A CRITIQUE OF SOME ASPECTS OF IRRIGATION SYSTEM DESIGN IN SUDAN

by

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Background

General description of the Nile River System

For Sudan and Egypt, the Nile River system is the main source of livelihood with the non-Nilotic streams contributing in a comparatively smaller measure for the development of the irrigation systems. The Nile is a dominating physical feature in Sudan and is one of the largest rivers in Africa and the longest river in the world. Its basin has an area of 2.9 million square kilometers extending from latitude 4° South to latitude 31° North and covering the entire area of Uganda and the cultivated land of Egypt, one-third of Ethiopia, a substantial portion of Sudan and parts of Kenya, Tanzania, Zaire, Rwanda and Burundi. The basin represents one-tenth the area of Africa and about one-third area of the riparian countries.

The Nile which is a product of a tropical environment, flows Northwards into the Mediterranian sea stretching over a distance of 6650 kms from its remotest source in Tanzania and covering areas exhibiting varieties and contracts in topography, climate, vegetation and people.

The Nile basin is divided into 5 sub-basins-the White Nile, the Sobat, the Blue Nile, the Atbara and the main Nile.

The White Nile sub-basin has a catchment area of 378,000 km². An important feature of the whole catchment is the prevalance of swamps caused by poor drainage coupled with climatic conditions favourable to vegetation growth. From Nimule northwards, the river is known as Bahr EL Jebel. Northwards at the tail end of the swamps, the Bahr EL Jebel is joined by Bahr EL Ghazal and the two together flow outwards as the White Nile. While passing through the Sudd region, the White Nile looses on the average about 50% of its annual flow through evaporation and evapotranspiration.

South of Malakal at about latitude 9° - 30', River Sobat joins the White Nile. The Sobat sub-basin with a catchment area of 224,000 km² is characterised by its mountainous topography and heavy forest. After joining Sobat, the White Nile flows northwards confined by high banks until it joins the Blue Nile at Khartoum. The Blue Nile sub-basin has a catchment area of 325,000 km² and lies on the north eastern side of the Ehiopian plateau. The source of the Blue Nile is Lake Tana.

After the confluence of the White Nile and the Blue Nile at Khartoum, the river is called the Main Nile and flows northwards till it meets river Atbara. The Atbara sub-basin lies in Ethiopia & Sudan between latitude 12° and 15°N and longitude 36° and 40°E with a catchment area of 69,000 km². After its confluence with the Atbara, the Main Nile meanders through the great desert forcing its way through

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five cataracts until it flows into the Mediterranean sea. The general plan of the Nile and its main tributories is shown in Figure (1) and the flow chart of river Nile supply system in figure (2). The main Nile starting at Khartoum receives on the average two-thirds of its flow from the Blue Nile while the White Nile contributes the other one-third.

Water Resources Availability

The Nile river system within Sudan provides the main source of water for the Irrigated Agricultural projects of the country which is heavily dependant on the Agricultural products for export earnings. The total annual average yield of the river Nile as measured at Aswan is 84,000 million m³. Sudan's share of only 22,000 million m³ according to the Nile waters agreement with Egypt is fast approaching full utilisation and future water resources development projects of Sudan are therefore, likely to be restricted on this account.

Some Irrigation Systems adopted in Sudan

General review

Several systems of Irrigation are being adopted in the various locations in Sudan. The adoption of a certain method need not necessarily be based on the common practice in the community. The several factors that determine the best method to irrigate the land are its slope, the crops to be irrigated, the water supply, the permeability of the soil and its water holding capacity.

In the farming system of certain locations in Northern Sudan, plots varying from 40m² to 50m² are watered separately. The water is applied by opening the embankment of the gadwal and flooding the whole plot.

The Gezira Angaya Irrigation System

With the Agricultural developments of Sudan heavily weighted on crops such as wheat, groundnuts, cotton, vegetables etc., the furrow system or its modified versions are generally used in almost all the large irrigation development projects of the country. The method most widely used is known as the Sudan Gezira Angaya Irrigation system which was developed specifically for the largest Irrigation project of Sudan - the Gezira scheme. A diagramatic representation of the Gezira Angaya Irrigation System is shown in figure (3) along with six other modified versions of the method.

