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Simplified design procedure for settling basins with inclined plates in irrigation canal network using trapping efficiency criterion

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ABSTRACT

Aim: The aim of study was to develop an analytical procedure to improve the sediment removal efficiency of the sediment settling basin with a better design, conserve the cultivated land and application of the design model.

Materials and Methods: The adopted analytic approach assumed the prevalence of velocity distribution in uniform flow conditions and used simplified one-dimensional equations to insure reduced flow turbulence by determining Froude Number. The proposed procedure led on periodical flushing of the sediment basin and on the offer of an alternative option to insert inclined plates in the basin to improve its loading rate and to upgrade its trapping efficiency. In the model, geometric configurations of the basin were identified, which can remove even the fine sediment (0.055 to 0.22mm) from the flow with high removal efficiency determined following Camp (1946).

Results: The application of the scheduled flushing mode of operation proposed by the developed model revealed a substantial reduction in the area occupied by the basins with higher trapping efficiency. Application of the analytical design procedure for the design of efficient sediment basins in earth irrigation canals supplied with sediment-laden water resulted in the economizing area occupied by the basin system compared to current designs. Employing the concept of periodical flushing of sediment-laden water resulted in the reduction of basin capacity compared to end-season flushing recommended by many consultants.

Conclusion: It was concluded that these results have an important role in optimizing the design to enhance the Small Sediment removal efficiency of the settling basin.

Keywords: Trapping efficiency; sediment basin; Gezira Scheme; Inclined plates

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Introduction

Diverting river flow into canal irrigation networks or power and pumping plants is hindered by its reduced capacity due to the accumulation of sediment. When a canal receives water with sediment load above its sediment transport capacity and effective measures are not taken for its control, canal gets silted up. The conveyance capacity of run-of-the-river irrigation networks is reduced by the accumulation of sediment (Nandana and Mavendra, 1997). The adoption of a suitable scheme or device (ejector or excluder) for sediment removal depends on the type of sediment (wash, bedload or suspended load), land availability, and costs of initiation, and maintenance.

Most of the desilting basins proposed in Irrigation networks or hydropower projects are based on an arrangement having increased basin cross-sectional area to reduce the velocity of flow to such an extent that sediment particles settle within it efficiently, during a whole season with a high sediment storage capacity. Such design philosophy results in wide rectangular basins occupying a large area. Knowledge and understanding of the basic hydraulic and sediment principles are necessary, at the irrigation canal intake site, for selecting the proper type of sediment removal device (guide walls, vortex tubes, surface, bottom vanes, settling basins, and drop inlet diversion structures). Model studies using analytical and physical simulation techniques are usually used to design settling Basins to remove excessive amounts of suspended sediment in Run-of-the River irrigation networks on basis of Sediment

Trapping Efficiency. Sediment deposited in settling basins is removed by sluicing, dredging, or mechanical or manual means. Sediment basins although they are somewhat effective in the removal of fine sediment particles they are criticized by the large area they occupy. The existing relationships on the design of sediment basins (either plane or vortex basins) were not found to yield satisfactory results over the whole range of data, and at various operating conditions (Goula et al. [2007] presented a numerical model using a spreadsheet for developing relationships for computing efficiency of sediment basins that yields similar results to Camp‟s (1946). Stamou et al (1989) derived a typical relation for the efficiency (removal ratio) of settling basins, in experimental rectangular flume by dimensional analysis. The relation found by the authors qualitatively confirms solutions obtained by numerical simulations with the diffusion-advection equation. Analysis of all the available data has led to a new relationship for efficiency. The parameters (L/D) and (w/u) were found to govern the efficiency. Where (L) was the length of the settling basin, (D) was the depth of flow in the settling basin, (u) shear velocity in the settling basin, and (w) fall velocity of the sediment in clear water. The entrainment, transportation, and subsequent deposition of sediment depend not only on the characteristic of flow involved but also on the properties of the sediment itself... The most important property is the fall velocity which is dependent on the size, shape, and specific weight of the particle. Due to the complexity of the settling phenomenon of particles it has been studied rather intensively during the last three decades. Nandana and Mavendra (1997) reviewed in detail the sediment desilting basin design works using analytical (two- dimensional, numerical methods) and hydraulic models of many investigators including Hussein, (2006); Fornshell (2000), Yon and, Lee (2000); Mohanarangam, and Stephens (2009)' Stamou et al (1989) and Zhiyao et al. (2008) concluded that a satisfactory agreement was found to exist between the observed values of sediment concentration and its values computed using the method proposed. In addition, the use of Camps (1946) trap efficiency as reported by Omar et al (2015) can satisfactorily meet the requirement of acceptable basin design.

