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Diversion Systems

Numerical modeling for Settling Basin Design

Nile Basin Capacity Building Network

NBCBN-RE

Numerical Modeling for Settling Basin Design

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Project Title
Knowledge Networks for the Nile Basin
Using the innovative potential of Knowledge Networks and CoP's in strengthening human and institutional research capacity in the Nile region.
Implementing Leading Institute
UNESCO-IHE Institute for Water Education, Delft, The Netherlands (UNESCO-IHE)
Partner Institutes
Ten selected Universities and Ministries of Water Resources from Nile Basin Countries.
Project Secretariat Office
Hydraulics Research Institute – Cairo - Egypt
Beneficiaries
Water sector professionals and Institutions in the Nile Basin Countries

Short Description

The idea of establishing a Knowledge Network in the Nile region emerged after encouraging experiences with the first Regional Training Centre on River Engineering in Cairo since 1996. In January 2002 more than 50 representatives from all ten Nile basin countries signed the Cairo Declaration at the end of a kick-off workshop was held in Cairo. This declaration in which the main principles of the network were laid down marked the official start of the Nile Basin Capacity Building Network in River Engineering (NBCBN-RE) as an open network of national and regional capacity building institutions and professional sector organizations.

NBCBN is represented in the Nile basin countries through its nine nodes existing in Egypt, Sudan, Ethiopia, Tanzania, Uganda, Kenya, Rwanda, Burundi and D. R. Congo. The network includes six research clusters working on different research themes namely: Hydropower, Environmental Aspects, GIS and Modelling, River Morphology, flood Management, and River structures.

The remarkable contribution and impact of the network on both local and regional levels in the basin countries created the opportunity for the network to continue its mission for a second phase. The second phase was launched in Cairo in 2007 under the initiative of; Knowledge Networks for the Nile Basin. New capacity building activities including knowledge sharing and dissemination tools, specialised training courses and new collaborative research activities were initiated. The different new research modalities adopted by the network in its second phase include; (i) regional cluster research, (ii) integrated research, (iii) local action research and (iv) Multidisciplinary research.

By involving professionals, knowledge institutes and sector organisations from all Nile Basin countries, the network succeeded to create a solid passage from potential conflict to co-operation potential and confidence building between riparian states. More than 500 water professionals representing different disciplines of the water sector and coming from various governmental and private sector institutions selected to join NBCBN to enhance and build their capacities in order to be linked to the available career opportunities. In the last ten years the network succeeded to have both regional and international recognition, and to be the most successful and sustainable capacity building provider in the Nile Basin.

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FOREWORD

This report is one of the final outputs of the research activities under the second phase of the Nile Basin Capacity Building Network (NBCBN). The network was established with a main objective to build and strengthen the capacities of the Nile basin water professionals in the field of River Engineering. The first phase was officially launched in 2002. After this launch the network has become one of the most active groupings in generating and disseminating water related knowledge within the Nile region. At the moment it involves more than 500 water professionals who have teamed up in nine national networks (In-country network nodes) under the theme of "Knowledge Networks for the Nile Basin". The main platform for capacity building adopted by NBCBN is "Collaborative Research" on both regional and local levels. The main aim of collaborative research is to strengthen the individual research capabilities of water professionals through collaboration at cluster/group level on a well-defined specialized research theme within the field of River and Hydraulic Engineering.

This research project was developed under the "Cluster Research Modality". This research modality is activated through implementation of research proposals and topics under the NBCBN research clusters: Hydropower Development, Environmental Aspects of River Engineering, GIS and Modelling Applications in River Engineering, River Morphology, flood Management, and River structures.

This report is considered a joint achievement through collaboration and sincere commitment of all the research teams involved with participation of water professionals from all the Nile Basin countries, the Research Coordinators and the Scientific Advisors. Consequently the NBCBN Network Secretariat and Management Team would like to thank all members who contributed to the implementation of these research projects and the development of these valuable outputs.

Special thanks are due to UNESCO-IHE Project Team and NBCBN-Secretariat office staff for their contribution and effort done in the follow up and development of the different research projects activities.

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EXECUTIVE SUMMARY

Numerical modeling for design of settling basin using the computer program SSIIM is demonstrated in this study. The theoretical backgrounds of numerical modeling relevant to the design of settling basin is presented and discussed. The sediment settlement theory, on which existing design methods are based and the shape and size of settling basins is set, is also studied. The full design procedure of an example design is presented and the result is analyzed and discussed. The relationships between the different design-parameters of a settling basin are also tested using the computer program to gain insight in to their parametric relationship. From the design trial, it is concluded that the numerical modeling can be of much help to the design engineer for an efficient and cost effective design of settling basin. The possible draw backs in implementing the numerical modeling computer program SSIIM in designing of settling basins is also investigated and remedies are proposed.

