The Biowin Advantage

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Using a Model Primary Settling Tank

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Introduction

In this edition of ***The BioWin Advantage***, we are going to learn how we can use model settling tank elements (normally used as secondary settling tanks) to simulate primary settling tank behaviour.

Background on Ideal and Model Settlers

In the following section, background information on the differences between "ideal" and "model" settling tanks in BioWin is presented. The example discussed in this edition of ***The BioWin Advantage*** will employ a model settling tank based on the Double-Exponential settling velocity model. Accordingly the background information presented will focus on this type of model; however, the reader should note that there are other settling velocity models available in BioWin.

Ideal Settling Tanks

Ideal settling tanks have a user-defined volume and depth. The total volume is divided into two sub-volumes (a "thickened" or "sludge" volume and a "clarified" or "liquid" volume – the relative volume proportions are specified by the user). A constant or time-varying solids capture percentage also can be defined. The underflow also may be constant or time-varying.

At steady state conditions, the mass coming out of the sludge volume zone will be the same as the mass entering it, and specifying the flow split (e.g. the underflow rate) and the solids capture percentage will completely define the mass balance around the unit.

Under dynamic loading, the mass coming out of the sludge volume may not be the same as that coming in; however it may not fluctuate as much as that coming in because the sludge zone volume has an attenuating effect. Consider the following mass balance equation on TSS for the sludge zone, assuming a 95% solids removal:

Accumulation = Mass In – Mass Out

$$\frac{\partial C}{\partial t} \cdot V = 0.95 \cdot Q_{in} C_{in} - Q_{out} C_{out}$$

where C = TSS concentration (kg/m^3), V = sludge zone volume (m^3), Q = Flow rate (m^3/d).

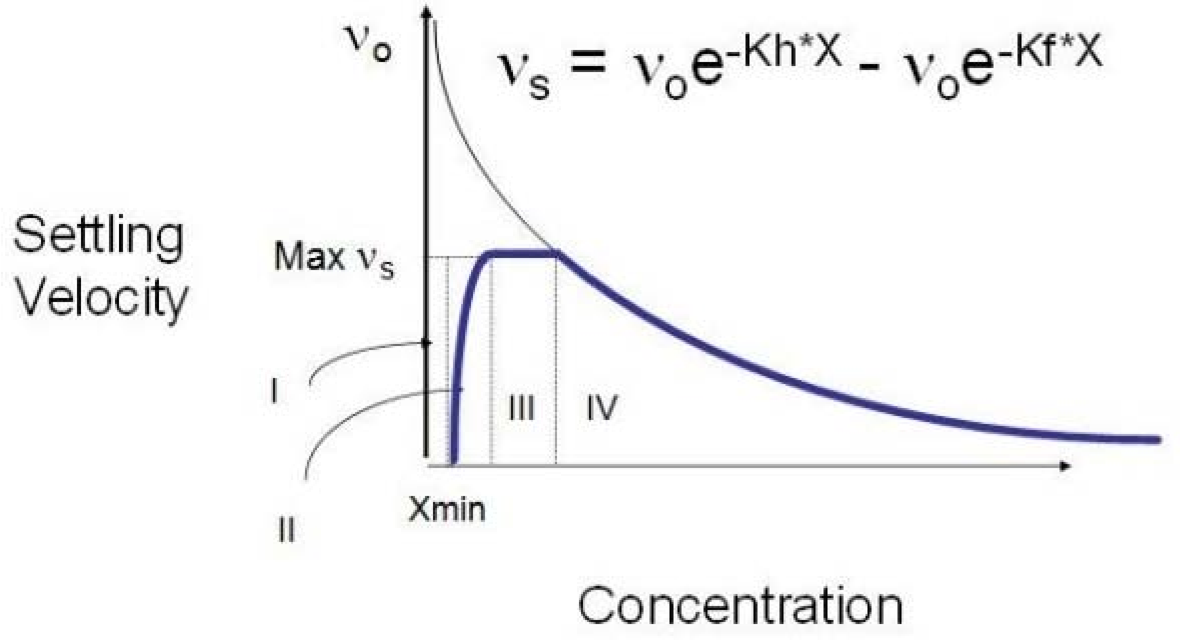
For the steady state case, the change in concentration with respect to time is zero, so the left hand side of the above equation goes to zero. Then the concentration out the bottom (COUT) may be obtained algebraically. But for the dynamic case, this term may not necessarily be zero - it could be positive or negative depending on what is happening in the sludge zone, and in this case, the term involving the volume of the thickened sludge zone does not drop out to zero. Therefore in a dynamic loading case, the volume of the sludge zone will affect the concentration coming out the bottom.

How much of an impact it has depends on the volume, the variability of the incoming load, etc.

Model Settling Tanks (Double-Exponential)

A previous edition of ***The BioWin Advantage*** highlighted some general aspects of 1-D settling models. The interested reader can download that at the following location:
http://www.envirosim.com/bwa/5/bwa15.pdf

A model settling tank using the Double-Exponential settling velocity model uses the following function (shown as the thick blue line) to vary the sludge settling velocity with concentration:



where V_0 = maximum Vesilind settling velocity, Kh = hindered zone settling parameter, Kf = flocculent zone settling parameter, and X = is the total suspended solids concentration.