Nandana and Mavendra (1997) reported that settling basins were formed by widening the approach channel and lowering its floor through an expansion transition, to reduce the mean velocity of flow into the basin. However, various combinations of width, depth, and length of the basin are possible to achieve desired removal efficiency in a given situation. Taking the cost of land for the straight and prismatic portion of the basin as the criterion, equations need to be developed for its best geometric configuration (Stamou et al (1989), Nandana and Mavendra (1997) Experimental investigations on the determination of the sediment removal efficiency of settling basins from the present and earlier studies have been carried out for checking the accuracy of the existing empirical and analytical relations and for the development of new ones. The effect of continuous flushing of a sediment-water mixture from the settling basin versus planned flushing on its removal efficiency needs to be studied through the analysis of experimental data. One way to increase the settling tanks' performance is to introduce inclined plates to Increase the settling area and improve their hydraulic regime. Extensive research on the performance and optimization of inclined plates, as well as the mechanism of the sedimentation process in lamella settlers, were carried out in sewage systems and domestic water supply, but not frequently used for irrigation water supply. Many studies have focused on the hydraulic regime in the settling tank. Of these studies, Stamou et al (2009) used a numerical model to study the flow and settling process of settlement of suspended sediment. Demir (1995) assumed large importance to the effectiveness of baffles in decreasing eddy conditions and turbulence in the distribution of incoming water and investigated the optimum angle of the baffle in the lamellar settling tank at various linear velocities. The suspended sediment removal efficiency was assumed by many investigators to be constant if the increase and/or decrease of settling area and flow rate were proportional (Goula et al., 2007) because other factors such as vortex and density current have been considered as non-impacting ones. Kowalski (2004) compared the suspended sediment removal efficiency in the conventional tank and the lamella settling tank taking into account the density, viscosity, and mass fraction of solid particles. Different types of tube settlers were examined by Fujisaki and Terashi (2005) to obtain a higher solid separation capacity. In all these studies it is not possible to predict all factors that contribute to suspended sediment removal efficiency in lamella settling tanks. In experimental conditions, and the practical operation of lamella settlers it is a big challenge to evaluate all factors affecting the settling process that is the reason why the application of simulation is essential in the evaluation of the whole process.

Lahmeyer (2011) reported that the Suspended Sediment Concentration (SSC) measured at El Koro in the Nile River shows remarkable seasonality in its magnitude from few values in 3 to4 months in flood period to high values of 10 to 13 gm/liter and can be determined from 5- year regression analysis by the relation:

$Q < 1{,}600$m3/s; $SSC=0.0000 x Q$; $1600<Q<9000$ (ascending) $SSC= 4.7035 X \ln Q - 34.559$; $9{,}000>Q> 1{,}600$(descending); $SSC= 0.1896 X \exp (0.0003 x Q)$; SSC = in g/l and Q in m3/s.

The irrigated agricultural development in Sudan is dependent on the Blue Nile water. The Blue Nile River is characterized by high sediment during its flood (140 million tons per year) which has major influences on the design and operation of the reservoirs built across the river and the canalization network of the schemes irrigated from it. This resulted in large operational costs incurred every year in dredging the sediment from reservoirs and canal systems. A sediment monitoring program is launched in 1988 in Gezira Scheme and the Blue Nile and revealed that in Gezira Scheme on average 8.5 million tons of sediment enter the scheme every year. More than 97% of this sediment is very fine (63 microns known as wash load); therefore, standard methods of sediment exclusion at the intakes will not offer a solution. More than 70% of the sediment can be excluded if the canals gates are closed during the period 20th July to 31st August. A recent study (Hussein, 2006) has estimated the sediment yield of the Blue Nile upstream Ed Deim as 480 tons per square kilometer per year (T/km2 /year). The historical sediment data, 1933 - 1938, shows that the mean sediment concentration entering Gezira main canal in August is 700 ppm (Mohamed, 2001), compared to 26,561 ppm recorded downstream Sennar on 18th July 2008 (Gismalla, 2009); Ahmed (2003) reported that the rate of sedimentation of Sennar reservoir in the period (1925 - 1981) had never exceeded 0.5 % per year (4.6 million m3) of the original capacity. In the Roseires reservoir, dredging of 100,000 to 350,000 m3 of sediment in front of the power intakes is done annually. Such accumulation of sediment in the reservoirs was reported to result in a reduction in irrigated area and hydropower generated due to loss of storage (Hussein et al, 1994).

