IMPROVING THE OPERATION AND MAINTENANCE FOR BETTER SEDIMENT AND WATER MANAGEMENT IN GEZIRA SCHEME, SUDAN

AMELIORER L'EXPLOITATION ET LA MAINTENANCE POUR LA MEILLEURE GESTION DU SEDIMENT ET DE L'EAU DU REGIME DE GEZIRA AU SOUDAN

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ABSTRACT

Improving the efficiency of irrigation via sediment management is needed for adequate water supply and food production. This study is being carried out in Gezira Scheme in Sudan. The scheme has a total area of 880,000 ha and uses 35% of the Sudan's current allocation of Nile waters. The Scheme is irrigated from the Blue Nile River, characterized by high sediment load, which causes severe sedimentation problems in irrigation canals and poses real operation and maintenance challenges. The aim of this study is to reduce the impacts of sediment deposition in the irrigation canals by improving the operation and maintenance procedure.

The operation and maintenance procedures in Gezira Scheme have been investigated. The relation between the water delivery system and the different levels of service (flexibility, adequacy and efficiency) has been evaluated according to the different flow control structures. The sedimentation problem and its effect on the operation are also highlighted. Furthermore, different scenarios of operation schedules and maintenance activities in the scheme are proposed for effective sediment and water management. Comparative analysis and optimization techniques are proposed by comparing the demand with supply to get the best scenario for least sediment deposition by using the SETRIC model. It is a one dimensional model based on sub-critical flow, quasi-steady, for gradually varied flow and it can simulate sediment transport under non-equilibrium as well as equilibrium conditions. A module will be introduced to the SETRIC model to deal with cohesive sediment. The model will be calibrated

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and validated using data collected from field work. The possibilities to improve the sediment and water management by improving the operation and maintenance in the Gezira Scheme have been addressed.

Key words: *Sediment management, Gezira Scheme (Sudan), Sediment transport model, Hydraulic performance of canals.*

RESUME ET CONCLUSIONS

Améliorer l'efficacité de l'irrigation par la gestion des sédiments est nécessaire pour l'approvisionnement en eau adéquat et la production alimentaire. Cette étude est réalisée en Gezira au Soudan. Le régime est l'un des plus grands régimes d'irrigation sous une direction unique dans le monde. Le régime a une superficie totale de 880.000 ha et utilise 35% de l'allocation actuelle du Soudan des eaux du Nil. Le régime est irrigué à partir du fleuve du Nil Bleu, caractérisée par forte charge sédimentaire, ce qui entraîne de graves problèmes de sédimentation dans les canaux d'irrigation et pose le fonctionnement et les défis réels d'entretien. Le but de cette étude est de réduire les impacts de la sédimentation dans les canaux d'irrigation, en améliorant le fonctionnement et la procédure d'entretien.

Les procédures de fonctionnement et d'entretien dans Gezira ont été étudiés. La relation entre le système de distribution d'eau et les différents niveaux de service (flexibilité, d'adéquation et d'efficacité) a été évaluée selon les différentes structures de contrôle de flux. Le problème de sédimentation et son effet sur l'opération est également mis en évidence. En outre, différents scénarios de programmes de fonctionnement et d'entretien dans le système sont proposées pour les sédiments et la gestion efficace de l'eau. Analyse comparative et des techniques d'optimisation sont proposées en comparant la demande et l'offre pour obtenir le meilleur scénario pour le dépôt des sédiments au moins en utilisant le modèle SETRIC. Il s'agit d'un modèle unidimensionnel basé sur le débit sous-critique, quasi-stationnaire, écoulement uniforme ou non uniforme (progressivement débit variable) et il peut simuler le transport des sédiments dans des conditions non-équilibre, ainsi que des conditions d'équilibre. Un module sera présenté le modèle de SETRIC pour faire face à des sédiments cohésifs. Le modèle sera calibré et validé à partir des données recueillies auprès de travaux sur le terrain. Les possibilités d'améliorer la gestion des sédiments et l'eau en améliorant l'exploitation et la maintenance dans le périmètre de Gezira ont été abordées.

