Please read and send in as full discussion as possible at earliest date

The Canadian Society of Civil Engineers

INCORPORATED 1887.

ADVANCE PROOF *(Subject to revision)*

NOTES ON THE REGULATION OF THE RIVER NILE.

By A. W. Robinson, M. Can. Soc. C. E.

The subject of the regulation of the River Nile is a very large one, and covers so many interesting conditions that not much more can be done than scratch the surface, so to speak. The fascination of Egypt, its history, its ancient civilization, its imperishable monuments, its strange mixture of the old and new, its complex political system, its wonderful climate and great river, all would attract the attention, but the subject must be restricted to some points more directly connected with the engineering questions, which center about the control of the River Nile.

The River Nile has for ages been a river of mystery. Only in recent times has the riddle of its sources been solved, and even yet there is much about it that is still to be discovered. The lower portion of the river, through Egypt proper, has, from earliest times, been well known, and the monuments which still remain testify to the greatness and skill of the ancient civilization.

Since the British occupation a complete transformation has taken place in the state of the country, largely due to the engineering works carried out by the Irrigation Department. The Nile is truly the life-blood of Egypt, and its conservation is the most important question before the country. The earlier efforts of the irrigation engineers have been attended with such success, and have resulted in so much financial profit to the country, that they have at once furnished both the incentive and the means to carry out still greater improvements.

Leaving out much detail, and much that has already been recorded elsewhere, the following notes will give a brief idea of the present stage of these works, and of the conditions leading up to them.

Basin of the Great Lakes.—A portion of the Nile has its rise in that great system of lakes of which the Albert and Victoria Nyanza are the chief. Lake Victoria is the direct supply of the Upper White Nile, the overflow of this lake being carried by the Victoria Nile and discharged into Lake Albert. The Semliki River carries the discharge of Lake Albert Edward also into Lake Albert, the outlet of which flows northward under the name of Bahr el Gebel, or Upper White Nile.

The drainage area of Lake Victoria is about 150,000 sq. miles, and the lake itself, 26,000 sq. miles, or a little smaller than Lake Superior. The level of this lake is 3,700 ft. above the sea. The Albert Nyanza has 32,000 sq. miles drainage area, and an elevation of 2,100 ft. above the sea.

A network of rivers runs all through the country, many of them as yet unexplored. Only during the last few years have engineers penetrated the district, and are now keeping systematic records to determine the rainfall, evaporation, and flow of the rivers. The evaporation of the water under the tropical sun reaches a very high figure.

The Sudd Region.—Bahr el Gebel extends from 2°N. to 9°30′ N., a distance of 525 miles, but the actual length of the river is much greater, owing to bends. In the northern half of this river is the great swamp region covering an area of probably 20,000 sq. miles, through which the river wanders in a series of channels and lagoons, in places losing its identity owing to the growth of vegetation called "Sudd," (an Arabic word meaning dam or obstruction). In this great area the volume of water suffers a further loss, the amount of which is now being definitely determined by a series of gaugings and measurement of river discharges. The effect of the numerous channels and variations in season and rainfall is, however, so complicated that only by a careful analysis of observation extending over a series of years can a definite conclusion be arrived at.

The growth of vegetation over this swamp region consists mainly of the papyrus reed, which grows in great luxuriance. The roots form a tangled mass with the decaying tops that have fallen upon them, and frequently float upon the water in large fields, the mat being strong enough to bear considerable weight. Over the swamp area the water is from two to six feet deep, with a layer of very soft mud on the bottom, into which the roots reach. The stems of the papyrus are from 10 to 18 feet in height, smooth and tapering, of triangular section with rounded corners, and are surmounted by a plume of fine green sprays. The fibre of the stems would have a value for fuel or paper-making, if means could be devised for harvesting and marketing on a sufficiently large scale, but at present the obstacles seem insuperable

The encroachment of the papyrus mat upon the open water of the river channel has often been such as to close up the river channel altogether, but since the advent of dredging machines and the more frequent passage of steamers, the trouble has not occurred.