The canals of irrigated schemes in Sudan clay plains are designed on the assumptions of the regime theory that sediment is in balance and the rate of incoming sediment exceeds its sediment transporting capacity. The growth of aquatic weed increases silt deposition rates and aggravates the problem. On average the aquatic weeds and 16.5x106 m3 of sediment are removed by mechanical sediment clearance. The average sediment removal is increased reported to 265x106 m in the last decade (Gismalla, 2009), and Lawrence (1991) claims that more than 60% of the annual operating budget in the Gezira Scheme goes to sediment clearance. Gismalla (2009) stated that the negative impacts of sediment deposited in irrigation canals and control structures are: Reduced and interrupted irrigation supplies; Increased height of canal banks; Overtopping due to high water levels; More aquatic weed growth; Reduced crop yields; Damage to canals physical specifications and hydraulic characteristics; Blockage of access roads and rise in field levels. The trend of the sediment load entering the Gezira scheme shows an increasing rate (0.56 million tons per year) and this sediment s is deposited in the system as follows: Main canals 4% Major & branch canals 23% Minor canals 35% Passed to fields 38% (Wallingford, 1990), and more than 80% of sediment is deposited in the first reach of the canals. As an outcome of the sediment monitoring program (Gismalla, 2009), and review of past studies (Lawrence (1991) in the Gezira Scheme the most possible management options to apply are to Change the present mode and timing of irrigation, improve the quality of clearance practices, and adopt sediment exclusion by introducing settling basins at the first reaches of the Major and Minor canals.

As a remedy to the silt accumulation problem in the Gezira Scheme Wallingford-HRS study (1990) proposed one centralized basin at the head of the system with a length of 5.7 Km, a width of 570 m, and a water depth of 3.0 m. This designed basin would have a 60% trapping efficiency which is equal to the trapping of the system without any sediment exclusion facilities. None of the proposals by HRS Wad Medani has been realized so far and the problem remains unresolved to date. The current system of sediment removal is the application of maintenance dredging which is executed by a fleet of 64 draglines, 31 hydraulic excavators, 19 bulldozers, and 22 graders.

Hussein et al. (1986) and Gismalla et al. (2006) envisage the options for sediment management in irrigation canals to change the algorithm used in the design of irrigation canals by using deep and narrow cross-sections for 8500 km of Minor Canals for conveying the incoming fine sediment to the fields and to change the existing night storage canal delivery system to a continuous one (Hamid, 2001). They suggest excluding sediment entry to the Gezira canal network by closing the main supply system for six weeks period starting in July II to August Ill, but this requires to abandon cultivating Groundnut crops and look for alternative late sowing crops (in September). Gismalla et al. (2006) claim that simulation studies show that there is low trap efficiency of the options suggested by Hussein et al. and HRS-HRL (1994) joint study to construct sediment basins by enlargement of the first reaches of major and Minor Canals and the one at the head of the Gezira canal system at Sinnar.

Lahmyer (2011) to solve the problem of sediment accumulation in the Merowe Irrigation Project-PCI it is feasible (in comparison to mechanical sediment removal) to construct, in three phases, a centralized desilter at one location (the head of the system) after the offshore Golid pump station of (MIP-PC1) which consist of two parallel basins of 4Km length, bed width of 46m each and a water depth of 3.74m (3.5 storage depth), side slope of 1:2, length of 4000 m, and bed slope of 1.1cm/kilometer to result in trapping efficiency in the range of 30 to 39% % for sediment fractions of 0.048, 0.010, and 0.002 mm.

The basin's design is based on water demand over one year to be implemented in three stages 30 m3/s,70m3/s, and 90 m3/s for stages one, two, and three respectively, to remove 1.43 million tons of silt-fine sand (8 to 13 gm/liter) deposited during four-month flood period (mid-June to mid-October). The supply canal depth is 3.74 m, velocity is 0.77 m/s, and a bed width of 46 m, a side slope of 1:2, and a length of 4000 m. Thus the total depth in each desilting basin is 7.2 m. These basins require three dredgers to remove the accumulated sediment at end of 8 months. Flushing is to be made at the season end when the river flood levels are low.

To improve the performance of the space-limited settling basin, the lamella and inclined plate settler are widely used (Takayanagi et al, 1997). In this study, a simplified design procedure for settling basins using the Camp (1946) trapping efficiency criterion is developed. The procedure depends on the balance of settling time with the retention time The main objectives of this study are three folds: First to develop an analytical procedure to improve the sediment removal efficiency of the sediment settling basin with a better design by modification of the geometric configuration of basin hydraulic structures by periodic flushing actual area and in consideration that the procedure will be applicable to both lined and unlined desilting basins. Second: to conserve the cultivated land by determining the specifications of inclined plates inserted within the basin to enhance basin power to remove fine sediment. Third: to apply the design model for the case of the Gezira Scheme.