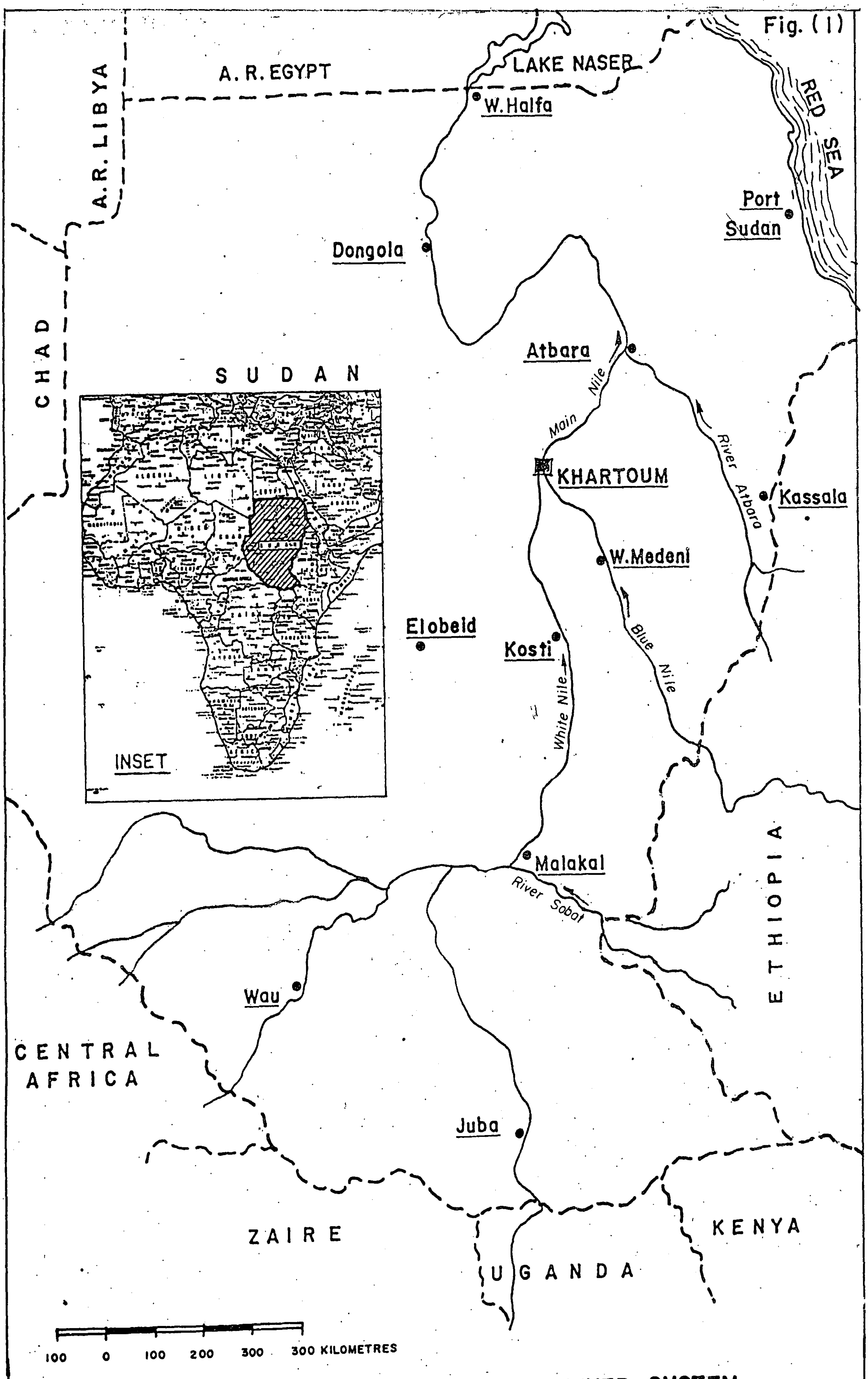
A continuous flowing main canal supplies water to branch and major canals which themselves flow continuously. These canals follow no regular pattern, their route and capacity conforming with the topography and areas commanded. Similarly the main drainage system follows the natural depressions.

Minor canals, water courses (AXX) and farm ditches (AVI) conform to a regular standardised pattern. Their design capacities are based on either daylight (12 hours) watering with night deliveries being stored in minor canals constructed oversize for this purpose or for continuous watering on a 12 hour or 24 hour basis. Minor canals vary in size, commanding areas from 300 feddans (126 Ha) to 12,000 feddans, (5040 Ha) but always spaced a distance of 1.42 km.

Water from the minor canals to the water courses (AXX) is supplied through steel or concrete pipes 35 cm internal diameter with a valve upstream which can be set for four different openings.

Water courses (AXX) are spaced 292

Fig. (1)



THE GENERAL PLAN OF THE NILE RIVER SYSTEM.