The river discharge at the lower end of the swamp is fairly constant throughout the year, the flood variations being slight. This is due to the fact that, the origin of the river being in the Great Lakes, the lakes themselves serve as reservoirs to equalize the seasonal variations, and also the great swamp region serves as a further regulator of the variable quantity issuing from the Great Lakes.

Tributaries of the Nile.—After leaving the swamp region the only tributaries entering the Nile are the three rivers from the east, the Sobat, the Blue Nile, and the Atbara. These three rivers differ greatly in their characteristics, and it is necessary to consider them carefully to gain a correct idea of the very peculiar behaviour of the waters of the Nile. After receiving the Atbara, a short distance above Berber, the Nile receives no further tributaries but pursues its way alone through a practically rainless country for a distance of 1,600 miles to the sea, ever giving up its waters to supply the needs of the eleven million people who live along its banks. So great is the demand upon the river that for fully three months in the year no water at all reaches the sea, the sluice gates of the last great dam below Cairo being tightly closed, and even caulked, to prevent leakage.

Losses by Evaporation.—Under the tropical sun, and passing for the greater part of its length through a rainless country, the Nile is continuously losing its water. It has been estimated that the evaporation from the surface of the river alone is as much as $\frac{3}{4}$" per day, and in addition there is the loss by absorption into the banks. A great reduction is also caused by the spilling over into the great swamp region of the Bahr el Gebel. This area may be likened to a huge evaporating pan of about 20,000 sq. miles in area, and the river can be observed visibly flowing over its edges into the swamp. So many and complicated are the causes operating in this region to reduce the water that a long series of careful observations will be necessary before definite conclusions can be drawn, and these observations are now being made. Sir William Garstin estimates that from 50 to 60% of the volume of the White Nile is lost in passing through this swamp. It is here, therefore, that plans are being made so to regulate and control the river that this loss may be reduced.

Sources of the Alluvial Deposit.—All the water which reaches lower Egypt is derived either from the White Nile or its two tributaries, the Blue Nile and the Atbara. The waters of the White

Nile, as has been already pointed out, are mainly derived from the outflow of the Great Lakes in equatorial waters, the tributaries, Bahr el Ghazal and Sobat supplying a small amount. This outflow suffers great diminution, mainly on account of the evaporation in the swamp district. The discharge of the White Nile, being a lake overflow, is, therefore, fairly uniform throughout the year, and the water is comparatively clear, and does not carry any alluvion. The silt-bearing floods of the River Nile, with which probably all are more or less familiar, are derived entirely from the Atbara and the Blue Nile. These rivers are subject to enormous annual fluctuations; the flood discharge of the Blue Nile is as much as 10,000 cubic metres per second, or more than forty times its lower water discharge, while the Atbara has the peculiarity of flowing during the flood season only, and being entirely dry for a period of the year. These rivers take their rise in the Abyssinian mountains, where the rainy season produces a torrential flood discharge and sends down enormous volumes of a reddish brown mud, the finer particles of which remain in suspension and are deposited along the entire length of the Nile, and eventually discharged into the sea. It is this silt-bearing flood which, from time immemorial, has been the great fertilizing agency of Egypt and the Nile valley. The discharge of the flood waters and the resulting deposit upon the land have always been a matter of great concern to the population. Were it not for the fertilizing agency of the annual floods, combined with the extraordinary regularity with which the floods take place and the uniformity of the rise of the river, the wonderful agricultural sources of Egypt would not exist.

When the Blue Nile is in flood the waters rise to a much greater extent than those of the White Nile, and a peculiar flowing upwards is observed in the White Nile for a considerable distance above the confluence at Khartoum. The White Nile, some distance above Khartoum, is of great width, and thus serves to some extent as an equalizing reservoir.

The great rise in these rivers occurs during August and September, when the event of the flood waters is looked for in lower Egypt with the greatest interest, and all the irrigation canals and basins are prepared, as far as possible, to receive it.