It should be noted that the value of X is calculated as follows:

X = (Solids Concentration in Layer - X_{min})

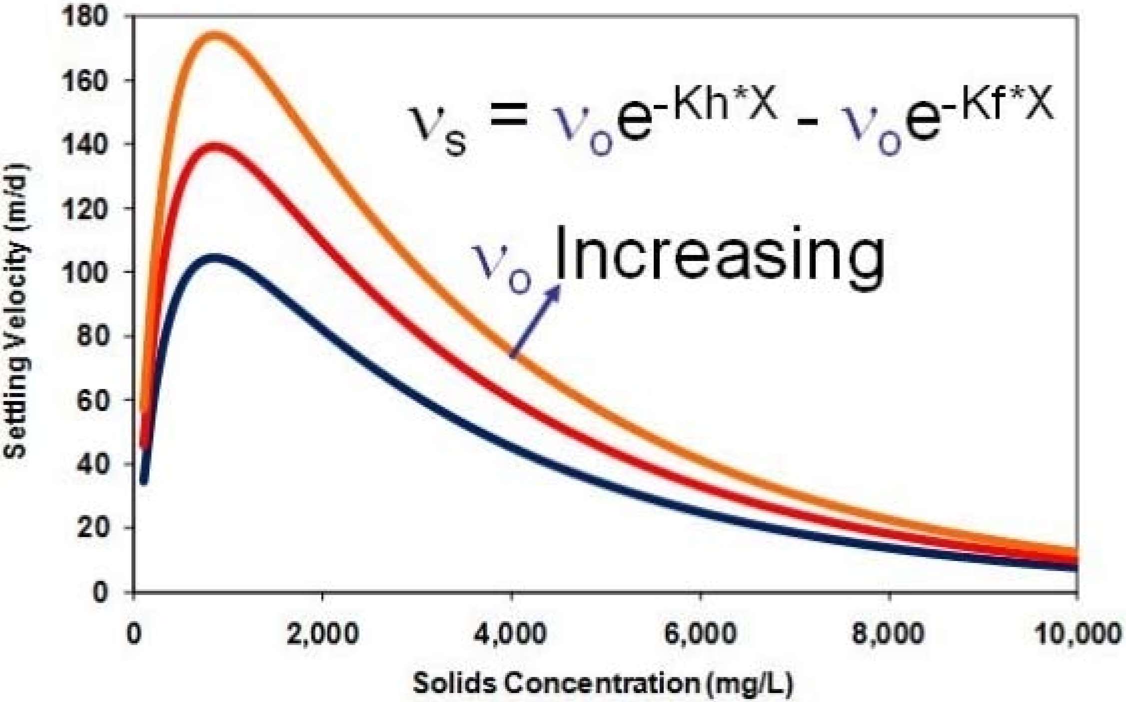
Where X_{min} is the minimum attainable solids concentration in a layer, and is defined as:

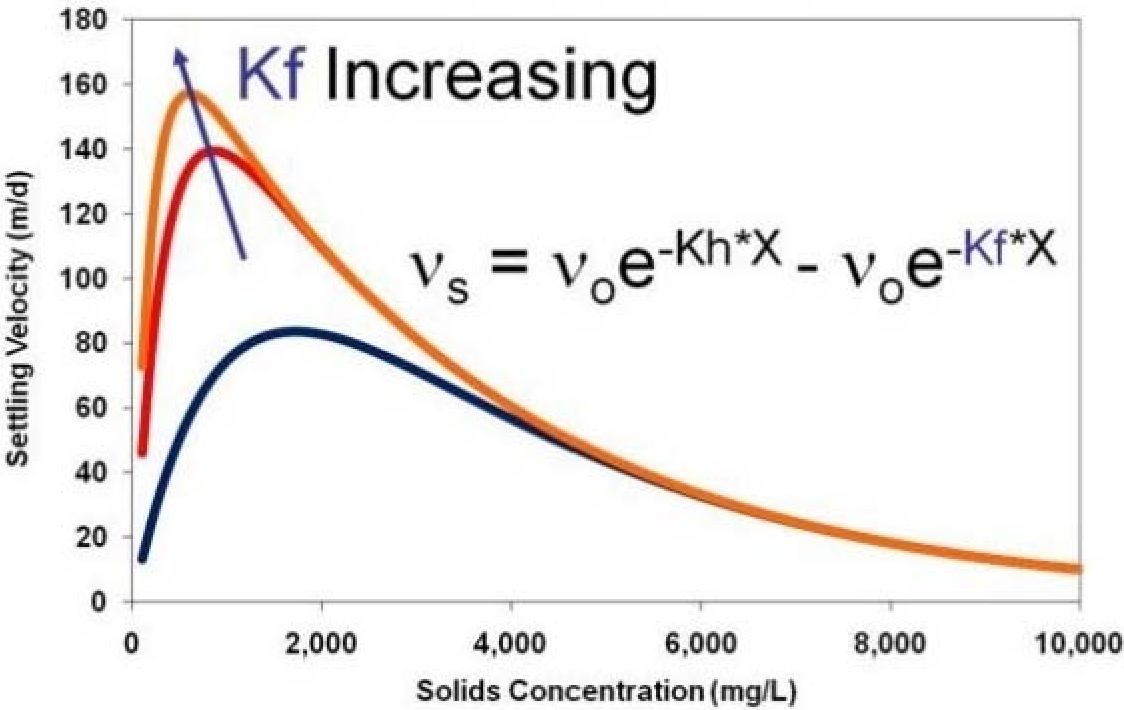
Minimum of ("maximum non-settleable" TSS and "the product of the non-settleable fraction and the feed concentration")

