



In this edition of *The BioWin Advantage* we will be exploring one-dimensional (1-D) settling models and their application in the BioWin wastewater process simulator. We'll look at what they can do, what they can't do, and how we can use them to explore aeration tank/secondary clarifier interactions. Along the way, we'll also demonstrate how to simulate a hydraulic storm event, and use some of BioWin's powerful charting capabilities.

1-D Settling Models

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These models have been around for many years. Although a detailed discussion is beyond the scope of this e-newsletter, the main principle underlying a 1-D settling model is that an empirical model that correlates zone settling velocity to sludge concentration is used to set up and solve mass balances over the discretized depth of the secondary clarifier.

Although 1-D models have been extended over the years to improve predictions of effluent suspended solids, compression settling, *etc.* they are mainly focussed on this principle. They do not consider behaviour in any other direction aside from the vertical; to go beyond that single dimension requires the implementation of sophisticated computational fluid dynamics (CFD) models. With a 1-D model we can look at the following process aspects:

- Sludge mass exchange between the aeration tanks and secondary settling tanks
- Effluent and return solids concentrations
- Vertical solids concentration *versus* depth profiles
- Biological activity (denitrification, phosphorus release, *etc.*)

We cannot look at the following aspects - these require CFD modeling:

- Settler geometry (e.g. circular *versus* rectangular tanks)
- Short-circuiting, density currents, *etc.*
- Impact of design details such as sludge removal mechanism geometry, baffles, *etc.*

In general, the main advantage of 1-D models is that they are simple to implement and computationally fast, relative to CFD models. Furthermore, they have been demonstrated to give good predictions of basic process interactions such as sludge mass shifts, effluent suspended solids levels, *etc.* As such, it is likely that they will continue to be an important part of a modeler's toolkit.

1-D Models in BioWin

Featured Article

One-Dimensional Settling Models

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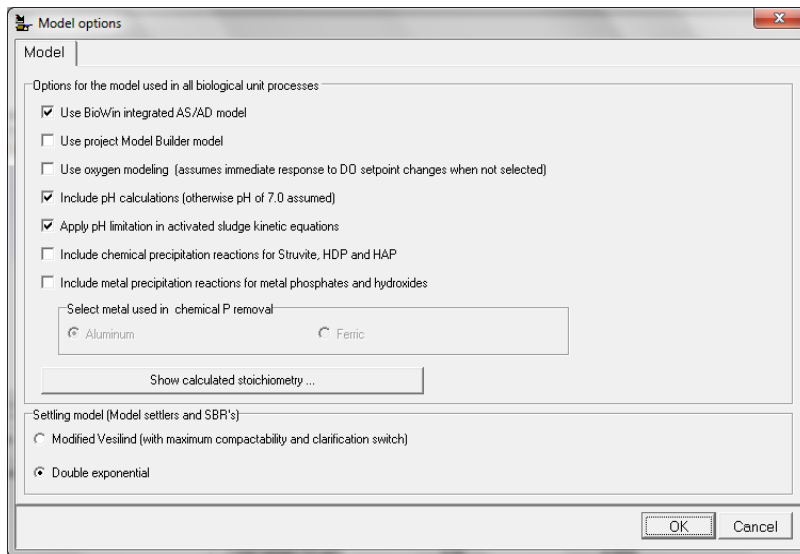
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BioWin users can choose between two empirical settling velocity-solids concentration models in BioWin. The models are:

1. **Modified Vesilind**
2. **Double Exponential**

Details on each model are provided in the BioWin documentation and will not be repeated in depth here. Briefly, although these models behave quite similarly, there are a few subtle differences which lend them strength in particular situations.

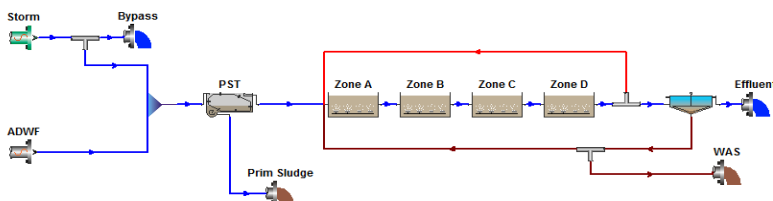


The Modified Vesilind approach places a user-definable restriction on the maximum concentration that the sludge can achieve in the secondary clarifier. As such, this model can be useful for simulating bulking sludges that don't thicken well, or SBRs with short settle/decant periods that may only achieve a certain wastage concentration from the underflow.

The Double Exponential approach uses an interlayer flux transfer limitation in its mass balance equations which allows it to better simulate continuous vertical solids concentration versus depth profiles even under shock dynamic hydraulic loading changes. Since the latter scenario is the one we will be demonstrating in this issue of *The BioWin Advantage*, we will use the Double Exponential model.

