Water balance Simulation Model for Optimal Reservoir Sizing and Multi-crop Cultivation Area for Small Scale Water Harvesting in rainfed farming System at Khor Abu Farga - Gadarif -Sudan

Mohammed Abdelmahmood El shikh, Haitham R. Elramlawi, and Hassan I. Mohamed

***Abstract*—** Asimulation model is developed for determining the optimum reservoir operating policy and maximum size of area for supplemental irrigation of field crops by harvesting rainwater. The developed software is a user-friendly algorithm, using Excel and Visual Basic Application (VBA) programs and water balance principles. Rate of sedimentation and useful life time of the reservoir were estimated using the trap efficiency approach. The model is applied for the case of Khor Abu Farga- Gadarif-Sudan using the actually measured runoff rates and traditionally cultivated crops in the area. The results showed that the developed deterministic model can be successfully applied to generate optimal monthly operating policies (releases) for a one-year period for different inflows and sediment rates resulting from climate changes and different levels of crop area allocation ratios. By implementing the proposed model, under normal rainfall year, using the dependable inflow rate and types of crops grown in Gedareif area, the results showed that the required optimum command cultivated area is 16000 ha to safely a crop rotation based on Sunflower as dominant crop, and the required small reservoir capacity is 0.6 Mm^3 for 56 years of age. However, for dry years cultivated area decreases to 4500 ha and the reservoir capacity drops to 0.21 Mm^3 with a life span of 63 years.In contrast, for wet years the maximum cultivated area is 30,000 ha while the reservoir capacity rises to 0.86 Mm^3 with a life span of 54years. Sensitivity analysis confirms that results obtained by the model is logical; agree well with theoretical concepts and results presented by other researchers. The procedure is relatively easy to apply and can be used as a decision support tool for cropping patterns of an irrigated area and irrigation scheduling.

***Keywords*—** Water Harvesting, modeling and simulation, reservoir size, Sediment deposition, trap efficiency**.**

I. INTRODUCTION

MOST rainfed areas with low rainfall suffer from low and unstable crop yield. In these low rainfall areas, the water use efficiency is extremely low since most of the rainwater is lost by soil surface evaporation and/or runoff. Therefore, the productivity of the land and water (Water Use Efficiency WUE) are both low. However, it is reported by many investigators that use of water harvesting, the productivity of the rainwater can be significantly improved, through concentrating the rainwater on part of the land. Often, one life- saving irrigation to rainfed crops at the most critical growth stage could substantially improve yield.

In most of the rainfed areas, rainwater conservation measures cannot conserve all the rainwater and a certain amount of runoff loss is bound to occur. Because of an ever-increasing demand for irrigation water and the unreliability of stream flow in arid and semi-arid regions, design and performance evaluation of reservoir operation is important and particularly difficult task.

Generally, optimal multi-cropping pattern and irrigation areas associated with appropriate reservoir operation and irrigation scheduling are essential for increasing the overall efficiency of reservoir irrigation systems. The most important aspect of operations is the release of the right quantity of water at the right time to irrigation areas to achieve greater benefits.

The design of small reservoirs needs a very careful analytical study. At present, decisions on their location, size and area to be irrigated by them are based on local experience. People have also been using mass curve technique, sequent peak algorithm, modified Gould's probability method, linear and dynamic programming models as described by Mcmahan and Mein (1978) for determining storage capacity of the reservoir and the maximum area to irrigate. According to Loucks et al. (1981), mass curve and sequent peak methods are not suitable when seepage and evaporation looses are important considerations as the case of arid zone situations. As given by Palmer et al. (1982 a and b) other methods such as Hurst's procedure, probability matrix methods also have limitations such as considering the constant draft, and the limited information on the stochastic nature of irrigation water requirements in supplementary irrigation in semi-arid regions. There is an increasing awareness among irrigation planners and engineers to design and operate reservoir systems for maximum efficiency to maximize their benefits. Accordingly, significant work has been done on reservoir operation for known total irrigation demand and on the optimal allocation of water available to crops at the farm level. Very few studies

Mohammed Abdelmahmood El shikh, Department of Agricultural Engineering, Faculty of Agricultural Technology and Fish Science, University of Neelain.