The four regions in the figure above are described as follows:

1. In region I, the settling velocity is zero since the suspended solids concentration reaches the minimum attainable suspended solids concentration.
2. In region II, the settling velocity increases with suspended solids concentration since it is strongly influenced by the flocculent nature of the solids – the behaviour of this zone is strongly influenced by the value selected for Kf.
3. In region III, settling velocity is independent of suspended solids concentration since it is hypothesized that solids particles have reached a maximum attainable size. The settling velocity in this region is set by the maximum practical settling velocity, V_0'.
4. In region IV, hindered settling becomes the dominant process and the settling velocity function reduces to the "classic" Vesilind function. The behaviour of this zone is strongly influenced by the parameter Kh.

The following diagrams illustrate the impact of changing the parameters V_0, Kf, and Kh:


180
160
140
120
100
80
60
40
20
0
Settling Velocity (m/d)
0
2,000
4,000
6,000
8,000
10,000
Solids Concentration (mg/L)
$\nu_s = \nu_o e^{-Kh*X} - \nu_o e^{-Kf*X}$
ν_o Increasing


180
160
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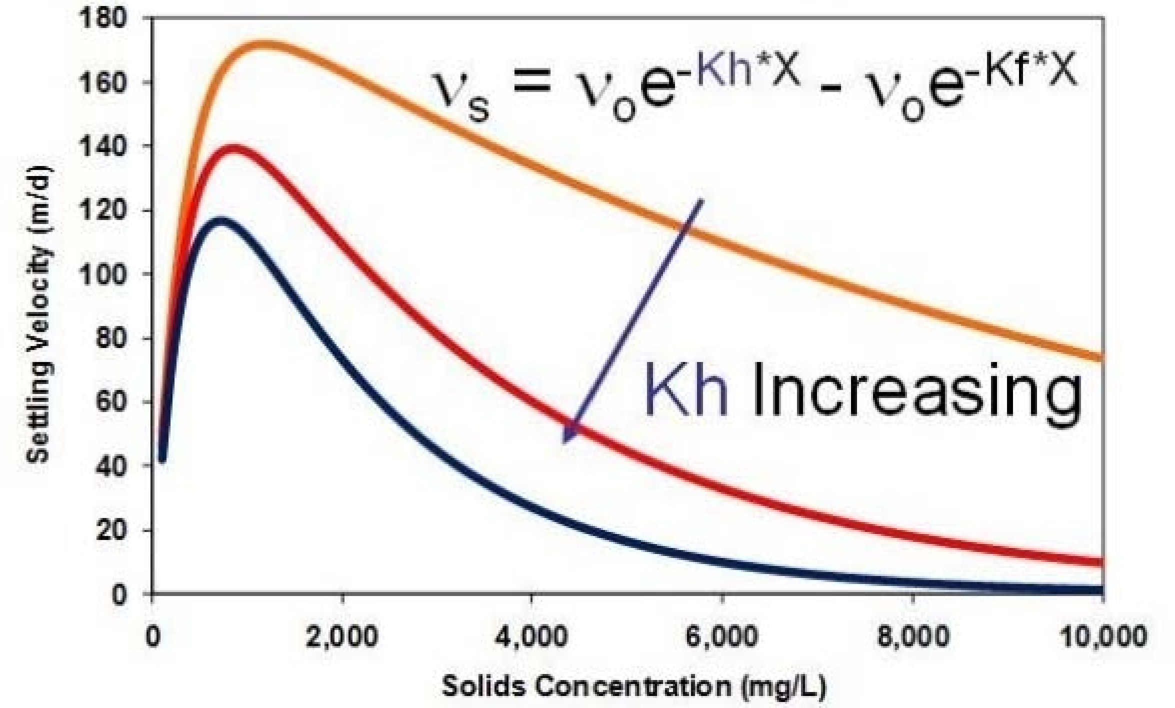
120
100
80
60
40
20
0
Settling Velocity (m/d)
0
2,000
4,000
6,000
8,000
10,000
Solids Concentration (mg/L)
Kf Increasing
$\nu_s = \nu_o e^{-Kh*X} - \nu_o e^{-Kf*X}$



One advantage of the Double-Exponential model formulation is that it is quite flexible, and can be used to simulate a variety of different settling regimes that may be found in different types of settlers.

The following table provides suggestions of parameter values that can be used as a starting point (in SI units):