ABBREVIATIONS & ACRONYMS

η	Sediment removal efficiency
η_0	Limiting value of η obtained for a given value of $\frac{w}{u_*}$
k	Coefficient in Garde et al formula
L	Length of settling basin
w	Settling velocity of particles
u_*	Shear velocity
D	Depth of settling basin
h	Flow depth in the approach channel
B	Settling basin width
b	Width of approach channel
n	Mannnig's roughness coefficient
g	Gravitational acceleration
Q_{si}	Sediment load entering the settling basin
Q_{so}	Sediment load leaving the settling basin
ρ	Density of water
k	Kinetic energy
δ_{ij}	Dissipation of the kinetic energy
k	A constant equal to 0.4
y	The distance to the wall
K_s	Equivalent to a diameter of particles on the bed
E	An empirical parameter equal to 9.0
c	Concentration in volume fractions
S_c	Schmdit number
C_{bed}	The equilibrium sediment concentration close to the bed
ρ_s	Density of sediment
ρ_w	Density of water
ν	Viscosity of water
τ	Bed shear stress

τ_c	Critical bed shear stress
q_b	Bed load
Γ	Diffusion coefficient
Δ	Bed form height
d	Water depth
k_s	Effective roughness
λ	Bed form length

1. INTRODUCTION

Settling basins are used for removing excess sediment entering irrigation or power canals taking off from an alluvial river. Most of the sand fraction of the suspended sediments should be removed in order to maintain hydraulic transport capacity of the waterway and to reduce the abrasion of turbines and silting of irrigation canals.

The main aim of settling basin design is to allow suspended particles to settle out from the water body and deposit on the bottom of the basin by reducing the turbulence level in the water flow. Then the deposits are removed by different means like flushing and excavation.

Settling basins are formed by widening the approach channel and lowering its floor through an expansion transition so as to reduce the mean velocity of flow into the basin. Irrespective of method of disposal of settled sediment, i.e. intermittent flushing, scraping and sluicing, mechanical dredging and hydraulic flushing types, the aspect of their design to determine the dimensions i.e. length, width and depth remain the same.

Settling basin design is guided by the fall velocity of the particles which shall be excluded. The fall velocity is function of density, size, shape and concentration of the particles which shall be excluded and to some extent water temperature. The hydraulic design of a settling basin has objectives:

- Uniform flow distribution in vertical and horizontal planes.
- No dead pocket in basin at entrance or exit so as to avoid eddies
- Ease and efficient removal of deposits

For inlet and outlet transition zone, specific care is needed as it is main challenge from hydraulic design point of view. The velocity in the settling chamber is low, so if uniform flow is not achieved till the end of entrance transition zone, it will be remain non uniform throughout the basin and trap efficiency will reduce drastically. It’s preferable to have a good length (appx. 10-12 times width of inlet) straight before the transition zone starts at inlet. This will help to get rid-off secondary currents. Inlet transition zone should have a gradual expansion and care should be taken so that there is no separation of flow near walls. An opening angle less than 10 to 12 degree is good if possible. Depending on sediment load and flushing interval or method, there should be provision of dead space for sediment accumulating at the bottom of the basin. Different types of settling chambers and different methods of removal of sediments have been developed and are in use.

Though some of the existing methods are based on analyses of extensive amounts of laboratory data and serve as practical tools for design, these methods are based on assumption of rectangular settling basin and fall short when trying to design relatively complex and possibly efficient and cost effective designs.

Moreover, boundary conditions such as Flow velocity and turbulence at inlet of settling basin affect the performance efficiency of settling basins. Therefore it is essential that the transition zone at inlet is also designed integrated with the overall structure. But, the existing design methods are not sufficient and a more elaborate calculation method should be applied that uses as much of the influential variables. i.e. inlet and outlet transition zone geometries, roughness of bed and wall material, bottom geometry of settling basin. Nevertheless, with today’s readily available powerful personal computers and public domain programs, numerical models can be used to simulate the flow of water and sediments settling patterns, enabling the study of more complex shaped settling basins for efficient and cost effective design.

1.1 Objective of the Study

The general objective of this study is to investigate an improved way of design of settling basins using available numerical modeling computer programs.

For this, the specific objectives of this study are:

- To review literature on existing design methods and investigate possible scientific gap
- Demonstrate application of the numerical modeling computer program, SSIIM
- Analyze the performance efficiency of settling basin having differing geometry cases for an efficient and cost effective design

2. DESIGN OF SETTLING BASIN

2.1 Design Methods

Empirical and analytical methods of computation of settling basin efficiency have been proposed by Camp (1964), Dobbins (1944), Sumer (1977) and the United States Bureau of Reclamation [(USBR), Vanoni (1975)].

Garde et al (1990) checked the methods of Camp, Sumer and Vanoni and found that all of them predict higher efficiencies than the observed ones. They attribute their inaccuracies to the overlooking of flow separation on vertical separation of sediment in the region close to the inlet depression on the bed. Based on their data, Garde et al (1990) developed a predictor equation for the length of the basin L:

$$\eta = \eta_0 (1 - e^{-(\frac{kL}{D})}) \quad (1)$$

Where, η =removal efficiency

η_0 = Limiting value of η obtained for a given value of $\frac{w}{u_*}$ at large values of L/D

k = Coefficient

D = Depth of flow in the basin

and $\eta = \frac{Q_{si} - Q_{so}}{Q_{si}} x100$

Where, Qsi and Qso= incoming and outgoing sediment loads respectively.

Accurate estimates of the basin efficiency were given by all of the methods for coarse sediments, i.e., when sediment size d> 0.4 mm. For finer sediments the predictions were poor, in particular, all of the above methods produced inaccurate results for the data having v/u* < 0.4 (Raju et al, 1999). where, v is the fall velocity of sediment particle, and u* is the shear velocity of flow in the approach channel. Overall, the methods of Camp-Dobbins and Sumer were found to give results less accurate than those of Garde et al. and the USBR.

