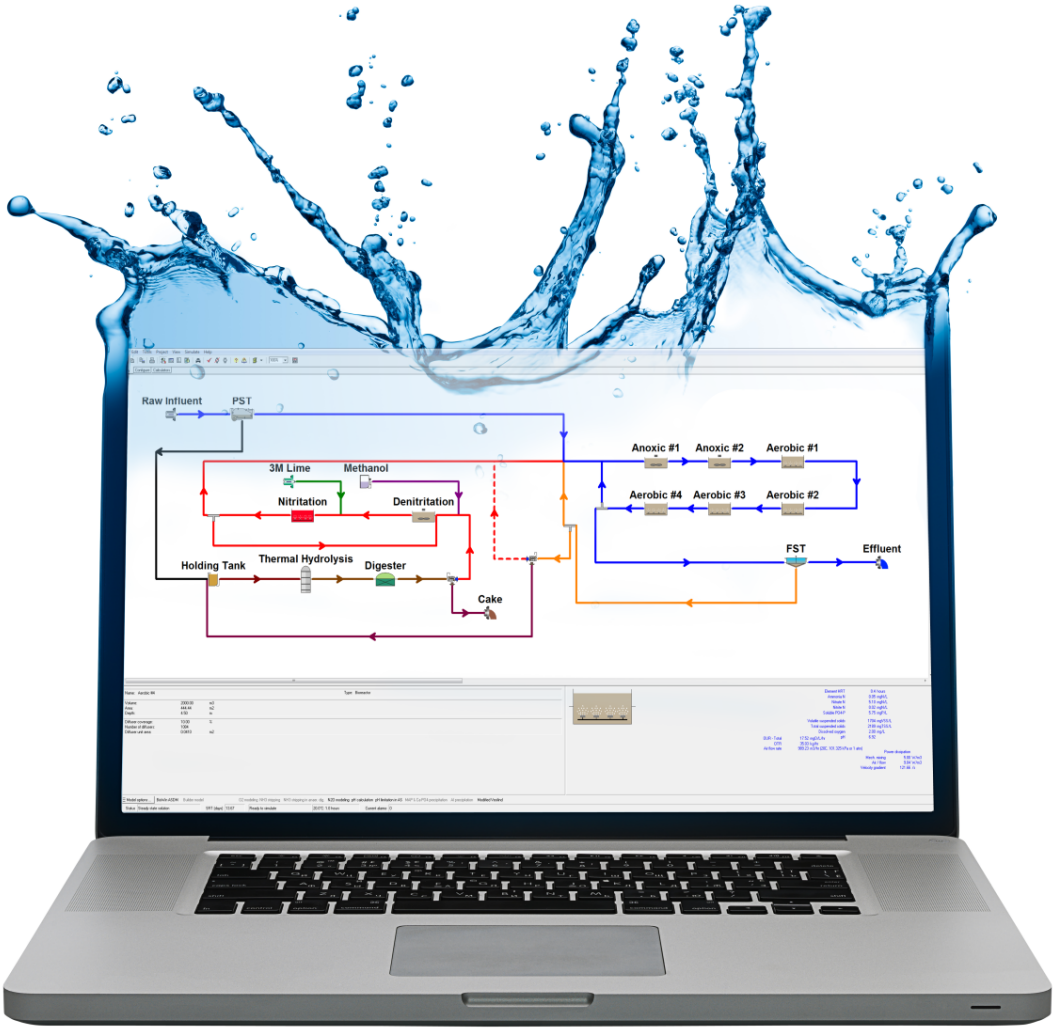
BioWin Advantage Volume 9 - Number 1 - February 2020



Taking a Process Train Offline in BioWin

Introduction

In this issue we will be exploring how to

We will then use this configuration to

simulate the removal of a process train for service/maintenance (*i.e.* taking a train offline). The “trick” for doing this is to use BioWin’s Variable Volume Bioreactor element where a “normal” bioreactor typically would be used. We will look at the basic requirements to set up a Variable Volume Bioreactor that allows us to simulate the situation where one process train is taken out of service and the mixed liquor is drained from this “offline” train.

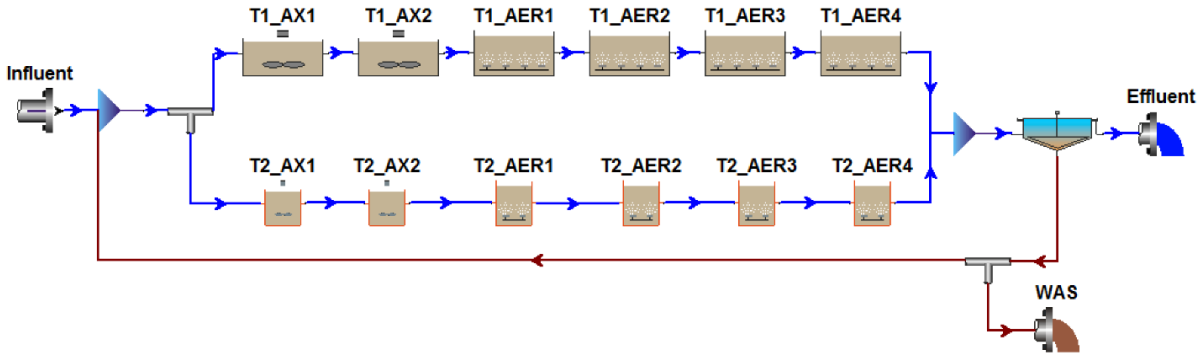
investigate the impact that taking one train out of service has on the remaining process trains, the secondary clarifier and the effluent quality.

File :

- One train Offline

The BioWin Configuration

The BioWin configuration we will use is shown below. For this BioWin Advantage scenario, the train that will be taken out of service is simulated using Variable Volume bioreactor elements in place of “standard” bioreactors. The use of Variable Volume bioreactors allows the “shut down” event to be modelled as an outflow event (*i.e.* aeration is turned off and the train is drained).



The process configuration consists of 2 parallel plug flow trains. The first section of each train (30%) is anoxic (AX) while the remainder of the trains (70%) is aerobic (AER). Two reactors are used to simulate the plug flow anoxic portion, while 4 reactors are used to simulate the plug flow aerobic portion. The total volume of the process is 13 Million Gallons (Mil. Gal.). The plant receives an average flow of 25 mgd of municipal wastewater, which gives an average hydraulic retention time of 12.5 hours. For the propose of this example, this total volume is equivalent to having 5 trains in operation. The top train called T1 uses bioreactor elements to represent 4 of the 5 process trains. Therefore, the volume of train T1 is equivalent to 4/5ths of the total volume or 10.4 Mil. Gal. Each anoxic reactor in T1 has a volume of 1.2 Mil. Gal., a depth of 15 feet and is operated as un-aerated. Each

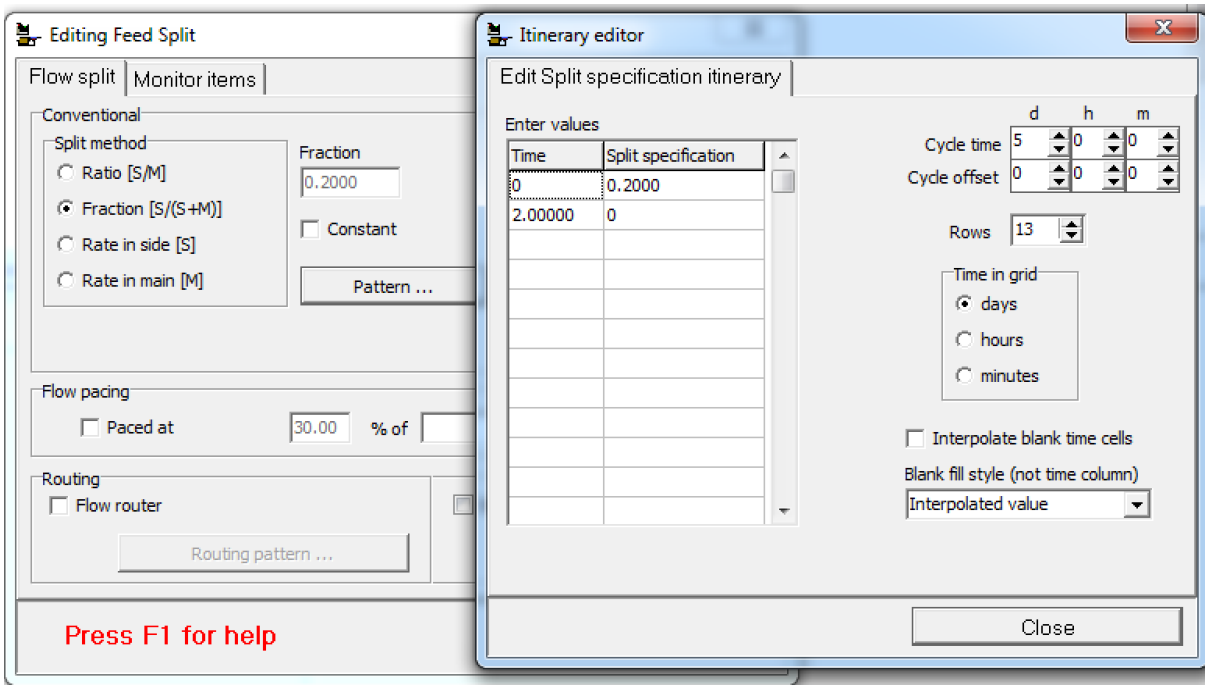
aerobic reactor in T1 has a volume of 2 Mil.Gal., a depth of 15 feet and is operated with a constant DO set-point of 2 mg/L.

