The irrigation system of Egypt is largely one of development through ages. Not so much in increase of area as in system. It is highly probable that at one time there was a much larger area under cultivation in Upper Egypt and Nubia than at present. The surroundings of the great Temples are now waste lands, and there are many evidences, in what are now desert places, that at one era there existed a large population. Mounds of broken pottery exist, where there is nothing but the sterile desert of drifting sand. From ancient writings, it is also evident that Egypt once contained a much larger number of people than it does at present. It was once both the trade and scientific centre of the world, and, possibly, it paid to cultivate land at a greater outlay than it now does. A cause for the decrease may be accounted for by the constant change of ownership, as each generation sees a change in the ruling power in Egypt. The history of our own time is somewhat appalling, in so far that a score of battles have been fought in Egypt and the Soudan, and some 100,000 to 200,000 lives have been sacrificed in war. The same process has been going on through ages.

The irrigation of Egypt was for many centuries obtained from the natural overflow from the Nile during the flood season, submerging the lands for one or two months in the year; the crops being sown in the mud as the waters subsided. Then came the division of the area into sections, called basins, and afterwards came the canalization of Lower and Upper Egypt. The basin system is partly still in vogue in Upper Egypt.

In the first instance, we will examine, in as brief detail as possible, the irrigation of Lower Egypt. This country has a comprehensive system of Supply Canals, both numerous and large.

The apex of the Delta of Egypt is a little north of Cairo. The Nile dividing into two main branches, the one on the west side, called the Rosetta, and the eastern branch the Damietta; each of these have several affluents, termed Bahrs, of different names. Along the coast of the Mediterranean are a series of shallow lakes or marshes, the water of which is salt or brackish. The Delta itself forms a triangle with a base along the sea of 150 miles, having Alexandria at the western angle and Port Said at the eastern. The distance from apex, at Cairo, to the sea being 130 miles. Situated within this triangle are the cultivated lands of Lower Egypt. They are wholly dependent upon an artificial supply of water to produce a crop. Beyond the limits where the water reaches is desert.
The cultivated area of Lower Egypt is 2,740,211 acres, which supports a population of three million people. There are about a million inhabitants in the various towns, inclusive of Cairo and Alexandria.

The soil of the Delta is rich alluvial deposit, varying in depth from 30 to 150 feet, composed of carbonates of lime and magnesia, oxides of iron, and a considerable amount of volcanic detritus.

To the volcanic regions of Abyssinia, Egypt owes the main part of its rich deposit, while to the great swamp regions of the White Nile it is indebted for its organic matter, and to the basin of the Sobat tributary for its lime. Between these constituents, says Sir Wm Willcocks, "a soil is formed difficult to surpass by any artificial mixture of valuable ingredients."

Every kind of tree, except the date palm, is rare in Egypt. The trees generally met with are acacias, sycamores, mulberries and the banana. There are no carriage roads outside the towns. The land is too valuable for space for roads, trees or fences. All transport is carried by pack camels and donkeys. The rich travel on horses, the poor on donkeys, but more often the fellah journeys on foot.

The horticultural products of the country comprise the date, orange, citron, pomegranate, vine, olive, banana, while the melon is grown in abundance. The vegetables include all varieties, except the potato. Lentils are also grown and much used. There is also a Mandarine orange called "gergus effendi," which is largely grown.

The crops raised are wheat, maize of several varieties, barley, cotton, sugar and rice. Then there is the clover crop, which is a rank grower, and flourishes freely where there is a plentiful supply of water.

It may not be out of place here to describe, as briefly as possible, the character and habits of the population of the country, as they are factors in an irrigation system.

There are two distinct races in Egypt—the Muslim Arab and the Christian Copt. On the whole, the Fellahen are a fine race of people, one of the best in the world. They are handsome, well formed, capable of great development, hard-working, perhaps sly and cunning, but possessing great facilities for administration.

The Fellah, that is, the peasant, is a contented individual, working from daylight till dark, submitting calmly to the inevitable. He has few luxuries and few movable effects, possibly for a very good reason. He has been ground by oppression from generation to generation, consequently he bears his fate calmly. He has few amusements, and his only ambition is to obtain three or four wives, who work for him. He cultivates the soil himself a little, and his wives do the rest. Children work at an early age, both male and female. Work goes on for seven days in the week, in one monotonous round. He is much given to talking, and loves gossip, and, as a narrator of fables, is an entertainer. He has no literature, and few can read or write. His food is frugal, and seldom passes beyond bread, milk and vegetables. He is a gentleman in his manners, and of a kindly disposition; but, like many others, he is a contradiction, for he is cruel when he gets his enemy in his power.

The implements used in cultivation are those that have been
common to the country for centuries. He ploughs with a wooden plough, harrows with a log of wood with spikes of iron in it, and breaks up the clods with a mallet. He sows by hand, and reaps the same way. Thrashes with sticks, and grinds his corn by a hand-mill. He has no barrows, but excavates the earth by an adze-shaped instrument into baskets, which are carried to the place required by women. His implements are antiquated, but light. Light work and long hours is the system of labour. In spite of his antiquated systems, there is no country in the world so well cultivated, and few produce a higher revenue per acre.