The method of Garde et al. (1990) expresses the removal efficiency in terms of the non-dimensional variables v/u* and L/D. Here, L is basin length, and D is flow depth in the basin.Also, in the USBR method, removal efficiency is expressed in terms of v/U and L/D. U is the average flow velocity in the basin. Both methods indicate an increase in efficiency with an increase in L/D. However, it is obvious that removal efficiency increases with an increase in L and/or D. Therefore the parameter L/D may not be appropriate for characterizing the removal efficiency.

At smaller values of v/u*, the following functional relationship was arrived at by (Raju, 1999) for the basin efficiency

$$\eta = 11.7 (\frac{w}{u})^{0.81} (\frac{BL}{hb})^{.23} (\frac{D^{\frac{1}{6}}}{n\sqrt{g}})^{.98} \quad \text{for} \quad \frac{w}{u_*} < 2.5 \quad (2)$$

where B = basin width; b = width of approach channel; h = flow depth in the approach channel; n = Manning's roughness coefficient of the basin; and g = gravitational acceleration. The non-dimensional variables included in (2) relate to the flow, the geometric and the roughness characteristics. Hence, these are expected to satisfactorily explain the variations in the removal efficiency of the basin (Raju et al, 1999).

Vittal et al. (1999) has shown that the design of a settling basin can be done in a cost effective manner by the right combination of Depth and Width for a desired mean velocity and based on the relative construction and Material cost at the particular location of construction. Moreover, inlet transition zone should have a gradual expansion so that there is no separation of flow near walls.

2.2 Numerical Modelling

Numerical modeling for the design of settling basins requires a model for the flow field that includes turbulence modeling and also the model for the simulation of a diffusion- advection equation for suspended load transport. There are different types of numerical models called 'Computational Fluid Dynamic' (CFD) programs, available for one two and three dimensional analysis with varying degree of sophistication and reliability. Some of which are PHOENICS, STAR-CD, CFX, FLUENT and FLOW-3D, TELEMAC, MIKE3, DELFT-3D, CH3D, TABS and SSIIM.

Among these, the SSIIM program solves the Navier-Stokes equation in a three-dimensional non-orthogonal grid. The program also solves convection-diffusion equations for various water quality constituents. i.e. sediments, pollutants etc. SSIIM is an abbreviation for Simulation of Sediment Movements in Water Intakes with Multiblock Option. The program has a graphical user interface with an interactive grid editor containing several algorithms simplifying the construction of the grid. The main program contains graphical presentation of results in multiple dimensions which can be run simultaneously with the solution of the differential equation. Moreover, the program is public domain software which can be accessed easily and because it is open source software, there is the added advantage of being able to modify the program for specific purposes in the future. Therefore, it is selected in this study to demonstrate the use of numerical models for design of settling basins.

2.3 Theoretical Basis

2.3.1 Water Flow Calculation

The SSIIM program works by solving the Navier-Stokes equations for turbulent flow in a three dimensional geometry to obtain the water velocity. The Navier-Stokes equations for non-compressible constant density flow can be modeled as follow:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = \frac{1}{\rho} \frac{\partial}{\partial x_j} (-P\delta_{ij} - \rho \overline{u_i u_j}) \qquad (3)$$

Where,

$\frac{\partial u_i}{\partial t}$ = transient term

$u_j \frac{\partial u_i}{\partial x_j}$ = the convective term

$\frac{1}{\rho} \frac{\partial}{\partial x_j} P\delta_{ij}$ = pressure term and

$\frac{1}{\rho} \frac{\partial}{\partial x_j} \rho \overline{u_i u_j}$ is the Reynolds stress term.

The equations are discretized with a control-volume approach. An implicit solver is used also for the multi block option. The SIMPLE method is the default method used for pressure-correction. The Power-law scheme or the second-order upwind scheme is used in the descretization of the convective terms.

2.3.2 The Turbulence Model

To evaluate the Reynold's shear term in eq. (3), a turbulence model is required. The k-ε model is one of the turbulence models that can be used to calculate the turbulent shear stress.

The eddy viscosity concept is introduced to model the Reynolds stress term:

$$-\overline{u_i u_j} = V_T \left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) + \frac{2}{3}k\delta_{ij}) \tag{4}$$

The model calculates the eddy-viscosity as:

$$V_T = c_\mu \frac{k}{\varepsilon^2} \tag{5}$$

Where k is the kinetic energy defined by

$$\kappa = \frac{1}{2}\overline{u_i u_j} \tag{6}$$

k is modeled as

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{V_T}{\sigma_k}\frac{\partial k}{\partial x_j}\right) + P_k - \varepsilon \tag{7}$$

Where P_k is given by

$$P_k = V_T \frac{\partial U_j}{\partial xi}\left(\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j}\right) \tag{8}$$

The dissipation of k is denoted ε , and is modeled as

$$\frac{\partial \varepsilon}{\partial t} + U_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{V_T}{\sigma_{k_i}}\frac{\partial \varepsilon_i}{\partial x_j}\right) + C_{\varepsilon 1}\frac{\varepsilon}{k}P_k + C_{\varepsilon 2}\frac{\varepsilon^2}{k} \tag{9}$$