Irrigation Methods in Lower Egypt.—There are two principal methods of irrigation in lower Egypt. The first and older of these, which has been in use from time immemorial, is the overflooding or basin system. By this method the land to be irrigated is enclosed in sections by an earthen embankment, and the water during the flood is allowed to enter and remain standing within these enclosures until it has precipitated all the alluvium, after which the flood subsides and the water is drawn off. As soon as the surface of the ground is dry enough to carry a yoke of oxen, it is scratched or plowed after a fashion with a wooden stick, and the crop immediately put in. So rapid is the growth that crops come to maturity before the moisture has been entirely exhausted from the sub-soil. It is not possible by this method of irrigation to give the ground any further supply during the season. Naturally, the harvesting of a good crop under these conditions is attended with considerable risk, and if the flow is insufficient or other conditions not wholly satisfactory, a loss ensues. To remedy this state of affairs the natives have resorted to crude methods of raising the water from the river after it falls to the lower level, and allowing it to flow upon the land in small quantities; this method of irrigation is still practiced throughout the valley of the Nile.

The second method of irrigation, which is superseding the old flood system as far as possible, is known as perennial irrigation. By this method the water is distributed as required over the land in a systematic way throughout the whole season from a network of canals which draw their supply from the river. In order to make these canals effective it is necessary to be able to control the level of the river at the point of entrance to the distribution system, and to provide these entrances with permanent works in the way of sluice gates and waste weirs so that the amount of water may be regulated.

Native Water Lifts.—The two principal machines used by the natives for raising water are the "Sakkia" and "Shaduf," and from a mechanical point of view these devices are very interesting.

The "Sakkia" is a mechanical device by which the water is elevated, through heights varying from 10 to 30 ft., by means of an endless chain of earthen jars, the motive power being a pair of oxen. The construction is of the most primitive kind, and is entirely without any ironwork. The materials of which it is made are Nile mud, palm trees, grass fiber and raw-hide. It is interesting as a development of the use of the materials at hand, by which a very serviceable and satisfactory machine is constructed with engineering skill of an unconscious kind. The oxen are made to travel in a circle and rotate a vertical shaft, to which is fixed a toothed wheel about 6 ft. in diameter. This wheel engages with a smaller one similarly toothed on the end of a horizontal shaft which is carried out beneath the road on which the oxen travel. These wheels thus act as bevel gearing, the teeth being merely wooden pegs in the rim, which after some use wear themselves to a bearing. On the end of the horizontal shaft is a sort of sprocket wheel or revolving cage over which are suspended two strands of fibrous rope, which dip down beneath the water surface, and to which are attached at intervals earthen jars holding a couple of gallons each. A trough formed of a hollowed palm tree receives the discharge from the earthen jars and conducts it away.

The movement and mechanism cause a curious creaking sound which is well known along the banks of the Nile, and day and night the movement must be kept up in order that the crops shall not suffer. Various efforts have been made to introduce engineering skill into the construction of these "Sakkias" by building them with steel shafts, iron gears and chain of buckets constructed on what one might think to be a more durable plan. As a rule these efforts have resulted in failures as the natives do not understand machinery, and have no means of repairing it when the parts become broken or worn out. The writer has seen a modern steel "Sakkia," designed by an engineer and built in a machine shop, lying rusty and worthless upon the bank, while near by was the old wooden device tied together with thongs of rawhide still doing business, and built much the same as in the days of the Pharaohs.

The other device, called the "Shaduf," is of much cheaper construction and is worked by hand. It consists of a simple lever mounted on a post, to one end of which is attached a long slender rod holding a bucket, and to the other end is attached a counter weight—an arrangement similar to the device used by the inhabitants of the Province of Quebec to raise water from the wells. One of these machines will raise from 10 to 12 buckets of water per minute through a height of 8 to 10 ft., and the natives will keep at this work hour after hour. As a rule, it requires 2 or 3 of these "Shadufs" in successive stages to make the lift required. It is stated that there are about 100,000 of these water-lifting appliances worked by the natives along the banks of the Nile.