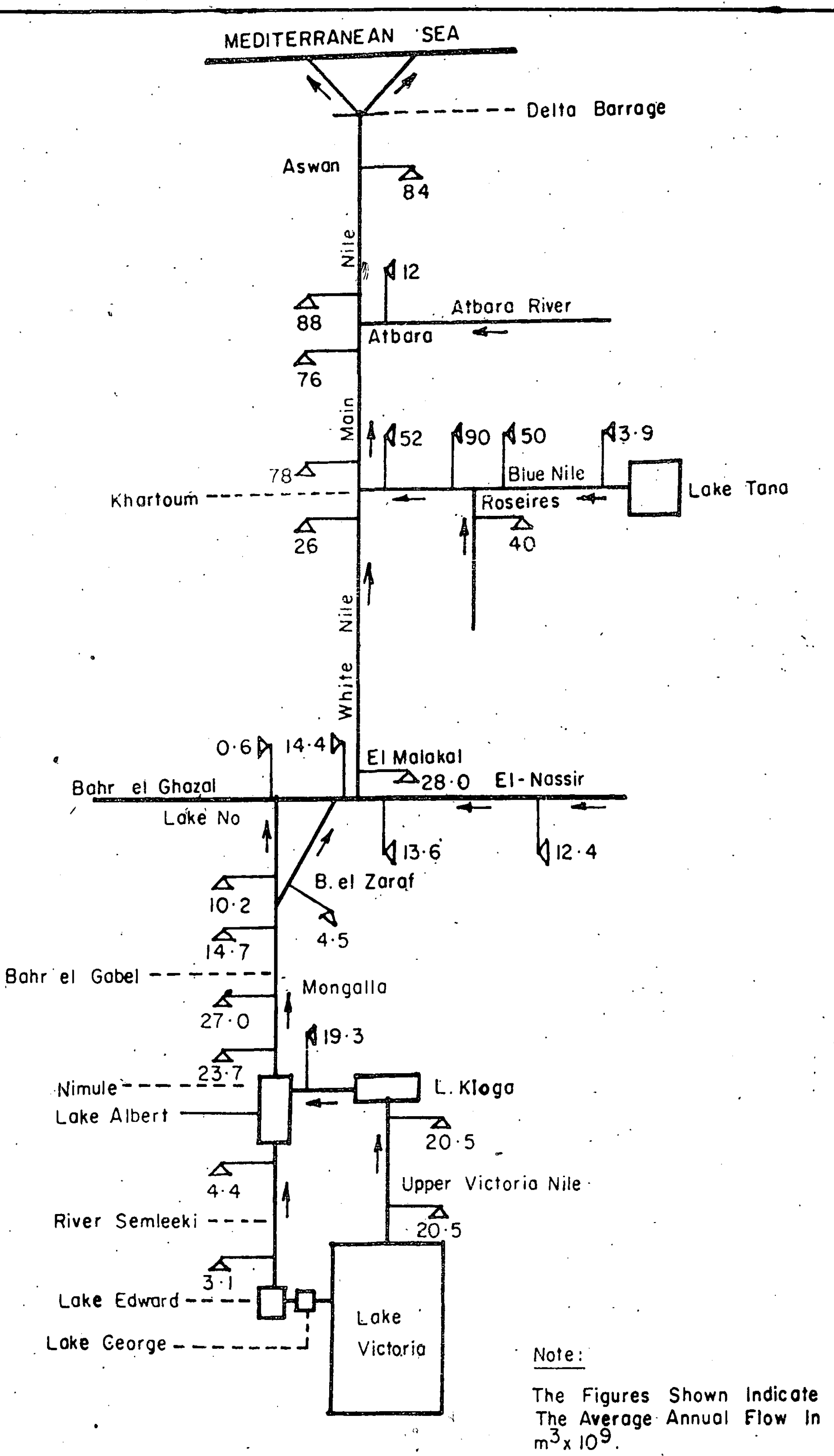


Fig. (2) FLOW CHART OF SUPPLY TO RIVER NILE

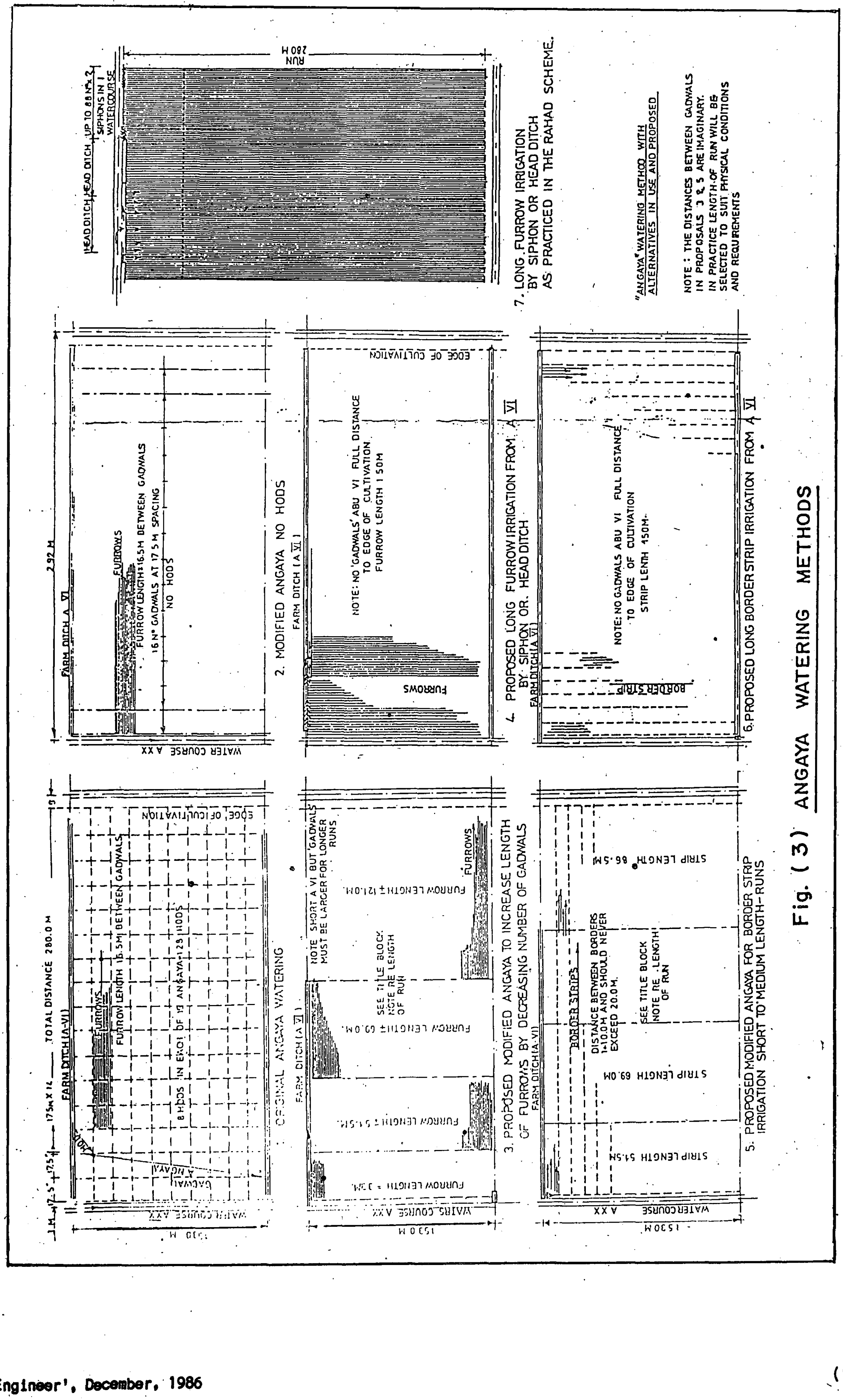


Fig. (3) ANGAYA WATERING METHODS

metres which include 6 metres for the water course and 6 metres for a road. The area supplied by a water course varies up to a maximum of 90 feddans (37.8 Ha) and is designated a "number", although the spacing seldom varies from the standard 292 m.

A number is divided into 10 feddan (4.2 Ha) plots called "Hawashas" each supplied by a farm ditch (AVI) running along its longest side, the dimension of a hawasha being 280 m x 150 m. The farm ditch is supplied from the water course through a steel, concrete or plastic pipe from 185 mm to 250 mm diameter and 2.0 m to 2.5 m long.

On occasions it is convenient to supply three or four water courses from a single offtake from the minor. The sub-minor canal supplying the group of water courses is termed a double Abu XX (D/AXX) and has twice the carrying capacity of a water course.

In the "Angaya" system no provision has been made for in-field drainage. With the low permeability of the clays, surplus water remain on low spots until it evaporates or is gradually absorbed by the soil.

Watering is achieved by dividing the 10 feddan (4.2 Ha) hawasha into 16 "Angaya" each containing 8 "hods". One "hod" of each "Angaya" is opened for simultaneous watering of 16 "hods". The watering of the 16 "hods" should be completed in about 3 hours at the recommended duty and the 10 feddan (4.2 Ha) "hawasha" in two - 12 hour days. This system of watering is known as the angaya watering system.

With intensive cropping programmes the "hod" by "hod" system and dayling watering have been largely abandoned in Sudan. Water courses and farm ditches are allowed to flow continuously at about half the daylight watering rates resulting in average watering periods of 7 to 10 days for a "hawasha" of 10 feddans (4.2 Ha).

