Numerical Modeling of Non-uniform Flow in Settling Basins

Hanne Nøvik, Abha Dudhraj, Professor Nils ReidarBøe Olsen, Dr. Meg B Bishwakarma and Professor Leif Lia





Hanne Nøvik | Abha Dudhraj | Nils ReidarBøe Olsen | Meg B Bishwakarma | Leif Lia

Abstract : The settling basins for hydropower plants are designed to remove suspended sediments from the water flow. The inlet geometry of the settling basin may cause formation of recirculation zones and high turbulence, which may lead to diminished trap efficiency, and as a consequence, turbine erosion. Most analytic approaches for calculating the trap efficiency of settling basins are based on the assumption of a uniform flow; hence, simplified one-dimensional equations are used to determine the velocity distribution and the turbulence characteristics of the flow. However, the velocity field in settling basins is often unevenly distributed, and the simplified equations are not always applicable. This study describes a new method for improving the assessment of settling basin performance. The idea is to extract values for the velocity distribution and the turbulence characteristics along the settling basins from computational fluid dynamic (CFD) models. The extracted CFD values are then used as input parameters to the standard analytical approaches for calculation of settling basin trap efficiency. This promising method is tested on a case study of a physical model of the settling basin for the Lower Manang Marsyangdi Hydropower Project in Nepal. The CFD calculations turn out to provide additional information to the sedimentation calculations in settling basins, and are useful for the assessment of different design alternatives at an early stage.

Key words: Settling basin, trap efficiency, CFD, hydropower, Nepal

Introduction

Settling basins for hydropower plants in sediment loaded rivers are designed to remove suspended sediment particles, which may cause erosion and damage to the turbines, and which cost for the repair and replacement of turbine components. In the settling basin, the suspended particles larger than a certain size are supposed to settle and deposit on the bottom. The deposited sediments are then removed from the settling basin by various methods.

The settling basin must be designed for reducing the turbulence level in the water flow in order to allow for the sediment particles to settle. The trap efficiency of a settling basin, η, is the reduction in the sediment concentration, c, from the inflow to the outflow, which is defined as:

Most analytic approaches used today for calculating

$$\eta = \frac{c_{in} - c_{out}}{c_{in}}$$

the sediment concentrations, and trap efficiency of settling basins are based on the assumption that the area intended for the settling of sediments named the effective surface area of the settling basin, A_s has a close to uniform flow. Hence, simplified one-dimensional equations are applied to determine the velocity distribution and turbulence characteristics of the flow. These conventional approaches predict the trap efficiency well, as long as there is an evenly distributed flow throughout the effective settling area of the basins. However, observations from field and laboratory studies indicate that settling basins with recirculation zones and secondary currents within the defined effective surface area of the settling chambers are less efficient than predicted. The geometry and inflow conditions have a strong influence on the water velocity distribution and the turbulence levels in the settling basins. The influence of the geometry can be difficult to implement as one-dimensional parameters in the analytical approaches. The technology of computation fluid dynamic (CFD) calculations is well-known, and has also been used for engineering purposes in the hydro power industry for more than a decade (Groeneveld 1999). Today, the computational tools provide for reasonable calculation time and the opportunity to benefit from these powerful computational tools for the design of settling basins.

The motivation for the current study is to assess the performance of settling basins based on CFD calculations of the flow patterns and the corresponding turbulence characteristics, without including the complex sediment transport in the CFD models. The results from the CFD calculations are used to adjust and improve the input parameters used in the commonly used trap efficiency calculation methods. This new approach is tested on the hydraulic physical model of the settling basins of the Lower Manang Marsyangdi Hydropower Project built at the Hydro Lab Pvt. Ltd. in Kathmandu, Nepal.

In this paper, the governing characteristics affecting the trap efficiency of sediments in a settling basin are described, followed by a chapter on design principles and existing trap efficiency calculation methods, before the new approach for assessing the settling basin performance is presented and tested on a case study.

Flow Characteristics Affecting the Trap Efficiency

Suspended particles are primarily carried with the water flow, and transported with a velocity more or less equal to the ambient water velocity (Hazen 1904). The gravity force draws the particles downwards, with a resulting fall velocity, w, whereas the turbulence motion of the water flow tends to lift the sediment particles. The trap efficiency of a settling basin depends on the velocity field distribution and the turbulence level.

A turbulence characteristic that can be measured directly is the turbulent kinetic energy, k, of the fluctuating motion in three directions, *i*, *j* and *k* at a given point in the flow (Rodi 1980):

$$k = \frac{1}{2}\left(u'^2_i + u'^2_j + u'^2_k\right)$$

Where u' is the velocity fluctuation. The turbulent kinetic energy, k, describes the energy in the turbulent eddies.

The turbulent fluctuations in the water may be described by the stress tensor component, the Reynolds stresses, $\overline{u_i' u_j'}$, where u' is the velocity fluctuation in a given direction i and j (Nezu and Nakagawa 1993). Boussinesq (1877) introduced the eddy-viscosity, ν_T, (in an analogy to the viscous stresses in the laminar flow) for modeling the turbulence. The eddy-viscosity concept is based on the turbulent stresses (the Reynolds stresses) being proportional to the mean-velocity gradients (Nezu and Nakagawa 1993).