2.3.3 Wall Laws

The velocity gradient towards the wall is often very steep. If it is to be resolved in the grid, this will require too many grid cells. Instead, wall laws are used. This means that the velocity profile follows a certain empirical function called a wall law. The wall law for rough boundaries is used, as given by Schlichting (1979)

$$\frac{U}{u_x} = \frac{1}{k}\ln\left(\frac{30y}{k_s}\right) \tag{10}$$

Where, the shear velocity is denoted ux and κ is a constant equal to 0.4. The distance to the wall is y and the roughness, ks is equivalent to a diameter of particles on the bed. Wall laws for smooth boundaries are given as:

$$\frac{U}{u_x} = \frac{1}{k}\ln\left(\frac{Eyu_x}{\nu}\right) \quad \text{For} \quad \frac{Eyu_x}{\nu} > 11 \tag{11}$$

$$\frac{U}{u_x} = \frac{Eyu_x}{\nu} \quad \text{For} \quad \frac{Eyu_x}{\nu} < 11 \tag{12}$$

Where E is an Empirical parameter equal to 9.0

2.3.4 Sediment Flow Calculation

Sediment transport is conventionally divided in bed load and suspended load. The suspended sediment load can be calculated with help of convection-diffusion equation for the sediment concentration, c,(volume fraction in SSIIM)

$$\frac{\partial c}{\partial t} + u_j \frac{\partial c}{\partial x_j} + w\frac{\partial c}{\partial z} = \frac{\partial}{\partial x_j}(\Gamma \frac{\partial c}{\partial x_j}) \tag{13}$$

The fall velocity of the sediment particles is denoted w. the diffusion coefficient Γ is taken from the k- ε model:

$$\Gamma = \frac{V_T}{s_c} \tag{14}$$

s_c is the schmdit number, set to 1.0 as default.

For suspended load, Van Rijn (1987) developed formula for the equilibrium sediment concentration, Cbed close to the bed.

$$C_{bed} = 0.015 \frac{d^{0.3}[\frac{\tau - \tau_c}{\tau_c}]^{1.5}}{a[\frac{(\sigma_s - \sigma_w)g}{\sigma_w v^2}]^{0.1}} \tag{15}$$

Where, the sediment particle diameter is denoted d, a is a reference level set equal to the roughness height. τ is the bed shear stress, τ_c is the critical bed shear stress for movement of sediment particles according to shield's curve, σ_w and σ_s are the density of water and sediment. v is the viscosity of the water and g is the acceleration of gravity. In addition to the suspended load, the bed load. q_b Can be calculated using the Van Rijn's formula for bed load as:

$$\frac{q_b}{D^{1.5}{}_{50}\sqrt{\frac{(\rho - \rho)}{\rho}}} = 0.053 \frac{[\frac{\tau - \tau_c}{\tau_c}]^{2.1}}{D^{0.3}{}_{50}[\frac{(\sigma_s - \sigma_w)g}{\sigma_w v^2}]^{0.1}} \tag{16}$$

The bed form height is calculated by Van Rijn's equations (1987):

$$\frac{\Delta}{d} = 0.11(\frac{D_{50}}{d})^{0.3}(1 - e^{(\frac{\tau - \tau_c}{2\tau_c})})(25 - (\frac{\tau - \tau_c}{\tau_c})) \tag{17}$$

Where, d = the water depth

The effective roughness is computed as (Van Rijn, 1987)

$$k_s = 3D_{90} + 1.1\Delta(1 - e^{\frac{25\Delta}{\lambda}}) \tag{18}$$

Where,

λ = the bed-form length calculated as 7.3d.

2.3.5 Stability and Convergence

The water flow calculation has to be done prior to the sediment flow calculation. The solution method is to guess a starting value for the variables and then iterate to get a better solution. Several different criteria exist to decide if the solution is converged. The most common criteria to decide if the solution has converged are to check that the residuals for the various variables in the solution are under a tolerable minimum value. The residual is a measurement of how large the deviation is between the current value and the values in the current iteration. Starting from the guessed values, several iterations are done to improve the result. To reduce instability of the solution, relaxation coefficient between 0 and 1 is used.

3. SSIIM Program

The SSIIM program has two versions, SSIIM1 and SSIIM2. For this demonstrative study, the presentation of SSIIM1 is believed to be adequate and therefore is adhered to. SSIIM can be used on different operating systems. The Windows version consists of one window and a menu. At start up, the window shows text with information about convergence and the run, figure (3-1).

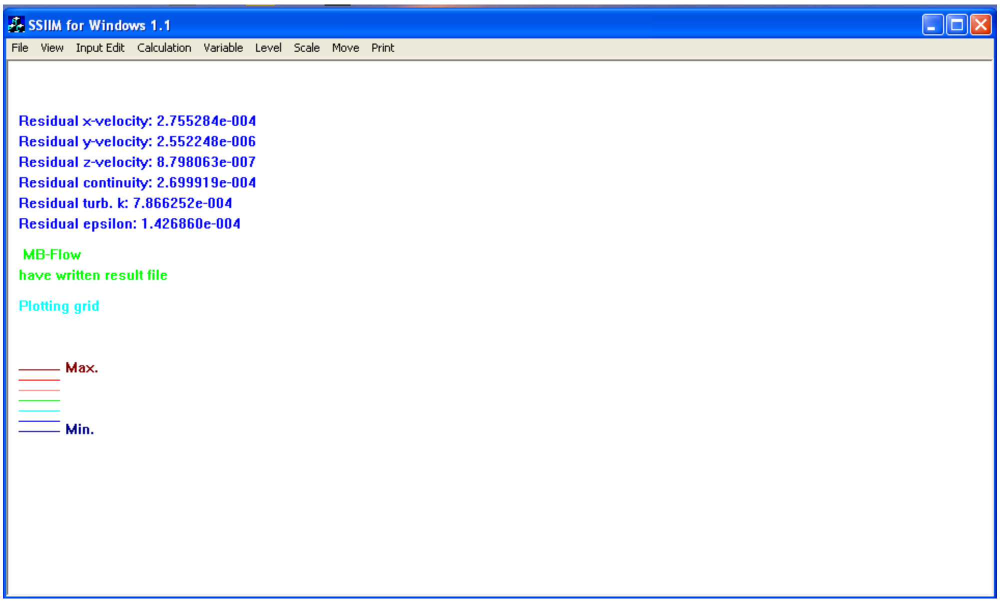

Figure 3-1: Text window of the SSIIM program showing the residuals for the iterative calculations of the six parameters