Mots clés : *Gestion du sédiment, régime du Gezira (Soudan), modèle du transport de sédiment, performance hydraulique des canaux.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

In the coming decades population growth will take place particularly in the emerging and least developing countries. Consequently, water management of large irrigation systems is a key issue to increase productivity and assure future food security. The efficient operation, well executed and effective management of irrigation schemes are needed for improving the hydraulic performance of the canals, enhance the crop yields and ensure sustainable production. Irrigated agriculture remains to be the main option to boost the country's economy in general and elevate the living standard of the majority of those population in particular, whose livelihoods are attached to farming and livestock. There is a great need to enhance the researches and a variety of tools such as water control and regulation equipment, decision support systems and models, as well as field survey and valuation techniques.

Sudan has a large irrigated agriculture sector, totalling more than 2 million hectares out of about 84 million hectares that are potentially arable agricultural area. The potential arable agricultural lands are used to a limited extent because of poor or absence of water resources management practices. About 93% of the irrigated area is under governmental schemes; the remaining 7% belongs to private sector. The Nile and its tributaries are the main source of water for 93% of irrigated agriculture, and of this the Blue Nile River accounts for about 67% (Central Intelligence Agency (CIA), 2004). Gravity flow is the main form of irrigation. The upstream of the Blue Nile River Basin witnesses severe erosion and loss of top soils, with sedimentation and morphological changes in the downstream of the basin. These are attributed to the degradation in the upper basin that leads to high velocity of the flow; increase the flood hazard and the sediment load downstream. About 140 million tons of sediment is annually transported by the Blue Nile River to Sudan (Hagos, 2005). This high sediment load has a major influence on the design and operation of the reservoirs built across the river (Sennar and Roseires) and the irrigation schemes. Consequently, reduction in the storage capacity of those reservoirs has affected the water supply to the irrigation schemes, which was the main purpose of the construction of these reservoirs besides hydropower generation.

Many studies dealing with sediment transport in the irrigation systems have been conducted in the past. Jinchi *et al*. (1993) found that with some adjustments in the discharge in a certain time interval it is possible to transport the sediment to the farm field where sediment is taken as a natural resource. Buhtta *et al*. (1996) and Belaud and Baume (2002) concluded that it is more useful to improve the hydraulic performance of the canals and reduce the sediment deposition by improving the maintenance activity. Sherpa (2005) and Sutama (2010) applied different operation scenarios by changing the discharge and sediment concentration to reduce the sedimentation. Paudel (2010) proposed a new approach for the design of alluvial canals carrying sediment loads. Instead of using the maximum concentration the approach suggests the concentration that results in net minimum erosion/deposition and concluded that it is possible to reduce the sediment deposition problem by proper design and management of the system. Munir (2011) found that the hydraulic performance of the automatically downstream controlled canals can be improved by improving hydrodynamic stability and reducing the response time, and suggested an improvement in the operation. The concept of this paper postulates that the operation and maintenance of an irrigation scheme has a major influence on the hydrodynamic behaviour of canals and hence on sediment movement and deposition. This paper describes a part of research for four years. The main objective of this research is to reduce the impacts of sediment deposition in irrigation canals by improving the operation and maintenance procedure.

2. GEZIRA SCHEME

This study is being carried out in the Gezira Scheme in Sudan. The scheme, which is one of the largest irrigation schemes under a single management in the world, is located in the arid and semi-arid region between the Blue Nile and the White Nile south of Khartoum. Figure 1 illustrates the location of Gezira Scheme. The scheme is chosen as a case study because it acts as a model for other irrigation schemes in Sudan and due to its significant contribution to the economics and socio-economics of Sudan. The scheme has a total area of 880,000 ha and uses 35% of Sudan's current allocation of Nile waters. This represents 6.0 - 7.0 billion m^3/year. The scheme produces 65% of the country's cotton, 70% of wheat, 32% of sorghum, 15% of groundnut and 20% of vegetables (Elhassan and Ahmed, 2008). In addition, it produces more than 1.7 million of animal heads (these include cattle, camels, sheep and goats), so it is considered as one of the most important schemes for food security in the country. The total number of farmers in the scheme is about 114,000 (owned farms) among them 12,000 female (Elhassan and Ahmed, 2008). In the last years there was reduction in the productivity of the scheme .The reasons were many but one of the most important was the water management problem. The land productivity was mostly between 1.0 to 3.2 tons/ha for sorghum, 0.6 to 2.4 tons/ha for wheat and 1.1 to 2.5 tons/ha for groundnuts compared to the optimum yield obtained at Gezira Research Station is 4.75 tons/ha, 3.57 tons/ha and 5.5 tons/ha for sorghum, wheat, and groundnut, respectively (Adeeb, 2006).

