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RESEARCH ARTICLE

DESIGNING OPTIMAL OPEN CHANNEL BASINS FOR SEDIMENT REMOVAL

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ABSTRACT

In this paper the basic theory and approach to optimize the size of desilting basin with open channel flow is summarized. A comparison has been done for the ideal and practical basins where the effect of turbulence is taken into account. Where the space is not a constraint, there is a problem of choosing the longer, wider and shallower basins in front of the designers. The same has been illustrated with the help of the examples. Also the need for efficient inlet divergence for distributing the inflow and suspended sediments uniformly is suggested, the hydraulic efficiency of which can be best judged on models. The scope is limited to gravity sedimentation – i.e. to settling out discrete particles which retain their individual settling characteristics without interference or flocculants effects. Discussion is limited to horizontal flow basins.

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INTRODUCTION

A river carries a substantial quantity of sand and finer particles in suspension, this material cannot practically be excluded at the intake. A settling basin, in which the velocity of the off taking flow is reduced to enable the suspended sediment i.e. sand and heavier silt load to settle out under gravity, is used in such circumstances to reduce the sediment load in the downstream system. The river intake installations, where desilting basins are commonly used are as follows:-

i) In irrigation schemes, to reduce the sediment load to a level which can be mainly transported by the distribution system through to the fields, thus mitigate the problems of sediment deposition in the canals. (The sediment transport capacity of irrigation canals is often restricted due to the flat water surface slopes needed to maintain command.)
ii) In Hydropower schemes, to reduce the sediment load to acceptable levels from the viewpoint of (a) sediment transport capacity of the supply system to the power station and, (b) damage to machinery.

In this paper the basic theory and approach to optimize the size of desilting basin with open channel flow is summarized. The scope is limited to gravity sedimentation – i.e. to settling out discrete particles which retain their individual settling characteristics without interference or flocculants effects. Discussion is limited to horizontal flow basins. Operation of desilting basin and method of removal of sediment deposits from the basin have also not been discussed here.

METHODOLOGY

This paper is based on literature available for design optimization of desilting basin along with the analytical calculations for various combinations of its dimensions. The outcome from physical modeling for desilting basins regarding the inlet arrangement and some innovative solutions are also presented in this paper. This outcome helps the designer to decide the optimum dimensions of desilting basin to be provided as per the existing site conditions.

Ideal Desilting Basin: Initially, the desilting basins were designed on the basis of detention periods. These detention periods along with rate of inflow determined the volume of the desilting basin and taking into consideration the space available, the size of tank i.e. length, width and depth used to be fixed up. However, Hazen presented theory as early as in 1904 that the removal of suspended matter depends upon surface area and not upon tank volume. Later on Camp, Lamble, etc. also stressed the above views and have given theoretical equations in its support. Thus, the shallow tank having the surface area equal to the deeper tank is equally effective in removal of suspended sediment. Since the forward velocity in the shallow tank is more than in deeper tank and as the settlement is function of fall velocity to forward velocity, the above hypothesis appear to be incorrect at its face value though proved by theory. This misunderstanding takes place as the compensation of the effect of increase in forward velocity by corresponding reduction in vertical distance to be negotiated is not clearly brought out in the theoretical equation. This aspect has, therefore, been illustrated with the help of actual examples for ideal basins vide Appendix-A. The ideal horizontal desilting basin as shown below in Figure 1, demonstrates basic theory of sedimentation developed by Hazen. In the case of ideal basin, that for a discrete particle: (a) removal is independent of basin depth and flow through velocity, (b) for a given discharge and suspended sediment load, removal is a function of basin surface area. From the appendix-A, it would be seen that for the 100% removal ratio, the length of basin remained the same though the flow depth varied by many times.

In the case of ideal basin, that for a discrete particle: (a) removal is independent of basin depth and flow through velocity, (b) for a given discharge and suspended sediment load, removal is a function of basin surface area. From the appendix-A, it would be seen that for the 100% removal ratio, the length of basin remained the same though the flow depth varied by many times.

