kilomètres, or 65,000 million square mètres. A raising or a depression of the level by one mètre would give a discharge of fully 30 times more than is wanted at Cairo, and to raise the lake one mètre would require the whole of an ordinary Nile flood for 65 days!

The Albert Nyanza, with its western catchment basin, might also furnish something. To take this enormous quantity of water off the flood-supply by impounding it in the rainy months on the Equator would most seriously reduce the Nile flood-discharge at Aswân, and would convert a fair flood into a bad one. This difficulty would have to be faced by using all the Nile valley barrages, which, as will be seen further on, are necessary for the distribution of a summer supply in the Nile valley.

The second method of impounding water in the Nile valley is by damming up the river itself at the points where the granite reefs cross the Nile, and where there either are, or were, cataracts. In this category is included Gebel Silsilal, where the river flows through a hill of sandstone of good quality.

By erecting great dams to receive the water, 60 feet high or more, we could produce a lake with a length of at least 120 miles, and a depth, assuming the low Nile to be 6 feet deep, of 66 feet at the north end and 6 feet at the south end. Above Aswân this raising of the water would not drown much land. And at Gebel es Silsilah there is an old lake, now dry, and about 20 feet above water-level, which, if flooded to a depth of 5 mètres (16 feet), would have an area of about 30,000 acres.

The possible granite sites for this great dam are Aswân, Kalabshah, the second cataract, and the head of a long series of small rapids—a place called Dâl.

There has been much contention on this point. About twenty years ago a Society was founded called *Société d'Etudes du Nil.* It sent out men to study the river and to find out where, in ancient times, there was cultivation where the river never rises now. Although there was an immense amount of romantic writing and exaggerated deductions from actual observations, the Society produced a real project for throwing a dam across the river at Gebel es Silsilah. This project was seriously worked out by an able engineer, M. Jacquet, of high professional standing in France. The remainder of the proposals were brought out by a Dr. de la Motte, of no experience as an engineer, and cannot be looked on as a serious project. The project of M. Jacquet was estimated to cost 4 millions sterling.

Again, M. Prompt, the French member of the Board of Railways, in 1889-90 brought out a series of proposals to make the Nile navigable to Khartum by erecting dams of a moderate height at all the cataracts As these dams would not have any under-sluices, the only thing likely to fail would be the locks for navigation cut round their flanks. M. Prompt also incidentally stated that though the navigation works would not pay in tolls, still the impounding of about 1500 millions of cubic mètres of water would be so valuable to Egypt that the Government could put on a summer water-tax, and so recoup itself.

The English engineers in the Egyptian service pointed out, however, that the ponded reaches of the river would rapidly fill up with deposit, which at the same time would be temporarily taken away from the present irrigated area. And, after the reaches had filled up, the retaining capacity of the reservoirs above the dams would cease, and things would be no better than now.

The public interest was, however, so strongly roused by the scheme of reservoirs, that the Government found it necessary to depute an engineer to make actual surveys of the possible sites, and to examine whether the large areas of Dr. de la Motte were at the levels he alleged them to be.

This engineer, Mr. Willcocks, one of the inspectors of irrigation, aided by a small staff, took levels and made surveys. The results of the first year were that the Kom Ombo plain, or dried lake, was smaller than estimated by Dr. de la Motte; also that the Aswân cataract was very favourable from an engineering point of view; also that Kalabshah, though its granite was not so hard as that of Aswân, was a practicable site. Lastly, that the plain of Dakkah belonged to a quite different series of depressions, and had no connection with the ancient Nile deposits, as it was not less than 400 feet above the Nile.

Unfortunately Mr. Willcocks became possessed of a desire to flood the beautiful Temple of Philæ, and went out of his way to make absurd proposals to sell it to the Americans. The indignation of the scientific and artistic world was loudly expressed, and I think now, as I then said in my note on Mr. Willcocks' report, that a lower dam at Philæ would do better and thus spare Philæ, and it would be much safer, even though the cost were greater, to have several dams of a moderate height at points farther south. In the winter of 1891-92 surveys were also extended, and the second cataract in the Egyptian territory was, as far as possible, examined. Unfortunately the Dervishes prevent any scientific examinations of the Dâl site.