Taking the revenue-producing area of Lower Egypt at 2,737,418 acres, 935,000 acres are under summer crops, yielding £9,470,000; 1,280,000 acres are under flood crops, yielding £4,760,000; 2,106,500 acres are under winter crops, yielding £9,040,000. Practically the whole area yields a double crop per year, which may be valued at £23,270,000, or £8.1 per acre per annum. It may be interesting and instructive to examine these figures in detail, from which it will be found that the strength of the agriculture of Egypt is in one or two special products. These details are available from the Egyptian Government reports, and will be considerably in excess rather than below the figures given.

The summer crops are:

- Cotton ... 826,000 acres at £10.57 ... £8,730,000
- Sugar cane ... 4,000 acres at £10.00 ... 40,000
- Vegetable gardens 35,000 acres at £10.00 ... 350,000
- Rice ... 70,000 acres at £5.00 ... 350,000

935,000 £9,470,000

Flood crops consist of:

- Dates ... 1,100,000 trees, yielding £0.40 ... £440,000
- Maize ... 1,200,000 acres, yielding £3.5 per acre ... 4,200,000
- Flood rice... 80,000 acres, yielding £1.5 per acre... 120,000

1,280,000 £4,760,000

Winter crops:

- Tobacco ... 2,500 acres at £20 ... £50,000
- Flax ... 4,000 acres at £10 ... 40,000
- Vegetables ... 35,000 acres at £10 ... 350,000
- Wheat... 920,000 acres at £4 ... 3,680,000
- Barley ... 330,000 acres at £2 ... 660,000
- Beans ... 330,000 acres at £4 ... 1,320,000
- Clover... 735,000 acres at £4 ... 2,940,000

2,356,500 £9,040,000

*Making a total of £23,270,000.

To accomplish this, there are 4582 miles of summer canals and 163 miles of flood canals. There are also 33,673 Sakiehs or Persian wheels, 2176 portable engines, and 379 stationary engines. I regret:

* Vide Sir W. Willcock's Report.
that I have no photograph of the Persian wheel, as it is possibly the oldest water lifting appliance in the world, and is still largely in use.

One of the principal crops of Egypt is the cotton crop, and, it will be remembered, its introduction into the country was what may be described as an accident, caused by the great dearth of raw material during the American Civil War.

The yield per acre of wheat is also very considerable, being, from good land, 33 bushels per acre. The value is about 4s. per bushel, and the straw returns £2 per acre, bringing the gross return up to £7 per acre. The straw is used for food for animals, also for fuel, being mixed with dung. The cost per acre for ploughing, sowing, reaping and threshing is about £1, leaving a profit of £6 per acre, less land tax. Sir William Willcock places the expenses of the wheat crop at £2.4 per acre, while M. Saurez states that the cost is 10s. per acre.

Sir William Willcock's estimate is made up as follows:—

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ploughing and sowing</td>
<td>£0.4</td>
</tr>
<tr>
<td>Seed</td>
<td>0.5</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.5</td>
</tr>
<tr>
<td>Weeding and reaping, etc.</td>
<td>1.0</td>
</tr>
<tr>
<td>Total</td>
<td>£2.4</td>
</tr>
</tbody>
</table>

If Sir William is correct the cost is extremely high, and is nearly double what it costs in Victoria. With wages per man of 2s. per day, possibly M. Saurez is nearer the mark. Cotton produces a crop worth £13 per acre. The cost of preparing land, planting, weeding and gathering is estimated at £6.15, leaving a profit of £7.35 per acre, according to Sir William Willcocks, while M. Saurez puts the gross return at £17 per acre, and expenses at £3 per acre, leaving a profit of £14 per acre. The one double the other. Sugar cane yields £24 per acre, and the expenses are £10, leaving a profit of £13 per acre. Clover yields a profit of £4 per acre. The estimated yields from irrigated land vary considerably by different authorities, which may be explained, to some extent, by the times at which such estimates were made, as the market value of the products vary from time to time. Even allowing for these, however, there is a wide margin. It is always most difficult to obtain reliable information of yields, as few farmers have either the time or the inclination to keep records. In Egypt, it may be assumed that the net returns, after paying working expenses and taxes, is £8 10s. per acre.

The climatic conditions and quality of soil of a country or district, and the crops that can be profitably raised by the artificial application of water under such conditions, are an important consideration in any irrigation enterprise.

The system of rotation of cropping in Egypt is:

**Summer.**
- 1st year: Cotton.
- 2nd year: Maize.
- 3rd year: Maize.

**Winter.**
- Beans and clover.
- Wheat and clover.
- Clover or fallow.
All land in Egypt is practically in possession of the Government, and the holders are lessees of the Crown, to whom they pay the annual rent or land tax. This land tax varies in different districts, and on different lands and under different classes. The land is classed as Karagi when it pays full revenue, and Ushuri when deductions are made. The distinction is not so much in quality as in rights enjoyed by the owners, which arise from a multitude of causes, some honest, some otherwise. Sir William Willcocks states that the land taxes amount to £1.40 per head of population, or £1.92 per acre of cultivated land.

I shall endeavour to describe as briefly as possible the mode of habitation, system of living, and the irrigation in the fields by reference to a portion of the Province of Monufieh, lying north of Tantah, which is practically in the centre of the Delta. This is typical of the Egyptian provinces. The plans for the district were made by myself in 1881. The country is divided into provinces, called Mouderehs, which are subdivided into villages, under the control of a Sheikh, and sub-Sheikhs. The villages differ in area, and are most irregular in boundary. Why such deviations should be made in boundaries is not easily explained, as the country is practically level.