Practical Desilting Basin: In appendix-A, the effect of turbulence is not taken into consideration and the examples pertain to ideal basin only, as mentioned above. In reality, the turbulence increases with forward velocity which results in lifting more number of particles under settlement, which would result in reducing the removal ratio and hence it may be apprehended that the hypothesis proved for ideal basins would not hold good for practical basins. This apprehension is also removed with the help of illustrative examples for practical basins given in Appendix-B. In Appendix-B, the design chart given by T.R. Camp, shown below in Figure 2, is used which takes into account the effect of turbulence in retarding the settlement. This effect of turbulence has been proved by Dobbins by laboratory studies.

However, there is a limit to which the increase in the forward velocity would be permissible. This is determined by critical velocity for various sizes of particles to prevent the bed scour. For this purpose, T.R. camp has adopted Shield's transport function. Some other functions on critical velocity concept are also available for this purpose. Thus, using Creager & Justin curve, the critical velocity for 0.2 mm sediment could be about 0.0253 m/sec. Applying this concept to the practical basins in Appendix-B, it would be seen that forward velocity (0.167 m/s) in basin 1, is more than the critical velocity and since the gain in removal ratio is only 3.3% with double the depth, the basin is clearly uneconomical. Similarly in case of basin 3, the velocity is 0.666 m/sec which is more than critical velocity and hence the velocity is reduced by doubling the width than the depth as shown in Appendix-C for modified basins. From Appendix-C, it would be seen that the removal ratio for modified basin 3 is 100%. The comparison of basin 2 and modified basin 3 is given in Table 1. Thus, Table 1 clearly brings out the superiority of shallower basin as later shows 12% gain in removal for the same volume.

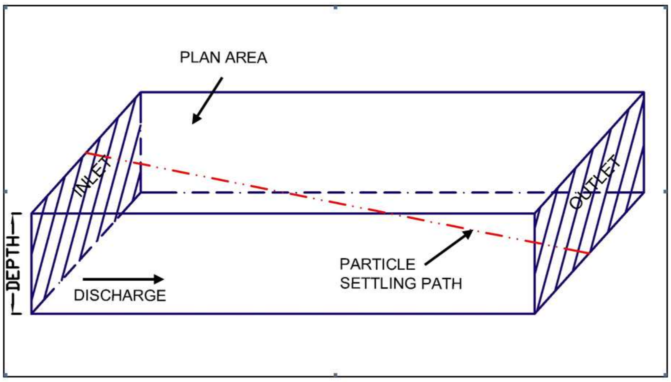


Figure 1. Ideal Desilting Basin

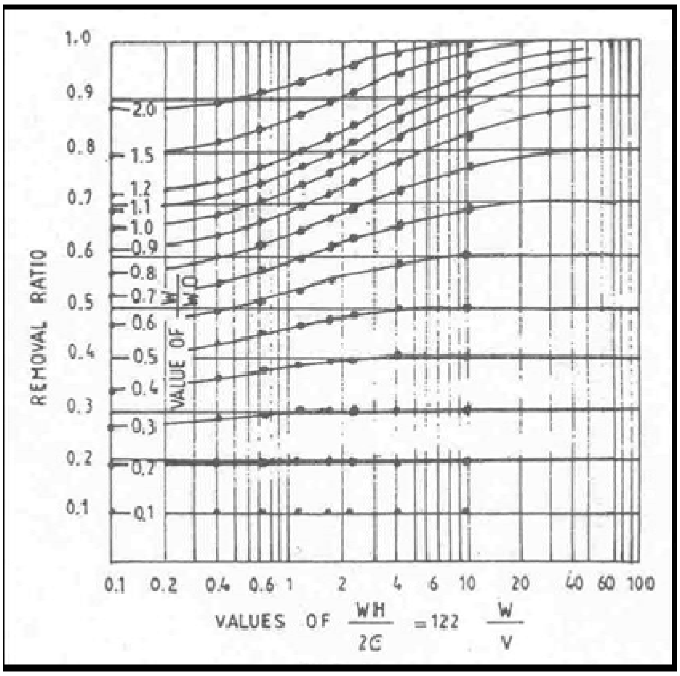


Figure 2. Sediment Removal Function Proposed By Camp

From Appendix-B, it would be seen that for 50% reduction in flow depth, corresponding reduction in removal ratio is only 3%. Similarly, for 75% reduction in flow depth, reduction in removal ratio is only 14.3% and for 95% reduction in flow depth, reduction in removal ratio is 20.90%. Thus, drop in removal ratio is not commensurate with reduction in flow depth. It would therefore be seen that the initial conclusion of 'shallower tanks are economical' still holds good.