The scheme irrigates from the Blue Nile River (from Sennar Dam) by two main canals, Gezira (with capacity 168 m^3/s) and Managil (with capacity 186 m^3/s), meet together at K57 (57 km from Sennar Dam). At this junction, the irrigation water flow is measured using the headworks which distribute water to all parts of the scheme. From this point the sediment is also diverted to the scheme. In Gezira Scheme the major canals take off from the main and branch canals, and supply water to minor canals. The branch canals take water from the main canal and supply it to the major canals where the irrigated area is distant from the main canal. The minor canals deliver water to the tertiary canals which are named Abu XX which supply water to Abu VI (each Abu XX irrigates 37.8 ha) as shown in Figure.1.

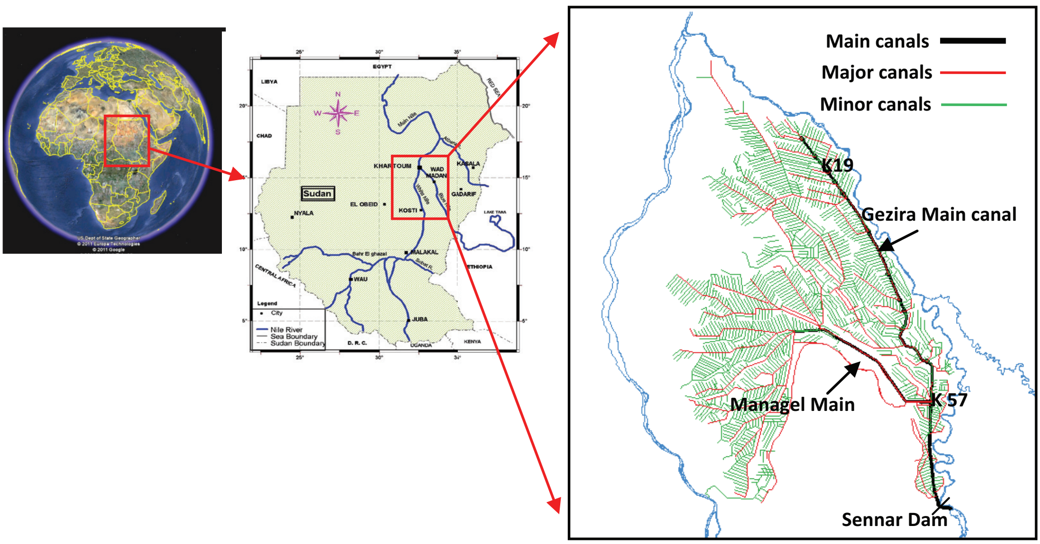

Fig. 1. Gezira Scheme layout

The Gezira Scheme is managed by the Sudan Gezira Board (SGB) as a government enterprise. In 2010, the SGB was assigned all responsibility for the operation and maintenance of the canals. In 2005, the SGB established a new act for managing the scheme 'The Gezira Scheme Act of 2005' and now it attempts to activate this act. According to the 2005 act, SGB was composed of 17,000 water user groups according to the number of the minor canals which were named Water Users Association (WUA). According to this Act the farmers will responsible for the operation and maintenance of the minors and the field canals. Moreover, the farmers have the right to choose the cropping pattern.

3. SEDIMENTATION PROBLEM IN GEZIRA SCHEME

The Gezira Scheme is facing severe sediment accumulation in its irrigation canals, which represents a challenge to those responsible for the operation and maintenance of these canals. The problems of siltation in the canal systems are getting worse every year and clearance cost is increasing constantly. The records of the Ministry of Irrigation and Water Resources (MOIWR) show that between 1933 and 1938 the mean sediment concentration entering the Gezira main canal in August was only 700 ppm, while the average sediment concentration in August of 1988 and 1989 increased to 3,800 ppm; an increase of more than five times (Wallingford, 1990a). The increase in sediment concentration continued to about 8,700 ppm in July 2005 according to MOIWR records but in the last three years it reduced, the reason of this reduction is questionable. Figure 2 shows the relation between the sediment loads, sediment concentration and water delivery in Gezira main canal during the flood period; between July and mid October when most of sediment entering the scheme. There is a variation of the sediment load entering the Gezira main canal. Figure 3 shows that the sediment load is more depending on the sediment concentration than on the discharge and following the same trend of sediment concentration. This implies that any improvement in the land use practice upstream of the Blue Nile will reduce the quantity of sediment entering the scheme.