The bottom train called T2 uses variable volume bioreactor elements to represent 1 of the 5 process trains. The volume of train T2 is equivalent to $1/5^{th}$ of the total volume or 2.6 Mil. Gal. Train T2 represents the train that will be taken offline and drained for maintenance/repairs. Details describing how the variable volume bioreactors are set up is provided in the next section.

The influent wastewater parameters are summarized in the table below. The process operates at an SRT of approximately 12 days. A model clarifier element is used to simulate secondary settling. The model clarifier has an area of 56,000 f^2 and a depth of 15 feet.

Influent Parameter	Concentration
Total COD (mg/L)	500
cBOD (mg/L)	245.8
TKN (mg N/L)	40
Ammonia (mg N/L)	26.4
Total P (mg P/L)	6.5
Orthophosphate (mg P/L)	3.25
pH	7.3
Alkalinity (mmol/L)	6
TSS (mg/L)	223.41
VSS (mg/L)	245.8
ISS (mg/L)	25

RAS is mixed with the influent flow (1:1) before it is divided into each train. Under normal operation *i.e.* before the scheduled maintenance event, T1 receives $4/5^{th}$ of the flow while T2 receives $1/5^{th}$ of the flow. After T2 is taken offline for maintenance, T1 will receive 100% of the flow. **In this example, the simulation will be run for 2 days under normal operation. After two days of normal operation, train T2 will be taken out of service and the simulation will continue for 3 days with T2 offline.** In order to simulate this, a flow split pattern has been specified in the splitter element called 'Feed Split'. The split method specified is **Fraction [S/(S+M)]**. Clicking on the **Pattern…**button will open the **Split specification itinerary** shown below. Within the itinerary, a **Cycle time** of 5 days has been entered. From day 0 to day 2 the split specification is 0.2 or $1/5^{th}$ of the flow. On day 2, T2 is taken offline so the split specification is 0 since 100% of the flow will be directed to T1.



Setting up the Variable Volume Tanks

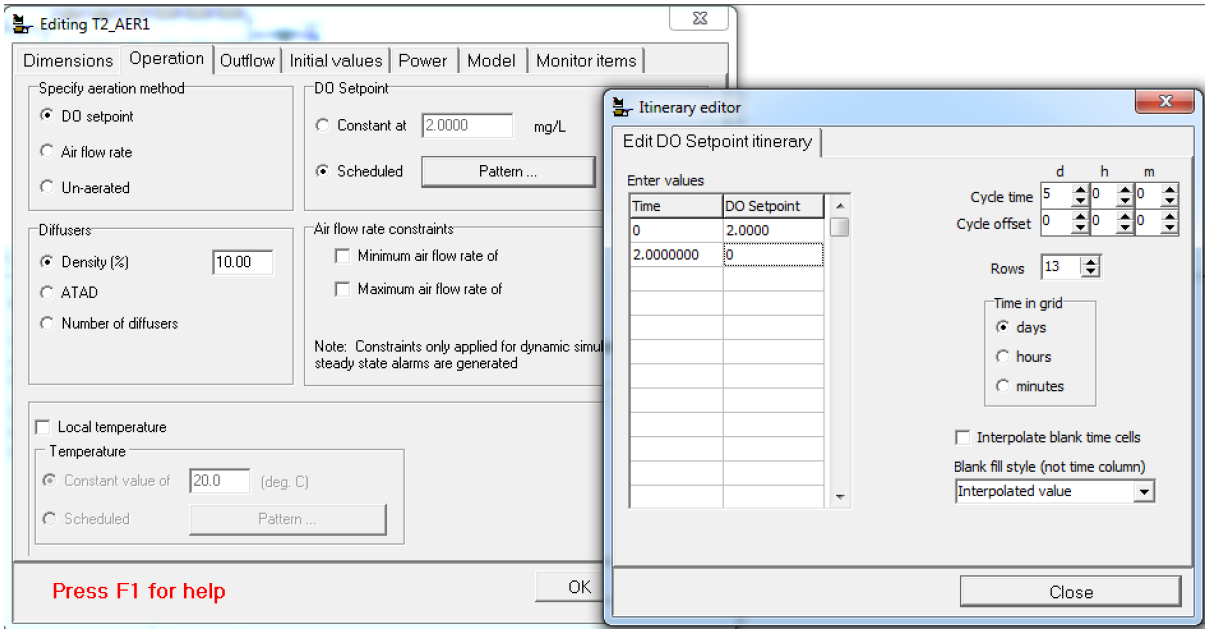
As mentioned above, the simulation will be run for 2 days under normal operation. After two days of normal operation, train T2 will be taken out of service and all of the flow will be directed to T1. Taking T2 out of service will require switching off aeration and draining T2. The contents of T2 will be drained over an 8-hour period. In order to simulate this “shut-down” event, scheduled patterns for aeration and outflow are required. Other considerations for setting up the variable volume bioreactors are outlined below. Detailed information on using variable volume bioreactors in BioWin is summarized in Appendix A.

Specifying Dimensions

When specifying an outflow pattern in a variable volume bioreactor, the outflow always tries to attain the current specified pattern rate, except when physically constrained (*i.e.* when the variable volume bioreactor is full or empty) (see Appendix A). Therefore, when setting up the Variable Volume bioreactor for this application it is important to ensure that the bioreactor is not operating as “full”. Some freeboard is required to ensure the liquid volume inside the Variable Volume bioreactor does not equal the full volume. This freeboard can be incorporated into the total volume of the tank specified on the **Dimensions** tab. The total volume of T2 is 2.6 Mil. Gal with 30% anoxic and 70% aerobic, therefore the required volume of each anoxic basin is 0.3 Mil.Gal. (0.3 Mil.Gal x 2 reactors = 0.6 Mil.Gal. Anoxic) while the required volume of each aerobic basin is 0.5 Mil.Gal. (0.5 Mil.Gal x 4 reactors = 2 Mill.Gal. Aerobic). In order to incorporate some freeboard however (see Appendix A), the volume entered on the **Dimensions** tab for both Anoxic (AX) reactors is 0.4 Mil. Gal. while the volume entered on the **Dimensions** tab for all four Aerobic (AER) reactors is 0.6 Mil. Gal. The depth in all 6 variable volume reactors is specified as 15 feet (equivalent to T1).

Specifying Operation

Shutting down T2 for maintenance requires switching aeration off. Since the first two tanks of T2 (T2_AX1 and T2_AX 2) are anoxic, the **aeration method** can be kept as **Un-aerated** through both normal operation and during shutdown. However, an aeration pattern is required for the 4 remaining reactors (T2_AER1 – T2_AER4). The **aeration method** in these 4 tanks is specified as **DO setpoint**. Clicking the **Pattern…** button opens the **DO Setpoint Itinerary** shown below. Within the itinerary, a **Cycle time** of 5 days is specified. For the first two days of normal operation (i.e. from **Time** 0-2 days) the DO setpoint is entered as 2 mg/L. On day 2 when T2 is taken offline, the DO setpoint is entered as 0 mg/L.