The content of the window can be changed by choosing different sub-options in the view option of the menu. Changing the view will also change the main menu. The different views are:

- Map graphics with contour plots or vectors
- Longitudinal/ cross-sectional profiles
- Grid Editor

Normally a SSIIM-run starts by reading input files, or generating the grid using the Grid-Editor, figure (3-2).

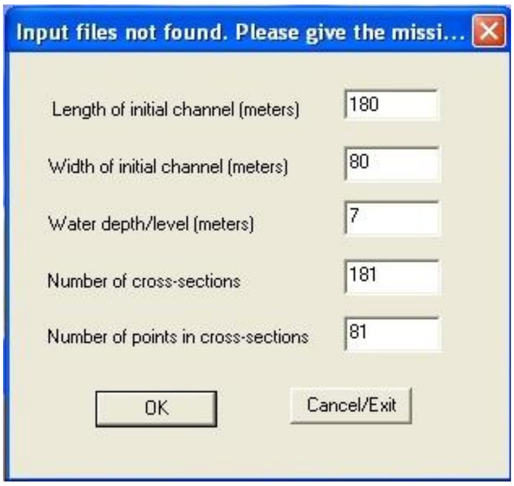

Figure 3-2: SSIIM Dialog Window for setting the initial parameters of the structure

Then the data should be saved in the koordina files before the computation is started and the results are viewed, figure (3-3).

As an input for model four main things are needed as follow:
1. Geometry of the hydraulic structure
2. Water inflow/outflow data
3. Sediment data
4. Different controlling parameters

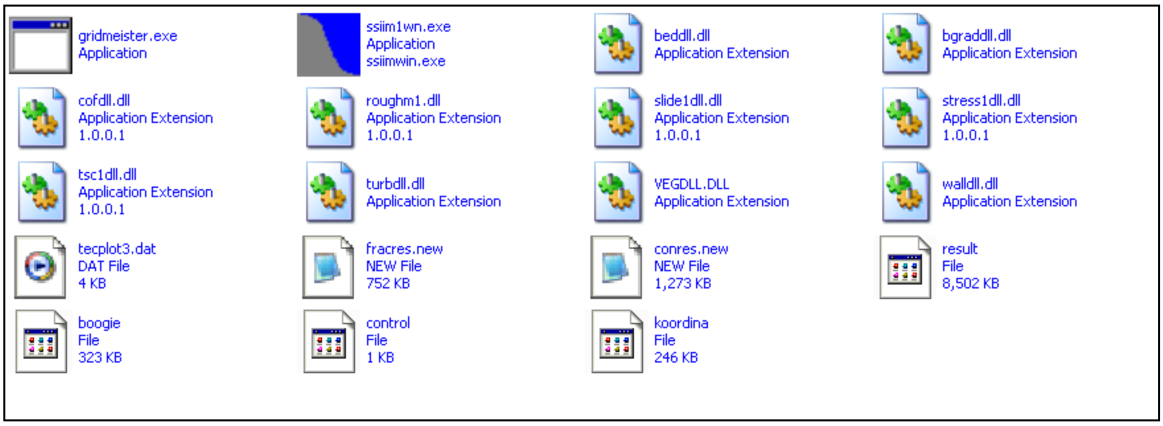

Figure 3-3 Files used in a particular SSIIM project for a numerical model

Hydraulic system is modeled by means of x, y and z co-ordinates with a structured grid. Coordinates are points where grid lines meet. Grid lines define cells between them. The variables are calculated in the centre of each cell. The geometry have six surfaces. The water surface or the roof of the basin defines the sixth surface of the three dimensional water body.

Control file controls all parameters of the initial and boundary conditions such as, the water inflow and outflow, the roughness and sediment size, fall velocity and concentration at inflow, as in figure (3-4).

control - Notepad

File Edit Format View Help

```
T                                   title field
G 1 105 78 4 2      grid and array sizes
G 3 0.000000 33.333333 66.666667 100.000000      vertical grid distribution
G 8 0 0 0 77 0 7 0.352 0 0
W 1 76.923000 190.000000 7.100000
W 2 3 1 52 105
K 1 40000 60000
K 2 0 1
S 1 0.0004 0.05
S 2 0.0001 0.007
I 1 100
I 2 100
```

Figure 3-4: Control file opened in a Window's Notepad for editing

The water inflow/outflow has to be specified for all boundaries where water is flowing into or out of the water body. Water velocities are given by three dimensional vectors. Also the sediment concentration at inflow is required. Friction and shear stress is calculated in the program based on the roughness.

The bed concentration is recalculated as simulation proceeds. In SSIIM different option can be used. The evaluation of changes in bed elevation is obtained by satisfying continuity of the sediment fluxes on the bed boundaries. For each particle size same process is followed. For total change a summation of changes for each particle size is summed up.