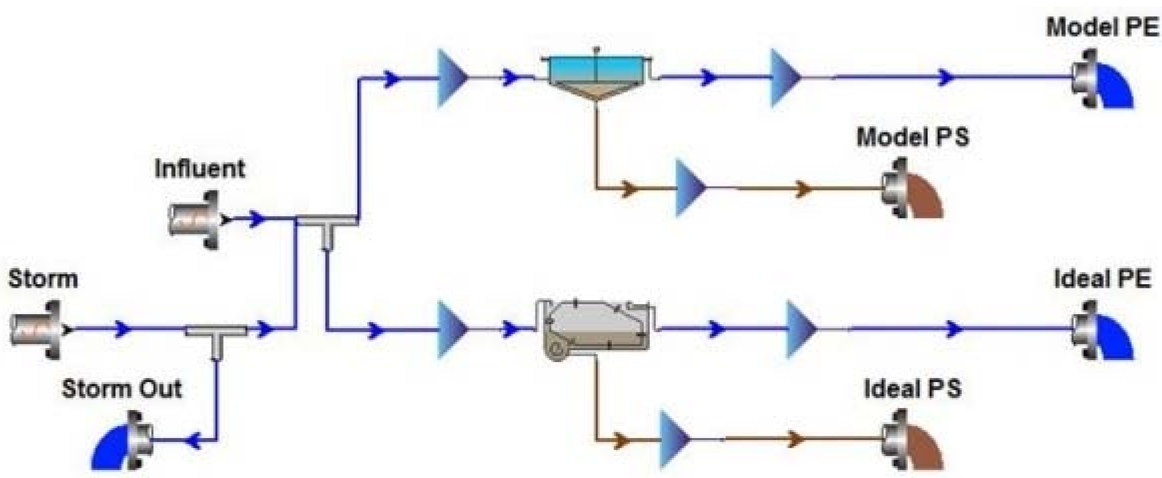
PARAMETER	SECONDARY CLARIFIER	PRIMARY CLARIFIER	GRAVITY THICKENER
Maximum Vesilind settling velocity (V_0, m/d)	410	220	410
Maximum practical settling velocity (V_0', m/d)	270	220	270
Hindered zone settling parameter (Kh, m^3/kg)	0.4	0.4	0.4
Flocculent zone settling parameter (Kf, m^3/kg)	2.5	1.0	0.55
Maximum non-settleable TSS (mg/L)	20	20	20
Non-settleable fraction	0.001	0.99	0.001

The example that follows will iillustrate how we can set up a model clarifier unit to represent a primary settling tank. Simulations comparing the response of an ideal primary settling tank to a model primary settling tank under both “normal” and “storm” modes will be discussed.

Simulating a Primary Settling Tank – Ideal & Model

*Please refer to **BioWin Advantage #5 – One Dimensional Settling Models** for details on strategies for simulating the input of storm events and other pertinent background.*

The BioWin layout shown below (download bwc file here) can be used to compare predicted primary settling tank performance using both ideal and model primary settling tanks.