Haitham R. Elramlawi, Center of Dryland Farming and Studies, Faculty of Agricultural and Environmental Sciences, University of Gadarif, Sudan.

Hassan I. Mohamed, Department of Agricultural Engineering, Collage of Agricultural Studies, Sudan University of Science and Technology, Sudan.

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have been conducted to derive optimal reservoir operation policies integrating the reservoir operation with the on-farm utilization of water by the various crops.

Decision making for reservoir releases for irrigation involves many subtle considerations such as the nature and timing of the crop being irrigated, its stage of growth, the competition among different crops for the available water and the effect of a deficit water supply on the crop yield. Water release from the reservoir is utilized by the crops in the form of evapotranspiration (ET). In determining the amount of release from a reservoir, it is therefore necessary to consider the crop water requirement in relation to the crop growth and its yield (Ghahraman and Sepaskhah, 2002). A large body of the literature dealing with crop-water production functions focuses the answer of the question to the impact of water scarcity at different times of growing season in the crop yield. The most usable relationships are Jensen's (1968) and Doorenbos and Kassam (1979).

The sediment inflow rate into a particular reservoir is, in general, a function of the watershed characteristics such as drainage area, average land and channel slope, soil type, land management and use, and hydrology. The rate of storage reduction in a reservoir due to sedimentation usually depends on the rate of sediment inflow; type of sediment material (sand, silt, clay); consolidation rate of the existing sediment deposits; type of dam outlet structures; and operation of the dam.

The general objective of the study is to improve agricultural production in the rainfed areas by developing a computer-aided algorithm for design of optimum size of reservoir for water harvesting in Wadi systems, and for estimation of acceptable size of area to cultivate.

Specific objectives include:

(1) Development of software package for sizing optimum water harvesting reservoir capacity with minimum silt deposition and maximum age.

(2) Aid decision maker in selecting optimum cropping mix that cope with climatic changes, conserve water resources and minimize soil erosion.

(3) Apply the design model for the case study of Wadi Abu Farga in Gadarif area to assess the potential for design of small reservoir for runoff water harvesting and for improving agricultural production in the rainfed mechanized sorghum production areas Some Common Mistakes

II. Materials and methods

Development of the Simulation Model:

The Analytical Framework theoretical Concepts:

Using Visual Basic Application and Excel program a user-friendly software is developed to find out the optimal size of the on-farm reservoir in terms of reservoir capacity to maximize field area per each crop and minimizing silt deposition by simulating the water balance model parameters of multi-crop fields and the on-farm reservoir. The menu driven system is flexible enough to simulate the water harvesting reservoir sizes for various combinations of the water harvesting reservoir geometry, field sizes, and the cropping systems. The user has to specify the crops to be grown in the fields, irrigation management practices of the crops, meteorological data, sediment load coefficients, watershed runoff rate, and field sizes. Evapotranspiration sub-model is embedded with the main model to compute the ET from the meteorological data.

The developed model, referred to as water balance computer program (WBCP), can be used as a decision-aid for improving water harvesting via two folds: determination of water balance in the small dam (reservoir) and determination of their life age. Hence, the main functions of WBCP model are:

(1) Determination of adjusted inflow (theoretical volume of runoff, pan evaporation, precipitation, evapotranspiration and requirement due to prior right).

(2) Specifying the demand for the area cultivated and evapotranspiration. (By choosing crop(s), percentage of area allocated for each crop, total cropped area and crop coefficients).

(3) Quantitatively identifying the storage capacity by find the different between the adjusted inflow and the demand. As the same time will find the incoming silt enter to the dam.

(4) Determination of the age of small dam The program was made of subroutines and set of modules which include: Data input Supply module, demand module, water balance module and life age of dam module.

The Analytical Framework theoretical Concepts: The developed program assumptions include:

1- Storage Capacity: Design capacity computations is based on planned inflow volumes and rates over the storage period, and outflow volumes and rates required for meeting planned irrigation system needs.