The Base Plant

This BioWin configuration is based on an actual plant in the Asia-Pacific region. A process flowsheet is shown below:



Some pertinent design features of the system are listed in the table below.

ATTRIBUTE	VALUE
Average Influent Flow	3.97 mgd
Maximum Daily Flow	5.95 mgd
Average Influent BOD Load	6914 lb/d
Average Influent TSS Load	6168 lb/d
Average Influent TKN Load	1555 lb/d
Minimum Design Temp	20°C
Total Aeration Volume	2.35 mil. gal.
Average Zone D MLSS	2,771 mg/L
Average WAS Flow	31,700 gpd
Secondary Clarifier Volume	1.585 mil. gal.
Secondary Clarifier Area	16,146 ft ²
Secondary Clarifier Depth	13.1 ft
Average Clarifier SLR	8.4 lb/ft ² /d
Average Clarifier SOR	239 gal/ft ² /d
RAS Flow	1.98 mgd (50%)
Average Effluent Ammonia	0.10 mgN/L

Other details of interest include:

- The configuration has the ability to return mixed liquor from the final zone to the first zone for nitrogen removal if the first zone is unaerated; this feature currently is not used.
- The configuration incorporates a **Storm** input (for further information, see below); a flow splitter is used to control whether or not the storm flow enters the treatment plant (for scenario simulation purposes). A state variable input is used to simplify the addition of storm flow plus some additional inerts (25 mg ISS/L).
- The secondary clarifier is big! For average conditions, the SLR and SOR are below suggested design ranges (e.g. Metcalf & Eddy, 4th Edition). However, the size is large due to two main factors:
 - The storm event is brief (6 hours) but significant (see the chart below).
 - The sludge settleability is de-rated from the BioWin defaults which represent a well-settling sludge.

Simulating a Storm Event

Suppose we want to simulate the impact of a storm event. The effect of the storm mainly is hydraulic in nature; only an additional 25 mg/L of ISS is added during the storm and no other additional load (e.g. BOD, TKN) is associated with it. If we open the BioWin file [Sludge Mass Shift \(US Units - with DE Model\).bwc](#) that accompanies this document, we can open up the Album and see a variety of charts illustrating the system inputs and response.

NOTE : you will need to be running the latest version of BioWin (3.1.0.833) to view the file accompanying this e-newsletter - if you receive a message about this when trying to open the file, the best course of action is to download the latest version from <http://www.envirosim.com/bw31setup.exe>

Simulating the system is quite straightforward and requires completing the following steps:

1. Double-click the flow splitter immediately downstream of the **Storm** element and on the **Flow split** tab, ensure that the **Fraction $[S/(S+M)]$** is set to zero. This ensures that initially, the **Storm** input will not be allowed into the main process and will be directed to the **Bypass** output.
2. Solve the steady state (you can use the **From Current** option to get a quick solution).
3. Run a dynamic simulation for say 3 days from **Current values**.
4. When the simulator is paused, double-click the flow splitter immediately downstream of the **Storm** element and on the

Flow split tab, ensure that the **Fraction $[S/(S+M)]$** is set to one. This ensures that the **Storm** input will be directed into the main process.

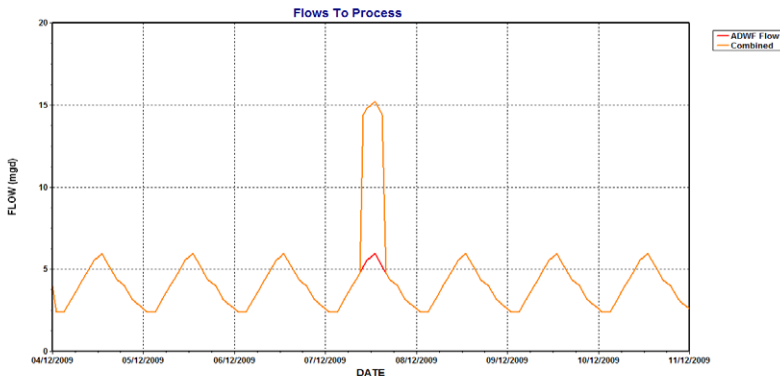
5. On the paused dynamic simulator control, click the "play" button and continue the dynamic simulation for one day.
6. When the simulator is paused again, double-click the flow splitter immediately downstream of the **Storm** element and on the **Flow split** tab, ensure that the **Fraction $[S/(S+M)]$** is set to zero. This ensures that for the remainder of the simulation, the **Storm** input will not be allowed into the main process and will be directed to the **Water Bypass** output.
7. On the paused dynamic simulator control, click the "play" button and continue the dynamic simulation for three days. When the simulator is paused, click the "stop" button to terminate the simulation.

