GPS-X Lite Exercises

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GPS-X Lite Exercises

Refer to the ***Quick Start Guide GPS-X Lite*** available from the Help selection on the menu bar for supporting information on how to perform specific actions that will be used in the following exercises.

For more detailed content related to the fully-functional version of GPS-X, users can reference the ***Technical Reference for GPS-X*** and ***Complete User Guide for GPS-X***.

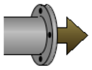
Note:

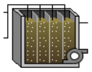
- GPS-X Lite implements a limited version of the International Water Association Activated Sludge Model no. 1 (ASM1).
- The simulation results obtained in GPS-X Lite can differ slightly based on several factors including the model's initial conditions, convergence criteria, and rounding. Therefore, you may observe minor variances between the model results and provided solutions. If you find significant differences (>0.1%) then we recommend that you check your model setting and model inputs.
- Refer Appendix -A for more details of the biological models used in GPS-X Lite.

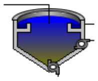
Exercise 1 – Configuration of the Starting Point Layout

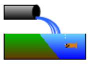
Note: Only make the specified changes outlined in the steps below as this layout will be used at the starting point for all subsequent exercises.

1. Open a new model layout in GPS-X Lite. (You will be prompted with “Close current layout”; choose Yes.)
2. Navigate to the process table on the left-hand side of the window.
3. Within the appropriate process group, left-click and drag the following process objects onto the drawing board.
    - Influent – Wastewater Influent
    - Suspended Growth Processes – Plug-Flow Tank
    - Secondary Clarifiers – Circular Secondary Clarifier
    - Tools – Wastewater Outfall



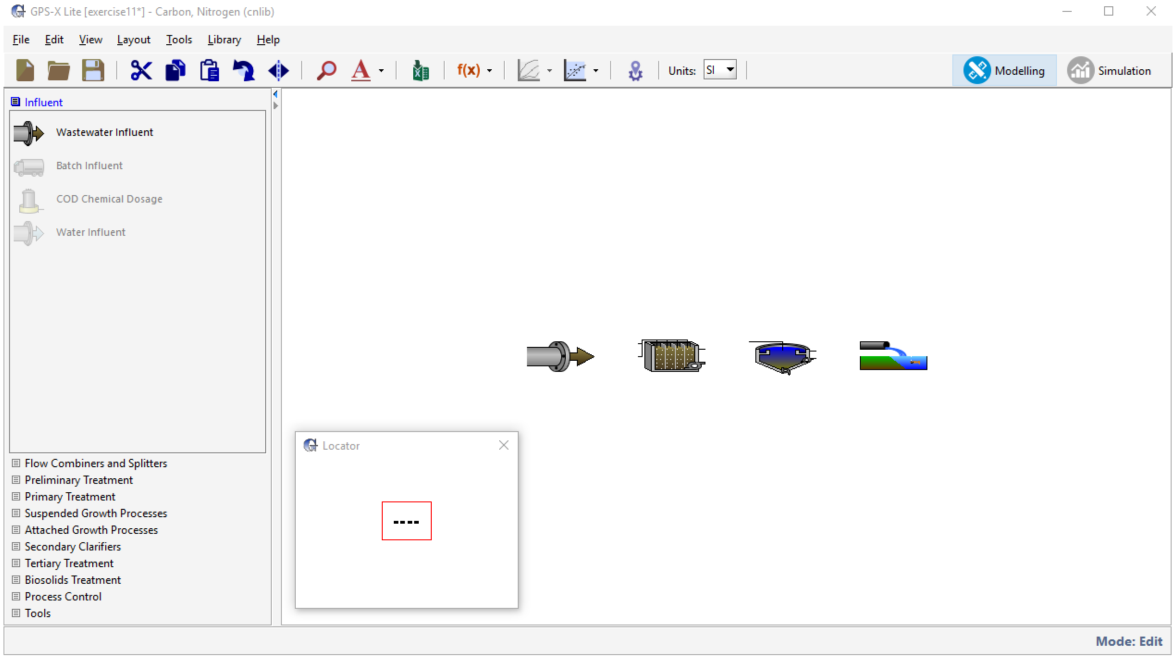


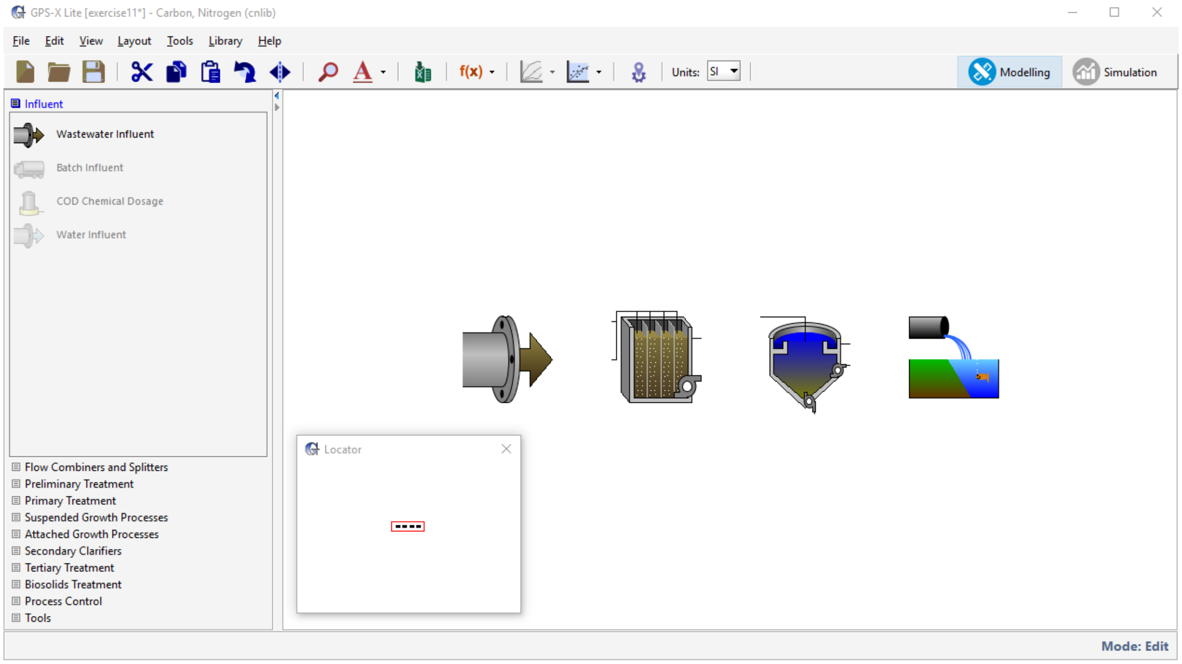




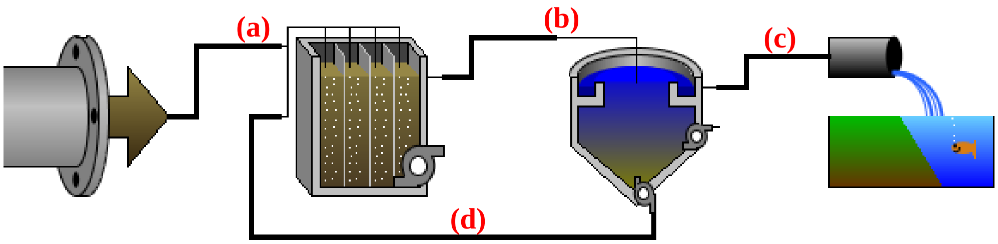
Note: In GPS-X Lite only specific unit objects are available to the user. All items that are greyed-out are disabled and have only been included to demonstrate what is available in the fully functional version of GPS-X. In addition, users have access to only one instance of each available object.

4. Select the Locator button and zoom-in on the model layout so there is less white space showing on the drawing board and the icons are enlarged.



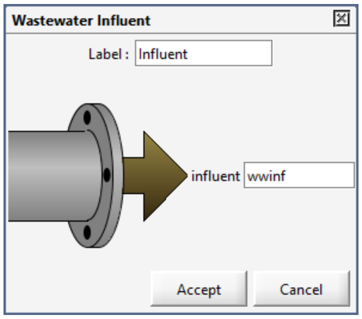


5. Create the following connection paths:
    a) Wastewater Influent → PFR Influent (upper reactor connection point)
    b) PFR Effluent → Secondary Clarifier Influent
    c) Secondary Clarifier Effluent → Wastewater Outfall
    d) Secondary Clarifier Underflow (the bottom connection point from the reactor) → PFR Recycle Influent (lower reactor connection point)



Note: The stream connections must be exactly as specified in the image above.

6. Click on the Labels button located on the toolbar to display the stream and object names. Make the following adjustments to the names of the model objects by right-clicking on the object and selecting *Labels…* from the dropdown menu.
   - Wastewater Influent:
     - Label: Influent
     - influent: wwinf

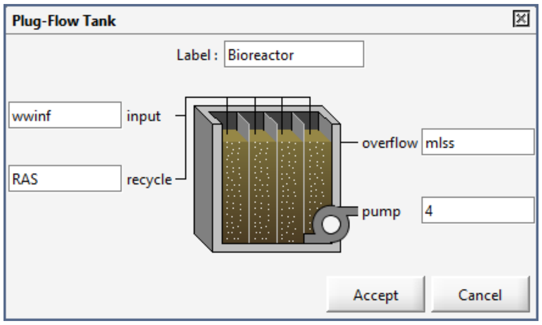


Wastewater Influent

Label : Influent

influent wwinf

   - Plug-Flow Tank:
     - Label: Bioreactor
     - input: wwinf
     - recycle: RAS
     - overflow: mlss



Plug-Flow Tank

Label : Bioreactor

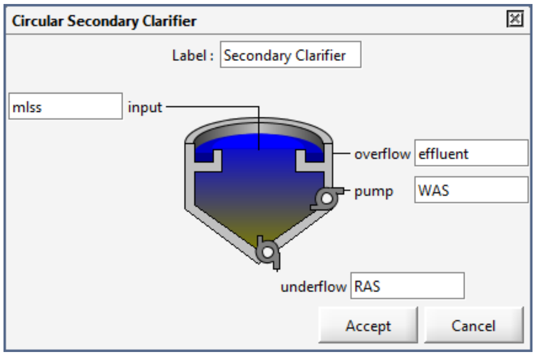
wwinf input

RAS recycle

overflow mlss

pump 4

   - Circular Secondary Clarifier:
     - Label: Secondary Clarifier
     - influent: mlss
     - overflow: effluent
     - pump: WAS
     - underflow: RAS



Circular Secondary Clarifier

Label : Secondary Clarifier

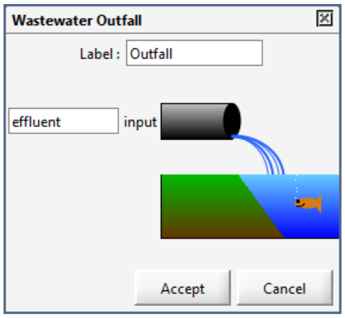
mlss input

overflow effluent

pump WAS

underflow RAS

- Wastewater Outfall:
  - Label: Outfall
  - input: effluent



Wastewater Outfall

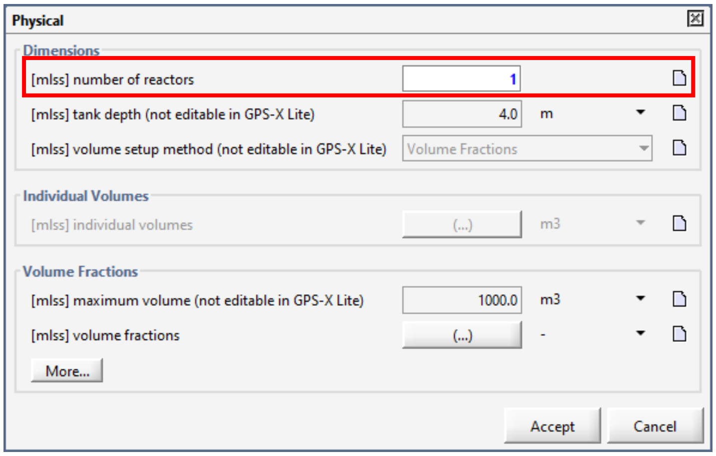
Label : Outfall

effluent input

Note:

- Once you have specified the name of a stream in one location, the name will automatically appear at the other end of the connection.
- After specifying labels, they will not appear in a reloaded layout unless *View > Display Labels > Stream/Objects* has been selected.

7. Right-click on the Bioreactor and go to *Input Parameters > Physical* and set **the number of reactors** to **1**. This change allows the PFR model object to be modelled as a complete mixed (CM) reactor.



Physical

Dimensions

[mlss] number of reactors 1

[mlss] tank depth (not editable in GPS-X Lite) 4.0 m

[mlss] volume setup method (not editable in GPS-X Lite) Volume Fractions

Individual Volumes

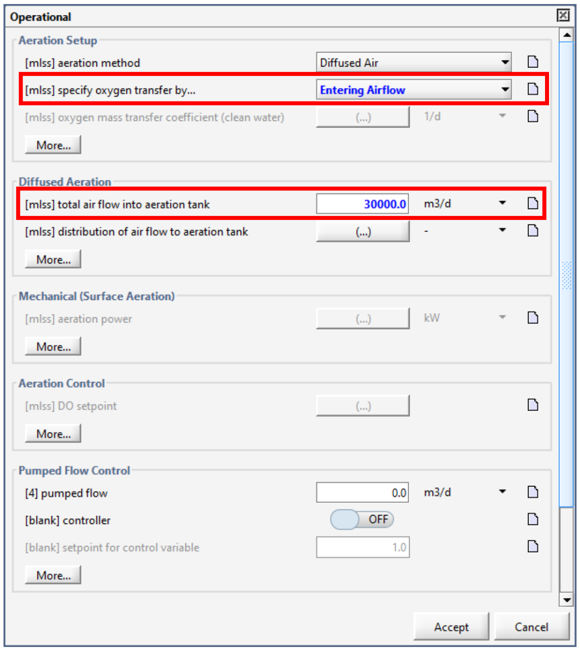
[mlss] individual volumes (...) m3

Volume Fractions

[mlss] maximum volume (not editable in GPS-X Lite) 1000.0 m3

[mlss] volume fractions (...) -

8. Right-click on the Bioreactor and navigate to *Input Parameters > Operational* and change the **specify oxygen transfer by…** to **Entering airflow**, and set the **total air flow into aeration tank** to **30,000 m^3/d**.



Operational

Aeration Setup

[mlss] aeration method: Diffused Air

[mlss] specify oxygen transfer by...: Entering Airflow

[mlss] oxygen mass transfer coefficient (clean water): (...) 1/d

Diffused Aeration

[mlss] total air flow into aeration tank: 30000.0 m3/d

[mlss] distribution of air flow to aeration tank: (...) -

Mechanical (Surface Aeration)

[mlss] aeration power: (...) kW

Aeration Control

[mlss] DO setpoint: (...)

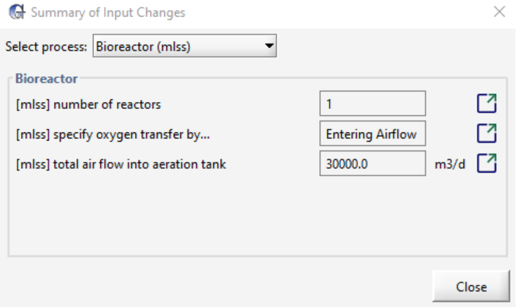
Pumped Flow Control

[4] pumped flow: 0.0 m3/d

[blank] controller: OFF

[blank] setpoint for control variable: 1.0

9. A useful feature in GPS-X Lite is the ability to quickly review the changes the user has made to the default model settings. Right-click on the Bioreactor and navigate to **Summary of changes**. In the form that appears you should see a list of all input changes.



Summary of Input Changes

Select process: Bioreactor (mlss)

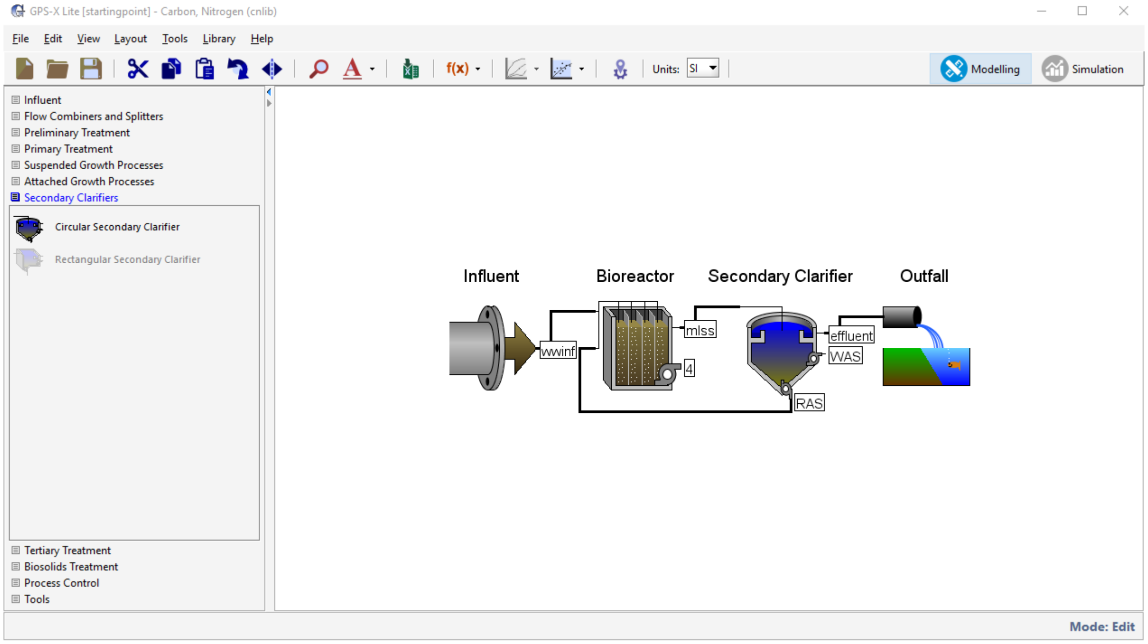
Bioreactor

[mlss] number of reactors: 1

[mlss] specify oxygen transfer by...: Entering Airflow

[mlss] total air flow into aeration tank: 30000.0 m3/d

10. Click on the arrow button to the right of the **total air flow into aeration tank** variable in the form. The same form in Step 8 should appear. Close this window.
11. Save the model layout under an appropriate name (i.e. startingpoint).

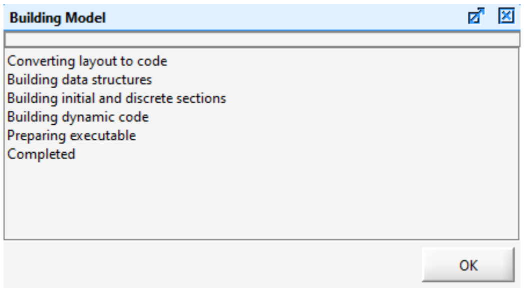


To become familiar with how to navigate to various parts of the interface, recreate and fill out the table below through completion of the following steps. Make note of the units indicated in the table.

(**Exercise 1 – Question 1**)

	Model Object	Parameter	Unit	Value
Modelling Mode	Wastewater Influent	Influent Flow	m^3/d	
	Bioreactor	Maximum Volume	m^3	
	Secondary Clarifier	Surface	m^2	
Simulation Mode	Influent	Ammonia	mgN/L	
	Bioreactor	Temperature	C	
	Bioreactor	Hydraulic Residence Time	hr	
	Secondary Clarifier	TSS Removal Efficiency	%	

12. Right-click on the Wastewater Influent object and navigate to *Flow > Flow Data* and report the value of the **influent flow** rate.
13. Right-click on the Bioreactor and navigate to *Input Parameters > Physical* and report the value of the **maximum volume**.
14. Right-click on the Secondary Clarifier and navigate to *Input Parameters > Physical* and report the value of the **surface area**.
15. Switch into **simulation mode**. The “Model Builder” will activate if this is the first simulation to be conducted with the layout and its parameters. Once the model is built, run the simulation by pressing the Start button located in the bottom-left corner of the interface, on the simulation toolbar.

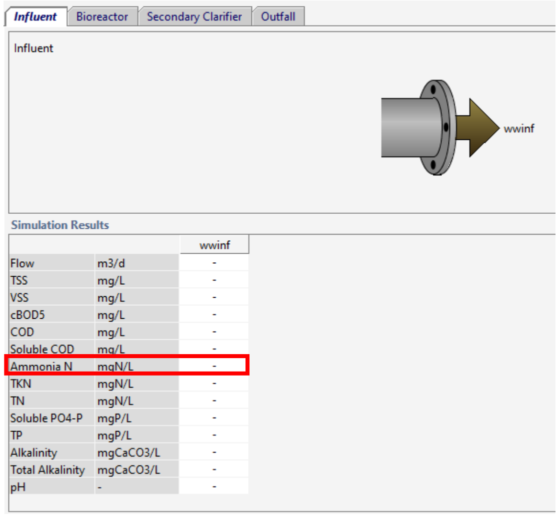


Converting layout to code
Building data structures
Building initial and discrete sections
Building dynamic code
Preparing executable
Completed

Note: Values will appear in the locations specified in the images below once the simulation has been run.

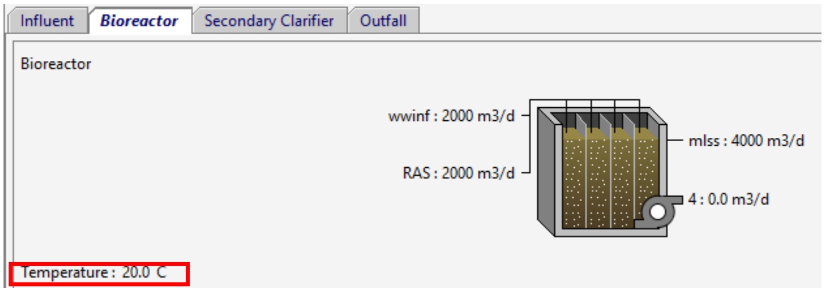
Below the Outputs menu ribbon, output tabs have been automatically created for the four model objects on the drawing board: Influent, Bioreactor, Secondary Clarifier, and Outfall.

16. Select the *Influent output tab* and report the **ammonia concentration** under the Simulation Results header.

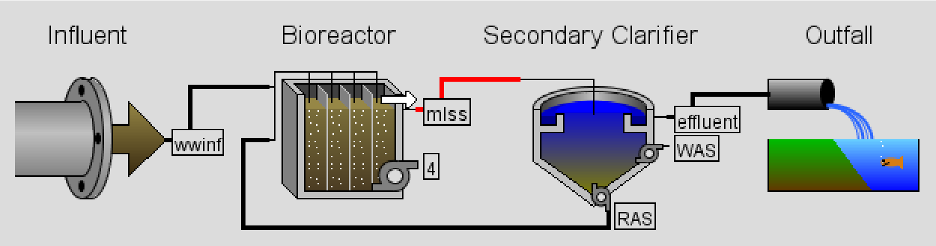


		wwinf
Flow	m3/d	-
TSS	mg/L	-
VSS	mg/L	-
cBOD5	mg/L	-
COD	mg/L	-
Soluble COD	mg/L	-
Ammonia N	mgN/L	-
TKN	mgN/L	-
TN	mgN/L	-
Soluble PO4-P	mgP/L	-
TP	mgP/L	-
Alkalinity	mgCaCO3/L	-
Total Alkalinity	mgCaCO3/L	-
pH	-	-

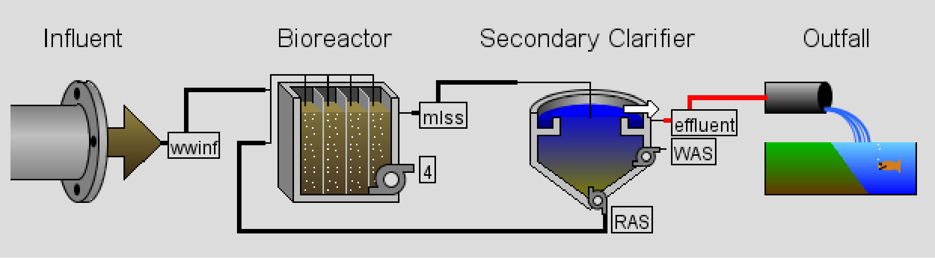
17. Select the *Bioreactor output tab* and report the **temperature** in the top section of the panel.



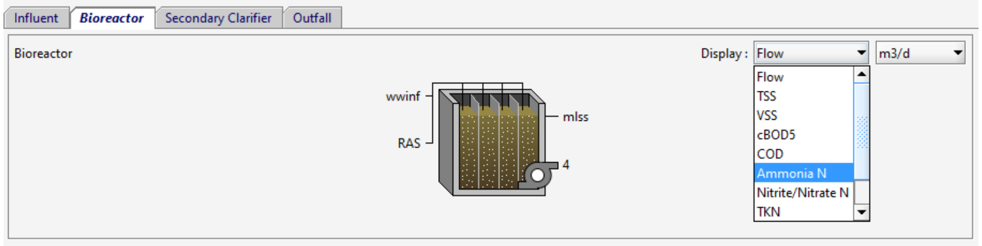
18. Right-click on the mlss stream of the Bioreactor (ensure that the mouse changes to a connecting arrow before clicking) and navigate to *Output Variables > Hydraulic Variables and* report the **hydraulic residence time** in the table.



19. Right-click on the effluent stream of the Secondary Clarifier (ensure that the mouse changes to a connecting arrow before clicking) and navigate to *Output Variables* > *Performance Variables and* report the **TSS removal efficiency** in the table.



20. Select the *Bioreactor output tab*, and in the top-right corner of the panel, choose from the **Display** dropdown, **Ammonia N**. Notice that the values of the streams on the bioreactor image will become updated. Report a screenshot of these results. (**Exercise 1 – Question 2**)



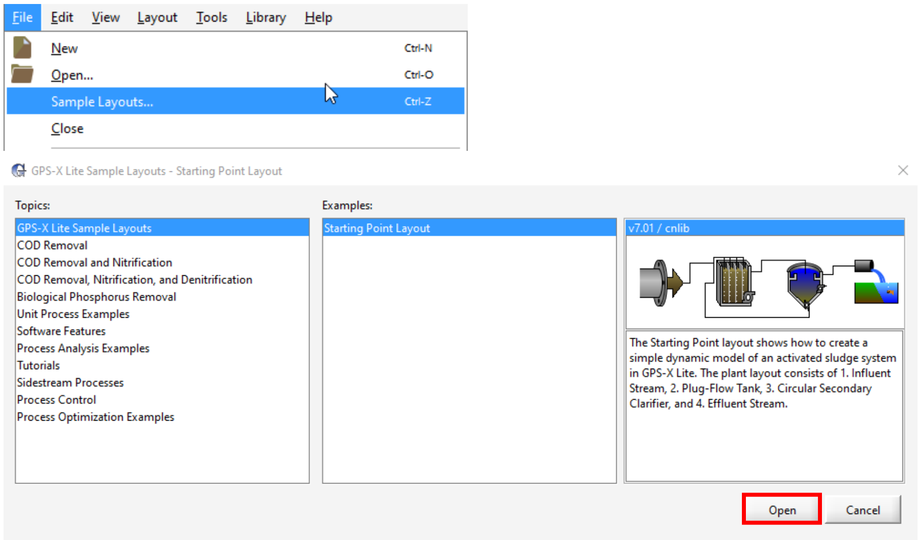
Exercise 2 – Influent Advisor

This exercise will explore two concepts related to wastewater influent characterization.

a) Relationship between state and composite variables using the GPS-X influent advisor tool
b) Effect of influent characterization on plant performance

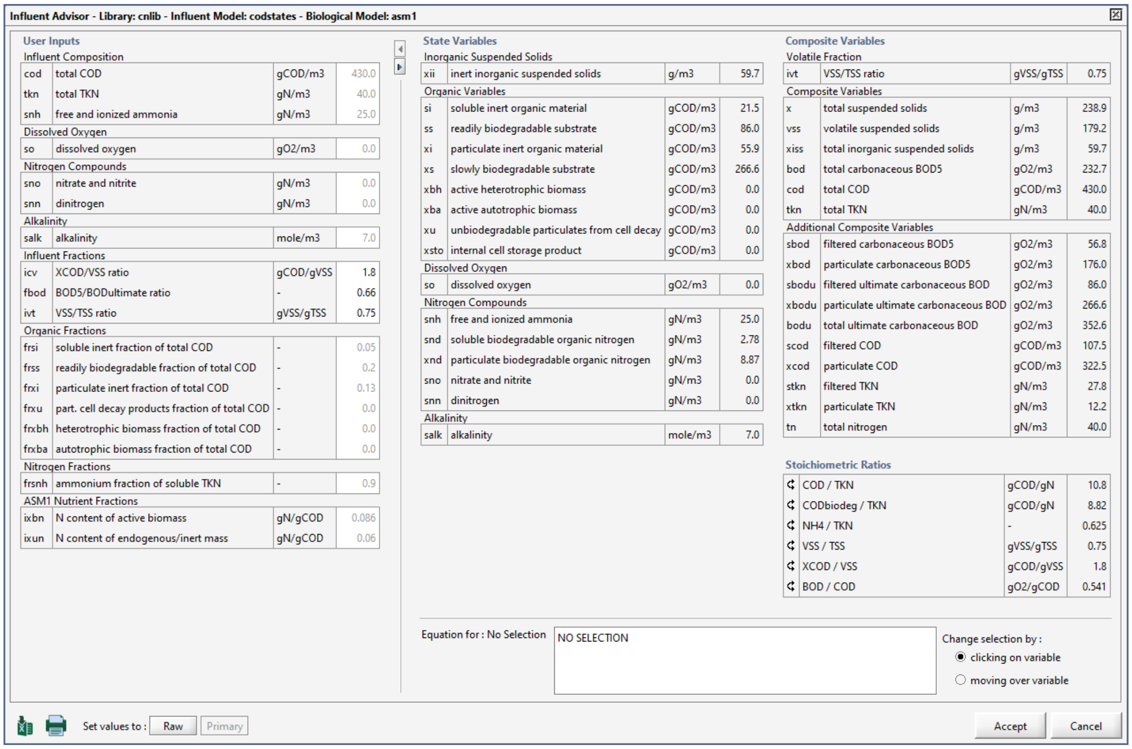
1. Open the Starting Point model layout developed in Exercise 1 and save it under a different name.

   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*



The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. Switch into Modelling Mode.
3. Right-click on the Influent Wastewater object and navigate to *Composition > Influent Characterization* to open the **Influent Advisor** tool.



Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition

cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Influent Fractions

icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Organic Fractions

frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0

Nitrogen Fractions

frsnh	ammonium fraction of soluble TKN	-	0.9

ASM1 Nutrient Fractions

ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids

xii	inert inorganic suspended solids	g/m3	59.7

Organic Variables

si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction

ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Composite Variables

x	total suspended solids	g/m3	238.9
vss	volatile suspended solids	g/m3	179.2
xiss	total inorganic suspended solids	g/m3	59.7
bod	total carbonaceous BOD5	gO2/m3	232.7
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0

Additional Composite Variables

sbod	filtered carbonaceous BOD5	gO2/m3	56.8
xbod	particulate carbonaceous BOD5	gO2/m3	176.0
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

⇄	COD / TKN	gCOD/gN	10.8
⇄	CODbiodeg / TKN	gCOD/gN	8.82
⇄	NH4 / TKN	-	0.625
⇄	VSS / TSS	gVSS/gTSS	0.75
⇄	XCOD / VSS	gCOD/gVSS	1.8
⇄	BOD / COD	gO2/gCOD	0.541

Equation for : No Selection

NO SELECTION

Change selection by :
● clicking on variable
○ moving over variable

The Influent Advisor is divided into 3 sections: User Inputs, State Variables, and Composite Variables. The following segment provides some background into how these variables are related in the carbon, nitrogen library (cnlib) in GPS-X.

User Inputs – these values are editable by the user (Note: **access is limited to Influent Fractions** in GPS-X Lite)

State Variables – these are the basic variables that are continuously integrated in the model over time. In practical applications the state variables are typically not easily measurable or interpretable.

Composite Variables – these are variables that are calculated (composed of) the state variables. Unlike the state variables, the composite variables can be combined into forms that are typically measured, such as TSS, BOD, COD, and TKN.

The box-and-arrow diagrams below demonstrate the relationships that exist between the user inputs and state and composite variables. The notation is as follows:

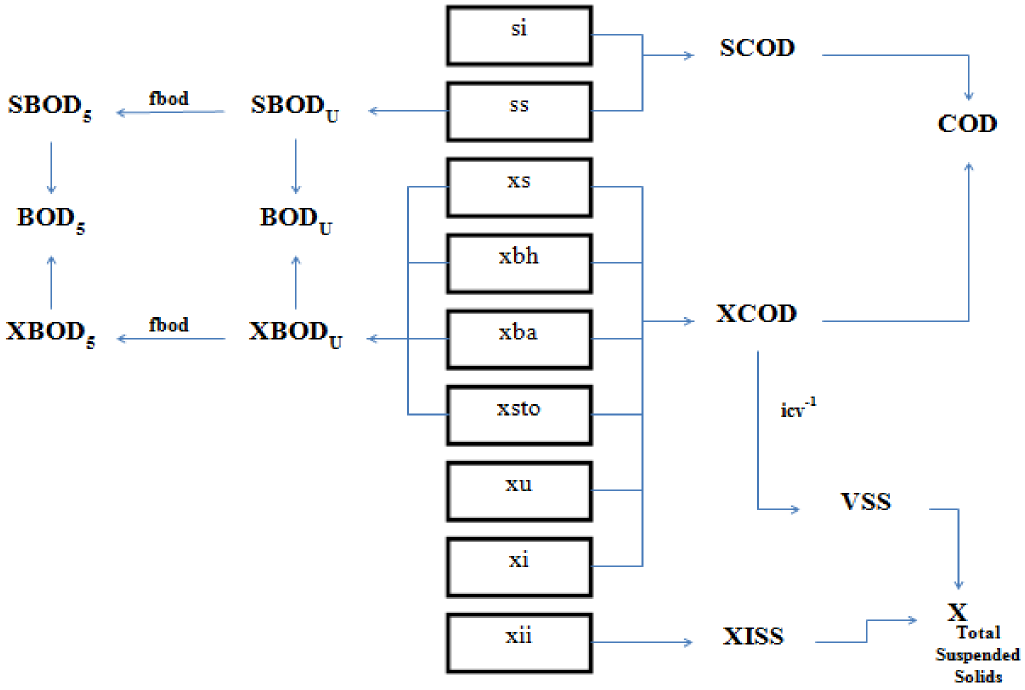
- Variables in **BOLD CAPITALS** are the composite variables
- Connection line shows the direction of the calculation
- Multiple lines converging indicate summation
- Stoichiometric parameters above a connection line indicate multiplication of the parameter with the previous boxed variable
- A broken line indicates that the stoichiometric parameters are model dependent

Note: GPS-X uses the usual assumption that 1 mg ultimate BOD equals 1 mg of degradable COD.

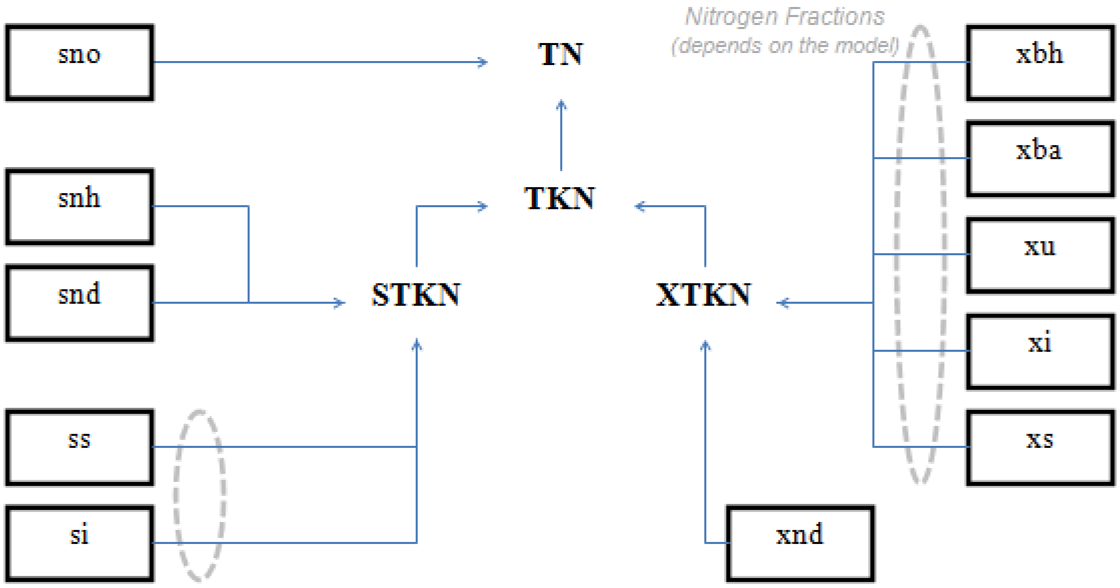
The definitions of the state and composite variables used in diagrams are summarized in the table below.

State Variables		Composite Variables	
si	Soluble inert material	**BOD_5**	5-day Biological Oxygen Demand
ss	Readily biodegradable soluble substrate	**$SBOD_5$**	Soluble BOD_5
xs	Slowly biodegradable substrate	**$XBOD_5$**	Particulate BOD_5
xbh	Heterotrophic biomass	**BOD_U**	Ultimate Biological Oxygen Demand
xba	Autotrophic biomass	**$SBOD_U$**	Soluble BOD_U
xsto	Internal cell storage products	**$XBOD_U$**	Particulate BOD_U
xu	Unbiodegradable cell products	**COD**	Chemical Oxygen Demand
xi	Particulate inert material	**SCOD**	Soluble COD
xii	Inorganic inert particulate	**XCOD**	Particulate COD
sno	Nitrite and nitrate	**X**	Total Suspended Solids
snh	Ammonia nitrogen	**VSS**	Volatile Suspended Solids
snd	Soluble organic nitrogen	**XISS**	Total Inorganic Suspended Solids
xnd	Particulate biodegradable organic nitrogen	**TN**	Total Nitrogen
		TKN	Total Kjeldahl Nitrogen
		STKN	Soluble TKN
		XTKN	Particulate TKN

a) Relationship between the CNLIB state variables and the TSS, BOD, and COD composite variables



b) Relationship between the CNLIB state variables and the TN and TKN composite variables



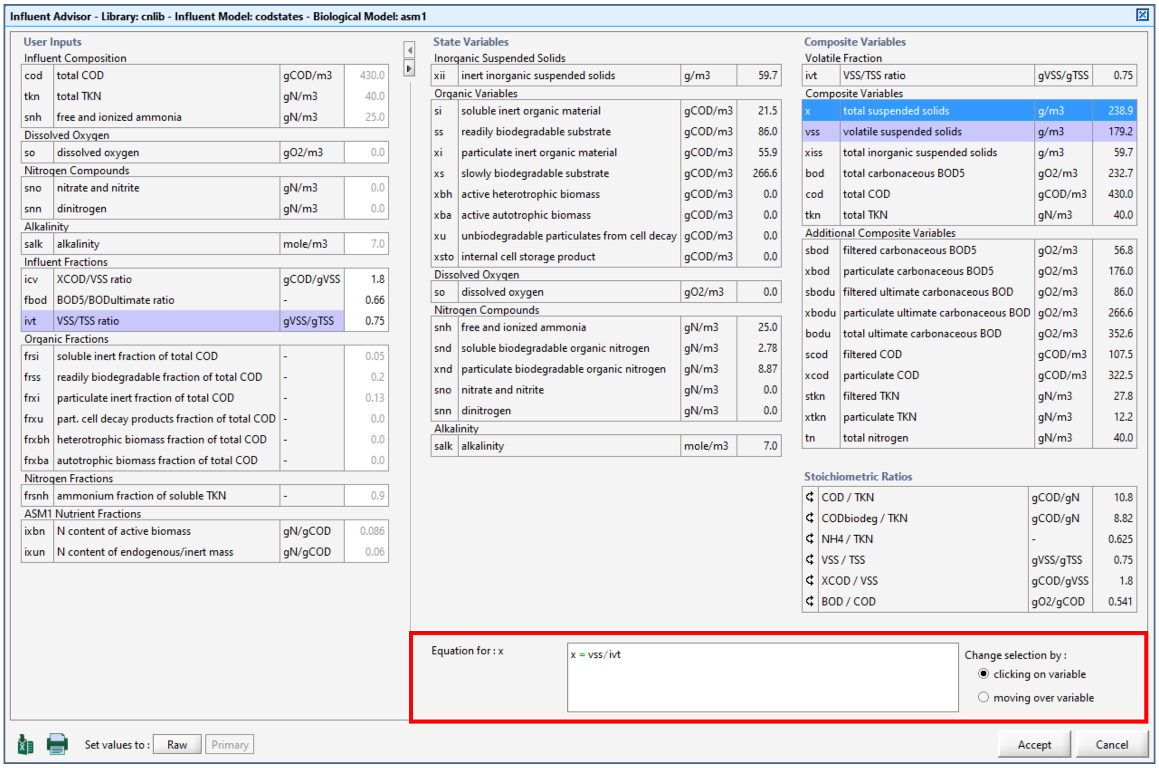
Visualization of the relationships outlined above can be explored using the GPS-X Influent Advisor tool.

4. Select the **total suspended solids (x)** variable within the 3rd panel in the window under the Composite Variables header.

   Selection of this variable should highlight the volatile suspended solids variable (vss) under the Composite Variables panel and the VSS/TSS ratio (ivt) under the User Inputs column.

   This relationship is also presented at the bottom of the window in the form of an equation:

$$x = \frac{vss}{ivt}$$



Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition			
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0
Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
Nitrogen Compounds			
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
Alkalinity			
salk	alkalinity	mole/m3	7.0
Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
ivt	VSS/TSS ratio	gVSS/gTSS	0.75
Organic Fractions			
frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0
Nitrogen Fractions			
frsnh	ammonium fraction of soluble TKN	-	0.9
ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	59.7
Organic Variables			
si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0
Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
Alkalinity			
salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction			
ivt	VSS/TSS ratio	gVSS/gTSS	0.75
Composite Variables			
x	total suspended solids	g/m3	238.9
vss	volatile suspended solids	g/m3	179.2
xiss	total inorganic suspended solids	g/m3	59.7
bod	total carbonaceous BOD5	gO2/m3	232.7
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
Additional Composite Variables			
sbod	filtered carbonaceous BOD5	gO2/m3	56.8
xbod	particulate carbonaceous BOD5	gO2/m3	176.0
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

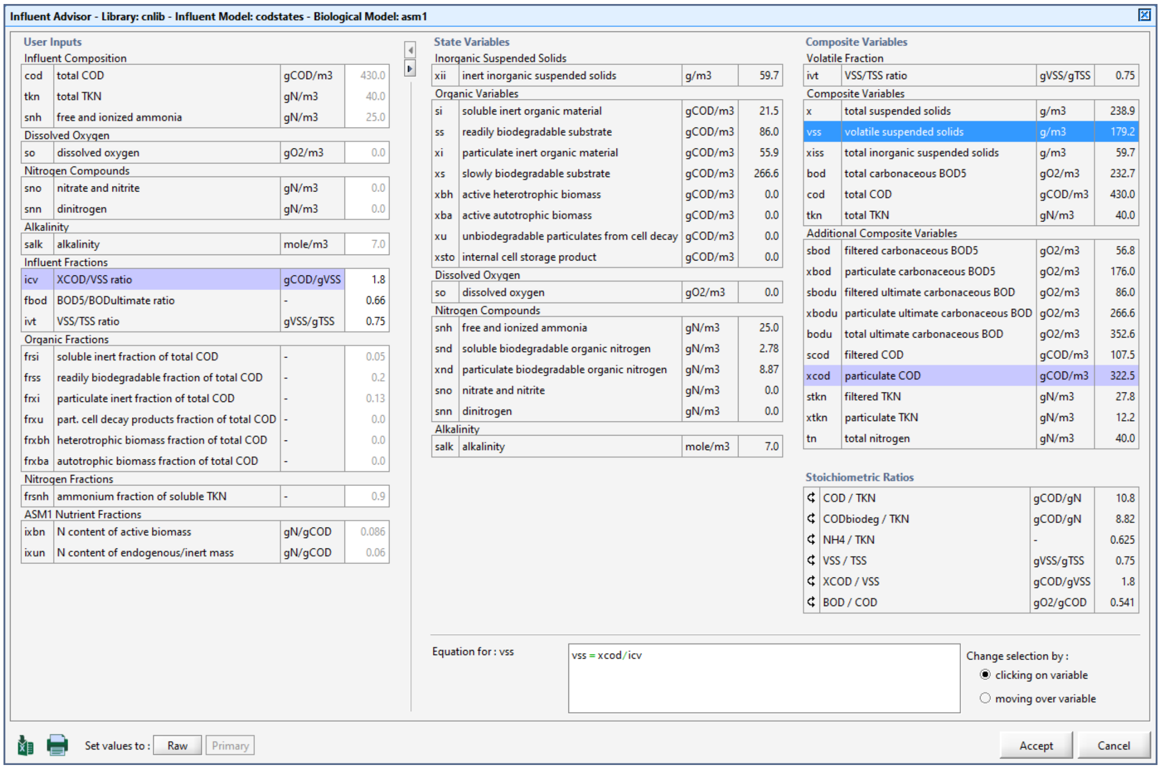
COD / TKN	gCOD/gN	10.8
CODbiodeg / TKN	gCOD/gN	8.82
NH4 / TKN	-	0.625
VSS / TSS	gVSS/gTSS	0.75
XCOD / VSS	gCOD/gVSS	1.8
BOD / COD	gO2/gCOD	0.541

Equation for : x

x = vss/ivt

Change selection by :
● clicking on variable
○ moving over variable

5. Select the volatile suspended solids variable to determine how this composite variable is calculated.



Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition			
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0
Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
Nitrogen Compounds			
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
Alkalinity			
salk	alkalinity	mole/m3	7.0
Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
ivt	VSS/TSS ratio	gVSS/gTSS	0.75
Organic Fractions			
frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0
Nitrogen Fractions			
frsnh	ammonium fraction of soluble TKN	-	0.9
ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	59.7
Organic Variables			
si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0
Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
Alkalinity			
salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction			
ivt	VSS/TSS ratio	gVSS/gTSS	0.75
Composite Variables			
x	total suspended solids	g/m3	238.9
vss	volatile suspended solids	g/m3	179.2
xiss	total inorganic suspended solids	g/m3	59.7
bod	total carbonaceous BOD5	gO2/m3	232.7
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
Additional Composite Variables			
sbod	filtered carbonaceous BOD5	gO2/m3	56.8
xbod	particulate carbonaceous BOD5	gO2/m3	176.0
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

COD / TKN	gCOD/gN	10.8
CODbiodeg / TKN	gCOD/gN	8.82
NH4 / TKN	-	0.625
VSS / TSS	gVSS/gTSS	0.75
XCOD / VSS	gCOD/gVSS	1.8
BOD / COD	gO2/gCOD	0.541

Equation for : vss

vss = xcod/icv

Change selection by :
● clicking on variable
○ moving over variable

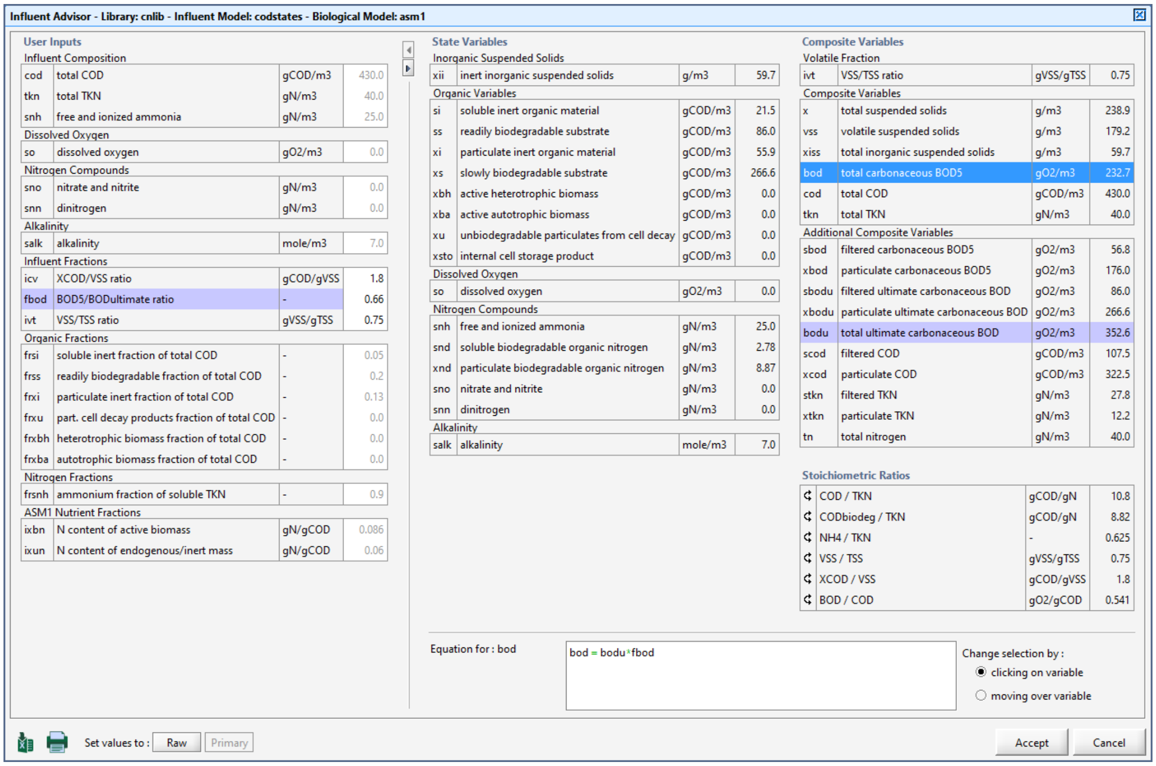
Substitute the equation for vss into the previous equation for x.

$$x = \frac{vss}{ivt}$$

$$x = \frac{\left(\frac{xcod}{icv}\right)}{ivt}$$

Now find the equation for *x* in terms of *cod*, *scod*, *icv*, and *ivt* by selecting the appropriate item to reveal the corresponding equation and substituting it into the above equation. In a similar manner determine the equation for *x* in terms of *cod*, *frss*, *frsi*, *icv*, and *ivt*. (Note: these variables define x solely in terms of user input variables.) (**Exercise 2 – Question 1**)

6. Select the total carbonaceous BOD_5 (bod) variable within the Composite Variables panel under the Composite Variables header.



Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition

cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Influent Fractions

icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Organic Fractions

frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0

Nitrogen Fractions

frsnh	ammonium fraction of soluble TKN	-	0.9

ASM1 Nutrient Fractions

ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids

xii	inert inorganic suspended solids	g/m3	59.7

Organic Variables

si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction

ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Composite Variables

x	total suspended solids	g/m3	238.9
vss	volatile suspended solids	g/m3	179.2
xiss	total inorganic suspended solids	g/m3	59.7
bod	total carbonaceous BOD5	gO2/m3	232.7
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0

Additional Composite Variables

sbod	filtered carbonaceous BOD5	gO2/m3	56.8
xbod	particulate carbonaceous BOD5	gO2/m3	176.0
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

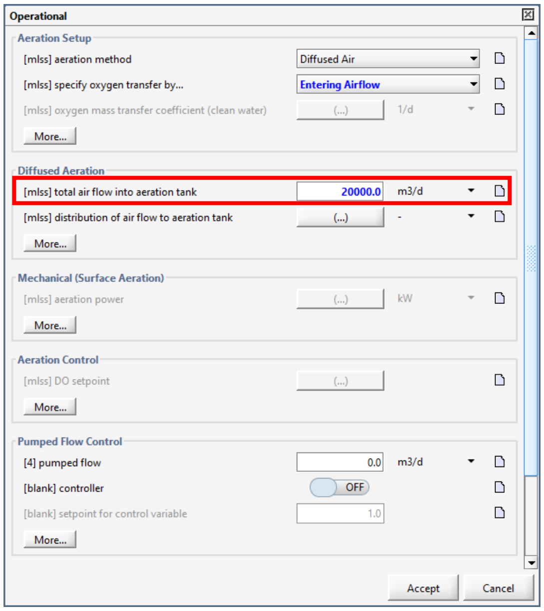
COD / TKN	gCOD/gN	10.8
CODbiodeg / TKN	gCOD/gN	8.82
NH4 / TKN	-	0.625
VSS / TSS	gVSS/gTSS	0.75
XCOD / VSS	gCOD/gVSS	1.8
BOD / COD	gO2/gCOD	0.541

Equation for : bod

bod = bodu*fbod

Change selection by :
● clicking on variable
○ moving over variable

7. Repeat the same process as in steps 4-5, to determine the equation relating total BOD_5 (bod) to total COD (cod) using the appropriate Influent Fractions” and Organic Fractions” parameters., (**Exercise 2 – Question 2**). Please note that xsto is not a state variable in ASM1 and it is not included in the calculations.
8. Close the Influent Advisor.
9. Right-click on the Bioreactor and navigate to *Input Parameters* > *Operational* and change the **total air flow into aeration tank** to **20,000 m^3/d**.



Operational

Aeration Setup

[mlss] aeration method	Diffused Air	
[mlss] specify oxygen transfer by...	Entering Airflow	
[mlss] oxygen mass transfer coefficient (clean water)	(...)	1/d

Diffused Aeration

[mlss] total air flow into aeration tank	20000.0	m3/d
[mlss] distribution of air flow to aeration tank	(...)	-

Mechanical (Surface Aeration)

[mlss] aeration power	(...)	kW

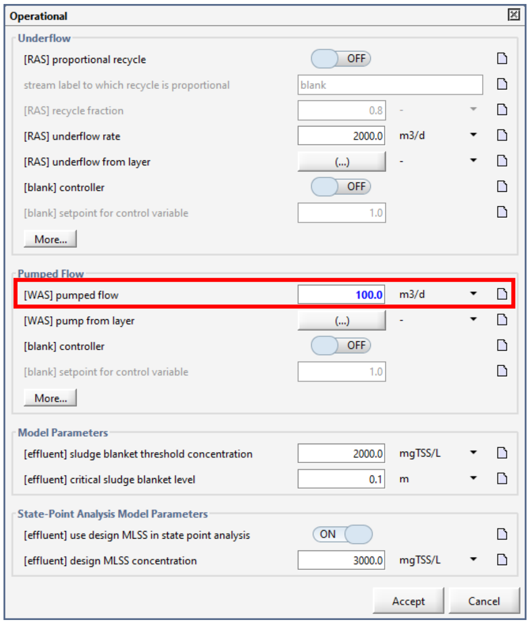
Aeration Control

[mlss] DO setpoint	(...)

Pumped Flow Control

[4] pumped flow	0.0	m3/d
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

10. Right-click on the Secondary Clarifier and navigate to *Input Parameters* > *Operational* and change the **pumped flow** to **100 m^3/d**.



Operational

Underflow

[RAS] proportional recycle	OFF	
stream label to which recycle is proportional	blank	
[RAS] recycle fraction	0.8	-
[RAS] underflow rate	2000.0	m3/d
[RAS] underflow from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

Pumped Flow

[WAS] pumped flow	100.0	m3/d
[WAS] pump from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

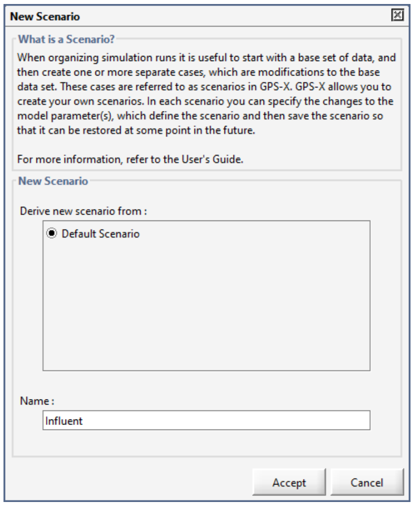
Model Parameters

[effluent] sludge blanket threshold concentration	2000.0	mgTSS/L
[effluent] critical sludge blanket level	0.1	m

State-Point Analysis Model Parameters

[effluent] use design MLSS in state point analysis	ON	
[effluent] design MLSS concentration	3000.0	mgTSS/L

11. Switch into Simulation Mode. Rebuild the model when prompted.
12. From the Simulation Toolbar navigate to *Scenario* > *New* and create a new scenario called “Influent.”