2- Structure storage capacity must provide sufficient volume to meet variations in water demand within the irrigation period. Structure capacity shall provide adequate storage for inflow while maintaining sufficient water levels to insure proper operation of outlet works and provide uniform outflow rate during planned irrigation events. Provide additional capacity as needed for sediment storage.

3- Compute demand flow rates based on the consumptive use-time relationship using anticipated irrigation efficiencies, conveyance losses, and other uses such as, seepage, and evaporation.

4- The model is made as interactive with the user and it is assumed that the program will start estimating water balance when the reservoir is full and at its maximum capacity. The user is requested to enter the suggested initial water volumes that equal to the capacity estimated by the program.

Crop water demand:

The plant production process depends mainly on three factors: soil, plant and atmospheric conditions. Each contributes to and must be considered in the calculation of the consumptive use. In a mathematical model the effect of these factors is included by the following steps:

1. Calculation of the potential evapotranspiration ET, Estimation of crop coefficient (Kc) for adjustment of the actual evapotranspiration ETa.
2. Working days/month, and Working hrs/day.
3. Precipitation (mm/month) and Effective Precipitation (mm/month).

The Model outputs:

The outputs of the model are

1. Adjusted inflow and water demand,
2. Design capacity for the reservoir,
3. Average annual sediment deposit,
4. Proper life of the reservoir (small dam).

Model application

General:

As model application, the developed model is used to simulate the water harvesting reservoir sizes for the Grain Sorghum (Sorghum bicolor *L*), Sesame (Sesame indicum L.) and Sunflower (Helianthus annuus) cropping systems using the experimental observed and meteorological data of the study area located at Khor Abu Farga, Gedaref in eastern Sudan.

The Climate in the Gedaref region is semiarid with mean annual temperature of 28.5oC; Minimum temperature is 17 o C in January while maximum temperature is 47oC in April to May.The Gedaref state has a unique farming system. It is formed as a result of the introduction of mechanized rain-fed farming system.

Wadi Abu Farga is one of the most important wadis in Gadarif state with total catchment area of 4756.0 Km^2 and 117 Km length. The wadi starts to have branches at Gadarif town (El.599.0 m msl), and at villages of Kasab and at Azaza, to finally discharges in RahadRiver (El. 434.0 m msl) with 40 m width. Maximum watercourse slope is 0.001 m/m and maximum watershed slope is 0.008 m/m. Main branches includes El Daeef, and El Radeef, Kasab. The delineated catchments for this study lies between 14 65 and 13 54 N and 34 57 E and 36 27 E. It comprises an area of about 724738930.5 m^2.

The soil in AbuFarga is black clay (Vertisoils) with 45 - 80 % clay content (SCS. US Soil Conservation Services, USDA). There are five hydro-meteorological stations in the study area (Abu Farga, Abu Gomada, El Azaza El Daeef, and El Rawashda). Water flow is measured using float method to determine flow velocity and conducting topographical study for cross-sectional area and staff to measure water levels.

The data collected includes, meteorological, soil and crop data. The sources of data are Ground Water and Wadies Administration -Surface Water Section. Abu Fargha station, Gedaref state Ministry of Agriculture and Animal Wealth, and Gedaref state Water Corporation, department of Ground water and external station.

The water requirement of the candidate crops (Water demand) is determined from climatic data of Gedaref meteorological station using FAO Penman-MonteithETo., Method (Allen et al., 1998).

Monthly data for runoff data, pan evaporation rate, effective rain fall is taken as input for water balance module to determine water Supply. Specific weight of sediment, and sediment coefficients were collected from the site. (SPSS) is used for analysis of variance for the complete randomized design (CRD)Publication Principles

III. Results and Discussions

Model application

Determination of maximum area to cultivate in reference to optimum reservoir size:

For planning purposes it is essential to estimate the maximum total crop area to cultivate. Determination of such area shall be made under normal climatic conditions (rainfall, and evapotranspiration) and using the dominant crops of rain fed areas of Gedarif (Sorghum, Sesame and Sunflower) with each crop is using one third of the total area. Following FAO (1992) and Arora and Geol (1994) procedure and for a new reservoir with both rainfall and inflow in the period of August to October of Khour Abu Farga then, the maximum area to cultivate is 110 ha (Table 1.).