$$-\overline{u_i' u_j'} = \nu_T\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}k\delta$$

where δ_{ij} is the Kronecker delta and *k* the turbulent kinetic energy (Eq.1.2). The eddy-viscosity, ν_T, characterizes the transport and dissipation of energy in the smaller scale flow, and is assumed to be essential for suspended particle transport. The eddy-viscosity, ν_T, depends on the velocity field and turbulence, and it varies significantly from point to point in a flow. According to Rodi (1980), the eddy-viscosity concept is still the basis for most turbulence models, and has successfully been used in many practical calculations. The eddy-viscosity cannot be measured directly. Nevertheless, according to Keefer (1971), the depth average eddy-viscosity for natural, uniform rivers can be approximated by:

$$\nu_T = 0.11 \cdot U_* \cdot H$$

Where U_* is the shear velocity and H is the water depth. The shear velocity scales the turbulence in uniform open-channel flows (Nezu and Nakagawa 1993), and is regarded as the most fundamental scaling parameter for uniform open-channel flows. The shear velocity is also difficult to measure directly, but there exist several methods for estimating U_* in hydraulic research (Rowiński, Aberle et al. 2005). For uniform rivers, a simplified method for the estimation of the shear velocity is done by use of the energy slope, S_e, in the canal and the hydraulic radius, R_h:

$$U_* = \sqrt{gR_h S_e}$$

The energy slope for uniform rivers can be estimated from the Manning's formula where:-

$$S_e = \left(\frac{Qn}{AR_h^{2/3}}\right)^2$$

Q is the water discharge, A is the cross section area and n is the Manning's friction factor which needs to be estimated. This simplified method for finding U_* is commonly used for settling basin trap efficiency calculations, but is not accurate for more complex flow situations. The recirculation zones in a settling basin contribute to maintaining suspended sediment particles in motion, since the suspended particles has more or less the same velocity as the ambient water flow. The governing parameter defining the turbulence level in conventional settling basin trap efficiency calculations is the shear velocity, U_* (Camp 1946;Vanoni 1975; Garde et al. 1990).

Design Principles and Trap Efficiency Calculation Methods for Settling Basins

The settling basin must be designed to reduce the turbulence level in the water flow so that the sediment particles will settle. Favorable flow conditions are slow transit velocity, u_t, through the basin, an evenly distributed flow without any recirculation zones or secondary currents and low turbulence effects. The net effective surface area, A_s, of the settling basins shall only include the area of the basin where the flow is evenly distributed over the width and depth in the water body. The performance of a settling basin is mainly governed by the geometry of the basin, namely the size and the shape (Lysne et al. 2003).

There are three main analytical approaches for the hydraulic design of settling basins, all based on one-dimensional equations and evenly distributed flow. Suspended particles in rivers have a fall velocity, w, in stagnant water that is primarily dependent on the submerged weight and the size and form of the particle, but also on the temperature and viscosity of the water (Vanoni 1975). The ideal particle approach of Hazen (1904), for no turbulence, requires the ratio between the fall velocity, *w*, and the average horizontal velocity in the basin, u_t, to be equal or larger than the ratio between the depth of the basin, *H*, and the length of the basin, *L*,:

$$w = \frac{Hu_t}{L} = \frac{Q}{A_s}$$

Note that the effective surface area, A_s, is the governing parameter in the expression of the velocity ratio, and A_s is therefore important in trap efficiency calculations. Camp (1946) and Dobbin's (1944) method also includes the influence of turbulence in the water flow, described by a variant of the Rouse number (Rouse 1937); w/U_*. A reduced turbulence level, and hence an increased Rouse number, increases the trap efficiency, η. Moreover, the Camp-Dobbin diagram is widely used for design purposes today.

The second design approach is the concentration approach which assumes fully mixed conditions. Vetter's method is presented in Vanoni (1975) and the trap efficiency is defined as:

$$\eta = 1 - e^{-\frac{wA_s}{Q}}$$

Garde et al. (1990) compared their own experimental data of trap efficiency and experiments from Singh (1987), with the existing Camp-Dobbins' relation (Dobbins 1944; Camp 1946), the U.S.B.R relationship (Vanoni 1975) and the Sumer relationship (1977). All the computed efficiencies, η, were much larger than actually measured efficiencies for finer particles. In an attempt to improve the efficiency calculation, Garde et al. (1990) developed a new, exponential relationship:

$$\eta = \eta_0 \left(1 - e^{-\alpha L/H}\right)$$

where η_0 is the limiting trap efficiency and α a coefficient, both obtained from diagrams for a given w/U_* ratio. Methods for including geometry parameters are suggested by Raju et al. (1999) and Ortmanns (2006), and both methods improved the trap efficiency calculations for some cases.

A third method for sediment concentration calculations through settling basins is to divide the settling basin into cells and use a two-dimensional discretization scheme to solve the diffusion-convection equation, Eq. 1.9 (Patankar 1980):

$$u_i \frac{\partial c}{\partial x_i} + w \frac{\partial c}{\partial z} = \frac{\partial}{\partial x}\left(\nu_T \frac{\partial c}{\partial x_i}\right)$$

The sediment concentration, c, in all the cells throughout the basin are calculated as a weighted average of the sediment concentration in the neighboring cells (Olsen 2012). The convective sediment concentration fluxes, caused by the mean water velocity and the fall velocity of the sediment particles, are given on the left side of Eq. 1.9. The diffusive fluxes, caused by the turbulence and the velocity gradients are given on the right side of the equation. The water velocity distribution and turbulence field in the vertical direction, the horizontal velocity, u_i, and the eddy-viscosity, ν_T, are considered to be constant in the entire basin. Therefore, the same weighted average factors can be used for all the cells in a discretization scheme. The use of constant weighted average factors is common practice in sediment concentration calculations of settling basins today, but is not accurate as the ν_T may differ significantly throughout the flow field (Olsen 2012).

A number of numerical models have been proposed for more refined settling basin design assessment, among others: Stamou et al. (1989), Adams and Rodi (1990), Atkinson (1992), Olsen and Skoglund (1994), Olsen and Kjellesvig (1999), Dufresne, Dewals et al. (2011) and Shrestha (2012). The overall conclusion is that CFD models can be used to assess a settling basin design, but that the sediment transport is very complex.