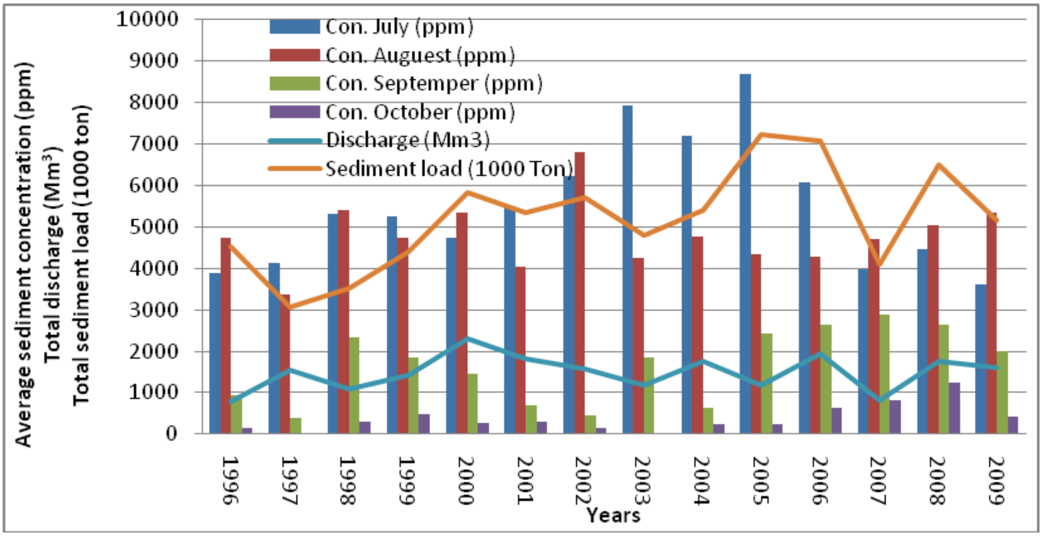

Fig. 2. The average sediment concentration, total discharge and total sediment load entering Gezira main canal downstream Sennar Dam between July and October (1996-2009)

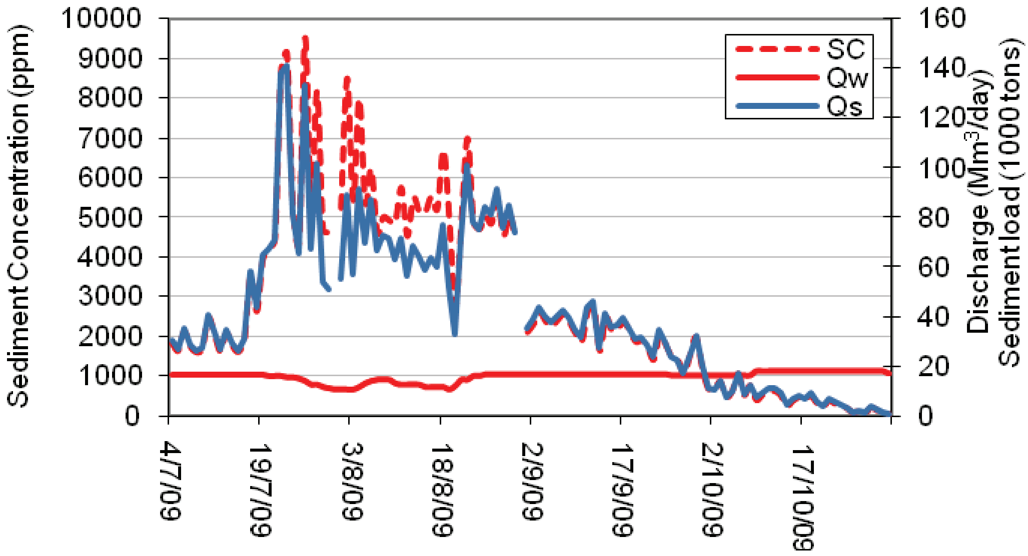

Fig. 3 The relation between daily sediment load (Qs), sediment concentration (Sc) and discharge (Qs) in Gezira main canal between July and October 2009

Joint efforts were carried out by HR Wallingford and the MOIWR in 1988. They indicated that about 97% of the sediment entering the scheme during the flood season consists of silt and clays and that 70% of the sediment settles in the irrigation canals over a short period from mid-July to the end of August. The study also concluded that the approximate distribution of sediment deposition is: 5% in the main canals; 23% in branch and major canals; 33% in minor canals and that 39% passed to farm fields. Most of the sediment settling in the major and minor canals occurs in the first reach.