Modification of the Angaya System - Long furrow irrigation

In the standard lay-out, the farm ditch (AVI) is eliminated and furrows watered directly from the water courses (AXX) either individually by syphon or in groups making a ditch supplied by a cut through the water course bank. The length of the furrow is 280 m and slopes may vary from 0. to 200 cms per km. To achieve the required rate of discharge through the syphon to irrigate a furrow in a reasonable length of time (3 to 4 hours depending on slope) an average head of 20 cms across a 5 cms diameter syphon must be maintained.

A major problem that arises in long furrow irrigation is the ponding of water at the ends of the furrow if the water is not cut off at the correct time. If this is not properly adhered to, it is thought that about 10% of the total water applied is lost and unless this water can be utilised elsewhere for small gardens, tree plantations etc., budgetting for such a loss is totally unacceptable. Another disadvantage of the long furrow system is that on shallow land slopes, a high degree of land preparation is essential.

Current Design Concepts - Their Impact on Operation and Maintenance

Layout of canalisation

The main canals are laid out on the main ridges and the major canals on the secondary ridges. These canals follow no regular pattern, their route and capacity conforming with the topography and the areas commanded. Similarly the main drainage system follows the natural depressions.

Minor canals, (AXX) and (AVI) conform to a regular standarised pattern. The distances between Abu VI, Abu XX

Table I

Standard Distances:

(i) Distance between AVI S.