Therefore, once the requirement of critical velocity is satisfied, further gain in the removal ratio could be achieved by increasing the surface area either by widening or lengthening. In order to bring out the superiority of widening above lengthening, calculation for basin 2 are also revised in Appendix-C by doubling its length. Comparison of modified basin 2 and 3 are given in Table 2.

Table 1. Comparison between Basin 2 of Appendix –B and basin 3 of Appendix –C

Description	Length (m)	Width (m)	Depth m	Volume (m^3)	Surface area (m^2)	Removal ratio (%) for 0.2 mm dia.
Basin 2 of Appendix -B	40	30	3	3600	1200	88%
Modified basin 3 Col. (2) in Appendix -C	40	60	1.5	3600	2400	100%

Table 2: Comparison between Modified Basin 2 and modified basin 3

Description	Length (m)	Width (m)	Depth m	Volume (m^3)	Surface area (m^2)	Removal ratio for 0.2 mm dia.
Modified basin 2	80	30	3	7200	2400	100%
Modified basin 3	40	60	1.5	3600	2400	100%

(a) Dry Condition **(b) Running condition (Return Flow)**

Photo 1: View of Model (Original Design)

From Table 2, it would be seen for same surface area wider basin is economical. Thus,

a) Wider and shallow basins are most economical.
b) Narrow, shallow and longer basin are next economical
c) Narrow and deep basins are uneconomical.

Inlet Divergence in Desilting Basins: The need for a good inlet divergence design cannot be overemphasized – poor inlet divergence design is probably the factor most responsible for "poor" basin performance in Hazen's classification. To achieve good hydraulic efficiency and effective use of the settling zone, the inlet divergence strictly needs to distribute inflow and suspended sediment uniformly over the vertical cross-sectional area of the settling zone. Clements has shown that horizontal velocity variations across the width of a rectangular tank affect the hydraulic efficiency considerably more than velocity variations in depth provided always that bed scour is avoided. Principal attention therefore needs to be given to uniform inflow distribution in the horizontal plane.

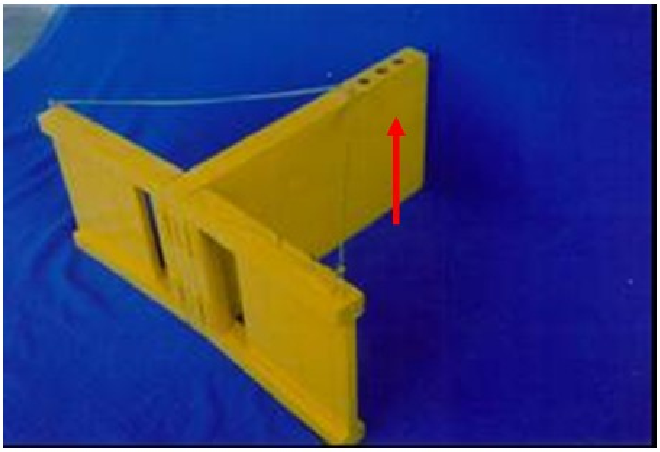
CWPRS Innovations for Inlet Divergence: The flow in the wide inlet divergence is highly unstable due to sub-critical expansion and it is seen that there is a return flow on both the sides in the basin and considerable accumulation of deposited sediment which pushes the return flow further ahead in the basin leading to extra length requirement. Since wider basins pose the problem of flow distribution in the inlet divergence, narrow, shallow and longer basins have been preferred so far. Thus, if the problem of flow distribution in the inlet divergence could be obviated by installing some device, the basin could economize to great extent by making them wider, shallower and shorter. The various flow equalizing devices tested on the models at CWPRS are discussed in brief.