The sediments accumulate up in the head reach and along the canals, create water delivery difficulties, pose serious threats to the system network, such as blocking the off-take pipes and gates, raise canal beds and reduce canal conveyance capacity (Ahmed, et al., 2006). The bed rising causes problematic control and operation, this results in higher water levels than the designed values leading to frequent break or overtopping of canals banks. Moreover, most of the hydraulic structures became out of functioning and some are totally submerged. Thiruvarudchelvan (2010) assessed the irrigation efficiency in Gezira Scheme using satellite data and concluded that the irrigation efficiency was 22%, relative water supply 4.6 and overall consumed ratio 0.35 at scheme level for 2007/2008 season.

Each year large investments are required to maintain or to upgrade these systems and to keep canals in an acceptable condition for irrigation purposes. In earlier years when the irrigation canals were in better condition, removal of 5 to 7 Mm^3 (million cubic metres) of sediment annually was considered to be satisfactory (World Bank, 2000). In the last ten years the canal condition has deteriorated to an extent that they failed to satisfy the crop water requirements and the average estimation of annual sediment removal reached 16.5 Mm^3, cost more than US$ 12 million (Gismalla, 2009). There is a great variation in the estimates of the annual sediment deposition in Gezira Scheme, since they are based on estimation and not on authentic studies. Elhassan and Ahmed (2008) pointed out that the annual sediment deposition in the irrigation canals is about 16 Mm^3 while El Monshid *et al*. (1997) reported that annually 19 Million tons of sediment accumulated in Gezira Scheme but the accuracy of the values is questionable, because both studies did not mention the measuring methods they used. The scheme now is suffering from the huge amount of sediment that accumulates at the banks of the canals and obstructs the clearance work. Most of the canal cross-sections are over-dug and this improper excavation lead to large undulation of the canal beds and change in physical and hydraulic properties of canals, which accelerates the rate of sediment deposition (Hussein, *et al*., 1986). Besides that, the clearance work is not according to the actual requirements but depends on the availability of budget, machines and priorities are given to the worst conditions. The clearance work is not based on survey because of the absence of technical staff (surveyors) to restore the canals on their design shape.

The aquatic weed growth is also a serious problem in Gezira Scheme, especially during the winter time, when the irrigation water is clean. Growth of aquatic weeds aggravates the sedimentation rate while the sediment deposition furnishes a good environment for weeds to grow. About 60% of the operation and maintenance cost of the irrigation management in the Sudan irrigated schemes goes to sediment and aquatic weeds clearance. However, many approaches have been implemented to mitigate the aquatic weed problem with little success and many failures. Traditionally, manual labour was used for removal of weeds, but this practice has been abandoned due to health hazards (such as Bilharzias). Excavators with specialized weed-cutting equipment are used to remove weeds from the canals, but it faces lack of funds for maintenance to keep them working properly.

Under such conditions, key area of potential improvements concerns operation. The aim of this paper is to reduce the impact of sediment deposition by proposing operation strategies.

4. OPERATIONAL CHALLENGE

In Gezira Scheme the irrigation is based on the demand system. Users can obtain the water directly from a supply point (field outlet pipe) with one week fixed duration. The control structures were designed to maintain a constant upstream level that is controlled by manually operated means (Plusquellec, 1999). The upstream control systems are supply oriented, have limited flexibility and require agency management. There are two types of the regulation devices; sluice gates and movable weirs.

At the upper level of the system; the cross structures at the main canal are undershot structures (sluice gates). The effect of the change in discharge rates is very significant to the change in water level. The movable weirs were installed as head and cross regulators on major canals and at head regulators on most of the minor canals for discharge up to 5 m^3/s which are very sensitive to the change of the water level. The worst case occurs when there is an undershot structure in the main canal and overshot at the offtakes of the major canals for the above mentioned reasons, which is the case in most of the major canals in Gezira Scheme. The offtake structure plays a critical role in delivery water to meet level of service specification.