A New Approach for Assessing Settling Basin Performance

A new approach for assessing settling basin performance is tested on a case study of the physical model of the settling basins of the Lower Manang Marsyangdi HPP. The commercial CFD code STAR CCM+ is used to assess recirculation zones and the effective surface area of the settling basin, A_s, in addition to the eddy-viscosity, ν_T, and the shear velocities, U_*. The numerical values for A_s, U_* and ν_T, are used as input parameters to the Camp-Dobbins diagram for trap efficiency, the Vetter's method, and in the discretization schemes for solving the diffusion-convection equation for sediment concentration. The goal is by use of parameters from the CFD models to obtain more accurate predictions of the trap efficiency for settling basins with the conventional design tools for settling basins.

Physical Model Set-up

A 1:40 physical scale model of the settling basins of the planned 144 MW Lower Manang Marsyangdi Hydropower Project (LMM HPP) has been constructed at the Hydro Lab Pvt. Ltd, Kathmandu, Nepal (Figure 1). There are eight submerged inlets divided on two separated settling basins that are designed for a total discharge of Q = 57m³/s. The Froude scaling law gives a corresponding discharge in the physical model equal to 0.0056 m³/s.

The sediment loaded water enters through submerged inlet gates, flows through the gravel traps, and then through a pressurized approach section before entering into the settling basins. The length of the settling basins with its full width is L=160 m in the prototype and L=4.0 m in the model scale. The width, B, of the model is B = 0.875 m. The water depth, H, in the settling basin during the measurements was maintained at H=0.345 m, corresponding to H=13.51 m in the prototype. The water discharge through the settling basin was measured

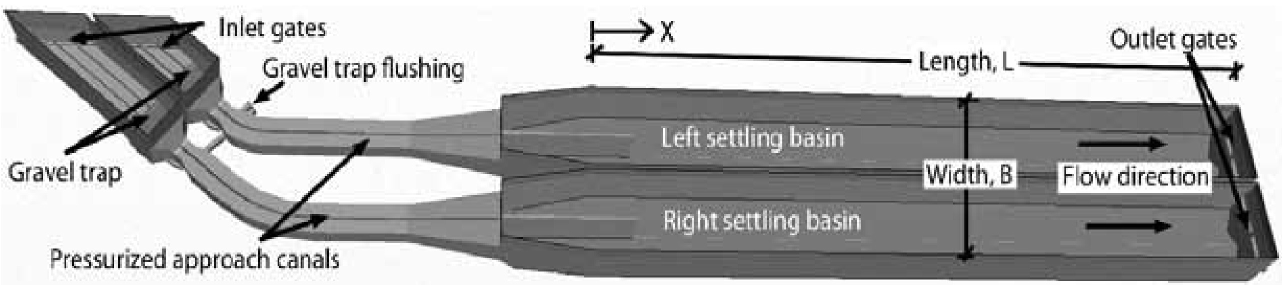

Figure 1. Proposed settling basins on the physical model of LMM HPP.

at the downstream outlet with a V-notch gauge. The average velocity, $\overline{u_t}$, in the settling basin chambers during the measurements was u=0.022m/s, and the average Reynolds number in the physical model is $Re = \frac{UR_h}{\nu} \approx 2900$, (larger than 750, hence fully turbulent as in the prototype where Re=7*10^5).

Velocity and turbulence measurements in the settling basins were taken with a Sontek 16-MHz side-looking 3D MicroADV (SonTek 2013) at six cross sections, with 18 point measurements at each cross section. The measurements were taken for 60s with a sampling rate of 50 Hz. The velocity distribution over the eight inlets was measured with a Mini Air 20 Micro propeller (Omni 2013) at the left, center and right side of each of the eight inlets since ADV measurements were not possible because of the shallow flow. The model is built of Plexiglas and painted plywood. The Manning's number is assumed to be n=1/110=0.009, and the value corresponds to n = 1/60 = 0.017 in the prototype. The Manning's value normally used for acrylic materials is in the range (0.009-0.01), and the value n = 0.009 is the lowest recommended value for smooth, non-metal surfaces in the Manning's value table in Chow (1959). The value n = 0.017 is representing the roughness of concrete canals with gravel on the bed. Note that the low Manning's number for the physical model is exceeding the valid range for the Manning's formula, whereas for the prototype the chosen value may be too coarse. The Manning's values for the settling basin in physical models are difficult to verify because the decrease in the energy line is very small. In this study, the decrease was within the measuring limitations, and n is therefore only assumed.

Numerical Model Set-up

The commercial program STAR CCM+ was used to solve the Reynolds Average Navier-Stokes equation for the water body of the physical model of the settling basins. A 3D implicit unsteady solution, in which the water surface is calculated with the Volume of Fluid (VOF) method, was chosen. Based on a grid sensitive test, a grid with 2.0 million rectangular cells was used. A refinement of the grid was done at the inlet, the outlet, at the water surface and at the entrance to the approach canals.

Three different turbulence models were tested in order to assess the sensitivity, namely the standard k-[ε model, a standard k-ω method and the complex and computational time costly Reynolds stress transport model (CD-adapco 2013). The inlet boundary conditions were set to 'velocity inlet' with velocities obtained from the propeller measurements at the physical model. The outlet boundary was set to 'pressure outlet' with a pressure level according to the measured water level at the outlet. The top of the model was set to pressure outlet with pressure equal to atmospheric pressure. For the boundary condition for the bottom and the walls, a sensitivity analysis of the boundary roughness was conducted. Plexiglas and painted plywood has relatively smooth surfaces. The impact of the selected wall law equations was tested with a smooth wall compared to a low roughness r = 0.0001m. The effect of an absolute roughness r = 0.001m, which is rougher than 'rough concrete' according Colebrook (1939), was also tested. The model runs with different wall roughness values were performed on set-ups with the k-ε turbulence model. The impact of the three turbulence models, was tested on model set-ups with wall roughness r = 0.001m.

The velocities and the turbulent kinetic energy, k, in the points corresponding to the location of the ADV measurements were extracted for a converged solution. Velocities were extracted at the same rate as the ADV measurement: 50 data sets every second in the solution time, over a period of 60 seconds.