Specifying Outflow

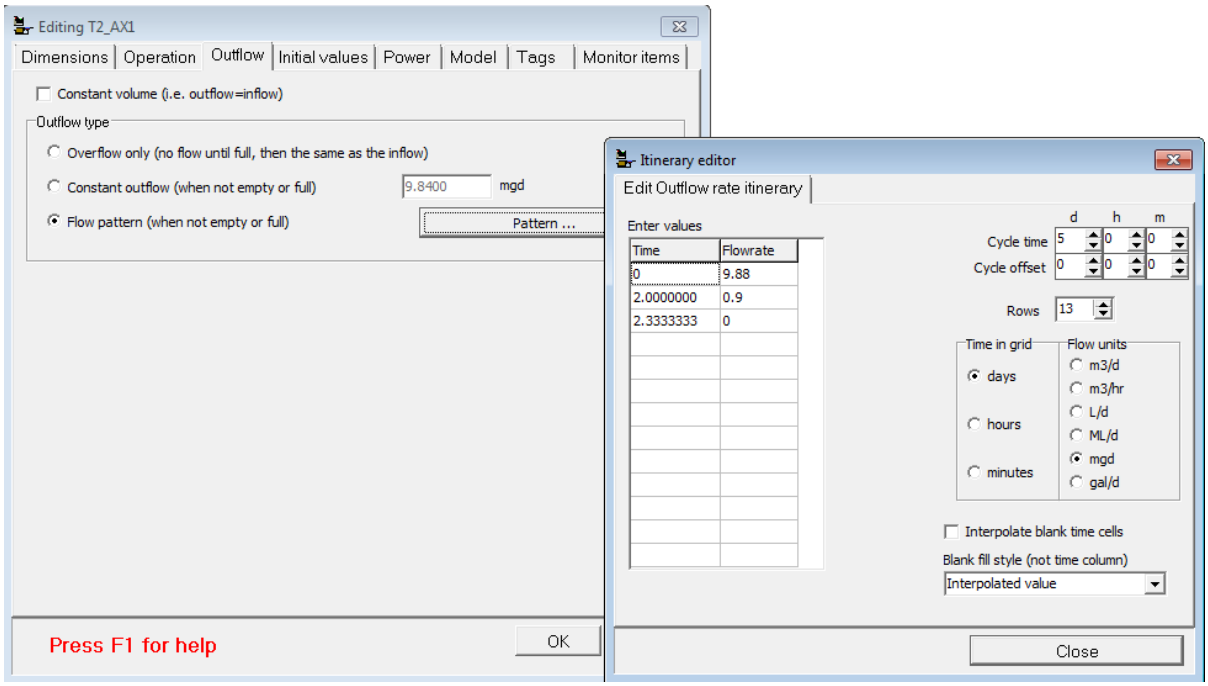
During normal operation, the variable volume bioreactors operate at a constant liquid volume since the influent flow is constant. In order to ensure a constant liquid volume, the outflow must be set equal to the inflow. For this example, inflow to T2 is equal to $1/5^{th}$ of the total sum of the influent flow plus the return flow minus the flow wasted or 9.88 Mil. Gal. Once T2 is taken offline and the inflow is set to zero, the contents of T2 is set to drain over an 8-hour period. In order to set this up for tanks in series, a cascade approach is required where the outflow must account for the current volume in the tank and the volume within all of the tanks before it. For example, the volume of the first reactor in the train will drain into the second reactor, and the second reactor will now have to drain the volume of reactor 1 and 2 to empty and so on down the train until the last reactor is draining the full volume of all 6 tanks within the train.

In all of the variable volume bioreactors, the **Outflow type** is specified as **Flow Pattern (when not empty of full)**. Clicking **Pattern…**opens the **Outflow rate itinerary**, shown

below. Within each itinerary, a **Cycle time** of 5 days is specified. In order to maintain a constant volume during the first two days of normal operation, at Time 0 the flowrate is set to 9.88 Mil.Gal. which is equivalent to the inflow to each reactor. On day 2 the variable volume reactors begin to drain. The flow rate on day 2 differs in each reactor to account for the sum of the volume of the proceeding reactors as described above. The Outflow rate itinerary shown below, is for the first reactor in the train, T2_AX1. This reactor is only required to drain its own volume of 0.3 Mil. Gal over the 8-hour period. Starting at 2 days, the outflow rate required is calculated as:

$$Outflow\ rate = \frac{0.3\ Mil.Gal.}{8\ hours} \cdot \frac{24\ hours}{day} = 0.9\ mgd$$

The table below summarizes the volume required to drain from each tank in T2 and the required outflow rate. At time 2.333 days (or 8 hours after day 2) the outflow rate is set to 0.



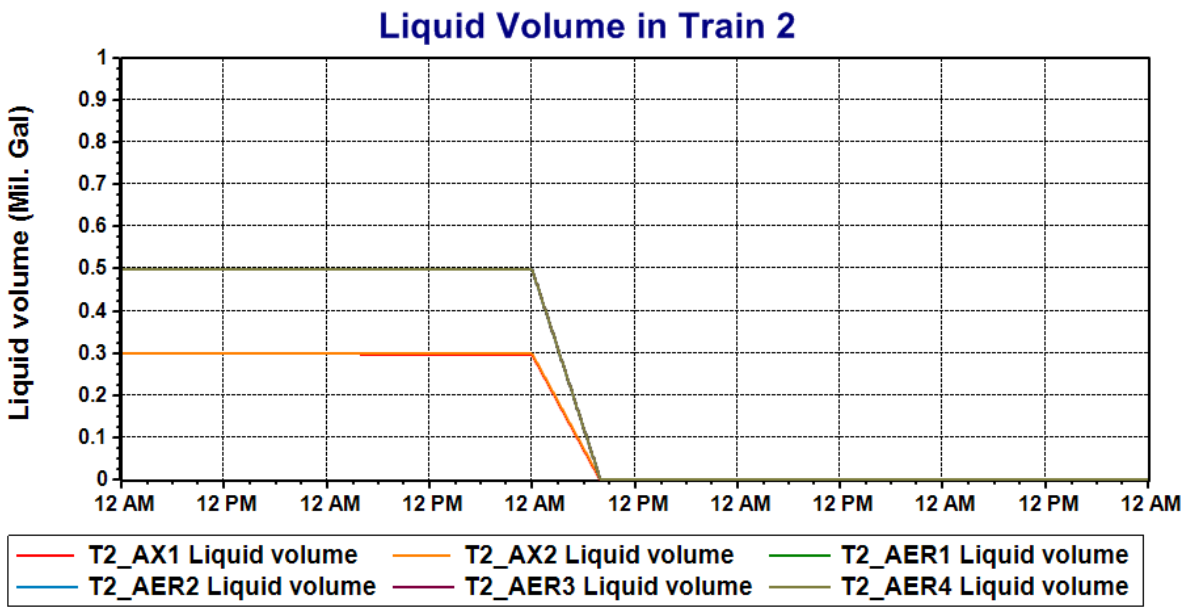
Reactor	Volume Required to Drain (Mil.Gal.)	Outflow Rate (mgd)
T2_AX1	0.3	0.9
T2_AX2	0.6	1.8
T2_AER1	1.1	3.3
T2_AER2	1.6	4.8
T2_AER3	2.1	6.3
T2_AER4	2.6	7.8

Specifying Initial Values

This example starts under normal conditions where the variable volume bioreactor is operating under constant volume. Therefore, the **initial liquid hold-up** must be configured to ensure the liquid volume starts at the correct operating volume. Since freeboard was required to ensure the variable volume reactors are not physically constrained, the required **initial liquid hold-up** was determined by dividing the required operating volume by the total volume specified on the **Dimensions** tab. For example, T2_AX1 and T2_AX2 have a required operating volume of 0.3 Mil. Gal. and a total volume of 0.4 Mil. Gal. therefore the initial liquid hold-up is 75 **% of full** (*i.e.* 0.3/0.4). For T2_AER1 – T2_AER4, the required operating volume is 0.5 Mil. Gal and the total volume specified is 0.6 Mil.Gal. therefore the **initial liquid hold-up** is 83.33 **% of full** (*i.e.* 0.5/0.6).