The Anglo-Indian engineers in the service of the Egyptian Government are all in harmony on the point that these dams must pass the flood through the dam at a low level, so that the river may flow in flood-time at about the same height as now. This is the only way to prevent the river-bed filling up with deposits from the silt-laden waters of the flood. The tunnels in the body of the dam to pass the flood-water would add greatly to the expense, and render regulation a matter of the greatest difficulty.

There is another scheme which has been pushed into public notice by the efforts of an American gentleman, Mr. Cope Whitehouse. It is one of the penalties that Egypt has to pay for the laziness and want of push of her own Turkish Governors, that men of all nations go there and try to urge the Government on to great public works. This does not happen to European nations; no one, for example, goes and worries the Dutch to drain the Zuyder Zee, but we leave them to do so when they think fit. The scheme is to use the large depression to the south of the Fayûm as a storage reservoir. It is called the Wâdi Rayyân, which means in Arabic "the valley habitually irrigated." Dr. Schweinfurth has failed to find any traces of fresh water in it, and certainly no Nile mud. Mr. Cope Whitehouse, from the study of a map of the second century A.D., declares it was a part of Lake Mœris.

The project was studied in 1889 by Colonel Western, R.E., who designed a small canal to be cut through the hills bordering the Nile valley. In my opinion this canal was too small, and the alignment on the slope of the Fayûm would have produced much filtration and consequent destruction of land in the Fayûm. The storage of the water would relieve the Delta of dangerous floods; but in a succession of ordinary years would reduce the floods of the Delta to an inconvenient degree, and render regulation on the Barrage in flood a necessity. But the present Barrage, which only holds up water in summer, could not be used in flood, as its design is altogether too weak. Very heavy works would be required to guarantee the abstraction from the Nile of 100 millions of cubic mètres *per diem* during the flood to fill the Wâdi Rayyân. The cutting through the hill is very deep, but presents no serious difficulties to a properly maintained rock-cutting plant.

The question of increased summer irrigation by storage of water is, as I have shown, largely mixed up with the reclamation of the lower Delta. But the most remunerative application of the stored-up water is in Upper Egypt, where there is practically a tropical climate. But the people are not rich, neither are they educated and enlightened. So that if Government were suddenly to give water from the reservoirs, the country would fall into the hands of rich foreign capitalists who would dispossess the *Fellahîn* and cause much discontent. The establishment of vast sugar factories requires much capital, and their owners would gradually, by loans, possess themselves of the land, converting the *Fellahîn* into day-labourers. This is not at all good from a social point of view, and therefore I think the matter of reservoirs should be pushed very slowly. First, 10 million or so could be added to the discharge of the Delta canals; then a high-level canal with its barrages could be made in the high lands bordering the Nile for Kena, and Girga, and South Asyût.

But on no account would I abandon the basins. I myself believe, from what has occurred in the western Delta, that the desert sand, the old Typhon of the Egyptian mythology, would overwhelm much land. In addition to this, the difficulties in the way of drainage are very great, and the figures put forward lately by M. Prompt and Mr. Willcocks do not represent one-tenth of the sums necessary to remedy the evils attending on the introduction of summer irrigation throughout all Egypt. The river at Cairo would be thrown out of trim, and the high floods would come in August instead of the end of September, thus ruining much more cotton than now.

Appendix.—The following are some interesting statistics furnished by the resident engineer of the Abukîr Company (Mr. R. Lang Anderson), and forwarded to me by the kindness of the Directors. The Company's original agreement with the Egyptian Government was as follows :—

"Three years to be allowed to complete the canals and drains, during which no land-tax to be levied ; after that the land-tax to be, per *feddan* for 2 years, 1 piastre ; for the 3 next years, 5 piastres ; and after that 10 piastres for 5 years. Thereafter the same tax as similar lands in the neighbourhood." This has been since changed into L.E. 1000 for 10 years on the whole area of 29,621 *feddans*, and thereafter the same tax as similar lands. (An Egyptian pound [L. E.] = 100 piastres. There are 97½ piastres in the English pound sterling. A *feddan* is nearly an acre —really 4200 square mètres.)