When organizing simulation runs it is useful to start with a base set of data, and then create one or more separate cases, which are modifications to the base data set. These cases are referred to as scenarios in GPS-X. GPS-X allows you to create your own scenarios. In each scenario you can specify the changes to the model parameter(s), which define the scenario and then save the scenario so that it can be restored at some point in the future.

For more information, refer to the User's Guide.

Derive new scenario from :

● Default Scenario

Name : Influent

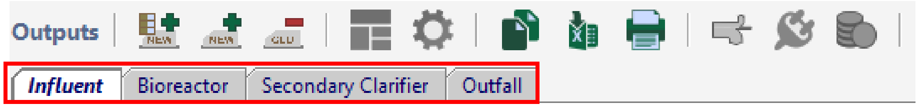
In the following scenarios you will explore the effect of changes in the influent characterization on the plant performance.

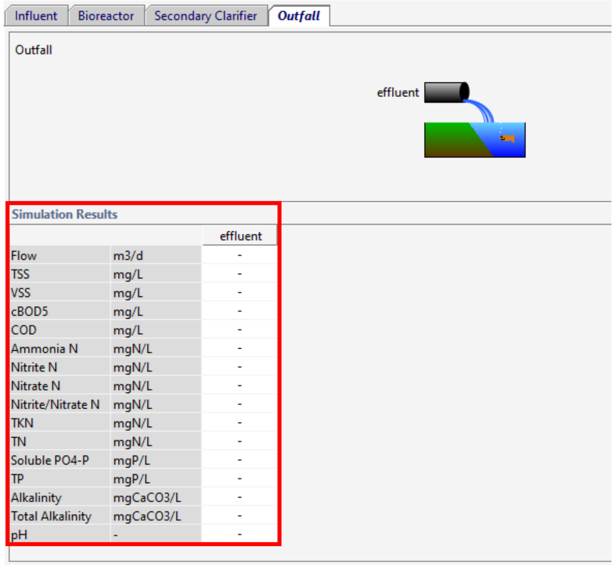
Scenario 1 – XCOD/VSS Ratio

In a word processor, create the table below to record your answers for the following steps.

	Influent	**Bioreactor**	**Secondary Clarifier**
XCOD/VSS Ratio = 1.8	TSS (mg/L)	MLSS (mg/L)	RAS TSS (mg/L)
	VSS (mg/L)	MLVSS (mg/L)	Effluent TSS (mg/L)
XCOD/VSS Ratio = 1.4	TSS (mg/L)	MLSS (mg/L)	RAS TSS (mg/L)
	VSS (mg/L)	MLVSS (mg/L)	Effluent TSS (mg/L)

13. Run the simulation at steady-state. By default, the XCOD/VSS Ratio (icv) is set to 1.8, fbod= 0.66, and ivt = 0.75. Check the Influent Advisor (Step 3 above).
14. Through navigation to the various output tabs, record your observations in the table. In addition, report a screenshot of the simulation results on the Outfall output tab. (**Exercise 2 – Question 3**)

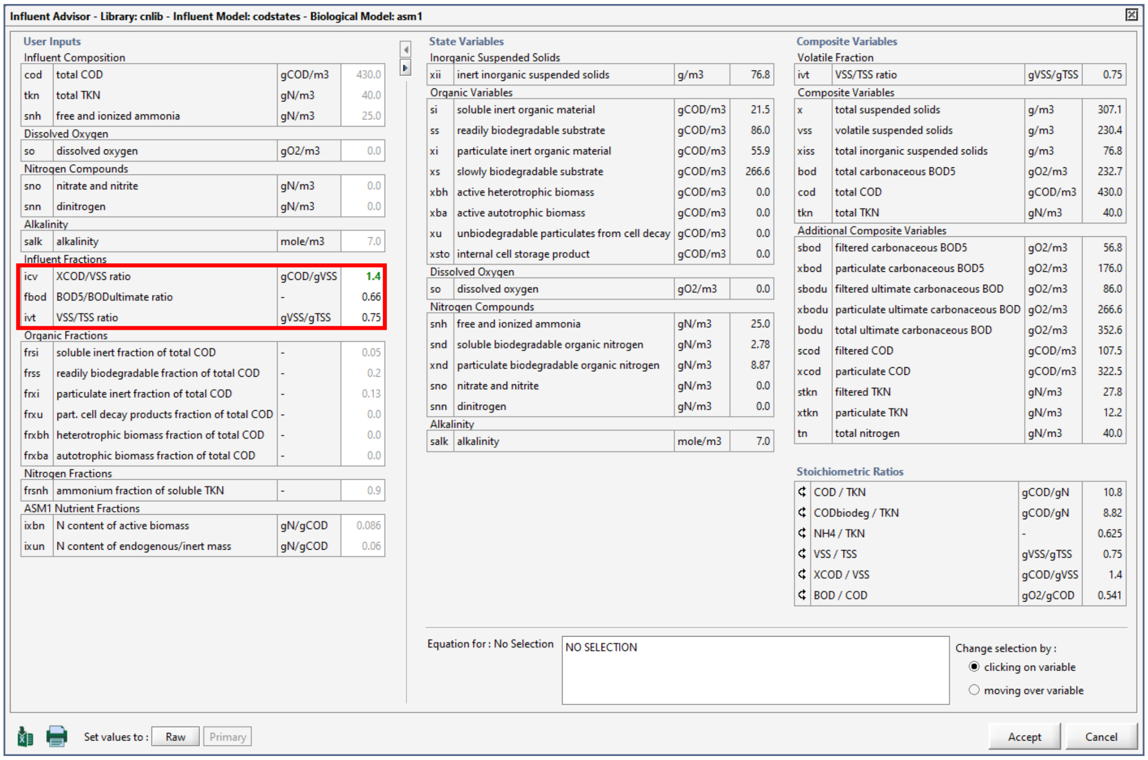




Simulation Results

		effluent
Flow	m3/d	-
TSS	mg/L	-
VSS	mg/L	-
cBOD5	mg/L	-
COD	mg/L	-
Ammonia N	mgN/L	-
Nitrite N	mgN/L	-
Nitrate N	mgN/L	-
Nitrite/Nitrate N	mgN/L	-
TKN	mgN/L	-
TN	mgN/L	-
Soluble PO4-P	mgP/L	-
TP	mgP/L	-
Alkalinity	mgCaCO3/L	-
Total Alkalinity	mgCaCO3/L	-
pH	-	-

15. Right-click on the Influent Wastewater object and navigate to *Composition* > *Influent Characterization*. In the User Inputs panel, under the Influent Fractions header adjust the XCOD/VSS ratio (icv) to 1.4. (**Note**: In Simulation mode, you can edit the Influent Characterization ONLY in new scenarios, not the Default Scenario.)


Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition			
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0
Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
Nitrogen Compounds			
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
Alkalinity			
salk	alkalinity	mole/m3	7.0
Influent Fractions			
icv	XCOD/VSS ratio	gCOD/gVSS	1.4
fbod	BOD5/BODultimate ratio	-	0.66
ivt	VSS/TSS ratio	gVSS/gTSS	0.75
Organic Fractions			
frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0
Nitrogen Fractions			
frsnh	ammonium fraction of soluble TKN	-	0.9
ASM1 Nutrient Fractions			
ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids			
xii	inert inorganic suspended solids	g/m3	76.8
Organic Variables			
si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0
Dissolved Oxygen			
so	dissolved oxygen	gO2/m3	0.0
Nitrogen Compounds			
snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0
Alkalinity			
salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction			
ivt	VSS/TSS ratio	gVSS/gTSS	0.75
Composite Variables			
x	total suspended solids	g/m3	307.1
vss	volatile suspended solids	g/m3	230.4
xiss	total inorganic suspended solids	g/m3	76.8
bod	total carbonaceous BOD5	gO2/m3	232.7
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
Additional Composite Variables			
sbod	filtered carbonaceous BOD5	gO2/m3	56.8
xbod	particulate carbonaceous BOD5	gO2/m3	176.0
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

COD / TKN	gCOD/gN	10.8
CODbiodeg / TKN	gCOD/gN	8.82
NH4 / TKN	-	0.625
VSS / TSS	gVSS/gTSS	0.75
XCOD / VSS	gCOD/gVSS	1.4
BOD / COD	gO2/gCOD	0.541

Equation for : No Selection

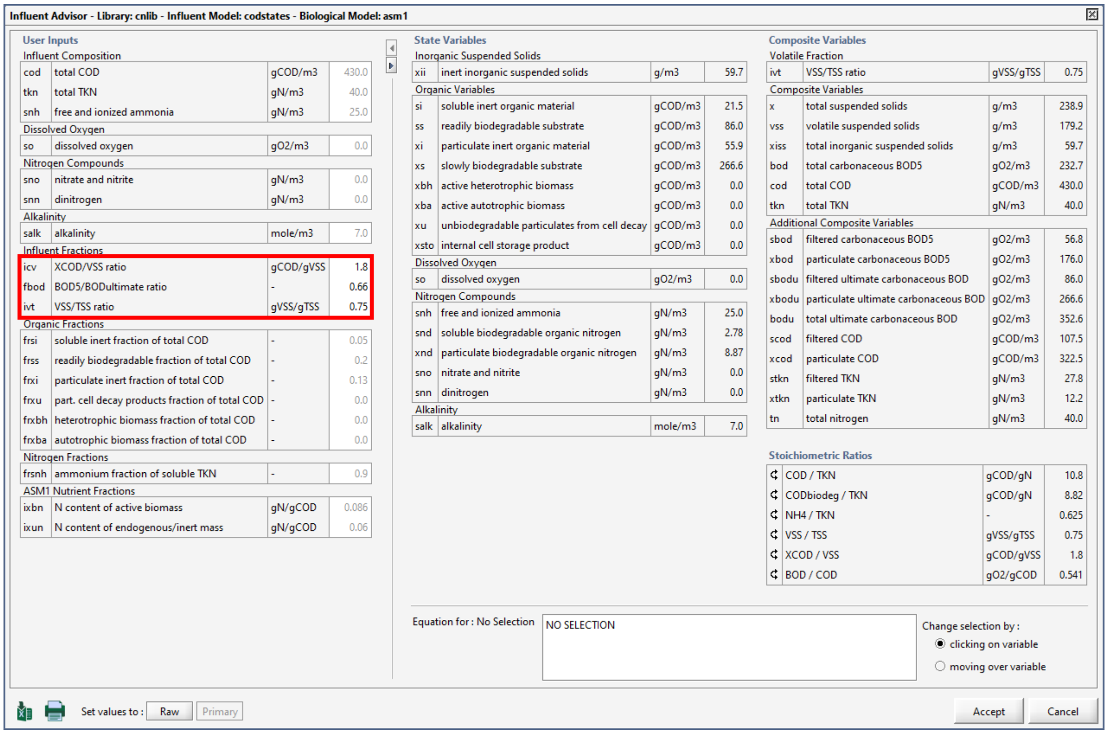
NO SELECTION

Change selection by :
● clicking on variable
○ moving over variable

16. Rerun the simulation. Complete the table and report a screenshot of the results shown in the Outfall output tab. (**Exercise 2 – Question 4**)

Scenario 2 – BOD5/BODultimate ratio (Exercise 2 – Question 5)

17. Right-click on the Influent object and navigate to *Composition* > *Influent Characterization*. Set all user inputs to the default values (icv = 1.8, fbod = 0.66, ivt = 0.75).



Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition

cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Influent Fractions

icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Organic Fractions

frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0

Nitrogen Fractions

frsnh	ammonium fraction of soluble TKN	-	0.9

ASM1 Nutrient Fractions

ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids

xii	inert inorganic suspended solids	g/m3	59.7

Organic Variables

si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction

ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Composite Variables

x	total suspended solids	g/m3	238.9
vss	volatile suspended solids	g/m3	179.2
xiss	total inorganic suspended solids	g/m3	59.7
bod	total carbonaceous BOD5	gO2/m3	232.7
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0

Additional Composite Variables

sbod	filtered carbonaceous BOD5	gO2/m3	56.8
xbod	particulate carbonaceous BOD5	gO2/m3	176.0
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

⇄	COD / TKN	gCOD/gN	10.8
⇄	CODbiodeg / TKN	gCOD/gN	8.82
⇄	NH4 / TKN	-	0.625
⇄	VSS / TSS	gVSS/gTSS	0.75
⇄	XCOD / VSS	gCOD/gVSS	1.8
⇄	BOD / COD	gO2/gCOD	0.541

Equation for : No Selection

NO SELECTION

Change selection by :

● clicking on variable

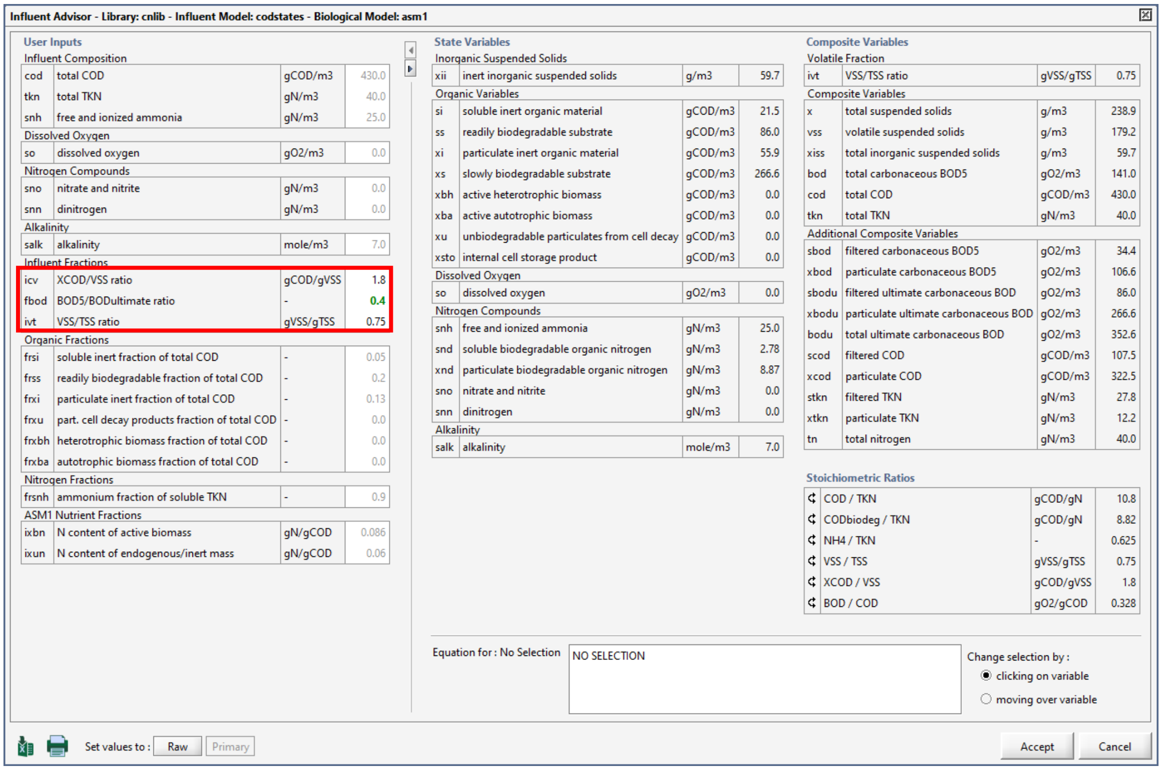
○ moving over variable

Set values to : Raw Primary

18. With all user inputs at the default values complete the first row of the table below with values from the Influent Advisor.

	Location	Total Carbonaceous BOD5 (bod)	Filtered Carbonaceous BOD5 (sbod)	Particulate Carbonaceous BOD5 (xbod)
BOD5/BODultimate ratio = 0.66	Influent (wwinf)			
	Bioreactor Effluent (mlss)			
BOD5/BODultimate = 0.4	Influent (wwinf)			
	Bioreactor Effluent (mlss)			

19. Close the Influent Advisor and run the simulation.
20. Right-click on the mlss steam and navigate to *Output Variables* > *Composite Variables* and complete the second row within the table. The value for mlss total carbonaceous BOD5 is provided in the first screen. Select the More… button to find another screen with filtered carbonaceous BOD5 and particulate carbonaceous BOD5 values.
21. Repeat steps 17-20 after adjusting the **BOD5/BODultimate ratio** in the Influent Advisor to **0.4**. Report the values in final two rows of the above table. Discuss the results.



Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition

cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Influent Fractions

icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.4
ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Organic Fractions

frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0

Nitrogen Fractions

frsnh	ammonium fraction of soluble TKN	-	0.9

ASM1 Nutrient Fractions

ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids

xii	inert inorganic suspended solids	g/m3	59.7

Organic Variables

si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction

ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Composite Variables

x	total suspended solids	g/m3	238.9
vss	volatile suspended solids	g/m3	179.2
xiss	total inorganic suspended solids	g/m3	59.7
bod	total carbonaceous BOD5	gO2/m3	141.0
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0

Additional Composite Variables

sbod	filtered carbonaceous BOD5	gO2/m3	34.4
xbod	particulate carbonaceous BOD5	gO2/m3	106.6
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

COD / TKN	gCOD/gN	10.8
CODbiodeg / TKN	gCOD/gN	8.82
NH4 / TKN	-	0.625
VSS / TSS	gVSS/gTSS	0.75
XCOD / VSS	gCOD/gVSS	1.8
BOD / COD	gO2/gCOD	0.328

Equation for : No Selection

NO SELECTION

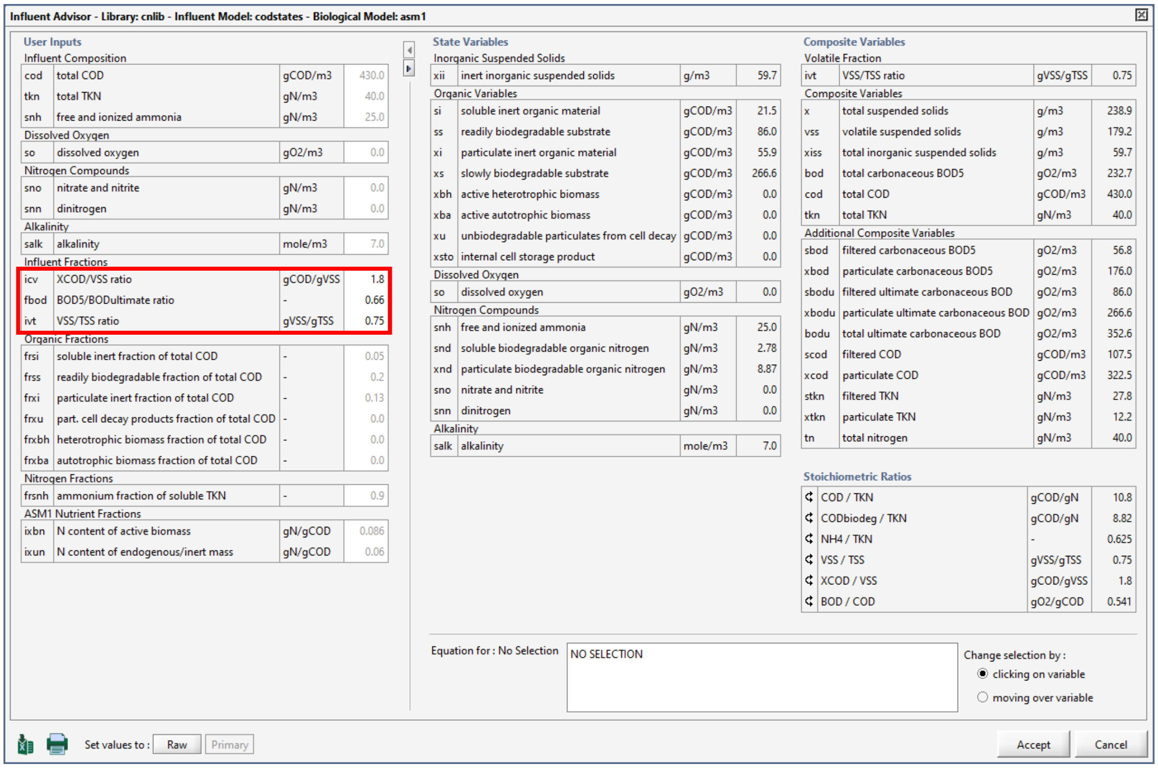
Change selection by :
● clicking on variable
○ moving over variable

Scenario 3 – VSS/TSS Ratio (Exercise 2 – Question 6)

In your word processor create the table below to record your responses for the following scenario.

		VSS/TSS Ratio = 0.75	VSS/TSS Ratio = 0.9
Influent	TSS (mg/L)		
	Total Inorganic Suspended Solids (mg/L)		
Bioreactor	MLSS (mg/L)		
	Ammonia (mg/L)		
Secondary Clarifier	Solids Loading Rate (kg/(m2.d))		
	RAS COD (mg/l)		
Outfall	TSS (mg/L)		
	cBOD$_5$ (mg/L)		
	COD (mg/L)		
	TN (mg/L)		

22. Open the Influent Advisor and reset the **BOD5/BODultimate ratio** to the default value of **0.66**. From the Composite Variables column of the Influent Advisor record the influent concentrations of **total suspended solids (x)** and **total inorganic suspended solids (xiss)** in the first two rows within the VSS/TSS Ratio = 0.75 column of the table.



Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition

cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Influent Fractions

icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Organic Fractions

frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0

Nitrogen Fractions

frsnh	ammonium fraction of soluble TKN	-	0.9

ASM1 Nutrient Fractions

ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids

xii	inert inorganic suspended solids	g/m3	59.7

Organic Variables

si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction

ivt	VSS/TSS ratio	gVSS/gTSS	0.75

Composite Variables

x	total suspended solids	g/m3	238.9
vss	volatile suspended solids	g/m3	179.2
xiss	total inorganic suspended solids	g/m3	59.7
bod	total carbonaceous BOD5	gO2/m3	232.7
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0

Additional Composite Variables

sbod	filtered carbonaceous BOD5	gO2/m3	56.8
xbod	particulate carbonaceous BOD5	gO2/m3	176.0
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

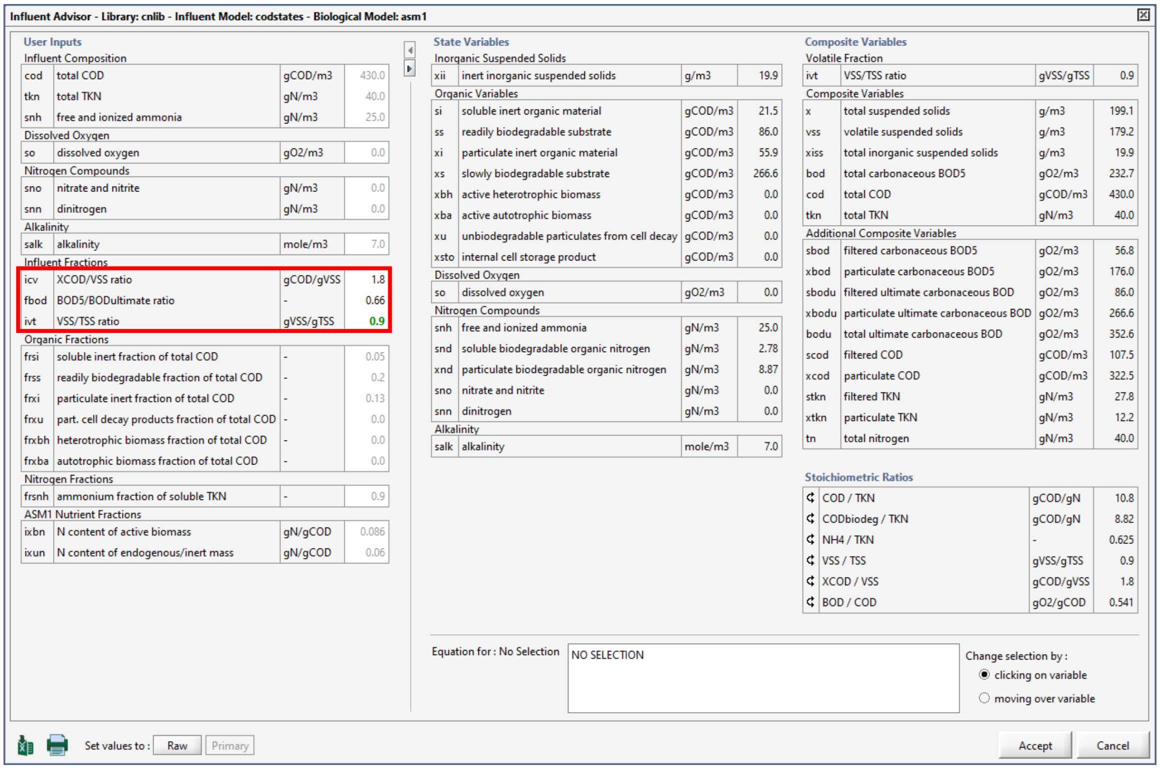
COD / TKN	gCOD/gN	10.8
CODbiodeg / TKN	gCOD/gN	8.82
NH4 / TKN	-	0.625
VSS / TSS	gVSS/gTSS	0.75
XCOD / VSS	gCOD/gVSS	1.8
BOD / COD	gO2/gCOD	0.541

Equation for : No Selection

NO SELECTION

Change selection by :
● clicking on variable
○ moving over variable

23. Close the influent advisor and run the simulation. Complete the table by accessing the appropriate output tabs.
24. Repeat steps 22-23 for a **VSS/TSS Ratio** of **0.9** to complete the second column of the table.



Influent Advisor - Library: cnlib - Influent Model: codstates - Biological Model: asm1

User Inputs

Influent Composition

cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0
snh	free and ionized ammonia	gN/m3	25.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Influent Fractions

icv	XCOD/VSS ratio	gCOD/gVSS	1.8
fbod	BOD5/BODultimate ratio	-	0.66
ivt	VSS/TSS ratio	gVSS/gTSS	0.9

Organic Fractions

frsi	soluble inert fraction of total COD	-	0.05
frss	readily biodegradable fraction of total COD	-	0.2
frxi	particulate inert fraction of total COD	-	0.13
frxu	part. cell decay products fraction of total COD	-	0.0
frxbh	heterotrophic biomass fraction of total COD	-	0.0
frxba	autotrophic biomass fraction of total COD	-	0.0

Nitrogen Fractions

frsnh	ammonium fraction of soluble TKN	-	0.9

ASM1 Nutrient Fractions

ixbn	N content of active biomass	gN/gCOD	0.086
ixun	N content of endogenous/inert mass	gN/gCOD	0.06

State Variables

Inorganic Suspended Solids

xii	inert inorganic suspended solids	g/m3	19.9

Organic Variables

si	soluble inert organic material	gCOD/m3	21.5
ss	readily biodegradable substrate	gCOD/m3	86.0
xi	particulate inert organic material	gCOD/m3	55.9
xs	slowly biodegradable substrate	gCOD/m3	266.6
xbh	active heterotrophic biomass	gCOD/m3	0.0
xba	active autotrophic biomass	gCOD/m3	0.0
xu	unbiodegradable particulates from cell decay	gCOD/m3	0.0
xsto	internal cell storage product	gCOD/m3	0.0

Dissolved Oxygen

so	dissolved oxygen	gO2/m3	0.0

Nitrogen Compounds

snh	free and ionized ammonia	gN/m3	25.0
snd	soluble biodegradable organic nitrogen	gN/m3	2.78
xnd	particulate biodegradable organic nitrogen	gN/m3	8.87
sno	nitrate and nitrite	gN/m3	0.0
snn	dinitrogen	gN/m3	0.0

Alkalinity

salk	alkalinity	mole/m3	7.0

Composite Variables

Volatile Fraction

ivt	VSS/TSS ratio	gVSS/gTSS	0.9

Composite Variables

x	total suspended solids	g/m3	199.1
vss	volatile suspended solids	g/m3	179.2
xiss	total inorganic suspended solids	g/m3	19.9
bod	total carbonaceous BOD5	gO2/m3	232.7
cod	total COD	gCOD/m3	430.0
tkn	total TKN	gN/m3	40.0

Additional Composite Variables

sbod	filtered carbonaceous BOD5	gO2/m3	56.8
xbod	particulate carbonaceous BOD5	gO2/m3	176.0
sbodu	filtered ultimate carbonaceous BOD	gO2/m3	86.0
xbodu	particulate ultimate carbonaceous BOD	gO2/m3	266.6
bodu	total ultimate carbonaceous BOD	gO2/m3	352.6
scod	filtered COD	gCOD/m3	107.5
xcod	particulate COD	gCOD/m3	322.5
stkn	filtered TKN	gN/m3	27.8
xtkn	particulate TKN	gN/m3	12.2
tn	total nitrogen	gN/m3	40.0

Stoichiometric Ratios

COD / TKN	gCOD/gN	10.8
CODbiodeg / TKN	gCOD/gN	8.82
NH4 / TKN	-	0.625
VSS / TSS	gVSS/gTSS	0.9
XCOD / VSS	gCOD/gVSS	1.8
BOD / COD	gO2/gCOD	0.541

Equation for : No Selection

NO SELECTION

Change selection by :
● clicking on variable
○ moving over variable

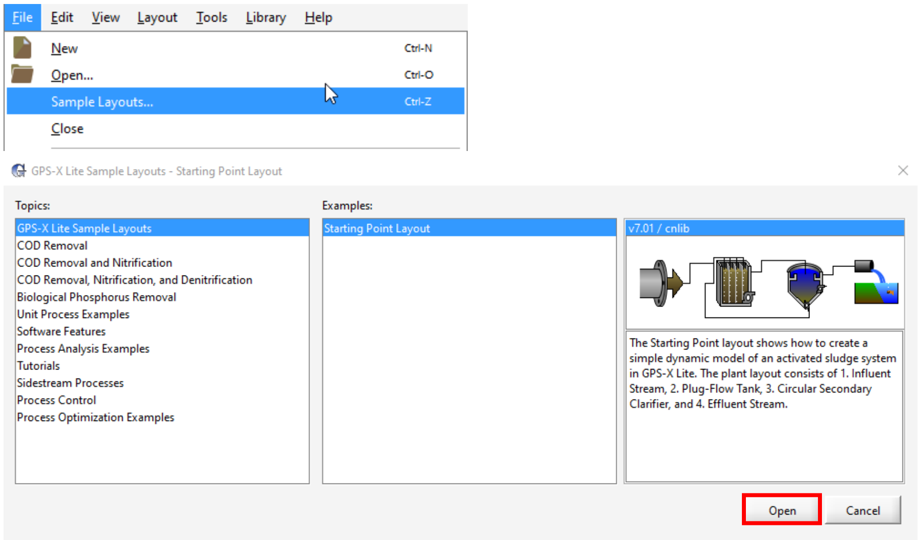
Exercise 3 – Comparing the Performance of Alternative Bioreactor Configurations

The purpose of this exercise is to compare the effluent quality from conventional activated sludge systems with different bioreactor configurations:

a) Complete mixed, no recycle
b) Complete mixed, biological solids recycle
c) Plug flow, biological solids recycle
d) Plug flow with step-feeding, biological solids recycle

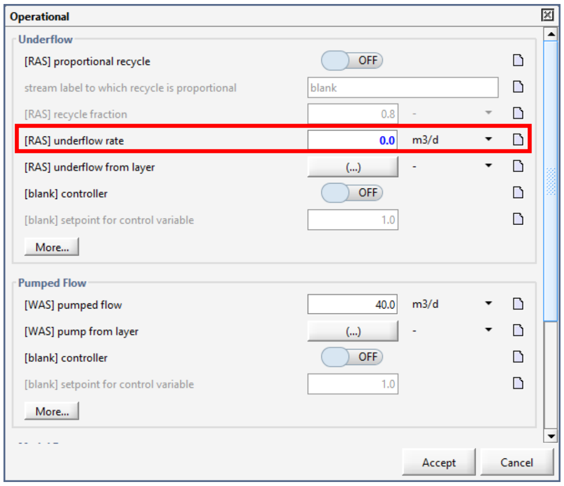
1. Open the Starting Point model layout that was developed in Exercise 1.

   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*



The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. Save the layout under a different name.
3. In modelling mode, right-click on the Secondary Clarifier and navigate to *Input Parameters > Operational*. Change the **underflow rate** to **0 m^3/d**; now there is no recycle between the clarifier and the aeration basin.



Operational

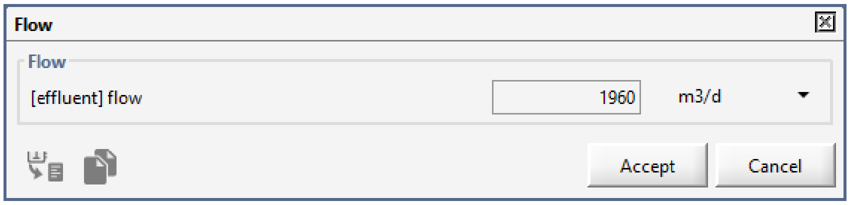
Underflow

[RAS] proportional recycle	OFF	
stream label to which recycle is proportional	blank	
[RAS] recycle fraction	0.8	-
[RAS] underflow rate	0.0	m3/d
[RAS] underflow from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

Pumped Flow

[WAS] pumped flow	40.0	m3/d
[WAS] pump from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

4. Switch into simulation mode. Rebuild the model when prompted.
5. Create a new output graph tab. Right-click on the tab and rename to “Operational Performance.”
6. Right-click on the Outfall object and navigate to *Output Variables* > *Flow*. From the flow dialog box that appears, drag the **flow** variable to the new graph tab. Right-click on the graph to change its display to **Digital** from the *Output Graph Type* dropdown. Follow the same steps for the subsequent output variables from the Outfall object (drag the variables to the existing digital graph):
   - Composite Variables: total suspended solids, total carbonaceous BOD_5
   - State Variables: dissolved oxygen, free and ionized ammonia

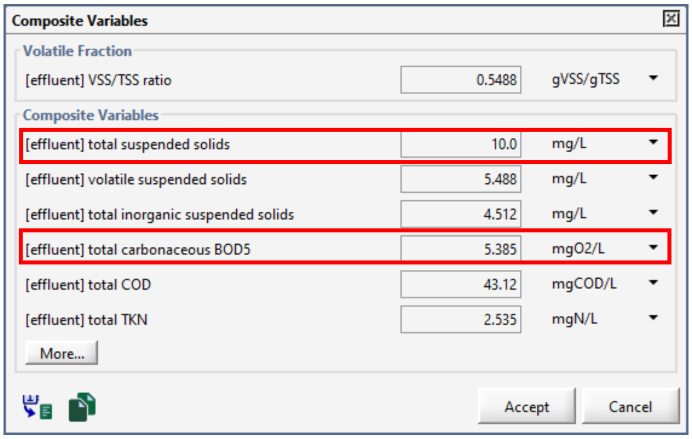


Flow

Flow

[effluent] flow	1960	m3/d

The screen for total suspended solids and total carbonaceous BOD_5 is as follows.



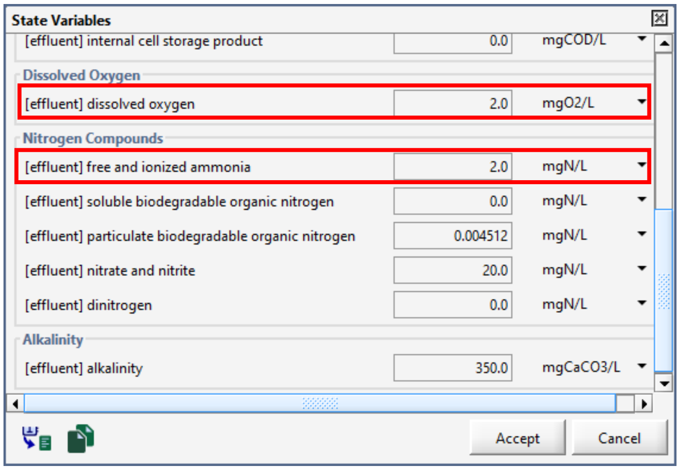
Composite Variables

Volatile Fraction

[effluent] VSS/TSS ratio	0.5488	gVSS/gTSS

Composite Variables

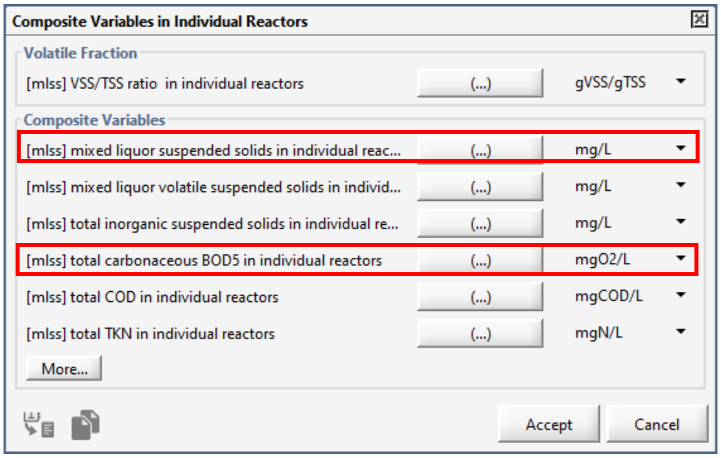
[effluent] total suspended solids	10.0	mg/L
[effluent] volatile suspended solids	5.488	mg/L
[effluent] total inorganic suspended solids	4.512	mg/L
[effluent] total carbonaceous BOD5	5.385	mgO2/L
[effluent] total COD	43.12	mgCOD/L
[effluent] total TKN	2.535	mgN/L



State Variables

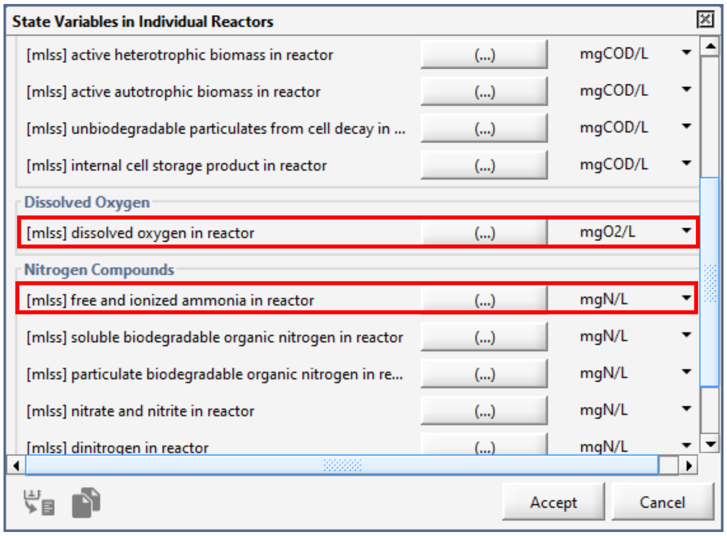
[effluent] internal cell storage product	0.0	mgCOD/L
Dissolved Oxygen		
[effluent] dissolved oxygen	2.0	mgO2/L
Nitrogen Compounds		
[effluent] free and ionized ammonia	2.0	mgN/L
[effluent] soluble biodegradable organic nitrogen	0.0	mgN/L
[effluent] particulate biodegradable organic nitrogen	0.004512	mgN/L
[effluent] nitrate and nitrite	20.0	mgN/L
[effluent] dinitrogen	0.0	mgN/L
Alkalinity		
[effluent] alkalinity	350.0	mgCaCO3/L

7. Right-click on the Bioreactor and navigate to *Output Variables > Composite Variables in Individual Reactors*. Left-click on the **mixed liquor suspended solids in individual reactors** variable name and drag it to the Operational Performance output tab to create a new graph in this tab. After dragging the mlss, press Accept in the dialog box. Follow the same steps to create individual graphs for the following output variables from the Bioreactor object:
   - Composite Variables: total carbonaceous BOD5 in individual reactors
   - State Variables: dissolved oxygen in reactor, free and ionized ammonia in reactor



Composite Variables in Individual Reactors

Volatile Fraction		
[mlss] VSS/TSS ratio in individual reactors	(...)	gVSS/gTSS
Composite Variables		
[mlss] mixed liquor suspended solids in individual reac...	(...)	mg/L
[mlss] mixed liquor volatile suspended solids in individ...	(...)	mg/L
[mlss] total inorganic suspended solids in individual re...	(...)	mg/L
[mlss] total carbonaceous BOD5 in individual reactors	(...)	mgO2/L
[mlss] total COD in individual reactors	(...)	mgCOD/L
[mlss] total TKN in individual reactors	(...)	mgN/L

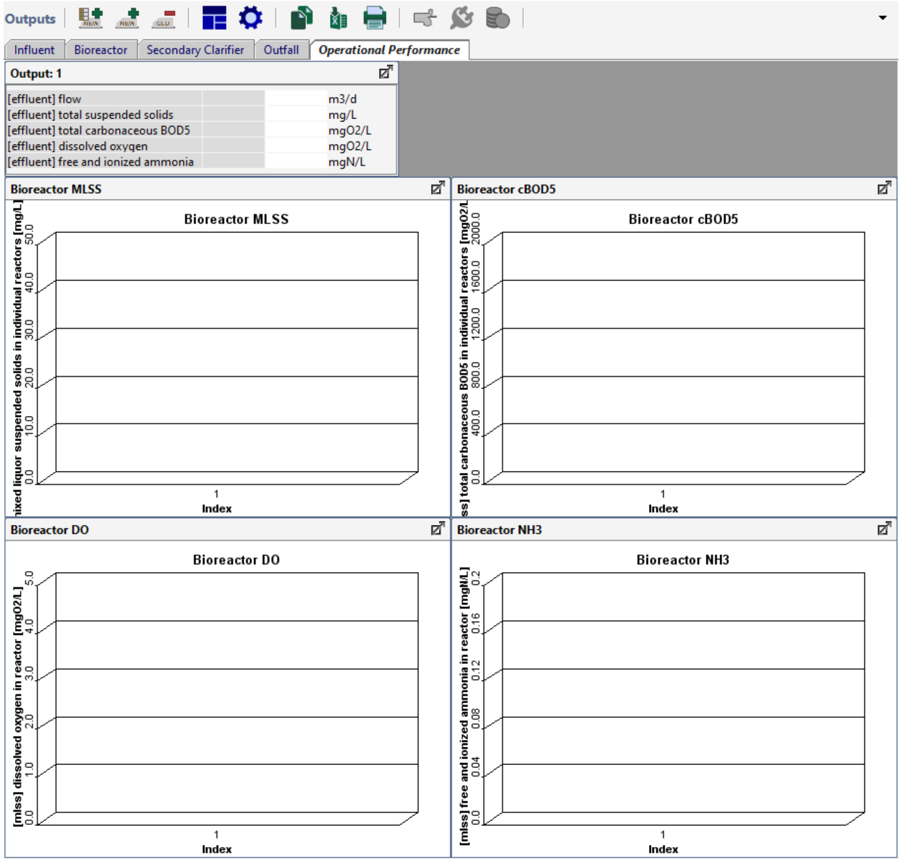


State Variables in Individual Reactors

[mlss] active heterotrophic biomass in reactor	(...)	mgCOD/L
[mlss] active autotrophic biomass in reactor	(...)	mgCOD/L
[mlss] unbiodegradable particulates from cell decay in ...	(...)	mgCOD/L
[mlss] internal cell storage product in reactor	(...)	mgCOD/L
Dissolved Oxygen		
[mlss] dissolved oxygen in reactor	(...)	mgO2/L
Nitrogen Compounds		
[mlss] free and ionized ammonia in reactor	(...)	mgN/L
[mlss] soluble biodegradable organic nitrogen in reactor	(...)	mgN/L
[mlss] particulate biodegradable organic nitrogen in re...	(...)	mgN/L
[mlss] nitrate and nitrite in reactor	(...)	mgN/L
[mlss] dinitrogen in reactor	(...)	mgN/L

8. Auto arrange the graphs to fit them into the output window.

9. Access the properties button for each graph and rename appropriately. Alternatively, right-click on a graph and select **Rename Output Graph…** to name a graph.

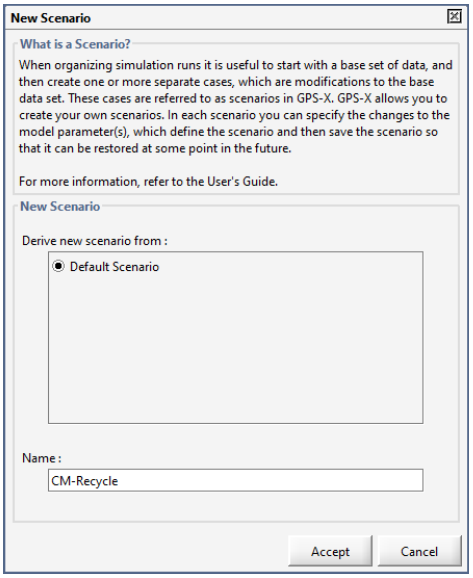


Output: 1

[effluent] flow			m3/d
[effluent] total suspended solids			mg/L
[effluent] total carbonaceous BOD5			mgO2/L
[effluent] dissolved oxygen			mgO2/L
[effluent] free and ionized ammonia			mgN/L

10. Run the simulation at steady-state. Take a screenshot of the results in the Operational Performance output tab. (**Exercise 3 – Question 1)**

11. Open the Sankey Diagram and take a screenshot to record the flow profile of the continuous mixed, no recycle configuration. Select the OK button in the bottom-right corner of the window to close the Sankey diagram. **(Exercise 3 – Question 2)**
12. You will now explore the effect of adding in the recycle stream from the secondary clarifier. Add a new scenario by navigating to *Scenario* > *New* from the simulation toolbar. Call the simulation "CM-recycle." Accept the form.



New Scenario

What is a Scenario?

When organizing simulation runs it is useful to start with a base set of data, and then create one or more separate cases, which are modifications to the base data set. These cases are referred to as scenarios in GPS-X. GPS-X allows you to create your own scenarios. In each scenario you can specify the changes to the model parameter(s), which define the scenario and then save the scenario so that it can be restored at some point in the future.

For more information, refer to the User's Guide.

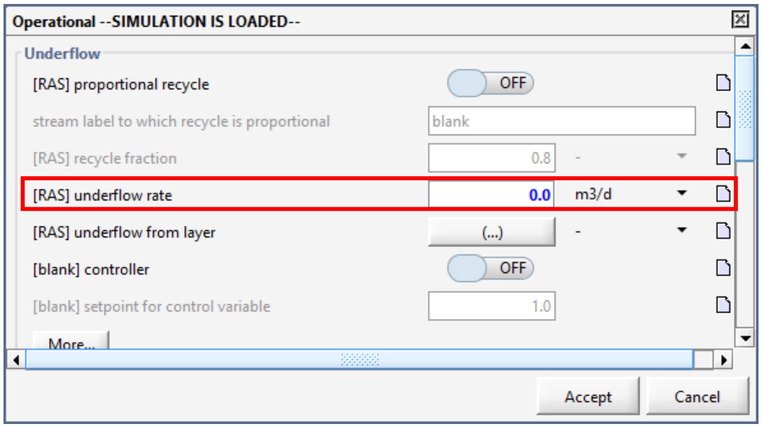
New Scenario

Derive new scenario from :

● Default Scenario

Name : CM-Recycle

13. Right-click on the Secondary Clarifier and navigate to *Input Parameters* > *Operational* and drag the **underflow rate** variable from the Underflow header to the input controller area. Right-click on the tab and rename this new input control tab to "RAS."

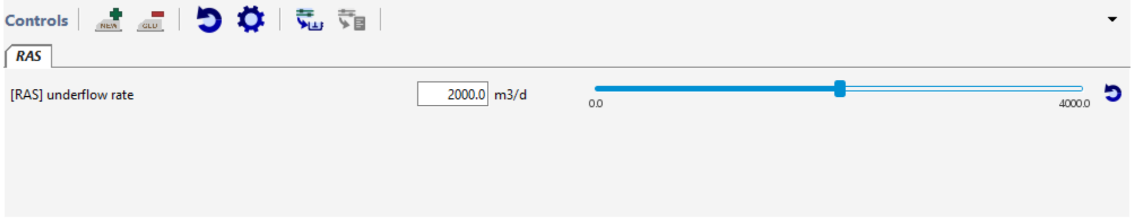


Operational --SIMULATION IS LOADED--

Underflow

[RAS] proportional recycle	OFF	
stream label to which recycle is proportional	blank	
[RAS] recycle fraction	0.8	-
[RAS] underflow rate	0.0	m3/d
[RAS] underflow from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

14. Select the RAS input controls property button and set the **maximum limit** to **4000 m^3/d**. Ensure to Accept the form to save the changes. Set the value of the slider to **2000 m^3/d** and rerun the simulation.

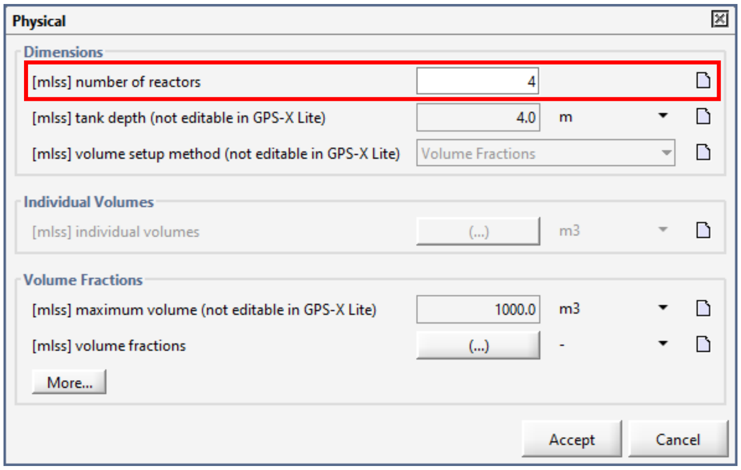


[RAS] underflow rate 2000.0 m3/d

15. Take screenshots of the results on the operational performance tab, and the Sankey diagram. (**Exercise 3 – Question 3)**

Now explore the effect of modelling the bioreactor as a PFR rather than a CM reactor.

16. In the existing model layout go to Save As… and save a copy of the model layout under a different name.
17. Switch back into modelling mode. Right-click on the Bioreactor and go to *Input Parameters > Physical*. Change the **number of reactors** to **4**. Accept this change. By default, the volume of the reactor (1000 m^3) will be divided into 4 equal sized basins (250 m^3).



[mlss] number of reactors 4

[mlss] tank depth (not editable in GPS-X Lite) 4.0 m

[mlss] volume setup method (not editable in GPS-X Lite) Volume Fractions

[mlss] individual volumes (...) m3

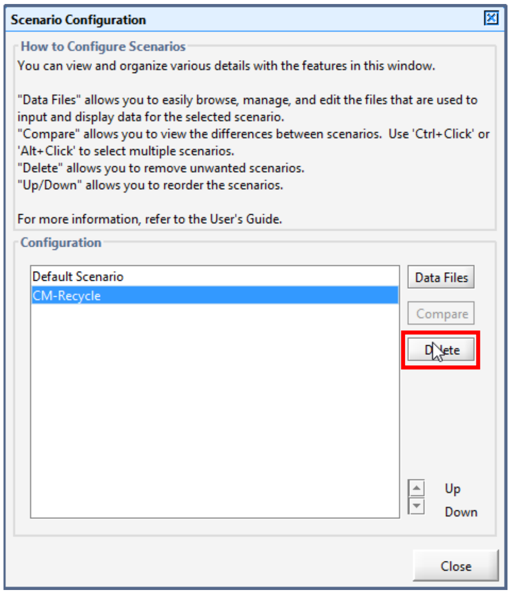
[mlss] maximum volume (not editable in GPS-X Lite) 1000.0 m3

[mlss] volume fractions (...) -

18. Switch into Simulation Mode. Rebuild the model when prompted.
19. Ensure you are working in the Default Scenario. Verify that the **underflow rate** variable on the RAS input control tab is set to **2000 m^3/d** and run the simulation. You should now see that the output graphs have 4 indexes representing the individual compartments within the bioreactors.
20. Take a screenshot of the results on the Operational Performance tab. (**Exercise 3 – Question 4)**

The final reactor configuration involves the addition of step feeding to the PFR.

21. You will now delete the old CM recycle scenario and create a new scenario for the PFR step feeding. In Simulation mode navigate to *Scenario > Configuration* from the Simulation Toolbar. Select the CM – Recycle scenario and click on the Delete button. Close this form.

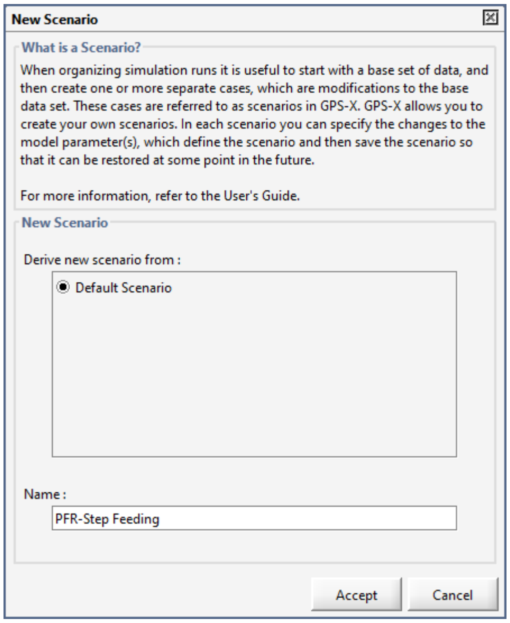


You can view and organize various details with the features in this window.

"Data Files" allows you to easily browse, manage, and edit the files that are used to input and display data for the selected scenario.
"Compare" allows you to view the differences between scenarios. Use 'Ctrl+Click' or 'Alt+Click' to select multiple scenarios.
"Delete" allows you to remove unwanted scenarios.
"Up/Down" allows you to reorder the scenarios.

For more information, refer to the User's Guide.

22. From the simulation toolbar select *Scenario* > *New*. Select the button next to Default Scenario then name the new scenario to "PFR-Step Feeding." Accept this form.



When organizing simulation runs it is useful to start with a base set of data, and then create one or more separate cases, which are modifications to the base data set. These cases are referred to as scenarios in GPS-X. GPS-X allows you to create your own scenarios. In each scenario you can specify the changes to the model parameter(s), which define the scenario and then save the scenario so that it can be restored at some point in the future.

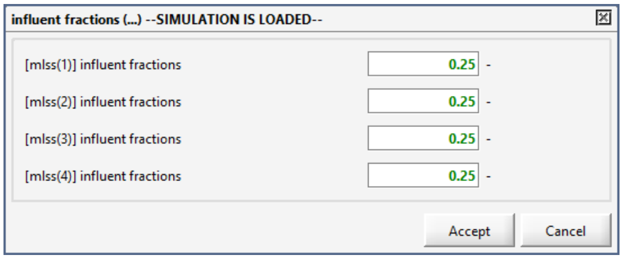
For more information, refer to the User's Guide.

Derive new scenario from :
● Default Scenario

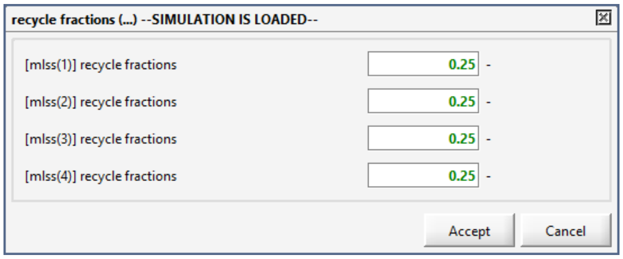
Name : PFR-Step Feeding

Note: The input control tab that was created earlier will still be present, do not delete it.

23. In this new scenario, right-click on the Bioreactor and navigate to *Input Parameters* > *Operational* and scroll down to the *Internal Flow Distribution Menu*. Select the **influent fractions** ellipse button and set all entries to **0.25**. Make the same change to the **recycle fractions**. The effect of these adjustments is that all the incoming flow to the Bioreactor will be split evenly between each of the four basins.