Materials and Methods

The main principle of the settling basin design was to reduce the mean flow velocity in the basin widening its width and lowering its floor through an expansion transition and restored through a contraction transition at the end of the basin. However, to maintain the same reduced mean velocity inclined plates can be installed inside the basin under the various combination of depth and width of flow in the basin combined with a certain length of the basin to achieve the desirable trapping efficiency of the particular size particles. These particles differ in their size, shape, and coagulation which results in differences in their settling velocities.

The ideal settling velocity is described by Stacks low, while the real settling rate of small clay particles in Nile water can be described by Zankes formula:

w = (1/900*d)*((1+(1.57*(10^5))*(d^3))^0.5)-1)..(1)

Where d=diameter in (cm). This relation is based on stagnant water without turbulences, water specific weight (Υw) of 1000 kg/m3, suspended particles (Ƴs) of 2.65Kg/m3 at 20oc temperature, and 0.7 particle shape factor. However, coagulation of particles results in higher settling velocity. The fall velocity of a particular size particle decreases with the increase of sediment concentration due to interference of other particles. Morris, and Fan, (1989) noted that under certain conditions the fall velocity of a particle increased due to group settling. This is due to the flocculation of a high concentration of finer materials. When particles coalesce to fall in a group the settling velocity increases. In this model, Zanke"s formula is adopted to express the worst case. The Sudan Hydraulic Research Center (HRC) at Wad Medan and HR-Wallingford (1990) researched siltation problems encountered at the Gezira Scheme. The analysis of a large number of samples revealed the specific weight of (0.8 t/m3 – 1.0 t/m3). Usually, settling basins are constructed in three compartments, inlet, settling, and outlet zone. The inlet and outlet transitions are crucial to evenly distribute the flow in the traverse direction to avoid turbulence. Horizontal velocity variation across the width of the basin affects the hydraulic efficiency considerably more than the velocity variations over the depth.

The inlet transition is to be designed for slowing down the velocity of flow by gradually increasing the width and the depth of the basin. To have even water distribution the inlet chamber is normally equipped with baffles and screens, submerged weir, and troughs with slots or orifices in walls or bottom. As reported by Lahmeyer (2011) recommends an inlet opening angle of a maximum of 16 degrees, while for outlet transition from low velocity to high velocity a larger angle of 460 is to be adopted. The vertical transition from canal bed to desilter bed in the inlet zone needs to be made with a horizontal transmission with an inclination angle of 1:16. Likewise, the vertical transition from the desilter is to the canal bed in the outlet zone needs to be made with a horizontal transmission with an inclination angle of 1:52 (Lahmeyer, 2011). The operating water level in the basin is usually controlled by an outlet weir.

Model Development:

Model Overview: The basic principle of an ideal basin was developed by Omar et al (2015). The following assumptions are made for an ideal horizontal settling basin; the flow is steady and uniform (plug flow); the flow is quiescent (i.e. no turbulence); solids entering in deposition zone are not suspended. Figure 1.0: shows a definition sketch of an ideal basin. To determine the length 'L' and width 'B' of the basin, consider a particle entering the basin at point A. Figure 1.0 establishes the relations: settling time = T = D/w; Retention time Ts =L/v; For For quiescent settling, all particles of settling velocity 'w' are removed when retention time equals to settling time. Thus;

$D/w = L/v = LA/Q = LDB/Q \Rightarrow w = Q/(BL) = Q/A$

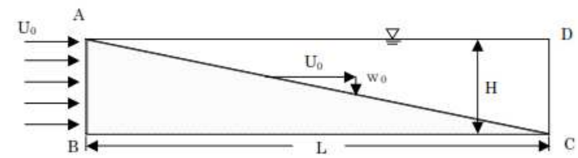

Fig 1: water flow in an ideal rectangular sediment settling basin

Where; D= is the depth of flow (m); S = as = is the cross-sectional area of basin (m2), L = is the length of the basin (m), B = is the width of the basin (m), V = is flow velocity in the basin (m/s) and Q = is the design discharge (m3/s).

In general for both real and ideal basins, the ratio (wAs/Q) can be regarded as a dimensionless indicator of the physical ability of a basin of surface area As to remove particles of fall velocity 'w' at supply discharge 'Q'. The ratio (Q/As) is termed as "surface loading".

Using the definition as shown in fig.1, the well-known overflow rate theory to the ideal rectangular settling basin is given by Eqn. (1)

$Wo = (Q/S) = (Uo*H*Wd)/(Wd*L) = Ud*(H/L)$ ….. (2)

Where: Q = the treatment capacity (m 3/s), Uo = the inflow velocity (m/s), H, W and L=the height (m), the width (m) and the length (m) of the basin respectively. Wo = the fall velocity of sediment (m/s) and S = the water surface area of the basin (m2). The equation above indicates that the treatment capacity is proportional to the surface area of the basin. This idea is applied to the inclined settling basin, as illustrated in fig.2. From the definition of the physical quantities given in fig.2, it is evident that:

$(d / (Wo * \cos\theta)) = (Lo/(Uo - Wo*\sin\theta))$ ------ (3)

Where: d=the depth of the tube settler, L * =the length of the tube, u =the suction velocity in this tube settler, and θ= the angle of inclination to the horizontal line.