The Company have, up to the end of 1892, reclaimed and sold 781 *feddans*, in 45 parcels, for £25,460. The payment is spread over 10 years. They are now arranging sales for 1590 *feddans*, in 5 parcels, at £20 a feddan.

Mr. Lang Anderson, from his experience on the spot and knowledge of the demand for land near Alexandria, is very hopeful of the ultimate reclamation of the lower levels, which are, of course, very salt. I had myself thought that this would be economically impossible with the pumps delivering the water into the sea. But in 1891-92 the Company and the Egyptian Government came to an agreement that the Company should make two syphon culverts under the Mahmûdîyah Canal, and pay the expense of cutting the drains to Lake Mareotis. They also agreed to make over the two 48" Gwynne pumps and their engines to the Government. The Government agreed on their side to erect the two pumps and their engines at Mex to drain Lake Mareotis, paying for the removal and the erection. The Government also will run the pumps in future at its own cost.

These terms are very advantageous to Government, as the question of the drainage of Lake Mareotis was yearly becoming more and more acute, owing to the extensive private reclamations of land in the Western Delta. To the Company this arrangement saves much expenditure in pumping, and gives a level in Lake Mareotis at least 1½ mètres below the level of the Abukîr Lake. I consider that this Company will be a success, and not result in absolute loss, like its French and English predecessors.

THE DISTRIBUTION OF TEMPERATURE OVER THE SEA.[1]

THE intensity of solar radiation, which varies during the day with the height of the sun above the horizon, and in the course of the year with the declination of the sun and the latitude of the place of observation, has been worked out by Lambert, Meech, Wiener, Angot, and Zenker. Wiener denotes by unity the amount of radiated heat any given place would receive were the sun during the whole of the given time in the zenith, and if there were no atmospheric absorption. The daily, monthly, and yearly quantities of radiation must then be less than unity, and Wiener calculates their value with great accuracy to five decimal places. He calculates them for rays falling on the confines of the atmosphere, which are undiminished in power by the absorption they undergo in passing through the air.

Of these five decimal places, Dr. Zenker omits the last, and the remaining ten-thousandths he denominates *rays*, and indicates them by r, so that the annual heating of the Equatorial regions is due to 3053 r. He has also, in his *Die Verteilung der Wärme auf der Erdoberfläche*, shown how many of these rays falling on the outer boundary of the atmosphere penetrate to the earth's surface, and are there absorbed. This relation for the annual radiation may be expressed by the formula $Y = aI - b$, where I is the radiation on the confines of the atmosphere, Y its amount on the earth's surface, and a and b constants. For the sea the equation becomes $Y = I - 520\ r$.

Now it has been possible, from the temperatures of two Siberian stations compared with the radiation they receive, to determine the heating power of solar rays in terms of the ordinary thermometric scale (outside the atmosphere $54{\cdot}4\ r = 1°$ C.), and hence the actual yearly temperatures of the air in the Pacific Ocean have been compared with those obtained from the equation. They exhibited in different latitudes the same differences as are given by the equation.

It would, however, be a mistake to suppose that the quotient of $I - 520\ r$ divided by 54·4 will give immediately in centigrade measurement the temperature of the corresponding latitude. This expression merely indicates the degree of insolation; the ultimate temperature depends, however, not only on insolation, but also on the initial temperature to which that of insolation is added. Only if this initial temperature were 0° C., would the formula give the temperature of the sea-air in degrees. The 520 r subtracted correspond to 9·56° C., and the resultant value of

[1] From an article by Dr. W. Zenker in *Petermanns Mitteilungen*, Bd. 39, No. 2.