[mlss(1)] influent fractions 0.25 -
[mlss(2)] influent fractions 0.25 -
[mlss(3)] influent fractions 0.25 -
[mlss(4)] influent fractions 0.25 -



[mlss(1)] recycle fractions 0.25 -
[mlss(2)] recycle fractions 0.25 -
[mlss(3)] recycle fractions 0.25 -
[mlss(4)] recycle fractions 0.25 -

24. Set the **underflow rate** (recycle) to **2000 m^3/d** from the input control slider variables tab and run the simulation. Record a screenshot of the effluent from the Operational Performance tab. (**Exercise 3 – Question 5)**
25. Save the model layout.

Completion of the previous steps should have yielded snapshots of the operational performance of each bioreactor configuration:

a) Complete mixed, no recycle
b) Complete mixed, biological solids recycle
c) Plug flow, biological solids recycle
d) Plug flow with step-feeding, biological solids recycle

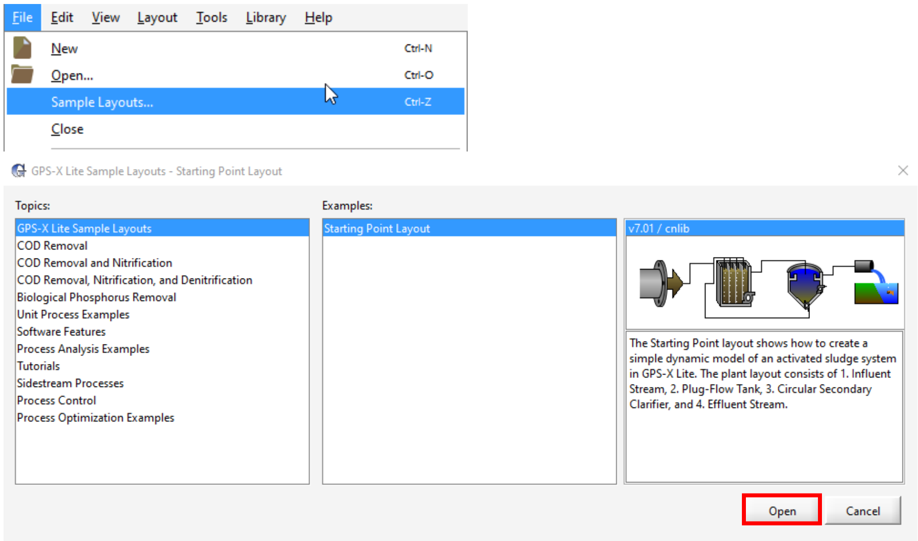
Prepare a discussion regarding the similarities and differences of each of these configurations and suggest reasons for the observations. (**Exercise 3 – Question 6)**

Exercise 4 – Plug-Flow Configuration

This exercise will explore the effect of the number of tanks in the plug-flow configuration.

1. Open the Starting Point model layout developed in Exercise 1.

   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*



The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. Save the Layout under a different name.
3. Switch into Simulation Mode in not already in this mode.
4. Select the New Table Tab button in the Outputs section of the window. In the Table Properties window that appears uncheck the include mass flows selection and the deselect all buttons under the stream choices and variable choices menus.

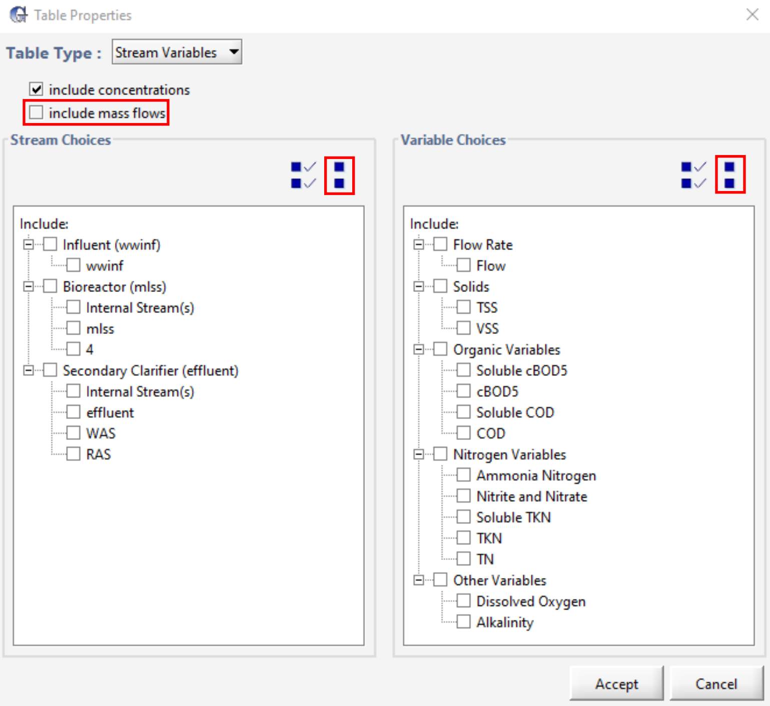


Table Type : Stream Variables

☑ include concentrations
☐ include mass flows

Stream Choices

Include:
- ☐ Influent (wwinf)
  - ☐ wwinf
- ☐ Bioreactor (mlss)
  - ☐ Internal Stream(s)
  - ☐ mlss
  - ☐ 4
- ☐ Secondary Clarifier (effluent)
  - ☐ Internal Stream(s)
  - ☐ effluent
  - ☐ WAS
  - ☐ RAS

Variable Choices

Include:
- ☐ Flow Rate
  - ☐ Flow
- ☐ Solids
  - ☐ TSS
  - ☐ VSS
- ☐ Organic Variables
  - ☐ Soluble cBOD5
  - ☐ cBOD5
  - ☐ Soluble COD
  - ☐ COD
- ☐ Nitrogen Variables
  - ☐ Ammonia Nitrogen
  - ☐ Nitrite and Nitrate
  - ☐ Soluble TKN
  - ☐ TKN
  - ☐ TN
- ☐ Other Variables
  - ☐ Dissolved Oxygen
  - ☐ Alkalinity

5. Select the following stream variables:
   - Stream Choices:
     i. Influent > wwinf
     ii. Bioreactor > Internal Streams, mlss
     iii. Secondary Clarifier > effluent, RAS
   - Variable Choices:
     i. Solids > TSS
     ii. Organic Variables > cBOD5
     iii. Nitrogen Variables > Ammonia Nitrogen, Nitrite and Nitrate
     iv. Other Variables > Dissolved Oxygen

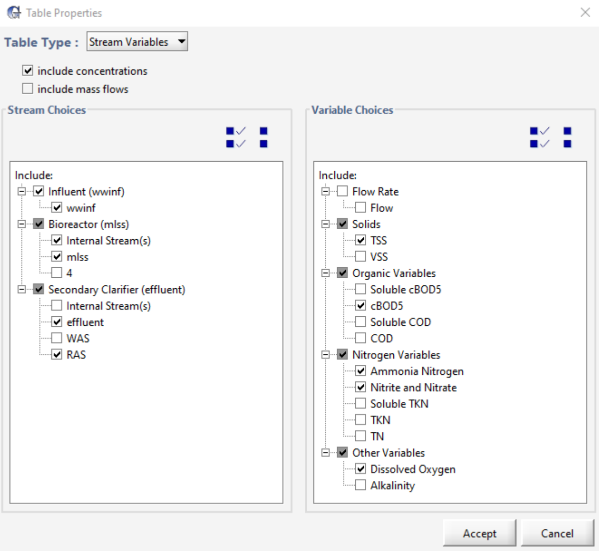


Table Type : Stream Variables

☑ include concentrations
☐ include mass flows

Stream Choices

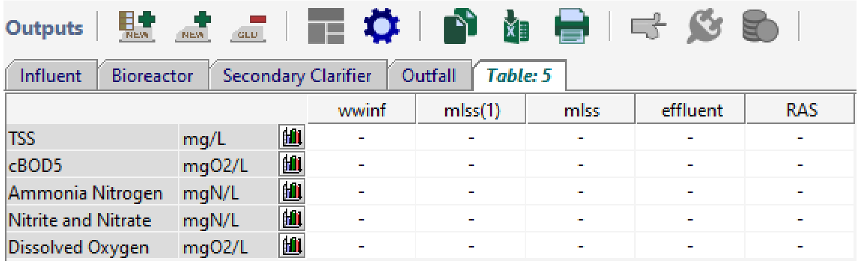
Include:
- ☑ Influent (wwinf)
  - ☑ wwinf
- ■ Bioreactor (mlss)
  - ☑ Internal Stream(s)
  - ☑ mlss
  - ☐ 4
- ■ Secondary Clarifier (effluent)
  - ☐ Internal Stream(s)
  - ☑ effluent
  - ☐ WAS
  - ☑ RAS

Variable Choices

Include:
- ☐ Flow Rate
  - ☐ Flow
- ■ Solids
  - ☑ TSS
  - ☐ VSS
- ■ Organic Variables
  - ☐ Soluble cBOD5
  - ☑ cBOD5
  - ☐ Soluble COD
  - ☐ COD
- ■ Nitrogen Variables
  - ☑ Ammonia Nitrogen
  - ☑ Nitrite and Nitrate
  - ☐ Soluble TKN
  - ☐ TKN
  - ☐ TN
- ■ Other Variables
  - ☑ Dissolved Oxygen
  - ☐ Alkalinity

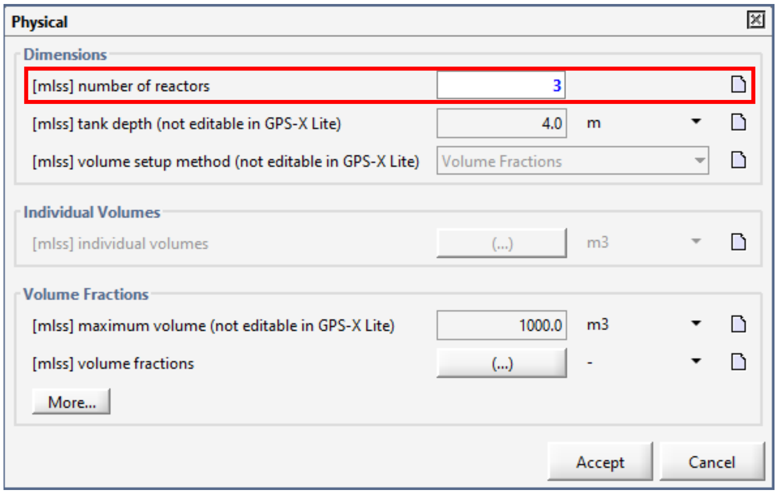
6. Acceptance of this form will create a table on a new output tab.

Note: If you make a mistake or desire to enter another item into the table, select the table and then the **Properties** button to access the properties menu.



			wwinf	mlss(1)	mlss	effluent	RAS
TSS	mg/L	📊	-	-	-	-	-
cBOD5	mgO2/L	📊	-	-	-	-	-
Ammonia Nitrogen	mgN/L	📊	-	-	-	-	-
Nitrite and Nitrate	mgN/L	📊	-	-	-	-	-
Dissolved Oxygen	mgO2/L	📊	-	-	-	-	-

7. Run the simulation at steady-state. Record a screenshot of the results in the output table. (**Exercise 4 – Question 1**)
8. Beside each of the output variable names is a **Create Bar Chart** button. Select the button for the cBOD5 variable. Record a screenshot of the bar chart that appears. (**Exercise 4 – Question 2**)
9. Switch back into modelling mode.
10. Right-click on the Bioreactor and navigate to *Input Parameters* > *Physical* and change the **number of reactors** to **3**. Accept this form and switch back into Simulation Mode. Rebuild the model when prompted.



Physical

Dimensions

[mlss] number of reactors	3	
[mlss] tank depth (not editable in GPS-X Lite)	4.0	m
[mlss] volume setup method (not editable in GPS-X Lite)	Volume Fractions	

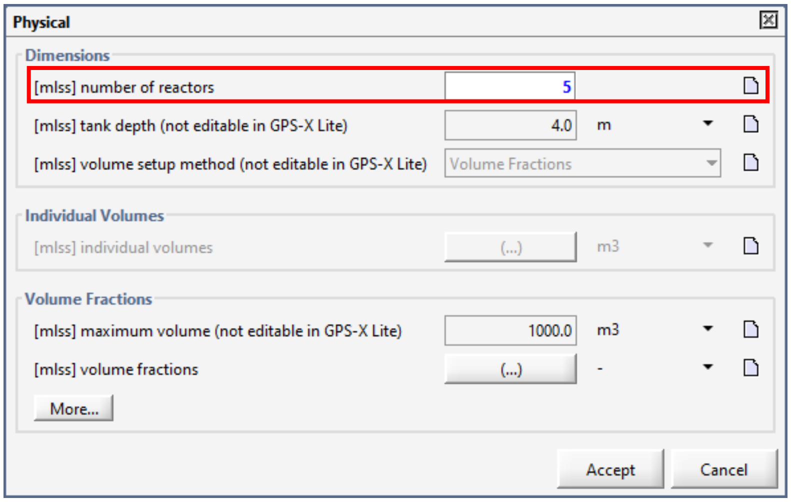
Individual Volumes

[mlss] individual volumes	(...)	m3

Volume Fractions

[mlss] maximum volume (not editable in GPS-X Lite)	1000.0	m3
[mlss] volume fractions	(...)	-

11. Run the simulation at steady-state and record a screenshot of the results in the output table. (**Exercise 4 – Question 3**)
12. Switch back into modelling mode.
13. Right-click on the Bioreactor and navigate to *Input Parameters* > *Physical* and change the **number of reactors** to **5**. Accept this form and switch back into Simulation Mode. Rebuild the model when prompted.


Physical

Dimensions

[mlss] number of reactors: 5

[mlss] tank depth (not editable in GPS-X Lite): 4.0 m

[mlss] volume setup method (not editable in GPS-X Lite): Volume Fractions

Individual Volumes

[mlss] individual volumes: (...) m3

Volume Fractions

[mlss] maximum volume (not editable in GPS-X Lite): 1000.0 m3

[mlss] volume fractions: (...) -

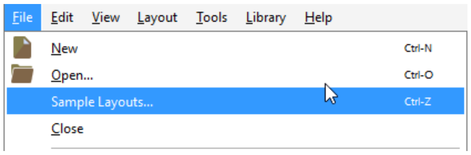
14. Run the simulation at steady-state and record a screenshot of the results in the output table. (**Exercise 4 – Question 4**)
15. Save the model layout.
16. Compare the bioreactor profiles from steps 7, 11, and 14. Suggest reasoning for your observations. Create bar charts as needed to support your reasoning. Is each bioreactor configuration able to achieve the same level of nutrient removal?

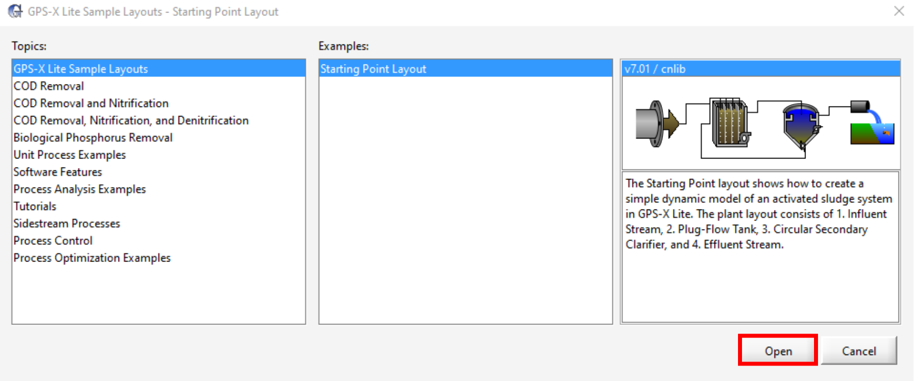
Exercise 5 – Effect of SRT and DO Control on Nitrification

The purpose of this scenario is to explore the effect of the solids retention time (SRT) and bioreactor dissolved oxygen (DO) concentration on the extent of nitrification.

1. Open the Starting Point layout that was created in Exercise 1.

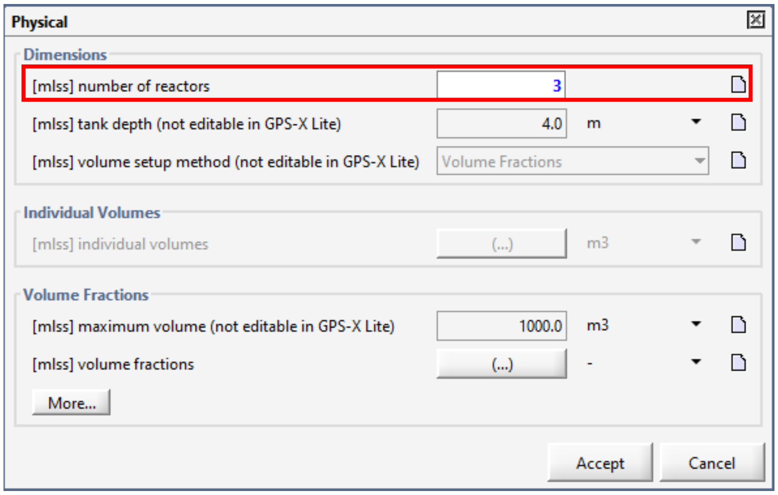
   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*





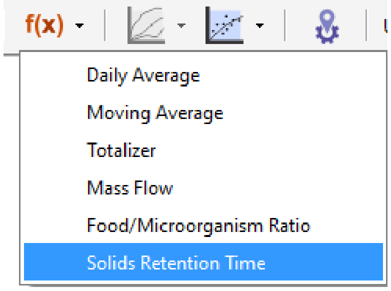
The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. Save the layout under a different name.
3. In modelling mode right-click on the Bioreactor and navigate to *Input Parameters > Physical* and change the **number of reactors** to **3**.



[mlss] number of reactors 3
[mlss] tank depth (not editable in GPS-X Lite) 4.0 m
[mlss] volume setup method (not editable in GPS-X Lite) Volume Fractions
[mlss] individual volumes (...) m3
[mlss] maximum volume (not editable in GPS-X Lite) 1000.0 m3
[mlss] volume fractions (...) -

f(x) 4. Select the Define button from the main toolbar and choose the Solids Retention Time option from the bottom of the list.



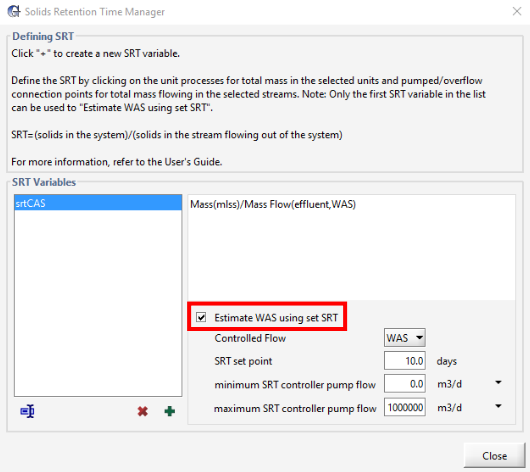
Select the green + button to create a new SRT variable and name it "CAS."

- This creates a new formula: Mass()/Mass Flow().

- The numerator will represent the mass of solids in the bioreactor, while the denominator will represent the mass flow of solids out of the system. To add to the numerator, simply left-click on the Bioreactor (the cursor changes to a hand). In the dialog box the selection for Reactors 1, 2, and 3 should be checked. Add to the denominator by hovering the mouse on the WAS stream connection point from the secondary clarifier until the cursor changes to an arrow, then left-click it. The equation should appear as: Mass(mlss)/Mass Flow(WAS). Now, hover the mouse over the clarified effluent from the secondary clarifier connection point until it changes to an arrow, then left-click to also add this to the denominator of the SRT equation.

Note: If you make a mistake, use the red x button next to the green plus button to delete the selected srtCAS; then redo creating the SRT variable.

- The final equation should appear as: Mass(mlss)/Mass Flow(effluent, WAS). Keep the window open.
- Select the "Estimate WAS using set SRT" button. Close this window.


Solids Retention Time Manager

Defining SRT

Click "+" to create a new SRT variable.

Define the SRT by clicking on the unit processes for total mass in the selected units and pumped/overflow connection points for total mass flowing in the selected streams. Note: Only the first SRT variable in the list can be used to "Estimate WAS using set SRT".

SRT=(solids in the system)/(solids in the stream flowing out of the system)

For more information, refer to the User's Guide.

SRT Variables

srtCAS

Mass(mlss)/Mass Flow(effluent,WAS)

☑ Estimate WAS using set SRT

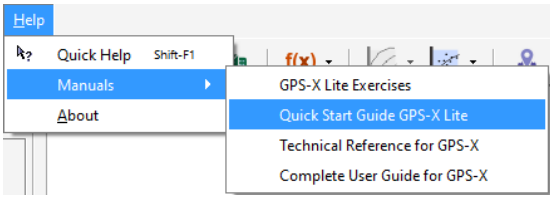
Controlled Flow: WAS

SRT set point: 10.0 days

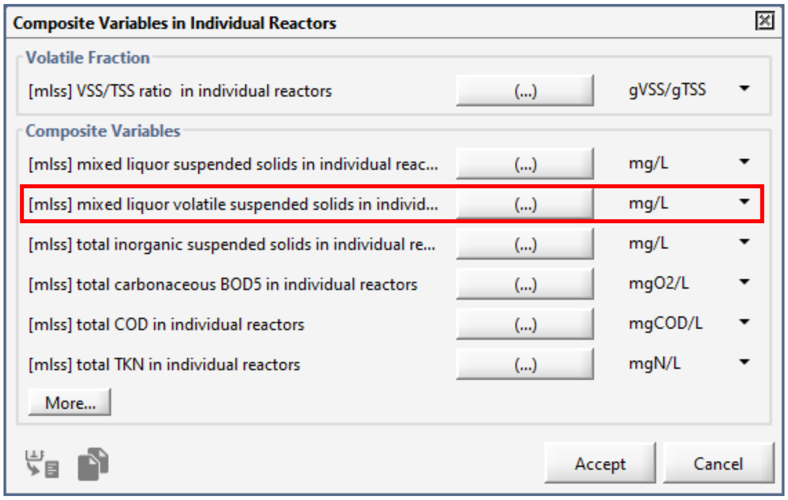
minimum SRT controller pump flow: 0.0 m3/d

maximum SRT controller pump flow: 1000000 m3/d

Note: If you require further information on setting up a new SRT variable, access the ***Quick Start Guide GPS-X Lite*** from the Help Menu.



5. Switch into Simulation Mode. Rebuild the model when prompted.
6. Create a new output graph and rename the graph tab to "Nitrification."
7. Right-click on the Bioreactor and navigate to *Output Variables > Composite Variables in Individual Reactors*. Left-click on the **mixed liquor suspended solids in individual reactors** variable name and drag to create a new graph on the Nitrification output tab.


Composite Variables in Individual Reactors

Volatile Fraction

[mlss] VSS/TSS ratio in individual reactors (...) gVSS/gTSS

Composite Variables

[mlss] mixed liquor suspended solids in individual reac... (...) mg/L

[mlss] mixed liquor volatile suspended solids in individ... (...) mg/L

[mlss] total inorganic suspended solids in individual re... (...) mg/L

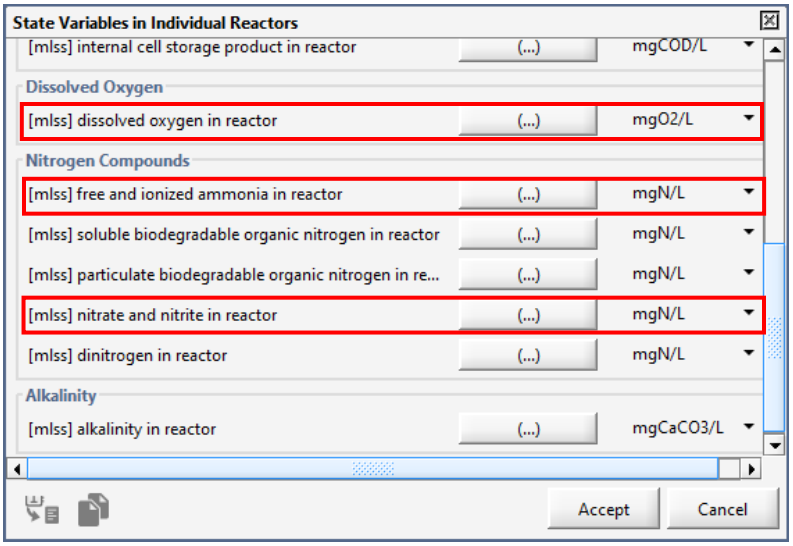
[mlss] total carbonaceous BOD5 in individual reactors (...) mgO2/L

[mlss] total COD in individual reactors (...) mgCOD/L

[mlss] total TKN in individual reactors (...) mgN/L

8. Right-click on the Bioreactor and navigate to *Output Variables > State Variables in Individual Reactors*. Drag the following output variables to the new graph tab.
   - Dissolved Oxygen – **dissolved oxygen in reactor**
   - Nitrogen Compounds – **free and ionized ammonia in reactor**
   - Nitrogen Compounds – **nitrate and nitrite in reactor**

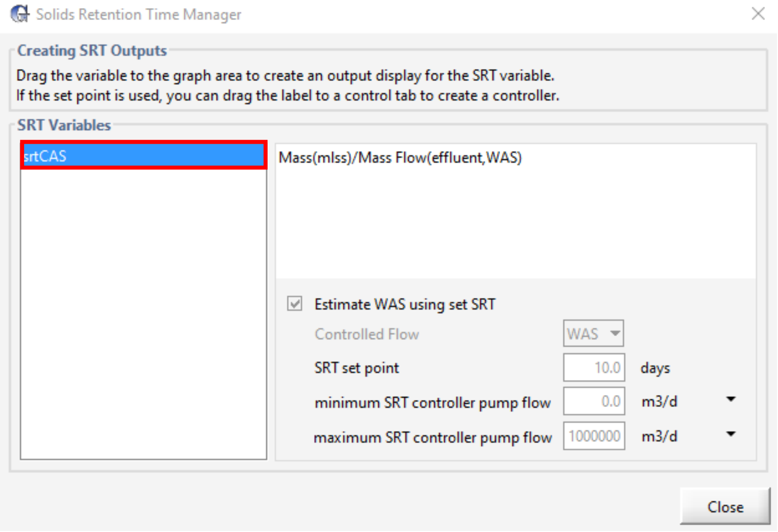
Rename each graph by accessing the property button for each graph.



State Variables in Individual Reactors

[mlss] internal cell storage product in reactor	(...)	mgCOD/L
Dissolved Oxygen		
[mlss] dissolved oxygen in reactor	(...)	mgO2/L
Nitrogen Compounds		
[mlss] free and ionized ammonia in reactor	(...)	mgN/L
[mlss] soluble biodegradable organic nitrogen in reactor	(...)	mgN/L
[mlss] particulate biodegradable organic nitrogen in re...	(...)	mgN/L
[mlss] nitrate and nitrite in reactor	(...)	mgN/L
[mlss] dinitrogen in reactor	(...)	mgN/L
Alkalinity		
[mlss] alkalinity in reactor	(...)	mgCaCO3/L

9. From the main toolbar go to *Define* > *Solids Retention* Time and drag the **srtCAS** variable to the Nitrification output graph tab. Right-click on this new graph and select **Digital** from the *Output Graph Type* menu.



Solids Retention Time Manager

Creating SRT Outputs

Drag the variable to the graph area to create an output display for the SRT variable.
If the set point is used, you can drag the label to a control tab to create a controller.

SRT Variables

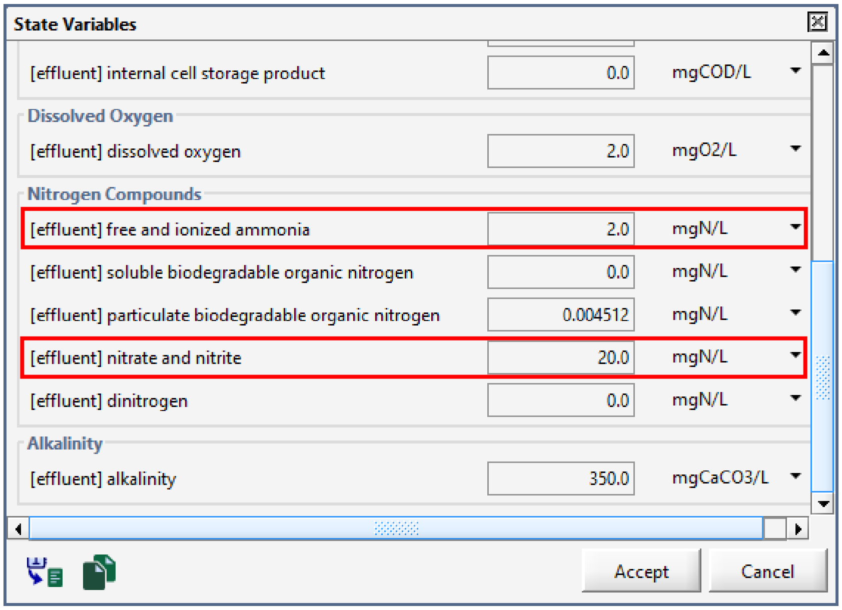
srtCAS

Mass(mlss)/Mass Flow(effluent,WAS)

☑ Estimate WAS using set SRT

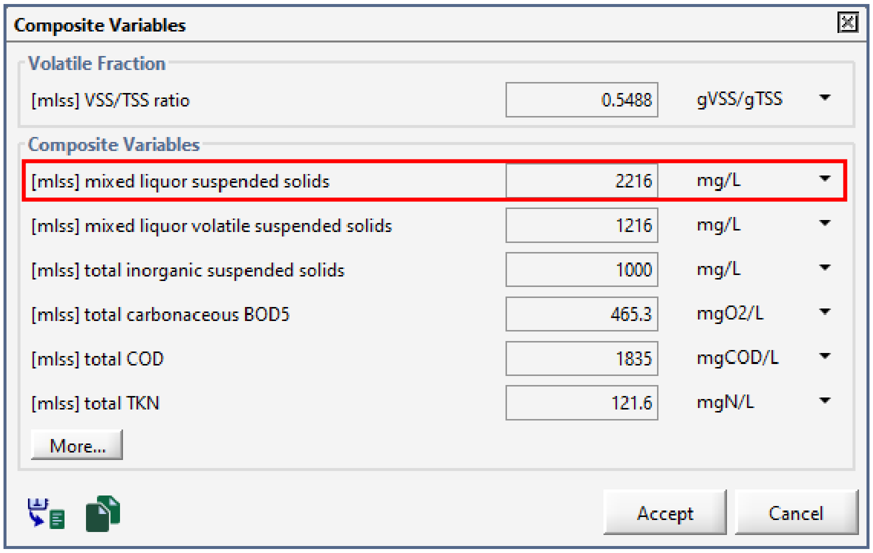
Controlled Flow: WAS
SRT set point: 10.0 days
minimum SRT controller pump flow: 0.0 m3/d
maximum SRT controller pump flow: 1000000 m3/d

10. Right-click on the effluent stream and go to *Output Variables* > *State Variables*. Drag the following variables to the same digital graph on the Nitrification tab.
    - Nitrogen Compounds – **free and ionized ammonia**
    - Nitrogen Compounds – **nitrate and nitrite**


State Variables

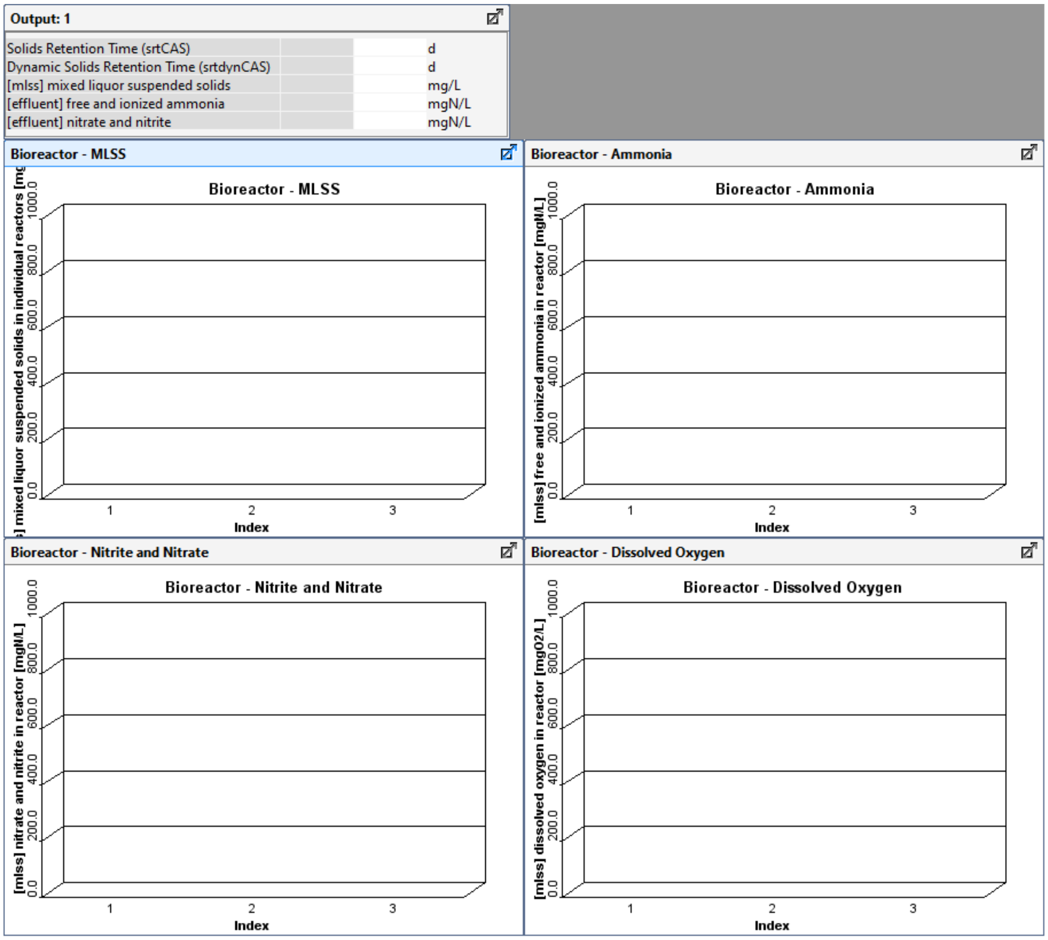
[effluent] internal cell storage product	0.0	mgCOD/L
Dissolved Oxygen		
[effluent] dissolved oxygen	2.0	mgO2/L
Nitrogen Compounds		
[effluent] free and ionized ammonia	2.0	mgN/L
[effluent] soluble biodegradable organic nitrogen	0.0	mgN/L
[effluent] particulate biodegradable organic nitrogen	0.004512	mgN/L
[effluent] nitrate and nitrite	20.0	mgN/L
[effluent] dinitrogen	0.0	mgN/L
Alkalinity		
[effluent] alkalinity	350.0	mgCaCO3/L

11. Right-click on the mlss stream at the connection point on the top-left of the reactor, hover until the cursor changes to an arrow, then go to *Output Variables* > *Composite Variables* and drag the **mixed liquor suspended solids** to the digital graph.


Composite Variables

Volatile Fraction		
[mlss] VSS/TSS ratio	0.5488	gVSS/gTSS
Composite Variables		
[mlss] mixed liquor suspended solids	2216	mg/L
[mlss] mixed liquor volatile suspended solids	1216	mg/L
[mlss] total inorganic suspended solids	1000	mg/L
[mlss] total carbonaceous BOD5	465.3	mgO2/L
[mlss] total COD	1835	mgCOD/L
[mlss] total TKN	121.6	mgN/L

12. Auto arrange the graphs in the output tab.

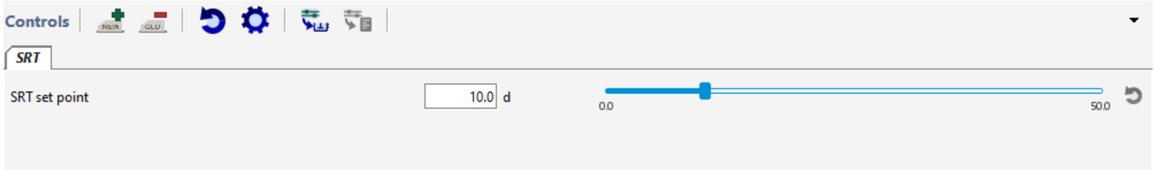


Output: 1

Solids Retention Time (srtCAS)	d
Dynamic Solids Retention Time (srtdynCAS)	d
[mlss] mixed liquor suspended solids	mg/L
[effluent] free and ionized ammonia	mgN/L
[effluent] nitrate and nitrite	mgN/L

Scenario 1 – Effect of SRT on Nitrification

13. Create a new input control tab and rename it to “SRT.”
14. From the Main Toolbar select *Define* > *Solids Retention Time* and drag onto the new input controls tab the **SRT set point**.



SRT set point 10.0 d

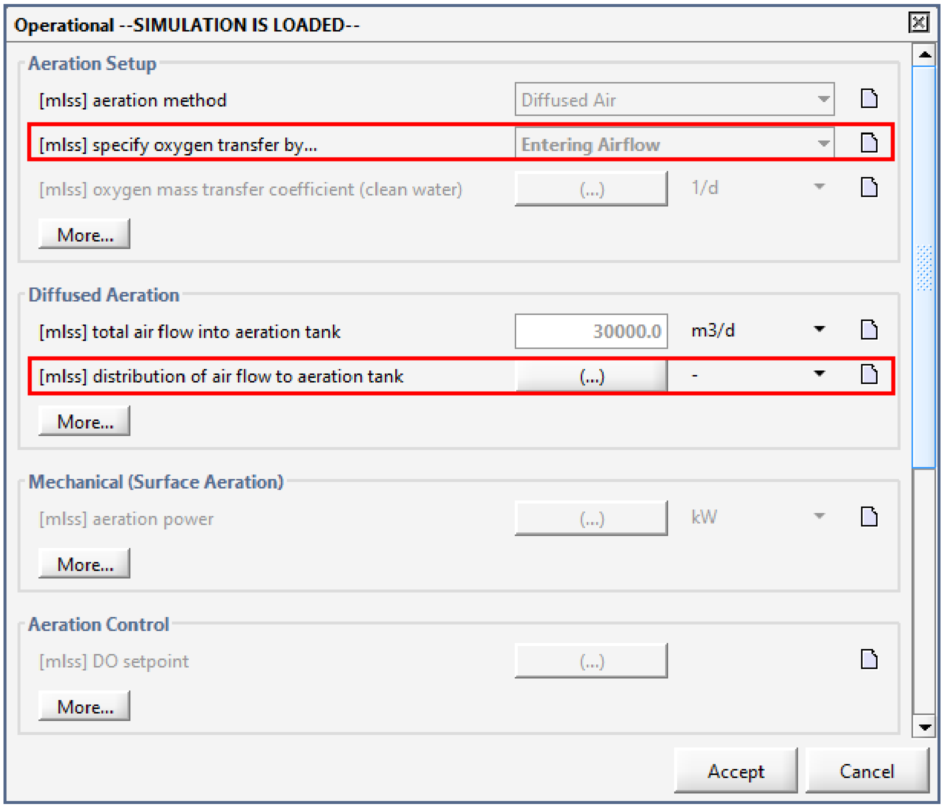
15. Run the simulation at **SRT set points** of **2, 6, 10, and 14 days** and record the values of the following from the Nitrification output tab:
    a. Mixed liquor suspended solids
    b. Free and ionized ammonia
    c. Nitrate and nitrite

Note: In the fully-functional version of GPS-X an analyze feature is available. This feature would allow the user to automatically run the simulation at the different SRT set points with the SRT setpoint presented on the x-axis rather than time.

16. In Excel, create a graph with SRT on the x-axis, and the recorded variables from Step 15 on the y-axis. Discuss the results. (**Exercise 5 – Question 1)**

Scenario 2 – Effect of Dissolved Oxygen on Nitrification

17. Create a new input controls tab and rename it to “DO Control.”
18. Right-click on the Bioreactor and navigate to *Input Parameters* > *Operational* and drag onto the input controls area the following variables:
    - Aeration Setup – **specify oxygen transfer by…**
    - Diffused Aeration – **distribution of air flow to aeration tank** (will create 3 controls due to the specification of 3 tanks in the physical menu of this object)


Operational --SIMULATION IS LOADED--

Aeration Setup

[mlss] aeration method — Diffused Air

[mlss] specify oxygen transfer by... — Entering Airflow

[mlss] oxygen mass transfer coefficient (clean water) — (...) 1/d

Diffused Aeration

[mlss] total air flow into aeration tank — 30000.0 m3/d

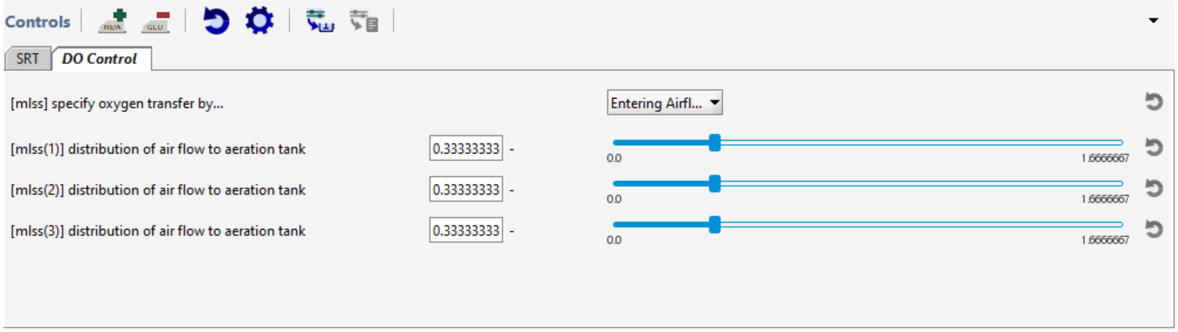
[mlss] distribution of air flow to aeration tank — (...) -

Mechanical (Surface Aeration)

[mlss] aeration power — (...) kW

Aeration Control

[mlss] DO setpoint — (...)



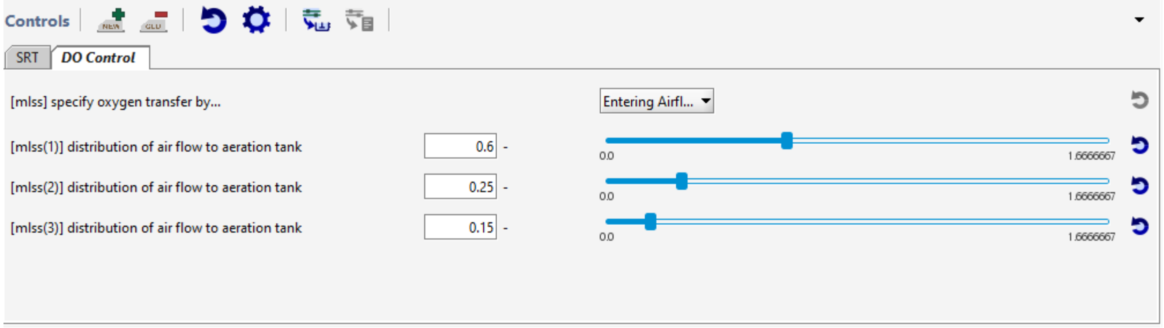
[mlss] specify oxygen transfer by... Entering Airfl...

[mlss(1)] distribution of air flow to aeration tank 0.33333333 -

[mlss(2)] distribution of air flow to aeration tank 0.33333333 -

[mlss(3)] distribution of air flow to aeration tank 0.33333333 -

19. Set the **SRT set point** to **5 days** in the SRT input controls tab.
20. Run the simulation at the default DO control settings and record a screenshot of the results on the Nitrification output tab. (**Exercise 5 – Question 2)**
21. In the input controls section set the **distribution of air flow to aeration tank** to **0.6, 0.25, and 0.15** for tanks 1, 2, and 3 respectively.



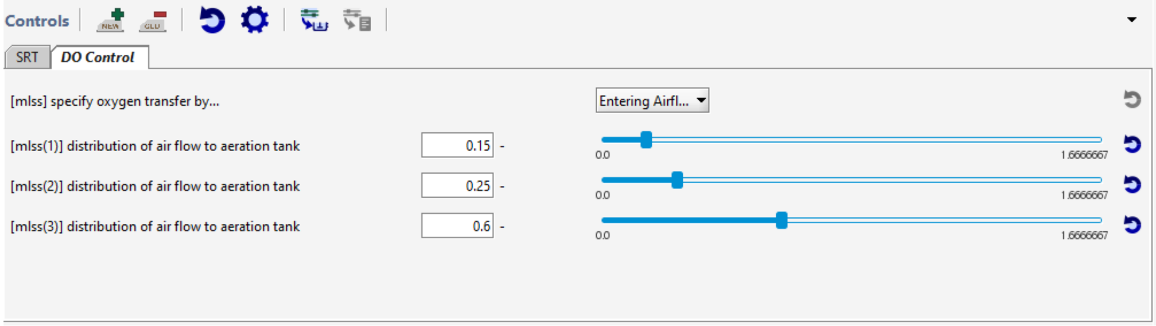
[mlss] specify oxygen transfer by... Entering Airfl...

[mlss(1)] distribution of air flow to aeration tank 0.6 -

[mlss(2)] distribution of air flow to aeration tank 0.25 -

[mlss(3)] distribution of air flow to aeration tank 0.15 -

22. Rerun the simulation and record a screenshot of the results on the Nitrification output tab. (**Exercise 5 – Question 3)**
23. In the input controls section set the **distribution of air flow to aeration tank** to **0.15, 0.25, and 0.6** for tanks 1, 2, and 3 respectively. Keep the **SRT Setpoint** at **5 days**.



[mlss] specify oxygen transfer by... Entering Airfl...

[mlss(1)] distribution of air flow to aeration tank 0.15 -

[mlss(2)] distribution of air flow to aeration tank 0.25 -

[mlss(3)] distribution of air flow to aeration tank 0.6 -

24. Rerun the simulation and record a screenshot of the results on the Nitrification output tab. (**Exercise 5 – Question 4)**
25. In the input controls area set the **specify oxygen transfer by …** to **Using a DO Controller**. By default, this will set the ***DO concentration in each tank to 2 mg/L***. Rerun the simulation and record a screenshot of the results in the Nitrification output tab. Compare and contrast the results from steps 20, 22, and 24. (**Exercise 5 – Question 5)**

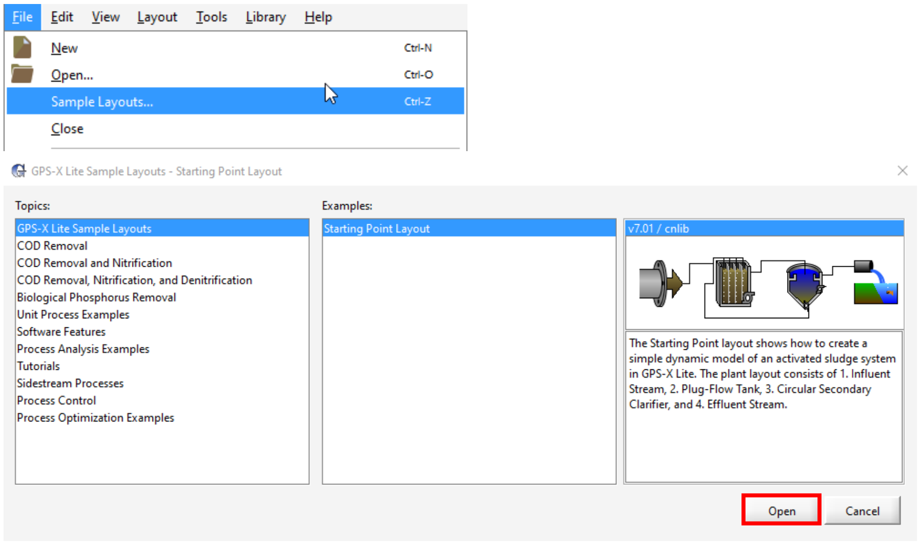
Exercise 6 – Temperature Effect on Nitrification

Biological nitrogen removal is highly dependent on temperature; therefore, nitrogen removal is an important consideration in the determination of summer versus winter operating conditions.

The objective of this exercise is to explore the effect of temperature on nitrification.

1. Open the Starting Point model layout developed in Exercise 1 and save it under a different name.

   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*

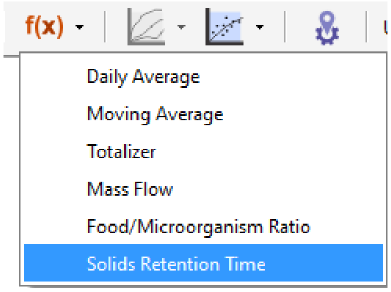


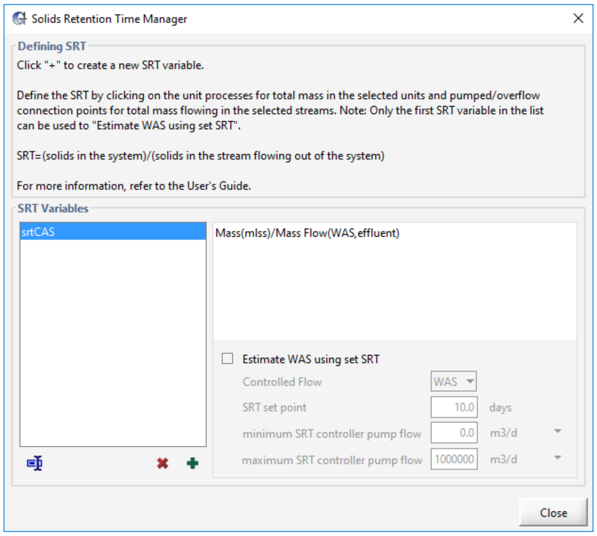
The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. In modelling mode, define the SRT calculation. From the main toolbar select *Define > Solids Retention Time*.

   Follow the steps in Step 4 of Exercise 5. In this case, the pop-up box for the numerator will only have Reactor 1 specified as opposed to three reactors above.

   Also, for this exercise, make sure that the “Estimate WAS using set SRT” box is unchecked.





Solids Retention Time Manager

Defining SRT

Click "+" to create a new SRT variable.

Define the SRT by clicking on the unit processes for total mass in the selected units and pumped/overflow connection points for total mass flowing in the selected streams. Note: Only the first SRT variable in the list can be used to "Estimate WAS using set SRT".

SRT=(solids in the system)/(solids in the stream flowing out of the system)

For more information, refer to the User's Guide.

SRT Variables

srtCAS

Mass(mlss)/Mass Flow(WAS,effluent)

☐ Estimate WAS using set SRT

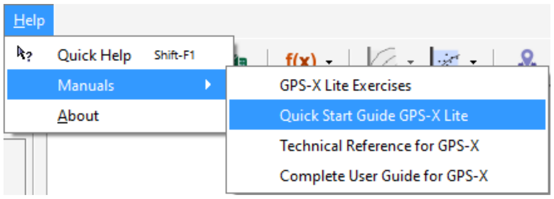
Controlled Flow: WAS

SRT set point: 10.0 days

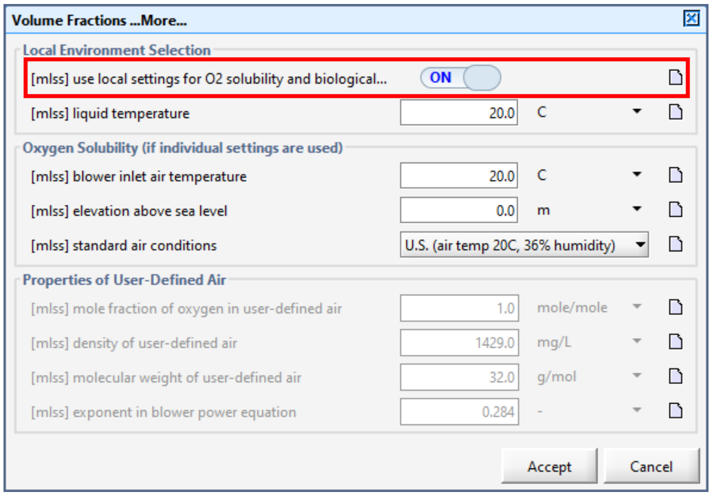
minimum SRT controller pump flow: 0.0 m3/d

maximum SRT controller pump flow: 1000000 m3/d

Close



3. Right-click on the Bioreactor and navigate to *Input Parameters* > *Physical* > *Volume Fractions More…* > *Local Environment Selection* and set the **use local settings for O2 solubility and biological activity** to **ON**. This allows for access to the liquid temperature which sets the temperature within the Bioreactor basins.



Volume Fractions ...More...

Local Environment Selection

[mlss] use local settings for O2 solubility and biological... ON

[mlss] liquid temperature 20.0 C

Oxygen Solubility (if individual settings are used)

[mlss] blower inlet air temperature 20.0 C

[mlss] elevation above sea level 0.0 m

[mlss] standard air conditions U.S. (air temp 20C, 36% humidity)

Properties of User-Defined Air

[mlss] mole fraction of oxygen in user-defined air 1.0 mole/mole

[mlss] density of user-defined air 1429.0 mg/L

[mlss] molecular weight of user-defined air 32.0 g/mol

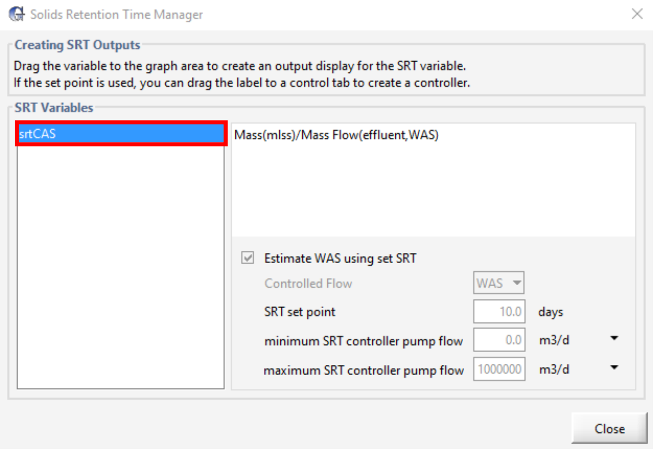
[mlss] exponent in blower power equation 0.284 -

Accept Cancel

4. Switch into Simulation Mode. Rebuild the model when prompted.
5. Create a new graph tab and call it "SRT."

f(x)

6. From the main toolbar navigate to *Define* > *Solids Retention Time* and drag the **srtCAS** variable to the new output tab. Right-click on the created graph and navigate to *Output Graph Type* > ***Digital***.



Creating SRT Outputs

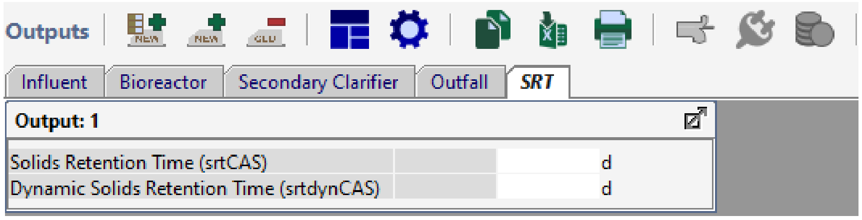
Drag the variable to the graph area to create an output display for the SRT variable.
If the set point is used, you can drag the label to a control tab to create a controller.

SRT Variables

srtCAS

Mass(mlss)/Mass Flow(effluent,WAS)

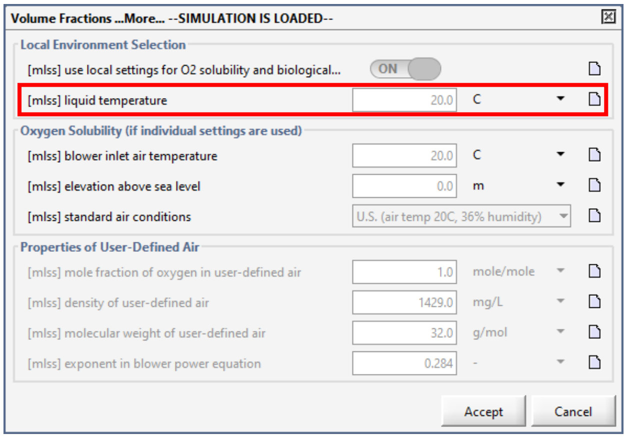
☑ Estimate WAS using set SRT
Controlled Flow: WAS
SRT set point: 10.0 days
minimum SRT controller pump flow: 0.0 m3/d
maximum SRT controller pump flow: 1000000 m3/d



Output: 1

Solids Retention Time (srtCAS) d
Dynamic Solids Retention Time (srtdynCAS) d

7. Right-click on the Bioreactor and go to *Input Parameters* > *Physical* > *Volume Fractions More…* menu and drag the **liquid temperature** variable to the input controls section. Rename the tab that is created to “Input Settings.”