Each term of the above equation equals the retention time of sediment particles in this plate in the ideal case. The expression for settling velocity (Wo) is given by:

Wo = (Q)/ (n*Ap*cos(θ)+As) ----------------- (4)

Where: Q=inflow rate (m3/s); n= number of inclined plates; Ap= inclined plate area (m2)(Ap=B*d where B= basin width and d is plate height); θ = plate inclination angle taken here as 60 degrees; As= surface area of the basin (m2)(As = Q/Vn) where Vn = flow velocity (m/s). This equation (3) is the basic equation of this case and it corresponds to Eqn. (1) in the rectangular setting basin. If we assume that the width of the tube is unit length, the right-hand terms of Eqn. (3) means the entered volume flow rate of suspension divided by the horizontally projected surface area of the tube settler. This means that the above-mentioned overflow rate theory can apply to the case of inclined tube settlers. Since the overflow rate theory assumes the ideal case, such as no wall friction, no density effect, no turbulence, we must check the applicability of this idealized theory, especially to the settling of waste-activated sludge.

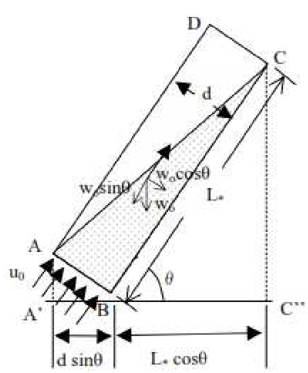

Fig 2: Inclined tube settler

The Model Design Rationale:

The optimum geometric configuration: Various combinations of depth, width, and length can be considered to achieve the targeted efficiency and the best combination is finally adopted. In this model besides the determination of the trap efficiency using the Camp method, an efficient desilter can be designed if it fulfills the following criteria

With length, width, and depth of a settling basin would be that:

a- The basin must produce a flow velocity below the value necessary to initiate movement of the bed material, and within the favorable settling velocity in the basin is in the range of 0.1 to 0.4 m/s, and sometimes to 0.77 m/s. Generally, a velocity of 0.2 m/s is recommended at the initial stage of settling basin design.

b-The net cross-sectional area for sedimentation provides enough area and space for the deposition of sediment (Stole, H, 1993).

c- The basin must be able to exclude the targeted particle size assessed in the design criteria.

d- The settling basin must be designed to ensure the stability of the settled particles such that there is no transport of the deposited sediment. Under critical conditions, the hydrodynamic forces acting upon a grain are just balanced by the resisting force of the particle. Shield's diagram is commonly used to determine if critical conditions are exceeded. In this model to check the stability, the boundary Reynolds Number is to be calculated and plotted and the design will be accepted if its value is more than one.

Trap Efficiency Computing Methods

There are several methods adopted for the design and computation of trapping efficiency of settling basins used for hydropower, water supply, and irrigation projects. Some of the methods commonly used are Camp's method, Hazen's method, Vetter's method, and the Physical model test. For this study Camps method given by Omar et al (2015)is used. The Camp's method: is based on the assumptions that; fluid velocity and the turbulent mixing coefficient are the same throughout the fluid and derived relation;

E = f[(was/Q) , (w/v*)]-------------------------- (5)

Where: E= the tapping efficiency; As =basin surface area (m3); v= shear velocity v= (To/ρ)^0.5=(g R S)^0.5; R=hydraulic depth (m); so= (; M= Manning factor = (1/n); n=roughness coefficient; So=(Q/MAR)^2; and (w/v) = dimensionless indicator of the effect of the fluid turbulence on a given particle size. The trapping efficiency is read in figure 1.0 for the computed values of (w/v*) and (wAs/Q).

Design criteria: The design of a settling basin aims to meet the following criteria

· Determination of the maximum size of particles that can enter the turbine without causing major damages and facilitate the exclusion of 95 to 100% of this and larger size particles.

·To manage with as minimum width as possible.

·To use the length that is available depending on the topography and intake location (topographical limitations).

· To optimize sediment exclusion for the cost parameters. Cost parameters in this context are; cost of downtime i.e generation loss cost of repair and maintenance of hydraulic machinery as well as civil, the initial cost of the underwater machinery, and the construction cost of the basin itself.

· To secure as high generation regularity as possible. To achieve this, the power plant should be in operation most of the time and the basin should have an adequate facility for flushing out the sediments with minimum loss of generation.