The example we've used here is a storm event, but we can use the above approach for any intermittent input that we'd like to examine the impact of - for example, a periodic industrial input, septage drops, *etc.* Note that we could extend the simulation by "automating" the periodic input, either by entering an on/off pattern in the influent element itself, or in the splitter that directs the input. However, the simple approach outlined above provides the most flexibility for simple scenarios and suits our purposes for now.

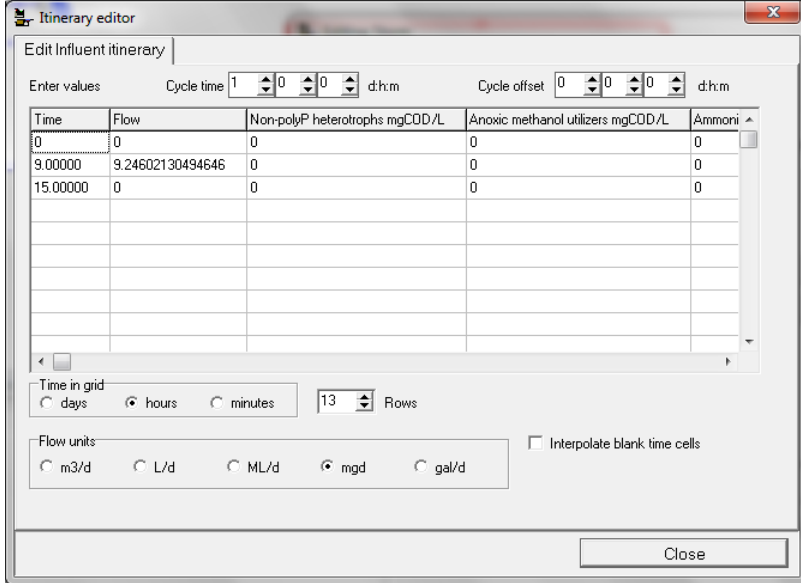
Results and Discussion

In this section we'll look at the various charts that have been added to the Album, discuss how they were created, and examine some of the process interactions that they help illustrate.

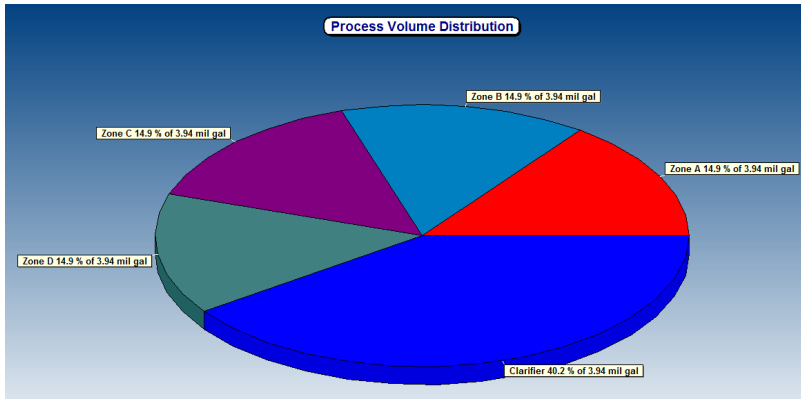
The first chart we see is the average dry weather flow (ADWF) and the total combined flow going to the treatment process.



This is a straightforward **Time Series** chart; one for the flow of the **ADWF** influent element, and another for the flow of the mixer just upstream of the primary settling tank. When the **Storm** input is not being directed to the process, the two lines lie on top of each other. When the **Storm** input is directed to the process, we see the combined flow jump up while the **ADWF** pattern remains the same. Note that although we allow the **Storm** input to be directed for an entire day of simulation, the pattern in the **Storm** input is such that flow only is turned on for 6 hours of that day, as seen from the screen capture below:



Before launching the dynamic simulation, we can use BioWin charts to tell us about the sludge mass distribution, i.e. how much of the total mass resides in each zone of the aeration tank, how much resides in the clarifier, etc. The best way to do this is to use the **Special** tab of the BioWin **Add series...** dialogue. First, let's look at the charts below:



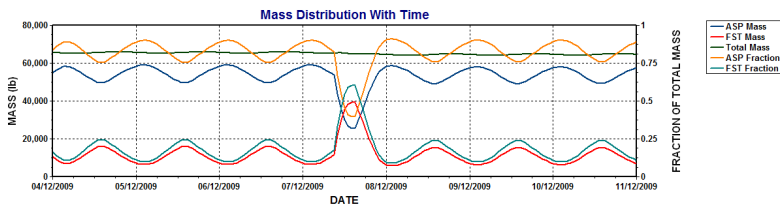
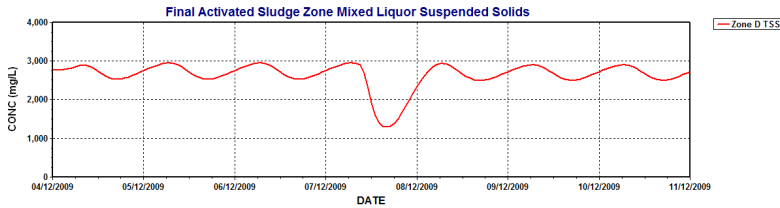
For detailed instructions on how to add one of these charts, launch the BioWin help (from the **Main** toolbar), go to the **Search** tab, and search on the term "plot mass fraction" - the first search result will take you to the step-by-step method. To explore specific features of the charts in the BioWin file accompanying this document, right-click anywhere on the chart and select a chart feature of interest. For example, right-click on either of the pie charts, select **Edit series...**, and click on the top **Series** tab. On the **General** tab, you can see how the strings "lbs" and "mil gal" have been entered in the **Values** formats of the mass and volume pie charts. If you click the **Marks** tab, you can see how the **Style** has been changed to **Label and Percent Total**.

From a process standpoint, these charts back up the earlier observation/hunch that the clarifiers are big! We can see that about 16% of the mass on average is residing in the clarifier, and the clarifier represents about 40% of the combined aeration+clarifier tankage. From a mass distribution standpoint, a few points are worth mentioning/remembering:

- Recall that we're running on average at 50% RAS, so we could do better at getting the sludge out of the clarifier and back to the aeration tanks (where it will do better work for us!).
- The model clarifier in this file has been discretized with 20 layers in the vertical direction. Users of 1-D settler models

should be aware that predictions of sludge mass distribution can vary depending on this discretization. 15-20 layers is a nice balance between numerical complexity and stable predictions.

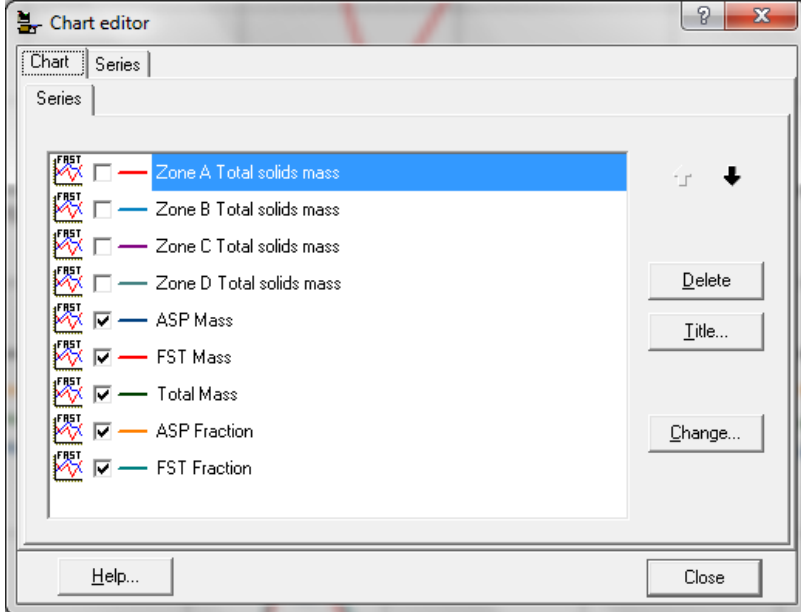
While these pie charts are quite useful for looking at steady state results, they will not be as helpful once we run the dynamic simulation and run the **Storm** input through the process, because the "pie slices" will be changing as we progress through the dynamic simulation - which is difficult to visualize or monitor! This is why the bottom chart on the next Album page (with the title **Mass Distribution With Time**) is more useful for interpreting dynamic results:



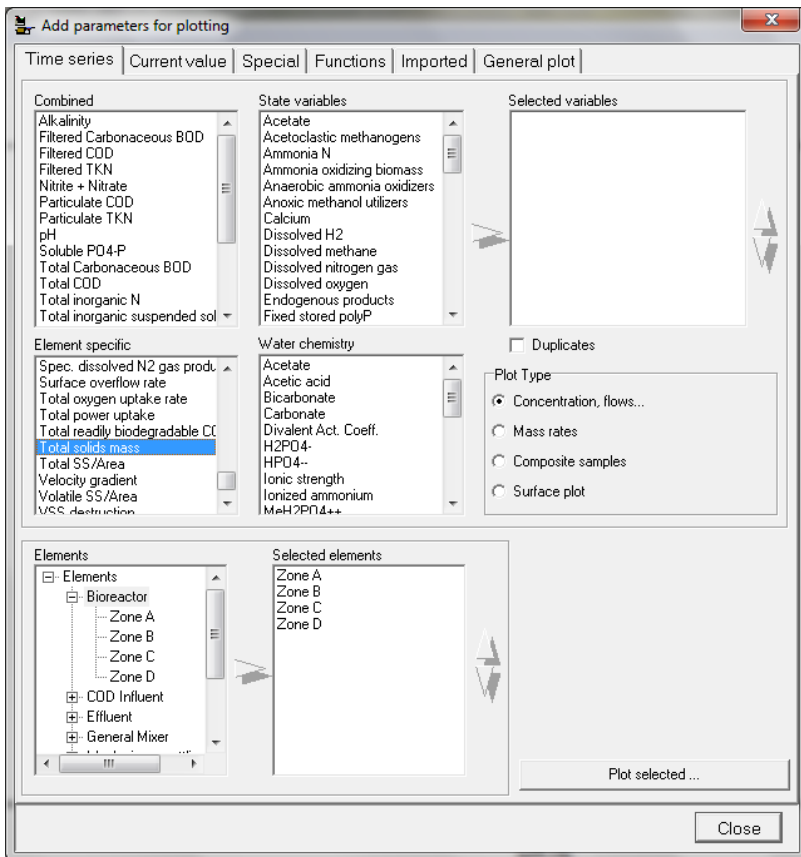
If we briefly look at the top chart, which plots the MLSS in the final aeration tank zone, we can see that when the storm flow comes through the plant, the MLSS drops. This reflects the shift in the solids mass distribution - but can we quantify the amount that is shifted? If we look at the bottom chart, we see that this is possible.

The various sludge masses are plotted to the left axis - i.e. the total (aeration tank + secondary clarifier) sludge mass, the aeration tank sludge mass (the legend entry used here is **ASP** for "activated sludge process"), and the secondary clarifier sludge mass (the legend entry used is **FST** for "final settling tank"). [We'll discuss specifics on how to add these series shortly.] For the first three days, we can see that there is some slight variation around an average, but where the sludge mass resides is relatively stable. [We would likely see less variation in the sludge mass distribution if we paced our RAS rather than using a fixed RAS flow.] When the storm flow is introduced, we see the aeration tank mass drop, and the secondary clarifier mass increase correspondingly. We can normalize the sludge shift on a fractional basis; this is plotted on the right-hand axis. [Again, we'll get to the "how to plot" aspect in a moment.] So we can see that under normal conditions, we have about 84% of our sludge in the aeration tank (which we saw on our steady state pie chart), and 16% in the secondary clarifier. However, when the storm flow is introduced, we see that a large portion of the sludge mass shifts from the aeration tank into the clarifier - at the peak of the storm event, only about 39% of the sludge mass resides in the aeration tank. Once the storm event passes, we see that the sludge mass shifts back to the "pre-storm" conditions, and since the total mass remains relatively constant, we must not have lost any significant amount over the clarifier weirs - we didn't "blow the blanket".

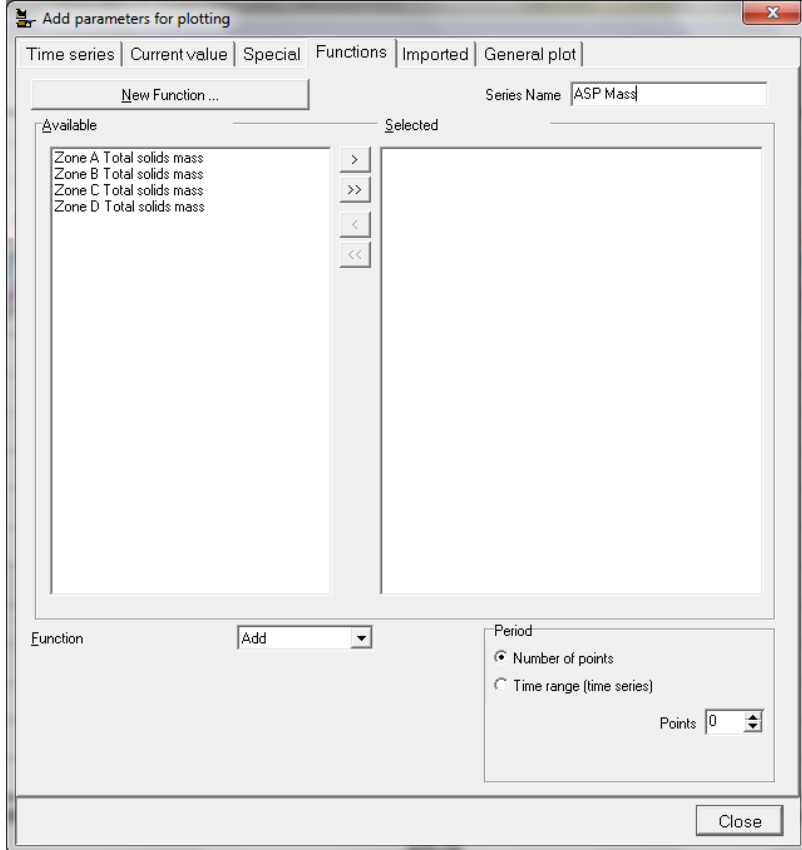
The creation of the "dynamic sludge shift" chart is worth discussing briefly. If you right-click on the chart, and choose **Edit series...**, you will see the following dialogue box, which gives a clue that there are some hidden series!