According to the classification of Malano and Van Hofwegen (2006) the upstream, manual and on demand system is a very unfavourable system of irrigation. The type of flow control is inadequate to deliver that level of service and the operation efficiency is low. However, the provision of a high level of service with this type of flow control requires additional staffing with greater skill for planning and execution of system operation. The situation becomes more complicated in this system with sedimentation problem in canals and lack of a communication system between gate keepers that disturbs the operations at regulators. Operation of the hydraulic structures is influenced by the sediment deposition in canals especially near movable weirs, which are sensitive to the fluctuation of water levels. It is become difficult to maintain the intended discharge into the minor canals. Therefore, this scheme needs an argent plan to enhance sediment and water management, needs a great care in management and if poorly managed, there is a potential for very high levels of inequity and unreliability which is the case in Gezira Scheme.

To improve the level of service of this system SGB accommodated a water operation plan that is more responsive to demand by applying the indenting system. The required discharge (indents) based on the water duty is rendered weekly by the sub-division engineer and he passes the required amount to the next upstream sub division engineer in the system with corrections for canal conveyance losses until the total is passed to the headwork of Sennar Dam where the headwork gates are adjusted to give the discharge required. Therefore, the water is supplied by fixed discharge for one week that means the water level at the main canal is maintained within a certain range of fluctuation. Unfortunately, this system is now not being applied in practices. On the other side, the water duty is number of hectares of land irrigated by cubic metre per day. It is not changed with time and gives an approximate estimation of water required during the crop season and it does not account for the losses occurring along the lengths of the canals (Santhi and Pundarikanthan, 2000). It is only approximation for allocating water and may result in a plan far from the crop needs.

At the minor canals level the types of night storage weirs were designed to be used as cross structures circular and rectangular types. The idea behind the night storage system is to store water during the night by closing all field outlet pipe gates of Abu XX canals and the gates of the cross structures along the minor canal at 6 pm and release it at 6 am in the morning. At night the water level in the reaches of the minor canals rises slowly to reach 20 cm above the full supply level (maximum water level) and flows from upstream reach to the downstream over the crest of the weir to give good command for irrigation during the day. At present, the night storage system is not working; farmers open field outlet gates 24 hours without supervision during the night to keep place with intensification and to cope with the deterioration of water supply due to the poor maintenance of canals (Plusquellec, 1999). The only way to return this system again by applying rotational operation at the field level but this system must be checked carefully against sediment transport since it may lead to more sediment deposition in the system.

5. SEDIMENT TRANSPORT MODEL

SEdiment TRansport in Irrigation Canals (SETRIC) model will be applied in this study. The model was developed by Mendez in 1998, it is a one dimensional steady state model for non-cohesive sediment. SETRIC model will be modified to deal with cohesive sediment, since most of the sediment in Gezira is silt and clay and is transported as suspended sediment, it is source limited, different from non-cohesive sediment which is capacity limited and function of flow velocity. The continuity equation and momentum equation of gradually varied flow and steady state flow are solved numerically in the model using predictor corrected method. The suspended sediment transport calculation is based on solving the one dimension diffusion equation. The morphological change of canals will be computed by solving the mass balance equation of sediment transport numerically use Lax modified method (Mendez, 1998). The model will be calibrated by adjustment the input parameters using the data collected from the fieldwork in 2011. For validation, the model will be run by using the measured field data of 2012 as input variables. The result on the morphological change that will be predicted by the model will be compared with the morphological change that results from the survey measurement at the beginning and the end of the flood season of 2012.

Data collection and field measurement

The focus will be on the major and minor canals in this study since most of the sediment is deposited in those canals. Two major canals have been selected at the head and the tail of the main canal. One minor canal is selected at the middle of each major canal.

An intensive field measurement was/will be carried out between June and October 2011 and 2012 since most of the sediment is entering the scheme in this period. Sediment concentration and water levels are measured on daily basis. Divers are installed at the offtakes of the major and minor canals for continued measurement records. Two cross-section surveys was/will be conducted in June and October in 2011 and 2012 at the beginning and the end of the flood season. The aim is to get the longitudinal profiles on the selected reaches.

6. SEDIMENT AND WATER MANAGEMENT

The hydraulic behaviour of the open channel systems with cross structure is sometime far from intuitive and requires a fairly long experience to manage. The absence of systematic operation rule is main problem of increasing the sedimentation and creates irrigation problems. There are diverse techniques available to engineers to solve sedimentation problems in irrigation canals. Each technique is suited to a particular set of circumstances; no technique can cover all circumstance.