Table I
Estimation Of Command Critical Cultivation Area

Months	Inflow (M m^3)	Demand (Mm^3)	Command Area (ha)
Jun	876949.0	0.0	0.0
Jul	3049909.0	0.0	0.0
Aug	5735479.0	742.0	7734.0
Sep	1405447.0	2119.0	663.0
Oct	202387.0	1832.0	110.0

(The critical command area =110 ha is the area that can be cultivated without short of water at any period).

To increase the total command cropping area this study suggests to harvest and store rainfall water. The establishment of maximum area to cultivate is directly related to maximize the reservoir capacity to satisfy the demand of the selected crops to grow. However, the maximum reservoir capacity in itself is usually constraint by amount of silt deposition which leads to decrease of reservoir age (Ngo Long Le, 2006; Hachum and Mohammad, 2007). The demand of crops is affected by size of area allotted for each crop, planting dates and changes in climatic conditions (mainly rainfall and evapotranspiration).

The model can be applied for determining the maximum area to cultivate with optimum crop area share under varying climatic conditions as judged by keeping the target reservoir age.

Assuming Normal conditions of Wadi inflow, rainfall, and equal command area for each crop then, total command area increases to 12,000 ha with a reservoir age of 56 years. Table 4.2 shows the maximum area to cultivate and minimum reservoir age at scenarios of four types of rotations (N=equal areas for each crop "each 33% of total area", R1=domination of Sunflower 50% of the area, R2=domination of sesame 50 % of the area, R3=domination of Sorghum 50% of the area) and three climatic conditions (wet, normal and dry).

It is evident from the table that crop rotation based on Sunflower (R1) resulted on maximum cultivation area under different climatic conditions. It is evident from table II. where the maximum command area is 30000 ha under wet climatic conditions and Sunflower as the dominant crop. The command area decreases under dry conditions significantly with maximum value of 4500 ha using Sunflowers base crop and same trend is reached under normal climatic conditions (Maximum area is 16000 ha with Sunflower as main crop).

TABLE II
OPTIMUM AREA TO CULTIVATE AND RESERVOIR AGE AT DIFFERENT SCENARIOS OF CROP ROTATIONS

Rotation \ Climate	Normal			Dry			Wet		
	Area (ha X1000)	Age (year)	Capacity Mm^3	Area ha	Age years	Capacity Mm^3	Area ha X1000	Age years	Capacity Mm^3
N (33% each crop)	12	56.13	0.6	3300	63.42	0.20	23	53.52	0.88
R1 (Sunflower 50 %)	16	56.13	0.6	4500	63.34	0.21	30	53.63	0.86
R2 (Sesame 50 %)	9	56.22	0.58	3000	62.86	0.23	16	53.8	0.81
R3 (Sorghum 50 %)	12	56.41	0.58	3500	63.29	0.21	25	53.69	0.87
Normal Rotation (33% each crop) & climate condition Without reservoir max area = 110 ha.									

As given in table II. prevalence of dry climate reduces total command cultivation area by 28 to 33 % compared to normal climatic conditions. For wet conditions and for all scenarios of allocation of area share the command area increases significantly. Maximum increase (by 208%) is achieved when Sorghum dominate the rotation due to its low demand for irrigation water compared to other two crops.

Determination of monthly releases for reservoir operation under normal climatic condition and optimum crop area allocation: The model specify the reservoir water releases in reference to crop area allocations during intra-seasonal periods for a known state of the system given by the initial reservoir storage, and inflow during the beginning of the intra-seasonal period (Dudley,1988).

Table III. shows the water balance for operating the reservoir for the case of maximum command cultivation area (16000) under normal climatic condition and using Sunflower as a dominant crop cultivated in 50% of the total area of 16000 ha. The table indicates that maximum reservoir capacity is 0.6 Mm3.

The data given in water balance for estimating reservoir capacity is a quantitative procedure to substitute the graphical tedious method suggested by Arora and Geol (1994) for determining optimum reservoir capacity.