The population live in clusters of houses bunched together as close as possible, surrounded by a wall having one or two gates, which are closed and guarded at night, "typical of all lands that have been
torn hither and thither by wars." There are watchmen around these walls all night, who call out their respective numbers at intervals. The alleys leading through the heterogenous mass of buildings are about 12 feet wide, and as irregular as possible. Into these enclosures humanity, beast and fowl retire at night, and emerge in the morning to work in the fields. There are no dwellings outside, and sanitation inside is absolutely of the worst possible.

The fields are all known by names, thus we find the field of Ibli-el-Woustani. The divisions of property are only marked by a little bank of earth, there being no fences in the country.

The canals are also typical of the canalisation of Egypt, from which some estimate can be formed of the enormous work done in providing irrigation works in Egypt. The canals supply the secondary channels which supply the fields. The process is extremely simple. They run banks of earth across the channels to raise the water, and cut them when the fields are flooded. A stop on one of the main canals is shown on drawings. It is made by placing planks in a vertical position in the opening, which are withdrawn when the water is required to flow on. The canal marked Assab on plan will be found to be spelt Kassad in some publications.

It may be advisable, at this juncture, to make some brief mention of the different machines used to lift the water from the main canals after the Nile has fallen, or to lift water from wells. Water of a slightly brackish quality is usually found from 15 to 30 feet below surface. The oldest appliance of animal power worked machine is the Sakieh, or Persian wheel, lifting water from various depths and giving a supply of 223 cubic metres in 12 hours, driven by a pair of oxen, and capable of irrigating half an acre in that time. This type of machine is by no means defective in design, and, modernised, is capable of giving a good efficiency. In this form it is used in Egypt, and, where animal power is necessary, a machine of this type, with buckets made of aluminium so as to secure a light weight in the moving parts, will still be largely used. The Shadoof, or a pole with bucket and counterpoise, is worked by two men, in alternate spells of one hour, and can lift 100 cubic metres per 12 hours, and can irrigate one-third of an acre.

A Natile is a peculiar form of water lifting appliance, formed by a mussel-shell shaped basket about 2 feet long; four strings are fastened to the basket, two on each end, and two men work at it by swinging the basket to and fro and scooping up the water. Four men, working in relays of two, can irrigate, in 12 hours, three-quarters of an acre. The lifts are one to two feet.

The scoop-wheel is a machine that has much to recommend it as a mechanical appliance for low lifts. It takes the water in at the outer edge, and discharges it at the centre. Lift, about 5 feet. The archimedean screw is also a very common form of machine, and varies in diameter of barrel from a few inches up to 10 feet. The greater size was found to be a mistake. Centrifugal pumps are also very common, both of English and French manufacture. Cotton stumps are used for fuel. Although much is being done to ensure irrigation by
gravitation, and a supply of water in summer from storage, there will still be use for water-lifting appliances.

The duty of water in Lower Egypt varies considerably. In winter, the average depth a field receives is 4 inches, and is supposed to be watered once in forty days. This means that a cubic foot of water per minute in channel is sufficient to water four acres in winter, according to Sir William Willcock's estimate. Other estimates double the quantity required, and make the duty of one cubic foot per minute capable of watering two acres. This duty, however, corresponds with Sir William Willcock's statement: "That if flush irrigation is possible the amount of water consumed may be put down at 22 cub. metres per 24 hours per acre; 22 cub. metres per 24 hours represents 770 cubic feet per day, or about one-half cubic foot per minute per acre."

Sir Hanbury Brown states "that 1000 cubic feet per diem per acre should be provided for the cotton crop, and for rice double that amount." These allowances are those which should be supplied at the head of the main canal to provide for loss by evaporation and seepage. The element of time is a large factor in the supply of water for irrigation purposes, as there is not much margin between the time of germinating and ripening.

As much has been said of Lower Egypt, or the Delta below Cairo, as it is possible to cram into the space allotted to a paper of this description, we will now pass on to Middle and Upper Egypt.

This district is situated south of Cairo, and extends to the First Cataract, at Assouan. A strip of land about, on average, of 10 miles wide on the west side of the Nile, containing about 2,000,000 acres. Here and there a little cultivation on the eastern bank. Here the basin system of irrigation is in use, with the exception of a strip supplied by the Ibrahimia Canal, two to six miles in width, alongside of and parallel to the river, and also the Fayoum district. The country is divided into basins by earthen banks running transversely to the river, starting from its bank and extending to the desert.

The formation being "deltaic," that is, the ground along the river is higher than that intervening between the Nile and the desert. The transverse banks enclose the areas, or only require a small bank along the river to do so. These enclosures may be subdivided by one or more dykes parallel to the direction of the river, in order to divide the low lands near the desert from the high lands near the river. The basins have canals to lead directly into them the flood waters of the Nile, charged with alluvium. The canal mouths are usually closed by earthen banks. Some of the canals are insignificant, while others carry up to 30,000,000 cubic metres per 24 hours.

Each system of basins possesses an escape, which allows the water, after it has deposited its alluvium and stood some forty days on the land, to flow back to the river, providing that the Nile has subsided sufficiently to allow it to do so; if not, the only alternative is to wait until it does. These basins have an average area of 11,400 acres; the average depth of flood is 4 to 5 feet. The country has the appearance of a sea, with islands at intervals, on which are the villages, similar to those of Lower Egypt. Communication is cut off except
along the intersecting banks. The cutting of the banks at the intake of the canals is usually done about 12th August, and is performed with ceremony. The operations of filling the basins last about forty days, and is over by the 22nd of September, or at latest by the 1st of October. They are dry about the middle of that month, when sowing broadcast on the slime commences. The seed then takes its chance, as it gets no more water.