In this study, there will be attempt to mitigate the accumulation of sediment deposition in canals by addressing different scenarios of operation rules. The first scenario will be the actual operation rule that is already applied in Gezira Scheme and assess it is effect on the sedimentation. Then propose improved methods for the operation by adopting different scenarios. Irrigation schedule can be adjusted on farm level to meet the crop water requirement by performed flexible arrangement rotation. The crop water requirement (CWR) will be computed using CROPWAT software. The software developed by Food and Agriculture Organization (FAO). Rotational water distribution will be introduced at the farm canals level to manage the inequity and inadequacy of the water distribution. The following parameters will be determined at each scenario:

- frequency of operation
- duration of operation
- the time at which work begins
- the rate of flow at each canal.

Two scenarios will be adopted for the major canal as illustrated in Figure 4; the first one by operate the canal with it is full capacity (design capacity) and the second one based on the CWR for the two operation options (schedules) for AbuXX:

- operation option 1: operate half of the numbers of Abu XX.
- operation option 2: any option that will be identified during the study based on the demand and supply according to the irrigated area. The change may be on the rate or duration or frequency.

Figure 5 shows two proposed systems of operation for the minor canals; night storage system and continues system. Each system will be investigated when the canal operate on it is full capacity and on CWR bases and apply different operation schedules (option 1 and 2)

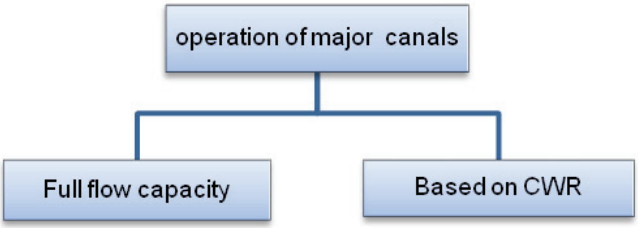

Fig. 4 The operation scenarios of the minor canals

The demands will be checked against the supply (availability of water supply at Sennar Dam) and canal conveyance capacity for all the above scenarios. The effects of each scenario on the sediment deposition will be addressed using SETRIC model. Optimization techniques and comparative analysis of the different scenarios to get the best one for least sediment deposition will be carried out.

The history of the selected canals in terms of sediment deposition and maintenance activities will be appraised and the current maintenance practices will be assessed. SETRIC model integrates the effects of the maintenance activities and canal condition due to growth of weed on the bank (which is always the case in Gezira Scheme) into the computation. The states of canal conditions are schematized into three maintenance scenarios; ideal, poor and adequate. The model will be a useful tool for decision making to decide when and where to mobilize the clearance efforts in order to reduce the clearance costs and improve the sediment removal practices.

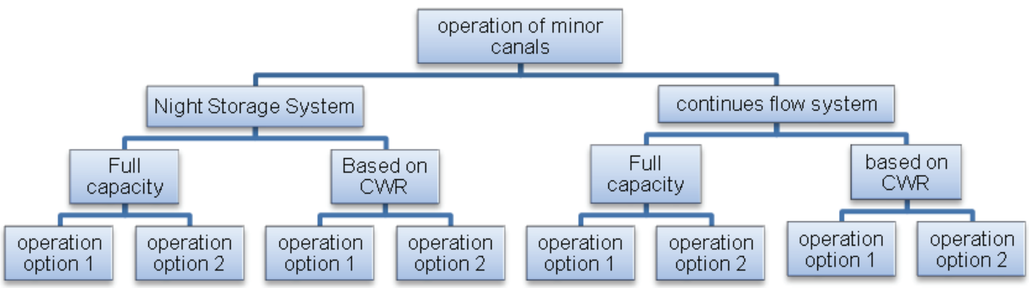

Fig. 5. The operation scenarios of the minor canals

7. CONCLUSIONS AND RECOMMENDATIONS

Technical improvement has been introduced with a detailed operation plan to reduce the sediment deposition and costs of routine maintenance that can be useful for the decision support systems. A mathematical model for fine sediment transport in irrigation canals will be developed for effective sediment and water management.

The manual upstream control systems require additional staff inputs and a good communication system to cope with the more intensive canal regulation requirement to change the flow conditions in the canal from stage to a new flow state. Changes in gates opening of the cross regulators must be according to the optimum time of adjustment to circumvent the disturbance and unsteady state condition in the system.

Upgrading the monitoring system for the whole system and creating a computerized database system is needed. Basic data on water levels, gate opening and sediment concentration should be recorded at all the cross regulators and offtakes for the major and minor canals that can help the canal managers to quick responses in case of water shortage and easily evaluate the actual situation of the system.

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