Steps in Design

To design the sediment trap the following steps given in the conceptual flow chart of figure 1.0 are to be taken:

i- *Model Inputs:* This include determination of grain size distribution of sediment, bedload, suspended load; the volume of sediment entering the intake for the period between two consecutive flushings; river discharge-stage relation (Q-h) at flushing gate; irrigation diversion requirement; topography at the location of sediment trap

ii- *Model Process:* The processes of the design model include two main phases: the operation phase and the flushing phase. During the design operating phase, the construction elements that affect system functioning in the proper state are to be specified, while during the flushing phase it is essential to determine the parameters that ensure adequate and sustainable basin storage capacity by maintaining acceptable and regular flushing out the particles designed to be settled into the basin, and this depends on the provision of the required flushing velocity and on selecting the type of flushing (continuous or intermittent), and on flushing removal method (gravity, or mechanical or manual).

1- Determination of design particle size to be conveyed through the irrigation system (usually, dn = 0.2 to 70 um (70x10^-6).

2- Determination of the required volume of sediment basin (Vn) function of concentration "C" in per mill, supply inflow rate On, (m3/s), and flushing interval (T)(sec): Vn = C*Qn*T. ------- (3)

3- Preliminary estimate of the average surface area of the sediment basin :

As = L*B= (Qn/w) ; Where: L= basin length (m); B Average width of conveyance profile (m); Qn=design diversion requirement (m3/s); w= fall velocity of design particle (m/s) to be taken from equation 1.0.

4- Determination of the energy gradient (in) in the sedimentation basin during normal operation using Strickler formula: vn = Kn* (Rn^ 2/3)* (in ^0.5) and Qn = vn* An Where: vn= average velocity during normal operation (m/s); Kn = roughness coefficient(m^1/3 / s); Rn= hydraulic radius (m) during normal operation; in= energy gradient during normal operation; Qn= design diversion requirement (m3/s);

An= wet profile during normal operation (m2), An = (Qn/vn) = (B*hn); Where (hn)= design water depth (=An/vn).

From the relation of (L/B)>8, it is possible to calculate B < (A/hc) – (z* hc); Where z is the side slope (according to soil type). Some authors (Lahmeyer (2011) take the width from the relation: B max= 7.2 *(Qn^0.5); others relate length (L) to width (B)as (L/B) >8

5- Determination of energy gradient(vs) during flushing to empty the basin using Strickler formula: vs = Ks * (Rs^ 2/3)* (is ^0.5), and Qs = 1.2Qn= vs* As; Where vs=average velocity during flushing (m/s);is=energy gradient during flushing; Qs=wet profile at the start of flushing; Rs= hydraulic radius at flushing = (As/Ps) ;Ps= wetter perimeter =B+2hs*((1+(z^2))^0.5); Where z = side slope; hs =wet water depth.

6- Determination of dimensions, elevations of sediment basin, and Length of sediment basin (L) from the volume need to be stored determined in step 2 and from the relation: (V)= 0.5*b*L+0.5*(is-in)*(L^2)*b by trial and error and check the design water level in the river or upper canal from stage-discharge relation (Q-h) for flood discharge with 5 in 1 year return period (Q1/5) to determine the water level at which flushing is possible

7- Check whether flushing is possible during the $Q_{1/5}$ flood discharge in the river or supply canal and note the basin length is (L1). For proper flushing the velocity should remain subcritical or Froude Number =Fr= ((v)/9gh)^0.5) <1.0

8- Check the particle diameter which is flushed by using the critical tractive force (t) =0.155+ 0.409*(d^2)/(1+0.177*(d^2))^0.5
=P*g*h=1000*9.8*hs*I to find the value of (d) where particles smaller than it will be flushed away.

9- Check the trapping efficiency using the Camp diagram (Figure 3) or by the relations:
E=1-exp ^((-1)*((Vs*L)/(Hn*Vn)))
Where: Vs=settling velocity (m/s);L=length of settling basin (m); hn=flow depth (m); u= mean flow velocity (m/s)

10- Adjust settling or fall velocity =wo = (hn* vn)/L , and vn = incoming flow velocity , (w/vn) and (w/wo). If trapping efficiency is not satisfactory increase the basin length from (L1) to (L2) till 95% efficiency is reached.

Determine flushing sluice and flushing canal using the relation: b*hs = bnf*hf ; Where: b=bottom width of sediment basin at flushing; hs = flushing water depth; bnf= net width flushing openings; hf= water depth in flushing opening by assuming several opening and number of piers and their spacing or width. By determining water depth, and with flushing velocity, 1:1 side slope, Strickler coefficient (Ks=35) and (b/h) ratio, and Manning formula it is possible to determine water flushing slope (if) and consequently design water level if river (or upper canal) bottom elevation is known. This will facilitate the determination of the dimensions of the intake structure.