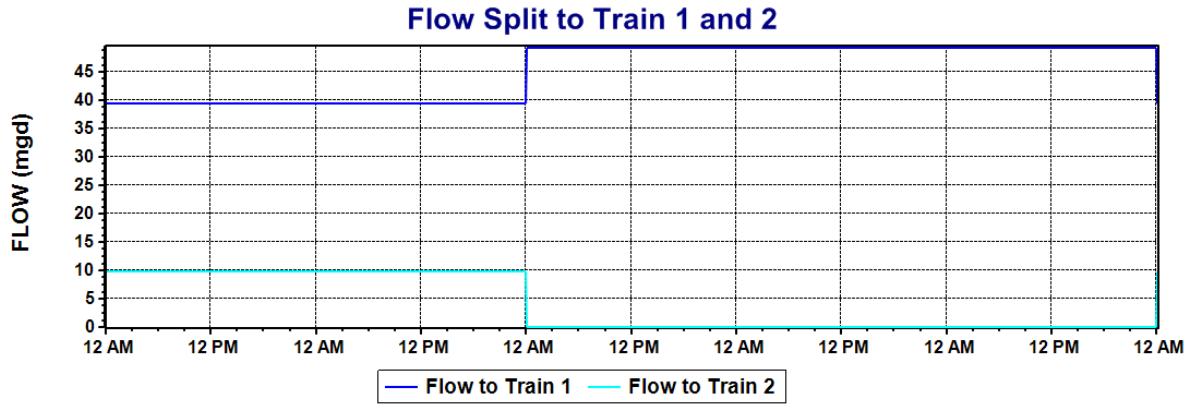
Setting up the BioWin Album

When simulating Variable Volume Bioreactors, it is a good idea to plot the liquid volume in the BioWin Album to monitor changes in volume and to ensure there is no unintended overflow (*i.e.* the liquid volume remains below the tank volume). In the example below, we can see the liquid volumes plotted for T2. The volumes are maintained at the expected operational volume for the first two days (*i.e.* 0.3 Mil. Gal for each anoxic basin, 0.5 Mil. Gal for each aerobic basin). At the start of day 2 the contents of each reactor are drained and the volume remains empty (*i.e.* at 0.02% of full) for 3 days.

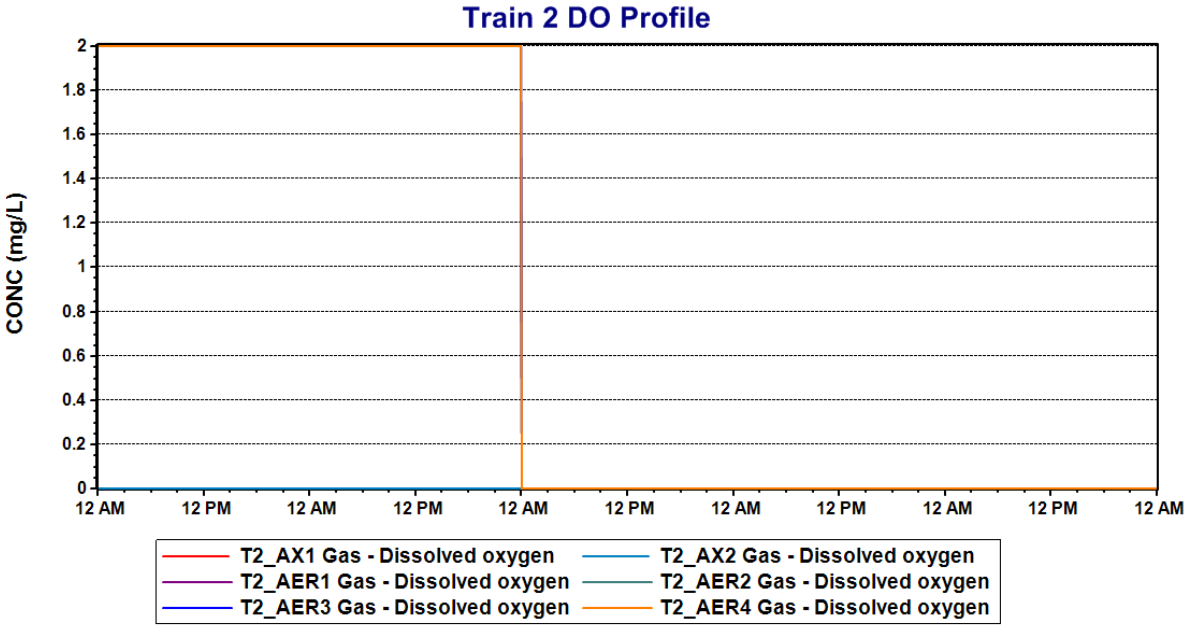


Since we also incorporated a schedule into the feed splitter the changes in operation can be easily tracked by plotting the flows in this splitter. We see at 12AM on the third day of operation the flow to the second train T2 (represented by the underflow of the feed splitter or the series called Flow to Train 2) falls to zero and the flow to the first train (represented by the main flow of the feed splitter or the series called Flow to Train 1) increases by

approximately 10 mgd.



The change in the DO pattern can also be easily tracked by adding a DO concentration plot to the album. The anoxic basins show a constant DO concentration of 0 mg/L. The aerobic basins show a DO concentration of 2 mg/L for the first two days then aeration is switched off on the third day and the DO concentrations fall to 0 mg/L.



In this example, scheduled events such as flow and DO concentration changes were specified using daily time intervals. BioWin's database **Display/data interval** is set to 5 minutes so daily changes are captured in the BioWin Album. If a scheduled event occurs at an interval less than BioWin's database display/data interval then this information will not be captured in the BioWin Album. It is important to ensure that BioWin's database display/data interval specified in **Project > Database > Data Interval** is set to a value equal to or lower than any timed operational event.

Running the Simulation

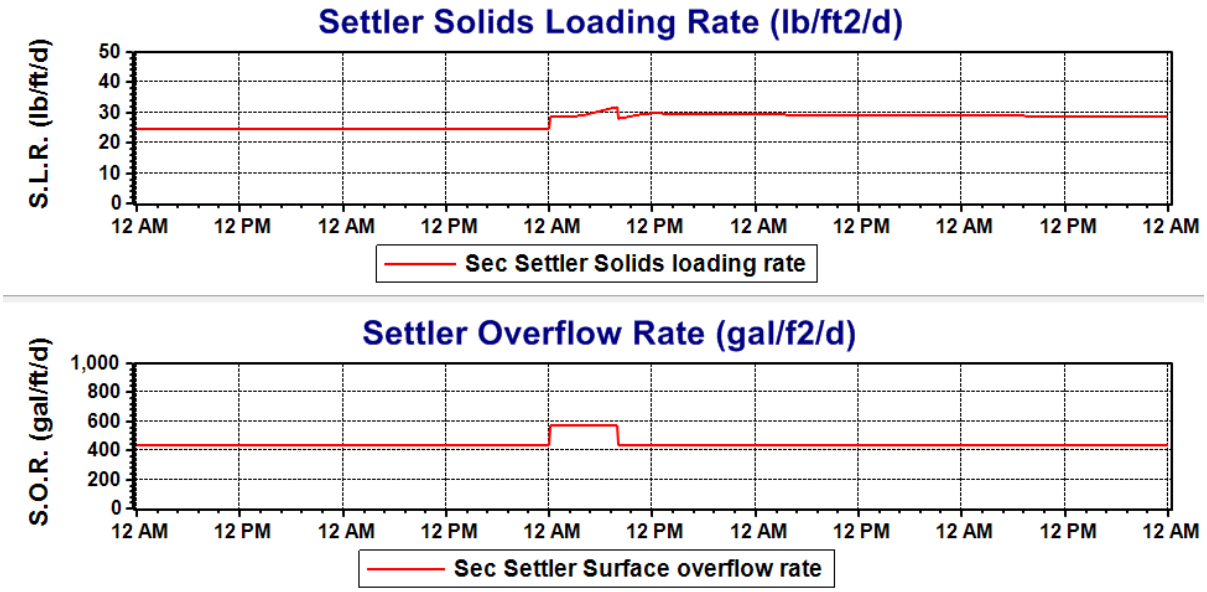
The BioWin file that accompanies this edition of the BioWin Advantage was simulated using the following steps:

1. A steady state simulation was run from seed values.
2. A dynamic simulation was run from current values for 5 days.

Upon finding a steady state solution, BioWin will show an alarm in each of the variable volume bioreactors indicated that the flow specifications could not be achieved. During a steady state simulation, BioWin uses the time-weighted average flow and concentrations for any timed operational pattern to find the steady state solution. In this case, the outflow that is being calculated in each variable volume bioreactor is higher than the time-weighted average inflow to the reactors so the specifications can't be achieved. BioWin will instead set the outflow = inflow to maintain a flow balance. We can ignore this alarm since BioWin's assumption of inflow = outflow makes sense for simulating the plant prior to taking the second train offline. Once a steady state solution is found a dynamic solution can be ran for 5 days from current values.