Sir William Willcock admires this system of basin irrigation. It has, he says, “been in use for 5000 years, and is economical as regards works.” It is precarious, however, as a low Nile or a break in the banks, which often happens, will reduce its value considerably. There is also the disadvantage that the land can only be watered once. On the other hand, the settlement of the matter in suspension in the water is an advantage. The system can only be carried out where the country is level, and the population is willing to submit to the inconveniences of being penned up for forty days at a stretch. In the system of basin irrigation, as much as 7350 cub. metres are used per acre down to half that quantity.

There are three canals in Upper Egypt of some note. The Sohagia Canal, which has its offtake furthest south, has a bed width of 210 feet, and a depth of 16 feet. The Bahr Yusuf has a bed width of 150 feet and a depth of 27 feet. The Ibrahimia Canal has its offtake at Dequr, a little below Assiout; it has a bed width of 120 feet and a depth of 27 feet, and has a flood carrying capacity of 130,000 cubic feet per minute.

Before referring to the more recent works for storage and diversion purposes, it will, perhaps, be advisable to describe the principal features of the Nile. The Nile is in itself a most interesting subject, and one that would require a whole paper to do it justice. To make up, however, for lack of verbal description, the appended plan has been prepared to show some of the main points of interest, so that the eye may take in the characteristics of the river from its source to the sea. For years it was doubtful where the Nile waters came from. That problem has now been definitely settled, and much praise is due to such travellers as Livingstone, Speke, Grant, Baker, Burton, Gordon and others for work done in this respect. The Nile has numerous tributaries, the chief of which are the White, the Blue or the River Abai, and the Sobat.

The White Nile has its source in the region of the equator, at Lake Victoria Nyanza, a lake of 25,000 square miles surface area, and with a reputed catchment area of three times that area, or 104,000 square miles, comprising about one and one-half times the size of Victoria. Its elevation is 3750 feet above sea level, and a distance of 3600 miles from the Mediterranean. Close to it are high mountains. Mount Kilmangaro has an altitude of 8000 feet above sea level, and Mount Kenia 8500 feet. The rainfall over the catchment is estimated at 4 feet per annum. It is stated that of this rainfall nine-tenths is evaporated in the lake, and that only one-tenth gets away down the river. The temperature is the same as that of Alexandria. The outlet of the lake is over the Ripon Falls, and then the
river passes over the Murchison Rapids, and joins the Albert Nyanza at a distance of 600 miles and a fall of 1725 feet, or about half the whole fall from Lake Victoria to the sea at Alexandria.

Following the course of the Nile downwards, it flows over the Fola Rapids, and on to Gondokora, a distance of 2781 miles from the sea, and having an elevation of 1771 feet. From Gondokora, the river becomes sluggish, and at Bor it breaks out into flat country and forms swamps, called Sudds. The course becomes blocked by reed banks formed by vegetable growth, on down to near the junction of the Sobat at Fashoda. This place is situated 2278 miles from the sea, and has an elevation of 1500 feet, giving a fall from Gondokora of 283 feet in 500 miles, or about 6 inches to the mile, and considerably less for a great part of the distance. The fall is not sufficient to create a current to carry along the vegetable growth from the lakes and higher reaches of the river, which forms itself into Sudds or banks, and blocks the stream. The region of the Sudds extends over a great area, and consequently causes great loss of water by evaporation, thus considerably decreasing the discharge of the river.

Sir William Garstin, the Secretary of State for Public Works of Egypt, has recently made a personal inspection of the White Nile, from Khartoum to the Victoria Nyanza, and he proposes to construct a new channel for the river on the eastern margin of the Sudd district, a distance of 200 miles, at an estimated cost of some £4,000,000. By this means it is proposed to mitigate the evils of a low Nile, and increase the summer flow.

Near Fashoda, the Sobat River joins the Nile on the east, and the Bahr Ghazelle on the west. The Sobat carries a large quantity of lime in solution, and its water is a milky colour. The Ghazelle contributes the organic matter. Leaving Fashoda, the course is through the Kordafan country down to Khartoum, at a distance of 1800 miles from the Mediterranean, and at an elevation of 1200 feet. This district is fairly good soil, and is well cultivated. It is not so rich as the Egyptian country. At Khartoum the Blue Nile joins the White. The Blue Nile takes its rise in Abyssinia, among the volcanic mountains surrounding Lake Dembea. These ranges attain an altitude of 14,000 feet above sea level. The lake itself is an extinct crater, and its level is 5700 feet above sea level. The Blue Nile carries in its water large quantities of volcanic earthy matter, giving it a blueish tint, from which it is named, its Abyssinian name being Abai. It is in flood during the months extending from July to September, the mean flow of which at Khartoum is stated to be 11,000,000 cubic feet per minute, and that of the White Nile 13,000,000 cubic feet per minute. The Blue Nile has a mean discharge during low flow of 700,000 cubic feet per minute.

Leaving Khartoum, which is connected with Wady Halfa by railway, the Atbara joins the Nile on the eastern bank, at a distance of 1600 miles from the Mediterranean, and is the last tributary to the Nile. Between this point and the coast the country is practically rainless. The Atbara ceases to flow during the summer months. After passing Berber the Nile flows through rough hilly country, and
over a series of rapids, called cataracts. The Fifth Cataract is the first formidable obstruction met with on the downward journey, and there are three between Berber and Dongola.