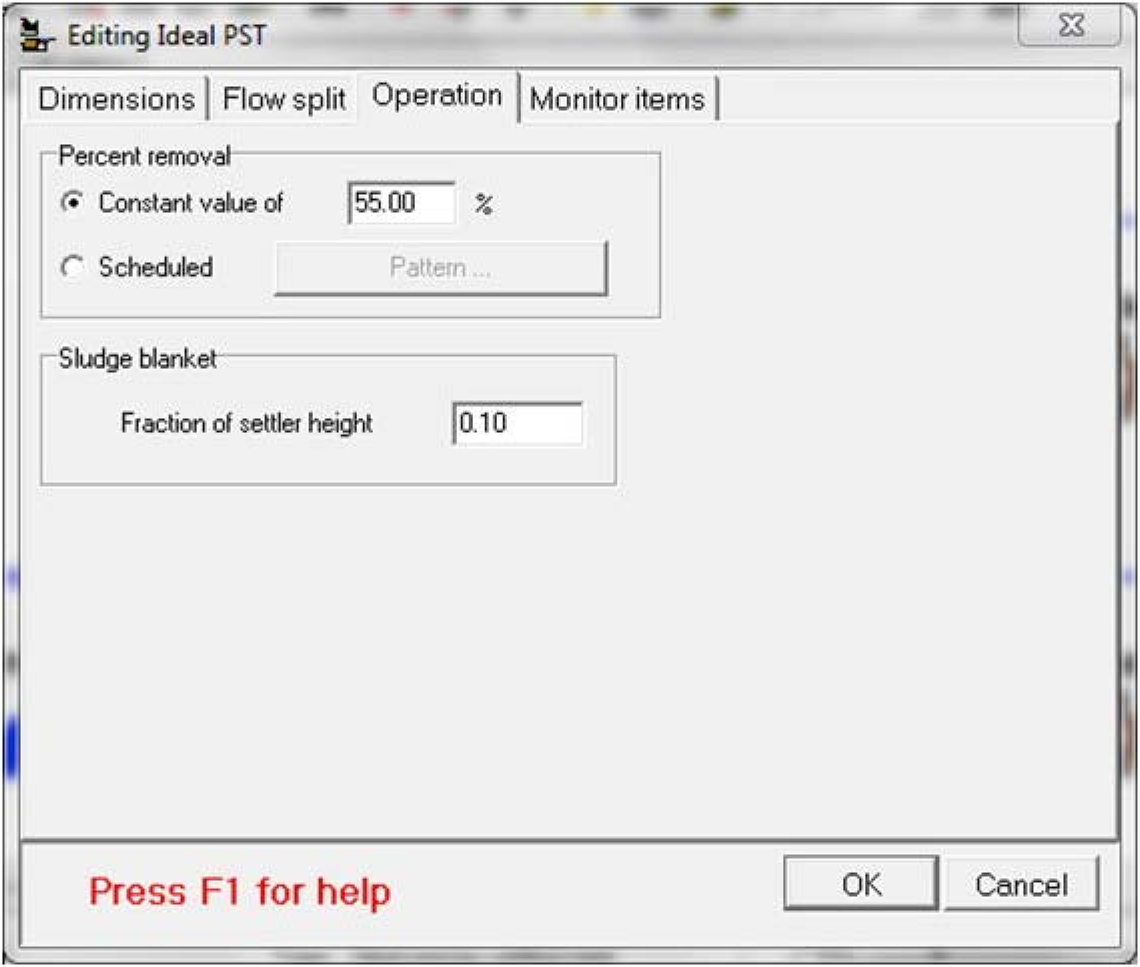


The layout includes two possible inputs: (1) a "typical" diurnal influent pattern named Influent, and (2) a "storm" input named Storm that if allowed to enter the process results in the total flow directed to each primary settling tank being doubled and the load increasing by 50%. Whatever flow is allowed into the process is divided equally between the two primary settling tanks. A number of general mixers are used in the layout to help with plotting inputs and outputs.

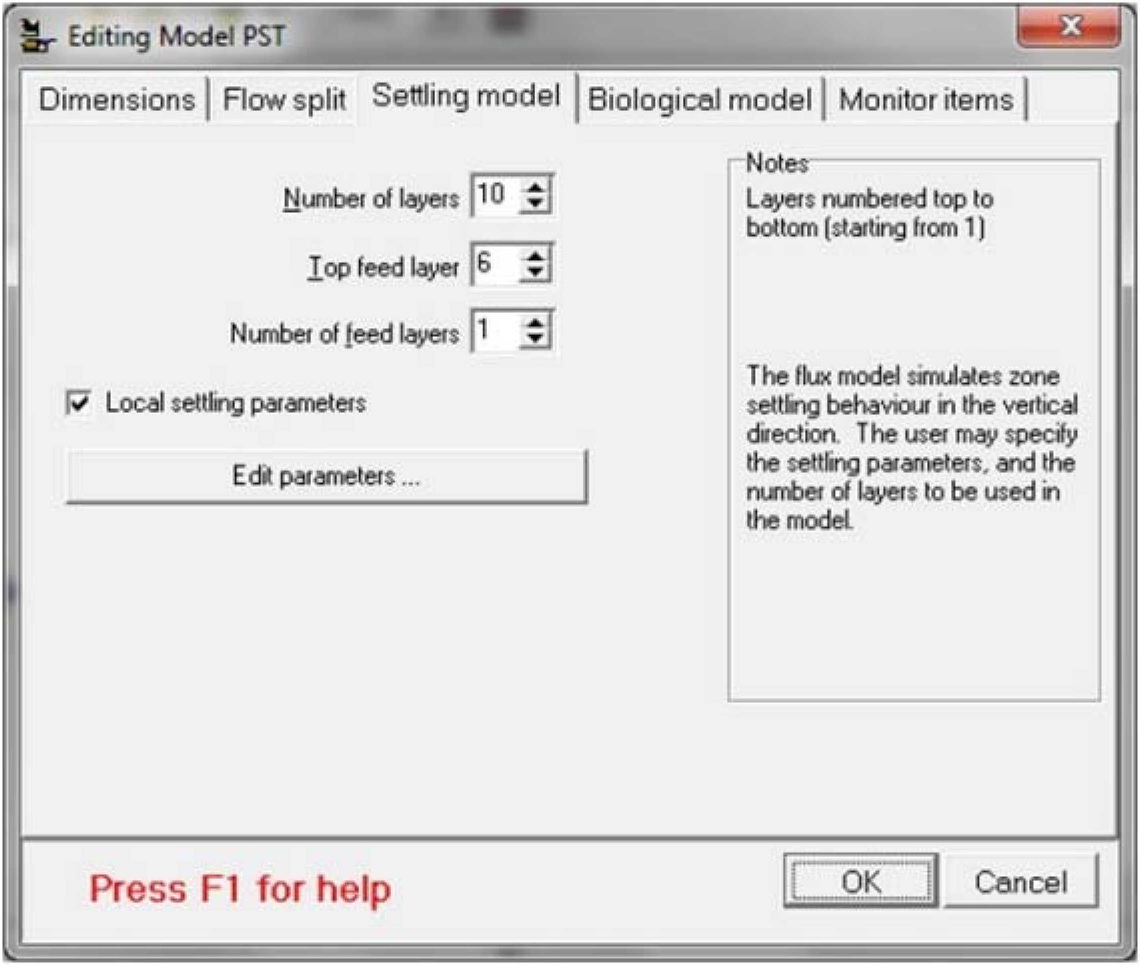
Some pertinent design features of the system are listed in the following table:

ATTRIBUTE	VALUE
Average Influent Flow	12.68 mgd
Maximum Daily Flow	19.88 mgd
Average Influent TSS Load	23,330 lb/d
Primary Settling Tank Volume (each)	0.4 mil. gal.
Primary Settling Tank Area (each)	5,400 ft^2
Primary Settling Tank Depth	10 ft
Primary Settling Tank Underflow	0.03 mgd
Average SOR	1,168 gal/ft^2/d