Regulating Works on Lower River.—For the distribution of the water over the land there is an extensive system of canals, some dating back to a remote period. The construction and operation of these canals are under the control of the Irrigation Department, administered in a very satisfactory and efficient manner by British officials, under whom are a large number of natives. As a rule, the supply of water is not sufficient to permit the native agriculturist to draw upon the canals continuously or to use all the water he would like. The use, therefore, is carefully restricted and conserved, and a system of rotation is adopted by which the consumer is allowed to have water only a certain number of days per month. This arrangement does not necessarily work to the injury of the farmer, as he would frequently flood his land with too much water if permitted to do so, and other individuals would not get enough. It will be seen that the irrigation official holds a position of much responsibility, and one in which tact is needed in dealing with the natives.

The Cairo Barrage.—At three points in the river barrages have been built with the object of controlling the level of the river, so that it will flow into the canals at the required rate. These barrages are quite distinct in their function from the Assuan dam as they are not required to create a storage reservoir, but merely to raise the level of the river to the required height.

The first barrage was constructed just below Cairo for the purpose of distribution throughout the delta of the Nile. It was built by an Egyptian engineer, named Mougel Bey, and opened in 1861, but was for a long time a failure, owing to its insecure construction and inability to raise the water sufficiently to run through the canals. It was not until 1884 that the project was revived and British engineers took hold of it against a great deal of local opposition. The story of the failure and reconstruction of this barrage is an interesting one and has frequently been recorded. After being rebuilt it proved entirely successful and was the beginning of a new era of prosperity to lower Egypt, the financial return from this work alone having been such that the annual increase in value of the cotton crop of the delta each year is about ten times the cost of the work. The original cost of the work was £460,000 sterling, and in the five years following the operation of the barrage the value of the cotton crop was £5,000,000 per year greater than during the previous five years.

The Assiut and Esneh Barrages.—The second and third barrages ascending the river are at Assiut and Esneh, respectively 408 and 643 miles above the sea. These two barrages are similar in construction to the one built many years ago at Cairo, differing only in details. The Esneh barrage is the more modern of the two, having been completed and opened in 1909. It was built by the well known firm of Messrs. John Aird & Co., who were also the contractors for the Assuan dam, and it is noteworthy that the work was completed and opened eighteen months before the expiration of the contract time. The Esneh barrage is 2,952 ft. in length, and is constructed in the form of an open weir having 120 sluiceways, which are ordinarily freely opened for the passage of water. These sluiceways are 16 ft. wide and are separated by stone piers, 6 ft. 6 in. thick, except those at every tenth opening, which are of extra thickness to provide additional reinforcement to the structure; they may be closed by means of gates, which are raised and lowered from a travelling crane. The maximum head of water to be controlled is about 10 ft. It must be understood that at high Nile the entire discharge of the river is allowed to flow freely through the sluices, and that they are only put in action during the low water season, in order to control the level for the distribution system. At the side of the barrage is a lock for the passage of boats.

The Nile Reservoirs.—In order to make the perennial system of irrigation of the fullest value, it has become necessary to provide more water during the low water season, as it is during this time that the greatest drafts are made upon the river for agricultural purposes. The Assuan reservoir was created for this purpose and finally completed in 1902, and the great dam at Assuan is unique, both in regard to size and to the great volume of water contained in the reservoir. This great work has been so often described that it is not necessary to refer to it more in detail, except to say that the results extending over the whole lower Egypt, below the dam, have been so satisfactory that the Egyptian Government has had every encouragement to proceed further and gain increased benefits.

Surveys have been made for the construction of reservoirs and dams at other points, and these may come in time, but for the present, at least, it has been decided to increase the height of the Assuan dam, so as to make the reservoir hold 2¼ times its previous volume. The maximum head of water held up by the Assuan dam is about 65 ft., and when raised it will hold about 23 ft. more, so that the total head will not be far from 100 ft. This will have the effect of backing up the water as far as Wadi Halfa, a distance of 200 miles.

Augmenting the Reservoir Supply.—It is believed that the doubling of the capacity of the Assuan reservoir will, for a time, supply every need, but there remains the question of providing the water during the season of exceptionally low water, and also the question of bringing an additional area of land under cultivation. With a view, therefore, of further conserving the water of the river and providing for the increase in population, the authorities are turning their attention to the source of the supply of the waters of the Nile, and have established a branch of the Irrigation Service in the far interior country of the Soudan, with headquarters at Khartoum. The work of this service being for the benefit of Lower Egypt, the expenses are met by the Egyptian Government, and although operating in the Soudan and regulating the River Nile throughout a vast stretch of country, the cost is not a charge on the Soudan.