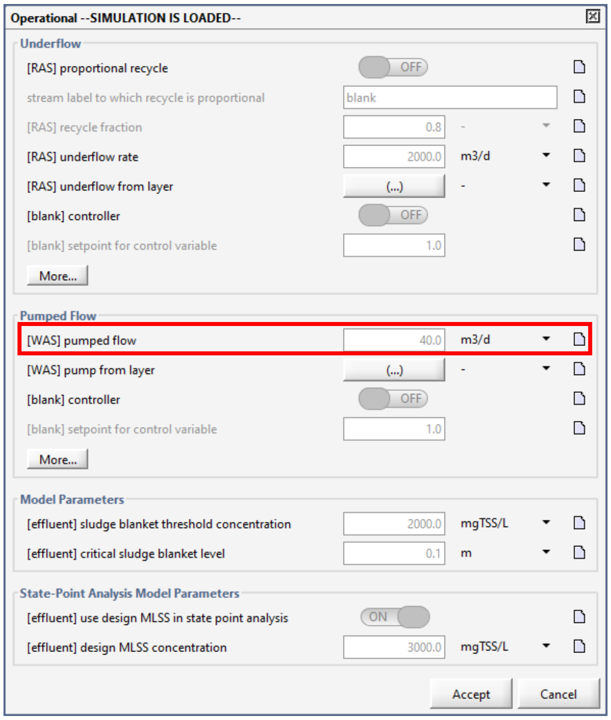
Volume Fractions ...More... --SIMULATION IS LOADED--

Local Environment Selection
[mlss] use local settings for O2 solubility and biological... ON
[mlss] liquid temperature 20.0 C

Oxygen Solubility (if individual settings are used)
[mlss] blower inlet air temperature 20.0 C
[mlss] elevation above sea level 0.0 m
[mlss] standard air conditions U.S. (air temp 20C, 36% humidity)

Properties of User-Defined Air
[mlss] mole fraction of oxygen in user-defined air 1.0 mole/mole
[mlss] density of user-defined air 1429.0 mg/L
[mlss] molecular weight of user-defined air 32.0 g/mol
[mlss] exponent in blower power equation 0.284 -

8. Right-click on the Secondary Clarifier and navigate to *Input Parameters* > *Operational* and drag the **pumped flow** variable to the input control Input Settings tab.



Operational --SIMULATION IS LOADED--

Underflow

[RAS] proportional recycle OFF

stream label to which recycle is proportional blank

[RAS] recycle fraction 0.8 -

[RAS] underflow rate 2000.0 m3/d

[RAS] underflow from layer (...) -

[blank] controller OFF

[blank] setpoint for control variable 1.0

Pumped Flow

[WAS] pumped flow 40.0 m3/d

[WAS] pump from layer (...) -

[blank] controller OFF

[blank] setpoint for control variable 1.0

Model Parameters

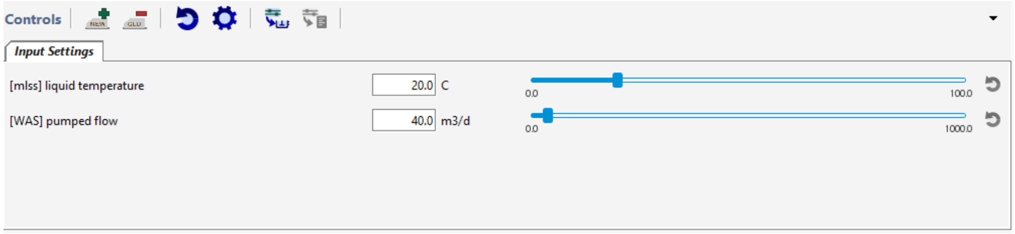
[effluent] sludge blanket threshold concentration 2000.0 mgTSS/L

[effluent] critical sludge blanket level 0.1 m

State-Point Analysis Model Parameters

[effluent] use design MLSS in state point analysis ON

[effluent] design MLSS concentration 3000.0 mgTSS/L



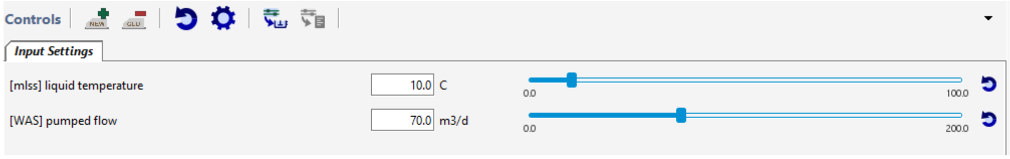
Controls

Input Settings

[mlss] liquid temperature 20.0 C

[WAS] pumped flow 40.0 m3/d

9. It has been stated that “The minimum SRT used to ensure nitrification at average conditions is 7 d at 10°C” [1]. Simulate these settings by adjusting the **liquid temperature** and the **pumped flow** to **10ºC** and **70 m^3/d**, respectively, in the input controls area. Run the simulation and observe the results. Take a screenshot of the results on the Outfall tab under the Simulation Results header. (**Exercise 6 – Question 1)**

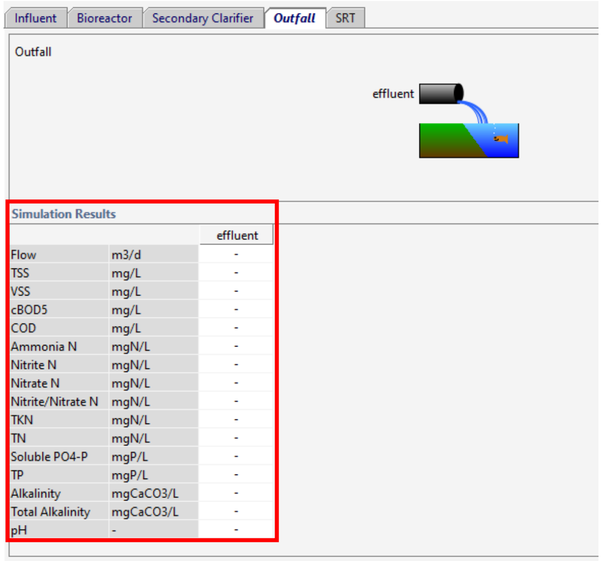


Controls

Input Settings

[mlss] liquid temperature 10.0 C

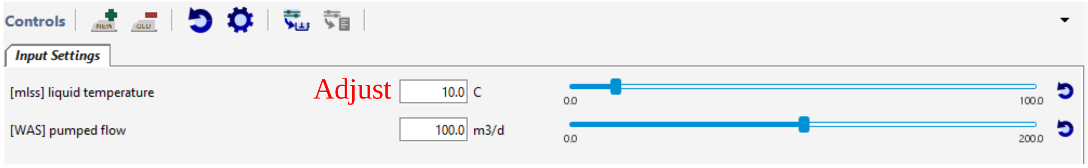
[WAS] pumped flow 70.0 m3/d



Simulation Results

		effluent
Flow	m3/d	-
TSS	mg/L	-
VSS	mg/L	-
cBOD5	mg/L	-
COD	mg/L	-
Ammonia N	mgN/L	-
Nitrite N	mgN/L	-
Nitrate N	mgN/L	-
Nitrite/Nitrate N	mgN/L	-
TKN	mgN/L	-
TN	mgN/L	-
Soluble PO4-P	mgP/L	-
TP	mgP/L	-
Alkalinity	mgCaCO3/L	-
Total Alkalinity	mgCaCO3/L	-
pH	-	-

10. In this exercise the SRT will be held constant to observe the effect of temperature on nitrification. Set the **pumped flow** variable to **100 m^3/d** (this will result in an SRT of approximately 5 days), and run the simulation at **liquid temperatures** of **20, 16, 12, 8, and 4 °C**. Create a plot in Excel of effluent ammonia vs. liquid temperature. Ensure appropriate axis labels and title are given. (**Exercise 6 – Question 2)**



[mlss] liquid temperature Adjust 10.0 C

[WAS] pumped flow 100.0 m3/d

Note: In the fully-functional version of GPS-X an analyze feature is available. This feature would allow the user to automatically run the simulation at the different bioreactor temperatures with the bioreactor temperature presented on the x-axis rather than time.

11. For temperatures 16 and 4ºC, determine the minimum SRT required to obtain an ***effluent ammonia concentration below 2 mgN/L***. Adjust the SRT by changing the WAS **pumped flow**. (**Exercise 6 – Question 3)**
12. Save the model layout.

Exercise 7 – Aeration Control

In a conventional activated sludge process, good aeration control is arguably one of the most important factors for the removal of ammonia and organics. This exercise will explore several factors that affect oxygen transfer including:

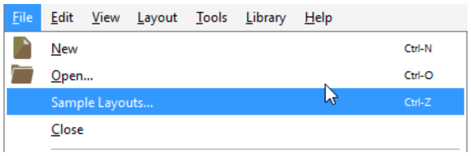
1. Equipment:
    a) Diffuser type
    b) Diffuser Density
    c) Diffuser Submergence
2. Operations:
    a) Solids Retention Time
    b) Airflow Rate per Diffuser
    c) Diffuser Fouling
3. Wastewater Characteristics:
    a) Temperature

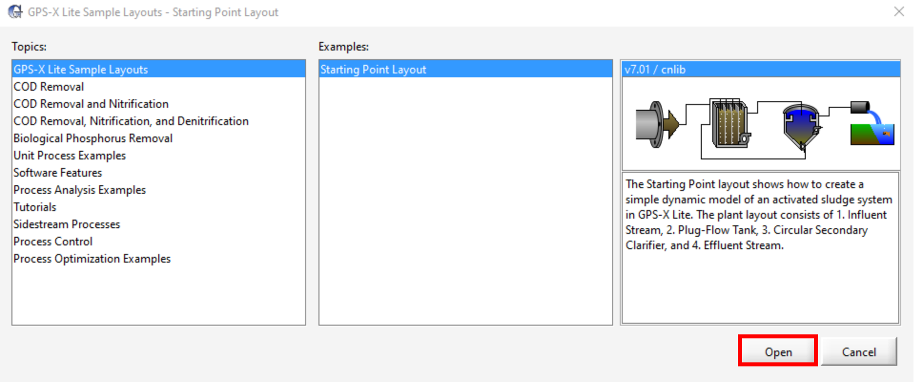
Create the following table to record answers to the questions presented in this exercise. **(Exercise 7 – Question 1)**

	Factor	**Factor Setting**	**Total Actual Oxygen Transfer Rate (OTR) (kg/d)**	**Effluent cBOD$_5$**	**Effluent Free and Ionized Ammonia**	**Observation**
Equipment	Diffuser Type	Fine Bubble	651	5.53	0.359	
		Coarse Bubble				
	Diffuser Density	0.2	651	5.53	0.359	
		0.8				
	Diffuser Submergence (height of diffuser from floor)	0.3	651	5.53	0.359	
		1.2				
Operations	Solids Retention Time	10 d	651	5.53	0.359	
		3 d				
	Total Air Flow into aeration tank	20,000 m^3/d	651	5.53	0.359	
		50,000 m^3/d				
	Diffuser Fouling	1.0	651	5.53	0.359	
		0.5				
Wastewater Characteristics	Temperature	20 °C	651	5.53	0.359	
		10 °C				

1. Open the Starting Point model layout developed in Exercise 1 and save it under a different name.

   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*



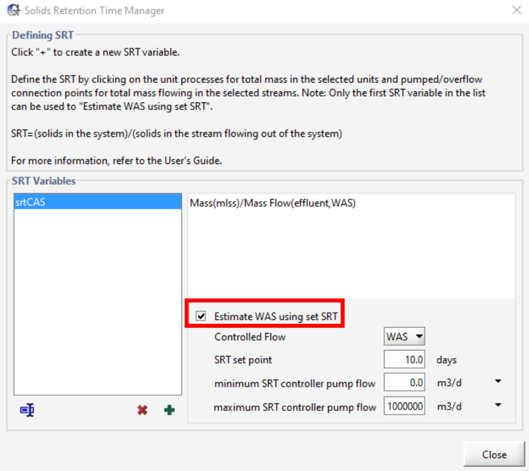


The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

Define the SRT calculation.

Follow the steps in Step 4 of Exercise 5. In this case, the pop-up box for the numerator will only have Reactor 1 specified as opposed to three reactors above.

- Select the "Estimate WAS using set SRT" button. Close this window.



Click "+" to create a new SRT variable.

Define the SRT by clicking on the unit processes for total mass in the selected units and pumped/overflow connection points for total mass flowing in the selected streams. Note: Only the first SRT variable in the list can be used to "Estimate WAS using set SRT".

SRT=(solids in the system)/(solids in the stream flowing out of the system)

For more information, refer to the User's Guide.

srtCAS

Mass(mlss)/Mass Flow(effluent,WAS)

☑ Estimate WAS using set SRT

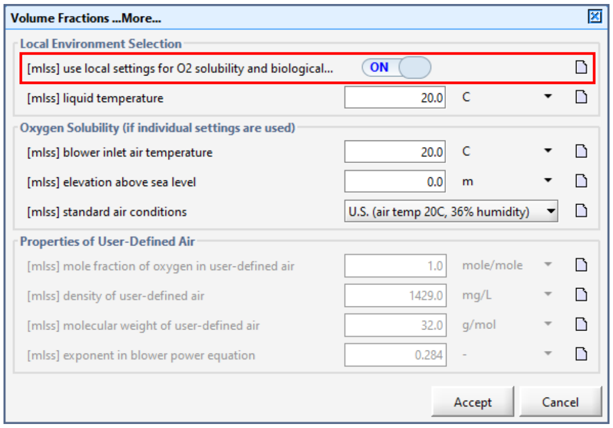
Controlled Flow: WAS

SRT set point: 10.0 days

minimum SRT controller pump flow: 0.0 m3/d

maximum SRT controller pump flow: 1000000 m3/d

2. In modelling mode right-click on the Bioreactor and navigate to *Input Parameters > Physical > Volume Fractions More… > Local Environment Selection* and set the **use local settings for O2 solubility and biological activity** to **ON**. This allows access to the liquid temperature which sets the temperature within the Bioreactor basins.



Volume Fractions ...More...

Local Environment Selection

[mlss] use local settings for O2 solubility and biological... ON

[mlss] liquid temperature 20.0 C

Oxygen Solubility (if individual settings are used)

[mlss] blower inlet air temperature 20.0 C

[mlss] elevation above sea level 0.0 m

[mlss] standard air conditions U.S. (air temp 20C, 36% humidity)

Properties of User-Defined Air

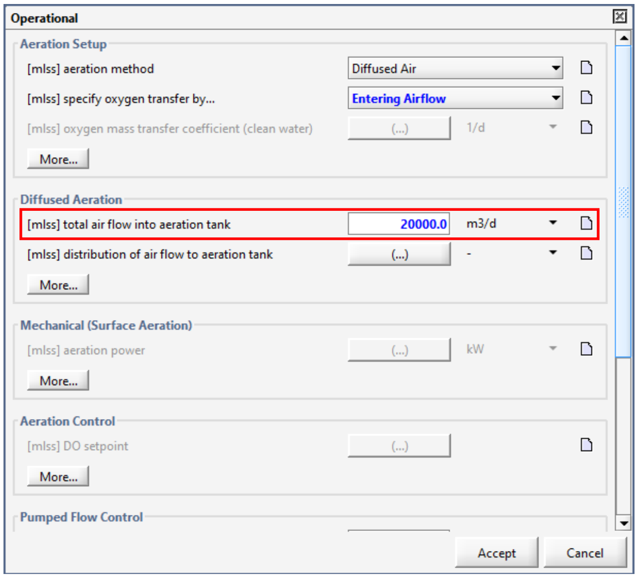
[mlss] mole fraction of oxygen in user-defined air 1.0 mole/mole

[mlss] density of user-defined air 1429.0 mg/L

[mlss] molecular weight of user-defined air 32.0 g/mol

[mlss] exponent in blower power equation 0.284 -

3. Right-click on the Bioreactor and navigate to *Input Parameters > Operational > Diffused Aeration header* and change the **total air flow into aeration tank variable** setting to **20,000 m^3/d**.



Operational

Aeration Setup

[mlss] aeration method Diffused Air

[mlss] specify oxygen transfer by... Entering Airflow

[mlss] oxygen mass transfer coefficient (clean water) (...) 1/d

Diffused Aeration

[mlss] total air flow into aeration tank 20000.0 m3/d

[mlss] distribution of air flow to aeration tank (...) -

Mechanical (Surface Aeration)

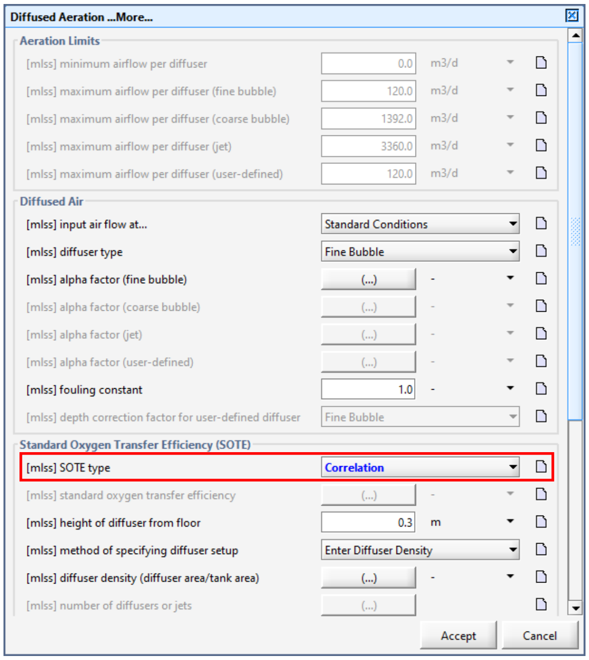
[mlss] aeration power (...) kW

Aeration Control

[mlss] DO setpoint (...)

Pumped Flow Control

4. Right-click on the Bioreactor and navigate to *Input Parameters > Operational > Diffused Aeration More… > Standard Oxygen Transfer Efficiency (SOTE)* and set the **SOTE type** to **correlation**.



Diffused Aeration ...More...

Aeration Limits

[mlss] minimum airflow per diffuser 0.0 m3/d

[mlss] maximum airflow per diffuser (fine bubble) 120.0 m3/d

[mlss] maximum airflow per diffuser (coarse bubble) 1392.0 m3/d

[mlss] maximum airflow per diffuser (jet) 3360.0 m3/d

[mlss] maximum airflow per diffuser (user-defined) 120.0 m3/d

Diffused Air

[mlss] input air flow at... Standard Conditions

[mlss] diffuser type Fine Bubble

[mlss] alpha factor (fine bubble) (...) -

[mlss] alpha factor (coarse bubble) (...) -

[mlss] alpha factor (jet) (...) -

[mlss] alpha factor (user-defined) (...) -

[mlss] fouling constant 1.0 -

[mlss] depth correction factor for user-defined diffuser Fine Bubble

Standard Oxygen Transfer Efficiency (SOTE)

[mlss] SOTE type Correlation

[mlss] standard oxygen transfer efficiency (...) -

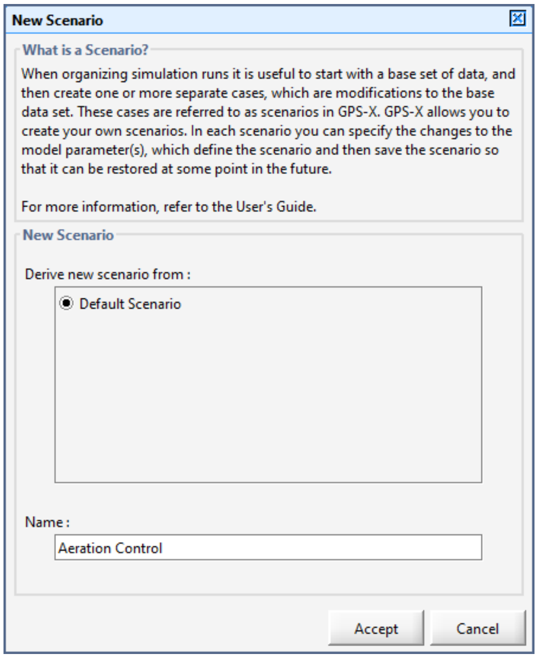
[mlss] height of diffuser from floor 0.3 m

[mlss] method of specifying diffuser setup Enter Diffuser Density

[mlss] diffuser density (diffuser area/tank area) (...) -

[mlss] number of diffusers or jets (...)

5. Switch into Simulation Mode. Rebuild the model when prompted.
6. Create a new scenario to explore the effect of the various factors on aeration control. Navigate to *Scenario > New* and call the new scenario “Aeration Control.”



New Scenario

What is a Scenario?

When organizing simulation runs it is useful to start with a base set of data, and then create one or more separate cases, which are modifications to the base data set. These cases are referred to as scenarios in GPS-X. GPS-X allows you to create your own scenarios. In each scenario you can specify the changes to the model parameter(s), which define the scenario and then save the scenario so that it can be restored at some point in the future.

For more information, refer to the User's Guide.

New Scenario

Derive new scenario from :

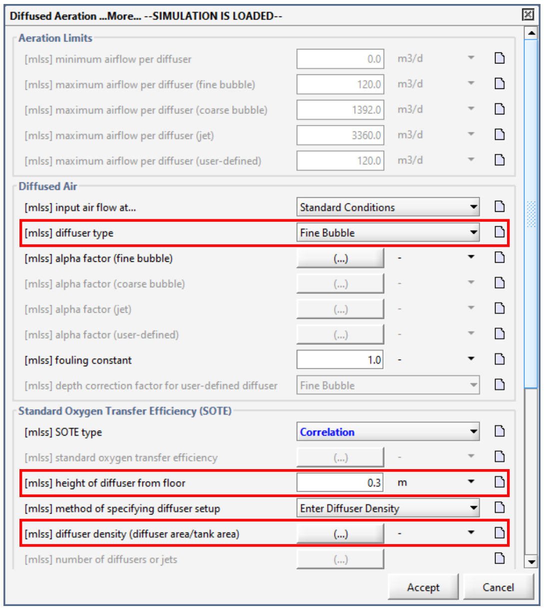
● Default Scenario

Name : Aeration Control

7. Create 3 input control tabs and relabel for each factor grouping: “Equipment Factors,” “Operational Factors”, “Wastewater Characteristics.”
8. Select the Equipment Factors input control tab and add the following variables to the tab.
    a. Bioreactor – *Input Parameters > Operational > Diffused Aeration More… > Diffused Air* **- diffuser type**

b. Bioreactor – *Input Parameters > Operational > Diffused Aeration More… > Standard Oxygen Transfer Efficiency (SOTE)* - **diffuser density (diffuser area/tank area)**

c. Bioreactor – *Input Parameters > Operational > Diffused Aeration More… > Standard Oxygen Transfer Efficiency (SOTE)* – **height of diffuser from floor**


Diffused Aeration ...More... --SIMULATION IS LOADED--

Aeration Limits

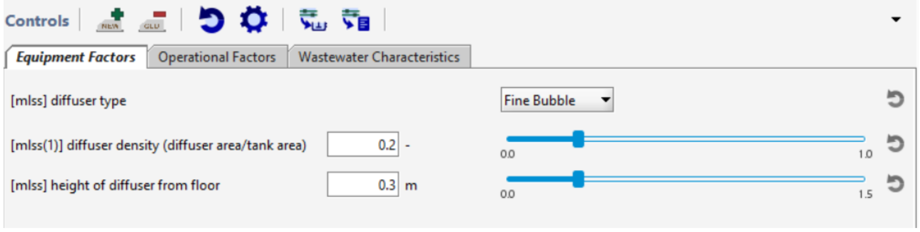
[mlss] minimum airflow per diffuser 0.0 m3/d
[mlss] maximum airflow per diffuser (fine bubble) 120.0 m3/d
[mlss] maximum airflow per diffuser (coarse bubble) 1392.0 m3/d
[mlss] maximum airflow per diffuser (jet) 3360.0 m3/d
[mlss] maximum airflow per diffuser (user-defined) 120.0 m3/d

Diffused Air

[mlss] input air flow at... Standard Conditions
[mlss] diffuser type Fine Bubble
[mlss] alpha factor (fine bubble) (...) -
[mlss] alpha factor (coarse bubble) (...) -
[mlss] alpha factor (jet) (...) -
[mlss] alpha factor (user-defined) (...) -
[mlss] fouling constant 1.0 -
[mlss] depth correction factor for user-defined diffuser Fine Bubble

Standard Oxygen Transfer Efficiency (SOTE)

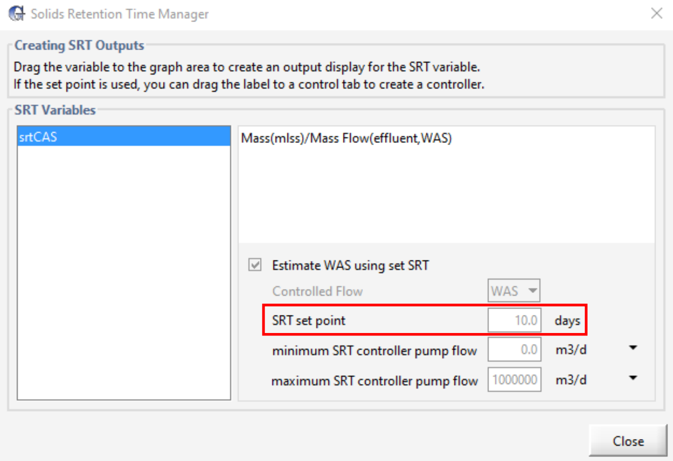
[mlss] SOTE type Correlation
[mlss] standard oxygen transfer efficiency (...) -
[mlss] height of diffuser from floor 0.3 m
[mlss] method of specifying diffuser setup Enter Diffuser Density
[mlss] diffuser density (diffuser area/tank area) (...) -
[mlss] number of diffusers or jets (...)



[mlss] diffuser type Fine Bubble
[mlss(1)] diffuser density (diffuser area/tank area) 0.2 -
[mlss] height of diffuser from floor 0.3 m

9. Select the Operational Factors input control tab and add to it the following variables:

   d. Define > Solids Retention Time > **SRT set point**



Creating SRT Outputs

Drag the variable to the graph area to create an output display for the SRT variable.
If the set point is used, you can drag the label to a control tab to create a controller.

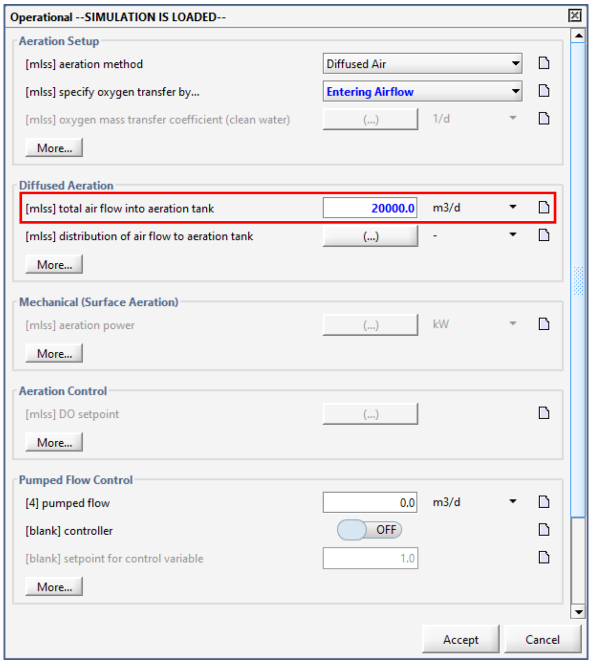
SRT Variables

srtCAS

Mass(mlss)/Mass Flow(effluent,WAS)

☑ Estimate WAS using set SRT
Controlled Flow WAS
SRT set point 10.0 days
minimum SRT controller pump flow 0.0 m3/d
maximum SRT controller pump flow 1000000 m3/d

e. Bioreactor – *Input Parameters > Operational > Diffused Aeration* – **total air into aeration tank**



Operational --SIMULATION IS LOADED--

Aeration Setup

[mlss] aeration method	Diffused Air	
[mlss] specify oxygen transfer by...	Entering Airflow	
[mlss] oxygen mass transfer coefficient (clean water)	(...)	1/d

Diffused Aeration

[mlss] total air flow into aeration tank	20000.0	m3/d
[mlss] distribution of air flow to aeration tank	(...)	-

Mechanical (Surface Aeration)

[mlss] aeration power	(...)	kW

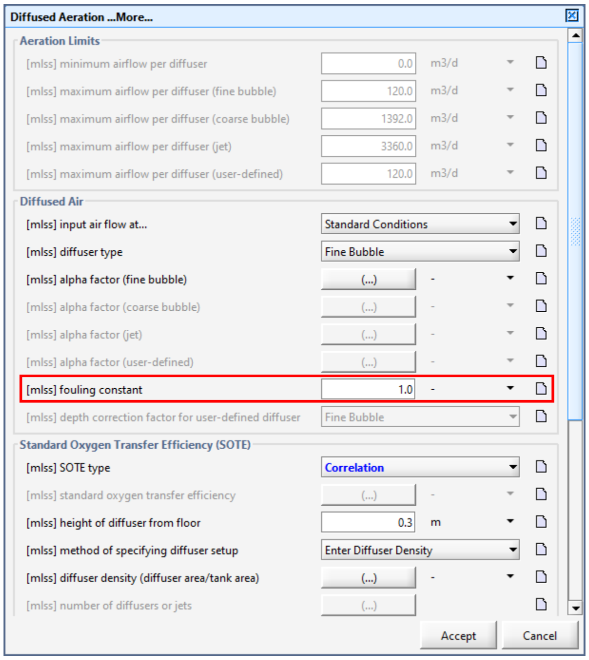
Aeration Control

[mlss] DO setpoint	(...)

Pumped Flow Control

[4] pumped flow	0.0	m3/d
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

f. Bioreactor – *Input Parameters > Operational > Diffused Aeration More… > Diffused Air* – **fouling constant**



Diffused Aeration ...More...

Aeration Limits

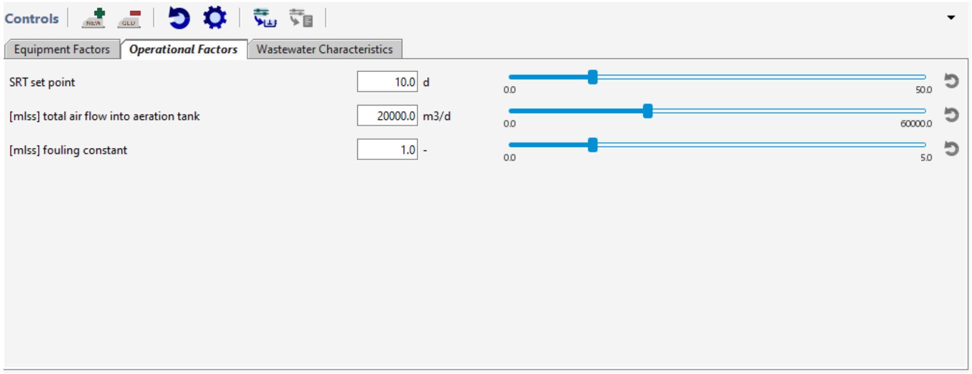
[mlss] minimum airflow per diffuser	0.0	m3/d
[mlss] maximum airflow per diffuser (fine bubble)	120.0	m3/d
[mlss] maximum airflow per diffuser (coarse bubble)	1392.0	m3/d
[mlss] maximum airflow per diffuser (jet)	3360.0	m3/d
[mlss] maximum airflow per diffuser (user-defined)	120.0	m3/d

Diffused Air

[mlss] input air flow at...	Standard Conditions	
[mlss] diffuser type	Fine Bubble	
[mlss] alpha factor (fine bubble)	(...)	-
[mlss] alpha factor (coarse bubble)	(...)	-
[mlss] alpha factor (jet)	(...)	-
[mlss] alpha factor (user-defined)	(...)	-
[mlss] fouling constant	1.0	-
[mlss] depth correction factor for user-defined diffuser	Fine Bubble	

Standard Oxygen Transfer Efficiency (SOTE)

[mlss] SOTE type	Correlation	
[mlss] standard oxygen transfer efficiency	(...)	-
[mlss] height of diffuser from floor	0.3	m
[mlss] method of specifying diffuser setup	Enter Diffuser Density	
[mlss] diffuser density (diffuser area/tank area)	(...)	-
[mlss] number of diffusers or jets	(...)	

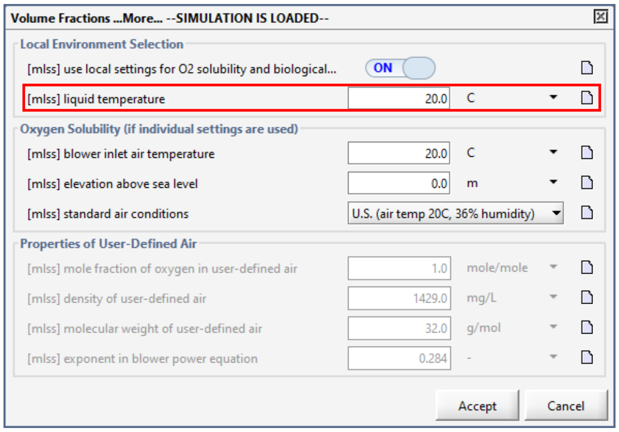


SRT set point 10.0 d (0.0 – 50.0)

[mlss] total air flow into aeration tank 20000.0 m3/d (0.0 – 60000.0)

[mlss] fouling constant 1.0 - (0.0 – 5.0)

10. Select the Wastewater Characteristics input controls tab and add to it the following variable:
    g. Bioreactor – *Input Parameters* > *Physical* > *Volume Fractions More…* > *Local Environment Selection* – **liquid temperature**



Local Environment Selection

[mlss] use local settings for O2 solubility and biological... ON

[mlss] liquid temperature 20.0 C

Oxygen Solubility (if individual settings are used)

[mlss] blower inlet air temperature 20.0 C

[mlss] elevation above sea level 0.0 m

[mlss] standard air conditions U.S. (air temp 20C, 36% humidity)

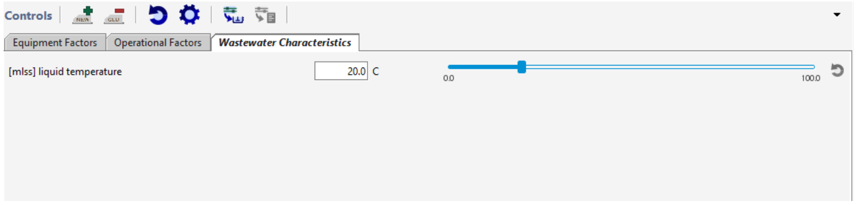
Properties of User-Defined Air

[mlss] mole fraction of oxygen in user-defined air 1.0 mole/mole

[mlss] density of user-defined air 1429.0 mg/L

[mlss] molecular weight of user-defined air 32.0 g/mol

[mlss] exponent in blower power equation 0.284 -



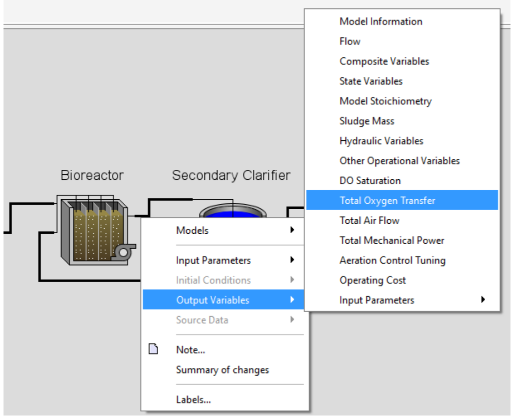
[mlss] liquid temperature 20.0 C (0.0 – 100.0)

11. Run the simulation and complete the previous table to explore the effect of each factor. **Ensure all variable settings are at the default values except for the factor of interest.**

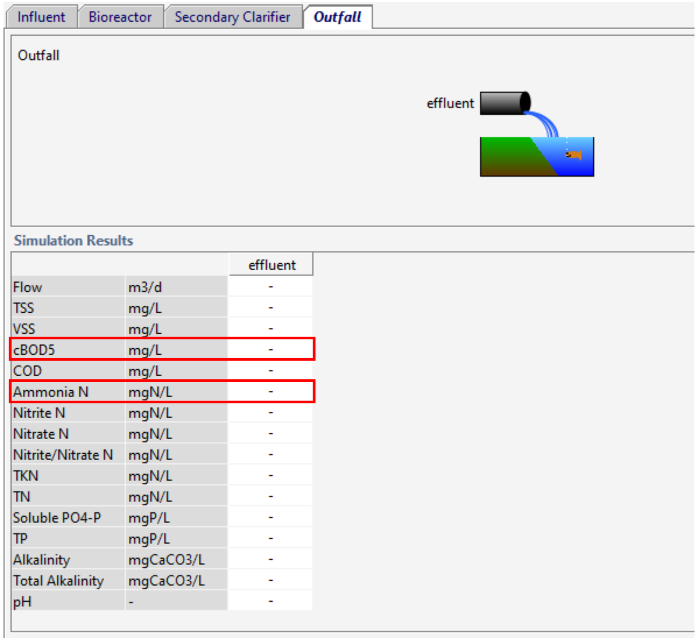
    Output results for entry into the table can be found in the following locations:

    a) Total Actual Oxygen Transfer Rate (OTR) (kg/d)

    Note: Hover on the mlss stream connection point of the Bioreactor and when the cursor becomes an arrow right-click and select *Output Variables* > *Total Oxygen Transfer*.



b) Effluent $cBOD_5$ and Effluent Free and Ionized Ammonia are found within the Outfall tab in the **Outputs** area.



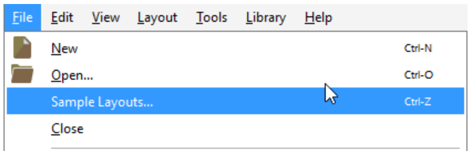
		effluent
Flow	m3/d	-
TSS	mg/L	-
VSS	mg/L	-
cBOD5	mg/L	-
COD	mg/L	-
Ammonia N	mgN/L	-
Nitrite N	mgN/L	-
Nitrate N	mgN/L	-
Nitrite/Nitrate N	mgN/L	-
TKN	mgN/L	-
TN	mgN/L	-
Soluble PO4-P	mgP/L	-
TP	mgP/L	-
Alkalinity	mgCaCO3/L	-
Total Alkalinity	mgCaCO3/L	-
pH	-	-

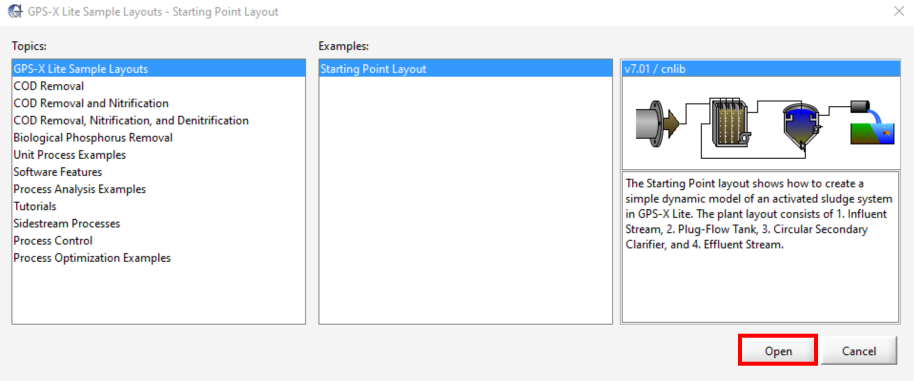
Exercise 8 – Total Nitrogen Removal: Nitrification and Denitrification

The objective of this exercise is to demonstrate how a PFR can be configured to allow for total nitrogen removal.

1. Open the Starting Point layout developed in Exercise 1 and rename appropriately.

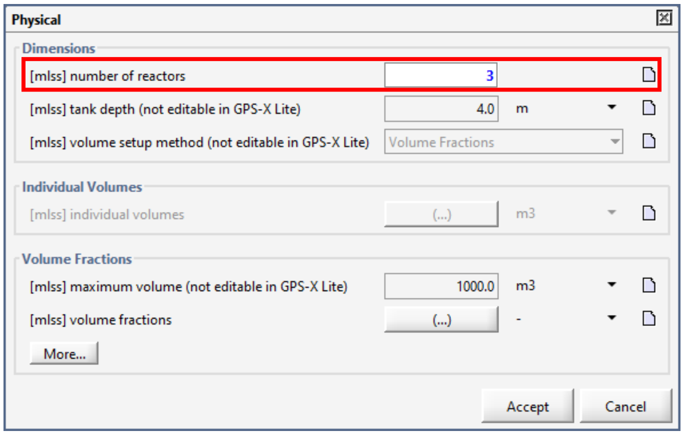
   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*





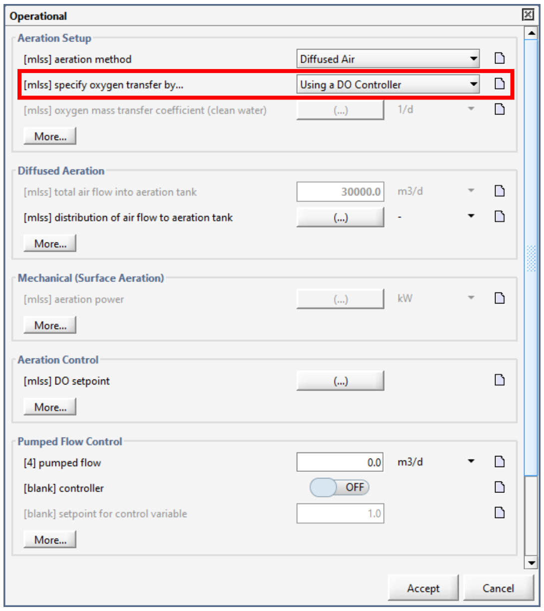
The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. In modelling mode, right-click on the Bioreactor and navigate to *Input Parameters > Physical* and change **the number of tanks** to **3**. This change allows the bioreactor to be modelled as a PFR with 3 equally distributed tanks.



[mlss] number of reactors 3
[mlss] tank depth (not editable in GPS-X Lite) 4.0 m
[mlss] volume setup method (not editable in GPS-X Lite) Volume Fractions
[mlss] individual volumes (...) m3
[mlss] maximum volume (not editable in GPS-X Lite) 1000.0 m3
[mlss] volume fractions (...) -

3. Right-click on the Bioreactor and navigate to *Input Parameters > Operational* and under the Aeration Setup header set the **specify oxygen transfer by…** to **Using a DO Controller**. This change will set the DO concentration to 2 mg/L in each of the aeration tanks.



Aeration Setup

[mlss] aeration method	Diffused Air	
[mlss] specify oxygen transfer by...	Using a DO Controller	
[mlss] oxygen mass transfer coefficient (clean water)	(...)	1/d

Diffused Aeration

[mlss] total air flow into aeration tank	30000.0	m3/d
[mlss] distribution of air flow to aeration tank	(...)	-

Mechanical (Surface Aeration)

[mlss] aeration power	(...)	kW

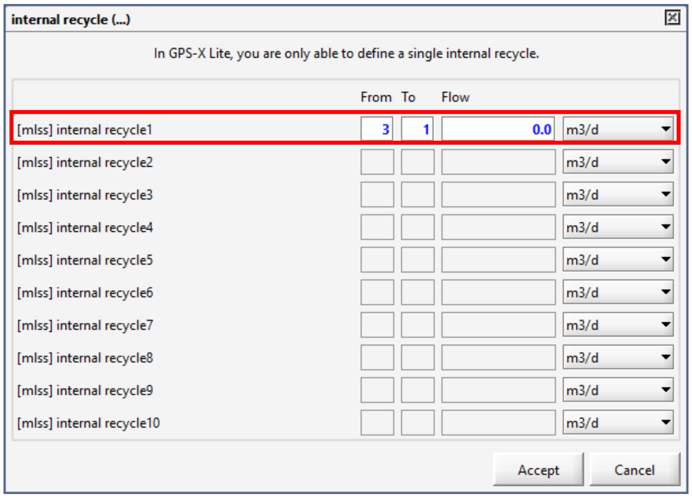
Aeration Control

[mlss] DO setpoint	(...)	

Pumped Flow Control

[4] pumped flow	0.0	m3/d
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

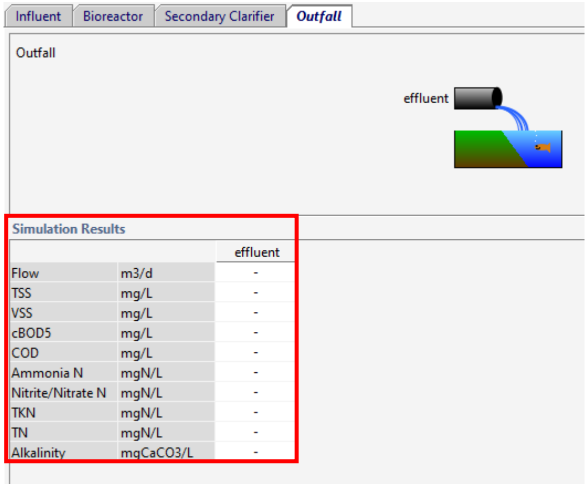
4. In this same form scroll to the bottom of the window to see the Internal Flow Distribution section. Select the internal recycle ellipse button and set the **From, To, and Flow** values to **3, 1, and 0 m^3/d**, respectively.



In GPS-X Lite, you are only able to define a single internal recycle.

	From	To	Flow	
[mlss] internal recycle1	3	1	0.0	m3/d
[mlss] internal recycle2				m3/d
[mlss] internal recycle3				m3/d
[mlss] internal recycle4				m3/d
[mlss] internal recycle5				m3/d
[mlss] internal recycle6				m3/d
[mlss] internal recycle7				m3/d
[mlss] internal recycle8				m3/d
[mlss] internal recycle9				m3/d
[mlss] internal recycle10				m3/d

5. Switch into Simulation Mode. Rebuild the model when prompted.
6. Run the simulation at steady-state and observe the simulation outputs in the Outfall tab. Record a screenshot of the results under the Simulation Results header within this tab. (**Exercise 8 – Question 1)**



		effluent
Flow	m3/d	-
TSS	mg/L	-
VSS	mg/L	-
cBOD5	mg/L	-
COD	mg/L	-
Ammonia N	mgN/L	-
Nitrite/Nitrate N	mgN/L	-
TKN	mgN/L	-
TN	mgN/L	-
Alkalinity	mgCaCO3/L	-

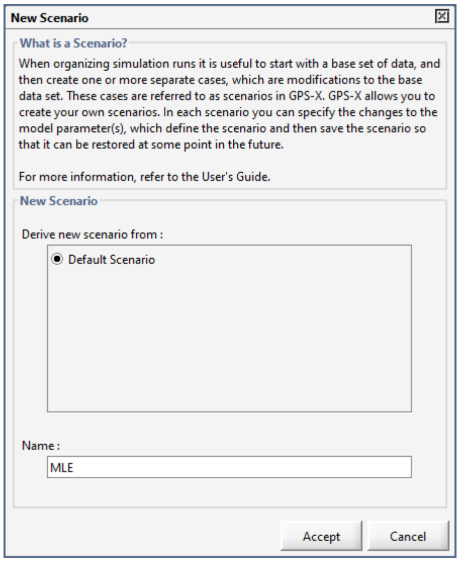
Observe the nitrogen variables and make the following observations:

- Low ammonia concentration indicates complete nitrification
- High nitrite and nitrate concentrations indicates incomplete denitrification

The nitrification process converts ammonia to nitrite and nitrate in an oxygen-rich environment, while the denitrification process converts nitrate to nitrogen gas (N_2) in the absence of oxygen.

Select the Bioreactor output tab. Notice that the DO concentration in all three tanks is 2 mg/L, as a DO controller is being used to maintain this oxygen-rich environment. With no oxygen-limited conditions present, denitrification is constrained.

7. Create a new scenario to explore the changes needed to allow for complete nitrogen removal. Navigate to *Scenario* > *New* from the simulation toolbar and call the new scenario “MLE.”



When organizing simulation runs it is useful to start with a base set of data, and then create one or more separate cases, which are modifications to the base data set. These cases are referred to as scenarios in GPS-X. GPS-X allows you to create your own scenarios. In each scenario you can specify the changes to the model parameter(s), which define the scenario and then save the scenario so that it can be restored at some point in the future.

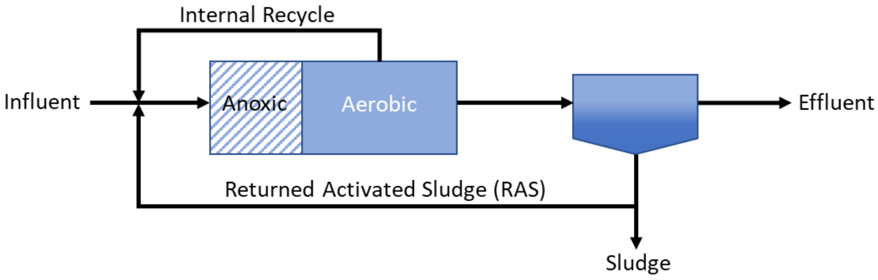
For more information, refer to the User's Guide.

Derive new scenario from :

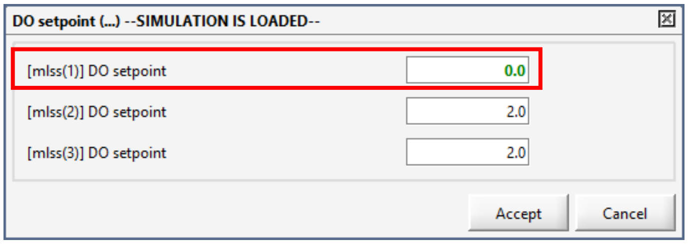
● Default Scenario

Name : MLE

MLE stands for Modified Ludzack-Ettinger. In this configuration, there are two zones, anoxic and aerobic, and two recycles, one being the RAS stream from the Secondary Clarifier and the other an internal recycle stream. The internal recycle allows for more nitrate to be fed into the anoxic zone directly from the aerobic zone.



8. Configure the PFR as an MLE system by creating an anoxic zone and specify an internal recycle rate. Right-click on the Bioreactor and navigate to *Input Parameters > Operational >Aeration Control header*. Select the **DO setpoint** ellipse button and change the **DO setpoint** in the **first tank** to **0 mg/L**.



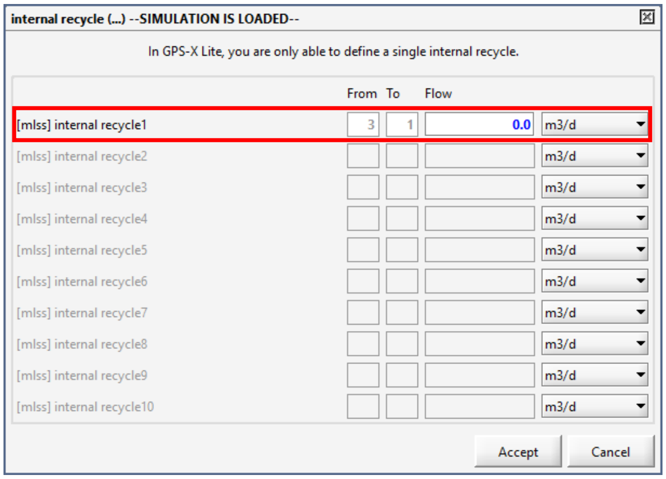
DO setpoint (...) --SIMULATION IS LOADED--

[mlss(1)] DO setpoint 0.0

[mlss(2)] DO setpoint 2.0

[mlss(3)] DO setpoint 2.0

9. Within the same window, scroll to the *Internal Flow Distribution header* menu. Select the internal recycle ellipse button and drag the **internal recycle1** variable to the input controls area.

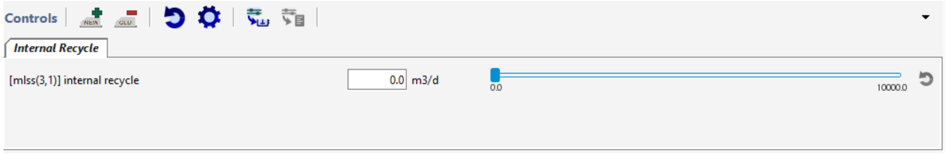


internal recycle (...) --SIMULATION IS LOADED--

In GPS-X Lite, you are only able to define a single internal recycle.

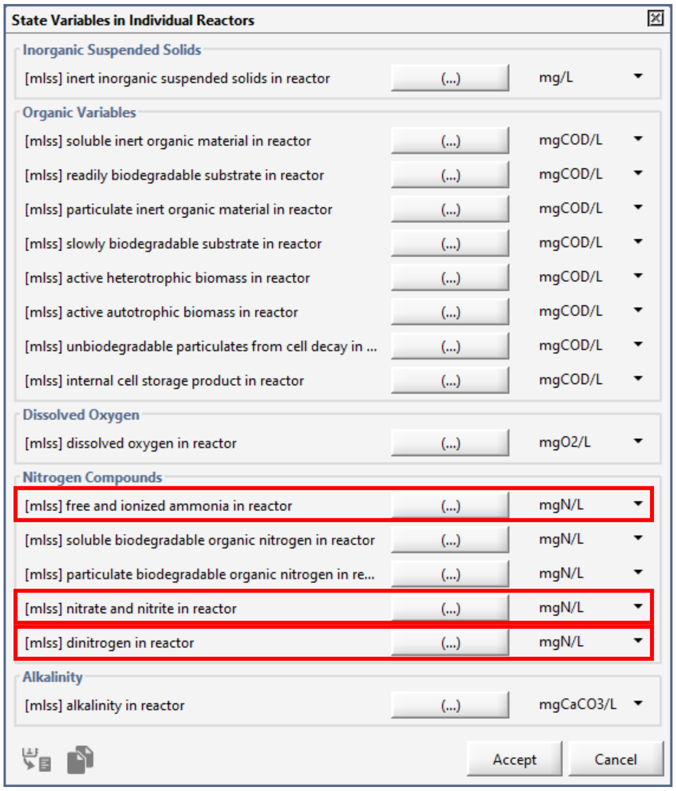
	From	To	Flow	
[mlss] internal recycle1	3	1	0.0	m3/d
[mlss] internal recycle2				m3/d
[mlss] internal recycle3				m3/d
[mlss] internal recycle4				m3/d
[mlss] internal recycle5				m3/d
[mlss] internal recycle6				m3/d
[mlss] internal recycle7				m3/d
[mlss] internal recycle8				m3/d
[mlss] internal recycle9				m3/d
[mlss] internal recycle10				m3/d

10. Rename the new input controls tab to “Internal Recycle”, then select the input controls property button and set the **max** value to **10,000 m^3/d**.