Results and Discussion

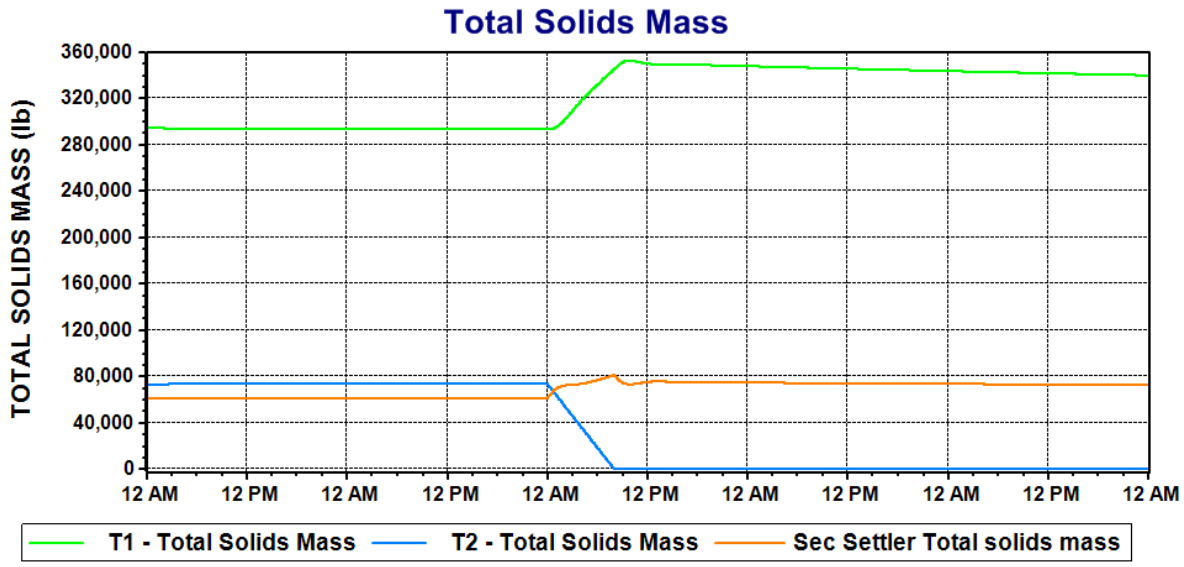
The BioWin Album contains many charts that are useful for interpreting the response of the system as T2 is taken offline. First, let's look at the secondary clarifier response to taking one train offline. Dynamic plots were added to the album to track the settler solids loading rate and the settler overflow rate over the 5 day dynamic simulation (shown below).

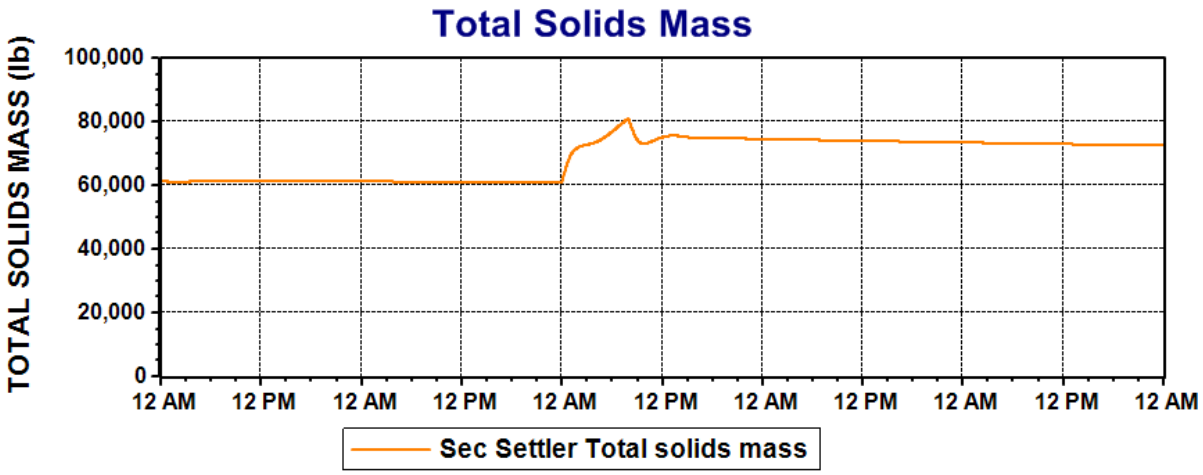


When T2 starts draining (at 12AM on the third day of the simulation) we see a spike in

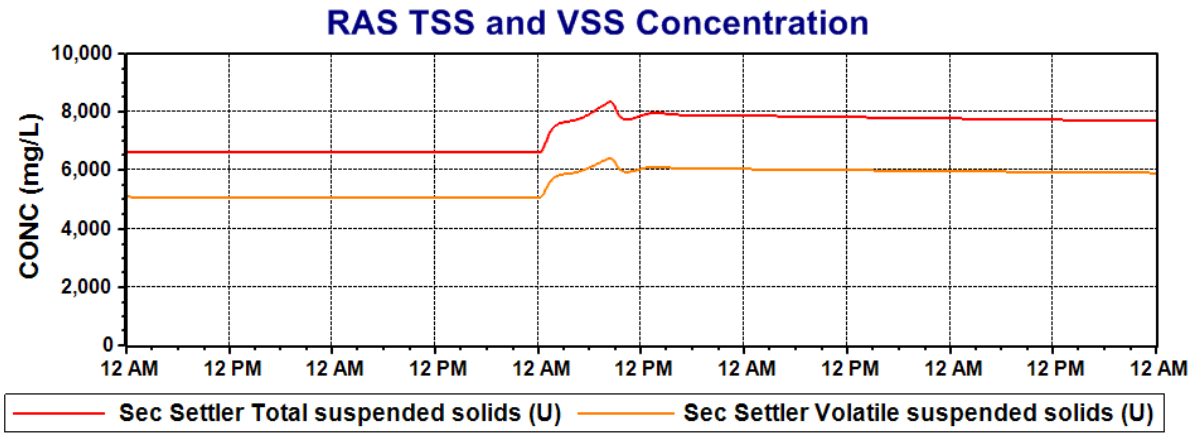
both the solids loading rate and the overflow rate. The spike in the overflow rate is sustained for the 8-hour period over which T2 is drained as a result of the increased flow to the clarifier during this time. Once the train has finished draining the overflow rate returns to its original value since the extra flow has ceased. The solids loading rate also increases over the 8-hour period that T2 is drained since additional mixed liquor is being sent to the clarifier. The solids loading rate remains higher than the original rate after T2 finishes draining since the solids inventory in T1 has increased. The shift in the solids inventory around the process can be tracked with the following dynamic profile plots:

- The total solids mass in T1, T2 and the secondary clarifier (the bottom plot shows the secondary settler total solids mass inventory at a larger scale) [**Note**: the total solids mass parameter is found in the element specific list of the chart editor, the total solids mass in each reactor representing T1 and T2 are summed respectively using function series to obtain the overall total solids mass in each train]