When it is considered that for thousands of miles the river through this arid country receives no tributaries and contains a population of about 11,000,000 people continually dipping up the water, it will be seen how important the question of conservation of the river becomes.

Navigation on River Nile.—The Nile has from ancient times been the highway of travel by navigation, and at the present time the amount of traffic by native boats is very considerable. The conditions on the Nile have developed a native boat peculiar to itself, and its strange appearance strikes the observer as being crude and inefficient. Upon closer examination it becomes evident that for every peculiarity in the construction of these native boats there is a reason. The details of construction have been evolved through thousands of years, so that the natives build their boats as a matter of course because they have always done so and there is no thought of change.

It is certain that no other boat could do the work of the native so well under the local conditions, and they are not only useful but picturesque. Among other peculiarities these boats are always built to draw more water at the bow than at the stern, and the keel at forward end is made very deep and strong. The object of this is plain enough when we consider that the boat is liable to run aground frequently on the sand bars, and if it were down at the stern instead of by the head, it would ride upon the sand bars and perhaps stay there. As it is, however, the deep keel at the forward end strikes the sand bar, holding the vessel with the stern free to move, and by swinging the stern from side to side the boat can be worked off.

The navigation of the Nile extends from the sea to the headwaters of the Bahr el Gebel, a distance of 2,900 miles, being interrupted only in places by the cataracts. There are six cataracts on the Nile between Assuan and Khartoum, to overcome which canals may be built, in course of time, so as to make navigation continuous. Already there is a lock at the Assuan dam to overcome the first cataract, and in this way there is continuous navigation from Cairo to Wadi Halfa, a distance of nearly 200 miles.

From Wadi Halfa to Khartoum traffic is carried on by rail, not only on account of the obstructions in the river, but because of the shortening of distance, the river making a great bend between these points. At Khartoum navigation is resumed and extends uninterruptedly for a distance of 1,090 miles into the interior before arriving at the foot of the rapids at the descent from the Great Lakes. The head of navigation at this point is about 375 miles from the Uganda railway, and when this distance is linked up by the railway there will be continuous transport by rail or river for the entire distance. The Cape to Cairo railway is, therefore, within reasonable distance of accomplishment, although a railway for the entire length does not seem to be necessary, when the great natural highway of the Nile furnishes such a splendid system of navigation.

The steamers in use on the Nile are generally of the light draft stern wheel type, although differing much in detail from those in use on the American rivers. Ordinarily a draft of water of four feet can be carried the entire distance, and there are very few points in the river which require any improvement.

Dredging and Embankment Operations.—The regulating works in the Soudan have not yet arrived at the stage of actual construction, but the engineers are engaged in making surveys and gaugings of the river, and are gradually accumulating accurate information upon which the necessary works may be carried out as required. It has been proposed to place various regulating works at the outflow of the Great Lakes, so as to control the discharge of those lakes and also to rectify the river through the swamp district. With a view to ascertaining on a practical basis just what can be done and what it would cost, an experimental dredge fleet has been built, consisting of three machines, each adapted to a different class of work. These machines are now in service, and upon the result of their work future developments will depend.

The first machine is a grab dredge to deal with the vegetation and soft mud. This vessel is a light draft river steamer of the stern wheel type having a boom at the forward end with the necessary machinery for operating the grab. A boat of this type can readily move from place to place on the river for experimental purposes, and is well adapted to clearing away the obstruction of the sudd and thus maintaining navigation.

The second type of dredge is a dipper dredge, intended primarily for embankment purposes. One of the principal requirements in the rectification of the swamp country is the construction of embankments to enclose the river and prevent its overflowing, while at the same time the section of the waterway is increased by excavation. In many cases cut-offs will be made in the river to shorten the distance, and the dipper dredge is well adapted to this class of work.