It was in this vicinity that Colonel Stewart, Mr. Power and others, when leaving Khartoum during the time General Gordon was besieged by the Mahdists, were wrecked and murdered. From Dongola to Wady Halfa, where the Second Cataract is situated, the Nile passes through wilderness, sometimes plain and sand, at others, and for the most part hilly country with numerous boulders on the sides of the hills. Here and there cultivation is found on the banks and islands. Possibly cultivation will be extended now the country is in a peaceful condition, which it has not been for the past twenty years.

The elevation of Halfa is 490 feet, and at a distance of 930 miles from sea. The next place of note along the course is Assouan, where we find the First Cataract, and also the Barrage and Reservoir recently constructed. The elevation here is 306 feet, and the distance from sea 722 miles.

Assouan, or the Ancient Syene, is a most interesting place. Practically surrounded by desert, it is here that many of the stones were quarried for the temples and other works. Some of the blocks are still in situ. The wedge holes cut for the purpose of quarrying the blocks are clearly visible. Here, also, is the ancient Nilometer, cut on the rocks of the island of Elephantine.

The island of Philae, with its temple, is situated at the head of the First Cataract. A little below Assouan are the lime and sandstone formations at Silsileh. Here it is supposed that an ancient Barrage existed, and at this point cultivation commences along both banks of the Nile. Passing down the river will be found the ruins of Thebes on the west bank, and the Temple of Karnak on the east. At Sohag, on the western bank, the Sohagia canal commences. At Assiout, a small town with a large market, the Ibrihima canal branches off, a work of recent years; also the Bahr Yusuf, which carries water for the district, east of the Ibrihima and down to the Fayoum, and, practically, to Cairo. The Fayoum is an oasis with Lake Kurum, which has a surface level of 133 feet below sea level. Cairo, the capital of the country, is a city of great interest. There is here an ancient Nilometer. Amongst some of its virtues may be mentioned an excellent water supply pumped from the Nile. It is now also, to some extent, sewered. The Nile at Cairo has a maximum discharge of 24,3 million cubic feet per minute.

A little below Cairo, the Nile divides into the Rosetta and Damietta branches, and the Delta begins; also the Ismiliah Canal branches off and carries fresh water to Suez. This is a work of considerable importance.

Having described the main features of the country, its requirements, and the water available to meet the demands, a short review of some of the more recent leading engineering works will be given. In making a selection of some, it is not to be supposed that they complete the list.

The Delta Barrage at the head of the Delta was intended to close
the two branches of the Nile and raise the summer level. To make this purpose more intelligible, it may be stated that the difference between summer level and flood is 20 to 30 feet. The work was commenced by Mehemet Ali in 1833, who proposed to dismantle the Pyramids and use the stone in building a dam, but he found some difficulty in carrying out his plan. He then changed his mind, and it was not until 1842 that Mogul Bey undertook the work, from designs prepared by Linant. There was the usual intrigue, common to the East, and Mehemet Ali, Mogul, Abbas, Mazher, and Linant all had a hand in the work, stopping at one time for years, and at another pushing on with too much energy. The work was finished in 1861, at a cost of £4,000,000.

The Rosetta Barrage is 465 metres between flanks, and the Damietta 535 metres. The two structures are separated by a revetment wall of 1,900 metres. In the middle of this space are the head works of the Rayah Menoufieh. The movable sluices were made 5.40 metres high and 5 metres wide. There were two peculiarities about these gates. The first was that gratings were placed at the sill of the gates, 13 inches high, fixed into the piers just above the platform. The object of these gratings was to prevent silt lodging in front of the gates when closed. The result, however, was to set up a destructive scour. The gates are arc shaped, and are supported at either ends by iron rods radiating from the arc to the centre. Here they are attached to massive iron collars working round cast-iron pivots. It was originally intended to close the gates by their own weight, and to raise them by pumping air into the hollow ribs. When an attempt was made to close the gates the structure showed signs of failure, and its use as a regulator was practically abandoned.

Many proposals were made to repair the weak points, but it was not until 1884, two years after the British occupation, that it was decided to alter and repair the structure.

Some description of these repairs may be interesting. The engineers considered the Barrage to be a thoroughly unsound work. Relying upon friction for its stability, it was determined to make the submerged weight of masonry bear a ratio of 50 to the pressure caused by the water going to be brought against the structure. Springs in the foundations might cause a slight subsidence of any part, but it could not be moved as a whole. The pressure of a head of 10 feet of water would be 3125 lbs. per lineal foot. The submerged weight of the platform was 103,983 lbs. per lineal foot. The co-efficient between them being 1.33. That this proportion might be 1/50, it was necessary to make the rubble talus everywhere where 131 feet wide and 10 feet deep, with a submerged weight per lineal foot of 51,668 lbs. This made the submerged platform and talus together 155,651 lbs. as compared to the pressure of 3125 lbs.

It may be explained that talus is a heap of stones formed somewhat in the shape of a human foot, and represents the foundation on which the structure is built. Therefore the bank of stones and the platform have 50 times the weight of the pressure of water on the gates. This proportion, which is substantial, prevents the weir
from being pushed bodily down stream. The foundations in the Valley of the Nile are very inferior, the formation being sand, and much charged with water at a depth of 15 to 20 feet below surface.