TABLE III
WATER BALANCE FOR RESERVOIR OPERATION AND RELEASES UNDER NORMAL CLIMATIC CONDITION AND SUNFLOWER - BASED ROTATION

Month	Adjusted inflow ($M.m^3$)	Demand ($M.m^3$)	Deficit ($M.m^3$)	Surplus ($M.m^3$)	Cumulative ($M.m^3$)
Jan	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00
Jun	0.77	0.00	0.00	0.77	0.77
Jul	2.98	0.00	0.00	2.98	3.75
Aug	5.69	0.00	0.00	5.69	9.44
Sep	1.46	0.00	0.00	1.46	10.89
Oct	0.20	0.00	0.00	0.20	11.10
Nov	0.00	0.34	-0.34	0.00	10.75
Dec	0.00	0.26	-0.26	0.00	10.50
Total	11.10	0.60	-0.60	11.50	10.50

TABLE IV

Month	Storage Volume (M.m^3)	Capacity	Drainage	Out Flow	Incoming Silt (Mm^3)	Incoming Silt (Kg)
Jan	0.00	0.0085	0.00	0.0	0.00	0
Feb	0.00	0.0085	0.00	0.0	0.00	0
Mar	0.00	0.0085	0.00	0.0	0.00	0
Apr	0.00	0.0085	0.00	0.0	0.00	0
May	0.00	0.0085	0.00	0.0	0.00	0
Jun	0.50	0.5000	0.27	0.27	1.18	1537
Jul	0.09	0.5900	2.89	2.89	28.16	36602
Aug	0.00	0.5900	5.69	5.69	178.40	231915
Sep	0.00	0.5900	1.46	1.46	237.66	308961
Oct	0.00	0.5900	0.20	0.20	246.58	320549
Nov	0.00	0.2465	0.00	0.34	231.54	301008
Dec	0.00	0.0085	0.00	0.26	220.69	286898
Total			10.50	11.70	1144.21	1487469

Table IV. explains the procedure used for predicting the expected reservoir capacity. The theoretical basis of the procedure is given by Arora and Geol (1994). Input data used include: average annual flood inflow of 11 mm^3, initial reservoir capacity of 0.6 mm^3, av. ann. sediment inflow of 1,487,469.0405 kg, sp. weight of sediment of 1,300 kg/m^3, assumed % of reservoir filling up in the first interval of 20%, and usual life of the reservoir will be terminate when this percent of reservoir storage capacity is filled at 80 %. The optimum reservoir age for water storage to satisfy the maximum cultivated area of 16000 ha under normal climatic conditions and with Sunflower as dominant crop (sown in 50% of the total cultivated area) is found to be 56 years which is accepted by many investigators (Arora, and Geol, 1994); Hachum and Mohammad, 2006).

Sensitivity analysis:

The sensitivity analysis indicates by how much the output of a model alters in relation to a unit change in the value of one or more of the inputs (Morgan, 2005). It is carried out to show if the model behaves rationally or not and to indicate how accurately values of the inputs need to be measured or estimated. Rational behavior is judged on whether the level of sensitivity of the factor in the model matches what is expected in reality and on whether the relationships between the output and controlling factors accord with what is observed in the field. Sensitivity analysis can be extended to evaluate whether the interaction between factors is correctly simulated and whether a model gives acceptable and reasonable results when operated under extreme conditions.

To achieve the model rational behavior and impacts of input and the accuracy of their estimation on output the average linear sensitivity parameter given by Nearig et al. (1989) is used, and expressed as shown below:

$$ALS = ((O_2-O_1) / (O_{avg})) / ((I2-I1) / I_{avg}) \text{ ----------------- } (21)$$

Where: Oavg., and $I_{avg.}$= are the respective average values of the two input and output values. I_1 and I_2 = are values of input parameter with a chosen range, plus and minus a percentage of a base value. O_1 and O_2 = are their respective output values.

The input parameters of rainfall, evapotranspiration (ET), and conveyance efficiency (Ec.) were increased above the normal climatic values by step of 10 % up to 40 % and at same time they are decreased by similar rate. The effect of unit change of each one of these inputs is estimated with respect to change of one unit output of silt load, storage capacity and reservoir age.