[mlss(3,1)] internal recycle 0.0 m3/d

11. Create a new graph output tab and rename it to “Nitrogen Variables.” Right-click on the bioreactor and navigate to *Output Variables > State Variables in Individual Reactors*. Drag the following **Nitrogen Compound** variables to the new output tab to create three new graphs:
    - Free and ionized ammonia in reactor
    - Nitrate and nitrite in reactor
    - Dinitrogen in reactor



State Variables in Individual Reactors

Inorganic Suspended Solids

[mlss] inert inorganic suspended solids in reactor	(...)	mg/L

Organic Variables

[mlss] soluble inert organic material in reactor	(...)	mgCOD/L
[mlss] readily biodegradable substrate in reactor	(...)	mgCOD/L
[mlss] particulate inert organic material in reactor	(...)	mgCOD/L
[mlss] slowly biodegradable substrate in reactor	(...)	mgCOD/L
[mlss] active heterotrophic biomass in reactor	(...)	mgCOD/L
[mlss] active autotrophic biomass in reactor	(...)	mgCOD/L
[mlss] unbiodegradable particulates from cell decay in ...	(...)	mgCOD/L
[mlss] internal cell storage product in reactor	(...)	mgCOD/L

Dissolved Oxygen

[mlss] dissolved oxygen in reactor	(...)	mgO2/L

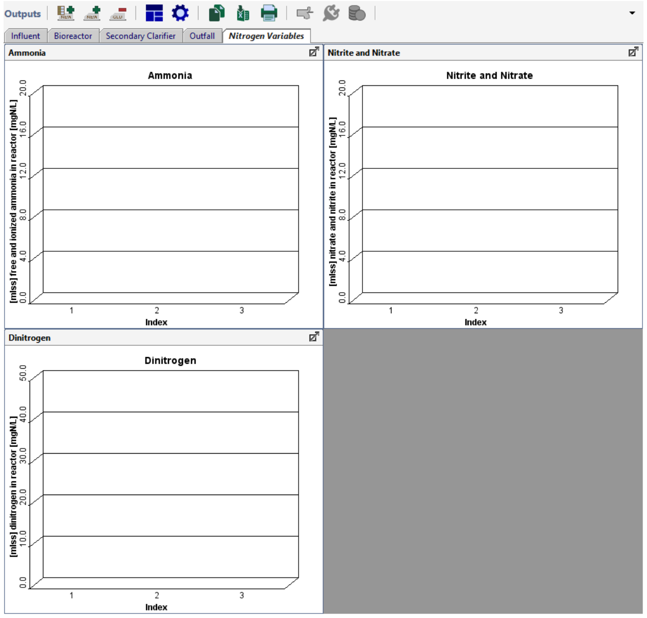
Nitrogen Compounds

[mlss] free and ionized ammonia in reactor	(...)	mgN/L
[mlss] soluble biodegradable organic nitrogen in reactor	(...)	mgN/L
[mlss] particulate biodegradable organic nitrogen in re...	(...)	mgN/L
[mlss] nitrate and nitrite in reactor	(...)	mgN/L
[mlss] dinitrogen in reactor	(...)	mgN/L

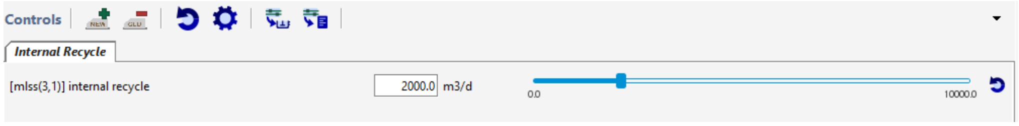
Alkalinity

[mlss] alkalinity in reactor	(...)	mgCaCO3/L

Rename each graph appropriately and auto arrange the graphs.

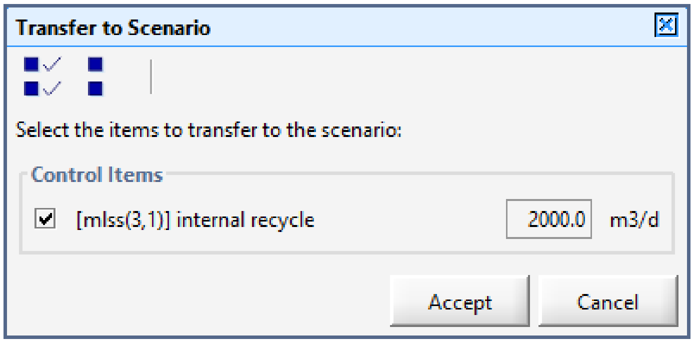


12. Run the simulation with the **internal recycle** set to **2000 m^3/d**. Record a screenshot of the Nitrogen Variables graphs. Discuss the results. (**Exercise 8 – Question 2)**



[mlss(3,1)] internal recycle 2000.0 m3/d

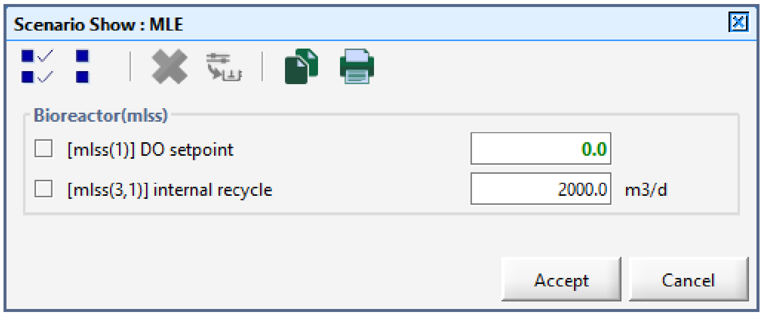
13. From the input controls area select the **Transfer controls to scenario** button. Within this window select the internal recycle variable and click Accept. This change allows the internal recycle rate to be held at 0 m^3/d and 2000 m^3/d in the Default and MLE scenarios respectively.



Select the items to transfer to the scenario:

☑ [mlss(3,1)] internal recycle 2000.0 m3/d

14. From the simulation toolbar navigate to *Scenario* > *Show*. This will provide a summary of the changes that have been made within a specific scenario. Close this window.



Scenario Show : MLE

Bioreactor(mlss)

☐ [mlss(1)] DO setpoint 0.0

☐ [mlss(3,1)] internal recycle 2000.0 m3/d

15. In Excel, create a graph of the effluent ammonia, nitrite/nitrate, TKN and TN, for **internal recycle rates** of **0, 2000, 4000, 6000, and 8000 m^3/d** (ie. y-axis = nitrogen variables, x-axis = internal recycle rates). (**Exercise 8 – Question 3)**

Note: In the fully-functional version of GPS-X an analyze feature is available. This feature would allow the user to automatically run the simulation at the different internal recycle rates with the internal recycle rates presented on the x-axis rather than time.

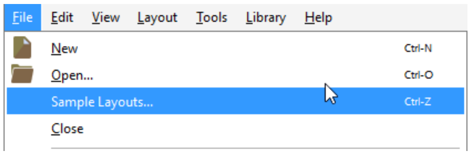
16. Save the model layout.

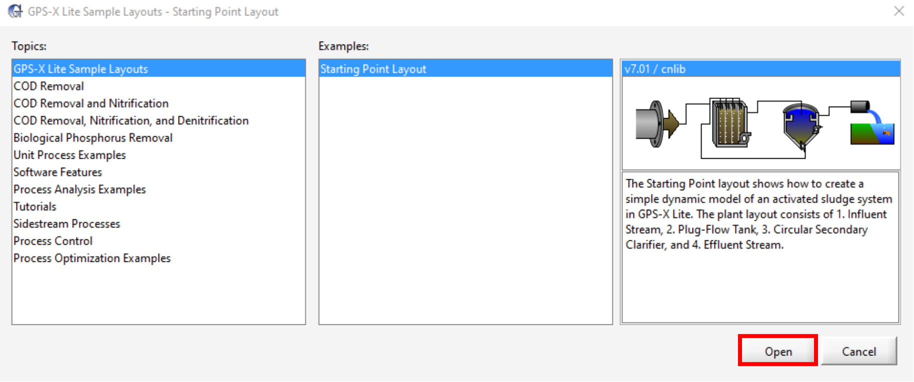
Exercise 9 – Exploring Kinetic Parameters

This exercise will explore the various factors that affect the growth of heterotrophs and autotrophs, including review of several key kinetic parameters.

1. Open the Starting Point model layout developed in Exercise 1.

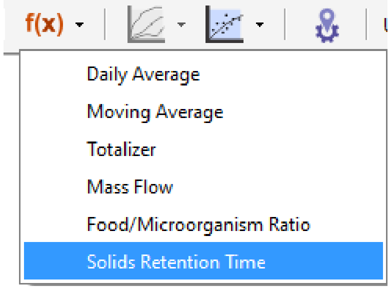
   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*





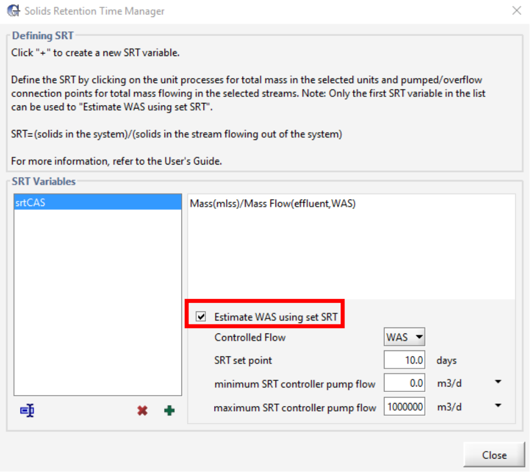
The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. Save the Layout under a different name.
3. Select the Define button from the main toolbar and choose the Solids Retention Time option from the bottom of the list.



Follow the steps in Step 4 of Exercise 5. In this case, the pop-up box for the numerator will only have Reactor 1 specified as opposed to three reactors in Exercise 5.

- Select the “Estimate WAS using set SRT” button. Close this window.



Click "+" to create a new SRT variable.

Define the SRT by clicking on the unit processes for total mass in the selected units and pumped/overflow connection points for total mass flowing in the selected streams. Note: Only the first SRT variable in the list can be used to "Estimate WAS using set SRT".

SRT=(solids in the system)/(solids in the stream flowing out of the system)

For more information, refer to the User's Guide.

srtCAS

Mass(mlss)/Mass Flow(effluent,WAS)

☑ Estimate WAS using set SRT

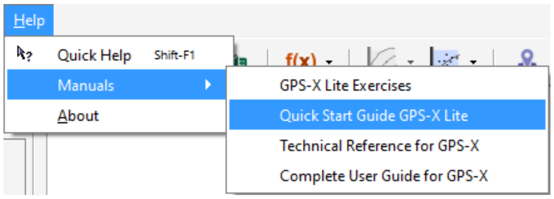
Controlled Flow: WAS

SRT set point: 10.0 days

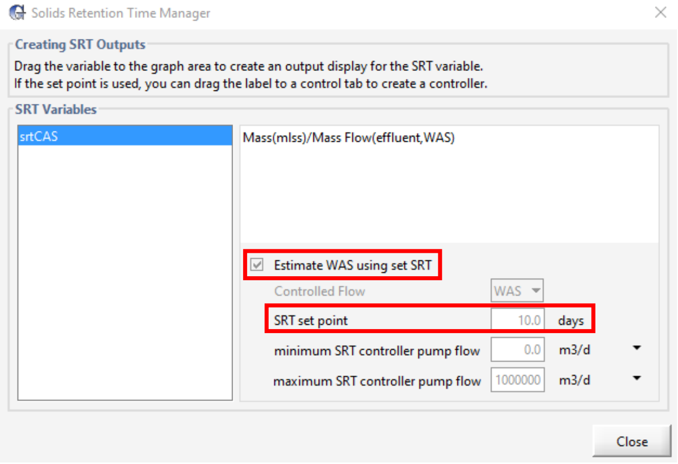
minimum SRT controller pump flow: 0.0 m3/d

maximum SRT controller pump flow: 1000000 m3/d

Note: If you require further support with setting up a new SRT variable, access the ***Quick Start Guide GPS-X Lite*** from the Help Menu.



4. Switch into Simulation Mode. Rebuild the model when prompted.
5. Create two new input control tabs, one called “SRT” and the other “Kinetics.”
6. To the SRT input control tab, add the following by dragging them to the tab:
    - Main toolbar - *Define* > *Solids Retention Time* > **Estimate WAS using set SRT**
    - Main toolbar - *Define* > *Solids Retention Time* > **SRT set point**



Drag the variable to the graph area to create an output display for the SRT variable.
If the set point is used, you can drag the label to a control tab to create a controller.

srtCAS

Mass(mlss)/Mass Flow(effluent,WAS)

☑ Estimate WAS using set SRT

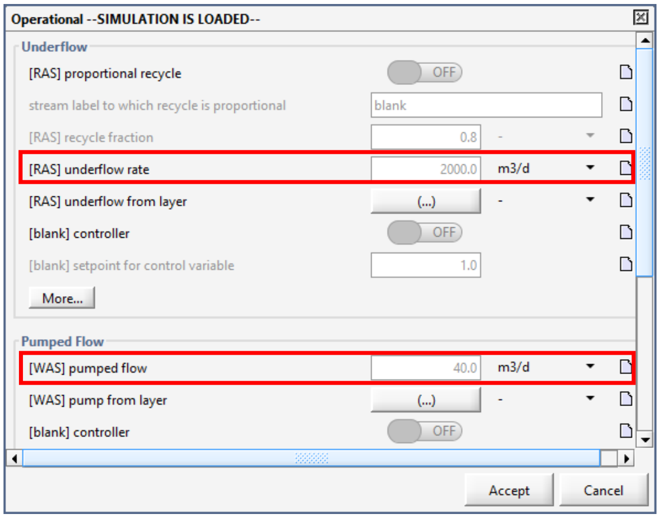
Controlled Flow: WAS

SRT set point: 10.0 days

minimum SRT controller pump flow: 0.0 m3/d

maximum SRT controller pump flow: 1000000 m3/d

- Secondary Clarifier > *Input Parameters* > *Operational* > *Underflow header* > **Underflow Rate**
- Secondary Clarifier > *Input Parameters* > *Operational* > *Pumped Flow header* > **Pumped Flow**



Operational --SIMULATION IS LOADED--

Underflow

[RAS] proportional recycle OFF

stream label to which recycle is proportional blank

[RAS] recycle fraction 0.8 -

[RAS] underflow rate 2000.0 m3/d

[RAS] underflow from layer (...) -

[blank] controller OFF

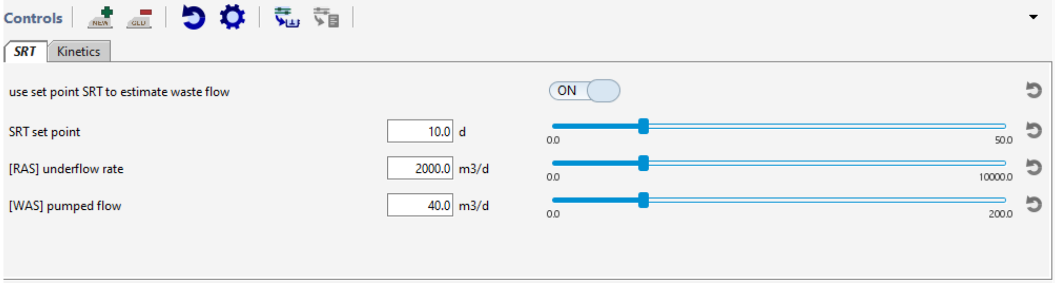
[blank] setpoint for control variable 1.0

Pumped Flow

[WAS] pumped flow 40.0 m3/d

[WAS] pump from layer (...) -

[blank] controller OFF



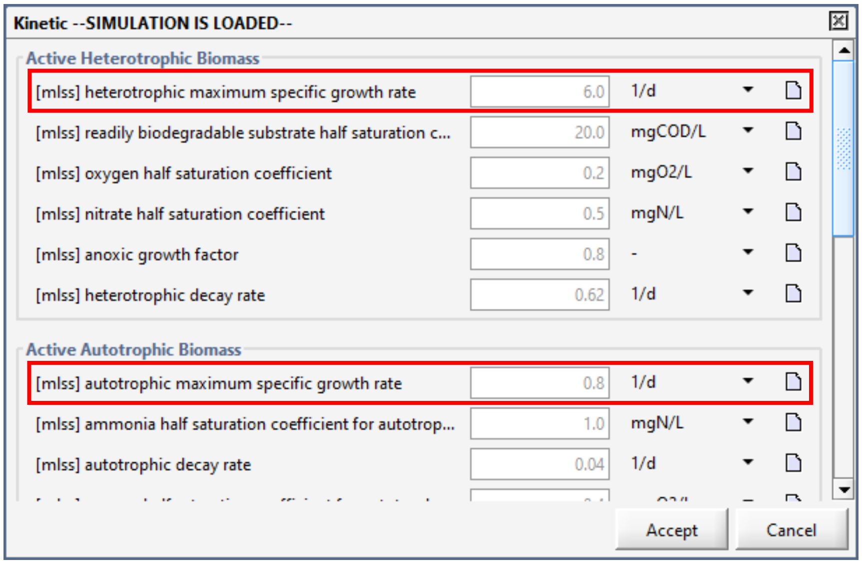
use set point SRT to estimate waste flow ON

SRT set point 10.0 d (0.0 – 50.0)

[RAS] underflow rate 2000.0 m3/d (0.0 – 10000.0)

[WAS] pumped flow 40.0 m3/d (0.0 – 200.0)

7. To the Kinetics input control tab add the following by dragging:
   - Bioreactor > *Input Parameters* > *Kinetic* > *Active Heterotrophic Biomass header* > **Heterotrophic Maximum Specific Growth Rate**
   - Bioreactor > *Input Parameters* > *Kinetic* > *Active Autotrophic Biomass header* > **Autotrophic Maximum Specific Growth Rate**

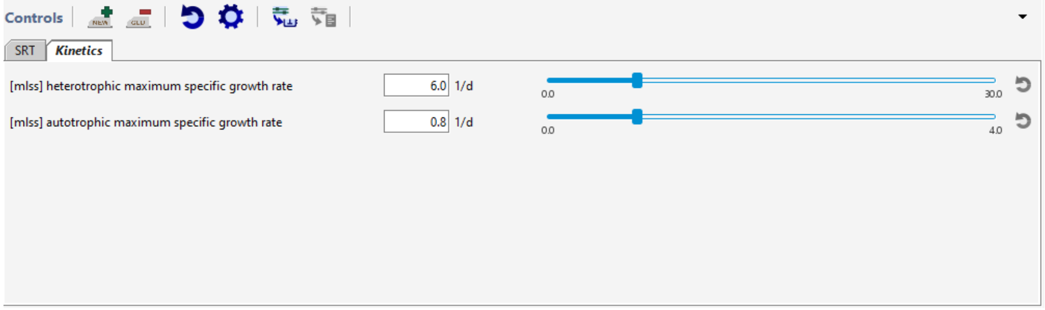


Active Heterotrophic Biomass

[mlss] heterotrophic maximum specific growth rate	6.0	1/d
[mlss] readily biodegradable substrate half saturation c...	20.0	mgCOD/L
[mlss] oxygen half saturation coefficient	0.2	mgO2/L
[mlss] nitrate half saturation coefficient	0.5	mgN/L
[mlss] anoxic growth factor	0.8	-
[mlss] heterotrophic decay rate	0.62	1/d

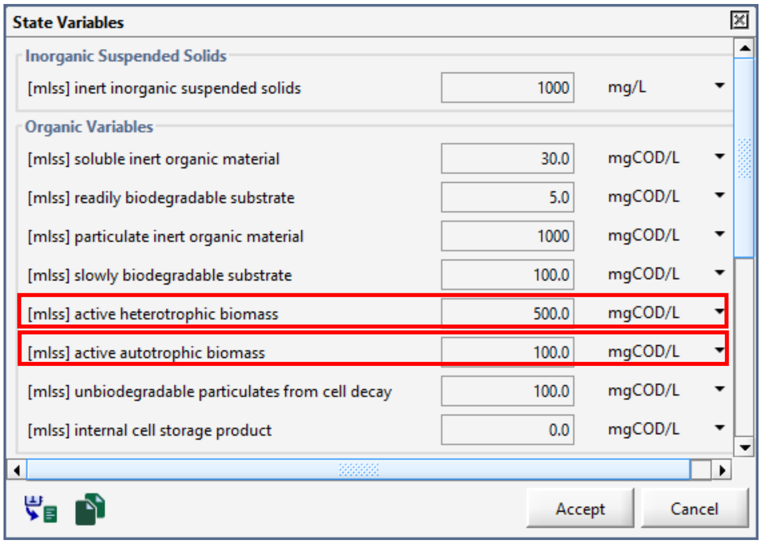
Active Autotrophic Biomass

[mlss] autotrophic maximum specific growth rate	0.8	1/d
[mlss] ammonia half saturation coefficient for autotrop...	1.0	mgN/L
[mlss] autotrophic decay rate	0.04	1/d



[mlss] heterotrophic maximum specific growth rate	6.0	1/d
[mlss] autotrophic maximum specific growth rate	0.8	1/d

8. Create a new graph output tab and rename it “Kinetics.”
9. Select the Define button from the main toolbar and navigate to Solids Retention Time. Add the **srtCAS** variable to the new graph tab. Change the graph type to **Digital** by right-clicking on the graph and navigating to *Output Graph Type*.
10. Right-click on the mlss stream and navigate to *Output variables* > *State Variables* > *Organic Variables header* and drag the **active heterotrophic biomass** variable to the new digital graph.
11. To this digital graph also add the **active autotrophic biomass** variable from the same output menu. Auto Arrange the digital graph.



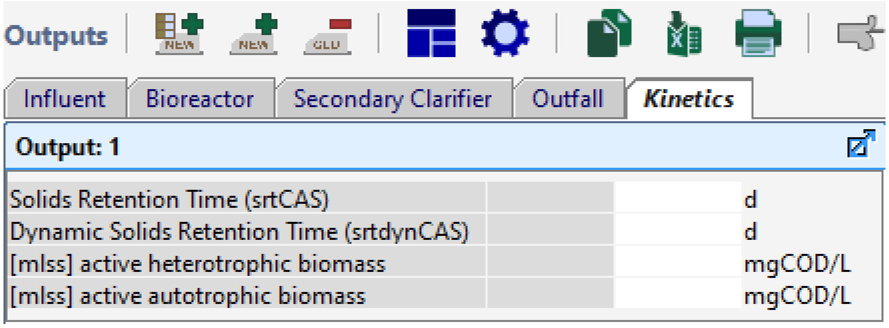
State Variables

Inorganic Suspended Solids

[mlss] inert inorganic suspended solids	1000	mg/L

Organic Variables

[mlss] soluble inert organic material	30.0	mgCOD/L
[mlss] readily biodegradable substrate	5.0	mgCOD/L
[mlss] particulate inert organic material	1000	mgCOD/L
[mlss] slowly biodegradable substrate	100.0	mgCOD/L
[mlss] active heterotrophic biomass	500.0	mgCOD/L
[mlss] active autotrophic biomass	100.0	mgCOD/L
[mlss] unbiodegradable particulates from cell decay	100.0	mgCOD/L
[mlss] internal cell storage product	0.0	mgCOD/L



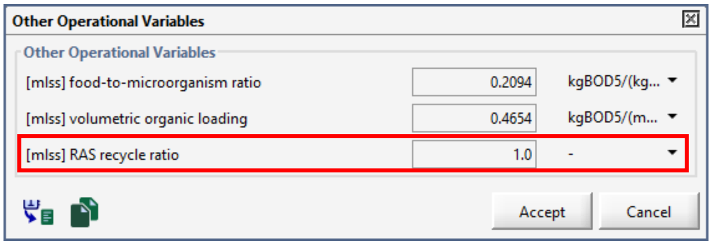
Output: 1

Solids Retention Time (srtCAS)			d
Dynamic Solids Retention Time (srtdynCAS)			d
[mlss] active heterotrophic biomass			mgCOD/L
[mlss] active autotrophic biomass			mgCOD/L

12. Run the simulation at steady-state for **SRT set points** of **2, 8, 14, and 20 days**. Create a plot in Excel of the heterotrophic and autotrophic biomass vs. SRT and discuss the results. (**Exercise 9 – Question 1)**

Note: In the fully-functional version of GPS-X, an analyze feature is available. This feature would allow the user to automatically run the simulation at the different SRT set points with the SRT set point presented on the x-axis rather than time.

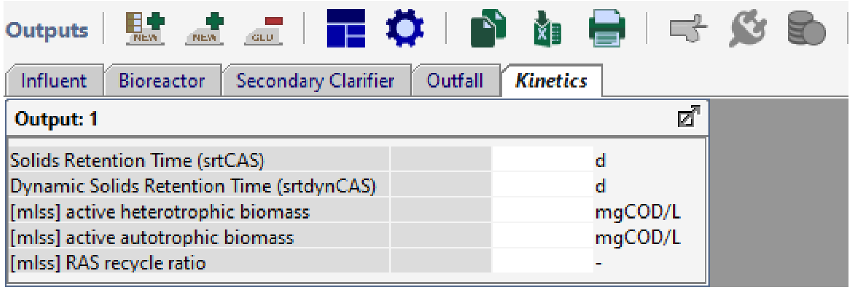
13. Hover over the mlss stream connection point on the bioreactor until the cursor changes to an arrow; then right-click on the mlss stream and navigate to *Output Variables* > *Other Operational Variables* and drag the **RAS recycle ratio** to the digital graph.



Other Operational Variables

Other Operational Variables

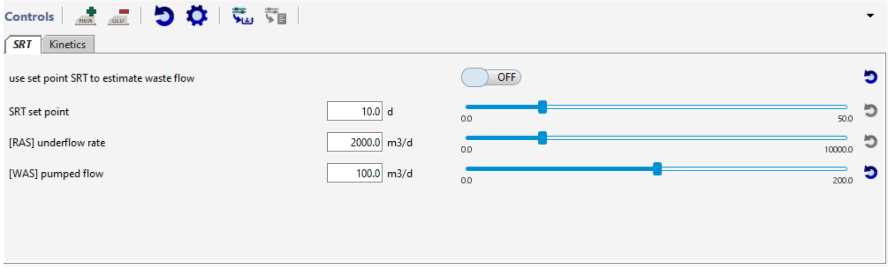
[mlss] food-to-microorganism ratio	0.2094	kgBOD5/(kg...
[mlss] volumetric organic loading	0.4654	kgBOD5/(m...
[mlss] RAS recycle ratio	1.0	-



Output: 1

Solids Retention Time (srtCAS) d
Dynamic Solids Retention Time (srtdynCAS) d
[mlss] active heterotrophic biomass mgCOD/L
[mlss] active autotrophic biomass mgCOD/L
[mlss] RAS recycle ratio -

14. In the SRT input control tab set the **use set point SRT to estimate waste flow** to **OFF** and set the **pumped flow** variable to **100 m^3/d**. This sets an SRT of approximately 5 days when the underflow rate is set to 2000 m^3/d.

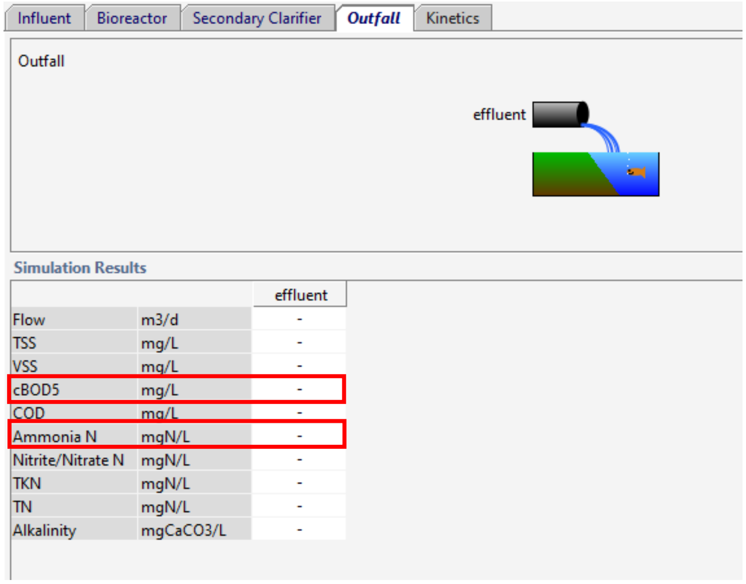


use set point SRT to estimate waste flow OFF
SRT set point 10.0 d
[RAS] underflow rate 2000.0 m3/d
[WAS] pumped flow 100.0 m3/d

15. Run the simulation as underflow rates of **1000, 2000, 4000, and 8000 m^3/d** and record the results for the heterotrophic biomass, autotrophic biomass, and RAS recycle ratio. Prepare a plot in Excel of the heterotrophic and autotrophic biomass vs. RAS recycle ratio and discuss the results. How does the plot compare to the one created in Step 12? (**Exercise 9 – Question 2)**

Note: In the fully-functional version of GPS-X an analyze feature is available. This feature would allow the user to automatically run the simulation at the different RAS recycle ratios with the RAS recycle ratio presented on the x-axis rather than time.

16. Reset all of the variables in the SRT input controls tab and switch to the Kinetics input controls tab.
17. Run the simulation with **heterotrophic maximum specific growth rates** of **4.8, 5.6, 6.4 and 7.2 1/d**. Prepare a plot in Excel of the effluent cBOD$_5$ and effluent ammonia vs. the heterotrophic growth rate. Discuss the results. (**Exercise 9 – Question 3)**



		effluent
Flow	m3/d	-
TSS	mg/L	-
VSS	mg/L	-
cBOD5	mg/L	-
COD	mg/L	-
Ammonia N	mgN/L	-
Nitrite/Nitrate N	mgN/L	-
TKN	mgN/L	-
TN	mgN/L	-
Alkalinity	mgCaCO3/L	-

Note: In the fully-functional version of GPS-X an analyze feature is available. This feature would allow the user to automatically run the simulation at the different heterotrophic growth rates with the heterotrophic growth rates presented on the x-axis rather than time.

18. In the Kinetics input control reset the heterotrophic maximum specific growth rate to 6.0 1/d and run the simulation with **autotrophic maximum specific growth rates** of **0.64, 0.76, 0.88 1/d**. Prepare a plot in Excel of the effluent cBOD$_5$ and effluent ammonia vs. the autotrophic growth rate. Discuss the results and compare to those in Step 17. (**Exercise 9 – Question 4)**

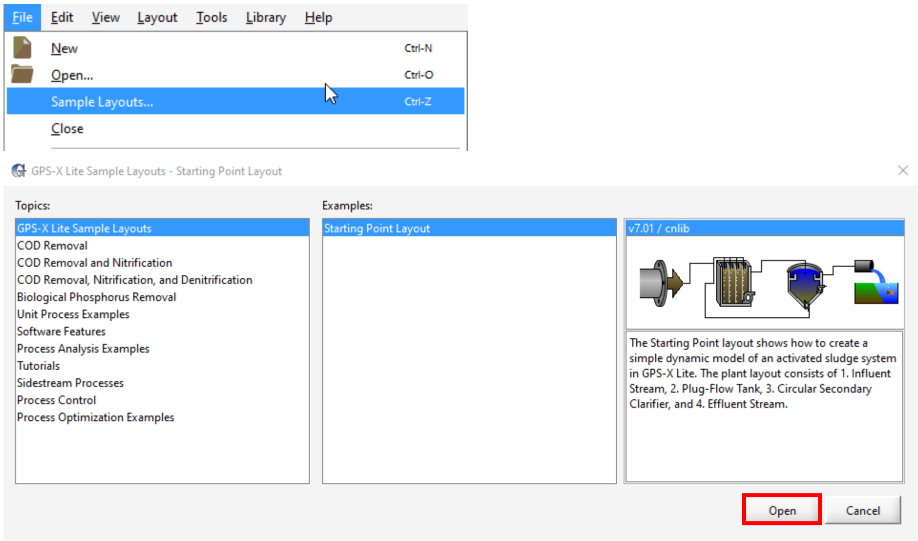
Note: In the fully-functional version of GPS-X an analyze feature is available. This feature would allow the user to automatically run the simulation at the different autotrophic growth rates with the autotrophic growth rates presented on the x-axis rather than time.

Exercise 10 – Secondary Clarifier Performance

Having a good secondary clarifier design is critical for ensuring low effluent solids and preventing operational upsets such as poor sludge settling. This exercise will explore several properties of clarifiers.

1. Open the Starting Point layout that was created in Exercise 1

Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*



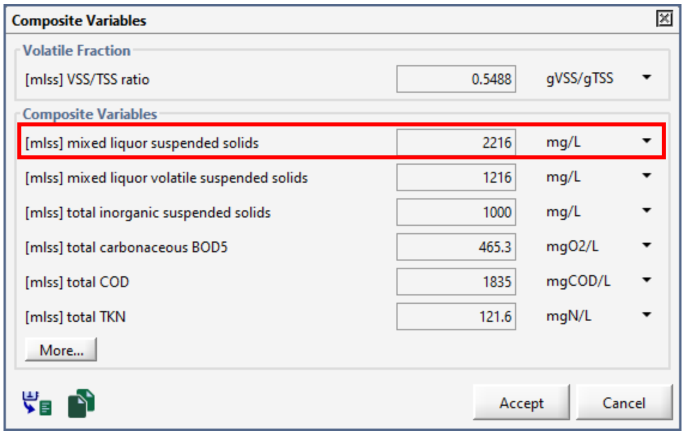
The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. Save the layout under a different name.
3. Switch into simulation mode.
4. Create a new graph output tab and call it "Clarifier Performance."

Add the following output variables to a ***single graph*** on the new output tab. Right-click on the graph and change to **Digital** from the *Output Graph Type* dropdown.

MLSS stream:

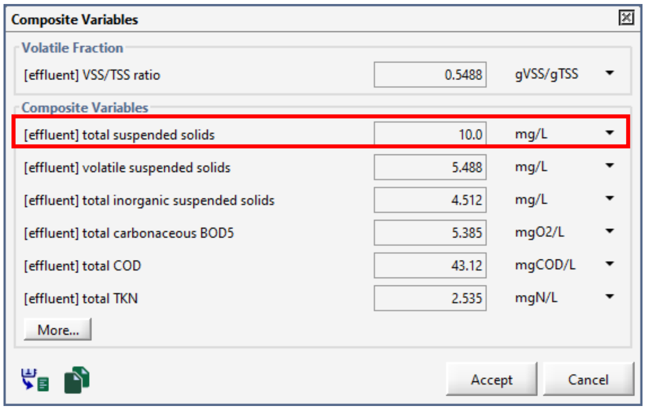
- *Output Variables > Composite Variables* → **mixed liquor suspended solids**



[mlss] VSS/TSS ratio	0.5488	gVSS/gTSS
[mlss] mixed liquor suspended solids	2216	mg/L
[mlss] mixed liquor volatile suspended solids	1216	mg/L
[mlss] total inorganic suspended solids	1000	mg/L
[mlss] total carbonaceous BOD5	465.3	mgO2/L
[mlss] total COD	1835	mgCOD/L
[mlss] total TKN	121.6	mgN/L

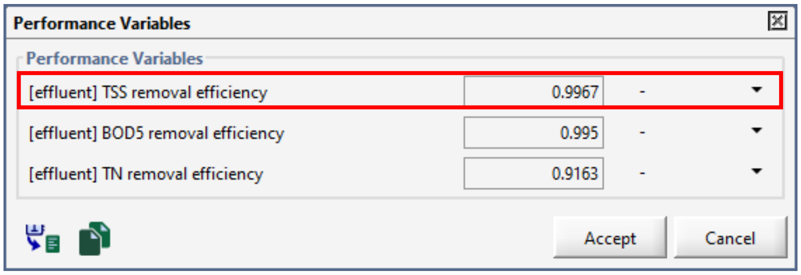
Effluent Stream:

- *Output Variables > Composite Variables* → **total suspended solids**



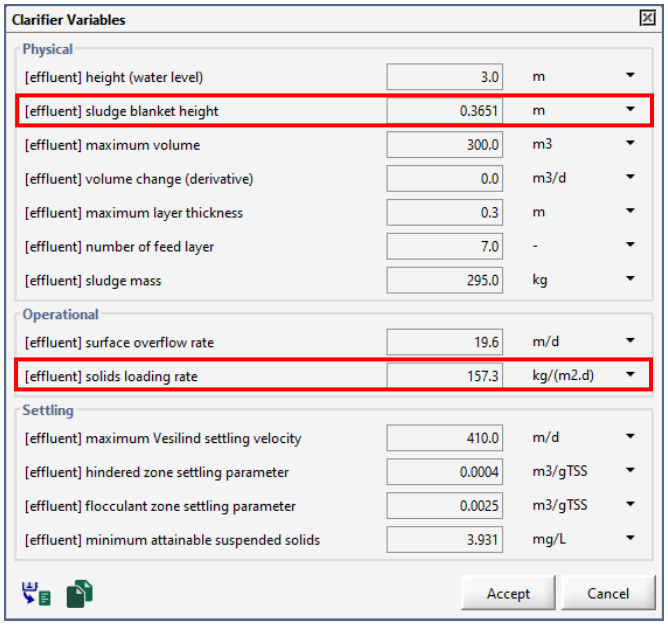
[effluent] VSS/TSS ratio	0.5488	gVSS/gTSS
[effluent] total suspended solids	10.0	mg/L
[effluent] volatile suspended solids	5.488	mg/L
[effluent] total inorganic suspended solids	4.512	mg/L
[effluent] total carbonaceous BOD5	5.385	mgO2/L
[effluent] total COD	43.12	mgCOD/L
[effluent] total TKN	2.535	mgN/L

- *Output Variables > Performance Variables* → **TSS removal efficiency**



[effluent] TSS removal efficiency	0.9967	-
[effluent] BOD5 removal efficiency	0.995	-
[effluent] TN removal efficiency	0.9163	-

- *Output Variables > Clarifier Variables* → **sludge blanket height**
- *Output Variables > Clarifier Variables* → **solids loading rate**



Clarifier Variables

Physical

[effluent] height (water level)	3.0	m
[effluent] sludge blanket height	0.3651	m
[effluent] maximum volume	300.0	m3
[effluent] volume change (derivative)	0.0	m3/d
[effluent] maximum layer thickness	0.3	m
[effluent] number of feed layer	7.0	-
[effluent] sludge mass	295.0	kg

Operational

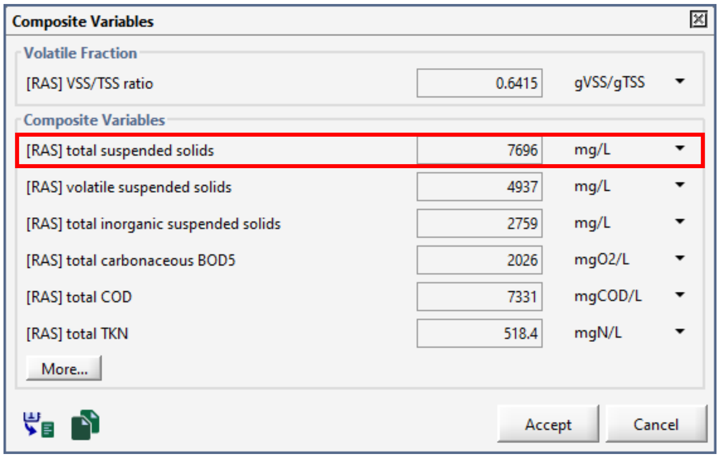
[effluent] surface overflow rate	19.6	m/d
[effluent] solids loading rate	157.3	kg/(m2.d)

Settling

[effluent] maximum Vesilind settling velocity	410.0	m/d
[effluent] hindered zone settling parameter	0.0004	m3/gTSS
[effluent] flocculant zone settling parameter	0.0025	m3/gTSS
[effluent] minimum attainable suspended solids	3.931	mg/L

RAS Stream:

- Output Variables > Composite Variables → total suspended solids



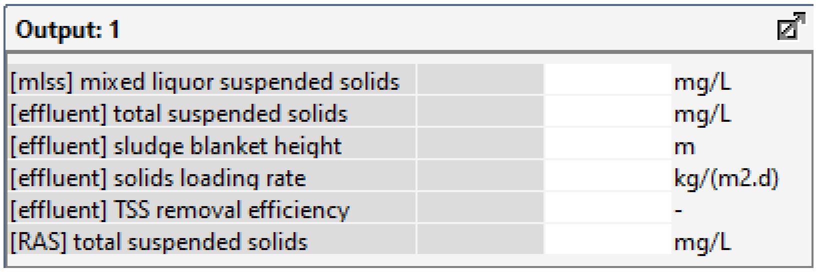
Composite Variables

Volatile Fraction

[RAS] VSS/TSS ratio	0.6415	gVSS/gTSS

Composite Variables

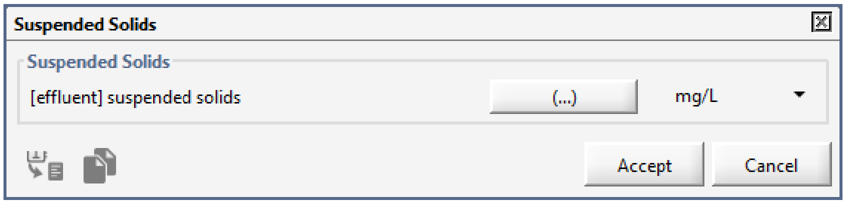
[RAS] total suspended solids	7696	mg/L
[RAS] volatile suspended solids	4937	mg/L
[RAS] total inorganic suspended solids	2759	mg/L
[RAS] total carbonaceous BOD5	2026	mgO2/L
[RAS] total COD	7331	mgCOD/L
[RAS] total TKN	518.4	mgN/L



Output: 1

[mlss] mixed liquor suspended solids		mg/L
[effluent] total suspended solids		mg/L
[effluent] sludge blanket height		m
[effluent] solids loading rate		kg/(m2.d)
[effluent] TSS removal efficiency		-
[RAS] total suspended solids		mg/L

5. Create a graph for the clarifier suspended solids in layers by right-clicking on the Secondary Clarifier, navigating to *Output Variables > Suspended Solids*, and drag the **suspended solids** variable to the Clarifier Performance output tab.

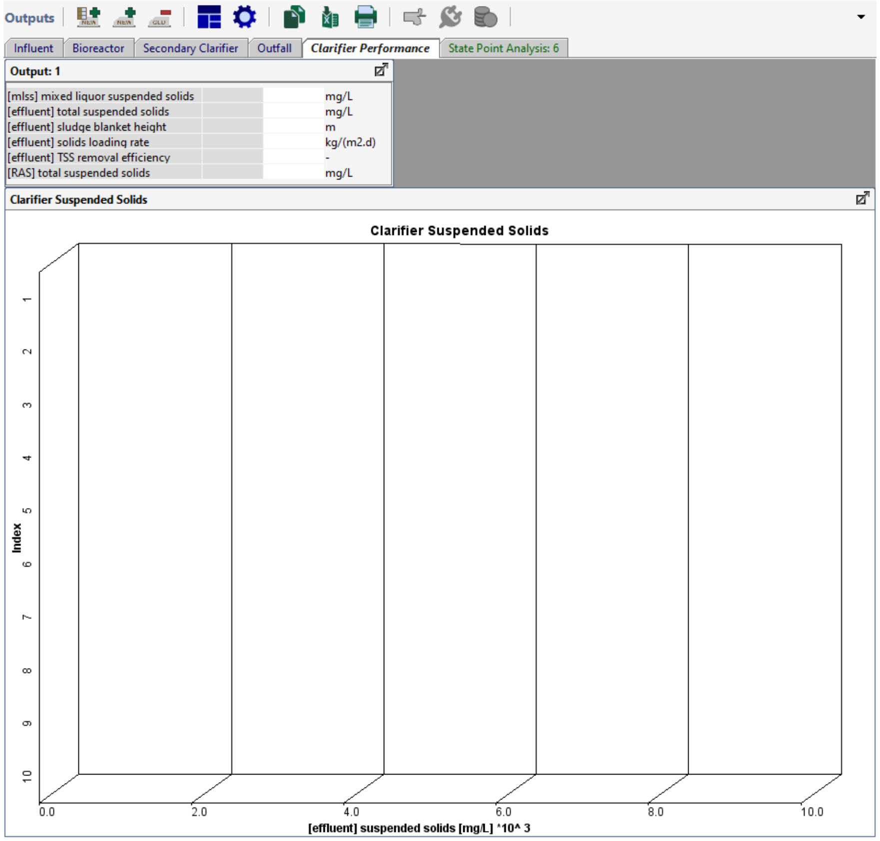


Suspended Solids

Suspended Solids

[effluent] suspended solids (...) mg/L

Right-click on the graph and change the *Output Graph Type* to **Bar Chart (Horizontal)**. Rename the graph to “Clarifier Suspended Solids.” Auto arrange the graphs.

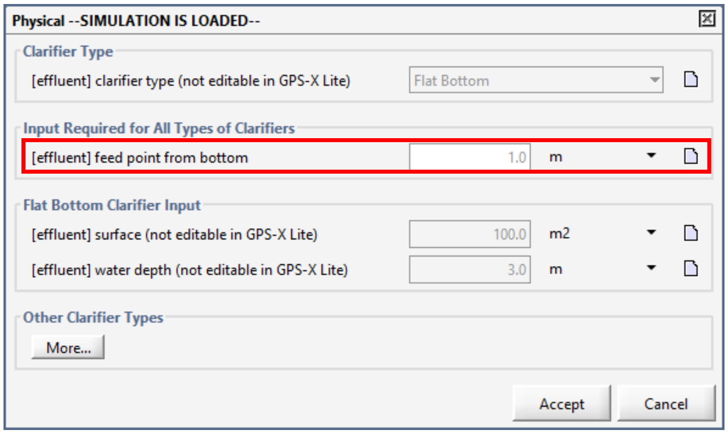


Output: 1

[mlss] mixed liquor suspended solids	mg/L
[effluent] total suspended solids	mg/L
[effluent] sludge blanket height	m
[effluent] solids loading rate	kg/(m2.d)
[effluent] TSS removal efficiency	-
[RAS] total suspended solids	mg/L

Clarifier Suspended Solids

6. Create a new input controls tab called “Clarifier Settling.”
7. To this new input control tab, add the following:
   - *Secondary Clarifier > Input Parameters > Physical > Input Required for All Types of Clarifiers header >* **Feed Point from Bottom**



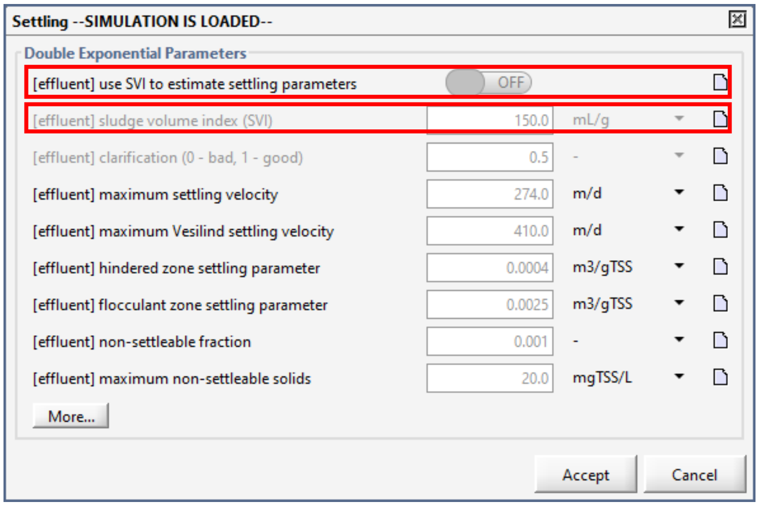
[effluent] clarifier type (not editable in GPS-X Lite): Flat Bottom

[effluent] feed point from bottom: 1.0 m

[effluent] surface (not editable in GPS-X Lite): 100.0 m2

[effluent] water depth (not editable in GPS-X Lite): 3.0 m

- *Secondary Clarifier > Input Parameters > Settling >* **Use SVI to Estimate Settling Parameters**
- *Secondary Clarifier > Input Parameters > Settling >* **Sludge Volume Index (SVI)**



[effluent] use SVI to estimate settling parameters: OFF

[effluent] sludge volume index (SVI): 150.0 mL/g

[effluent] clarification (0 - bad, 1 - good): 0.5 -

[effluent] maximum settling velocity: 274.0 m/d

[effluent] maximum Vesilind settling velocity: 410.0 m/d

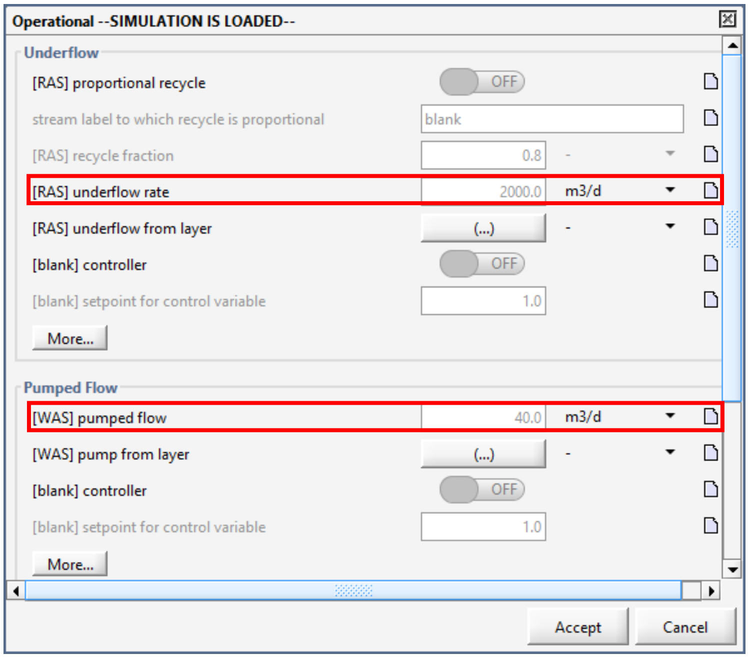
[effluent] hindered zone settling parameter: 0.0004 m3/gTSS

[effluent] flocculant zone settling parameter: 0.0025 m3/gTSS

[effluent] non-settleable fraction: 0.001 -

[effluent] maximum non-settleable solids: 20.0 mgTSS/L

- *Secondary Clarifier > Input Parameters > Operational >* **Underflow Rate**
- *Secondary Clarifier > Input Parameters > Operational >* **Pumped Flow**



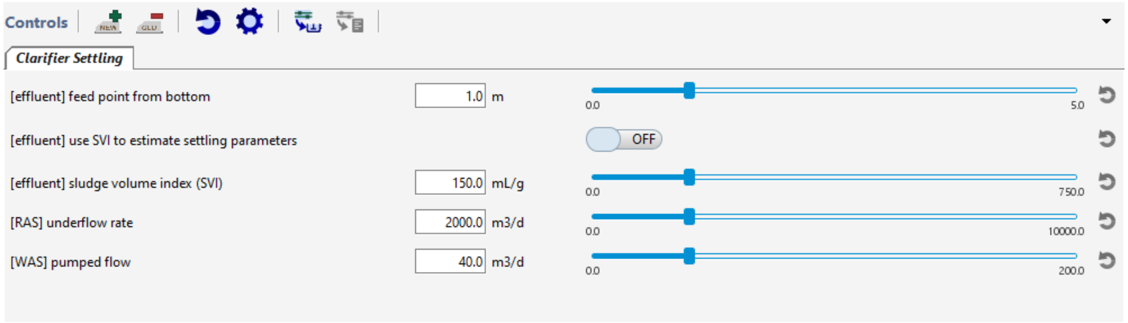
Operational --SIMULATION IS LOADED--

Underflow

[RAS] proportional recycle	OFF	
stream label to which recycle is proportional	blank	
[RAS] recycle fraction	0.8	-
[RAS] underflow rate	2000.0	m3/d
[RAS] underflow from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

Pumped Flow

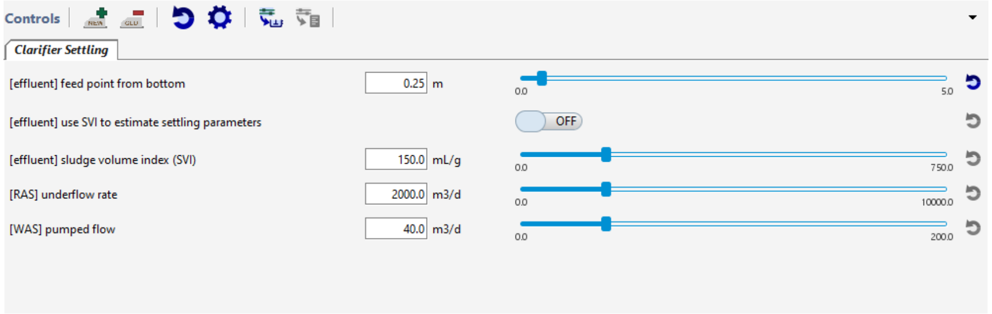
[WAS] pumped flow	40.0	m3/d
[WAS] pump from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	



[effluent] feed point from bottom	1.0	m
[effluent] use SVI to estimate settling parameters	OFF	
[effluent] sludge volume index (SVI)	150.0	mL/g
[RAS] underflow rate	2000.0	m3/d
[WAS] pumped flow	40.0	m3/d

The secondary clarifier object has a water depth of 3 m, and a default feed point from the bottom of 1 m. The feed point is an important design consideration and its effect on clarifier performance will be explored in the following section.

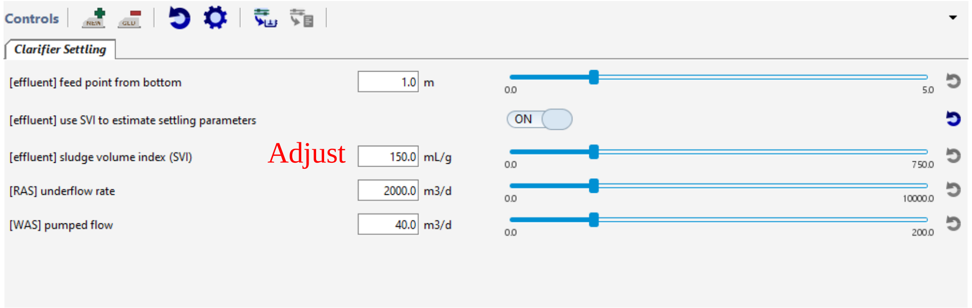
8. Run the simulation with all input control variables at their default values. Record a screenshot of the table and plot on the Clarifier Performance tab. (**Exercise 10 – Question 1)**
9. Change the **feed point from bottom** variable to **0.25 m**, rerun the simulation and take a screenshot of the results. Discuss the effect of a lower clarifier feed point. (**Exercise 10 – Question 2)**



[effluent] feed point from bottom	0.25	m
[effluent] use SVI to estimate settling parameters	OFF	
[effluent] sludge volume index (SVI)	150.0	mL/g
[RAS] underflow rate	2000.0	m3/d
[WAS] pumped flow	40.0	m3/d

The next section will explore the sludge volume index (SVI) parameter. This is not a physical design parameter but is rather a measurement of the ‘goodness’ of sludge settleability.

10. Click on the Reset button beside the slider of the **feed point from bottom** variable to reset it to **1.0 m**. Set the **use SVI to estimate settling parameters** to **ON**.
11. Run the simulation at **sludge volume index (SVI)** values of **50, 150, 250 mL/g,** recording the sludge blanket height and effluent total suspended solids. (**Exercise 10 – Question 3)**



[effluent] feed point from bottom 1.0 m (0.0 – 5.0)

[effluent] use SVI to estimate settling parameters ON

[effluent] sludge volume index (SVI) Adjust 150.0 mL/g (0.0 – 750.0)

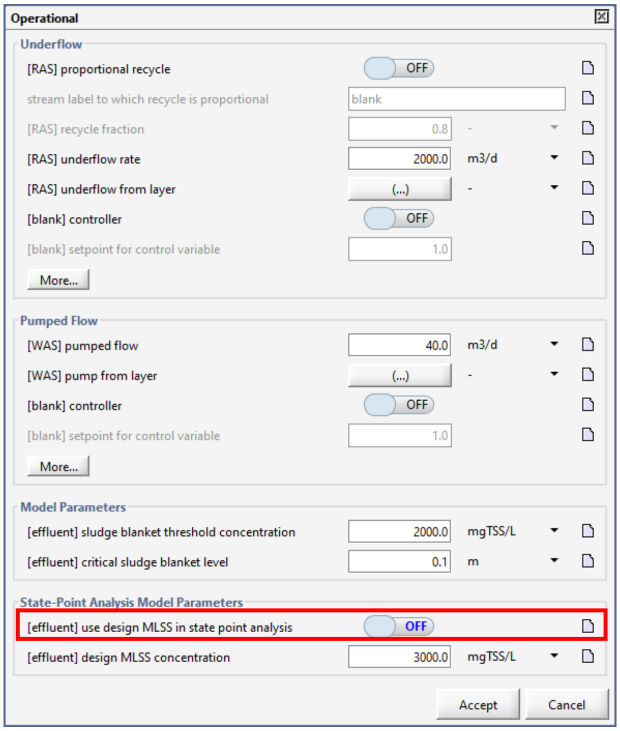
[RAS] underflow rate 2000.0 m3/d (0.0 – 10000.0)

[WAS] pumped flow 40.0 m3/d (0.0 – 200.0)

Is a lower or higher SVI more desirable in secondary clarifier treatment? Explain your answer.