What we see is that the **Total solids** mass has been plotted for each aeration tank zone, and then hidden by un-checking the box next to the series in the **Edit series...** dialogue box. These are just regular time series; the total solids mass parameter can be found in the **Element Specific** list on the **Time Series** plotting interface:



The **ASP Mass** series can then be created by summing the individual aeration tank zone mass series. In BioWin, we can do this very easily by adding a **Function Series**. [For detailed instructions on how to add one of these charts, launch the BioWin help (from the **Main** toolbar), go to the **Search** tab, and search on the term "add a function series" - the first search result will take you to general background and the steps] We can sum up the individual zone sludge masses and name that sum as a new series, as shown in the dialogue box below:



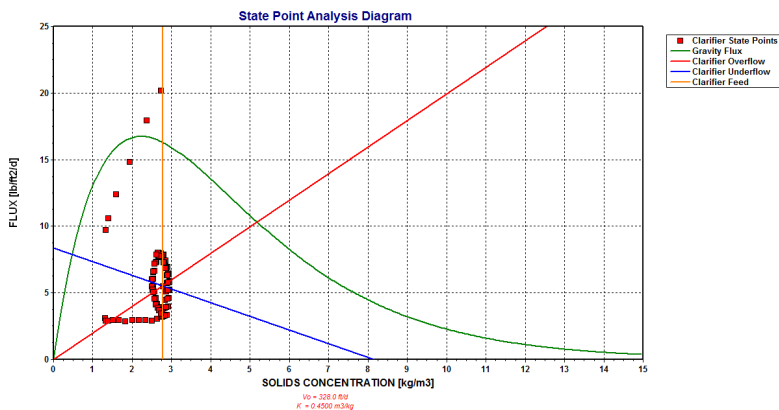
The dynamic fraction series plotted on the right-hand axis also are function series, generated using the "divide" function. For example, the **ASP Fraction** series is a function series where the **ASP Mass** series is divided by the **Total Mass** series. Function series greatly extend BioWin's charting capabilities!

The next few pages in the Album contain plots of RAS concentration, effluent TSS, solids loading rate, and surface overflow rate. These are all standard **Time Series** plots, and fairly straightforward from a process standpoint. The effluent TSS shows a significant jump that corresponds with the increased solids loading rate and surface overflow rate that result from the storm flow. This is the reason we see the aeration tank and RAS concentration dip very slightly after the storm event is finished. We'll come to a more detailed examination of the effluent solids spike in a moment, but for now we'll look at another chart that will help us interpret the results - a BioWin state point analysis (SPA) chart. To generate a SPA chart in BioWin, we simply right-click on a settling tank element, click on **Add to album...**, and select the **Chart...** option. In the resulting dialogue box, we'll see a **State Point** tab. By default all of the lines that may be added to a SPA diagram are checked, but BioWin allows extension of the traditional SPA diagram by allowing us to plot the state point "history" during a dynamic simulation if we wish. Having done this, we will get something like what we see in the Album below.

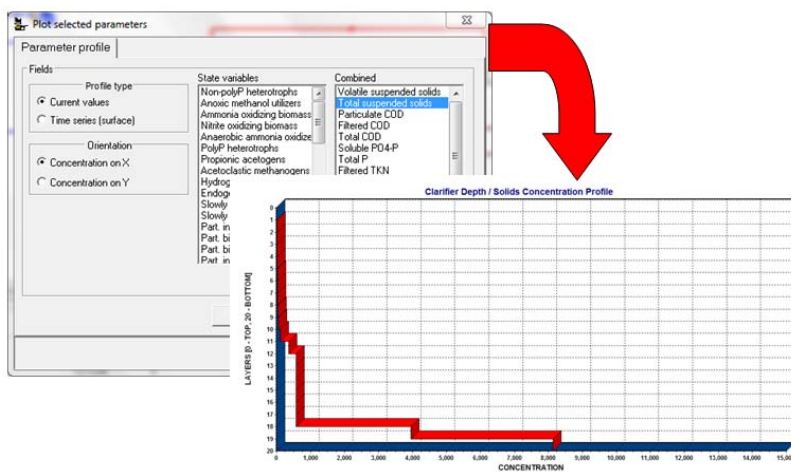
NOTE: *The gravity flux curve on the SPA diagram in BioWin always is generated using the Modified Vesilind V_0 and K values, since they are identical to the "classical" Vesilind settling model parameters. So, the red V_0 and K values that you see at the bottom of the SPA diagram will reflect the values in Project|Parameters|Settling|Modified Vesilind tab...However, we can still use the double-exponential model and generate a meaningful SPA diagram so long as we select Modified Vesilind parameters that give a similar sludge settling velocity/solids concentration profile to the one generated by our selected double-exponential model parameters - EnviroSim has a spreadsheet to assist with this for the interested user.*