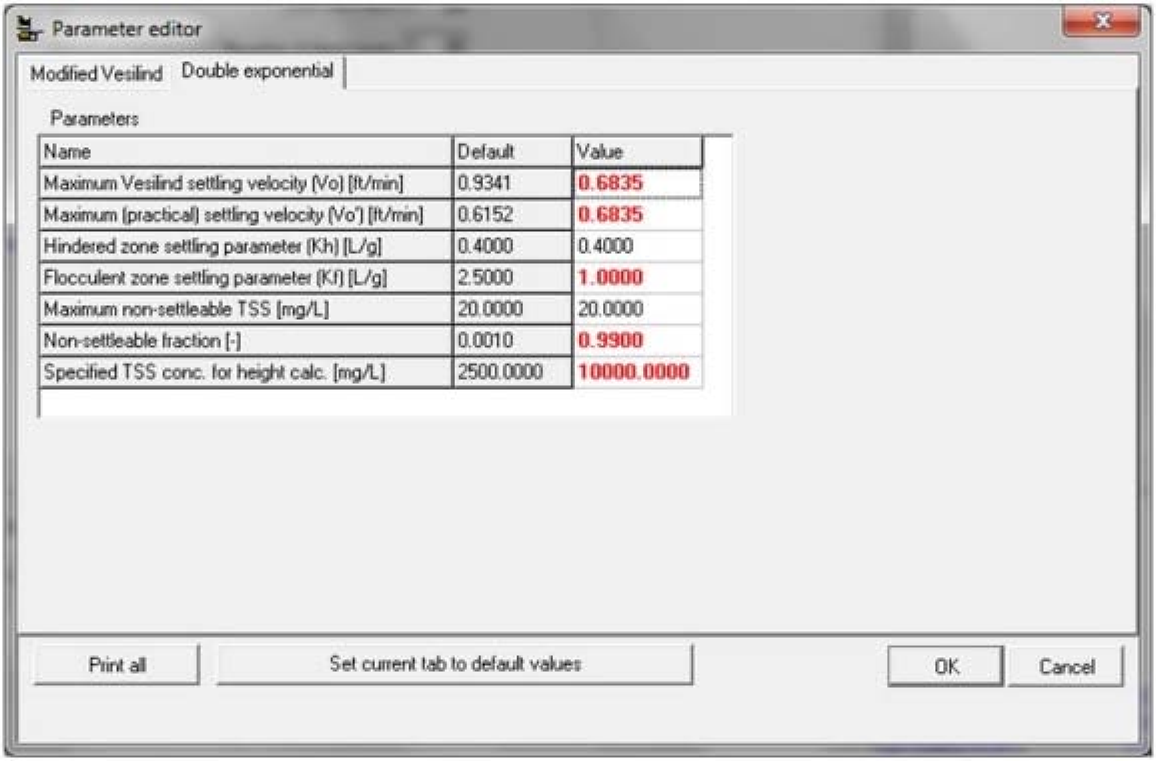
The ideal primary settling tank was set up with a 55% solids capture and a fixed sludge blanket height of 10% of the total depth, as shown below:



The model primary settling tank was set up with ten layers and Local settling parameters as shown below. If a model settling tank is used for both primary and secondary settling tanks in the same BioWin layout, then use of Local settling parameters is the safest way to ensure that the correct parameters are used in the various locations.



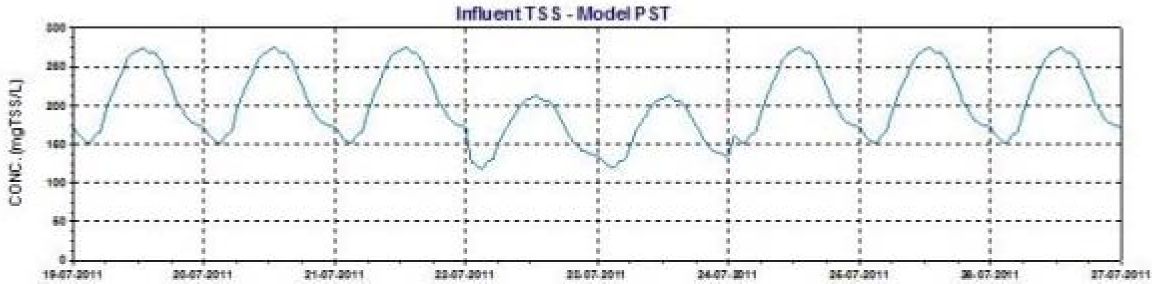
The settling velocity function parameters used for the model primary settling tank in this example are very close to those listed in the table above, with the exception of V_0 and V_0', which were increased slightly to 300 m/d. The parameters used are shown below in US units:



The BioWin file that accompanies this edition of ***the BioWin Advantage*** is a summary of the following steps:

1. First, a steady state simulation was performed with no stom input (the Storm In/Out splitter was set to a fraction of 0 to direct all flow to the bypass element).
2. A dynamic simulation was run for twenty days with no storm flow to establish the base dynamic system response.
3. The simulation was re-started and a dynamic simulation was run for three days with no storm input.
4. With the simulator paused, the Storm In/Out splitter was set to a fraction of 1 to simulate the storm flow entering the plant. Next, the dynamic simulation was continued for two days with storm flow entering the primary settling tanks.
5. With the simulator paused, the Storm In/Out splitter was set back to a fraction of 0 to simulate no storm flow entering the plant. Next, the dynamic simulation was continued for three days with no storm flow to return to the base system response.