Results

The results from the CFD models are compared with the measurements at the physical model. The extracted turbulence characteristics from the CFD models are compared to values obtained from one-dimensional equations. The calculated trap efficiencies of the settling basins with the standard methods were then compared for calculations with and without adjusted input parameters from the CFD calculations.

Compared Velocity Field

The velocity field in the physical model, measured with ADV, was compared to numerically calculated velocities in STAR CCM+. The velocity field at a height z/H=0.53 for a simulation with k-ε model and r=0.001m is shown in Figure 2. At the upstream end of the settling basins, the velocity field was unevenly distributed. The calculated velocities are comparable with the measured velocities in the downstream end of the settling basins, whereas at the upstream part of the settling basins more discrepancy was observed between the measured- and the calculated velocities.

ADV measurements compared with CFD results

The discrepancy at the upstream end might be due to recirculation zones where velocities vary strongly over the cross section. Hence, any inaccuracy in the location of the ADV measurements may cause change in the velocity. The velocities were averaged over 60 seconds, and a longer time series would also possibly have an impact on the results, as the prototype as well as the CFD calculations are unsteady and change over time. In order to assess the recirculation zones, the cross stream velocities were studied at given location in the length of the flow direction, x/H (see Figure 3).

The ADV measurements (black lines) show a clockwise cross stream current in both chambers. The CFD model suggests the same flow pattern, although the velocity vectors in the points are not identical. The recirculation zones in the upstream part of the settling basins are also visualized at the plan view velocity plot at z/H = 0.53 in Figure 4, where the velocities are unevenly

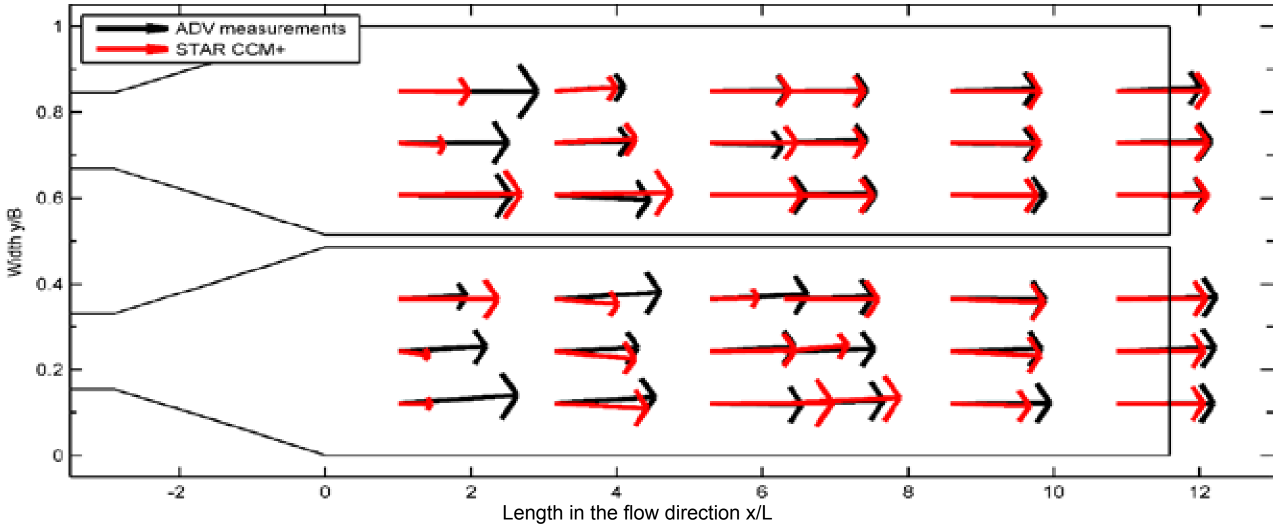

Figure 2. Velocity field, plan view at z/H = 0.53,

distributed. The effective surface area, A_s, is defined to be the area where the velocity distribution is close to being evenly distributed, though the definition "close to evenly distributed" is vague. A_s should not include any

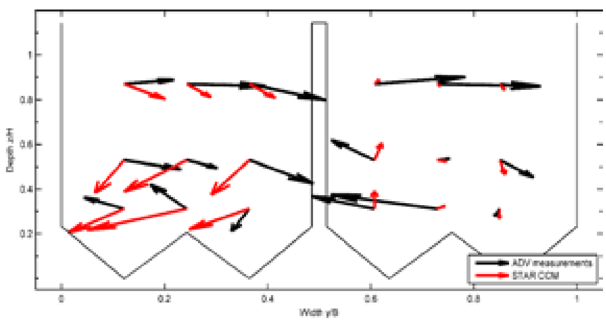

Figure 3. Cross sectional velocity field at the length in the flow direction x/H = 3.1. ADV measurements compared with the results from CFD model.

recirculation zones, nor any cross flow currents. The theoretical effective surface area is $A_s = L \times B$.In Figure 4, a suggested effective surface area A_s on a velocity plot at z /H=0.53 is marked.

Based on a rough graphical assessment of the effective surface area where no velocities are higher than 2 x u_t , the actual A_s seems to be approximately 67% and 62% of the theoretical A_s of the left- and right settling basins, respectively. Two times the u_t was a first attempt to define a criteria for A_s, but the criteria could also be related to a specified level of the turbulent kinetic energy. The definition of the criteria for A_s should be verified in further research. Nonetheless, the CFD tool is useful for comparing different designs, as well as adjusting the effective area, A_s, used for trap efficiency calculations.