When we look at the SPA diagram state point history, we get a clue as to why the effluent solids increased during our storm event. For much of the simulation, the state point moves around within the envelope of the Gravity Flux curve, which represents "safe" operation with respect to clarification (according to classical state point theory - a detailed

is beyond the scope of this document!). However, we can see that there is a period where the state points get up to very high values such that they are outside of the gravity flux curve - this of course is when our storm event hits. The slope of the clarifier overflow line (i.e. the SOR) increases, and the position of the vertical clarifier feed concentration (i.e. the final aeration tank zone MLSS) line moves to the left such that the state point position is high.

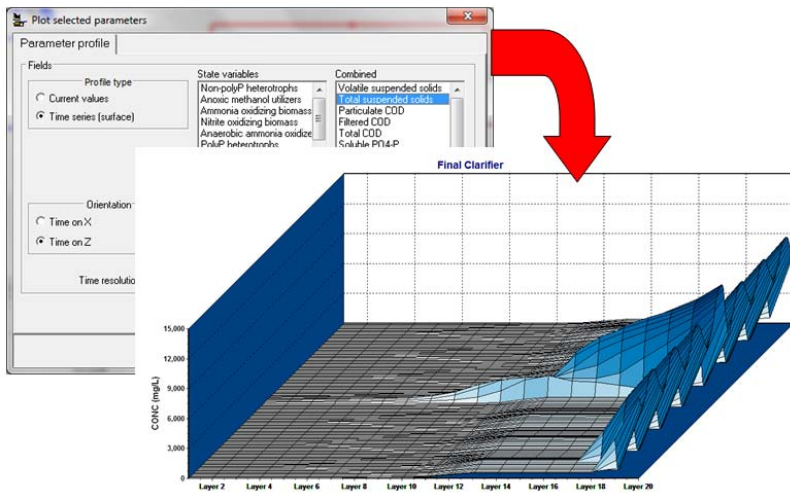


The last set of interesting plots related to the secondary clarifier focus on both the sludge mass distribution and the effluent suspended solids; these are the clarifier depth / solids concentration profiles - which we could also think of as sludge blanket plots. To generate one of these charts, we right-click on a settling tank element, click on **Add to album...**, and select the **Profile...** option. If we select a **Current values** type, the **Concentration on X** orientation, and the **TSS** variable like the dialogue box below, we'll get a steady state "snap shot" of the solids concentration over the depth of the secondary clarifier:

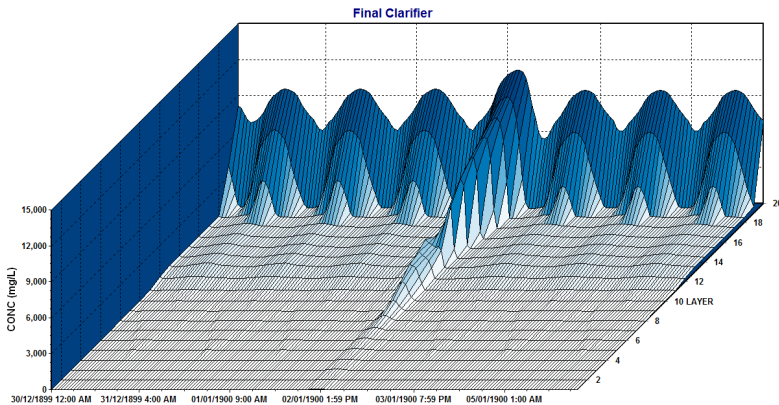


This type of plot is interesting, but like the pie charts discussed earlier, they are not too useful for dynamic simulations because we need to be watching them - they don't record the response "history" as the simulation progresses. It would be more useful/illustrative if we could get BioWin to show us the variation of this profile with time. With a surface plot, we can do just that.

To generate a surface plot, we right-click on a settling tank element, click on **Add to album...**, and select the **Profile...** option. If we select a **Time series (surface)** type, the **Time on Z** orientation, and the **TSS** variable like the dialogue box below, we'll get a solids concentration/depth profile plotted against time, with the time progressing into the page:

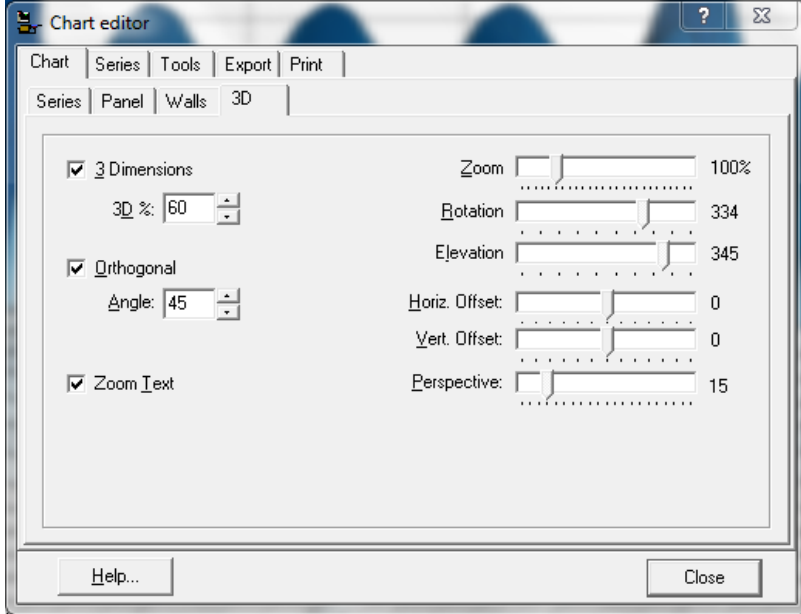


If we select the **Time on X** orientation, we'll get a solids concentration/depth profile plotted against time, with the time progressing along the x-axis, clarifier depth increasing into the page, and concentration on the vertical axis:

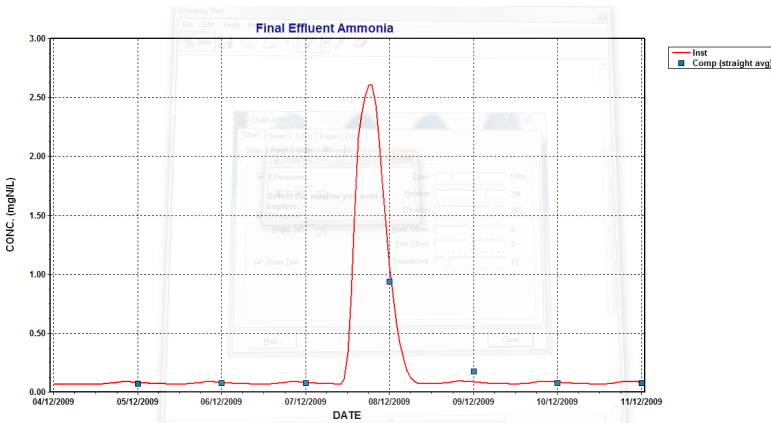


In both of these plots (arguably better in the second one), we can see how under normal loading, we don't carry much of a sludge blanket in the secondary clarifier. However, we can see when the storm flow passes through, the concentration in the bottom layer increases (we can also see that in the RAS time series plot earlier in the Album), and the concentration increases as we move up the clarifier - to the point where we see a slight solids "bulge" extending all the way up to the top layer (we can also see that in the effluent time series plot earlier in the Album).

The surface plot series are a nice visual aid for interpretation of secondary clarifier behavior. EnviroSim has found that getting them to look "right" takes a bit of playing with the 3D settings, which you can access by right-clicking on the plot, selecting **Edit options...**, and clicking on the 3D tab. A screen capture of the settings used for the second surface plot in the BioWin file accompanying this e-newsletter is shown below:



So we've seen how we can use a variety of charting techniques to explore how we can illustrate process interactions with a model secondary clarifier, such as sludge mass distribution, effluent TSS, etc. But so far, other than effluent suspended solids, we haven't thought about whether there might be any other process impacts associated with our storm surge. For example, this is a nitrifying plant. Will the effluent ammonia be impacted by the storm flow, even though no additional TKN load is associated with it? Let's take a look at the effluent ammonia:



From this plot, it is evident that there *will* be a process impact. The instantaneous effluent ammonia spikes to over 2.5 mg N/L, and the composite for that day is just under 1 mg N/L. Why? Recall that just over half the sludge gets pushed into the secondary clarifier during the storm event - not the most effective place for the nitrifiers to be! The result - a significant effluent ammonia peak, despite the lack of additional TKN load.

In Conclusion

In this edition of **The BioWin Advantage**, we've explored some of the capability of 1-D secondary clarifier models - what they can do, what they can't do, and how we can use some of BioWin's advanced charting capabilities to illustrate (for ourselves and our clients) potential process impacts and interactions.

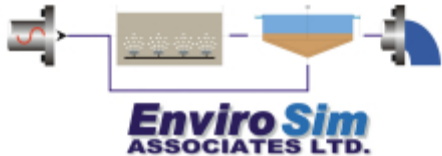
We trust that you found this technical topic both interesting and informative.

Please feel free to contact us at info@envirosim.com (Subject: The

BioWin Advantage) with your comments on this article or suggestions for future article.

Thank you and good modeling

The EnviroSim Team



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