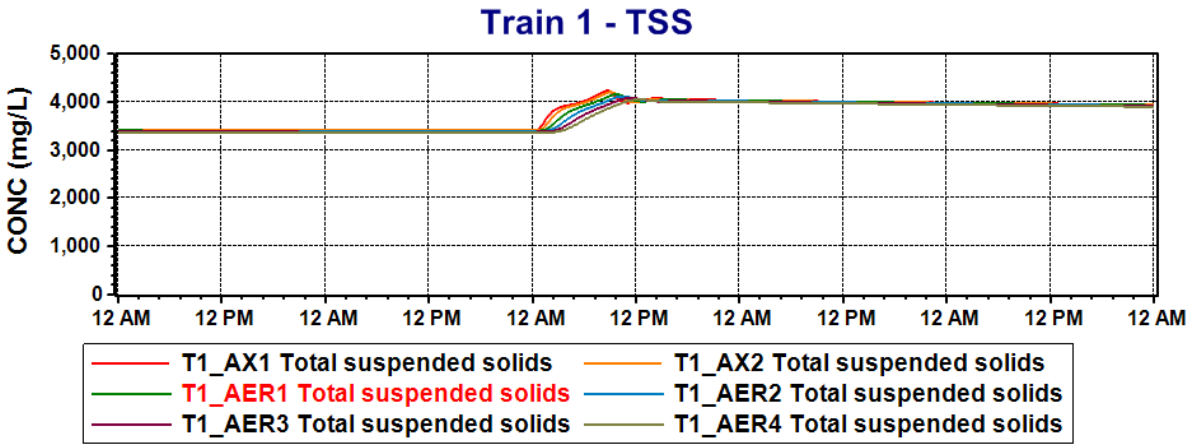




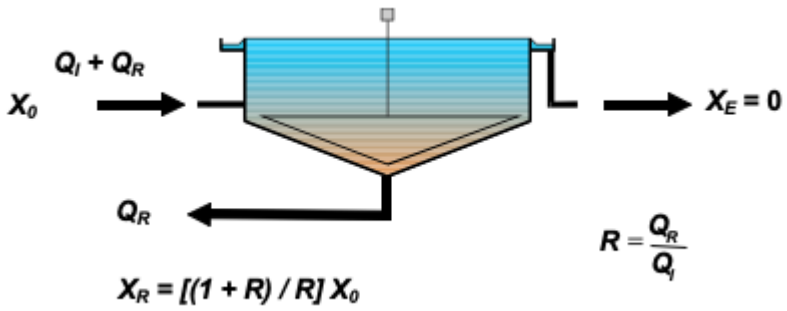
- The MLSS and MLVSS concentrations in the RAS, and



- The MLSS response in T1.



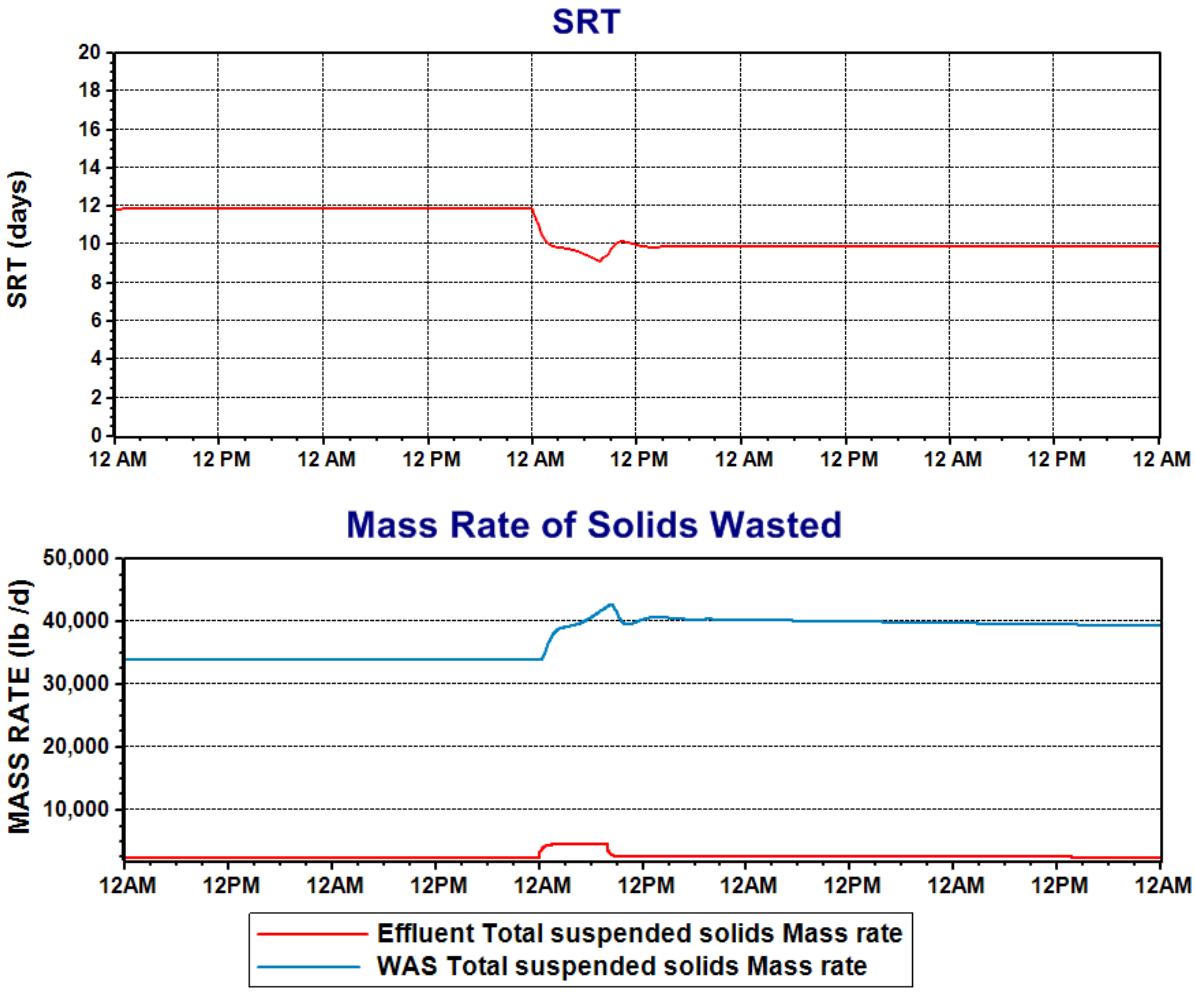
From the total solids mass plots we see that the solids inventory is shifted out of T2 into the clarifier and then into T1 via the RAS. This is illustrated by a decrease in solid mass in T2 and a corresponding increase in solids mass in the clarifier and T1. The solids shift into the clarifier results in an increase in the RAS concentration. If we consider a simplified mass balance around the secondary clarifier, the thickening factor that the settler provides is related to the ratio R of the RAS flow (Q_R) to the flow into the clarifier (Q_I) (note that this simple approach is useful for calculating thickening factors; BioWin does not assume that the effluent solids are zero and does in fact count for them):



Since the RAS rate is kept constant at 100% of the influent flow, when T2 solids are sent

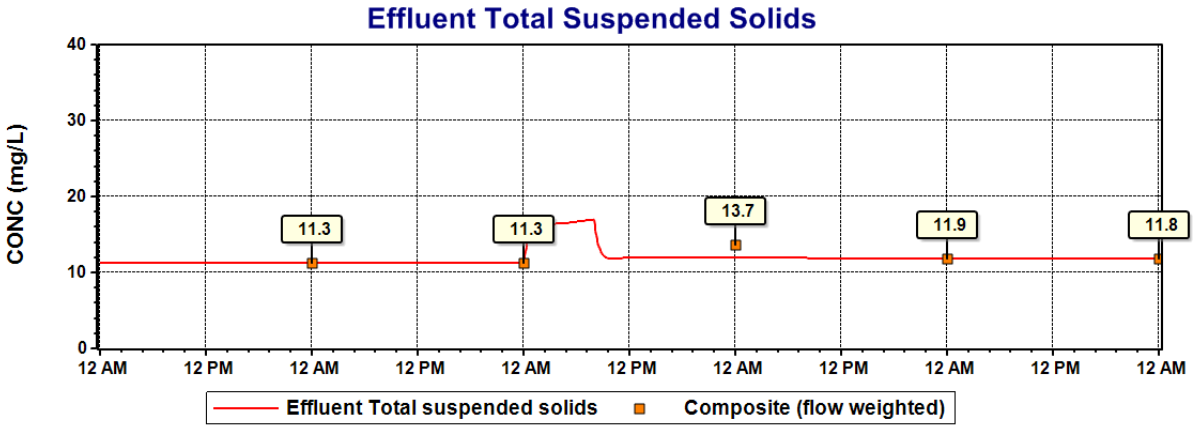
to the clarifier the flow to the clarifier increases (Q_I) resulting in a decrease in the thickening factor R to a value less than one since $Q_I > Q_R$. However, solving the mass balance for the RAS concentration X_R results in an expression where the R factor appears in the denominator. Since R is a fraction less than 1, dividing by R will act to increase the RAS concentration X_R. We see this increase in the RAS concentration in the RAS chart above. This increased RAS concentration sends more solids back to T1 resulting in an increase in the solids inventory and hence MLSS concentration in T1 as shown in the MLSS profile plot for T1 above.