11-If basin length is very large and there is a limitation in available space inclined plates can be employed with extra cost and with 95% trapping efficiency by the following steps:

a- Assume basin length and width are those which accommodate the volume of water and sediment to be stored during the flushing interval (l& B are constant)

b- Determine the specifications of the inclined plates by taking its Area=Ap

(Length (Lp) =width of the basin, its width = water depth=(d), suitable plate inclination angle (take 60 0C)), flow surface area without plate (As), and initial flow velocity (vn)

c- Determine adjusted spacing between plates = m = d sin (inclination angle)

d- Determine number of plates =n =L/m

e- Take the flow rate as design flow rate =Qd.

f- Assume an initial value for flow velocity (Vn)

g- Determine fall velocity wo =(Qd)/ (As+n*Ap*cos (inclination angle)).

h- Determine trapping efficiency (Ef) From the relations (w/wo) and (w/vn) and figure 2.0 or from Camp"s (1946) equation as stated by Omar et al (2015) (given in step9) and when using the graph if (Ef) value is less than 0.95 change the flow velocity (Vn) till (w/wo) reach 2.5 and efficiency reach 95%.

Data Collection

General: Data of canal characteristics, flow rate, and sediment measurement were collected from secondary sources and referred to in the text and on the reference list.

Golid pump Station: As part of the design of the Merowe irrigation project a pump station with a main canal and twin sediment basin was proposed to be installed for irrigating El Golid Irrigation Scheme on the left bank of the Nile River opposite El Gaba in accordance to contract MIP-PC1. The design details are given in The Technical Note No.9. Suspended sediment and flow measurement campaign was initiated from 2004 to 2008 at El Koro Station (215Km upstream of Merowe Dam and 400Km upstream of MIP-PC1 pump station). The input data collected and used in the developed model is shown in Table1.0 and 2.0.

Gezira Scheme: The present irrigated area of the Gezira scheme is 882,000ha and irrigate from Reservoirs in the Blue Nile River (Roseries and Sinnar).The entire network of earth canals comprises 2,300Km of the main, branch, and Major canals, and about 1,500 Minor Canals with a total length of over 8.000Km. Since the 1970s the build-up of sediment has increased massively especially in Minor Canals which consume a large sum of project revenue for mechanical dredging. The upper system (main, branch, and Major Canals) was designed using modified Lacey Regime Equations, while Minors were designed to store water during the night and commence irrigation during day time. These Minor canals are designed with large cross-sectional areas, low gradient, low flow velocities and thus act as sediment traps. This is evident by the heap of sediment dredged from the first reach of these Minor Canals. In 1988 and 1989 extensive sediment monitoring study was carried out in a joint venture between HR Wallingford of UK and HRS Wad Medani for sediment data collection and for recommending proper management options (50 locations for in-situ measurement throughout the project supplemented with canal surveys). The study reveals that 5.9 million tons of sediment entered this system in 1988, and 60 % of the sediment is deposited in the canal system and 40% pass-through to the fields creating severe land leveling problems. However, Gismalla (2006) reported that the sediment reached 8million tons. The deposited sediment in the period of July-October was suspended load with grains smaller than 63 microns (0.063mm) in silt and clay range indicating that sediment basins are the most suitable control structures. As a remedy to the problem Wallingford (1990) proposed to construct one centralized basin at the head of the system with a length of 5.7Km, a width of 570 meters, and a depth of 3 meters. The design basin would have 60% trapping efficiency which equals the trapping efficiency of the system without any sediment exclusion facilities. Atkinson (1992) Lawrence (1991) and Gismalla (2006) proposed to construct sediment basins in the first reach of the Main, Major, and Minor canals. He reported that Demas consultant recommends remodeling the Minor Canals to have narrow and deep sections and adopting a continuous irrigation mode of operation. All of these proposals were not implemented yet due to various reasons.

For purpose of application of the developed model data was collected (vide Table 1.0) from secondary sources including the Gezira Design Sheet Book, Wallingford study (1990), HRS, and Dam Implementation Unit (DIU) report, Gismalla (2006) reports, and articles, and some other thesis (Lawrence (1991), Mohammed 2011).