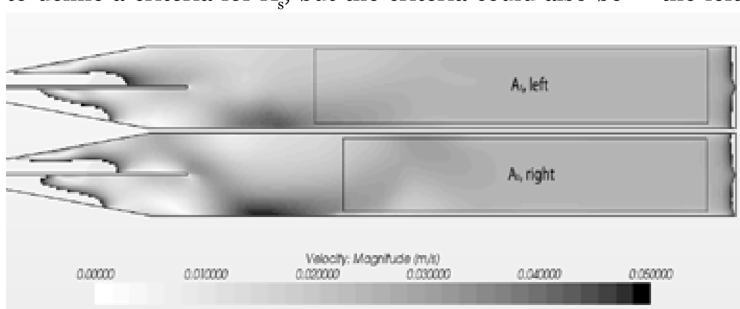

Figure 4. Plan view velocity plot of the settling basins, z/H=0.53. A suggested effective surface area, As, based on the CFD calculations of the velocity field is sketched.

Compared Turbulent Kinetic Energy

The turbulent kinetic energy, k, decreases as the flow propagate through the settling basin. The calculated values for k are compared to the measured k in both the right- (o makers) and left (diamond markers) settling basins in the physical model. The sensitivity to the chosen wall roughness, r, and different turbulence model is shown in Figure 5 (a) and (b), respectively.

Both the ADV measurements and the CFD calculations show that the turbulent kinetic energy decreases as the flow propagates through the basins. The variation between the calculated k-values obtained from the different turbulence model is caused by the different equations used for estimation of the Reynolds stress term in the Navier-Stokes equation. Differences in the Reynolds stress term will give slight differences in the velocities, the velocity gradients and hence also in the turbulent kinetic energy. However, the calculated values for turbulent kinetic energy correspond well with the measured values. Corresponding to the measurements and the calculations, the k is higher in the right than in the left settling basin, especially in the first half of the settling basins. There are higher velocities at the entrance to the right basin, than in the left basin, which is caused by slightly higher water discharge. Higher pressure in the outer bend may cause a higher energy gradient in the right approach canal with the largest bend, and hence higher discharge, velocities and k-values. As expected, the choice of turbulence models seems to be more important than the choice of wall roughness value. The simulations with different turbulence models give slightly larger variations in the calculated k-values than the

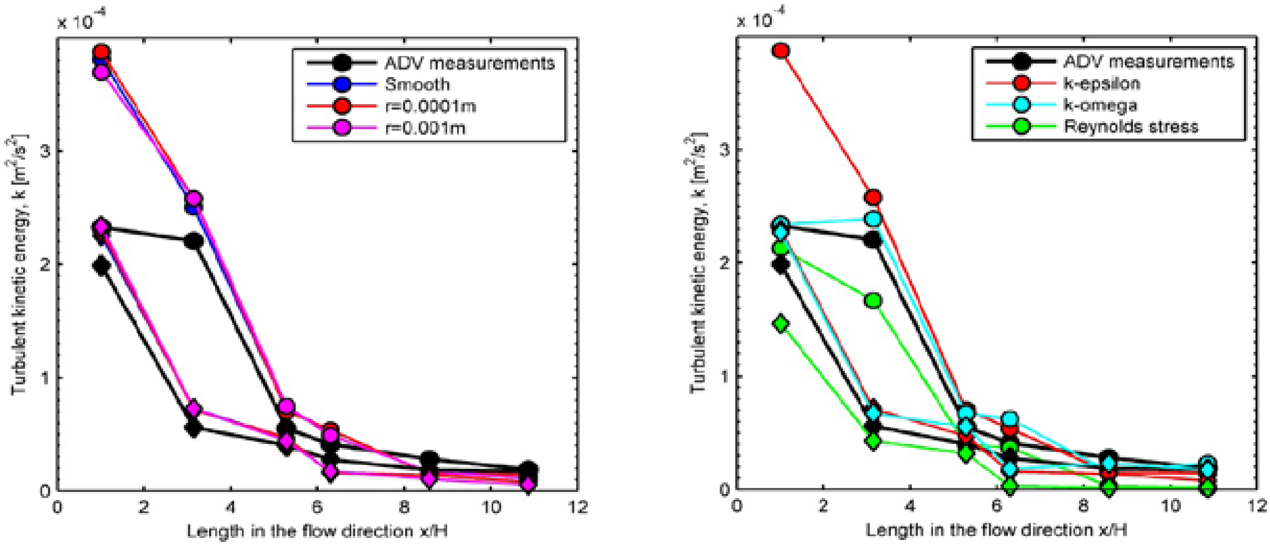

Figure 5. Development of the turbulent kinetic energy, *k*, in the right- (o) and left (diamonds) settling basins; (a) Sensitivity to the roughness value,(b) Sensitivity to the turbulence model.

simulations with different roughness values. However, the comparison between the computed and measured turbulent kinetic energy shows that the CFD model can predict the turbulence level with a reasonably high degree of accuracy.

Extracted Turbulence Characteristics from the CFD Models

The common parameter for scaling turbulence, the shear velocity U, is complicated to measure, and no near-bed velocity measurements were taken at the physical model of the LMM HPP. However, an average of the U_* was extracted from the CFD model between six cross sections throughout the settling basin (both basins included) as shown in Figure 6.

In contrast to the simplified one-dimensional value for the shear velocity, U_* (Equation 1.5), the numerical values for U_* shows the same decreasing pattern throughout the settling basin as the measured turbulent kinetic energy. There are some variations in the calculated U_* values between the different turbulence models, which is due to the differences in the Reynolds stress term, which result in slight difference in the velocities and hence also in the shear velocities. The trend is that the calculated values are in the range of 4.1 - 5.1 and 1.6 - 2.1 times the U_* obtained from Eq. 1.5, at the entrance and the downstream end of the settling basins, respectively. The significantly higher values for U_* from the CFD model compared to Eq. 1.5 are later used as input values to the trap efficiency calculations.