If we plot the SRT for the system (see chart below), we see a decrease in the SRT over the period when T2 is emptied. This corresponds to the increase in the mass rate of solids wasted in the WAS (see WAS mass rate plot below) since the WAS is split off from the RAS line.

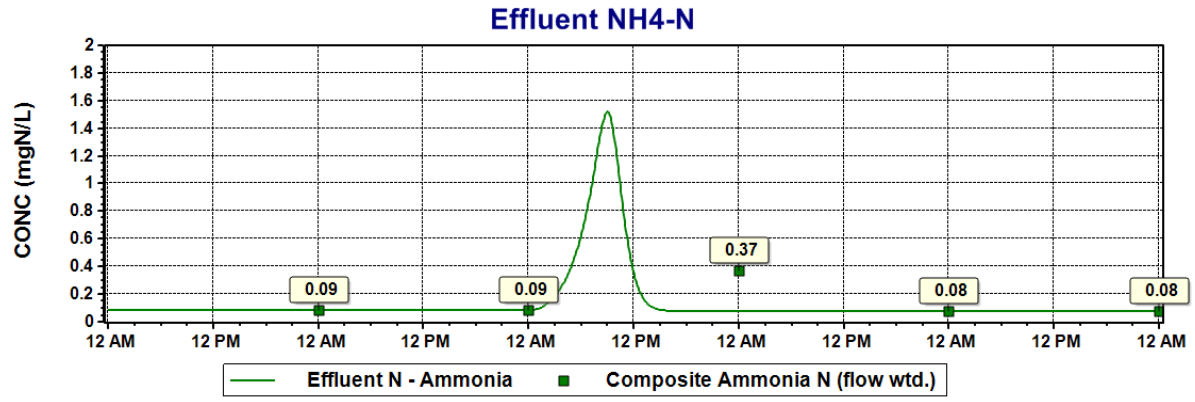


Finally, let's look at the effluent response to taking one train offline. The shift of solids out of T2 and into the clarifier results in a spike in the effluent solids concentration (see effluent TSS profile below) since settling performance is impacted by the higher solids loading rate. Twenty-four hour flow weighted composite effluent TSS concentrations show a small increase to approximately 13.7 mg/L TSS during the period when T2 is taken

offline.



A plot of the effluent ammonia (see below) shows some ammonia breakthrough during the 8-hour T2 draining event. This corresponds to the spike in effluent solids. In addition, the increased mass rate of solids wasted during the 8-hour draining event resulted in a reduction in the overall SRT which can decrease nitrification performance. A reduction in nitrification performance would be especially pronounced if the draining event occurred at the same time the plant was processing a peak flow. Using a simulation set up like this example would allow for the exploration of strategies to mitigate this type of breakthrough.



An important takeaway from this exercise is the use of the model clarifier element over an ideal clarifier element for the investigation of solids inventory changes. An ideal clarifier element applies a percentage removal to the clarifier inlet suspended solids mass rate and uses a fixed sludge layer which cannot migrate up or down. As such, the ideal clarifier does not account for the potential impact of factors such as surface overflow rate, solids loading rate, upstream aeration tank MLSS, or sludge accumulation in the clarifier on predicted effluent solids concentration and solids inventory as rigorously as the model clarifier element. The main benefit derived from using the model clarifier unit is that it gives some indication of potential problems of sludge blanket accumulation. As such, its use represents a more sophisticated modeling approach compared to the ideal clarifier element.

Conclusions

This addition of the BioWin Advantage shows us how to configure and simulate taking a train offline for service or maintenance and draining the solids from the train. The basic requirements of setting up a Variable Volume Bioreactor are described and the impact that taking a train out of service has on the secondary clarifier and effluent quality are investigated. The flexibility of BioWin's Variable Volume Bioreactor element is highlighted, along with the use of the BioWin Album for investigating our simulation set-up and results. The advantage of using a model clarifier element for investigating shifts in solids inventory is also illustrated.

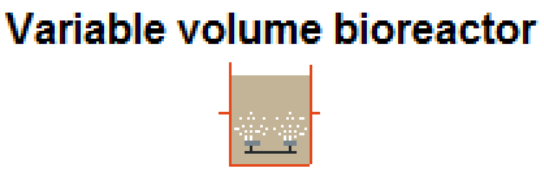
We trust that you found this technical topic both interesting and informative. Please feel free to contact us at support@envirosim.com **(Subject: The BioWin Advantage)** with your comments on this article or suggestions for future articles.

The EnviroSim Team

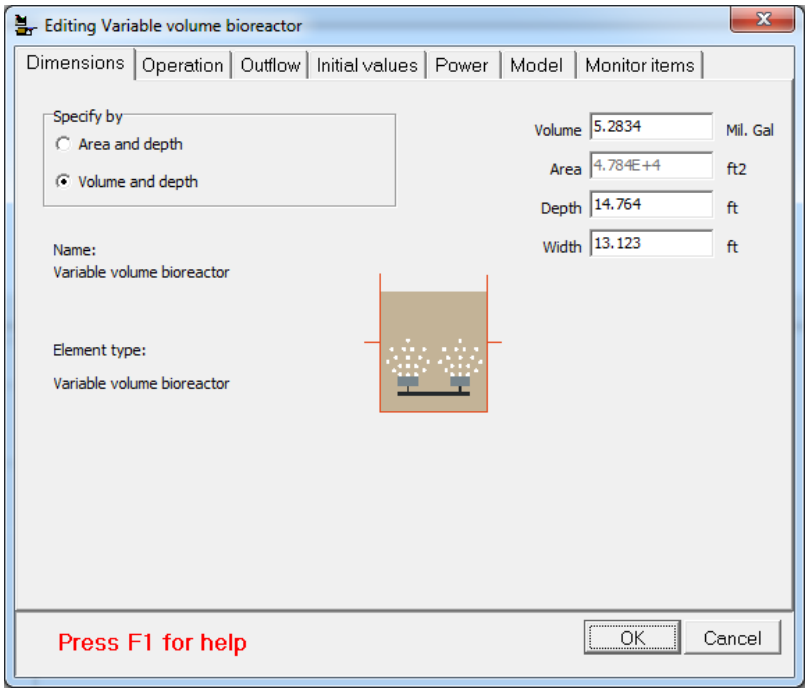
Appendix A

Brief Background on Simulating Variable Volume Bioreactors in BioWin

It is worth reviewing how a Variable Volume bioreactor might be simulated in BioWin. A Variable Volume bioreactor element, shown below, has a wide application in simulating various wastewater treatment processes. For example, this element can be used to simulate a batch reactor, an equalization basin, any process that requires intermittent decanting, or it can be operated at constant volume in place of a regular bioreactor element.



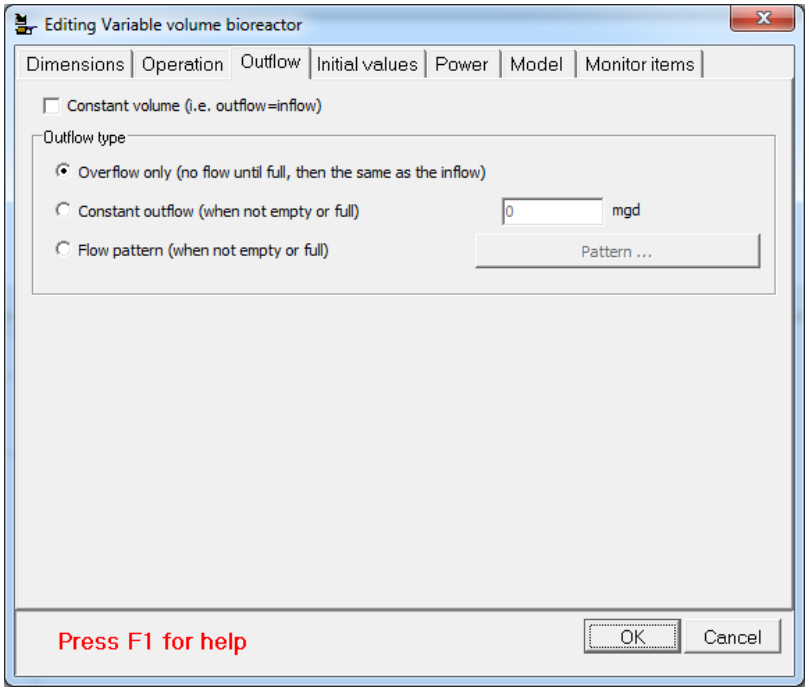
Double-clicking on the element opens the properties dialog box (see figure below). The properties dialog box is identical to that of a normal bioreactor, except for two additional tabs labelled **Outflow** and **Initial Values** (discussed further below). The physical dimensions of the variable volume tank can be entered in the **Dimensions** tab. Operating parameters such as aeration and diffuser specifications as well as local temperature be specified in the **Operation** tab. Power specifications for mechanical mixing can be entered in the **Power** tab. The **Model** tab allows the user to use / change local model parameters.