An intermediate file with the name 'boogie' (figure 3-5) is generated which shows print-out of intermediate results from the calculation. It also shows parameters as average water velocity, shear stress and water depth in the initialization. Trap efficiency and sediment grain size distribution is also written in this file. If any error occurs during the run of program, it is written here with explanation before the program terminates.

```
Iter: 100, Resid: 1.39e-003 2.07e-005 3.80e-006 8.91e-004 2.24e-002 6.89e-003
Cont: -4.35e-011, DefMax: 1.68e-002, U,V,W(105,3,4): 3.63e-001 1.06e-004 5.12e-006
Solution converged
 In suspinit

Shear in entrance: 0.104188
Using van Rijn's method with parameters: 0.015000 1.500000 0.300000
Have calculated bed sediment concentration
conc(1,2,2,2)=1.000000e-015
Initial bed material load is 1.540361e-010 kg/s for size 0.000400 meters
Corr. between calc. and given inflow of sediments
in upstream profile for l = 1 is: 6.49198e+011

Initial bed material load is 3.301166e-002 kg/s for size 0.000100 meters
Corr. between calc. and given inflow of sediments
in upstream profile for l = 2 is: 3029.23

Have read conres and fracres files

 ***** In morphology **********

Bed concentration flags: 0 0 0 0 0 0
Trap efficiency after 7 iter: all values in kg/s
 l=1: Trapped: 99.8733, Fluxes (I1,I2,J1,J2,K2): 100, 0.126674, 0, 0, 0 Resid: 0.000000
 l=2: Trapped: 53.6218, Fluxes (I1,I2,J1,J2,K2): 100, 46.3786, 0, 0, 0 Resid: 0.000003
BedMove(2,2) = 3.550077e-001 meters
BedMove(2,3) = 3.212997e-001 meters
BedMove(2,4) = 3.206094e-001 meters
BedMove(2,5) = 3.205914e-001 meters
BedMove(2,6) = 3.205894e-001 meters
BedMove(2,7) = 3.205886e-001 meters
```

Figure 3-5: The boogie file opened in a Windows Notepad

The result file is written when prescribed numbers of iterations have been calculated or when the solution has converged. The results are velocities in three dimensions, k, ε , pressure and the fluxes on all the walls of the cells. The data from this file is used as input for the sediment flow calculations.

4. APPLICATION OF SSIIM: SAMPLE DESIGN AND ANALYSIS

Because of lack of actual dimensions and performance evaluation data for an existing settling basin in the Nile Basin countries, a sample design is used for a settling basin for Mahri Bahli stage II project in UP, India, as presented in (Vittal et al., 1997). The design is analyzed using different existing design methods and also by using the computer program SSIIM to demonstrate the procedures of numerical modeling for a settling basin design.

The following are the design data.
Q= 190m^3/s
Manning's n= 0.013
Size of sediment to be removed= 0.25mm
Desired sediment removal efficiency $\eta =$ 95%

Design parameters of settling basin according to existing methods of Camp (1964) and Vittal (1997) are as in Table 4.1:

Table 4-1: Parameter values of a structure according to existing design methods

Item	Parameter value according to	
	Camp's (1964)	Vittal (1997)
Length	104	97
Width	76.95	80
Depth	7.11	7

These two designs are numerically modeled and tested for their sediment removal efficiency in removing sediment sizes of 0.4mm, 0.25 mm and 0.1 mm. uncertainty analysis is made by analyzing the change in removal efficiency when parameters of roughness(manning-strickler), length, width and depth change.

To demonstrate how an efficient design can be made and how the system can be modeled numerically, a design is made for the example case by starting from the parameters given by Camp's method and improving it implementing a gradual expansion using transitions.

4.1 Generation of the Grid

The basic concept of computational fluid dynamics is to divide the fluid geometry into elements or cells, and then solve an equation for each cell. The accuracy and convergence of a finite volume calculation depend on the quality of the grid, which are: Aspect ratio, expansion ratio and the orthogonallity of the grid.

The grid lines should be orthogonal as much as possible and in no case should be less than 90 degrees to each other to guard against false diffusion.

For the problem at hand, we first calculate the length and breadth of the grid about to be constructed to include the furthest points in a settling basin structure including the transition zones at inlet and outlet. From the figure:

- Total length of grid=104
- Total width of grid= 80

The grid shall be decided taking into consideration the complexity of the geometry so that to fully represent the irregularity at bends and change of slope, and the stability and convergence of the solution within acceptable computation time. For a grid cell size of 1m:

- No of cross sections in the stream wise direction= 105
- No of points in each cross section = 81.

This would give both an aspect ratio and expansion ratio of 1 which is acceptable. This is a preliminary sizing and the grid spacing will need to be changed if

1. the calculation time is found to be unacceptably high in which case it would be increased in either one or more directions
2. The solution does not converge with acceptable level of residual so that we will have to decrease the grid spacing in either one or more directions for a more refined calculation.

Locate the vertices of the final structure on the grid as shown in figure (4-1). And decide which peripheral grid points on the edge of the grid are to be moved to give the final shape of the structure and to assign depth values to important points by using “the give coordinates” menu Item from the define menu.