Theoretically the original Barrage should have stood; its failure was owing to inferior work being put into the foundations, most probably the cement washed out before it set by the rising water. Possibly there was not too much in at commencement. To this was added the action caused by the sheet piling on the down stream side being left projecting above the platform, which was struck by the water passing through the gratings under the sluices, shaking the material round them, and causing springs along its course. More sympathy than blame may be accorded to Linant, as the work was a difficult undertaking, under the most favourable conditions of supervision. He had to contend against intrigue, bribery and corruption of a superior degree.

In repairing the work, the system of dealing with springs in the foundations is worthy of some reference. It is common in mining work, and it is familiar to any who have had experience in building in wet ground. When a spring caused trouble in the foundations, a pipe four or five inches in diameter with a rose attached to the bottom of it was inserted and filled round with broken stone, over which clay was put and rammed down, forcing the water up the pipe. Cement concrete was built on the clay, and when this had set firm a cap was put on the pipe head, and the spring bottled up. No attempt was made to force cement into the pipe. A system of forcing cement grout under the foundations of the piers at a head of 50 feet pressure was adopted in the repairs with satisfactory results. The arc-shaped gates have been removed, and vertical free-roller gates substituted.

ASSIOUT BARRAGE.

Another work of a similar character to the Delta Barrage is the one recently constructed at Assiout in Upper Egypt. Its purpose is to raise the level of the Nile 9 feet 9 inches. It is 900 yards in length, and has 111 bays or openings 16 feet 5 inches wide, separated by piers 6 feet 6 inches wide, with abutment piers 13 feet in thickness after every ninth opening, and a lock of 52 feet 6 inches wide and 263 feet long. The work cost £1,000,000.

The foundations in which the structure is built are worthy of some detailed description. A row of cast-iron piles 13 feet 4 inches long are driven on the up and down stream sides, the distance between the two being 87½ feet. These piles are 2 feet 3½ inches wide, and are tongued and grooved, arrangements being made for grouting the joint with cement.

The floor consists of a layer of concrete 3 feet in thickness. On the floor is laid 7.0 feet of rubble masonry in cement mortar, the masonry and floor being extended over the tops of the piles, so as to afford facilities for dealing with springs that might occur between the concrete and the sheet piling. On the up-stream side of the floor there is a clay apron 49 feet in width and 4 feet 9 inches in thickness protected from scour by stone pitching. On the down-
I. Assiout Barrage.

II. Assouan Barrage—Up Stream.

III. Assouan Barrage—Down Stream.
stream side there is an upward filter-bed, likewise protected by pitching.

The lock gates are of the ordinary type; that is, they are in two equal doors swinging from a heel post and closing on each other in the centre. The opening and closing is performed in the usual way by chains attached to each gate, passing into recesses in the quay walls and worked from the surface by capstans.

Two regulator gates, each 10 feet high, are provided for, each opening in the Barrage. They work in grooves very similar to the sashes of a window, and are provided at junction with a staunching strip of teak. They are worked by an overhead travelling winch.

The grooves on which the gates work are of cast-iron, and each gate is provided with four rollers, which bear on a roller path a staunching angle bar; when the gate is down in position it engages on a planed staunching strip, and makes a water-tight closure.

The crab winches for lifting the gates travel on rails laid on longitudinal sleepers along the up-stream parapets, the axis of the winch barrels being vertically over the central web of the double grooves. Each gate is raised and lowered by two chains, one at each end of the gate; the chains engage on the winch on two separate barrels, mounted on the same axis and coupled together. Suggestions may be made for the improvement of the design in this class of structure. The superstructure is heavy, costly, and occupies about half the waterway. The subject can hardly be dealt with in this paper, but may come up in discussion.

ASSOUN BARRAGE.

Finally it is proposed to describe the Assouan Barrage, one of the most interesting hydraulic works in the world.

The work is one and a quarter miles long. Its height varies with the level at which the sound rock was found. The maximum height from foundations is 125 feet. The thickness of dam, at crest, is 23 feet, and at the deepest part 81 feet. The total weight of masonry is over one million tons. The difference in water level above and below the dam is 67 feet. The work is constructed of local granite, set in Portland cement mortar. The interior is of rubble, laid by hand, with about 40 per cent. of the bulk in cement mortar, four of sand to one of cement. All the face work is of courséd rock faced ashlar, except the sluice lining of 30 of the lower sluices, which is of cast-iron.

The dam is pierced with sluice openings of sufficient area to pass the flood discharge of the river, which may amount to 500,000 cubic feet per second. There are 140 such openings 23 feet high by 6 feet 6 inches wide and 40 more of half that height and same width. Those sluice gates, which are subject to heavy pressure at the time of movement, are of the Stoney roller pattern.

Navigation is provided by a ladder of four locks, each 263 feet long by 31 feet wide. The reservoir above the dam, as built, is calculated to hold about 1300 million cubic yards of water. It was originally intended to build the reservoir 26 feet higher, which would
have given a storage capacity of 3250 million cubic yards. This height would have submerged the Temple of Philae, to which there was strong opposition raised by archaeologists, and the project lies dormant.

There are five lock gates, the largest pair being 59 feet high by 31 feet 2 inches wide. They are of a unique design, being arranged to roll back into recesses in the side walls of the lock.

So much for the general outline of the dam. The details would occupy a paper of considerable length, but it will be endeavoured to condense them into as small a description as possible consistent with making them intelligible.