Using state point analysis curves can be a convenient method of observing the impact of different MLSS operating conditions on the clarifier performance. This is made easy in GPS-X as the software contains a built-in state point analysis tool.

12. Switch into modelling mode. Right-click on the secondary clarifier and navigate to *Input Parameters > Operational > State Point Analysis Model Parameters header* and switch the **use design MLSS in state point analysis** to **OFF**.



Underflow

[RAS] proportional recycle OFF

stream label to which recycle is proportional blank

[RAS] recycle fraction 0.8 -

[RAS] underflow rate 2000.0 m3/d

[RAS] underflow from layer (...) -

[blank] controller OFF

[blank] setpoint for control variable 1.0

Pumped Flow

[WAS] pumped flow 40.0 m3/d

[WAS] pump from layer (...) -

[blank] controller OFF

[blank] setpoint for control variable 1.0

Model Parameters

[effluent] sludge blanket threshold concentration 2000.0 mgTSS/L

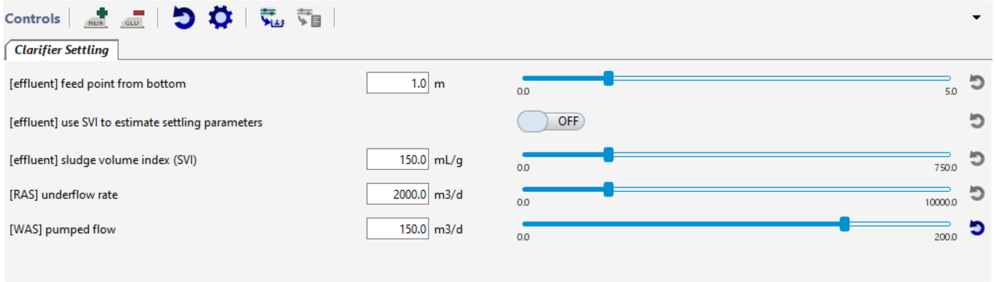
[effluent] critical sludge blanket level 0.1 m

State-Point Analysis Model Parameters

[effluent] use design MLSS in state point analysis OFF

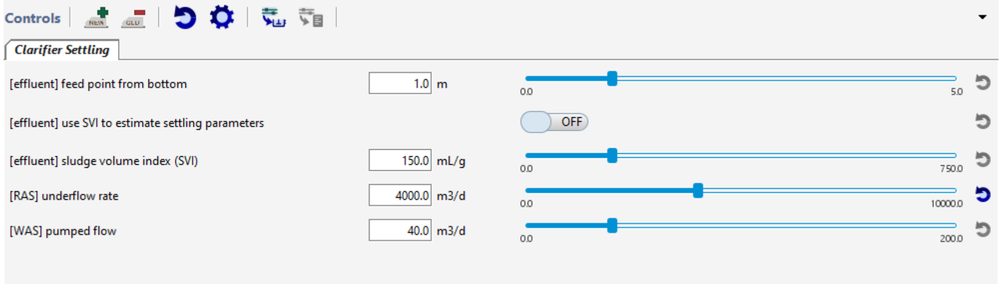
[effluent] design MLSS concentration 3000.0 mgTSS/L

13. Accept the form and switch back into simulation mode. Rebuild the model when prompted.
14. With all the input control variables at their default values, run the simulation at steady-state. (Default values: feed point- 1.0; use SVI- OFF ; sludge volume- 150; RAS underflow- 2000; WAS pumped- 40).
15. Right-click on the Secondary Clarifier and navigate to *Output Variables* > *State Point Analysis*. This will open a new output tab with a graph for the state point analysis for the secondary clarifier. Record a screenshot of this graph. (**Exercise 10 – Question 4)**
16. Within the input controls tab, set the **pumped flow** to **150 m^3/d**. Rerun the simulation and observe the effect on the state point analysis graph. Discuss the results of this adjustment to operations. (**Exercise 10 – Question 5)**



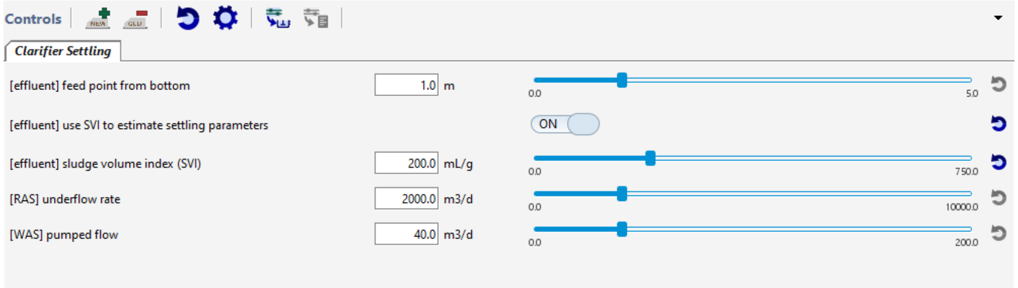
[effluent] feed point from bottom 1.0 m (0.0 – 5.0)
[effluent] use SVI to estimate settling parameters OFF
[effluent] sludge volume index (SVI) 150.0 mL/g (0.0 – 750.0)
[RAS] underflow rate 2000.0 m3/d (0.0 – 10000.0)
[WAS] pumped flow 150.0 m3/d (0.0 – 200.0)

17. Reset the **pumped flow** back to **40 m^3/d** and adjust the **underflow rate** to **4000 m^3/d**. Rerun the simulation and observe the effect of this change. Discuss the results. (**Exercise 10 – Question 6)**



[effluent] feed point from bottom 1.0 m (0.0 – 5.0)
[effluent] use SVI to estimate settling parameters OFF
[effluent] sludge volume index (SVI) 150.0 mL/g (0.0 – 750.0)
[RAS] underflow rate 4000.0 m3/d (0.0 – 10000.0)
[WAS] pumped flow 40.0 m3/d (0.0 – 200.0)

26. Reset the **underflow rate** back to **2000 m^3/d**. Set the **use SVI to estimate settling parameters** to **ON** and the **sludge volume index (SVI)** to **200 mL/g**. Run the simulation and observe the impact of this change. Discuss the results. (**Exercise 10 – Question 7)**



[effluent] feed point from bottom 1.0 m (0.0 – 5.0)
[effluent] use SVI to estimate settling parameters ON
[effluent] sludge volume index (SVI) 200.0 mL/g (0.0 – 750.0)
[RAS] underflow rate 2000.0 m3/d (0.0 – 10000.0)
[WAS] pumped flow 40.0 m3/d (0.0 – 200.0)

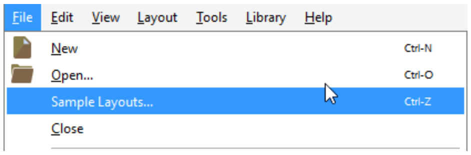
Exercise 11 – Anaerobic Digestion

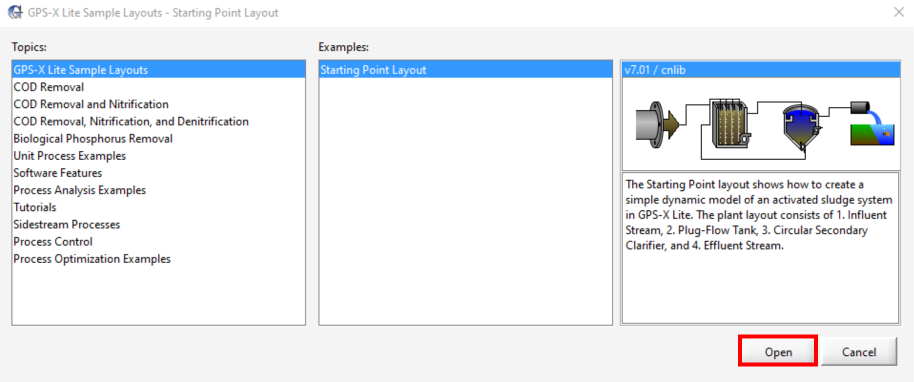
The objective of this exercise is to explore the effect of various factors on the anaerobic digester performance including:

a) Relationship between SRT and operating temperature
b) Relationship between operating temperature and gas production

1. Open the Starting Point model layout developed in Exercise 1 and save it under a different name.

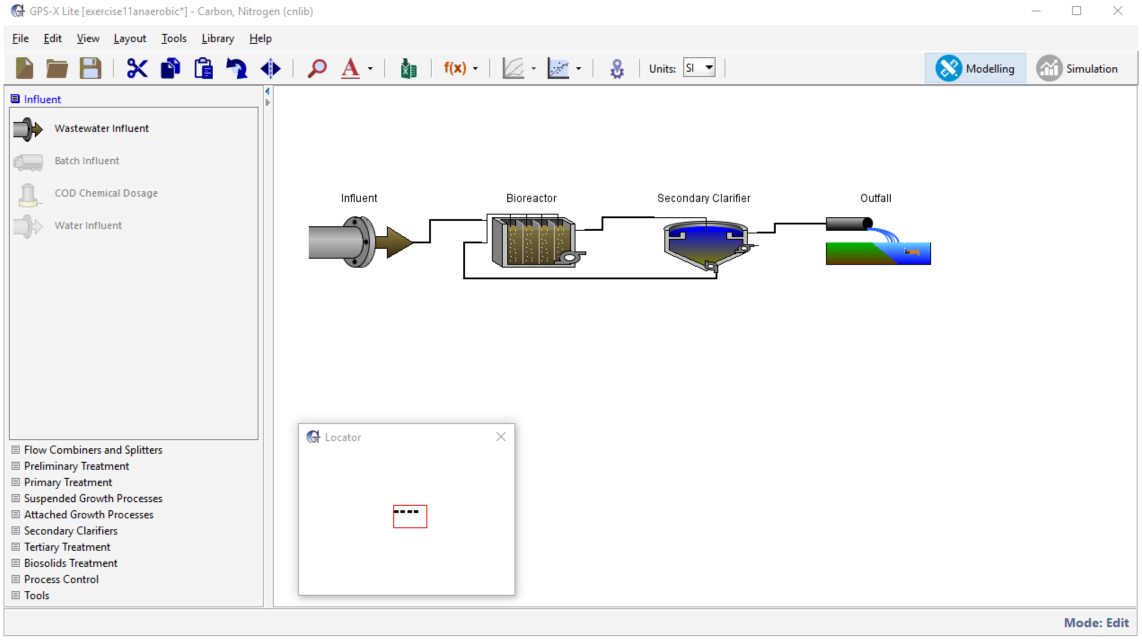
   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*





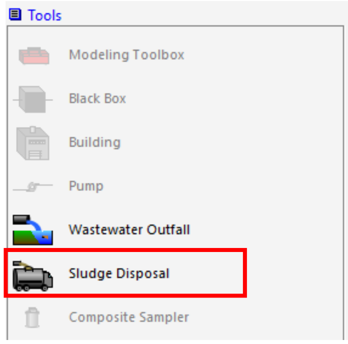
The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

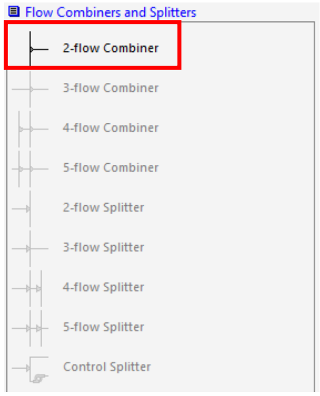
2. In modelling mode use the locator window to make more room at the bottom-right of the drawing board.

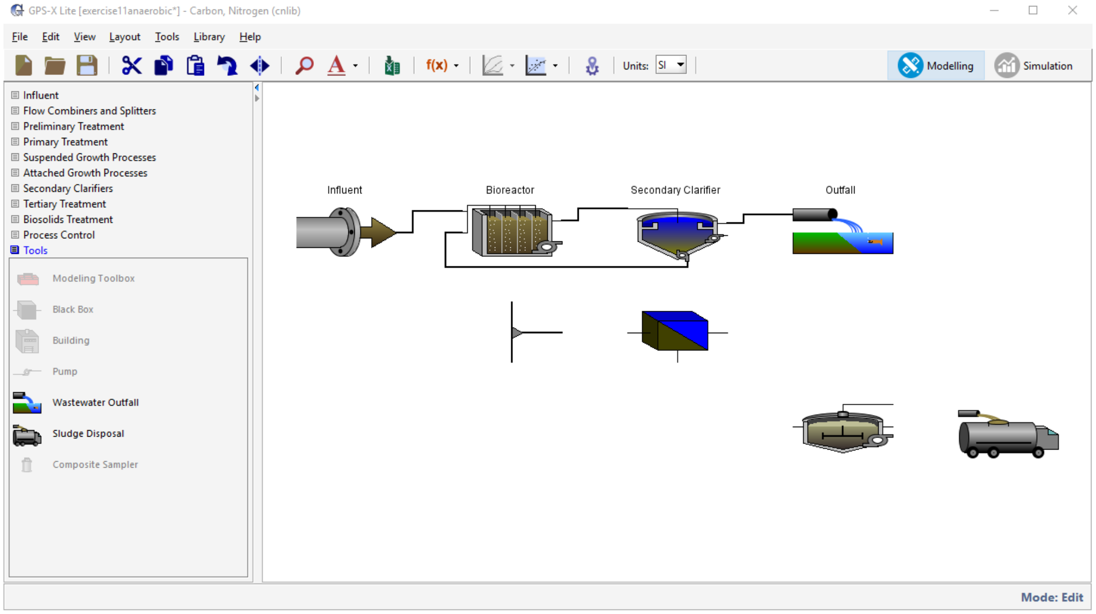


3. Locate the process table on the left-hand side of the Modelling window. Click on the Biosolids Treatment Tab, then drag an **Anaerobic Digestion** object and **Dewatering** object onto the drawing board.

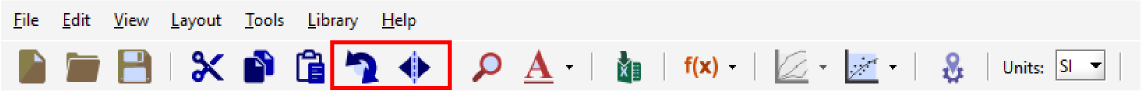
4. Click on Tools tab and drag a **Sludge Disposal** object onto the drawing board. Then click on the Flow Combiners and Splitters tab and drag a **2-Flow Combiner** object onto the drawing board.



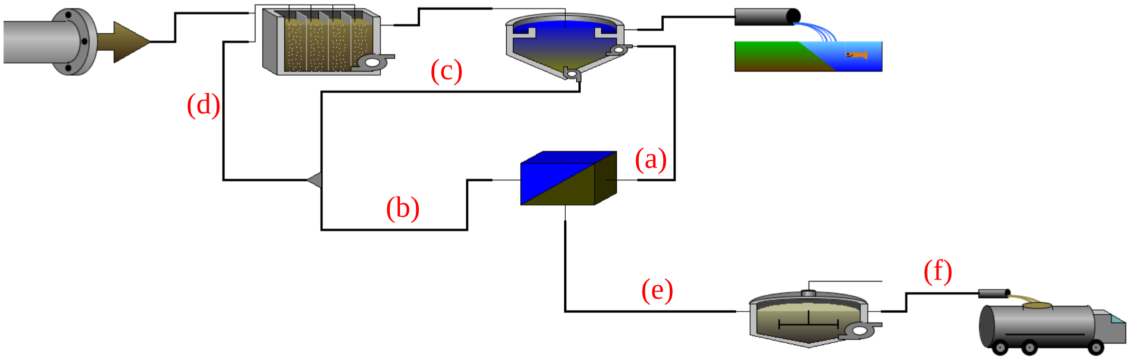




5. Arrange the objects as displayed in the image above. Use the Mirror and Rotate buttons on the main toolbar to help arrange the process objects, if necessary.

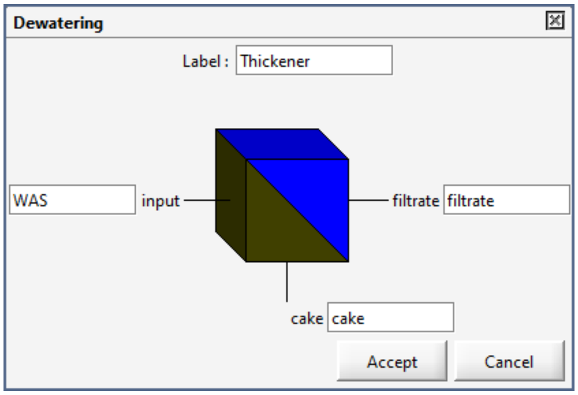


6. Delete the following connection by right-clicking on the connection line and selecting **Delete Connection**:
   - Secondary Clarifier Underflow → PFR Recycle Influent
7. Create the following connections between the process objects (an explanatory screenshot follows):
   a) Secondary Clarifier Pump → Dewatering Input
   b) Dewatering Filtrate → 2-Flow Combiner Input #2
   c) Secondary Clarifier Underflow → 2-Flow Combiner Input #1
   d) 2-Flow Combiner Output → PFR Recycle Influent
   e) Dewatering Cake → Anaerobic Digestion Input
   f) Anaerobic Digestion Overflow → Sludge Disposal Input



Note: Ensure the connections are exactly as specified as in the image above.

8. Add appropriate labels to the process objects and their respective streams so the final model layout appears as the image below.



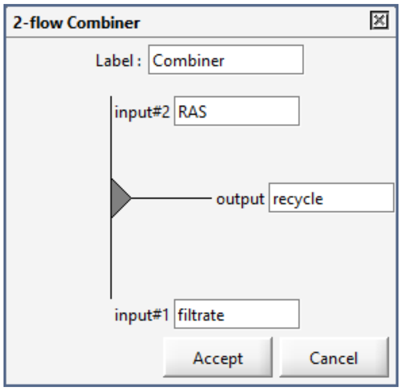
Dewatering

Label : Thickener

WAS input

filtrate filtrate

cake cake



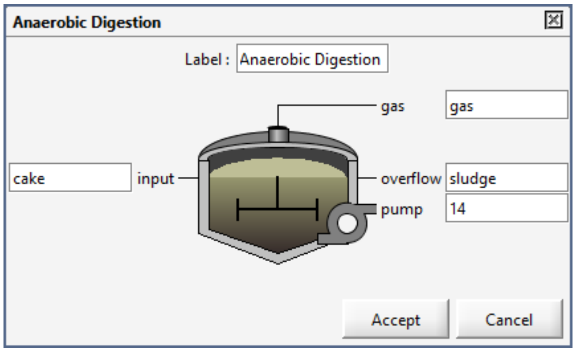
2-flow Combiner

Label : Combiner

input#2 RAS

output recycle

input#1 filtrate



Anaerobic Digestion

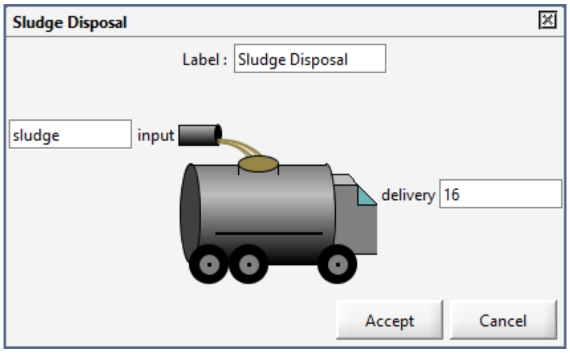
Label : Anaerobic Digestion

gas gas

cake input

overflow sludge

pump 14



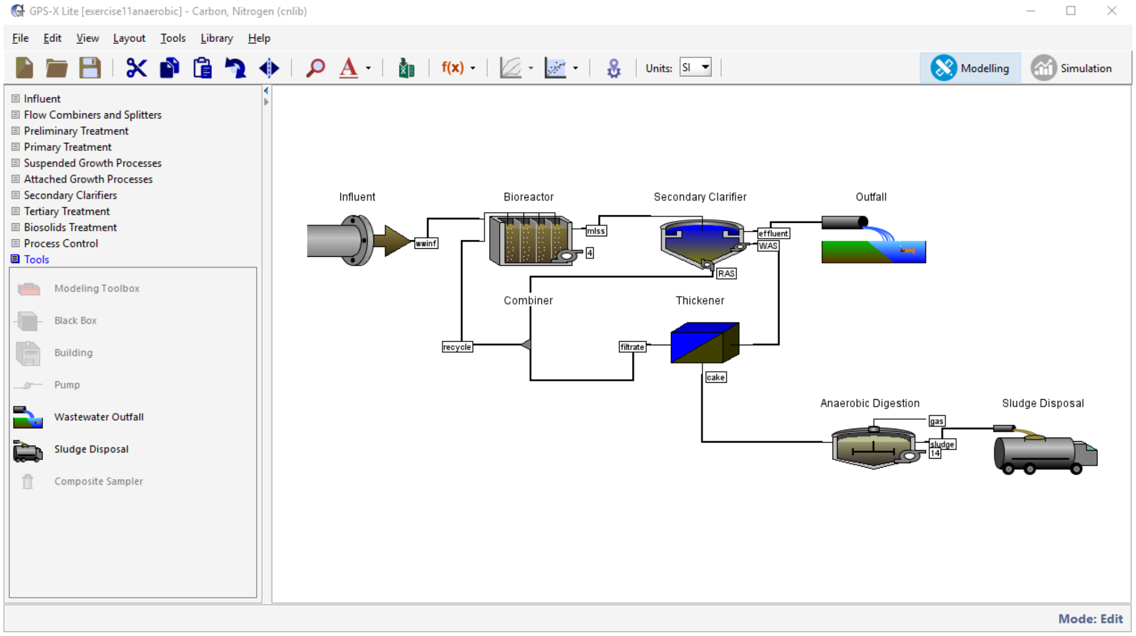
Sludge Disposal

Label : Sludge Disposal

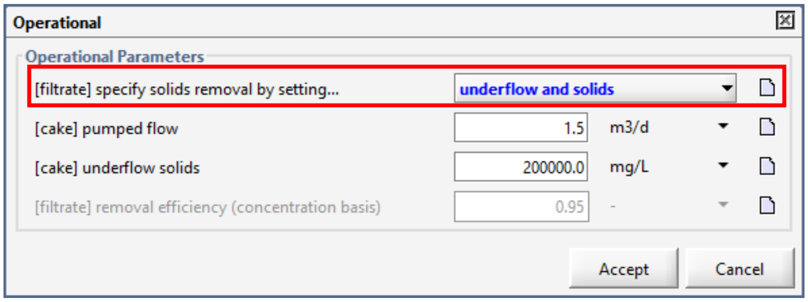
sludge input

delivery 16

Note: Depending on the sequence of placing the objects onto the drawing board, the default connection numbers may differ from the images above. This is not an issue; it is only important to ensure that your connections are between the appropriate objects as indicated below.



9. Right-click on the Thickener object and navigate to *Input Parameters* > *Operational* and change the **specify solids removal by setting…** to **underflow and solids**.



Operational

Operational Parameters

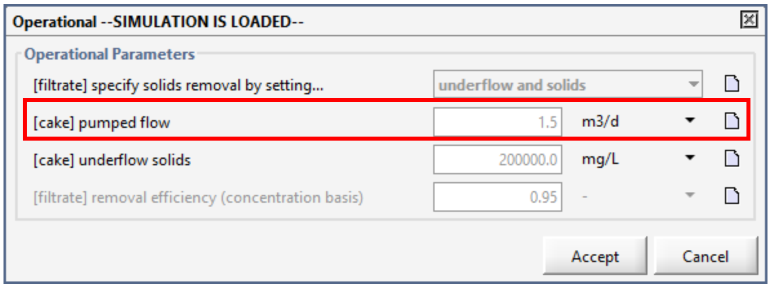
[filtrate] specify solids removal by setting...	underflow and solids	
[cake] pumped flow	1.5	m3/d
[cake] underflow solids	200000.0	mg/L
[filtrate] removal efficiency (concentration basis)	0.95	-

10. Switch into simulation mode.

Scenario 1 – Relationship Between Digester Operating Temperature and SRT (Exercise 11 – Question 1)

11. Create a new input controls tab and rename it “Anaerobic Digestion.”
12. Right-click on the Thickener object and navigate to *Input Parameters* > *Operational* and drag the **pumped flow** variable to the window under the new input controls tab. This variable will be used to control the SRT within the anaerobic digester.

Use the properties button to set the maximum flow to 90 m^3/d.



Operational --SIMULATION IS LOADED--

Operational Parameters

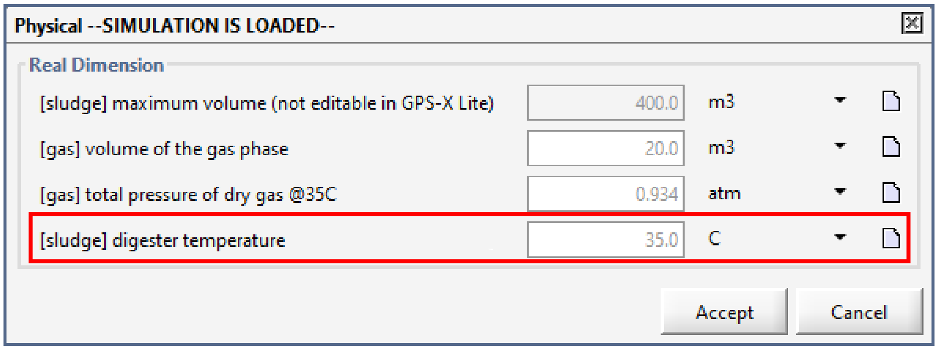
[filtrate] specify solids removal by setting... underflow and solids

[cake] pumped flow 1.5 m3/d

[cake] underflow solids 200000.0 mg/L

[filtrate] removal efficiency (concentration basis) 0.95 -

13. Right-click on the Anaerobic Digester and navigate to *Input Parameters* > *Physical* and drag the **digester temperature** to the input controls area.



Physical --SIMULATION IS LOADED--

Real Dimension

[sludge] maximum volume (not editable in GPS-X Lite) 400.0 m3

[gas] volume of the gas phase 20.0 m3

[gas] total pressure of dry gas @35C 0.934 atm

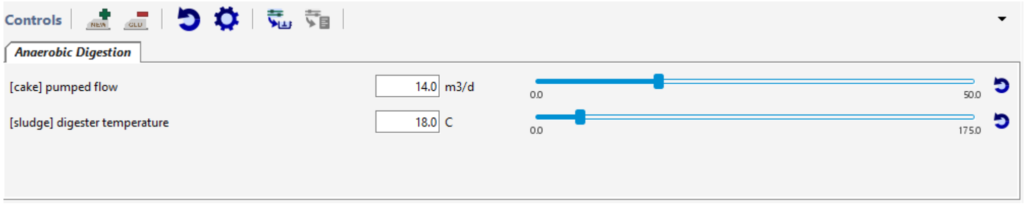
[sludge] digester temperature 35.0 C

To maintain the same amount of solids removal while changing the digester operating temperature, the HRT needs to be adjusted [1]. Complete the following table through completion of the steps below. **(Exercise 11 – Question 1)**

Note: The digester HRT is the same as the digester SRT in this scenario.

Temperature (ºC)	HRT (d)	Pumped Flow (m^3/d)	Sludge TSS (kg/d)	VSS Destruction (%)
18	28			
24	20			
30	14			
35	10			

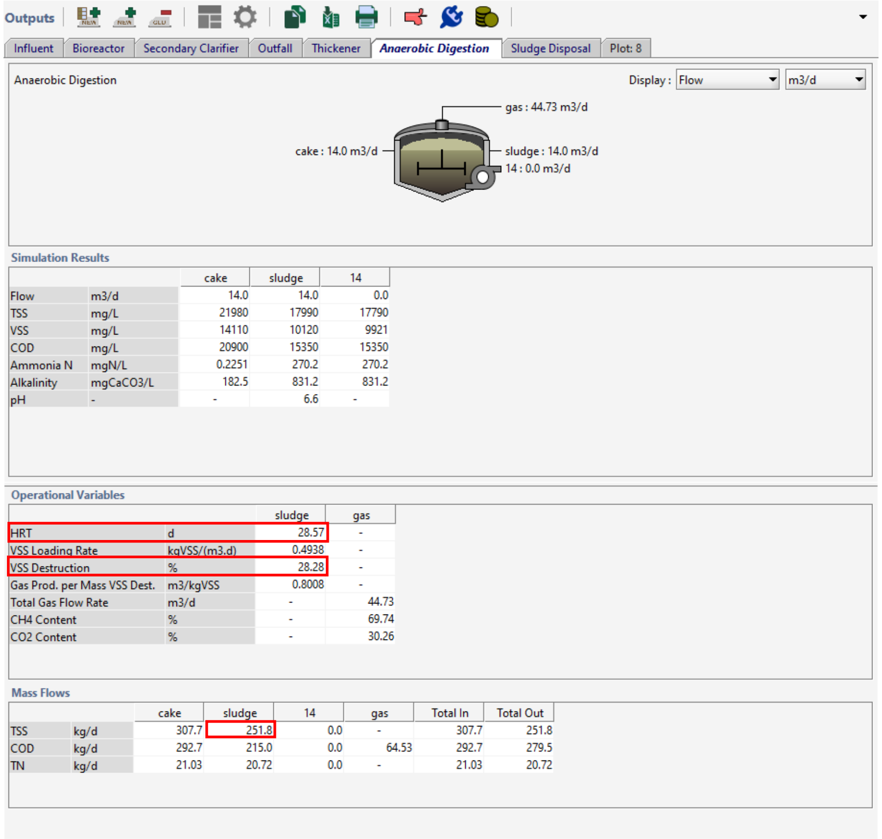
14. In input controls tab set the **digester temperature** to **18 ºC** and the **pumped flow** to **14 m^3/d** and run the simulation.



[cake] pumped flow 14.0 m3/d

[sludge] digester temperature 18.0 C

15. Select the Anaerobic Digestion output tab and observe the HRT value under the Operational Variables header. Notice that it is at approximately 28 days due to the adjustment of the pumped flow variable. Record the VSS destruction and sludge TSS values in the table.



Simulation Results

		cake	sludge	14
Flow	m3/d	14.0	14.0	0.0
TSS	mg/L	21980	17990	17790
VSS	mg/L	14110	10120	9921
COD	mg/L	20900	15350	15350
Ammonia N	mgN/L	0.2251	270.2	270.2
Alkalinity	mgCaCO3/L	182.5	831.2	831.2
pH	-	-	6.6	-

Operational Variables

		sludge	gas
HRT	d	28.57	-
VSS Loading Rate	kgVSS/(m3.d)	0.4938	-
VSS Destruction	%	28.28	-
Gas Prod. per Mass VSS Dest.	m3/kgVSS	0.8008	-
Total Gas Flow Rate	m3/d	-	44.73
CH4 Content	%	-	69.74
CO2 Content	%	-	30.26

Mass Flows

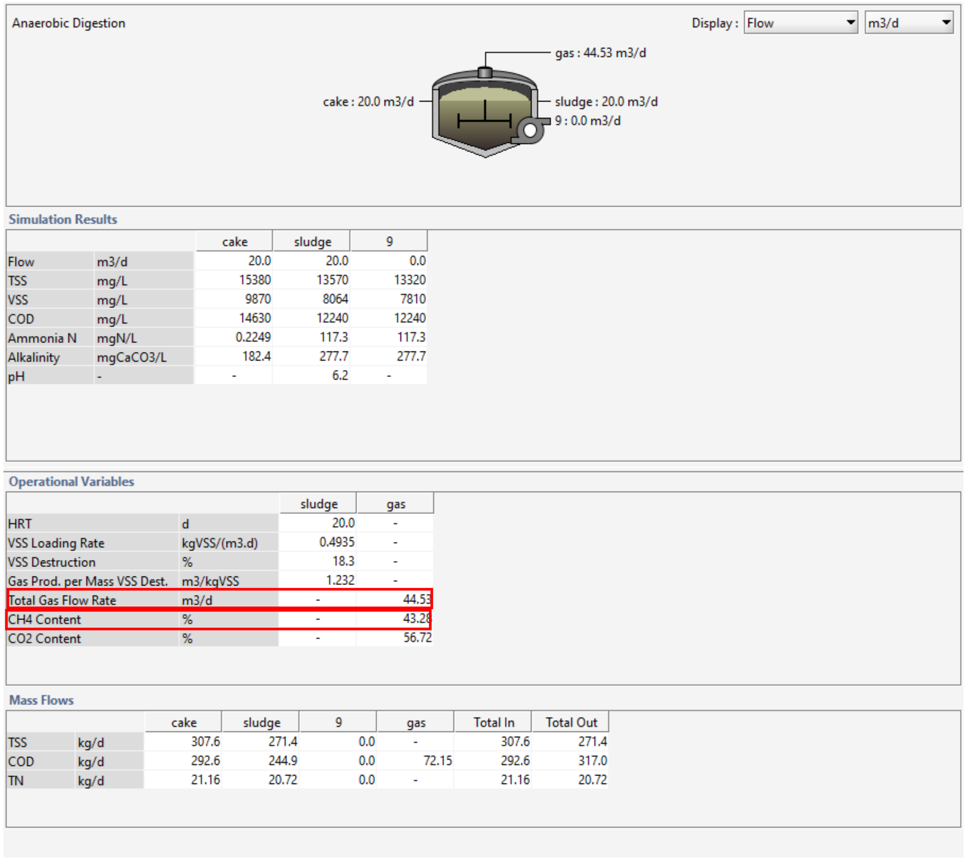
		cake	sludge	14	gas	Total In	Total Out
TSS	kg/d	307.7	251.8	0.0	-	307.7	251.8
COD	kg/d	292.7	215.0	0.0	64.53	292.7	279.5
TN	kg/d	21.03	20.72	0.0	-	21.03	20.72

16. Complete the remainder of the table through adjustment of the digester temperature and pumped flow rate in the Anaerobic Digestion input controls tab. You should notice that the digester performance remains relatively consistent, indicating that a lower operating temperature necessitates a higher operating HRT.

Scenario 2 – Relationship Between Digester Operating Temperature and Gas Production (Exercise 11 – Question 2)

The next section will explore the effect of the digester operating temperature on the quantity of methane gas production.

17. In the Anaerobic Digestion input controls tab set the **pumped flow** to **20 m^3/d**. Run the simulation at **digester temperatures** of **15 °C, 25 °C, and 35 °C** and record the gas flow rate of methane. This can be approximated by simply multiplying the CH_4 Content by the Total Gas Flow Rate in the Operational Variables section on the Anaerobic Digestion output tab.



Anaerobic Digestion

Display : Flow m3/d

Simulation Results

		cake	sludge	9
Flow	m3/d	20.0	20.0	0.0
TSS	mg/L	15380	13570	13320
VSS	mg/L	9870	8064	7810
COD	mg/L	14630	12240	12240
Ammonia N	mgN/L	0.2249	117.3	117.3
Alkalinity	mgCaCO3/L	182.4	277.7	277.7
pH	-	-	6.2	-

Operational Variables

		sludge	gas
HRT	d	20.0	-
VSS Loading Rate	kgVSS/(m3.d)	0.4935	-
VSS Destruction	%	18.3	-
Gas Prod. per Mass VSS Dest.	m3/kgVSS	1.232	-
Total Gas Flow Rate	m3/d	-	44.53
CH4 Content	%	-	43.28
CO2 Content	%	-	56.72

Mass Flows

		cake	sludge	9	gas	Total In	Total Out
TSS	kg/d	307.6	271.4	0.0	-	307.6	271.4
COD	kg/d	292.6	244.9	0.0	72.15	292.6	317.0
TN	kg/d	21.16	20.72	0.0	-	21.16	20.72

18. Create a graph in Excel of the Methane Gas Flow Rate vs. Digester Temperature. Discuss the effect that digester temperature has on the rate of methane production.

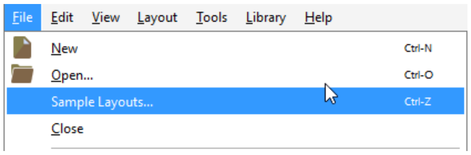
Note: In the fully-functional version of GPS-X an analyze feature is available. This feature would allow the user to automatically run the simulation at the different digester temperatures with the digester temperature presented on the x-axis rather than time.

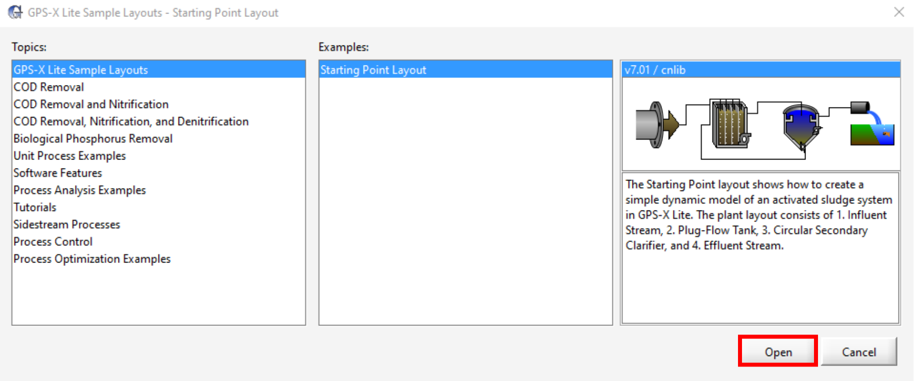
Exercise 12 – Mass Balance

GPS-X contains a useful feature that allows users to create a Sankey Diagram for flow, solids, and nutrient components throughout the plant. This exercise will explore this feature to aid in understanding how the fate of nutrients is affected by different operational settings.

1. Open the Starting Point model layout developed in Exercise 1 and save it under a different name.

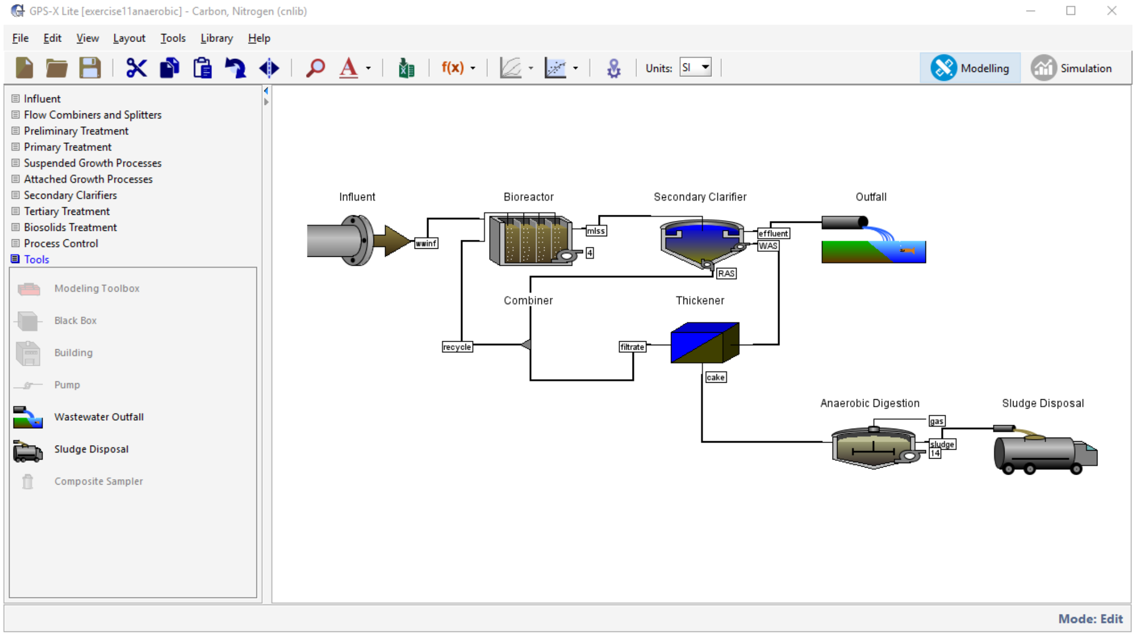
   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File* > *Sample Layouts…*





The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. Follow ***Steps 2-9 for Exercise 11***. (DO NOT change the operational parameters in the Thickener.)

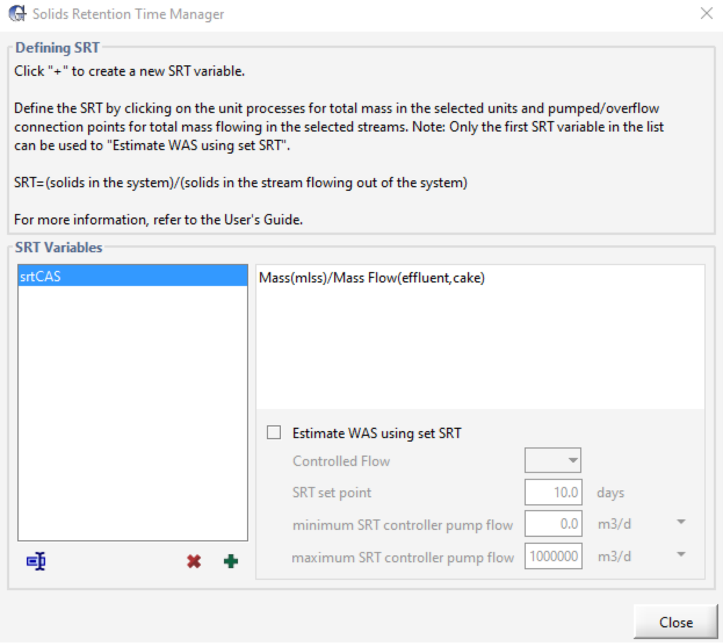


f(x)

- Select the Define button from the main toolbar and choose the Solids Retention Time option from the bottom of the list.

Follow the steps in Step 4 of Exercise 5. In this case, the pop-up box for the numerator will only have Reactor 1 specified as opposed to three reactors above.

- Note: Since this layout contains a Thickener, the loss of solids from the system are from the cake stream, rather than the WAS stream. Therefore, the equation should appear as Mass(mlss)/Mass Flow(effluent,cake) NOT Mass(mlss)/Mass Flow(effluent,WAS) .
- Ensure that the “Estimate WAS using set SRT” box in the Define window is unchecked.



Solids Retention Time Manager

Defining SRT

Click "+" to create a new SRT variable.

Define the SRT by clicking on the unit processes for total mass in the selected units and pumped/overflow connection points for total mass flowing in the selected streams. Note: Only the first SRT variable in the list can be used to "Estimate WAS using set SRT".

SRT=(solids in the system)/(solids in the stream flowing out of the system)

For more information, refer to the User's Guide.

SRT Variables

srtCAS

Mass(mlss)/Mass Flow(effluent,cake)

☐ Estimate WAS using set SRT

Controlled Flow

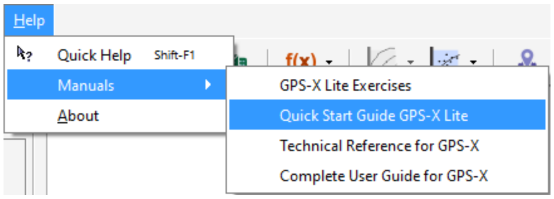
SRT set point 10.0 days

minimum SRT controller pump flow 0.0 m3/d

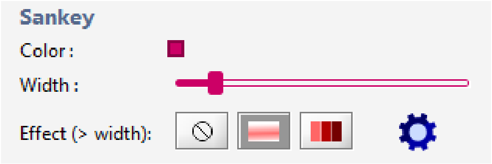
maximum SRT controller pump flow 1000000 m3/d

Close

Note: If you require further support with setting up a new SRT variable, access the ***Quick Start Guide GPS-X Lite*** from the Help Menu.

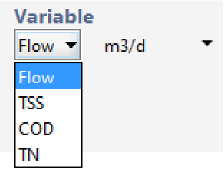


3. Switch into Simulation Mode.
4. Create a new graph output tab and rename it “SRT.” From the main toolbar go to *Define* > *Solids Retention* Time and drag the **srtCAS** variable to the SRT output graph tab. Right-click on this new graph and select **Digital** from the *Output Graph Type* menu.
5. Run the simulation at steady-state and open the Sankey diagram.
6. Under the Sankey heading at the top of the window select the **color box** and change the stream color to one of your choice.



7. Observe the flow rate and mass flow of TSS, COD, and TN across the plant by selecting the appropriate variable from the dropdown list that appears under the Variable header. Ensure that the values that you observe when running the simulation at the default setting are nearly the same as

those presented in the table below. (Numerical simulations can produce slightly variable results even for the same starting information.)



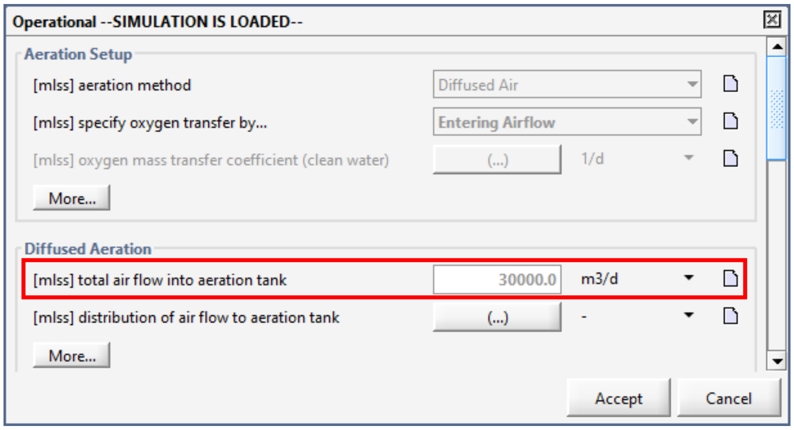
Variable	wwinf	mlss	effluent	WAS	RAS	filtrate	recycle	cake	sludge
Flow (m^3/d)	2000	4039	1999	40	2000	38.5	2039	1.5	1.5
TSS (kg/d)	477.8	16350	26.63	320.1	16010	15.4	16020	304.7	124.8
COD (kg/d)	860	15580	73.58	304	15200	15.51	15220	288.5	24.53
TN (kg/d)	80	1187	48.15	22.33	1117	1.923	1119	20.41	20.38

8. Perform a mass balance on the total nitrogen (TN). Does the mass of TN into the plant (wwinf) equal the mass of solids out of the plant (effluent, sludge)? If not, describe the location, quantity, and form of nitrogen, that makes up the difference. Use simulation results to support your answer. (**Exercise 12 – Question 1)**
9. Show that the masses of TSS and COD balance (in equals out) across the Thickener. (**Exercise 12 – Question 2)**
10. Right-click on the Secondary Clarifier and navigate to *Input Parameters* > *Operational* and drag the **pumped flow** variable to the input controls area. Rename the new input controls tab to “Operational Settings.”
11. Set the **pumped flow** variable to **173 m^3/d** (SRT = 3 days) and run the steady-state simulation.
12. Open the Sankey diagram and report the TN values in the table below. Discuss how the results compare to the default values. (**Exercise 12 – Question 3)**

Variable	wwinf	mlss	effluent	WAS	RAS	filtrate	recycle	cake	sludge
Default - TN (kg/d)	80	1187	48.15	22.33	1117	1.923	1119	20.41	20.38
TN (kg/d)									

13. Close the Sankey window and reset the pumped flow variable.

14. Right-click on the Bioreactor and navigate to *Input Parameters* > *Operational*. Under the Diffused Aeration header drag the **total air flow into aeration tank** variable to the input control tab and set the value to **15,000 m^3/d**.


Operational --SIMULATION IS LOADED--

Aeration Setup

[mlss] aeration method: Diffused Air
[mlss] specify oxygen transfer by...: Entering Airflow
[mlss] oxygen mass transfer coefficient (clean water): (...) 1/d

Diffused Aeration

[mlss] total air flow into aeration tank: 30000.0 m3/d
[mlss] distribution of air flow to aeration tank: (...) -

15. Rerun the steady-state simulation and open the Sankey diagram window. Report the COD values in the table below and discuss how the results compare to the default values. (**Exercise 12 – Question 4)**

Variable	wwinf	mlss	effluent	WAS	RAS	filtrate	recycle	cake	sludge
Default - COD (kg/d)	860	15580	73.58	304	15200	15.51	15220	288.5	24.53
COD (kg/d)									

16. Close the Sankey window and reset the **total air flow into aeration tank** back to **30,000 m^3/d**.
17. Right-click on the Thickener object and navigate to *Input Parameters* > *Operational* and drag the **removal efficiency (concentration basis)** variable to the input controls section.
18. Set the **removal efficiency** to **0.8**, rerun the simulation and open the Sankey diagram. Report the TSS values in the table below and discuss how the results compare to the default values. (**Exercise 12 – Question 5)**

Variable	wwinf	mlss	effluent	WAS	RAS	filtrate	recycle	cake	sludge
Default - TSS (kg/d)	477.8	16350	26.63	320.1	16000	15.4	16020	304.7	124.8
TSS (kg/d)									

Exercise 13 – Dynamic Operations

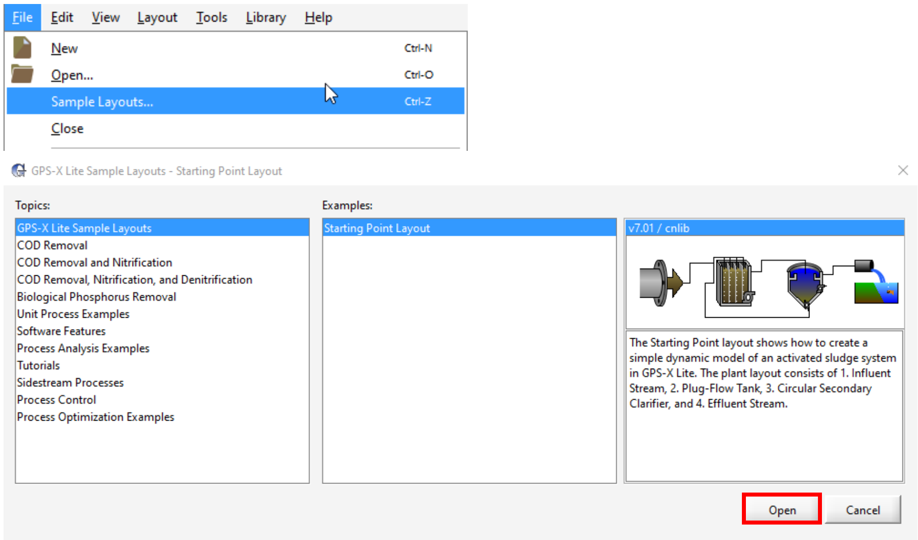
The purpose of this exercise is to explore the effect of the influent flow profile on operations.

Recreate the table below to record your answers for the following steps. (**Exercise 13 – Question 1)**

Daily Average			**Signal Integration**	
Flow Type	**Total Suspended Solids (mg/L)**	**Total Carbonaceous BOD (mg/L)**	**Free and Ionized Ammonia (mg/L)**	**Mass Flow Total Suspended Solids (kg)**
Data				
Sinusoidal				
Diurnal Flow				

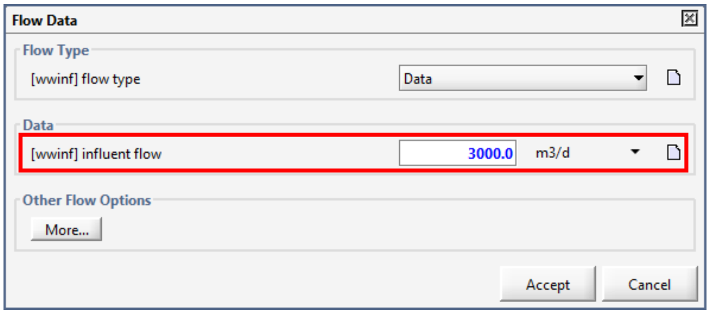
1. Open the Starting Point model layout developed in Exercise 1 and save it under a different name.

   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*



The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. In modelling mode right-click on the Influent Wastewater object and navigate to *Flow* > *Flow Data* and change the **influent flow** to **3000 m^3/d**.



Flow Data

Flow Type

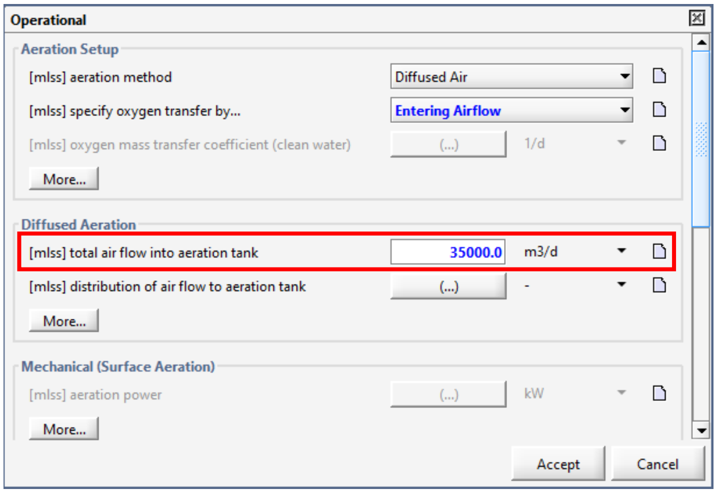
[wwinf] flow type: Data

Data

[wwinf] influent flow: 3000.0 m3/d

Other Flow Options

3. Right-click on the Bioreactor and navigate to *Input Parameters* > *Operational* and change the total **air flow into aeration tank** to **35,000 m^3/d**.



Operational

Aeration Setup

[mlss] aeration method: Diffused Air

[mlss] specify oxygen transfer by...: Entering Airflow

[mlss] oxygen mass transfer coefficient (clean water): (...) 1/d

Diffused Aeration

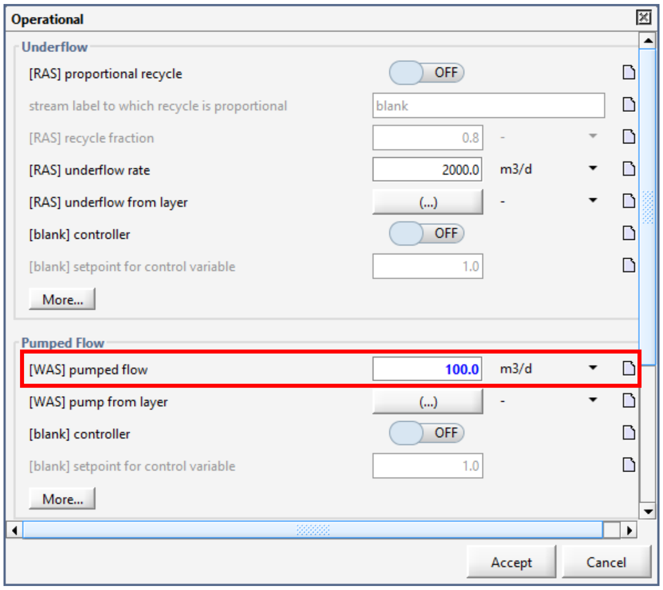
[mlss] total air flow into aeration tank: 35000.0 m3/d

[mlss] distribution of air flow to aeration tank: (...) -

Mechanical (Surface Aeration)

[mlss] aeration power: (...) kW

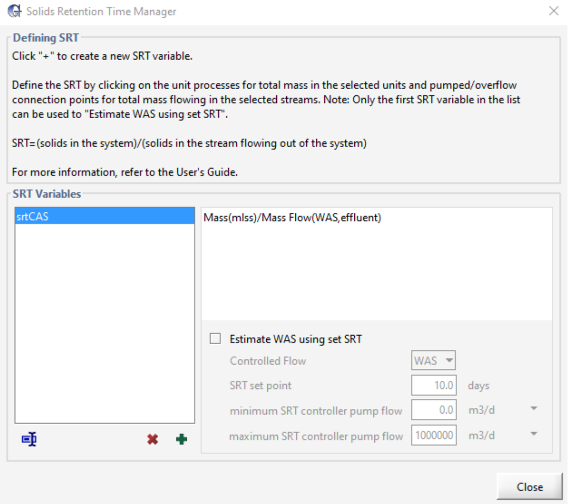
4. Right-click on the Secondary Clarifier and navigate to *Input Parameters* > *Operational* and set the **pumped flow** to **100 m^3/d**.