Flow Equalizer for URI - II Project: In case of Uri – II H.E. Project (on river Jhelum in J&K with installed capacity of 240 MW), the desilting basin is of trapezoidal section with bed width of 21 m, depth of 12 m above hopper top and length of 225 m designed for removal of 90% of sediment having size 0.3 mm diameter and above. The desilting was reproduced in the model to 1:30 Geometrically Similar scale as shown in Photo 1 (a). A 60 m long inlet transition with a bed slope of 1V:10.9H has been provided for uniform diffusion of flow entering into the desilting basin (WPRS 2005). For visualizing its performance the inlet discharge was simulated in the model and it was observed that the flow does not get diffused uniformly and the return flow is observed which follows right boundary in the upstream reach of the transition and left boundary near the entry to the desilting basin as seen in Photo 1 (b). The return flow in the inlet transition is not desirable as it causes deposition of sediment on its bed and accumulates over the time and hamper the overall functioning of the desilting basin. To avoid the return flow, a floating type flow equalizer as shown in Photo 2 (a) was tried in the model at a distance of 4.5 m from the beginning of inlet transition. With this floating structure, there was a considerable improvement in the flow. The flow was following the boundary smoothly and there was no return flow in the initial reaches of the desilting basin as seen in Photo 2 (b). Hence this type of flow equalizer was considered essential.

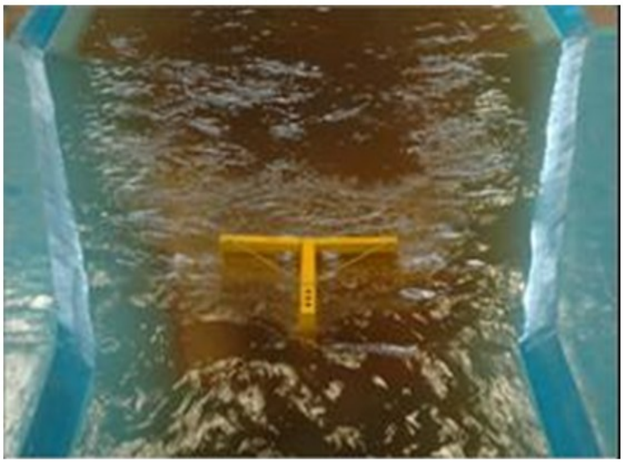
Flow Equalizer for Trishuli Project: The flow equalizer device was also used in case of Trishuli H.E. Project in Nepal. The overall view of the model showing various components of the project are shown in Photo 3. The flow equalizer was provided on the inlet transition of 170 m long and 33 m wide settling tank which was working well in the model to equalize the flow and the same was implemented in the prototype (CWPRS 1975). The flow equalizer invented at the CWPRS thus has considerable potential of utility in this field from equal flow distribution for the wider basins point of view. However, as a general rule, the inlet divergence layout should be tested on model.

RESULTS AND DISCUSSIONS

The design optimization for dimensions of desilting basins along with the analytical calculations for various combinations has been presented in Section 3.0 and 4.0.



(a) View of Flow equalizer



(b) Installed in model (No return flow)