The contracts for the work amounted to £1,800,000; that is, £1,500,000 for the general work, and £300,000 for the ironwork, which included sluices and lock gates. The actual cost was £3,450,000, an excess of £650,000, or 33 per cent. on original tender. "The rocks at the cataract are highly crushed and faulted igneous rocks of archæan age. The most abundant rock, and practically the only one that was exposed until excavation was commenced, is a coarse-grained red granite."

The beds of the channel of the river and under the alluvium, the granite alternates irregularly with dioritic and syenitic rocks of dark colour, and these, on account of their more basic composition, have undergone great decomposition under the continued agency of crushing and water action. They often form schistose micaceous masses soft enough to be taken out with a pick. Dykes of basalt quartzite and pegmatite cut the axis of the dam transversely in many places.

The above description is quoted from the official reports, by which it will be seen that the site was not what it appeared upon the surface, and the result was that the foundations had to be carried down 38 feet below level shown on contract drawings at one point and 13 feet and 6 feet in others.

Great praise is due to the administrative staff in meeting an unexpected difficulty of this nature, and it was an instance of fortune favouring the brave, for the Nile postponed its flood during the time the excavations were in progress. As may be expected, one of the greatest difficulties experienced was in closing the Bab's or channels of the cataracts.

The Bab-el-Kebir, or the big gate, was closed by depositing blocks weighing one to four tons in the course of the stream. In some cases two to four tons of small stone were packed into wire nets and used instead of large stones. The device was not altogether successful, as the wire was cut against the stone, and all the small stones were swept away.

As the channel was being closed, the current became so strong that large stones two to three tons in weight were frequently carried down stream. In closing the Bab-el-Sogair, a channel 28 feet deep, stones three to four tons weight were carried away. Two large railway waggons were filled with wire nets of stone each net weighing two to three tons. The nets were then wired together, and all secured to the waggons by steel ropes going over the nets and under the body.
of the wagons. The two wagons, each weighing 25 tons, were then run bodily into the gap. These formed a toe, which prevented the stones from being washed away.

These stone banks on the down-stream side of the dam rose up to a height of 49 feet and a top width of 30 feet. When the channels were closed, a sand bag cofferdam was erected in front of the stone suds. The banks of cofferdam were 26 feet wide on top with slopes 10 to 1 feet, and the greatest height was 60 feet; the slope on up-stream side was eventually flattened to 2 to 1. The leakage through these suds was comparatively little.

It was originally intended that the heating of the dam should be built in lime and burnt clay, as an abundant supply of both were available. It was found impossible to burn the clay and bring it on the ground at such a rate as was required. About 13,000 cubic yards were built with these materials.

The limestone was a nearly pure calcium carbonate; it was burnt with 2½ cwt. of coal to the ton, slaked and screened, and then ground in the mills with the burnt clay. The clay was made into bricks and burnt in clamps, using 1½ cwt. of coal per ton of clay. When burnt to a light red colour, it was broken by beating it with pieces of wood, and then screened and passed through a sieve of 400 meshes. The proportion of 3 clay to 2 lime, with 10 per cent. of sand, were ground in a mortar mill until thoroughly mixed. The average tensile strength, after 28 days, was 160 lbs. per square inch.

In laying the foundations a few small springs were visible when the surface was cleaned, and although the water came from hair cracks the pressure was considerable. The water was allowed to flow freely until the masonry around the springs had been built to a considerable height, and had set. To allow building, water from a spring was either conveyed by a small pipe to a pump or bailed out by hand. When the masonry around a well was of such a height as the water did not rise above it, the well was cleaned out and grouted up solid with neat cement to still water.

SLUICES.

There are 50 sluices, at reduced levels 92 metres, without rollers, 23 feet high and 6 feet 6½ inches wide. They have to withstand a head of 45 feet 11 inches. The grooves, sill and lintels are of cast-iron. The gate is formed of wrought steel joists and plates, faced with planed bars bearing against the machined face of the fixed frame work. The sluice is lifted by a six-part steel wire rope, winding two parts. There are 40 sluices at reduced level 96 metres and 100 metres, regulating discharge, when reservoir is full, and have 19 feet 8 inches and 32 feet 10 inches head over sill. The culverts are 6 feet 6½ inches wide by 11 feet 6 inches high. The sluice is built of a steel plated skin with rolled strengthening girders at the back, framed into cast-iron beams on each side, which form the roller path. On the top of the sluice is also fitted an adjustable bar, which shuts down on the lintel at the same moment as the bottom strikes the sill. Adjustable bars are fitted on each side of the face to reduce leakage as wear takes place.
The rollers are arranged in cradles formed of flat bars, and are hung in position on each side of the gate by steel wire ropes and attached to the gate. The barrel shaft of the crab is worked by means of a worm wheel and a worm fitted with a ball thrust bearing.

It was found that about one-sixth of the total work done was absorbed by pulley and rope gearing. The flexibility of different makes of ropes, which to all appearances were similar, was found to vary considerably. A rope which, when free, may easily bend by hand, be-
comes comparatively rigid when its wires are tightened and locked
together under a load.

_Sluices With Rollers._—These 25 sluices are 23 feet high and 6 feet 11/2 inches wide, and are for regulation when the 50 without rollers are lowered. The head above the sill of these sluices is 45 feet 11 inches. The sluice is built of heavy specially rolled steel joists, with steel skin plates and cast-iron roller path girders.

A vertical rod which is contained in a groove bolted to the skin of each side of the face is pressed by the water into the corner formed by the face of the sluice, and the face of the fixed frame, and thus makes a water-tight joint. The sluice is hung on a ten-part steel wire rope, winding two parts.