Operational

Underflow
[RAS] proportional recycle: OFF
stream label to which recycle is proportional: blank
[RAS] recycle fraction: 0.8 -
[RAS] underflow rate: 2000.0 m3/d
[RAS] underflow from layer: (...) -
[blank] controller: OFF
[blank] setpoint for control variable: 1.0

Pumped Flow
[WAS] pumped flow: 100.0 m3/d
[WAS] pump from layer: (...) -
[blank] controller: OFF
[blank] setpoint for control variable: 1.0

5. Select the Define button from the main toolbar and choose the Solids Retention Time option from the bottom of the list. Follow the steps in Step 4 of Exercise 5. In this case, the pop-up box for the numerator will only have Reactor 1 specified as opposed to three reactors above.
    - Ensure that the “Estimate WAS using set SRT” button is unchecked.


Solids Retention Time Manager

Defining SRT
Click "+" to create a new SRT variable.

Define the SRT by clicking on the unit processes for total mass in the selected units and pumped/overflow connection points for total mass flowing in the selected streams. Note: Only the first SRT variable in the list can be used to "Estimate WAS using set SRT".

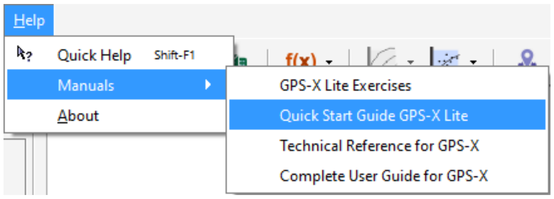
SRT=(solids in the system)/(solids in the stream flowing out of the system)

For more information, refer to the User's Guide.

SRT Variables
srtCAS
Mass(mlss)/Mass Flow(WAS,effluent)

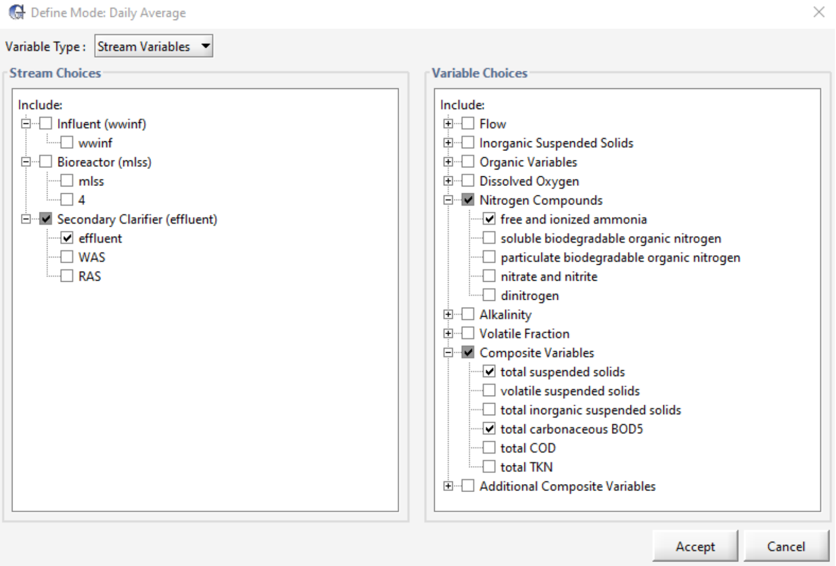
☐ Estimate WAS using set SRT
Controlled Flow: WAS
SRT set point: 10.0 days
minimum SRT controller pump flow: 0.0 m3/d
maximum SRT controller pump flow: 1000000 m3/d

Note: If you require further support with setting up a new SRT variable, access the ***Quick Start Guide GPS-X Lite*** from the Help Menu.



6. From the main toolbar select *Define* > *Daily Average*. Keeping the Variable Type as Stream Variables select the following:
   - Stream Choices:
     i. Secondary Clarifier (effluent) > effluent
   - Variable Choices:
     i. Nitrogen Compounds (click on the +) > free and ionized ammonia
     ii. Composite Variables (click on the +) > total suspended solids, total carbonaceous BOD5

   Accept the form to save the changes.



Define Mode: Daily Average

Variable Type : Stream Variables

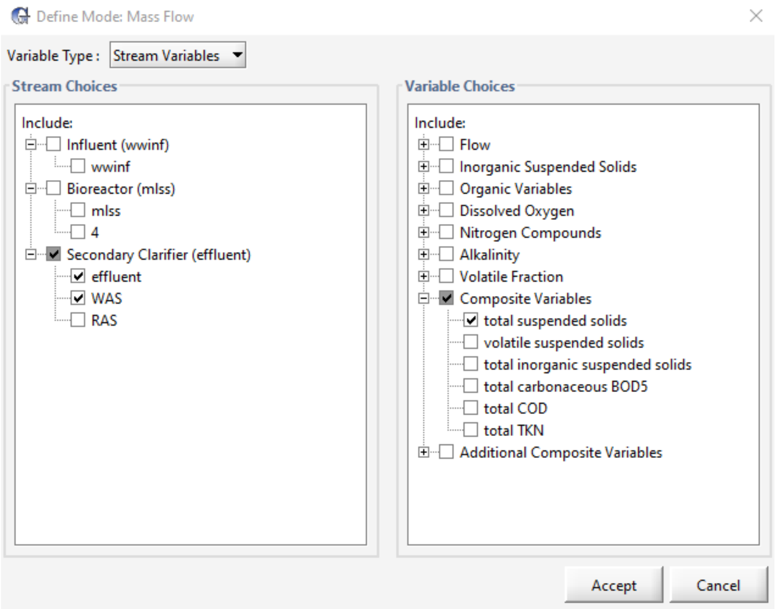
Stream Choices

Include:
- ☐ Influent (wwinf)
  - ☐ wwinf
- ☐ Bioreactor (mlss)
  - ☐ mlss
  - ☐ 4
- ☑ Secondary Clarifier (effluent)
  - ☑ effluent
  - ☐ WAS
  - ☐ RAS

Variable Choices

Include:
- ☐ Flow
- ☐ Inorganic Suspended Solids
- ☐ Organic Variables
- ☐ Dissolved Oxygen
- ☑ Nitrogen Compounds
  - ☑ free and ionized ammonia
  - ☐ soluble biodegradable organic nitrogen
  - ☐ particulate biodegradable organic nitrogen
  - ☐ nitrate and nitrite
  - ☐ dinitrogen
- ☐ Alkalinity
- ☐ Volatile Fraction
- ☑ Composite Variables
  - ☑ total suspended solids
  - ☐ volatile suspended solids
  - ☐ total inorganic suspended solids
  - ☑ total carbonaceous BOD5
  - ☐ total COD
  - ☐ total TKN
- ☐ Additional Composite Variables

7. From the main toolbar select *Define* > *Mass Flow*. Keeping the Variable Type as Stream Variables select the following:
   - Stream Choices:
     i. Secondary Clarifier (effluent) > effluent and WAS
   - Variable Choices:
     i. Composite Variables > total suspended solids



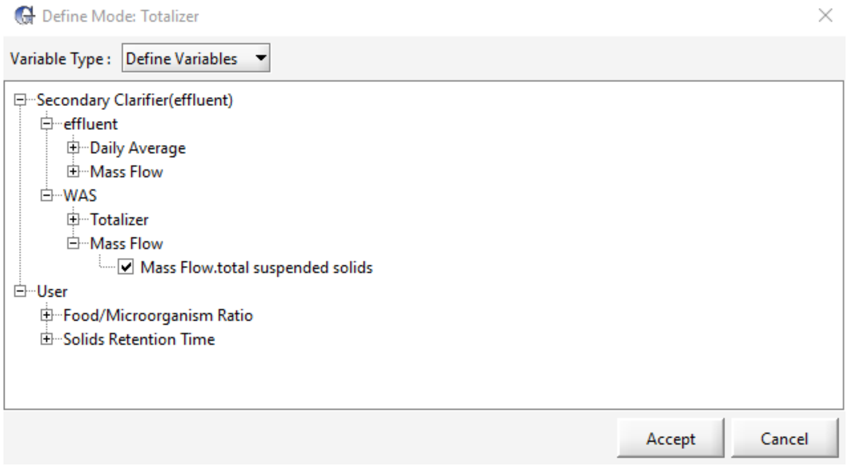
Include:
- ☐ Influent (wwinf)
  - ☐ wwinf
- ☐ Bioreactor (mlss)
  - ☐ mlss
  - ☐ 4
- ☑ Secondary Clarifier (effluent)
  - ☑ effluent
  - ☑ WAS
  - ☐ RAS

Include:
- ☐ Flow
- ☐ Inorganic Suspended Solids
- ☐ Organic Variables
- ☐ Dissolved Oxygen
- ☐ Nitrogen Compounds
- ☐ Alkalinity
- ☐ Volatile Fraction
- ☑ Composite Variables
  - ☑ total suspended solids
  - ☐ volatile suspended solids
  - ☐ total inorganic suspended solids
  - ☐ total carbonaceous BOD5
  - ☐ total COD
  - ☐ total TKN
- ☐ Additional Composite Variables

Accept the form to save the changes.

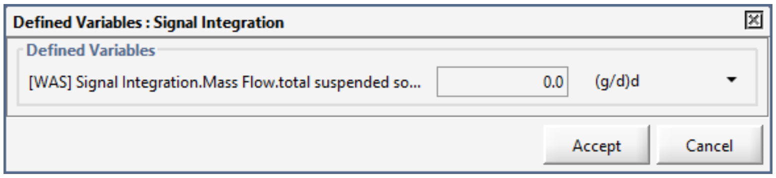
8. From the main toolbar select *Define* > *Totalizer*. Change the Variable Type to Define Variables and select the following:
   i. Secondary Clarifier (effluent) > WAS > Mass Flow > Mass Flow.total suspended solids

Accept the form to save the changes.



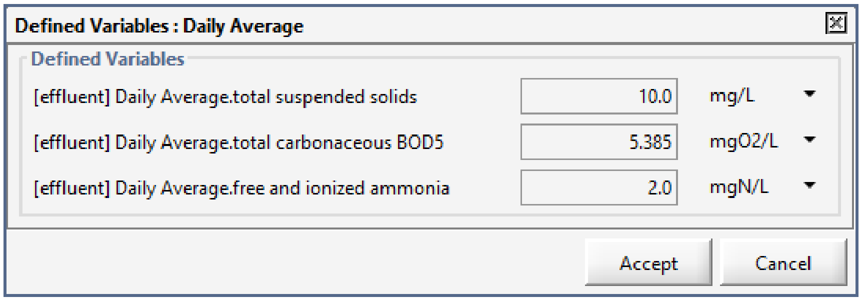
- Secondary Clarifier(effluent)
  - effluent
    - Daily Average
    - Mass Flow
  - WAS
    - Totalizer
    - Mass Flow
      - ☑ Mass Flow.total suspended solids
- User
  - Food/Microorganism Ratio
  - Solids Retention Time

9. Switch into Simulation Mode. Rebuild the model if prompted.
10. Create a new output graph tab and rename the tab to “WWTP Performance.” Right-click on the WAS stream (after the cursor changes to an arrow) and navigate to *Output Variables* > *Defined Variables* > *Totalizer* and drag the **Signal Integration.Mass Flow.total suspended solids** variable to the new graph tab. Right-click on the graph that is created and go to *Output Graph Type* > ***Digital***. Click on the *Output Properties…* button and change the unit of this variable to kg.

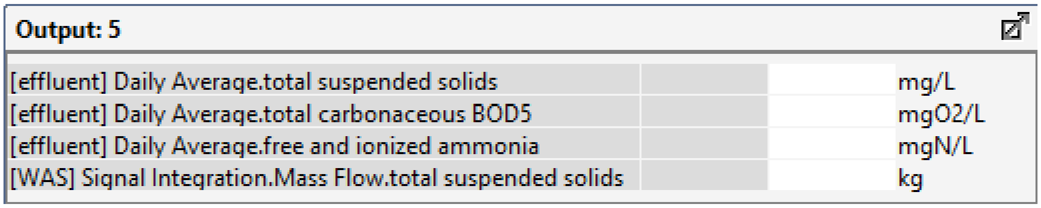


[WAS] Signal Integration.Mass Flow.total suspended so... 0.0 (g/d)d

11. To this same digital output graph add the following:
    - Effluent Stream – *Output Variables > Defined Variables > Daily Average*: **Daily Average.total suspended solids, Daily Average.total carbonaceous BOD5, Daily Average.free and ionized ammonia**

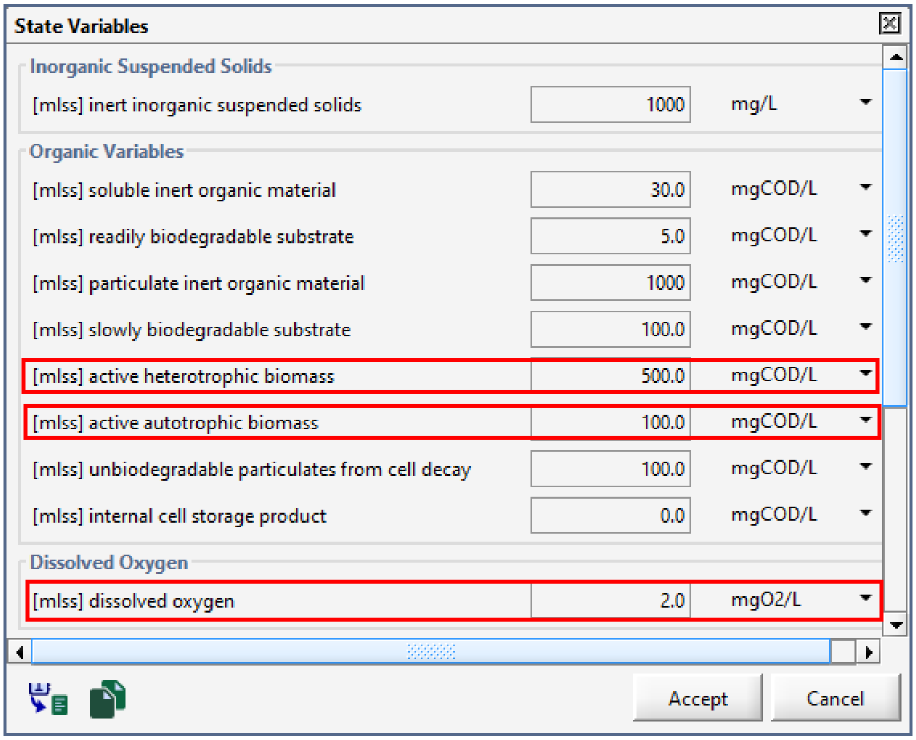


[effluent] Daily Average.total suspended solids 10.0 mg/L
[effluent] Daily Average.total carbonaceous BOD5 5.385 mgO2/L
[effluent] Daily Average.free and ionized ammonia 2.0 mgN/L



[effluent] Daily Average.total suspended solids mg/L
[effluent] Daily Average.total carbonaceous BOD5 mgO2/L
[effluent] Daily Average.free and ionized ammonia mgN/L
[WAS] Signal Integration.Mass Flow.total suspended solids kg

12. Create 4 new X-Y output graphs in the WWTP Performance output tab. All variables are accessed by hovering the cursor over the appropriate connection point then right-clicking and choosing the designated item(s).
    - Graph 1: Bioreactor
        i. MLSS Stream – *Output Variables > State Variables >* **active heterotrophic biomass, active autotrophic biomass, dissolved oxygen**. Place all three variables on the same graph.



Inorganic Suspended Solids

[mlss] inert inorganic suspended solids	1000	mg/L

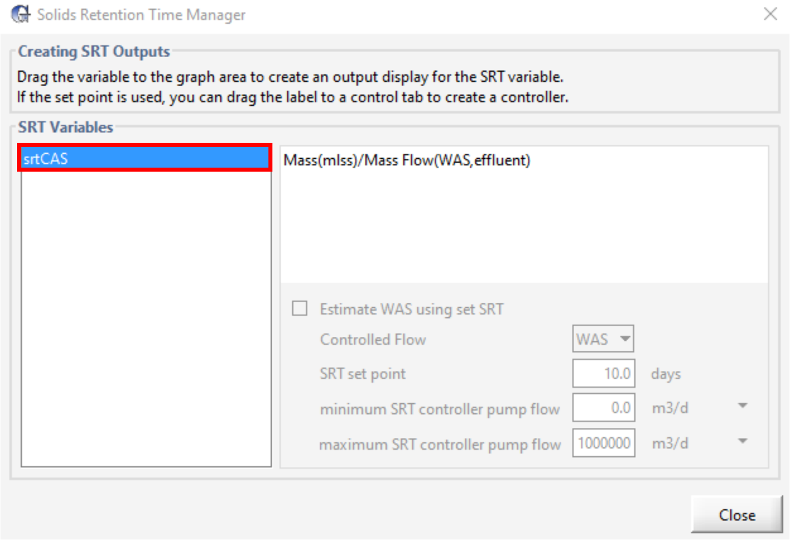
Organic Variables

[mlss] soluble inert organic material	30.0	mgCOD/L
[mlss] readily biodegradable substrate	5.0	mgCOD/L
[mlss] particulate inert organic material	1000	mgCOD/L
[mlss] slowly biodegradable substrate	100.0	mgCOD/L
[mlss] active heterotrophic biomass	500.0	mgCOD/L
[mlss] active autotrophic biomass	100.0	mgCOD/L
[mlss] unbiodegradable particulates from cell decay	100.0	mgCOD/L
[mlss] internal cell storage product	0.0	mgCOD/L

Dissolved Oxygen

[mlss] dissolved oxygen	2.0	mgO2/L

- Graph 2: SRT
    i. *Define* > *Solids Retention Time* > **srtCAS**



Creating SRT Outputs

Drag the variable to the graph area to create an output display for the SRT variable.
If the set point is used, you can drag the label to a control tab to create a controller.

SRT Variables

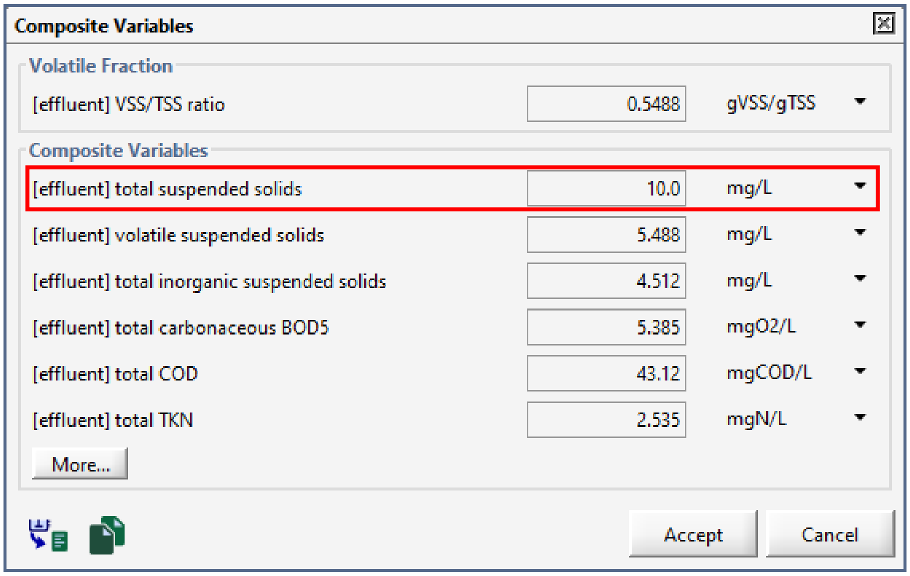
srtCAS

Mass(mlss)/Mass Flow(WAS,effluent)

☐ Estimate WAS using set SRT

Controlled Flow	WAS	
SRT set point	10.0	days
minimum SRT controller pump flow	0.0	m3/d
maximum SRT controller pump flow	1000000	m3/d

- Graph 3: Effluent Quality
    i. Effluent Stream – *Output Variables* > *Composite Variables* > **total suspended solids, total carbonaceous BOD5**. Place both variables on the graph.
    ii. Effluent Stream – *Output Variables* > *State Variables* > **free and ionized ammonia**. Drag this variable to the plot area.



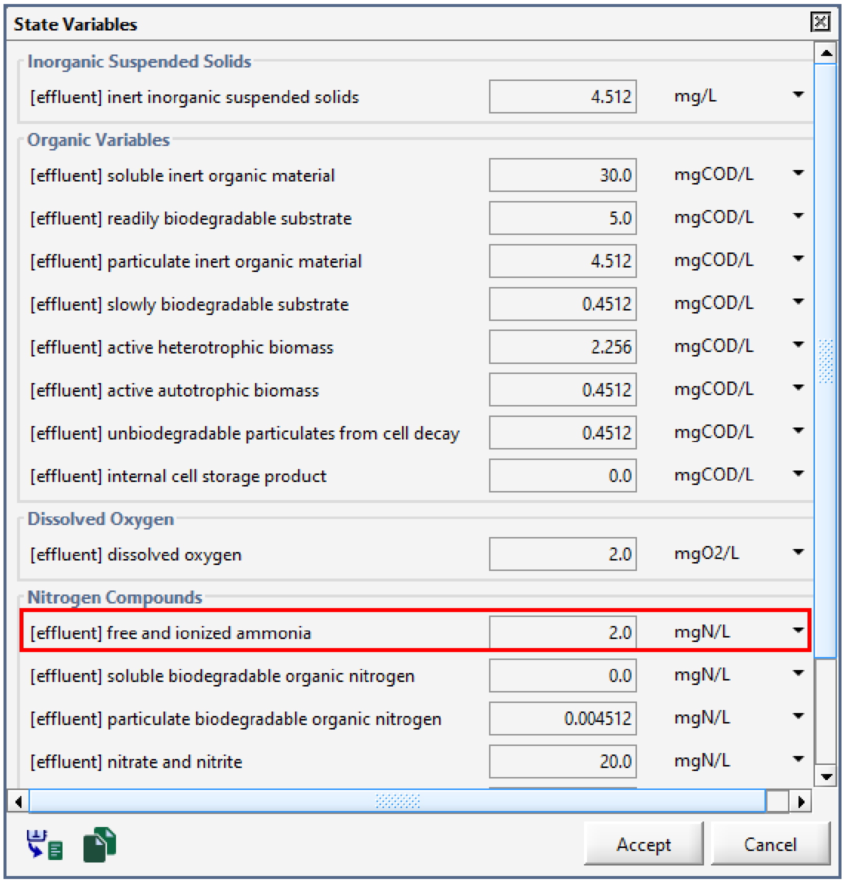
Composite Variables

Volatile Fraction

[effluent] VSS/TSS ratio	0.5488	gVSS/gTSS

Composite Variables

[effluent] total suspended solids	10.0	mg/L
[effluent] volatile suspended solids	5.488	mg/L
[effluent] total inorganic suspended solids	4.512	mg/L
[effluent] total carbonaceous BOD5	5.385	mgO2/L
[effluent] total COD	43.12	mgCOD/L
[effluent] total TKN	2.535	mgN/L



State Variables

Inorganic Suspended Solids

[effluent] inert inorganic suspended solids	4.512	mg/L

Organic Variables

[effluent] soluble inert organic material	30.0	mgCOD/L
[effluent] readily biodegradable substrate	5.0	mgCOD/L
[effluent] particulate inert organic material	4.512	mgCOD/L
[effluent] slowly biodegradable substrate	0.4512	mgCOD/L
[effluent] active heterotrophic biomass	2.256	mgCOD/L
[effluent] active autotrophic biomass	0.4512	mgCOD/L
[effluent] unbiodegradable particulates from cell decay	0.4512	mgCOD/L
[effluent] internal cell storage product	0.0	mgCOD/L

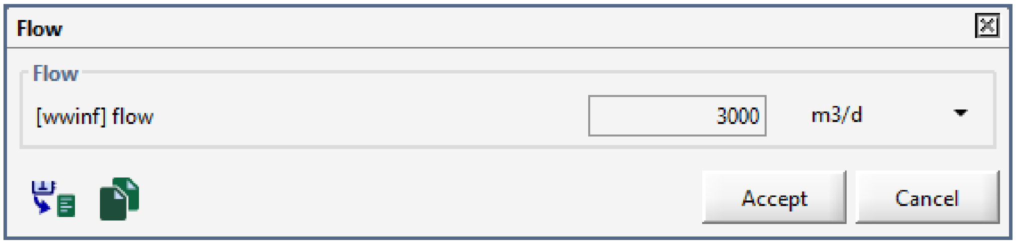
Dissolved Oxygen

[effluent] dissolved oxygen	2.0	mgO2/L

Nitrogen Compounds

[effluent] free and ionized ammonia	2.0	mgN/L
[effluent] soluble biodegradable organic nitrogen	0.0	mgN/L
[effluent] particulate biodegradable organic nitrogen	0.004512	mgN/L
[effluent] nitrate and nitrite	20.0	mgN/L

- Graph 4: Influent Flow
    i. wwinf steam – *Output Variables* > *Flow* > **flow**

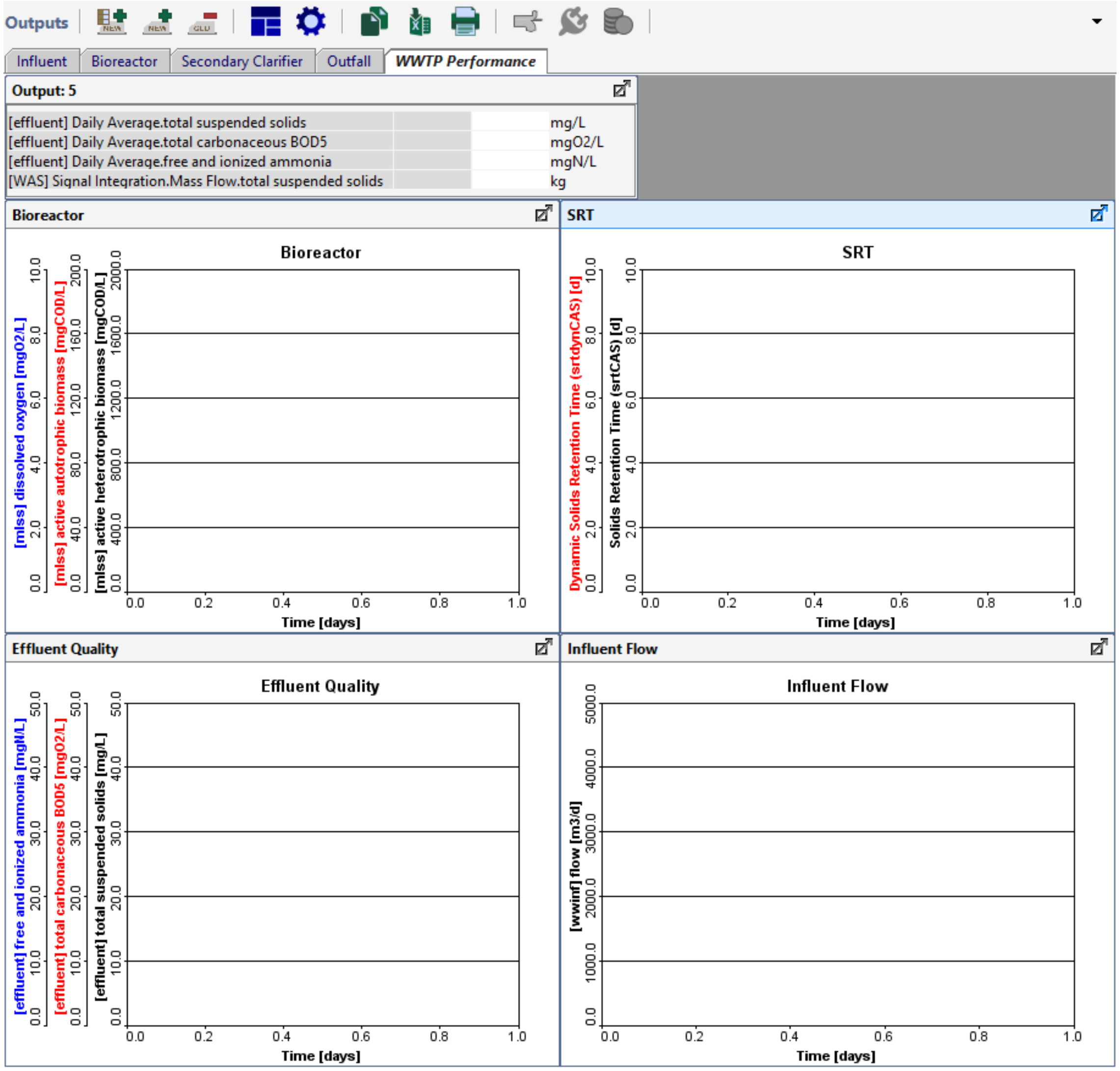


Flow

Flow

[wwinf] flow 3000 m3/d

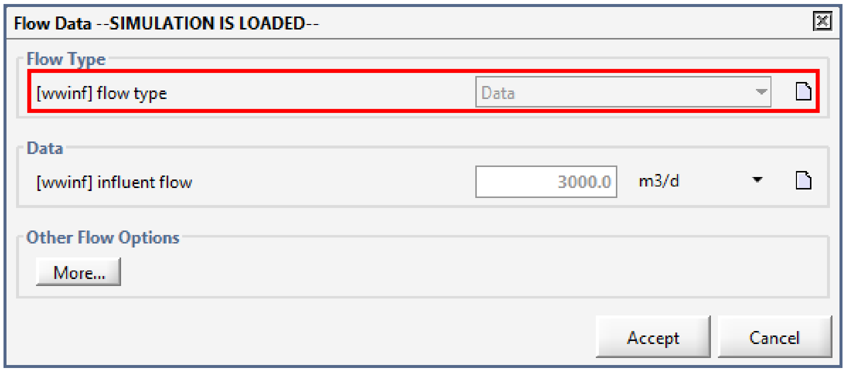
Auto arrange the graphs and rename them appropriately.



Output: 5

[effluent] Daily Average.total suspended solids	mg/L
[effluent] Daily Average.total carbonaceous BOD5	mgO2/L
[effluent] Daily Average.free and ionized ammonia	mgN/L
[WAS] Signal Integration.Mass Flow.total suspended solids	kg

13. Create a new input controls tab and rename it to “Operational Settings.”
14. Right-click on the Influent Wastewater object and navigate to *Flow* > *Flow Data*. Drag the **flow type** variable to the input controls tab.


Flow Data --SIMULATION IS LOADED--

Flow Type

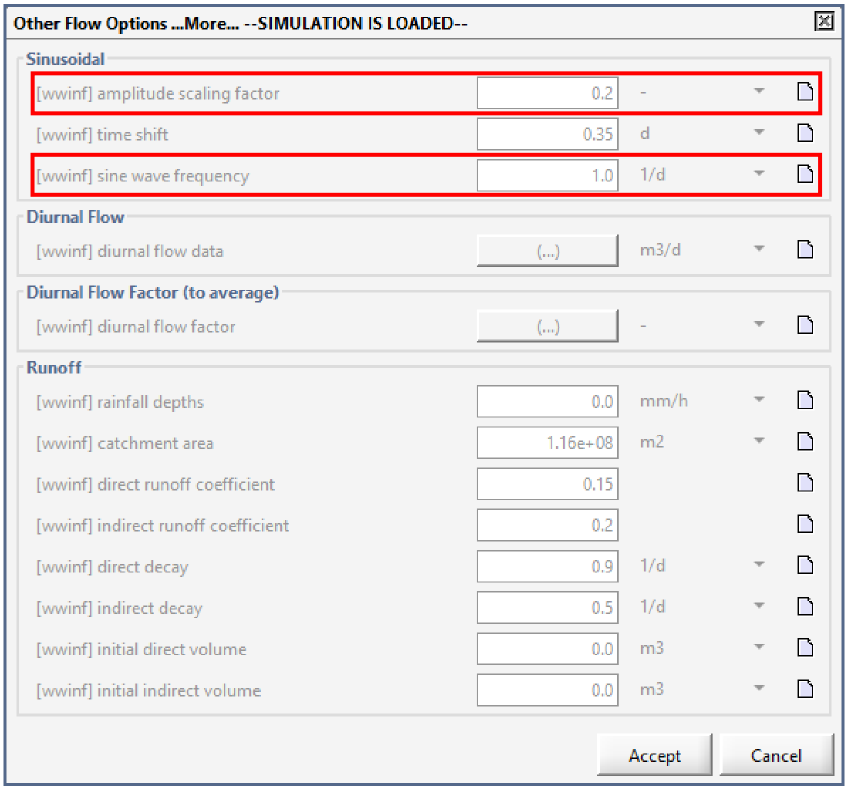
[wwinf] flow type	Data	

Data

[wwinf] influent flow	3000.0	m3/d

Other Flow Options

15. Within this same form select the *Other Flow Options More…* form and under the Sinusoidal header drag the **sine wave frequency** and the **amplitude scaling factor** to the input controls tab.


Other Flow Options ...More... --SIMULATION IS LOADED--

Sinusoidal

[wwinf] amplitude scaling factor	0.2	-
[wwinf] time shift	0.35	d
[wwinf] sine wave frequency	1.0	1/d

Diurnal Flow

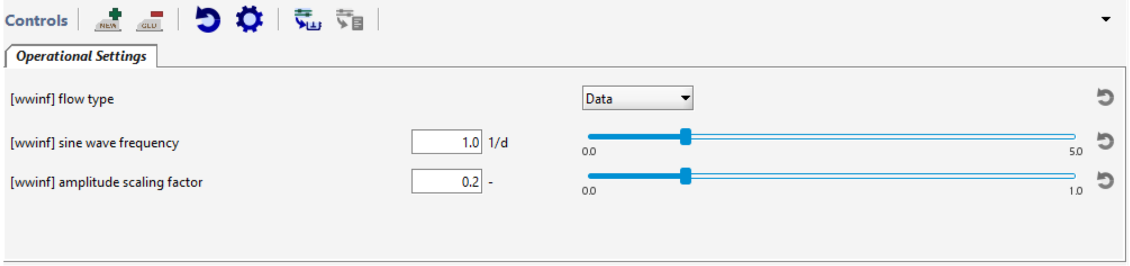
[wwinf] diurnal flow data	(...)	m3/d

Diurnal Flow Factor (to average)

[wwinf] diurnal flow factor	(...)	-

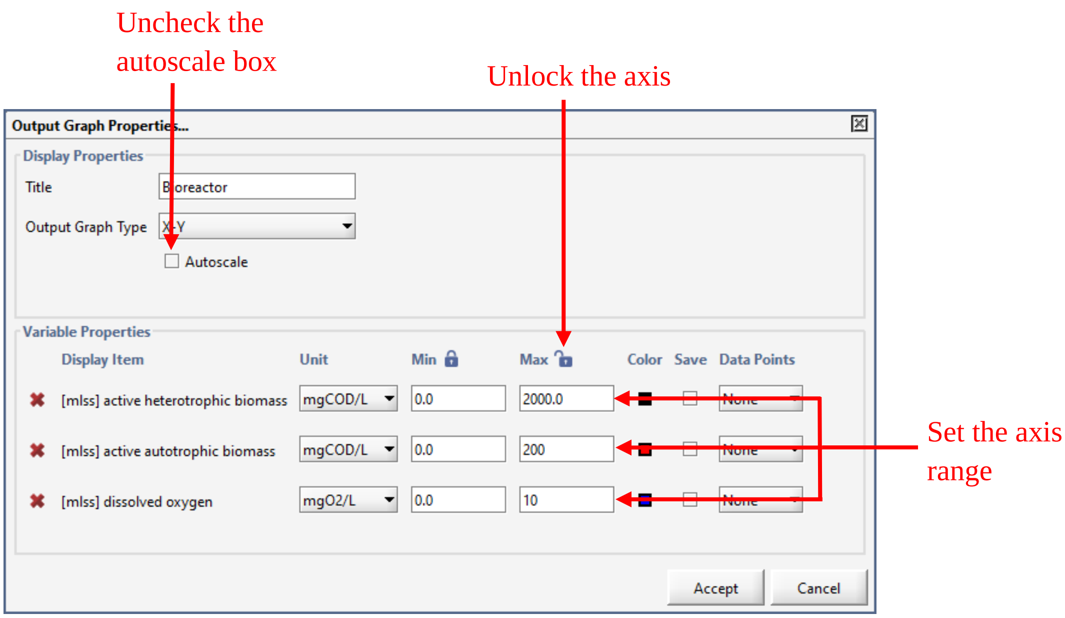
Runoff

[wwinf] rainfall depths	0.0	mm/h
[wwinf] catchment area	1.16e+08	m2
[wwinf] direct runoff coefficient	0.15	
[wwinf] indirect runoff coefficient	0.2	
[wwinf] direct decay	0.9	1/d
[wwinf] indirect decay	0.5	1/d
[wwinf] initial direct volume	0.0	m3
[wwinf] initial indirect volume	0.0	m3



[wwinf] flow type	Data	
[wwinf] sine wave frequency	1.0	1/d
[wwinf] amplitude scaling factor	0.2	-

In the following steps you will record screenshots of the outputs graphs. Select the Bioreactor graph under the WWTP Performance tab. Open the graph's properties window to adjust the autoscale and axes as shown in the screenshot below.



Uncheck the autoscale box

Unlock the axis

Set the axis range

Output Graph Properties...

Display Properties

Title: Bioreactor

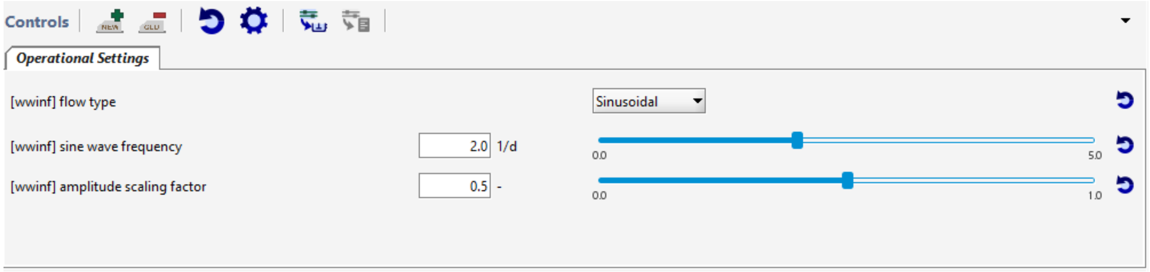
Output Graph Type: X-Y

☐ Autoscale

Variable Properties

	Display Item	Unit	Min	Max	Color	Save	Data Points
✖	[mlss] active heterotrophic biomass	mgCOD/L	0.0	2000.0	■	☐	None
✖	[mlss] active autotrophic biomass	mgCOD/L	0.0	200	■	☐	None
✖	[mlss] dissolved oxygen	mgO2/L	0.0	10	■	☐	None

16. In the Simulation Toolbar set the **Stop Time** to **1-day**. With the input controls at the default settings, run the simulation at steady state. Report the results in the first row of the table. Record a screenshot of the output graphs. (**Exercise 13 – Question 1)**
17. In the Operational Settings tab, change the **flow type** to **Sinusoidal**, the **sine wave frequency** to **2.0 1/d** and the **amplitude scaling factor** to **0.5**.



Operational Settings

[wwinf] flow type: Sinusoidal

[wwinf] sine wave frequency: 2.0 1/d

[wwinf] amplitude scaling factor: 0.5 -

18. Run the simulation for 1-day at steady-state and report the values in the 2nd row of the table. Record a screenshot of the output graphs. (**Exercise 13 – Question 2)**
19. In the Operational Settings tab change the **flow type** to **Diurnal Flow Factor** and run the simulation for 1-day at steady-state and report the values in the table. Record a screenshot of the output graphs. (**Exercise 13 – Question 3)**
20. Prepare a discussion regarding the following questions (**Exercise 13 – Question 4)**:
    - How are the daily average TSS, total cBOD$_5$, NH$_3$, and mass flow of solids affected by the flow type?
    - Compare the dynamic vs. instantaneous solids retention time between each flow type.

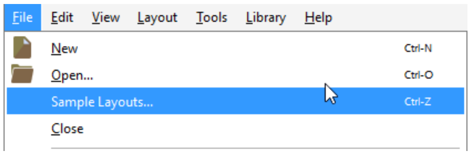
- How is the concentration of heterotrophic and autotrophic biomass affected by the flow type?

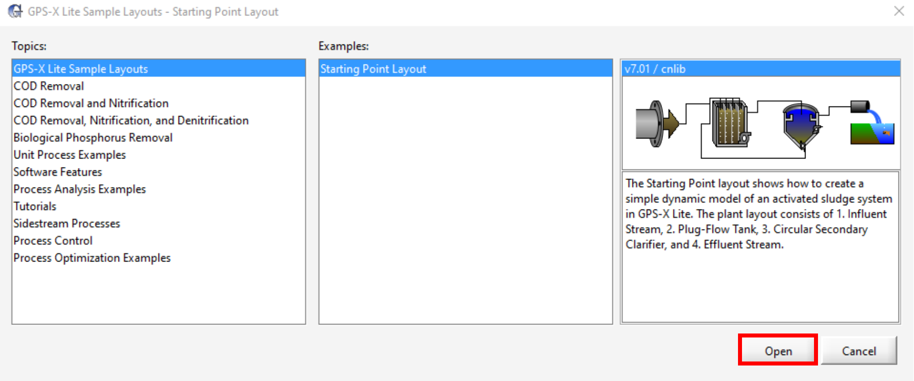
Exercise 14 – Aeration Strategy on Plant Performance and Energy

As observed in Exercise 7, aeration control has a strong impact on the plant performance. The objective of this exercise is to better understand the effect of the dissolved oxygen concentration in the aeration basin on plant performance.

1. Open the Starting Point model layout developed in Exercise 1 and save it under a different name.

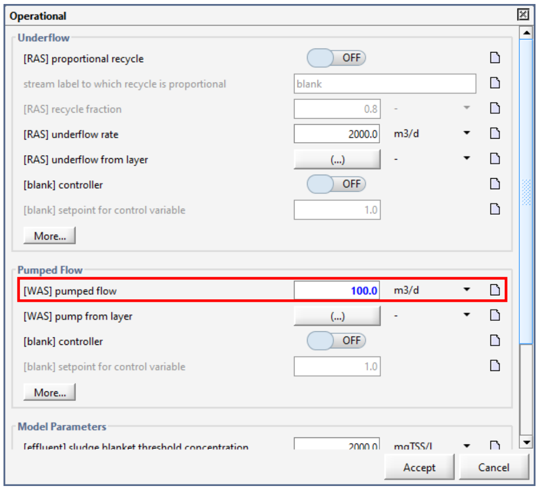
   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*





The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. In modelling mode right-click on the Secondary Clarifier and navigate to *Input Parameters > Operational* and change the **pumped flow** to **100 m³/d**.



Underflow

[RAS] proportional recycle	OFF	
stream label to which recycle is proportional	blank	
[RAS] recycle fraction	0.8	-
[RAS] underflow rate	2000.0	m3/d
[RAS] underflow from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

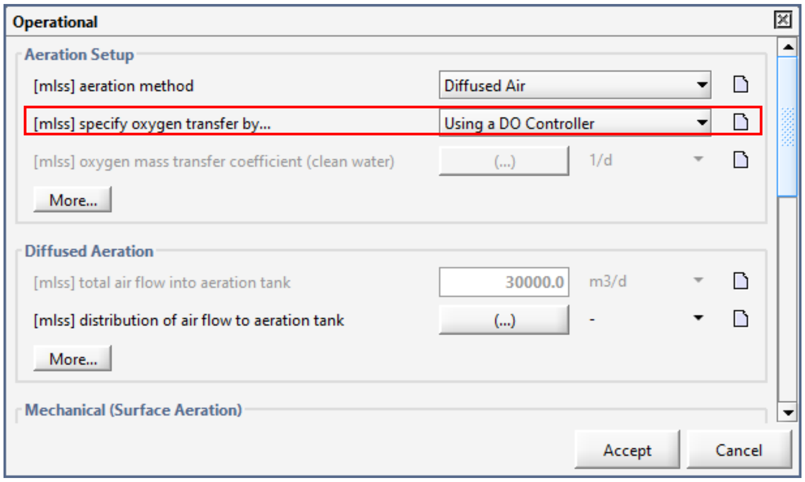
Pumped Flow

[WAS] pumped flow	100.0	m3/d
[WAS] pump from layer	(...)	-
[blank] controller	OFF	
[blank] setpoint for control variable	1.0	

Model Parameters

[effluent] sludge blanket threshold concentration	2000.0	mgTSS/l

3. Right-click on the Bioreactor and navigate to *Input Parameters > Operational* and under the heading “Aeration Setup” change the **specify oxygen transfer by…** to **Using a DO Controller**.



Operational

Aeration Setup

[mlss] aeration method: Diffused Air

[mlss] specify oxygen transfer by...: Using a DO Controller

[mlss] oxygen mass transfer coefficient (clean water): (...) 1/d

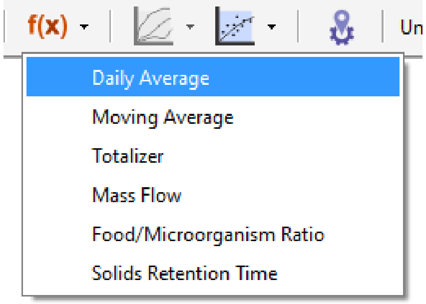
Diffused Aeration

[mlss] total air flow into aeration tank: 30000.0 m3/d

[mlss] distribution of air flow to aeration tank: (...) -

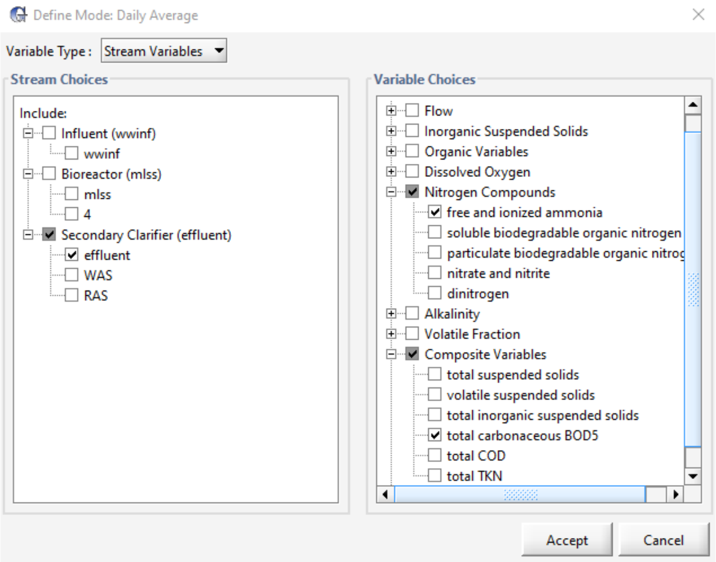
Mechanical (Surface Aeration)

4. From the Define menu on the main toolbar select Daily Average.



5. With the Variable Type set at Stream Variables make the following selections:

- Stream Choices:
  - i. Secondary Clarifier (effluent) > effluent
- Variable Choices:
  - i. Nitrogen Compounds > free and ionized ammonia
  - ii. Composite Variables > total carbonaceous BOD5

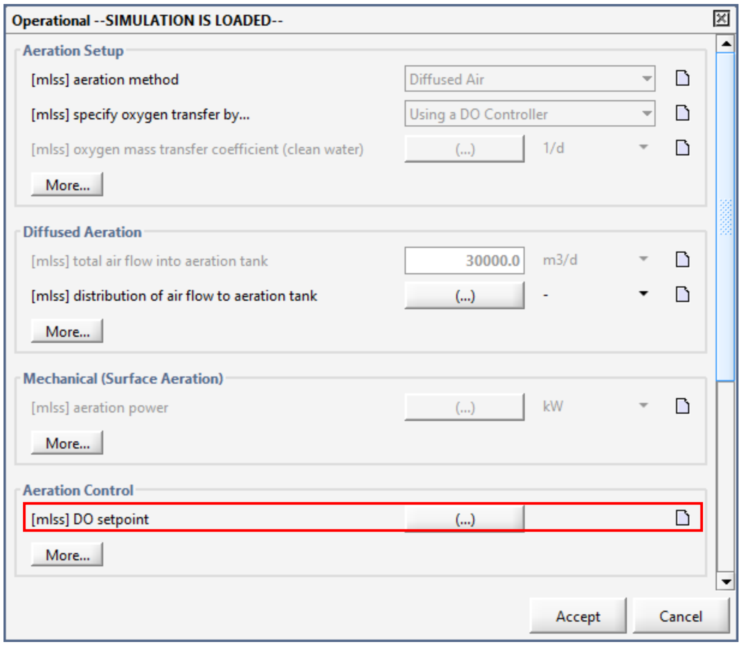


Variable Type : Stream Variables

Include:
- ☐ Influent (wwinf)
  - ☐ wwinf
- ☐ Bioreactor (mlss)
  - ☐ mlss
  - ☐ 4
- ☑ Secondary Clarifier (effluent)
  - ☑ effluent
  - ☐ WAS
  - ☐ RAS

- ☐ Flow
- ☐ Inorganic Suspended Solids
- ☐ Organic Variables
- ☐ Dissolved Oxygen
- ☑ Nitrogen Compounds
  - ☑ free and ionized ammonia
  - ☐ soluble biodegradable organic nitrogen
  - ☐ particulate biodegradable organic nitrog
  - ☐ nitrate and nitrite
  - ☐ dinitrogen
- ☐ Alkalinity
- ☐ Volatile Fraction
- ☑ Composite Variables
  - ☐ total suspended solids
  - ☐ volatile suspended solids
  - ☐ total inorganic suspended solids
  - ☑ total carbonaceous BOD5
  - ☐ total COD
  - ☐ total TKN

6. Accept this form and switch into simulation mode. Rebuild the model if prompted.
7. Create a new input controls tab and rename it to “DO Control.”
8. Right-click on the Bioreactor and navigate to *Input Parameters* > *Operational* > *Aeration Control header* and drag the **DO setpoint** variable to the input controls area.



[mlss] aeration method: Diffused Air

[mlss] specify oxygen transfer by...: Using a DO Controller

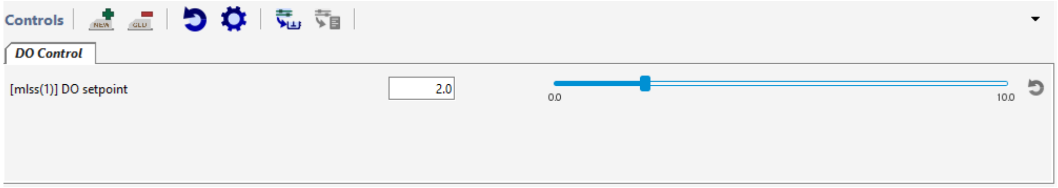
[mlss] oxygen mass transfer coefficient (clean water): (...) 1/d

[mlss] total air flow into aeration tank: 30000.0 m3/d

[mlss] distribution of air flow to aeration tank: (...) -

[mlss] aeration power: (...) kW

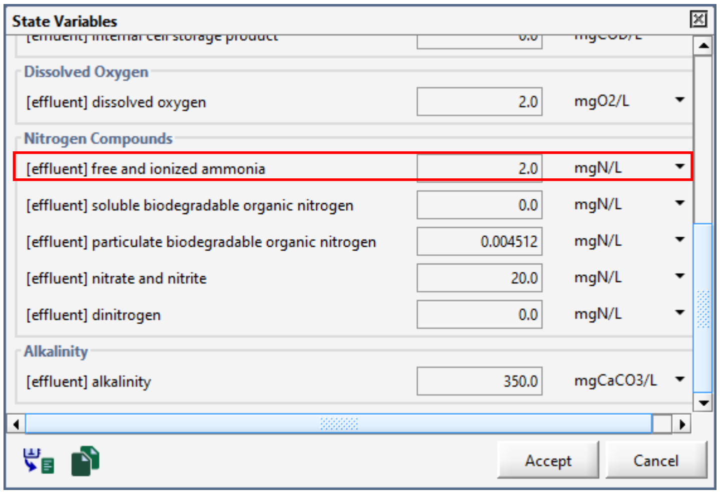
[mlss] DO setpoint: (...)



[mlss(1)] DO setpoint: 2.0

9. Create a new output graph tab called “Performance Variables” and add to it 3 new graphs. To access the designated variables, go to the connection point, hover until the cursor become an arrow, then right-click to access the menu.

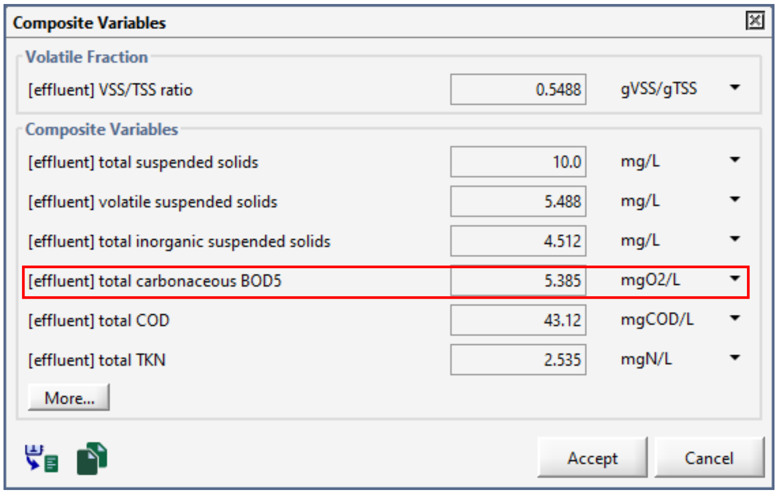
- Effluent Stream – *Output Variables* > *State Variables* > ***Free and Ionized Ammonia***



State Variables

[effluent] internal cell storage product	0.0	mgCOD/L
Dissolved Oxygen		
[effluent] dissolved oxygen	2.0	mgO2/L
Nitrogen Compounds		
[effluent] free and ionized ammonia	2.0	mgN/L
[effluent] soluble biodegradable organic nitrogen	0.0	mgN/L
[effluent] particulate biodegradable organic nitrogen	0.004512	mgN/L
[effluent] nitrate and nitrite	20.0	mgN/L
[effluent] dinitrogen	0.0	mgN/L
Alkalinity		
[effluent] alkalinity	350.0	mgCaCO3/L

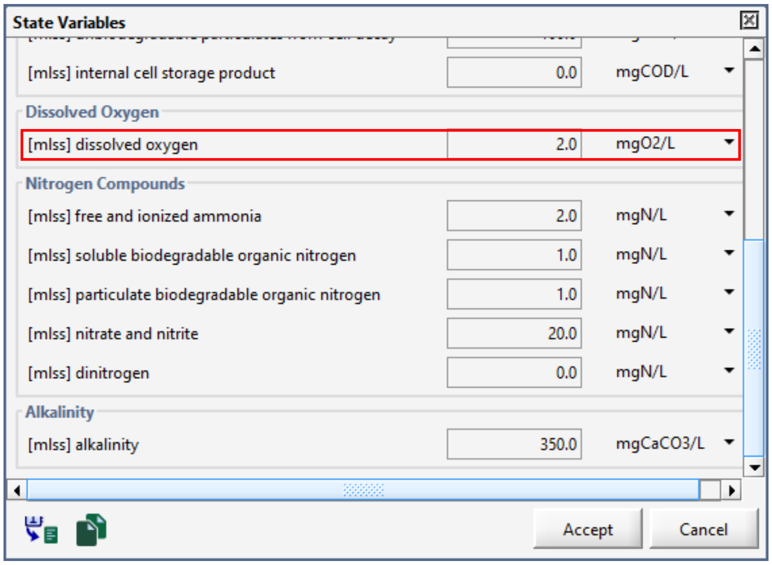
- Effluent Stream – *Output Variables* > *Composite Variables* > ***Total Carbonaceous BOD5***



Composite Variables

Volatile Fraction		
[effluent] VSS/TSS ratio	0.5488	gVSS/gTSS
Composite Variables		
[effluent] total suspended solids	10.0	mg/L
[effluent] volatile suspended solids	5.488	mg/L
[effluent] total inorganic suspended solids	4.512	mg/L
[effluent] total carbonaceous BOD5	5.385	mgO2/L
[effluent] total COD	43.12	mgCOD/L
[effluent] total TKN	2.535	mgN/L

- MLSS Stream – *Output Variables* > *State Variables* > ***Dissolved Oxygen***

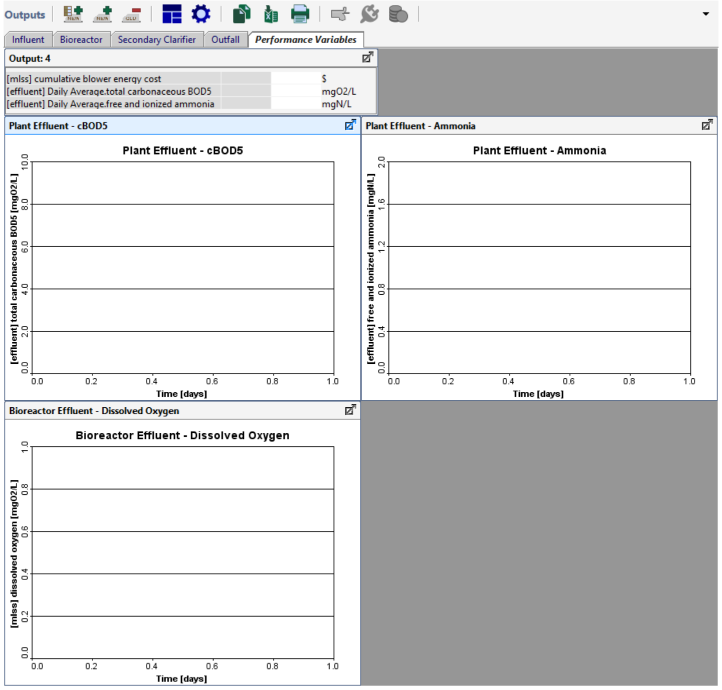


State Variables

[mlss] internal cell storage product	0.0	mgCOD/L
Dissolved Oxygen		
[mlss] dissolved oxygen	2.0	mgO2/L
Nitrogen Compounds		
[mlss] free and ionized ammonia	2.0	mgN/L
[mlss] soluble biodegradable organic nitrogen	1.0	mgN/L
[mlss] particulate biodegradable organic nitrogen	1.0	mgN/L
[mlss] nitrate and nitrite	20.0	mgN/L
[mlss] dinitrogen	0.0	mgN/L
Alkalinity		
[mlss] alkalinity	350.0	mgCaCO3/L

Rename the graphs appropriately.