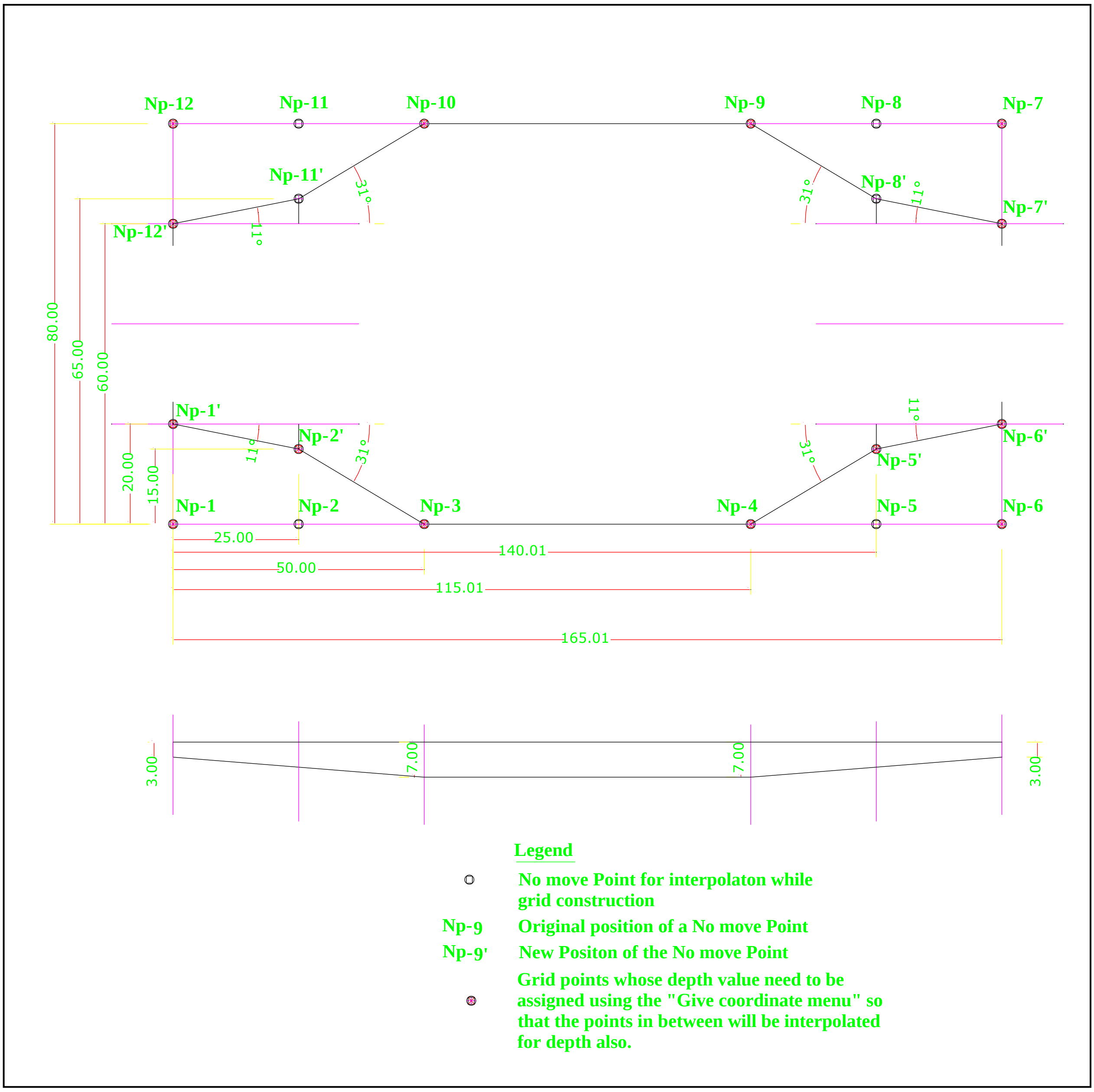

Figure 4-1: Design including the transition zone to be modeled numerically using the SSIIM program

In this example's case the interpolation is needed to be done in the stream wise direction so use the Transfinite-I interpolation scheme from the Generate menu of the grid editor Window. And finally use the implementation menu to make a 3-dimensional model.

4.2 Generation of Input Files

Generation of input files include setting the initial and boundary conditions. Drichlet boundary condition has to be given for the input and output flow and is set in the SSIIM by editing the control file.

The W 1 dataset is used to specify the sticklers (inverse of the Manning's) coefficient, the discharge and the water level to be used in a backwater computation.

The initial velocity is given using the G8 dataset. Given the velocity, it is also possible to estimate the shear stress at the entrance bed. Then the turbulent kinetic energy k at the inflow bed is determined by using a simple turbulence model as in eq. (16) to specify the eddy-viscosity

$$\kappa = \frac{\tau}{\rho\sqrt{c_\mu}} \tag{16}$$

This equation is based on equilibrium between production and dissipation of turbulence at the bed cell. The turbulence model k- ε is selected. And wall laws are fixed using eq.(10) to eq.(12) and κ_s this is set using the F16 dataset in the control file of the SSIIM program or else it will be calculated automatically from Manning's-Strickler friction coefficient.(Van Rijn, 1982).

The sediment concentration and inflow are set are set using the S data set and the I dataset in the control file as shown in Fig.3.4.

4.3 Comparison of Designs

The principle behind the design of settlement basins is to allow a particle entering the basin at the water surface level at upstream, enough time to settle to the bottom just before reaching the downstream end. This leaves room to investigate for a possible reduction of cross section area at upstream points. So that to save on material and construction cost of settling basin structures.

The designs in the Table 4.2 below are made for 95% removal efficiency with sediment of diameter 0.25mm. The higher efficiency predicted by the numerical model is because of assumption of smooth transition at inlet and outlet of structure which is unrealistic, necessitating the design of the transition zones in unison with the settlement structure.