10 Feddan (4.2Ha) plot	150m x 280m	
width of AVI	3m	
Distance between centre line to centre line of AVI	153m	

(ii) Distance between AXX S

10 Feddan (4.2Ha) plot	280m x 150m	
width of AXX	6m	
width of road	6m	
Distance between centre line to centre line of AXX	292m	

(iii) Distance between Minor Canals

Centre line of Minor to outer toe	9.5m	
width of road	6.0m	
½ width of AVI	1.5m	
Centre line of Minor to centre line of AVI		17.0m
9 Numbers of Howashas at 153m		1377.0m
½ width of AVI	1.5m	
width of road	6.0m	
Allow for minor drain	9.0m	
Outer toe to centre line of Minor	9[illegible]	
Centre line of Minor to centre line of AVI		6.0m
Distance between Minor		[illegible]m

(iv) Centre line of 1st AXX to parallel Minor

½ canal width
Road
½ XX width

(v) Centre line of 1st AXX to parallel Major

Centre line of Major to outer toe (say)	1.[illegible]
Outer toe to centre line of Gannakia	2.9m
Centre line of Gannakia to Outer toe	8.3m
Width of road	6.0m
½ width of AXX	3.0m
	38.0m

The distance should be increased to allow for a width of Major greater than that assumed and also allowance made for a wider roadway.

(vi) Centre line of last AXX to edge of cultivation

½ AXX width	3m
width of Howasha	280m
	283m

(vii) Centre line of last AXX to parallel minor

To edge of	283m		
Width of road	7m		
½ width of canal	9.5m		
	299.5m	say	300m
Add for drain			10m
	Total		310m

(viii) Centre line of last AXX to parallel Major

To edge of cultivation	283m		
Width of road	7m		
½ width of canal	19.5m		
	309.5m	say	310m
Add for drain			10m
			320m

(ix) Tail of Minor

10 m downstream centre line of AXX

(x) Reservations

(a) From edge of cultivation

Allow for road and Major drain 40m

(b) From centre line of Major 35m

(c) From centre line of Minor to edge of reservation

½ canal width	9.5m
Minor drain	9.0m
Road	7.0m
	25.5m

and minor canals for the Gezira Angaya system of canalisation is shown tabulated in Table 1 for the 10 feddan (4.2 hectares) plot size generally adopted in the large irrigation projects of the country.

Field and Minor canal design criteria

The field canals such as the DA XX, AXX and AVI are designed on the basis of the Mannings formula with $\frac{1}{n}$ = 50 and the section parameters are shown tabulated below:

	DAXX	AXX	AVI
a) Command-minimum F.S.L. to Plot	15 cms	10 cms	8 cms
Command-maximum F.S.L. to Plot	25 cms	20 cms	12 cms
b) Water slope - minimum	5 cms/ kilo	5 cms/ km	5 cms/ km
c) Mannings $\frac{1}{n}$	50	50	50
d) Discharge per 12 hours	10,000m³	5000m³	2000m³
e) Side slopes	2 : 1	2 : 1	2 : 1
f) Bed width	1:5 m	1:0m	0:60m
g) Depth	0.5m	0.4m	0.3m

The Minor canal sections vary depending on the area under its command. The bed width varies from 1 to 4 metres, with side slopes 2:1 and water depth computed from Mannings' formula with n = $\frac{1}{45}$. The minimum command from high ground level on the reach to flat F.S.L. is 20 cms while the maximum is 50 cms.

The design slopes for the required discharges are as follows:

Low supply slope from point of minimum command - 2 cms/km
Full supply slope from downstream of regulator - 5 cms/km
Night storage slope - 1 cm/km

The minimum night storage depth at downstream regulator is 20 cms while the mean depth and mean width between N.S.L. and F.S.L. should be sufficient to provide 5.1 m³ storage volume per gross feddan (0.42Ha).

Duty of water as defined in Sudan

The duty is the relation between the volume of water and the cultivated crop area which it matures. This is expressed in several ways - Acre-feet/ Acre-inches per Acre, Acres per cusec, cubic metres per feddan (o.42 Ha) per day, cubic metres per feddan (o.42 Ha), average depth of water in metres etc.

In Sudan, the "rate of flow" duty is called the "Factor". The gross factor is the water consumption per day in cubic metres per feddan (0.42 Ha) of gross area while the crop factor is the water consumption per day in cubic metres per feddan (0.42 Ha) of crop area. Factors vary throughout the season and in different districts due to climatic and soil conditions. There are "Peak factors" at the time of maximum demand and "Mean factors" over any period.

The duty may be specified at the field canal, minor head, major head and the main canal head. The general average values of the crop factors are 34 for minors, 32 for majors, 30 for branch canals and 28 at the main heads. As no detailed investigations have been carried out to determine the duties of the various crops, the figures given above are generally adopted for design purposes.