Photo 2. Flow Equalizer and its use in model for Uri Hydro Project

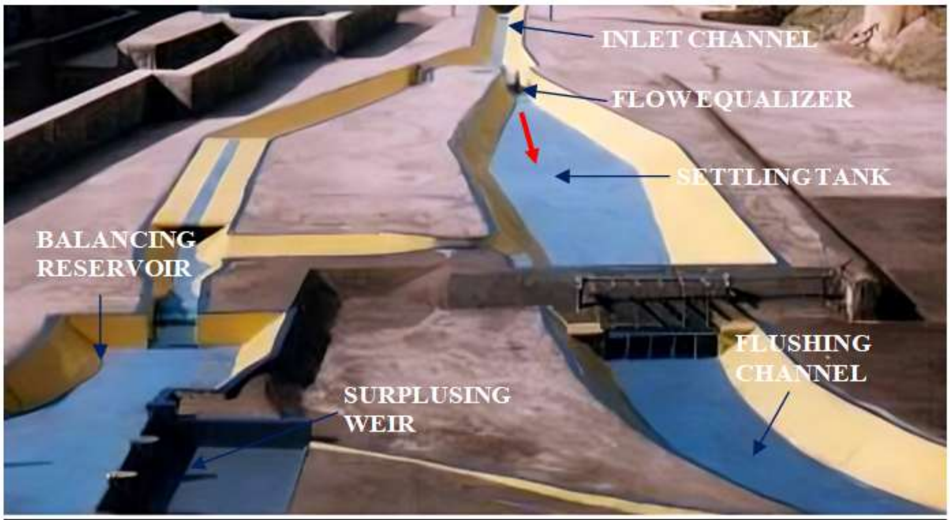


Photo 3. Flow Equalizer and its use in model for Trishuli Hydro Project

For a discrete particle in an ideal basin, removal is (a) independent of basin depth and flow through velocity, and (b) a function of basin surface area for a given discharge and suspended sediment load. Appendix-A shows that with a 100% removal ratio, the basin's length remained constant while the flow-depth, varied significantly. The impact of turbulence is ignored in ideal basins, but in practical basins, turbulence increases with forward velocity, lifting more particles under settlement and reducing the removal ratio. This aspect is considered with the illustrative examples for practical basins given in Appendix-B, wherein the design chart given by T.R. Camp is used which takes into account the effect of turbulence in retarding the settlement. Appendix-B shows that the drop in removal ratio is not commensurate with reduction in flow depth and concludes that the shallower tanks are economical. Further, as shown in Appendix-C, the velocity is reduced by doubling the width rather than the depth and it is seen that the removal ratio for modified basin 3 is 100% as against 78%. The comparison of basin 2 and modified basin 3 is given in Table 1 which clearly brings out the superiority of shallower basin. Therefore, once the requirement of critical velocity is satisfied, further gain in the removal ratio could be achieved by increasing the surface area either by widening or lengthening. In order to bring out the superiority of widening above lengthening, calculation for basin 2 are also revised in Appendix-C by doubling its length. Comparison of modified basin 2 and 3 are given in Table 2 wherein, it would be seen that for same surface area wider basin is economical. Thus, it can be concluded that:

a) Wider and shallow basins are most economical.
b) Narrow, shallow and longer basin are next economical
c) Narrow and deep basins are uneconomical.

This outcome helps the designer to decide the optimum dimensions of desilting basin to be provided as per the existing site conditions. Section 5.0 highlights the critical importance of designing an effective inlet divergence, as a poorly conceived inlet divergence is likely the primary contributor to suboptimal basin performance. For optimal hydraulic efficiency and effective utilization of the settling zone, the inlet divergence must ensure uniform distribution of inflow and suspended sediment across the vertical cross-sectional area. Traditionally, basins have been designed to be narrow, shallow, and elongated to mitigate the challenge of flow dispersion in the inlet divergence. However, if flow distribution at the inlet divergence can be effectively managed through the installation of a suitable device, basins could potentially be made broader, shallower, and shorter for greater efficiency. The discussion also includes various innovative flow equalizing devices that have been tested on models at CWPRS.

CONCLUSIONS

Based on the discussions, it is concluded that wider and shallower basins are the most cost-effective, followed by narrow, shallow, and longer basins. In contrast, narrow and deep basins are uneconomical. The size analysis of the desilting basin presented in this paper supports

Hazen's theory, which states that the removal of suspended matter depends on the surface area rather than the tank volume. Special attention must be given to ensuring uniform inflow distribution in the horizontal plane. To achieve optimal hydraulic efficiency and maximize the effectiveness of the settling zone, the inlet divergence must evenly distribute both inflow and suspended sediment across the vertical cross-section of the settling zone, necessitating a model study for validation.