Table 4-2: Removal Efficiency of settling basin computed with the numerical model SSIIM when designed according to existing methods of Camp (1964) and Vittal (1997)

Computed Efficiency using the Numerical model SSIIM for sediment sizes of	Camp	Vittal
0.4 mm	100	100
0.25 mm	99.96	99.97
0.1mm	68.25	63.94

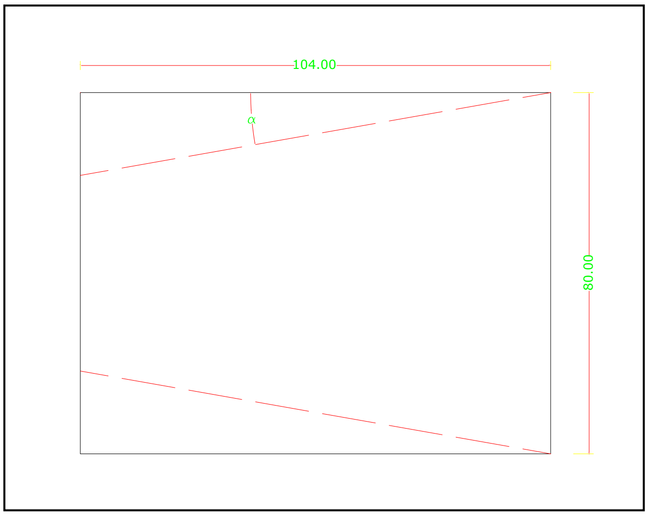

Figure 4-2: Horizontal expansion angle

Table 4-3: Varying width transition angles in stream wise direction

Angle	Removal efficiency in for sediment of size (in percentage)		
	0.4 mm	0.25mm	0.1 mm
0% (Original design based on Camp's method)	99.99	99.97	69.14
10	99.99	99.86	46.89
12.5	99.97	99.55	38.50
15	99.85	98.17	30.18

From the above table, it can be seen that using a narrower cross section at the upstream has a negative effect on the removal efficiency the settling basin. However, the effect is not very significant for the particular design problem. Although it can be argued weather to opt for a higher efficiency alternative or for a more cost efficient design, it rests on the designer's judgment and the seriousness of the problem downstream. i.e. we may adopt a less efficient and more cost effective design for irrigation purposes than for hydropower intake projects.

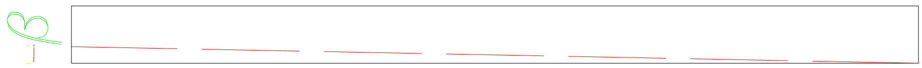

Figure 4-3: Bed Slope angle in the Stream wise direction

Table 4-4: Varying bed slope angles in stream wise direction

Slope	Removal efficiency in for sediment of size (in percentage)		
	0.4 mm	0.25 mm	0.1 mm
0%(Original design based on Camp's method))	100	99.97	69.14
0.5%	100	99.97	67.44
1%	100	99.97	65.45
2%	100	99.97	69.14
3%	100	99.98	54.15

4.4 Modified Design of Settling Basin with the Transition Zone

Assuming the incoming and outgoing waterways to be 40 wide and 3m deep, the velocity would be 1.58 m/s. Inlet transition zone should have a gradual expansion and care should be taken that there is no separation of flow near walls. Therefore, let's use a gradual opening of incremental angel of 15^0 for the transition zone giving the plan of the structure in the Figure 4.1.

Table 4-5: Removal efficiency of the modified settling basin when handling different sediment sizes

Sediment sizes of	Computed Efficiency using the Numerical model SSIIM
0.4 mm	99.99
0.25 mm	99.59
0.1mm	43.54

5. CONCLUSION AND RECOMMENDATION

The computer program SSIIM is found to be a convenient tool for Numerical modeling of the flow and sediment transport and settlement behavior in settling basins. This demonstrative study showed that numerical models in general and those made using the computer program SSIIM in particular can be used to design a more cost effective alternative settling basins.

From the analysis of removal efficiency of settling basin with differing geometry, it can be concluded that a rectangular basin both in plan and in longitudinal cross section, is not necessarily the optimum solution.

Settling basins that handle big discharges through them are large and costly, and their designs are at times complicated according to the method of sediment removal mechanism adopted and because of the need to provide a gradual transition at inlet and outlet. These factors render preparation of alternative designs for a cost effective design difficult. More research work should be directed at taking advantage of the SSIIM program’s Open Source nature by developing extra program modules and user interface elements to make the SSIIM program usable by the average design engineer in preparing the grid system, the initial and boundary conditions and to program optimization procedures for a cost effective design.

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NUMERICAL MODELING FOR SETTLING BASIN DESIGN

Numerical modeling for design of settling basin using the computer program SSIIM is demonstrated in this study. The theoretical backgrounds of numerical modeling relevant to the design of settling basin is presented and discussed. The sediment settlement theory, on which existing design methods are based and the shape and size of settling basins is set, is also studied. The full design procedure of an example design is presented and the result is analyzed and discussed. The relationships between the different design-parameters of a settling basin are also tested using the computer program to gain insight in to their parametric relationship. From the design trial, it is concluded that the numerical modeling can be of much help to the design engineer for an efficient and cost effective design of settling basin. The possible draw backs in implementing the numerical modeling computer program SSIIM in designing of settling basins is also investigated and remedies are proposed.

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