Sensitivity of changing rainfall**:**

It is can be deduced from Figure III. that: increase in rainfall results in decrease in reservoir storage capacity. However, when there is abundant rains no need to store water and depend on direct rainfed cultivations. The relation between rainfall amount and reservoir storage capacity may be quantified by the relation:

$$Y = 0.07 X + 0.25 \text{ ------------------------------- } (22)$$
$$(R^2 = 1.0)$$

With increase of rainfall more erosion in watershed will bring more sediment load that will be deposited in the reservoir. The amount of stored silt as function of rainfall may be estimated by the relation:

$$Y = -0.079 X + 15.26 \text{ ---------------------------------- } (23)$$
$$(R^2 = 0.996)$$

Reservoir age is negatively related to rainfall as given by the linear relation:

$$Y = 5.881 X + 24.71 \text{ --------------------------- } (24)$$
$$(R^2 = 0.964)$$

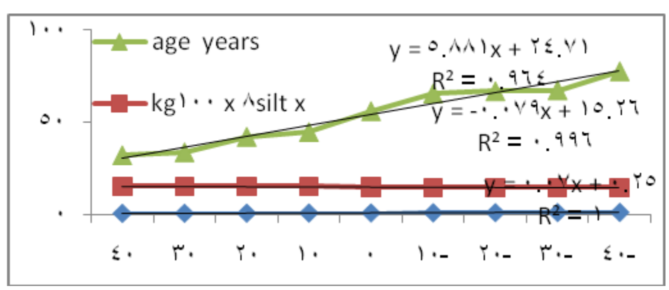

Fig. 3 Impacts of changing rainfall amounts on storage capacity, silt

The impact of sensitivity of changing rainfall amounts on storage capacity, silt load, and reservoir age is shown in Figure

(4). The equation of prediction of reservoir age shows a high slope (5.881) indicating sensitivity of reservoir age to variation of rainfall amounts. While the slope for silt (-0.079) and for storage (0.07) are small (less variations). Figure III. shows symmetrical variation in reservoir age for either increase or decrease of rainfall amounts. Silt load follow the same trend as that of age but with mild slope. For storage output their rate of change is small and it is hard to detect any sensitivity.

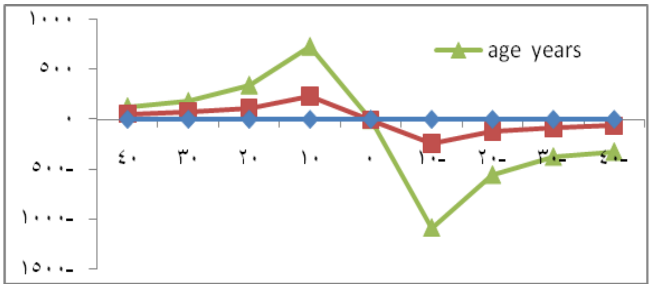

Fig.4 effect of changing one unit of rain fall amount on changing one unite of reservoir age,storage capacity and silt load.

`Sensitivity of changing evapotranspiration:

Figure V shows the effects of changing evapotranspiration at a rate of 10 % more and less than the normal climatic value on one unit increase/decrease of reservoir age, storage capacity and silt load. It is known from the model concepts and theoretical review that decrease of evapotranspiration had direct reduction on crop water demand and less water need to be stored and thereby less silt load. The result depicted in Figure V is in agreement with the concepts and results given by Arora, and Geol, 1994, and Hachum and Mohammad (2006). This may be quantified by the linear relation:

$$Y=0.113X+14.34 \quad \text{------------------------------------} \quad (25)$$
$$(R^2 = 0.994)$$

As given in Figure (4.4) increase in water demand due to increase in evapotranspiration is negatively related to reservoir age and can be quantified by the relation:

$$Y = 10.24X+98.29 \quad \text{--------------------------------} \quad (26)$$
$$(R^2 = 0.974).$$