List of Abbreviations:

Q	Discharge
b	Width of basin
d	Particle size to be removed
w	Fall velocity of particle
D	Depth of basin
T	Time required for particle to fall vertical distance D
v	Forward velocity
w_o	Required fall velocity
L	Length of basin

Declarations

- ***Availability of data and materials:*** Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.
- ***Competing interests:*** The authors declare that they have no competing interests
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Appendix -A

ILLUSTRATIVE EXAMPLES FOR THE IDEAL BASIN

I.Data:Discharge (Q) = 30 m^3/s
Width (b) = 30 m
Particle to be removed (d) = 0.2 mm
Fall velocity (w) = 0.0253 m/sec

II. Requirement: For 100% removal, particles at the surface at the entry should reach the bed till they travel from entry to exit.
III. Calculations:

Description	Basin 1	Basin 2	Basin 3	Basin 4
Flow depth, D (m)	6	3	1.5	0.5
Time (T) required for particle to fall vertical distance D = [$\frac{D}{w}$] seconds	237	120	60	20
Forward velocity (v)= $\frac{Q}{bD}$ m/sec	0.167	0.333	0.666	2.0
Hence, horizontal distance (L) traveled in time (T) = (T x v) m.	40	40	40	40
Thus, the length of basin required for 100% removal of sediment, (m)	40	40	40	40

As seen above, in case of ideal basin the surface area for desired removal remained unaltered though the flow depth reduced from 6.0 m to 0.5 m. Hence, shallow basins are more economical.

Appendix- B

ILLUSTRATIVE EXAMPLES FOR THE PRACTICAL BASINS

I.Data:Discharge (Q) = 30 m^3/s
Width (b) = 30 m
Particle to be removed (d) = 0.2 mm
Fall velocity (w) = 0.0253 m/sec

II. Requirement: To study the effect of turbulence on reduction in settlement.
III. Calculations:

Description	Basin 1	Basin 2	Basin 3	Basin 4
Flow depth, D (m)	6	3	1.5	0.5
Forward velocity (v)= $\frac{Q}{bD}$ m/sec	0.167	0.333	0.666	2.0
Time (T) required for particle to fall vertical distance D = [$\frac{D}{w}$] seconds	237	120	60	20
Vertical velocity (w_o) required to fall flow depth (D); = $\frac{D}{T}$ m /sec	0.0253	0.0253	0.0253	0.0253
Ratio of (Fall velocity / required fall velocity) i.e. $\frac{w}{w_0}$	1	1	1	1
And; 122 $\frac{w}{v}$	18.50	9.27	4.63	1.54
From the camp criteria, removal ratio, from Figure 2	0.91	0.88	0.78	0.72
% deduction in flow depth	-	$\frac{6-3}{6}x100 =$ 50%	$\frac{6-1.5}{6}x100 =$ 75%	$\frac{6-0.5}{6}x100 =$ 95%
% reduction in removal ratio	-	$\frac{0.91-0.88}{0.91}x100$ =3.3%	$\frac{0.91-0.78}{0.91}x100$ = 14.3%	$\frac{0.91-0.72}{0.91}x100$ = 20.9%

Appendix C

Illustrative examples for Widening and Lengthening the Basins

I. Data:(For basin 3 of Appendix –B)

Discharge (Q) = 30 m^3/s
Length (L) = 40 m
Depth (D) = 1.5 m
Particle to be removed (d) = 0.2 mm
Fall velocity (w) = 0.0253 m/sec

II. Modification: Width of basin increased from 30 m to 60 m.
III. Calculations:

Description	Modified **width** of basin – 3 of appendix - B	Modified **length** of basin – 2 of appendix - B
(1)	**(2)**	**(3)**
Forward velocity (v)= $\frac{Q}{bD}$ m/sec	0.333	0.333
Time (T) required for particle to fall vertical distance D = [$\frac{D}{w}$] seconds	120	240
Vertical velocity (wo) required to fall flow depth (D); = $\frac{D}{T}$ m /sec	0.0125	0.0125
Ratio of (Fall velocity / required fall velocity) i.e. $\frac{w}{w_0}$	2	2
And; 122 $\frac{w}{v}$	9.27	9.27
Removal ratio from Camp's criteria (%), from Figure 2	100	100

When length of basin is increased from 40 m to 80 m for basin 2 of Appendix – B, the calculations are shown in column (3) of the above table keeping the other data same.

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