Table 1 : Canal and flow data collected for typical canals of the Gezira Scheme and Golid Pump Station (MIP-PC1)

Canal Parameter	Minor Canal	Major Canal	Main Canal	Golid Pump Main Canal
b=Width m	3.00	20.00	50.00	46.00
y= Depth m	2.00	3.00	4.50	3.74
An = Flow Area m2	10.00	78.00	265.00	200.00
Qn=Design Discharge m3/s	0.25	15	186	45
So=Slope	0.00005	0.00008	0.00006	0.00008
K= (1/n) Stickler Coefficient	40.00	45.00	40.00	45.00
v= Flow velocity m/s	0.15	0.19	0.7	0.22
C= Concentration = gm/lit	0.0005	0.0005	0.0005	0.0006
D50=Particle Diameter at 50 sieve	6.95	7.89	8.8	7.89
z = Side Slope	1.00	2.00	2.00	2.00

Results and Discussion

Model Verification: The Data given (Table 2) showed results of the application of the developed model with and without using inclined plates about the design offered by the Lahmyer study (2011). The table indicated that the basin width is the same in the two design procedures, but the basin length (4Km) proposed by Lahmyer's study (2011), was significantly longer compared with that developed model (1.0 Km). This was because Lahmyer designed the basin to store water for four months while the basin designed by the developed model stores water for 14 days and flushes it out. However, construction and maintenance of the long basin is a high-cost undertaking. Installation of the inclined plate inside the basin results in a significant reduction of basin length but with the additional effort and costs to install 513 inclined plates. The cost of the land saved needed to be compared with the construction costs of the plates. Application of the developed model results in comparable trap efficiency with that given by Lahmyer's study (2011). Note that both design procedures resulted in comsarable settling velocities. When the developed model was used to generate the scenario of storing the water for a similar period used by Lahmyer's study (2011) typical values were obtained.

Table 2: Comparison of application of the developed model with Lahmyer study (2011) for the case of Golid pump station

Parameter	Lahmeyer Design	Developed Model	
		Without Plate	With Plate
Basin Width (m)	46	43	41
Basin Length (m)	4000	1000	346
Basin Depth (m)	7.24	2.27	1.35
Flow velocity m/s	0.14	0.77	0.06
Design Flow m3/s	45	45	45
Settling velocity m/s	0.0003	0.0031	0.0023
Settling particle diameter mm	6	15.5	15.5
No of Plates	---	---	513
Trap Efficiency %	100	95	95

Model Application: For purpose of model application input data for the model canal is collected (table 1.0). The obtained outputs include the case of installing an inclined plate (The with Case), and the case of basin with no inclined plate (The without Case). The case of each canal is presented as follows:

a- *Gezira Scheme- Basin in the head reach of Minor Canal:* It was depicted the results of the application of the developed model for the cases Minor Canals of Gezira Scheme. The data showed that it was possible to arrive at 95% trap efficiency without the additional costs of installation of inclined plates and with the least possible basin length of 75m. However, inserting inclined plates (232 in number) saved only 25% of the area to be occupied by the basin.

Specifications for flushing sluices were showed and details can be extracted from the model. However, although output data for the flushing canal are generated by the model they are not needed for the Canals of the Gezira scheme if the direction of the slope given was towards the direction of canal water intake.

b-*Gezira Scheme - Basin in the head reach of Major Canal:* The model outputs generated from the application of the developed model for the design of model Major Canals in Gezira Scheme are shown in Table 4.0. The table indicates the model's capability to design a settling basin with 95% using only 560 m of the length of the first canal reach. The real length of the Major canal's first reach depends on the topography, and in real cases, no direct irrigation is allowed from the Major canal. However, if the need arises water withdrawals from the basin to the Minor canal can be made at fortnight flushing schedule but with the special structure to minimize sediment lading water into such off taking Minor Canal.

Installation of 267 inclined plates at 60 degrees as given results in a substantial reduction of the area (64%). The decision to install the inclined plates in such a case becomes an economical decision.

c- Gezira Scheme - Basin in the head reach of Main Canal: The outputs from model application to design settling basin in The Gezira Main Canal is shown in Table 5.0. It is clear that the application of the developed model to design settling basin in the Gezira Main Canal (at Kilo 57) with 0.09 Km width and 4Km length out of the canal length of 145 Km with 95% trapping efficiency. Recall that Wallingford designs the sediment basin with a 7Km length with only 60 trapping efficiency. The difference between these two designs can be attributed to the large basin volume to store sediment-laden water for 4-months while the model store this water for only 14 days and then flushed it out. As depicted in Table 5.0 installation of 400 inclined plates reduce basin length by 82%. The developed model generates the specifications of the needed flushing sluice of 186 m3/sec.

Conclusions

The study concluded that it is possible to use the developed model with a simplified design procedure for settling basins with and without inclined plates in different capacities of irrigation canal network using trapping efficiency criterion and periodic flushing schedule. Application of the model in case of Gold pump station indicates model capability in reducing basin length compared to the design given by Lahmeyer. Likewise, applications of the developed model for canals with various capacities (Minor, Major, and Main Canals) in the Gezira Scheme, result in designing sediment basin with economized area occupied by the basin system.

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