The turbulence parameter used to solve the convection-diffusion equation (Eq.1.9) in the numerical schemes for sediment concentration calculations is the eddy-viscosity, V_T .Equations 1.4 and 1.5 yield the simplified one-dimensional value for V_T in the settling basin in the LMM physical model equal $V_T = 3.15\times10^{-5}\,m^2/s$. Based

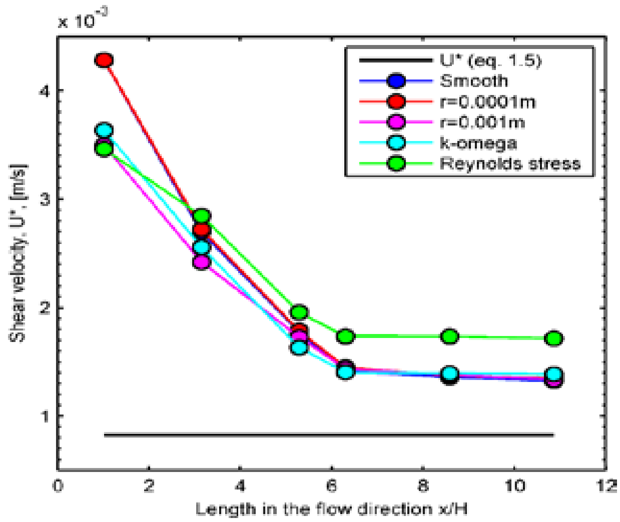

Figure 6.The shear velocity, U_* , through the settling basin for different CFD models, compared to the shear velocity from eq. 1.5.

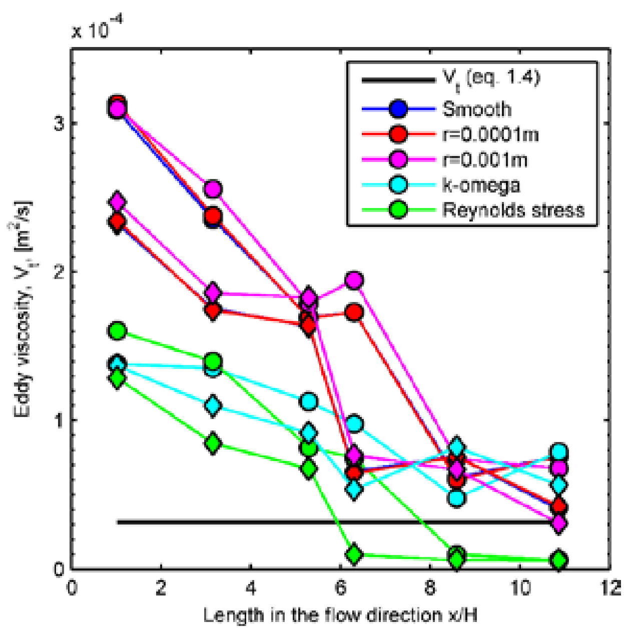

Figure 7. Development of the eddy-viscosity in the right (o) and left (diamonds) settling basins. The calculated values are compared to the eddy-viscosity from eq. 1.4.

on the CFD calculation, the eddy-viscosity also decreases downstream through the settling basin (Figure 7), with a higher value in the right than in the left basin, as for the k, caused by the different design of the approach canals.

The calculated V_T values are higher than the simplified one-dimensional value for V_T ranging from 10.0 to 4.1 times at the entrance to the settling basins, and ranging from 2.5 to 0.2 times at the downstream end. Furthermore, the different turbulence models used in the CFD calculations have a significant influence on the eddy-viscosity result, as for the k-values, because of the differences in the Reynolds stress term, the velocity gradients and hence also the eddy-viscosity.

The Effect on the Trap Efficiency Calculations

The impact from the CFD calculated values on the calculated trap efficiencies is assessed below. The settling basin at the Lower Manang Marsyangdi HPP is designed to trap 90% of sediment particles up to a grain size of 0.2mm and at water with temperature 10°C, the fall velocity for coarse silt fraction is w=0.02 m/s (Rouse 1937). The corresponding critical fall velocity in the physical model is w=0.003 m/s. With U_* from Equation 1.5, the corresponding value for the turbulence level as described by the Rouse number is $w/U_* = 3.8$. The value is high and indicates low turbulence and high trap efficiency. The higher values for U_* from the CFD models, Figure 6, decrease the Rouse number to 0.7-0.9 at the entrance and 1.7-2.3 at the downstream end. The estimates from the CFD results for the effective surface area, A_s ,reduce the velocity ratio $\frac{wA_s}{Q}$ from 1.98 to 1.32 and 1.23 for the left-and right settling basins, respectively.

Calculations of the sediment concentration from the convective-diffusive equation (Eq. 1.9) were performed for three cases; the standard method with constant V_T from Eq. 1.4, one with adjusted V_T values for each section of the settling basins, based on the CFD model and with both an adjusted V_T and reduced effective surface area, As. The inlet concentration is assumed to have an even distribution of 2,000 ppm at the upstream end of the effective surface area, A_s . The concentrations results are compared in Figure 8.

As shown in Figure 8, the sediment concentrations are higher at the downstream end of the settling basins for the calculations with V_T values and As extracted from the CFD-model than for the standard method with a constant V_T . The reduced effective surface area, As, seems to have more of an effect on the sediment concentration than the eddy-viscosity, V_T .The results from the convection-diffusion could possibly be more accurate if also local velocities from the CFD-model were included. The actual sediment concentrations have not been validated with measurements, but this should be done in further research.

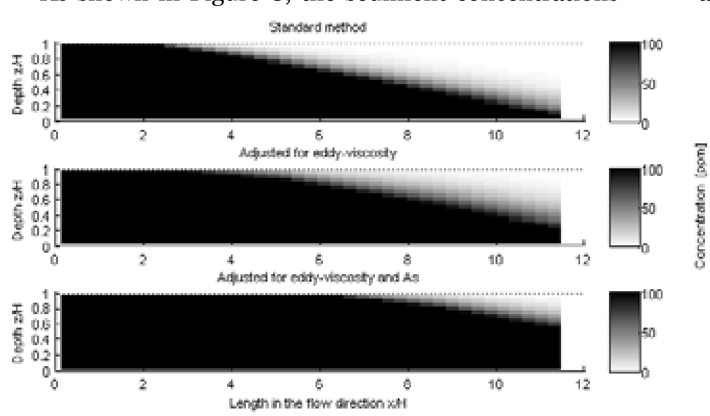

Figure 8. Sediment concentration through the settling basin (a) constant eddy-viscosity(b) eddy-viscosity from the CFD-model,(c) Eddy-viscosity and effective surface area, As, from the CFD-model.