The **Outflow** tab, shown below, offers options for specifying the outflow from this unit. By default, the **Outflow type** of **Overflow only (no flow until full, then the same as the inflow)** is selected. Checking the **Constant volume (*i.e.* outflow = inflow)** check box will allow you to operate the variable volume bioreactor with a constant volume (*i.e.* the same way as a normal bioreactor element). In this case, the entire liquid volume entered on the dimension tab is used for reactions. When **Constant volume (*i.e.* outflow = inflow)** is unchecked then an **Outflow type** can be specified. The following summarizes what the various outflow type selections do:

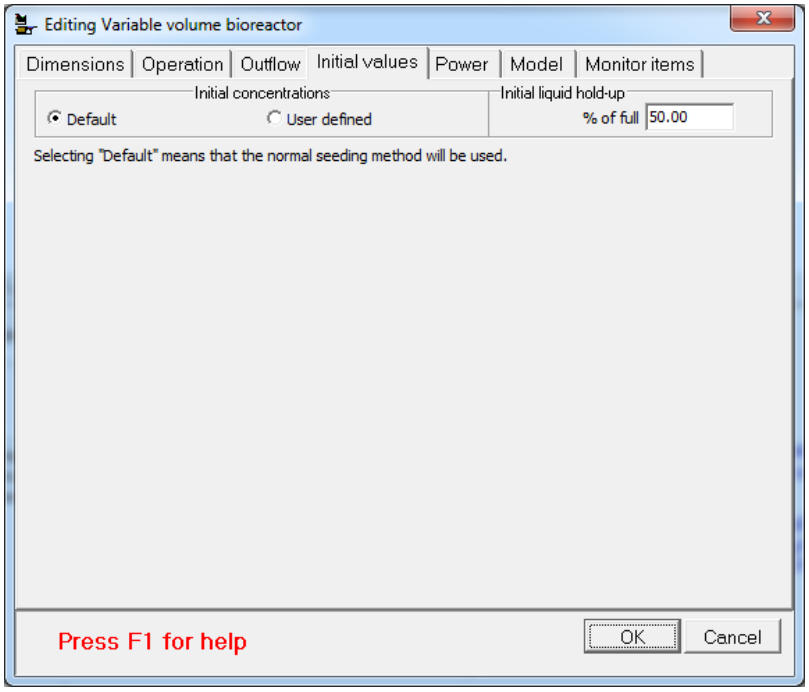
- **Overflow only (no flow until full, then the same as the inflow)**: the variable volume bioreactor fills up, and then overflows at the influent flow rate. This setting could be used to simulate start-up of a bioreactor.
- **Constant outflow (when not empty or full)**: the outflow always tries to attain the specified constant rate, except when physically constrained (*i.e.* when the variable volume bioreactor is full or empty).
- **Flow pattern (when not empty of full)**: selecting this option will activate the **Pattern…**button. Clicking **Pattern…**will open an outflow itinerary where a variable outflow pattern can be specified. The outflow always tries to attain the current specified pattern rate, except when physically constrained (*i.e.* when the variable volume bioreactor is full or empty).

Whenever the reactor is full, it will overflow at the influent rate regardless of the constant outflow setting. When the reactor is empty and the outflow rate is set higher than the influent rate, the reactor will only have an outflow equal to the influent flow, so as not to have a negative volume. If the outflow rate is set lower than the influent rate, then the reactor will begin to fill up.

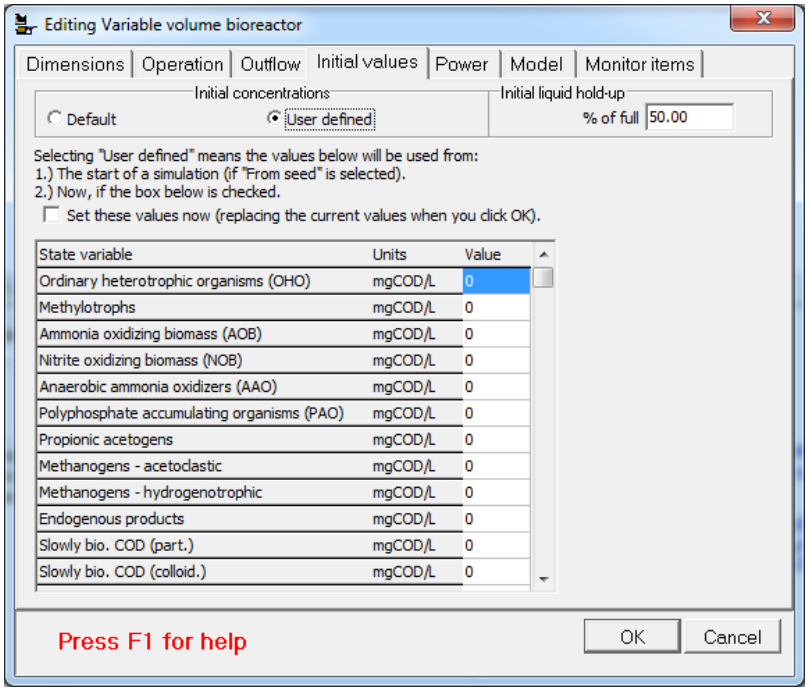


It's important to note that a variable volume bioreactor is considered to be "empty" when the volume is 0.02% of full and is considered to be "full" when the volume is 99.98% of full.

The **Initial values** tab, shown below, is used for specifying the initial settings for the variable volume/batch bioreactor concentrations and volume. The **Initial liquid hold-up** is used to specify the initial liquid volume in the reactor. The initial liquid volume is expressed as a **% of full** where "full" is the volume specified on the **Dimensions** tab. The lower and upper limits on this value are 0.02 and 99.98%, respectively. It's important to note that when a steady state simulation is run, the initial liquid hold-up volume will be used for calculations. When a dynamic simulation is run from seed values, depending on how the **outflow** is configured, the liquid volume within the variable volume reactor will either (1) start filling up beginning from the initial liquid hold-up, (2) start draining beginning from the initial liquid hold-up, or (3) remain the same if inflow=outflow.



There are two methods for setting up **Initial concentrations**. The first case is illustrated above where the **Default** option is selected. When this option is selected, BioWin applies default seed values for all the state variables (except volume) in the same manner it would for other bioreactor elements. The second case is illustrated below where the **User defined** option is selected. In this case, an editable list of state variables is displayed in the dialog box. This allows you to enter you own seed values for state variables in the variable volume bioreactor element.



If you choose **User defined** initial concentrations, then there are two conditions when the User defined initial concentrations can be used:

1. If the box labeled “**Set these values now…**” is checked then the concentrations specified are inserted in the state vector as soon as the **OK** button is clicked. This option overrides any existing state variable values. Consequently, a dynamic simulation started from this point will use the **User defined** initial concentrations regardless of whether you choose to start from **Seed** values or **Current** values.

2. If the box labeled “**Set these values…**” is NOT checked then the initial concentrations will be inserted in the reactor state vector when you begin a dynamic or steady state simulation AND choose to start the simulation from **Seed** values.

The use of these options is explained further in the BioWin Manual under **Building Configurations > Element Descriptions > Bioreactors > Variable Volume/Batch Bioreactor**.