The third type of dredge is a hydraulic machine. It is designed for taking wide cuts, deepening the bed of the river, and discharging the excavated material upon the banks, or over the embankment that may be made by the dipper dredge. In some places the three separate operations of the three dredges will proceed in sequence—one preparing the way for the other until the final result is obtained. They are, however, so constructed that each of them can work alone and complete its own section of the river.

Difficulties to be surmounted.—The difficulties to be surmounted in the conduct of a work of this kind are very great. The locality is one which is not only remote from the base of supplies, but it is entirely destitute of any resources whatsoever, and the climate makes it very hard for even the natives to work continuously, while Europeans must have frequent leave.

Added to this the question of fuel supply is a serious one. The fuel used is Welsh coal, and by the time it has reached its destination it has become very valuable. This coal is carried by ship through the Suez Canal and unloaded at Port Soudan on the Red Sea; from here it is carried to Khartoum, a distance of over 400 miles, where it is taken up the river about 800 miles by a towboat and barges. A special system of barges and towboat has been provided, by which a fleet of barges can be taken up at one time by being pushed ahead of the towboat, on the plan well known on the Ohio River. This plan has proved successful, and a boat of this type can navigate the crooked passages in the upper reaches of the river with great facility, and is able to keep the fleet supplied with coal by making one round trip per month.

Efficiency of British Administration.—In this connection reference must be made to the type of men who are carrying on these great works, especially the irrigation works of Egypt. Men of the highest character and ability, selected solely for their fitness, they hold their office untrammeled by the political exigencies of the day.

Those who heard or read the speeches of Earl Grey, before he left Canada, could not fail to be impressed with the spirit of pride and patriotism with which he referred to the beneficent influence which the British Empire is able to exert throughout the world. Wherever that influence extends, lawlessness and oppression are put down and liberty and righteousness maintained, while the country is developed for the good of the people, and those great works of civilization which are mainly the product of engineering skill are carried on.

Great Britain sends her best blood and brains to the farthest corner of the Empire, and nowhere is the power of a few able men to control vast forces better illustrated than in the British Administration throughout the 4,000 miles of valley of the Nile. The forces to be dealt with are hordes of savage men, as well as forces of nature. But a few short years ago the region where the works are carried on was terrorized by the Mahdi Now life and property are safe, and the lonely British officer who stands guard with his handful of native soldiers, preserves the peace of thousands of square miles of territory, while the engineer carries on his work of harnessing the Nile and making it possible for the natives to prosper.

These men are all actuated by that same spirit of patriotism to which Earl Grey referred, and the belief in the power of British institutions, and they appear to take a personal pride in being representatives of that power. Here in Canada we are differently situated. We are not a colonial dependency but a self-governing nation. Great Britain does not send us men of this stamp to rule us and execute our public works. We have within ourselves both the opportunity and the ability to develop our own resources to the fullest extent. Shall it be said that our great works are carried on less efficiently or by men with less worthy motives than in less-favoured parts of the Empire?

We have many men in our public service who are in every way worthy of the honour and esteem in which we hold them, but it is not always so, and in the rank and file especially we do not find that fitness is the sole test. Our younger men especially do not find in our public services that opportunity for a career, in which industry and merit, combined with high personal character untouched by political influence, would reach a just reward. It is, of course, out of place for this Society to take part in politics, but one might perhaps express the wish that all its members should, as far as they are able, lend their influence to the cause of civil service reform, to the end that our national undertakings may be carried on with greater efficiency, and the principles so admirably expressed by Earl Grey may find their counterpart in Canada, as well as in other portions of the Empire.

Intensive Cultivation—Egypt represents one extreme of intensity, having a population of over 1,000 per square mile and making use of every available square foot of ground. In this country we represent the other extreme in our wastefulness of the land. By a little care and knowledge it is possible for us to get much more out of our land than we do, and the beginning which has been made in irrigation in Alberta, where the rainfall is deficient, is a step in the right direction. Such a country properly irrigated will produce not only greater crops than a country at the mercy of the weather, but will produce them more reliably and with less risk of loss.