In contrast storage capacity shows positive relations with changes in evapotranspiration rate (Figure 4.4). It can be estimated by the linear relation:

$$Y = 0.113X+1.127 \quad \text{---------------------------} \quad (27)$$
$$(R^2 = 0.994)$$

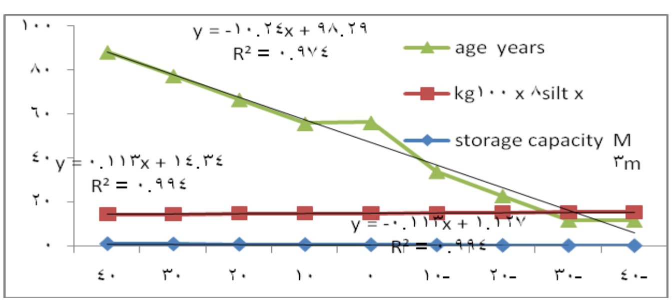

Fig. 5 Effects of changing evapotranspiration rate on reservoir age, storage capacity and silt load

Figure VI. indicates that reservoir capacity and age are more sensitive to low changes in evapotranspiration. As such, more accuracy is needed in measuring and recording evapotranspiration data when its values are small.

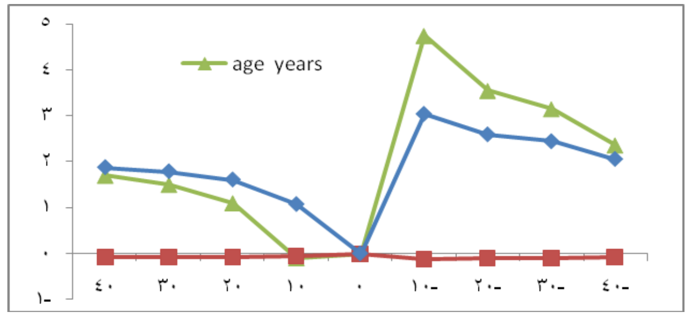

Fig. 6 Effects of changing one unit of evapotranspiration on one unit increase /decrease of reservoir age, storage capacity and silt load

Sensitivity of changing inflow rate:

As given in Figure VII, decrease in inflow rate reduce the incoming silt load and there by less silt deposition. The power relation for estimating silt as function of inflow rate is:

$$Y = 40.27X\text{-}0.74 \quad \text{--------------------------} \quad (28)$$
$$(R^2 = 0.840)$$

It is also evident from Figure VI. that the relation between inflow rate and reservoir age is negative and can be estimated by the polynomial relation:

$$Y = 2.166X2 – 7.398X + 37.44 \quad \text{-------------------} \quad (29)$$
$$(R^2 = 0.99)$$

However, Figure VI. shows that change of storage capacity with inflow rate is hard to quantify and it is almost stagnant. This result is clearer when sensitivity rate is estimated. Figure VII. shows that silt is more sensitive to increase in inflow rate. It also indicates that decrease in inflow rate results in pronounced reduction in reservoir age.

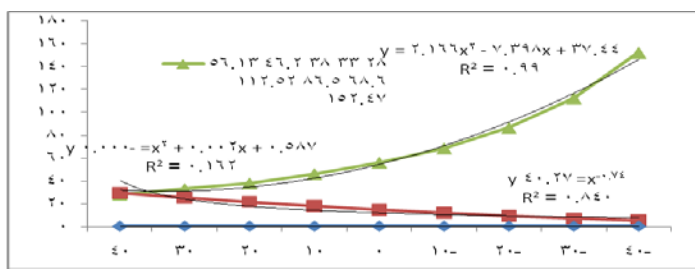

Fig. 7 Effects of changing inflow rate on reservoir age, storage capacity and silt load

Sensitivity of changing application efficiency**:**

As depicted in Figure VIII. low conveyance efficiency results necessitate increase of water demand and more storage volume in the reservoir. The relation may be linear and take the form:

$$Y = 0.068X + 0.302 \quad \text{--------------------------} \quad (30)$$
$$(R^2 = 0.944).$$