Sluices at reduced level 87.50 metres. The head of water above sill level is 60 feet 8 inches, giving a pressure on the sluice of 210 tons. The sluice is carried by a steel wire rope in ten parts arranged round pulleys on the gates and on girders at the pit top. Forced grease lubrication is used in the workings parts. Some of the sluice culverts have cast-iron linings 1/4 inches thickness of plates.

As boats have to pass through the locks at all heights of water level in the reservoir, the sill of the upper lock is 62 feet 4 inches below roadway, which necessitated a special design of gate. There are four locks 31 feet 2 inches wide and 262 feet 6 inches long.

Commencing at the upper end, the heights of the successive gates are—first, 59 feet; second, 59 feet; third, 45 feet 11 inches; fourth, 36 feet 1 inch; and fifth, 26 feet 3 inches. The total drop in the sill is 26 feet.

The great range in water level prevented the gates being floated, and they are therefore hung from above upon two sets of free rollers, which are supported by two bascule girders spanning the lock. The gates slide back into a recess into the side of the lock, after which the bascule girders are raised to allow the passage of vessels.

The 59 feet deep lock gate, with its carriage, weighs 105 tons, and requires a force of about one ton to travel it. The gate is formed of 14 horizontal bow string girders spaced so as to be practically equally loaded, bearing against two built-up jamb members faced with greenheart. The gates are designed to carry a pressure of 1568 tons.

The regulating sluices are placed in the gate. The roadway along the dam is carried over the top of the lock by a bascule bridge, having a span of 42 feet and a road width of 11 feet 6 inches. The object of the design of the Assouan Dam is to pass the flood waters of the Nile with as little obstruction as possible. The flood occurs each year, and extends over the same periods with little or any variation. As the water during flood season carries matter in suspension, it is important that the current should be retarded as little as possible to minimise settlement in the reservoir basin. For this reason and the height of the dam it would have been impossible to have constructed the dam with a crest overflow or diverted the water to spill over at the sides of the work.

It is difficult to see how the dam could have been constructed on
any other plan than that adopted. It may be open to discussion whether the design of the sluice ways and the manner of working are the best. Whether the vertical lift is the best mode of operating the gates, or could they be controlled in some better and less expensive manner. By a centre pin movement, either vertical or horizontal, or by an equilibrium water pressure, or by any other means. The lock gates are a most difficult and expensive design, rendered so by the variations of pressure changing frequently. It is hoped that the description given is sufficiently intelligible to afford a criticism of the various parts of the work.

Before closing the paper it may be interesting and possibly profitable to refer briefly to some of the projects that are at present under discussion with reference to future works. The principal difficulty is the demand for more water for summer irrigation. That is to augment the summer flow of the Nile. Additional storage works are required, and the question is where are they to be constructed.

The Soudan territory and Nubia are now factors in the problem, and the cotton trusts of America make it desirable that some independent field should be opened for raising cotton. Irrigation in Egypt is therefore now likely to increase as the demand for cotton becomes greater, and it is not improbable that the Soudan may prove a valuable territory for the purpose. The possibility of using the Victoria Nyanza as a storage appears to be unsuitable on account of the large surface it presents to evaporation. How far the statement made in reference to the quantity is correct, is open to serious doubt.

The Albert Nyanza, or some of the smaller lakes which are of a much lower level, might be available for storage purposes. With storage at the Lakes, the Sudd region between Lado and Fashoda would have to be overcome.

It may be possible and desirable to reduce the area of the Victoria Nyanza by draining. Using the water for summer irrigation for a number of years, and with the wealth so created set aside a percentage for further storage works and the contour river channel.

A reduction of three feet in the level of the Victoria Nyanza would send down the river as much water as the Assouan Dam would collect and supply in sixty-two years. If, therefore, the dam has increased the revenue of Egypt by £375,000 per annum, in sixty-two years there would be a return of £232,500,000 obtained by reducing the Lake 3 feet deep.

What the effect of the reduction would be on the country around the margin of the lake is not possible to say. Probably a vast improvement, as it would get rid of the detestable marshes, and may make areas available for cultivation. The Albert Nyanza and other lakes might be treated in a similar manner, and in course of time a large sum would be available for the construction of reservoirs in various places; along the course of the Nile reservoir sites abound at the cataracts. The Albert Nyanza, with one metre storage over its surface would represent a capacity of 6,500,000,000 cubic yards.

Lake Dembea, in Abyssinia, has a surface area of 1300 square
miles. Here, however, the question of evaporation is almost as serious as at Lake Victoria Nyanza.

Sir William Willcocks advocates raising the Assouan Dam by 20 feet and doubling the storage. This would necessitate dealing in some manner with the Temple of Philæ.

Lastly, there is the Wady Rayan project in the Fayoum, which has been under consideration for the past twenty or thirty years. The Rayan is a depression in the Fayoum, at a level of 150 feet below sea surface. The depression is said to be capable of storing two or three million cubic metres of water above the level, to which its contents could be used for supplementing the summer supply.

Part of the problem now before the engineering profession, in providing more storage accommodation, is to preserve the Temple of Philæ. Some of our members may be able to suggest some plan whereby this may be accomplished. It has already been proposed:

1st. To build it in by walls constructed around it.
2nd. To raise it bodily up on the same site.
3rd. To remove it and build it on the Eastern River Bank opposite its present site.
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