The results for the calculated trap efficiencies with the use of standard methods, although with adjusted effective surface area, As, eddy-viscosity, V_T , and turbulence level, w/U_* , extracted from the CFD-model are summarized in Table 1.

Uniform flow		CFD adjustment for non-uniform flow	
		Left	Right
Camp-Dobbins Method	100%	100%	99%
Vetter's Method eq. 1.7	86%	73%	
Gardeet al. eq. 1.8	93%	91%	
Convection-diffusion eq. 1.9	99%	Adjusted V_T : 98% Adjusted V_T , A_s : 95 %	

The calculated trap efficiency has been slightly reduced for all the different conventional calculation methods with adjusted input parameters from the CFD model.

Table 1. Trap efficiency calculations for LMM settling basins. Results with the use of simplified, one-dimensional turbulence parameters compared to results with the use of turbulence parameters adjusted from the CFD results.

Conclusions and Recommendations

The new approach for assessment of settling basins design presented in this paper is straight forward and promising. The geometry has a strong influence on the settling basins performance, and the CFD-models provide for additional information on the effective surface area and the turbulence characteristics for a given design. This study demonstrates that detailed information on velocity fields and the shear velocity, U_* , and the eddy-viscosity, V_T , can efficiently be calculated with available CFD-tools. Although, no sediment concentration measurements are available to validate the calculated trap efficiency, it is clear that an increased accuracy of the turbulence characteristics will increase the accuracy of the trap efficiency calculations with standard methods. For future research, sediment concentration measurements are recommended in combination with ADV measurements.

The study shows that the CFD-models can predict the velocity fields as well as the turbulent kinetic energy in the settling basin provided that a sufficiently fine grid resolution is achieved, and the time averaged values for the velocity field are preferred. The model is not very sensitive to the wall roughness, but is more sensitive to the selected turbulence model. Nevertheless, all the CFD-models are evaluated to be within a reasonable level of uncertainty. The CFD-calculated shear-velocities, eddy-viscosities and effective surface areas for the LMM HPP settling basins differ significantly from the simplified one-dimensional values assuming a uniform flow. By including a reduced effective surface area and the turbulence characteristics obtained from the CFD-models, the calculated settling basin trap efficiency is slightly decreased with the use of all of the standard calculation methods. The assessment of the turbulence, any recirculation zones and the effective surface area, As, are all essential for the optimal design of settling basins. CFD calculations can provide for valuable additional information to the standard methods for computing trap efficiency and an assessment of the performance of settling basins for hydropower plants.

_ _

Acknowledgments

The writers wish to thank Hydro Lab Pvt. Ltd. for construction of the physical model and for all their technical assistance during the measurements. We also wish to thank the Butwal Power Company (BPC) for providing us with data and for agreeing to publish the results.

Hanne Nøvik *MSc graduated in civil engineering from the Norwegian University of Science and Technology (NTNU) in 2007. She worked as a project engineer with planning of hydropower and hydraulic design for the consulting company, Sweco Norge AS, and for the Hydropower Company BKK Produksjon AS before she started her PhD on "Intake Hydraulics and Intake Design for Small Hydropower Plants" in 2010. From 2014 she will work in Multiconsult AS.*
Corresponding address: hanne.novik@ntnu.no

Abha Dudhraj *recently completed her MSc in Civil Engineering with specialization in hydropower development from NTNU, and is currently working as a hydropower engineer in a Norwegian water management Association company, Glommensog Laagens Brukseierforening (GLB).*

Nils Reidar B. Olsen *PhD, is Professor in Hydro mechanics at the Department of Hydraulic and Environmental Engineering of the NTNU, Trondheim, Norway. He completed his Dr. Ing. degree on 3D numerical modeling of water and sediment transport in 1991 and has since then continued to work on this topic. This has resulted in about 40 peer-reviewed articles in international journals. Prof. Olsen has worked on sediment projects in a number of countries, including Nepal, Zimbabwe, Pakistan, Costa Rica, USA, Switzerland, Germany and Austria.*

Dr. Ing. Meg B. Bishwakarma *is a hydraulic engineer and since last 8 years he is serving Hydro Lab Pvt. Ltd. as the General Manager. Prior to joining Hydro Lab in 2001, he worked with Butwal Power Company Ltd. in Nepal for about 12 years involving in the design, construction supervision, overall management and administration of different hydropower projects in Nepal. He has published more than 16 articles and papers in national and international journals and conference proceedings.*

Leif Lia, *PhD, is Professor in Hydro Power Structures at the Department of Hydraulic and Environmental Engineering of the NTNU, Trondheim, Norway. His main expertise is hydro power engineering and he has nearly 20 years of experience from planning, engineering and research in the topic.*

References

Adams, E. W. and W. Rodi (1990). "Modeling flow and mixing in sedimentation tanks." Journal of Hydraulic Engineering 116 (7): 895-913.

Atkinson, E. (1992). The desgin of sluiced settling basins. - A numerical approach. Rep. OD 124, Overseas Development Unit. HR Wallingford, UK.

Boussinesq (1877). "Turbulence models."

Camp, T. R. (1946). "Sedimentation and the Design of Settling tanks." Trans. ASCE, Vol III: pp. 895-936.

CD-adapco (2013). "User Guide STAR-CCM+ Version 8.02.008."

Chow, V. T. (1959). "Open-channel Hydraulics." McGraw-Hill Book Company, New York.

Colebrook, C. F. (1939). "Turbulent Flow in Pipes with Particular Reference to the Transition Region between the Smooth and Rough Pipe Laws." Journal of Institution of Civil Engineering 11: 133-156.