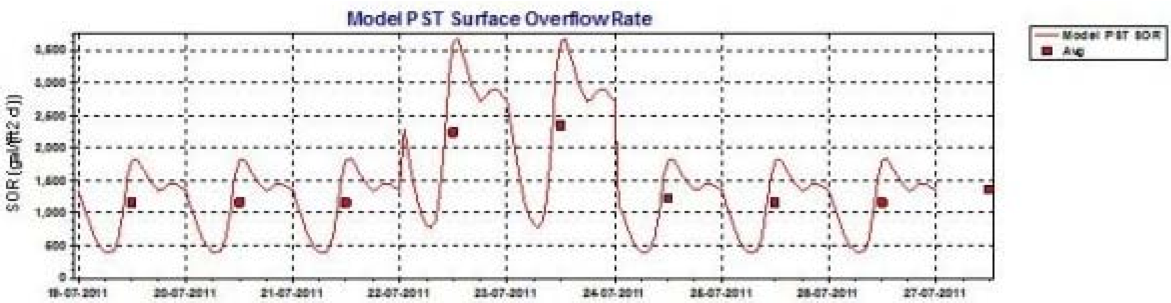
When the BioWin Album is opened, the first two tabs (one tab for the model primary settling tank, one tab for the ideal primary settling tank) each contain two charts: one chart showing the flow directed to the primary settling tank, and one showing the TSS concentration directed to the primary settling tank. The figures below show the flow and TSS patterns input to the model primary settling tank.

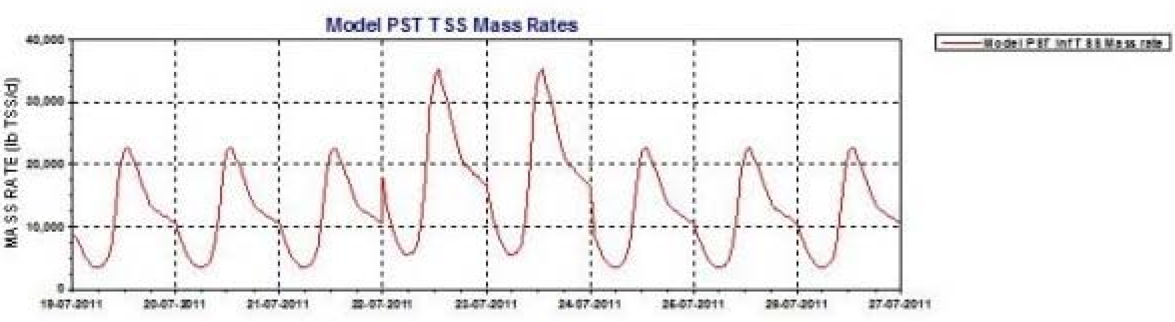


The following details are worth noting:

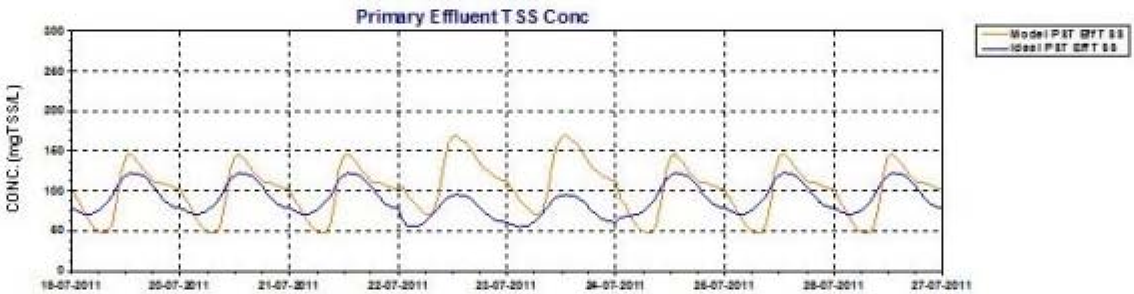
- On the fourth day of simulation when storm flow comes to the primary settling tanks, the flow is doubled.
- On the fourth day of simulation when storm flow comes to the primary settling tanks, the primary influent TSS concentration is decreased due to dilution.

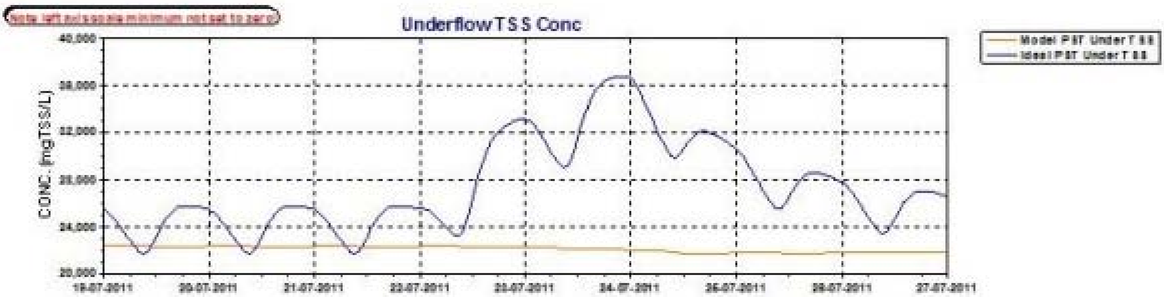
The surface overflow rate and primary influent TSS mass loading rate under normal and storm conditions are shown in the charts below:





The primary effluent and primary sludge solids concentration response patterns for the model and ideal primary settling tanks are shown in the following charts:





The following details are worth noting:

- During the first three days when no storm flow comes to the plant, the predictions for primary effluent TSS concentration are similar for the model and ideal primary settling tank. It is worth noting that the model primary settling tank effluent TSS pattern tends to follow the influent flow pattern, while the ideal primary settling tank effluent TSS pattern tends to follow the influent TSS concentration pattern.
- During the first three days when no storm flow comes to the plant, the predictions for primary sludge TSS concentration are quite different for the model and ideal primary settling tank. As discussed above, due to the fixed sludge blanket implemented in the ideal primary settling tank, the primary sludge TSS concentration exhibits a varying concentration with time. The model primary settling tank allows for varying sludge blanket depth, and as a consequence the predicted primary sludge TSS concentration tends to be nearly constant.
- When the storm flow enters the primary settling tanks on the fourth and fifth days, the predicted primary settling tank effluent TSS concentration patterns diverge. Even though the primary influent TSS concentration drops somewhat (due to dilution), the overall solids loading rate goes up by 50%, and the model primary settling tank predicts a corresponding increase in primary effluent solids concentration. The ideal primary settling tank continues to predict a primary effluent TSS pattern that mimics the primary influent TSS concentration; that is, the ideal primary settling tank predicts that the primary effluent TSS concentration will decrease during the storm event.
- The ideal primary settling tank is not sensitive to the increased solids loading rate; rather, fixed removal rate pushes all of the excess variability into the fixed sludge blanket layer, and the predicted primary sludge concentration shows a significant increase as a result. The predicted primary sludge concentration for the model primary

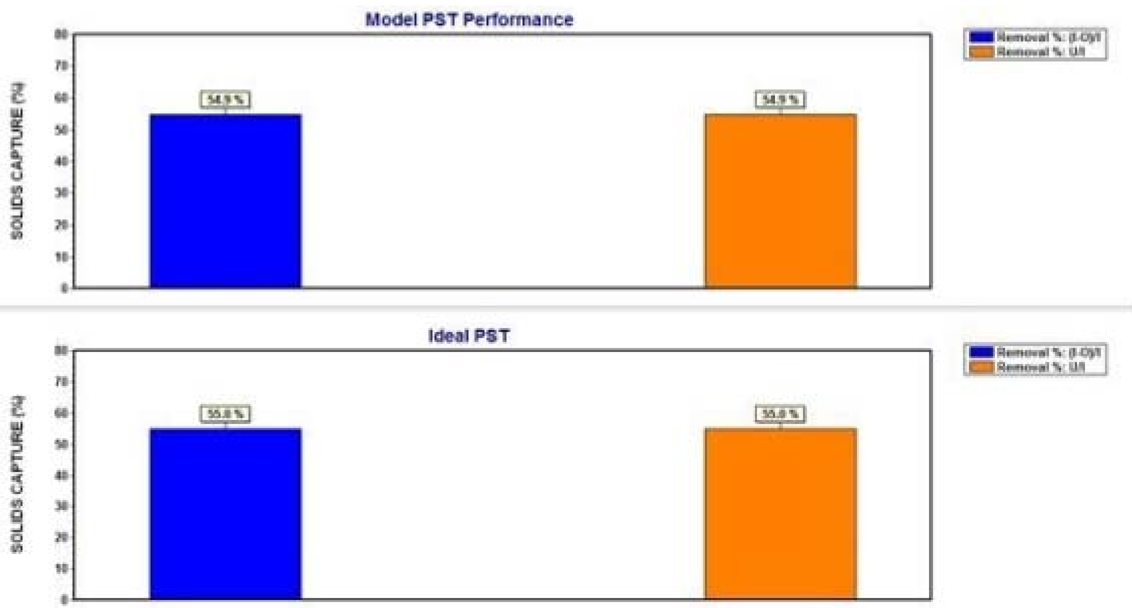
settling tank shows a slight decrease, due to the loss of solids to the primary effluent.

It is evident from the above discussion that the model primary settling tank gives more realistic predictions under storm flow conditions. It might be possible to implement a time-varying solids capture percentage in an ideal primary settling tank to give more realistic predictions, but this would be tedious. The advantage of the model primary settling tank approach is that an appropriate response to varying loading conditions is given automatically.

Conclusions

In this edition of ***The BioWin Advantage***, we've extended the model settling tank element normally used for secondary settling tanks to be applicable as a primary settling tank. A few closing remarks are worth noting:

- The accompanying BioWin file is useful for "calibrating" the parameters of the model settling tank to achieve a desired average solids capture rate. Charts have been set up (an example is shown below) that show both the steady state and dynamic solids capture rate for both the model and ideal primary settling tanks. A suggested approach is to input a desired solids capture rate in the ideal primary settling tank, and adjust the model primary settling tank parameters (starting with V0 and V0') until the predicted responses (under "normal" conditions) are similar.



- It should be pointed out that while using a model settler as a primary settling tank is an improvement over the ideal unit for some conditions, a further improvement would be a fully mechanistic model for the type of flocculent settling that dominates in primary settling tanks. For example, some practitioners are of the opinion that primary settling tank performance improves when the influent solids concentration increases, due to improved flocculation conditions. The model settler used for this example will not predict that improvement because it does not model flocculation in a fully mechanistic manner.

We trust that you found this technical topic both interesting and informative. Please feel free to contact us at info@envirosim.com (Subject: The BioWin Advantage) with your comments on this article or suggestions for future articles.

Thank you, and good modeling.

The EnviroSim Team

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