Field canal pipe outlets and regulators and Minor Canal Storage Weirs

The field outlet pipes provided to regulate the flows into field canals are generally 3 m long and are laid out either in single, two, three or four rows depending on the head available to release the required discharges. Pipe regulators are provided in the canal network with pipe diameters ranging from 0.35m to 2/1.01 metres according to the area irrigated. Well-type night storage weirs are provided in the minor canals with pipe diameters ranging from 1.0m to 3.0m. These storage weirs are operated so as not to exceed the designed N.S.L.

of 15 cms above F.S.L. Other type of weirs generally used are the "Well head regulators" "Moveable weirs" and "Moveable standing wave weirs".

Silting of Minor canals

The original designs of the canal were developed on a continuous watering basis. But since, night irrigation has been generally abandoned in many parts of Sudan, the main and major canals are allowed to flow continuously while the minor canals are used to store the water in the night and release the stored water during day in order to supply the 24 hour continuous irrigation water in the 12 hour day time period.

This practice has resulted in heavy silting of the minor canals which have to be desilted regularly incurring heavy expenditure. The spacing the minor canals according to the Gaziri Angaya system is 1.42 kms.

Flow control in Main and Major canals

With the comparatively flat topography over which the main and major canals traverse, it is very unlikely to find suitable canal storage sites and other means will have to be found to control the main and major canal flows to prevent wastage when the demand is low and shortfall when the demand increases.

Some concepts for improved performances

The irrigation systems developed for Sudan, specially the Gezira Angaya system, have evolved over years of study incorporating the most suitable and adoptable methods to match the topography and the type of crops cultivated. Inspite of continued research, there are yet a few aspects that need further improvement.

Surface Drainage

One such shortcoming is the problem of farm drainage. There is at present no provision to drain out the stagnant pools of water that accumulate in the farmers allotments. Due to the heavy clayey soils in the development areas, the rate of infiltration is very low and pools of water stagnate in some sections of the cultivated land until it is evaporated. These pools of water become ideal places for breeding vectors carrying diseases such as Malaria and Bilharsia. One of the technically feasible remedial measures to overcome this deficiency is to lay underground pipes to lead the stagnant water into the drainage lines. The cost of such an undertaking has to be carefully analysed and weighed against the benefits that can be derived.

Flow regulation to farms

The structures presently used for controlling field canal flows into the cultivated lands are the standard pipe regulators. When the water levels in the parent canals drop due to decreased discharges towards the tail end, the flow rate through these regulators also drop and adjustments have therefore to be made in the regulators to release the discharges required. This process becomes more complex if the farmers demands fluctuate frequently. A remedial programme of action is to install Nerpic constant discharge modules developed by Sogreah - France at the offtakes of the Abu XX and Abu VI channels. Outline diagrams of these modules are shown in Figure (4) & (5). Larger modules or modified versions could also be installed at the offtakes of the minor canals.

Design of stable canals and drop structures

Most of the canal designs had originally been made on the regime theory concept based on empirical relations developed in other countries. While there are no canal design criteria to perfectly match the application of theory to the varying conditions