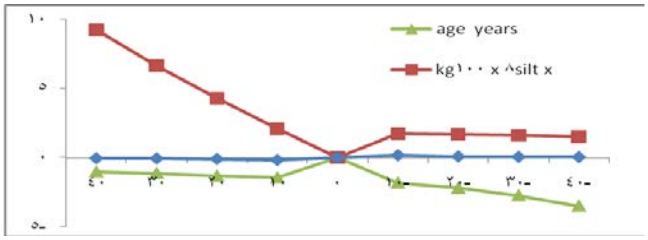

Fig. 8 Effects of changing one unit of inflow on one unit increase/decrease of reservoir age, storage capacity and silt load

Figure VIII. shows that with reduction of application efficiency more storage is needed to satisfy increase in demand. Increases of storage in the reservoir produce more silt accumulation and shorter reservoir life. This result is theoretically acceptable (Hachum and Mohammad, 2006).

For reservoir age the logical trend is the reduction of life of reservoir with reduction in conveyance efficiency due use of high volume of water storage (thereby increased silt load) to compensate for water wastage in canals (Garg, 2004). This relation is quantified in Figure 4.8 by:

$$Y = 6.064X + 26.58 \text{ ----------------- } (31)$$

$$(R^2 = 0.914)$$

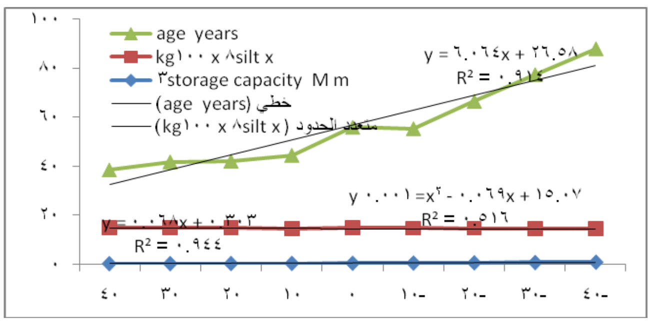

Fig. 9 Effects of changing inflow rate on reservoir age, storage capacity and silt load

Effects of changing one unit of Application Efficiency on one unit increase/decrease of reservoir age, storage capacity and silt load is given in Figure X. This Figure shows that silt load is more sensitive to reduction in application efficiency than other inputs.

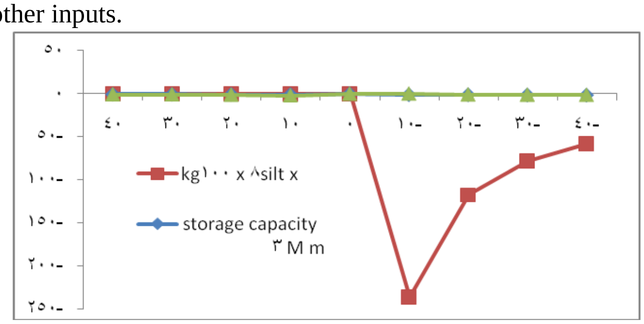

Fig. 10 Effects of changing one unit of inflow on one unit increase/decrease of reservoir age, storage capacity and silt load.

IV. Conclusions

The volume of water stored in the reservoir depends on the available runoff water, sediment load, evaporation losses and the water demand for each interval during the growing season. Two major features of the model distinguish it from the earlier its capability to consider interdependence of crop water allocations across time periods and its ability to provide an adaptive release policy.

Model application for the case of Wadi Abu Farga in Gedareif area-Sudan reveals that: the required optimum cultivated area to safely cultivate is about 2000 ha, and the required reservoir volume is about 29.23 Mm3 per ha of field area. These optimal values of reservoir capacity, minimum silt load and maximum age occurs at maximum demand rate of a crop mix of 25% sorghum, and 75% sesame. Variation of percentage area allocated for each cultivated crop results in significant differences only for reservoir capacity, and changes in run off rate results in significant differences in reservoir age only.

Sensitivity analysis confirms that results obtained by the model is logical; agree well with theoretical concepts and results presented by other researchers.

The developed water budget procedure is relatively easy to apply and can be used as a decision support tool for cropping patterns of an irrigated area and irrigation scheduling.

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