Dobbins, W. E. (1944). "Effect of turbulence on sedimentation." Trans. ASCE, Vol I 109: pp. 629-653.

Dufresne, M., et al. (2011). "Numerical investigation of flow patterns in rectangular shallow reservoirs." Engineering Applications of Computational Fluid Mechanics 5(2): 247-258.

Garde, R. J., et al. (1990). "Design of settling basins." Journal of Hydraulic Research 28(1): 81-91.

Groeneveld, J. (1999). "Computer Simulation Leads to Faster, Cheaper Options." Water Engineering and Management 146(6): 14-17.

Hazen, A. (1904). "On Sedimentation." Trans. ASCE, Vol. 53, paper 980.

Keefer, T. N. (1971). The relation of turbulence to diffusion in open-channel flows, Colorado State Univeristy. PhD thesis.

Lysne, D. K., et al. (2003). Hydraulic Design Hydropower Development. Trondheim, Norwegian University of Science and Technology. Vol 8.

Nezu, I. and H. Nakagawa (1993). "Turbulence in open-channel flows." Turbulence in open-channel flows.

Olsen, N. and M. Skoglund (1994). "Three-dimensional numerical modeling of water and sediment flow in a sand trap." Journal of Hydraulic Research 32 (6): 833-844.

Olsen, N. R. B. (2012). "Numerical Modelling and Hydraulics." Department of Hydraulic and Environmental Engineering, NTNU, Trondheim.

Olsen, N. R. B. and H. M. Kjellesvig (1999). "Three-dimensional numerical modelling of bed changes in a sand trap." Journal of Hydraulic Research 37(2): 189-198.

Omni (2013). "Data sheet MiniAir20 Mico Propellar." Retrieved 9/10/2013, from http://www.omniinstruments.net/flow-meters/air-flow-probes/miniair-20-portable-vane-anemometer-with-display. html.

Ortmanns, C. (2006). Entsander of Water power concern. Entsander von Wasserkraftanlagen. PhD thesis: v-210.

Patankar, S. V. (1980). "Numerical heat transfer and fluid flow." McGraw-Hill Book Company, New York.

Ranga Raju, K. G., et al. (1999). "Sediment removal efficiency of settling basins." Journal of Irrigation and Drainage Engineering 125(5): 308-314.

Rodi, W. (1980). Turbulence models and their application in hydraulics: A State-of-The-Art Review. T. F. Group, Institut für Hydromechanik, University of Karlsruhe.

Rouse, H. (1937). "Modern conceptions of the mechanics of fluid turbulence." Trans. ASCE, Vol. 102: pp. 463-554.

Rowiński, P. M., et al. (2005). "Shear velocity estimation in hydraulic research." Acta Geophysica Polonica 53(4): 567-583.

Shrestha, B. V. (2012). 3D Numerical Investigation on Settling Basin Layout. Department of Hydraulic and Environmental Engineering. Trondheim, Norway, Norwegian University of Science and Technology. MSc thesis.

Singh, K. K. (1987). Experimental Study of Settling Basins. Dept. of Civil Engineering, University of Roorkee, India. MSc thesis.

SonTek (2013). "Data sheet 16-MHz MicroADV." Retrieved 8/20/2013, from http://www.sontek.com/pdf/expdes/MicroADV-Expanded-Description.pdf.

Stamou, A. I., et al. (1989). "Numerical modeling of flow and settling in primary rectangular clarifiers." Journal of Hydraulic Research 27(5): 665-682.

Sumer, B. M. (1977). "Settlement of solid particles in open-channel flow." ASCE J Hydraul Div 103(11): 1323-1337.

Vanoni, V. A. (1975). "Sedimentation engineering." ASCE (Manual 54).

Continued from page 48

Lieke Melsen *obtained her BSc and MSc at Wageningen University, the Netherlands, in the field of Hydrology. As part of her Masters, she spent four months at the Nepal Engineering College to work on the project of Water Security in Peri-urban South-Asia. Currently, she is working as a PhD-student on parameter identification in hydrological models, at Wageningen University.*

References

Baidya, S. K., Shrestha, M. L., and Sheikh, M. M.,2008, Trends in daily climatic.

extremes of temperature and precipitation in Nepal, Journal of Hydrology and Meteorology, 5:38-51.

CBS (Central Bureau of Statistics), 2012, National Population and Housing Census 2011(Village Development Committee/Municipality), Government of Nepal, Kathmandu, Nepal.

Chaulagain, N. P., 2006. Impacts of Climate Change on Water Resources of Nepal: The Physical and Socioeconomic Dimensions. Msc thesis, University of Flensburg, Flensburg, Germany.

ICIMOD (International Center for Integrated Mountain Developmpent), 2007, Kathmandu Valley Environment Outlook. Ministry of Environment, Science and Technology (MoEST) and United Nations Environment Programme (UNEP), Kathmandu, Nepal.

Joshi, N. P., Maharjan, K. L. and Piya, L.,2011, Effect of climate variables on yield of major food crops in Nepal,Journal of Contemporary India Studies: Space and Society (1):19-26.

Narain, V. and S. Nischal, 2007. The peri-urban interface in ShahpurKhurd and Karnera, India, Environment and Urbanization, 19(1): 261-273.

Practical Action, 2009, Spatial and Temporal Variability of Climate Change Over Nepal (1976-2005), Kathmandu, Nepal.

Pradhan, P. and Perera, R., 2005, Urban growth and its impact on the livelihoods of Kathmandu valley, Nepal,Urban Resource Network for Asia and Pacific (URNAP), Urban Management Programme for Asia and the Pacific (UMP) Occasional Paper No. 63 (Thailand).

WECS (Water and Energy Commission Secretariat), 2011, Water Resources of Nepal in the Context of Climate Change, Government of Nepal, Kathmandu. Nepal.

WMO (World Meteorological Organization), 1966, Climate Change. Technical Report, 79.