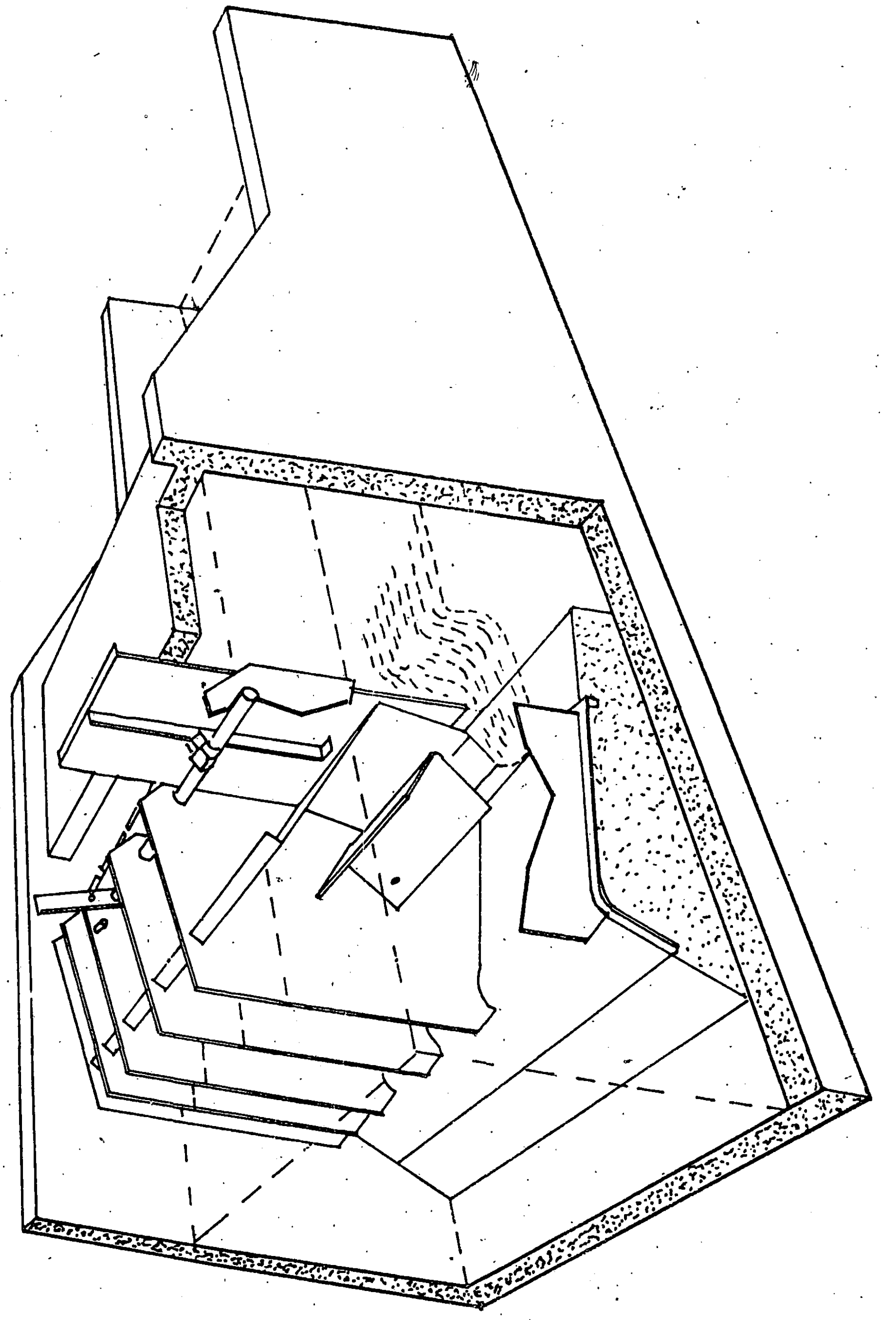
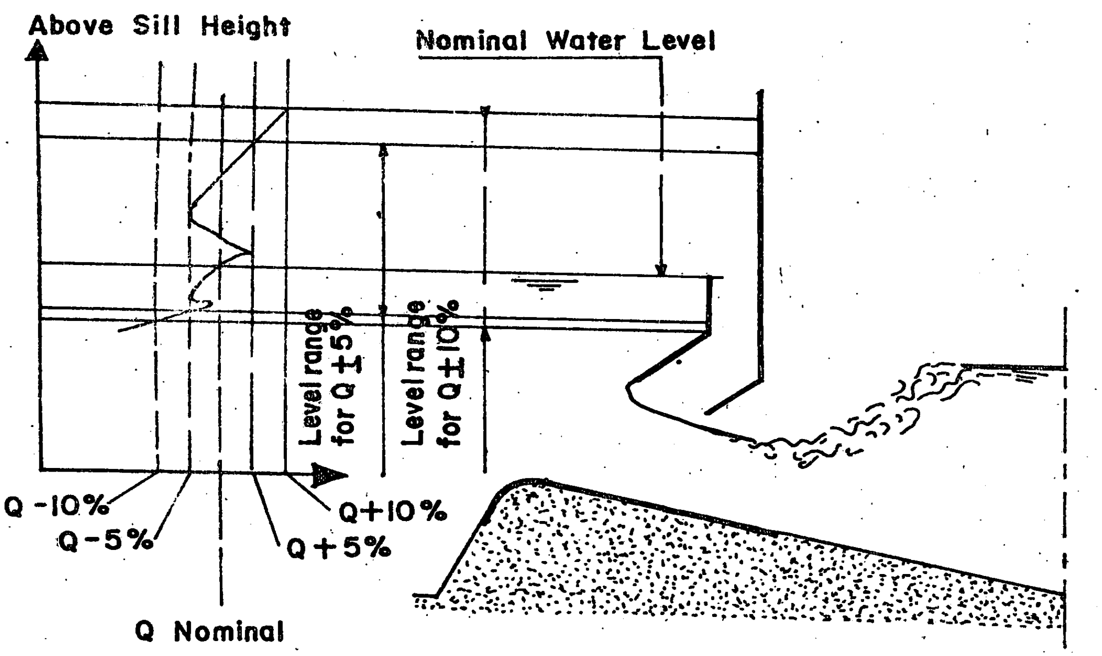


Fig. (4) PERSPECTIVE VIEW OF DOUBLE BAFFLE DISTRIBUTOR



DIAGRAMMATIC LAYOUT AND OPERATING CURVE FOR DOUBLE BAFFLE DISTRIBUTORS

NEYPIC DISTRIBUTOR TYPE $X_2 90$

Fig. (5)

in the field, it is certainly desirable to develop more stable canal sections to achieve more dependable canal operations and reduce recurrent maintenance expenditures for desilting. Although such a design approach is essentially a technical feature, it is necessary in the context of the present day conditions to place much emphasis in a design that also satisfies the needs of the settlers in other aspects of water use.

Extensive scouring is observed in the downstream of most of the drop structures on account of inadequate dissipation of the energy of the flowing water. The designs evolved for such drop structures need to be reassessed to prevent scouring and undermining of such structures. One remedial technique that can be incorporated for the main and branch canals is to dissipate the energy through mini hydro-electric generator units and utilise the power guaranteed for local consumption or injected into the national grid.

Main, Major and Minor canal flow regulation

With the farm water requirements as the main controlling factor, suitable strategies for supplying the water in time have to be formulated to prepare realistic water indenting procedures. This entails the computation of the travel time from the source of water and should be provided in the form of charts at the design stage or immediately after completion of the project, or in the alternative, automatic control gates to regulate the flows have to be installed at suitable intervals on the main and major canals in the existing schemes and incorporated in the designs in the future schemes to prevent wastage of water due to spilling when the demand is low and shortage of water when the demand increases. As night irrigation has been abandoned in Sudan, the minor canals serve as night storages causing heavy sedimentation and the resultant high recurrent investments needed for desilting. Research directed to find a suitable solution is urgently required so that the results of such a study can be incorporated in future design for better operation and maintenance.

Flow measurements

Very few measurement structures, if any, have been provided in most of the existing schemes. It is essential that the irrigation canal networks of Sudan already operating and those proposed for construction be provided with suitable measuring structures at strategic locations to ensure that the flows are released according to the demands to prevent wastage. Sudans principal water resources potential is derived from the Nile river system restricted further by the Nile waters agreement with Egypt. With Sudan's share of the Nile waters rapidly approaching full utilisation, it is essential that revised design concepts be introduced as a high priority in order to ensure maximum utilisation of Sudan's limited water resources.

Relevance and Adaptability to systems in Sri Lanka

Comparison of the two systems

The on-farm development patterns adopted in Sudan are the furrow systems and the modified versions to suit the crops being cultivated such as wheat, ground nut, cotton, vegetable etc.

In Sri Lanka, the major crop is rice and flooded basins are adopted for the cultivation of the crop which is kept ponded for the major part of the growing period. In general, the two systems are completely different and there is no similarity between the two methods of on-farm irrigation.

The layout of canalisation in the two systems are evolved on two different methods except in the layout of the field canal network. As suggested for the field canal network of the Irrigation Systems in Sudan, constant discharge modules of the type shown in Figure (4) and (5) can be advantageously introduced and installed in the systems of Sri Lanka at the field canal offtakes and also at the distributory canal offtakes, where applicable, to eliminate problems connected with shortfall in water issues at the tail end of these canal systems.

Canal design procedures generally adopted in Sri Lanka

One of the major deficiencies in the irrigation systems of Sri Lanka is in the design of the canal sections. Except in the larger schemes of Sri Lanka, the canals are designed using the Mannings' or Chezy's formula with assumed canal side slopes regardless of the characteristics of the embankment material forming the canal boundaries.

By this procedure, the canal sections adopted for construction change rapidly during operations due to siltation and scour and do not generally satisfy the requirements provided at the design state.

Recommended canal design procedure

A remedial approach is to adopt a design based on one of the theories of a stable canal section. Three main theories generally used are the (a) Regime theory (b) Maximum velocity theory and the (c) Tractive force theory. For the adoption of any one of these theories, detailed investigations have to be carried out to obtain the relevant data for design purposes. The adoption of any one of these theories need not be the only criteria for evolving a suitable canal section.

The design of the field canal networks of the irrigation systems of Sri Lanka in particular need to be reviewed in the context of the experience gathered up to now. The section of an erodible channel in which no erosion will occur at a minimum water area for a given discharge is termed the stable hydraulic section. In developing a stable hydraulic section for maximum efficiency employing the principle of tractive force, a theoritical cosine channel section has been evolved. Empirical profiles such as the ellipse and the parabol have also been suggested for this purpose. It is suggested that the field canal sections be designed as elliptic, parabolic or cosine profiles for improved performances to suit the particular soil type and other relevant field data.

Conclusions

General

A general review of the current practices and design methodologies adopted for the irrigation systems of Sudan has been presented along with some comments on the deficiencies that still exist. Modified versions of the furrow irrigation systems developed in Sudan after many years of study and research could probably be adopted in some of the upland cropping areas of Sri Lanka, whenever applicable, for similar climatic conditions. The development of sound and effective design principles for the main and distribution canal systems of both Sudan and Sri Lanka are urgently needed both for improved operational capability and overall savings in maintenance expenditure.

Design procedures for stable canal sections

A task committee is therefore recommended to be initially formed for directing studies and carrying out continuous research connected with design procedures of stable canal sections which form a vital component of any irrigation system.

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Glossary of local terms used

Gadwal - small embankment

Main canal - the primary supply canal

Major canal - Branch canal

Minor canal - Distributory canal

Abu XX - Large field canal supplying a 90 Feddan (37.4 Ha) plot

Abu VI - Small field canal taking off from a Abu XX to supply a 10 feddan (4.2 Ha) plot

Feddan - Measure of land area = 0.42 Ha

Hawasha - 10 Feddan (4.2 Ha) plot