10. Additionally, within this tab, add the Daily Average values as follows. Right-click on the effluent stream when the cursor changes to an arrow and navigate to *Output Variables* > *Defined Variables* > *Daily Average* and drag the **Daily Average.total carbonaceous BOD5** to the Performance Variables tab. Drag the **Daily Average.free and ionized ammonia** variable to this same graph. Change the graph type to **Digital** by right-clicking on the graph and navigating to *Output Graph Type*.
11. Right-click on the mlss stream and navigate to *Output Variables* > *Operating Cost* and drag the **cumulative blower energy cost** variable to the existing digital output graph.
12. Auto arrange the graphs.



Output: 4

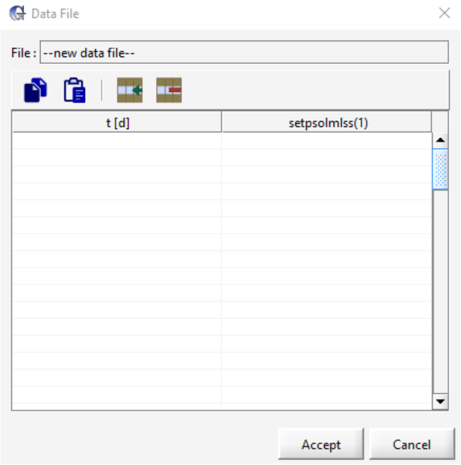
[mlss] cumulative blower energy cost		$
[effluent] Daily Average.total carbonaceous BOD5		mgO2/L
[effluent] Daily Average.free and ionized ammonia		mgN/L

The following sections will explore the effect of 2 scenarios on DO control and plant performance.

Scenario 1 – Continuous vs. Intermittent Aeration

To simulate the effect of intermittent aeration an input file can be created.

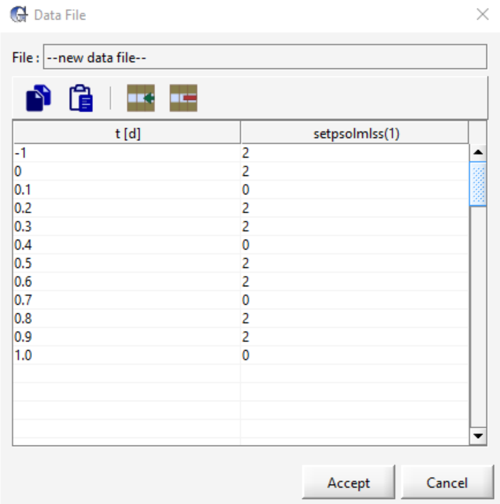
13. Right-click on the DO setpoint variable in the input controls section and select Data File… from the dropdown menu. This will open a window where you can set the value of the DO setpoint at user-specified time steps.



File : --new data file--

t [d]	setpsolmlss(1)

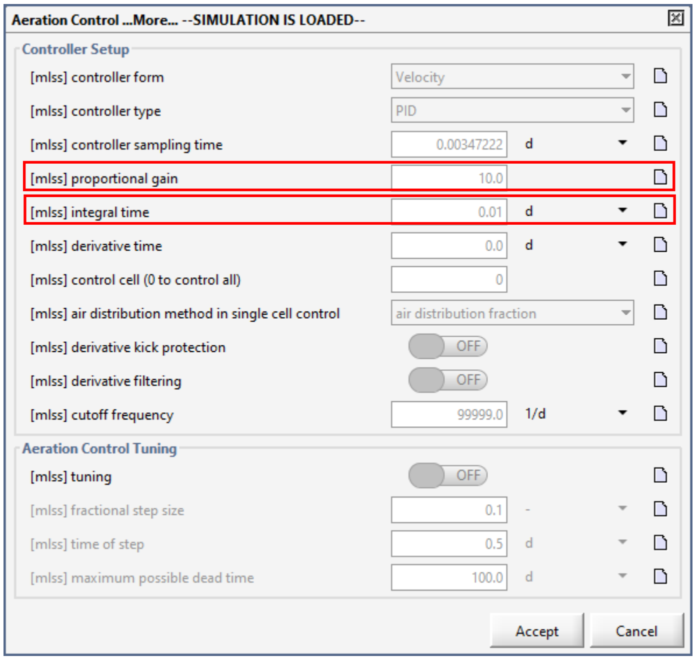
14. Create the following input in the data file. The value specified at t = -1 days is the steady-state DO setpoint.



File : --new data file--

t [d]	setpsolmlss(1)
-1	2
0	2
0.1	0
0.2	2
0.3	2
0.4	0
0.5	2
0.6	2
0.7	0
0.8	2
0.9	2
1.0	0

15. Accept this form and save the data file in an appropriate location.
16. Adjust the DO Setpoint controller settings. Right-click on the Bioreactor and navigate to *Input Parameters > Operational > Aeration Control > More …* and drag the **proportional gain** and **integral time** variables to the input controller tab.

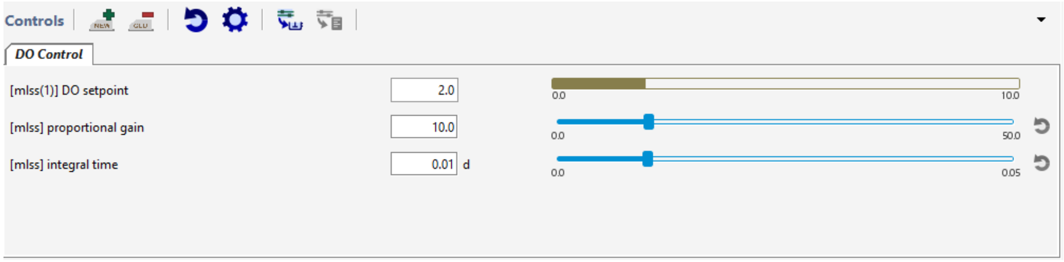


Controller Setup

[mlss] controller form	Velocity	
[mlss] controller type	PID	
[mlss] controller sampling time	0.00347222	d
[mlss] proportional gain	10.0	
[mlss] integral time	0.01	d
[mlss] derivative time	0.0	d
[mlss] control cell (0 to control all)	0	
[mlss] air distribution method in single cell control	air distribution fraction	
[mlss] derivative kick protection	OFF	
[mlss] derivative filtering	OFF	
[mlss] cutoff frequency	99999.0	1/d

Aeration Control Tuning

[mlss] tuning	OFF	
[mlss] fractional step size	0.1	-
[mlss] time of step	0.5	d
[mlss] maximum possible dead time	100.0	d

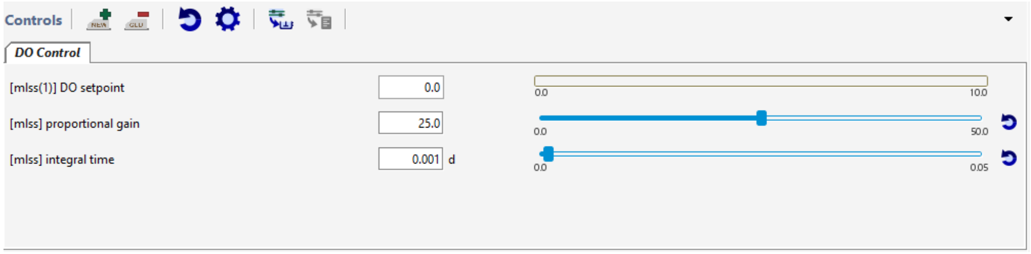


[mlss(1)] DO setpoint 2.0

[mlss] proportional gain 10.0

[mlss] integral time 0.01 d

17. Set the **proportional gain** and **integral time** to **25.0** and **0.001 d**, respectively.

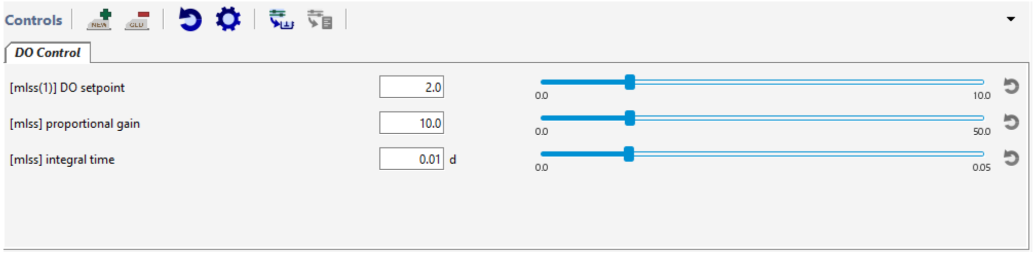


[mlss(1)] DO setpoint 0.0

[mlss] proportional gain 25.0

[mlss] integral time 0.001 d

18. In the simulation toolbar increase the stop time to 1 day and run the simulation. Record a screenshot of the results on the Performance Variables output tab. (**Exercise 14 – Question 1)**
19. Select the *Input Control Properties…* button and change the DO setpoint controller *type* from File Input to **Slider**. Accept the form. In the Input control window set the **DO setpoint** to **2.0 mg/L**.



[mlss(1)] DO setpoint 2.0

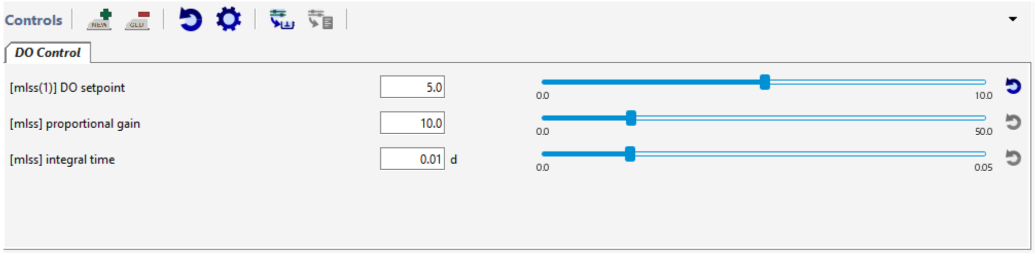
[mlss] proportional gain 10.0

[mlss] integral time 0.01 d

20. With the **Stop Time** at **1 day** run the simulation. Report the values for the daily average effluent cBOD$_5$ and ammonia concentrations, and the cumulative blower energy cost. Compare the results with those obtained from intermittent aeration. In your opinion is the extra cost of constant aeration worth it? (**Exercise 14 – Question 2)**

Scenario 2 – Effect of DO Setpoint on Aeration Energy Usage

21. In the input control, set the **DO setpoint** to **5 mg/L** and run the simulation with a stop time of 0-days. (No values will appear in the X-Y graphs.)



[mlss(1)] DO setpoint 5.0

[mlss] proportional gain 10.0

[mlss] integral time 0.01 d

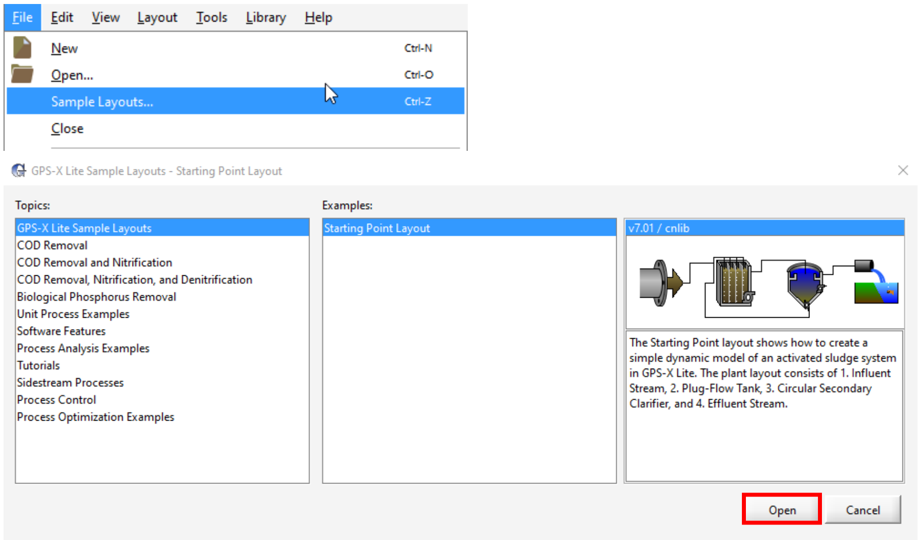
22. Open the Energy Usage Summary window. Record a screenshot of the Layout View with the Aeration Power variable selected from the banner at the top of the window. (**Exercise 14 – Question 3)**
23. Switch to the Table/Pie View tab at the top of the Energy Usage Summary window and select the Layout Total row. Record a screenshot of the resulting Layout Total Pie Chart. (**Exercise 14 – Question 4)**
24. Close the Energy Usage Summary window by clicking “OK” and select the Outfall output tab and report the value for the plant effluent cBOD$_5$ and ammonia. (**Exercise 14 – Question 5)**
25. Repeat steps 21 – 24 for a **DO setpoint** of **0.5 mg/L**. Compare the results with use of a DO setpoint of 5.0 mg/L and 0.5 mg/L. (**Exercise 14 – Question 6)**

Exercise 15 – Model Calibration

Modelling can provide a valuable tool for the exploration of a plant's performance and how it is affected by various operational settings. Although the default parameter settings in the GPS-X models are based on highly reviewed literature values, it is always necessary to perform a calibration to improve the fit of actual and model-predicted values as parameters can differ between plants.

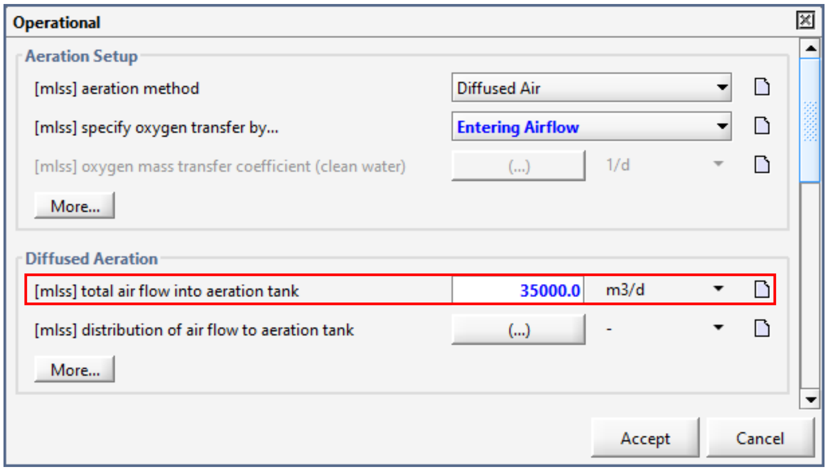
1. Open the Starting Point model layout developed in Exercise 1 and save it under a different name.

   Note: If you ran into any trouble with configuring the layout in Exercise 1, it can be accessed from the main toolbar by going to *File > Sample Layouts…*



The Starting Point layout shows how to create a simple dynamic model of an activated sludge system in GPS-X Lite. The plant layout consists of 1. Influent Stream, 2. Plug-Flow Tank, 3. Circular Secondary Clarifier, and 4. Effluent Stream.

2. In modelling mode, right-click on the Bioreactor and navigate to *Input Parameters > Operational* and under the Diffused Aeration heading adjust the **total air flow into aeration tank** to **35,000 m^3/d**.



[mlss] aeration method: Diffused Air

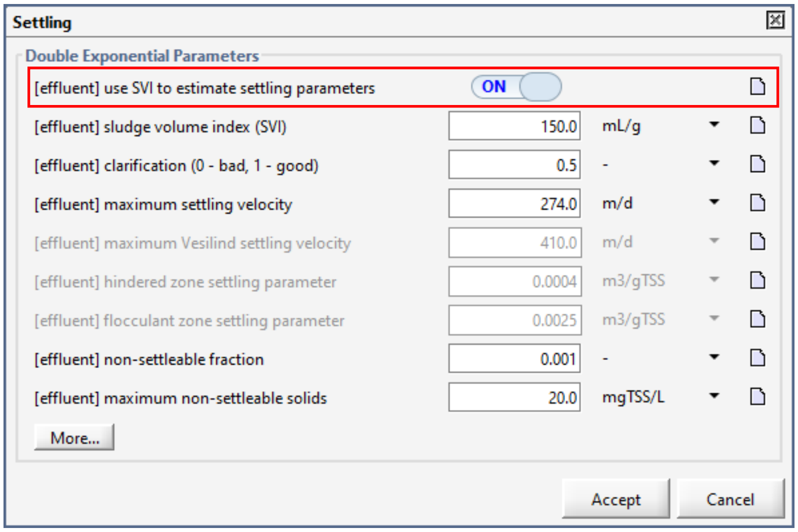
[mlss] specify oxygen transfer by...: Entering Airflow

[mlss] oxygen mass transfer coefficient (clean water): (...) 1/d

[mlss] total air flow into aeration tank: 35000.0 m3/d

[mlss] distribution of air flow to aeration tank: (...) -

3. Right-click on the Secondary Clarifier and navigate to *Input Parameters* > *Settling* and switch the **use SVI to estimate settling parameters** to **ON**.

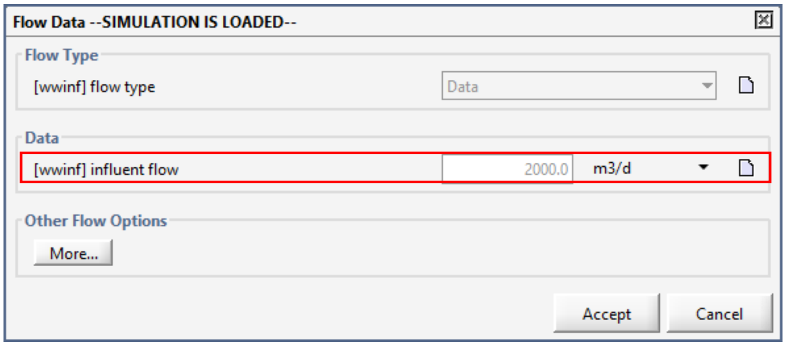


Settling

Double Exponential Parameters

[effluent] use SVI to estimate settling parameters: ON
[effluent] sludge volume index (SVI): 150.0 mL/g
[effluent] clarification (0 - bad, 1 - good): 0.5 -
[effluent] maximum settling velocity: 274.0 m/d
[effluent] maximum Vesilind settling velocity: 410.0 m/d
[effluent] hindered zone settling parameter: 0.0004 m3/gTSS
[effluent] flocculant zone settling parameter: 0.0025 m3/gTSS
[effluent] non-settleable fraction: 0.001 -
[effluent] maximum non-settleable solids: 20.0 mgTSS/L

4. Switch into Simulation Mode. Rebuild the model if prompted.
5. Create a new output graph tab and rename it to “Calibration.” To this tab, you will add four new graphs.
6. Hover on the connection point for the wwinf stream and when the cursor changes to an arrow right-click. Navigate to *Output Variables* > *Flow* and drag the **flow** variable to the output tab.



Flow Data --SIMULATION IS LOADED--

Flow Type

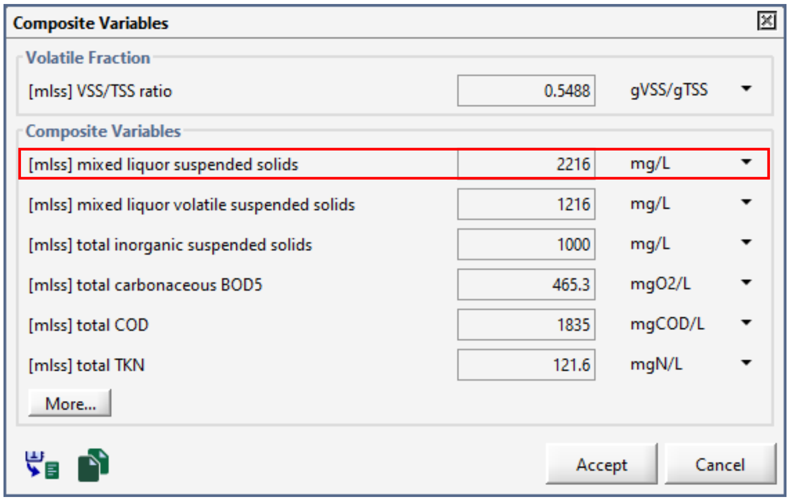
[wwinf] flow type: Data

Data

[wwinf] influent flow: 2000.0 m3/d

Other Flow Options

7. Right-click on the cursor changed to an arrow at the connection point for the mlss stream and navigate to *Output Variables* > *Composite Variables* and drag the **mixed liquor suspended solids** variable to the Calibration output tab.



Composite Variables

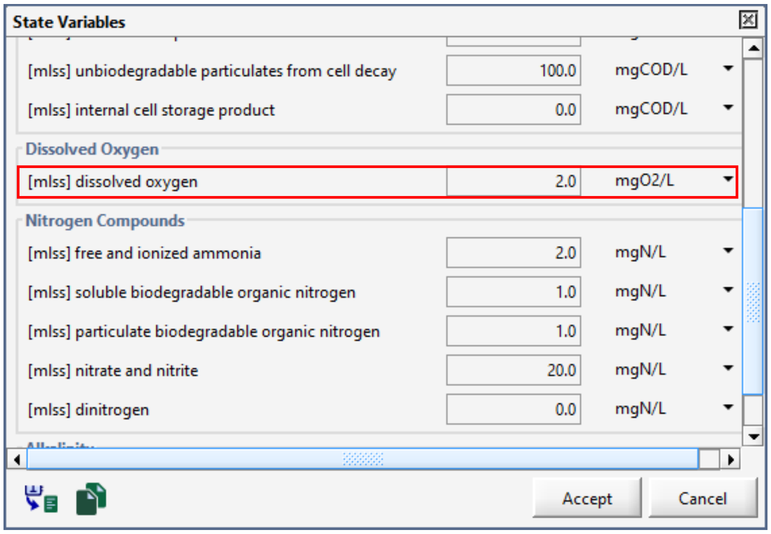
Volatile Fraction

[mlss] VSS/TSS ratio	0.5488	gVSS/gTSS

Composite Variables

[mlss] mixed liquor suspended solids	2216	mg/L
[mlss] mixed liquor volatile suspended solids	1216	mg/L
[mlss] total inorganic suspended solids	1000	mg/L
[mlss] total carbonaceous BOD5	465.3	mgO2/L
[mlss] total COD	1835	mgCOD/L
[mlss] total TKN	121.6	mgN/L

8. Right-click on cursor arrow shape on the mlss stream and navigate to *Output Variables* > *State Variables* and drag the **dissolved oxygen** variable to the same output tab.



State Variables

[mlss] unbiodegradable particulates from cell decay	100.0	mgCOD/L
[mlss] internal cell storage product	0.0	mgCOD/L

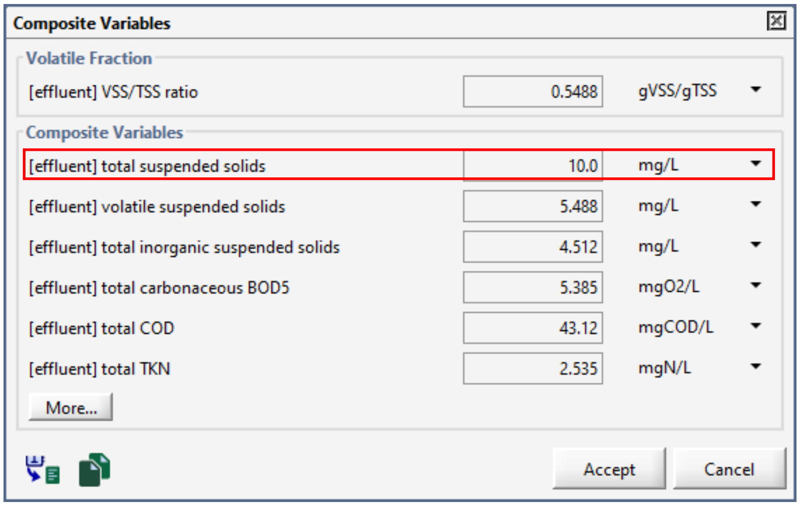
Dissolved Oxygen

[mlss] dissolved oxygen	2.0	mgO2/L

Nitrogen Compounds

[mlss] free and ionized ammonia	2.0	mgN/L
[mlss] soluble biodegradable organic nitrogen	1.0	mgN/L
[mlss] particulate biodegradable organic nitrogen	1.0	mgN/L
[mlss] nitrate and nitrite	20.0	mgN/L
[mlss] dinitrogen	0.0	mgN/L

9. Right-click on the cursor arrow shape at the connection point for the effluent stream and navigate to *Output Variables* > *Composite Variables* and drag the **total suspended solids** variable to the same output tab.



Composite Variables

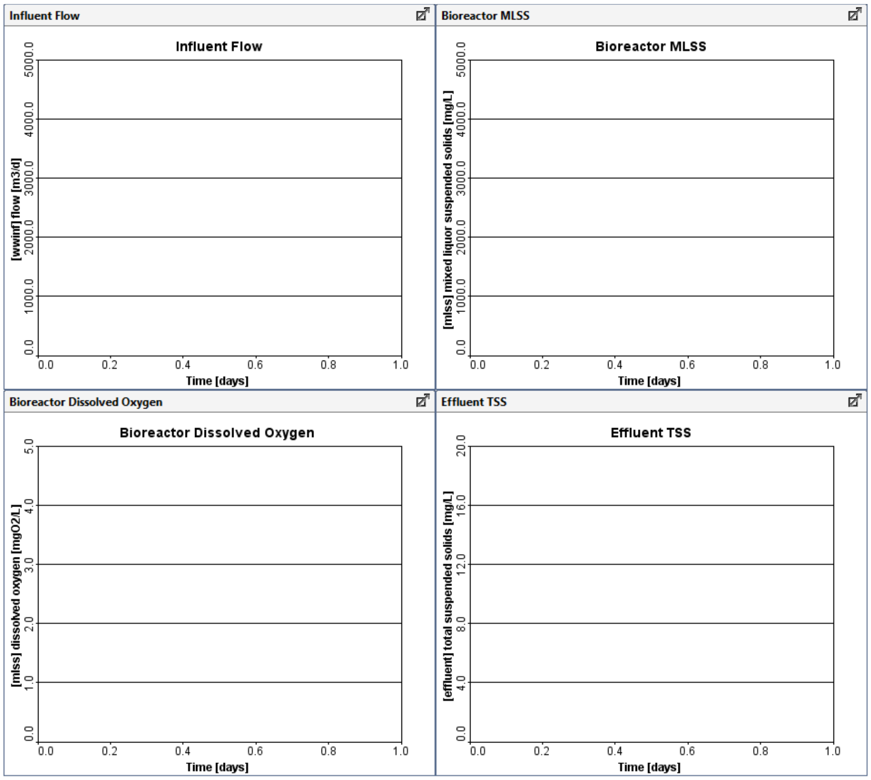
Volatile Fraction

[effluent] VSS/TSS ratio	0.5488	gVSS/gTSS

Composite Variables

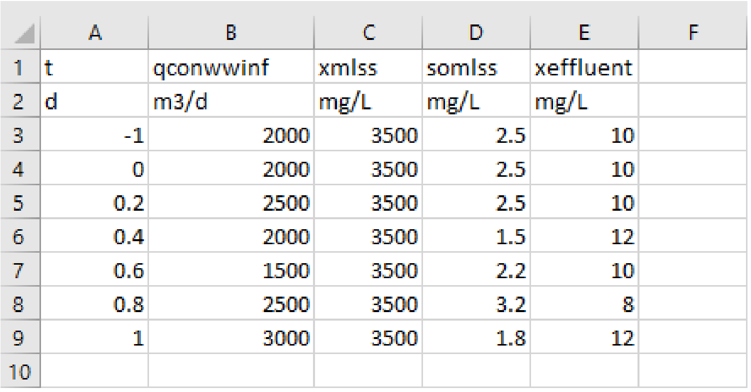
[effluent] total suspended solids	10.0	mg/L
[effluent] volatile suspended solids	5.488	mg/L
[effluent] total inorganic suspended solids	4.512	mg/L
[effluent] total carbonaceous BOD5	5.385	mgO2/L
[effluent] total COD	43.12	mgCOD/L
[effluent] total TKN	2.535	mgN/L

10. Rename the graphs appropriately and auto arrange in the output tab.



The next section of this exercise involves the creation of a data file.

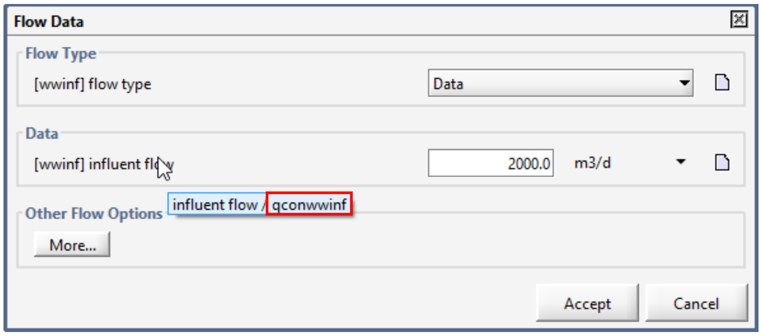
11. Open a new excel file and enter the following information:



	A	B	C	D	E	F
1	t	qconwwinf	xmlss	somlss	xeffluent	
2	d	m3/d	mg/L	mg/L	mg/L	
3	-1	2000	3500	2.5	10	
4	0	2000	3500	2.5	10	
5	0.2	2500	3500	2.5	10	
6	0.4	2000	3500	1.5	12	
7	0.6	1500	3500	2.2	10	
8	0.8	2500	3500	3.2	8	
9	1	3000	3500	1.8	12	
10						

- Row 1 contains the cryptic variable name of each parameter
    - qconwwinf is the influent flow variable (input)
    - xmlss is the mixed liquor suspended solids concentration (output)
    - somlss is the dissolved oxygen concentration in the mlss stream (output)
    - xeffluent is the total suspended solids concentration in the effluent stream (output)

    Note: You can verify these cryptic variable names by hovering your mouse over the variable name in GPS-X. Below is an example of this for the influent flow variable.



Flow Data

Flow Type

[wwinf] flow type: Data

Data

[wwinf] influent flow: 2000.0 m3/d

influent flow / qconwwinf

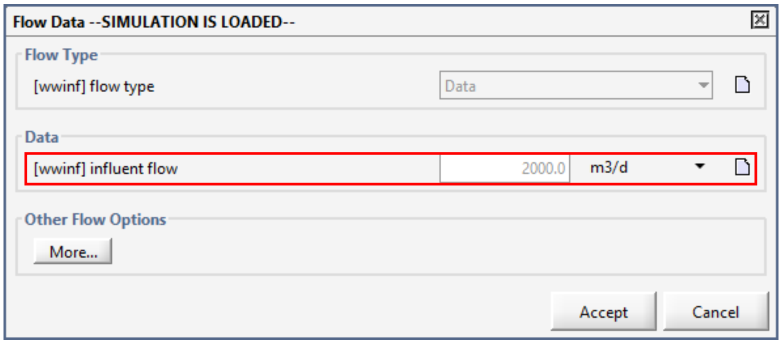
Other Flow Options

- Row 2 contains the measurement unit for each variable
- Row 3 contains the steady-state value of each variable
- Rows 4 – 9 contain the dynamic value of each variable

12. Save this excel file in an appropriate location.

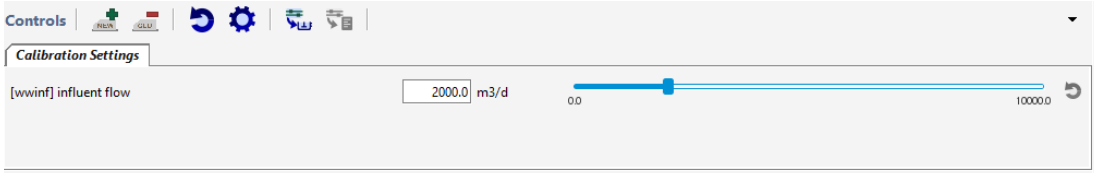
    Since the influent flow to the WWTP is an input in the data file, it needs to be added to the input controls area, so it can be automatically adjusted over the 1-day simulation window.

13. Right-click on the Influent Wastewater object and navigate to *Flow* > *Flow Data* and drag the **influent flow** variable to the input controls area. Rename the input tab to “Calibration Settings.”



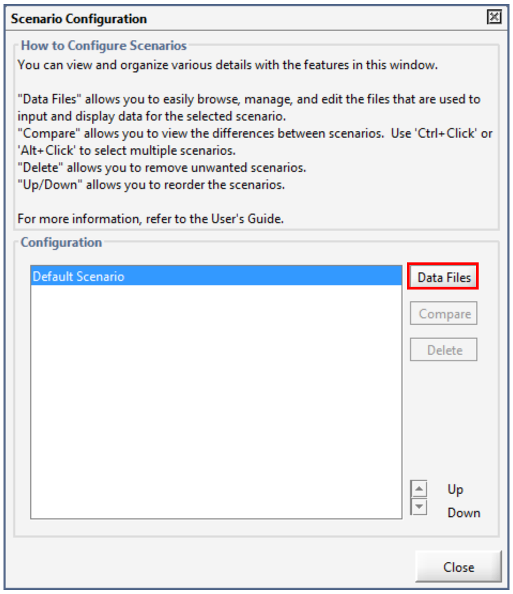
[wwinf] flow type: Data

[wwinf] influent flow: 2000.0 m3/d



[wwinf] influent flow: 2000.0 m3/d

14. In GPS-X Lite from the Simulation Toolbar navigate to *Scenario > Configuration* and select the Data Files button.

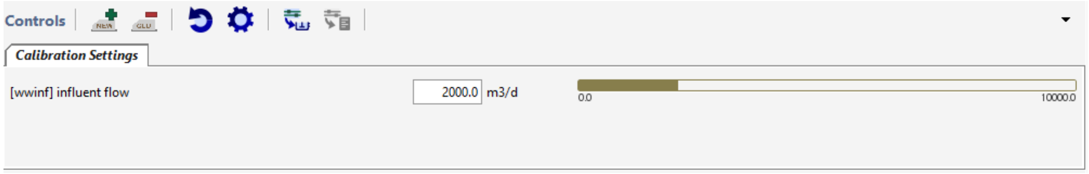


You can view and organize various details with the features in this window.

"Data Files" allows you to easily browse, manage, and edit the files that are used to input and display data for the selected scenario.
"Compare" allows you to view the differences between scenarios. Use 'Ctrl+Click' or 'Alt+Click' to select multiple scenarios.
"Delete" allows you to remove unwanted scenarios.
"Up/Down" allows you to reorder the scenarios.

For more information, refer to the User's Guide.

15. Select the Add… button and add the excel file that you previously created in Step 11. Once you accept this form you should notice that the influent flow variable in the input controls section changes from a slider-type to a file input-type controller.



[wwinf] influent flow: 2000.0 m3/d

16. Set the **Stop Time** to **1-day** and run the simulation at steady-state. Record a screenshot of the graphs on the Calibration output tab. (**Exercise 15 – Question 1**)

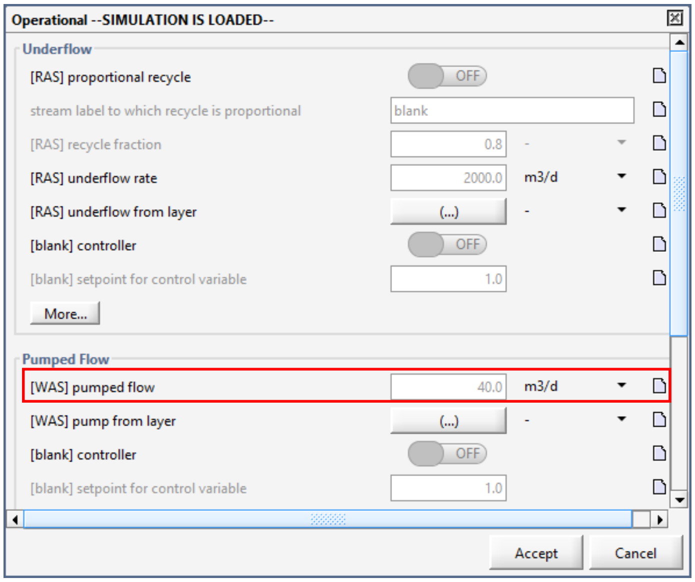
    You should notice that the actual values (points on the graph) and the simulation results (line) do not align. You will now explore the process of manually making changes to plant operations to improve the fit between the actual and simulation values.

    We will look at adjusting 3 parameters to improve the calibration:

    a) WAS pumped flow rate → A higher wastage rate decreases the MLSS concentration in the bioreactor
    b) Sludge Volume Index (SVI) → A lower SVI reflects improved clarifier settling allowing for lower effluent suspended solids
    c) Diffuser Fouling Constant → Increased fouling decreases the concentration of dissolved oxygen in the bioreactor

17. To the input controls area add the following:

- Secondary Clarifier – *Input Parameters* > *Operational* > **pumped flow**



Operational --SIMULATION IS LOADED--

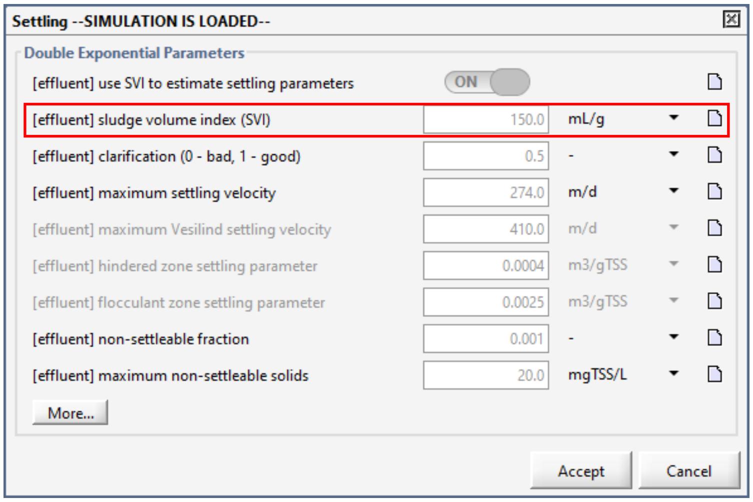
Underflow

[RAS] proportional recycle OFF
stream label to which recycle is proportional blank
[RAS] recycle fraction 0.8 -
[RAS] underflow rate 2000.0 m3/d
[RAS] underflow from layer (...) -
[blank] controller OFF
[blank] setpoint for control variable 1.0

Pumped Flow

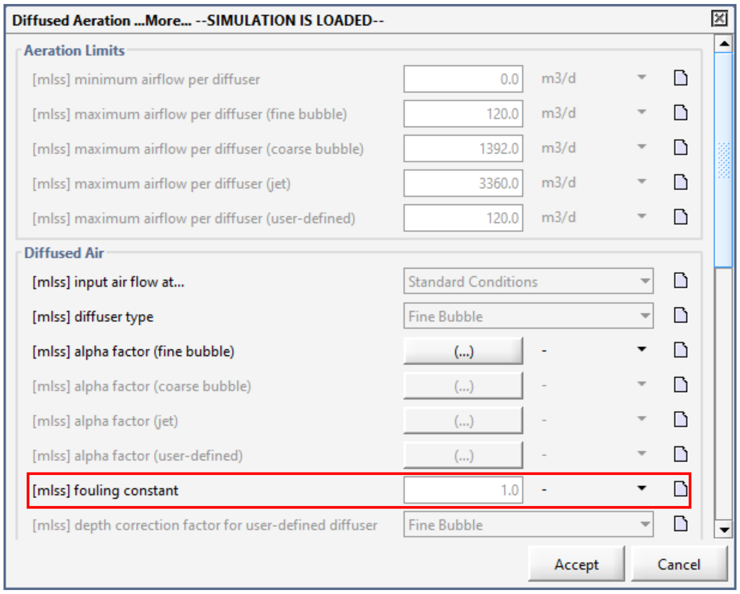
[WAS] pumped flow 40.0 m3/d
[WAS] pump from layer (...) -
[blank] controller OFF
[blank] setpoint for control variable 1.0

- Secondary Clarifier – *Input Parameters* > *Settling* > **sludge volume index (SVI)**

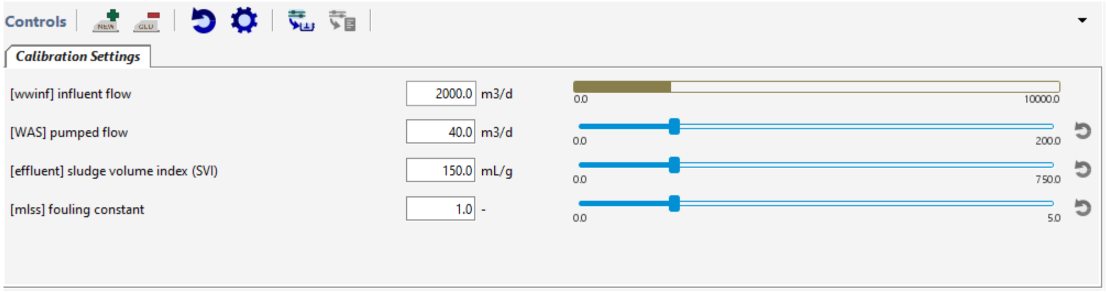


[effluent] use SVI to estimate settling parameters	ON	
[effluent] sludge volume index (SVI)	150.0	mL/g
[effluent] clarification (0 - bad, 1 - good)	0.5	-
[effluent] maximum settling velocity	274.0	m/d
[effluent] maximum Vesilind settling velocity	410.0	m/d
[effluent] hindered zone settling parameter	0.0004	m3/gTSS
[effluent] flocculant zone settling parameter	0.0025	m3/gTSS
[effluent] non-settleable fraction	0.001	-
[effluent] maximum non-settleable solids	20.0	mgTSS/L

- Bioreactor – *Input Parameters* > *Operational* > *Diffused Aeration More…*> **fouling constant**

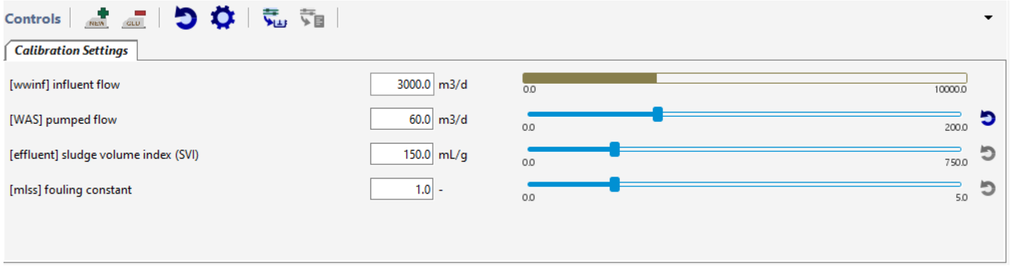


[mlss] minimum airflow per diffuser	0.0	m3/d
[mlss] maximum airflow per diffuser (fine bubble)	120.0	m3/d
[mlss] maximum airflow per diffuser (coarse bubble)	1392.0	m3/d
[mlss] maximum airflow per diffuser (jet)	3360.0	m3/d
[mlss] maximum airflow per diffuser (user-defined)	120.0	m3/d
[mlss] input air flow at...	Standard Conditions	
[mlss] diffuser type	Fine Bubble	
[mlss] alpha factor (fine bubble)	(...)	-
[mlss] alpha factor (coarse bubble)	(...)	-
[mlss] alpha factor (jet)	(...)	-
[mlss] alpha factor (user-defined)	(...)	-
[mlss] fouling constant	1.0	-
[mlss] depth correction factor for user-defined diffuser	Fine Bubble	



[wwinf] influent flow	2000.0	m3/d	0.0	10000.0
[WAS] pumped flow	40.0	m3/d	0.0	200.0
[effluent] sludge volume index (SVI)	150.0	mL/g	0.0	750.0
[mlss] fouling constant	1.0	-	0.0	5.0

18. Start by adjusting the **pumped flow** variable to **60 m^3/d** and run the simulation for 1-day.



[wwinf] influent flow 3000.0 m3/d

[WAS] pumped flow 60.0 m3/d

[effluent] sludge volume index (SVI) 150.0 mL/g

[mlss] fouling constant 1.0 -

You should notice that this pumped flow value causes the simulated MLSS concentration to decrease below the actual values on the output graph.

19. Continue to adjust the pumped flow variable to approximately match the actual bioreactor mlss concentration. Record the value of the pumped flow. (**Exercise 15 – Question 2**)
20. Next, adjust the **sludge volume index (SVI)** variable to **100 mL/g** and rerun the simulation. Keep the pumped flow value at the appropriate setting that you determined in Step 19.

    You should notice that this change helps to decrease the effluent TSS value.

21. Continue to adjust the sludge volume index (SVI) variable to approximately match the effluent TSS concentration. Record the value of the SVI. (**Exercise 15 – Question 3**)
22. Lastly, adjust the **fouling constant** to **0.95** and rerun the simulation. Keep the pumped flow value and sludge volume index value at the settings you determined in steps 19 and 21 respectively.

    You should notice that this helps to align the actual and model-predicted dissolved oxygen concentration in the bioreactor.

23. Continue to adjust the fouling constant to approximately match the bioreactor dissolved oxygen concentration. Record the value of the fouling constant (**Exercise 15 – Question 4**)

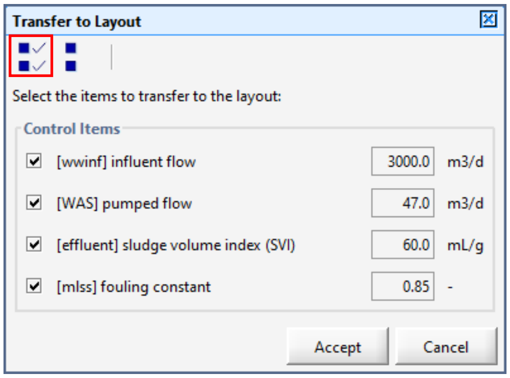
Adjustment of some of these parameters impacts more than one output parameter. For example, improving the secondary clarifier settling by lowering the SVI not only decreases the solids in the effluent but also increases the bioreactor mlss concentration.

24. Make further changes to the 3 calibration parameters until you are satisfied with the fit between the actual and model-predicted results. Record the values of each parameter setting and the results of the output graphs. (**Exercise 15 – Question 5**)

Once you have calibrated the parameter settings you can add them to the model layout, so they will appear in modelling mode, and as the base values in the Default Scenario in simulation mode. This will be done as follows.

25. Select the Transfer Values to Layout button in the Input Controls section. In the form that appears click on the checkmark button to select all items to be transferred to the layout.

    Once accepting this form, you will have to confirm that you want to transfer the values to the layout as this will result in a rebuild of the model.



Transfer to Layout

Select the items to transfer to the layout:

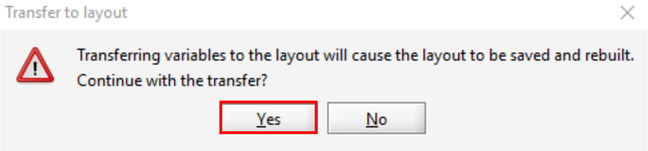
Control Items

☑ [wwinf] influent flow 3000.0 m3/d

☑ [WAS] pumped flow 47.0 m3/d

☑ [effluent] sludge volume index (SVI) 60.0 mL/g

☑ [mlss] fouling constant 0.85 -

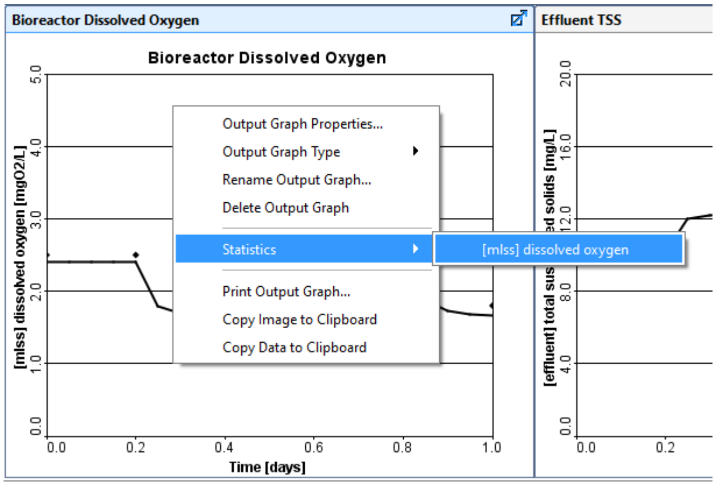


Transfer to layout

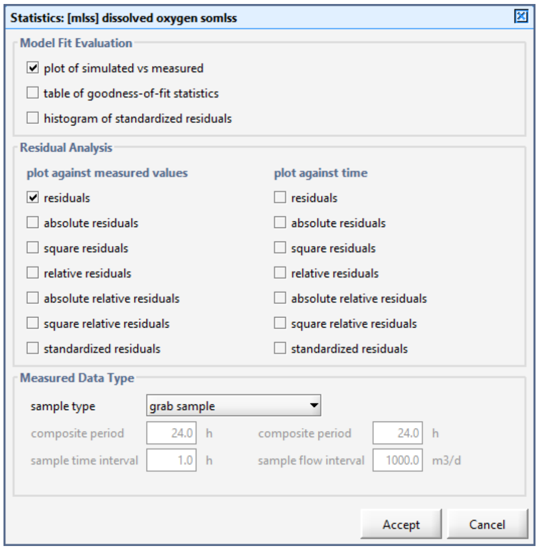
Transferring variables to the layout will cause the layout to be saved and rebuilt. Continue with the transfer?

A useful tool in GPS-X is the ability to conduct statistical analysis on graphical outputs.

26. Run the simulation for 1-day. Right-click on the dissolved oxygen graph and select *Statistics* > ***dissolved oxygen*** from the available menu.



27. From the window that appears, under “Model Fit Evaluation” select the **plot of simulation vs measured** and under “Residual Analysis” select **residuals**. Accept this form.



Statistics: [mlss] dissolved oxygen somlss

Model Fit Evaluation

☑ plot of simulated vs measured
☐ table of goodness-of-fit statistics
☐ histogram of standardized residuals

Residual Analysis

plot against measured values	plot against time
☑ residuals	☐ residuals
☐ absolute residuals	☐ absolute residuals
☐ square residuals	☐ square residuals
☐ relative residuals	☐ relative residuals
☐ absolute relative residuals	☐ absolute relative residuals
☐ square relative residuals	☐ square relative residuals
☐ standardized residuals	☐ standardized residuals

Measured Data Type

sample type: grab sample
composite period: 24.0 h
composite period: 24.0 h
sample time interval: 1.0 h
sample flow interval: 1000.0 m3/d

28. Two graphs appear. Separate them by clicking on one and moving it. Record screenshots of the two statistics graphs. (**Exercise 15 – Question 6**)

APPENDIX A: A Brief Discussion of Biotreatment Models in GPS-X™ (Lite)

This section provides additional information regarding the activated sludge and digestion model provided in GPS-X Lite. *Theory and Practice of Water and Wastewater Treatment*, 2nd ed. by Droste and Gehr is a complimentary text book to GPS-X Lite. The textbook which is geared to present the fundamentals of biotreatment (and other processes) at an undergraduate or first graduate course level uses some simplifications leading to some differences when compared to more advanced models with various refinements available in GPS-X Lite. This section will also describe the major differences between the biological models used in GPS-X Lite and the textbook models.

The commercial version of GPS-X offers the user a choice from many advanced and custom models for various wastewater treatment processes as well as a host of analytical tools. The discussion here will be confined to the two models supporting the textbook.

Consult the Technical Reference for GPS-X under the Help-Manual tab for further information.

Activated Sludge Model

As noted in the GPS-X manual for the application related to the textbook, GPS-X Lite implements the International Water Association (IWA) activated sludge model 1 (ASM1) which was the first of the more principled models developed under the aegis of the IWA. This model made significant improvements over historical approaches in describing aerobic suspended growth processes.

The ASM1 matrix is presented in Table 1. Compare it to Table 17.9 in the textbook. The advanced C-N model in the text, as noted in the text, has some simplifications to make the model algebraically manageable; of course, GPS-X with its numerical engine does not suffer any limitations of this nature. The most significant differences in the two models are as follows.

RATE EXPRESSIONS

In ASM1, the specific growth rate of heterotrophs includes a term for oxygen dependence.

$$\mu_{\mathrm{H}} = \mu_{\mathrm{Hm}} \frac{S_{\mathrm{S}}}{K_{\mathrm{S}} + S_{\mathrm{S}}} \frac{S_{\mathrm{O}}}{K_{\mathrm{OH}} + S_{\mathrm{O}}}$$

A typical value for K_{OH} is 0.2 mg/L At the minimum dissolved oxygen (DO) concentration of 2 mg/L recommended for an aerobic treatment process, the value of the oxygen hyperbolic expression is 0.91 and it approaches 1 at higher DO concentrations.

The anoxic heterotrophic growth expression contains the term, $\frac{K_{OH}}{K_{OH}+S_O}$, which is known as a "switching function" to turn it off and off in aerobic and anoxic conditions, respectively. Ideally, anoxic conditions should have zero DO (there is no aeration supplied in an anoxic tank, only incidental oxygen transfer at the water surface). For $S_O = 0$, the value of the switching function is 1.0.

Growth rate of autotrophs is also mediated by a hyperbolic DO expression.

HYDROLYSIS RATE EXPRESSION

See the note below Table 17.6 in the text. The ASM1 expression is more versatile and will yield better results.

ENDOGENOUS DECAY

ASM1 uses a death-regeneration approach to endogenous decay. In fact, the endogenous decay rate coefficient is a die-off coefficient. The degradable part of decayed microorganisms are simply rendered as X_S (degradable particulate matter). Concomitantly, degradable particulate organic nitrogen (in X_{ND}) is generated. The degradable particulates are hydrolysed to soluble degradable organics (S_S) and then metabolized to complete the death-regeneration cycle. Hydrolysis of degradable particulates also results in release of soluble organic nitrogen discussed below.

The text uses a net decay approach for endogenous decay (this approach was adopted in a later IWA model, ASM3). Endogenous decay simply results in the oxidation of the degradable portion of microorganisms. The endogenous decay incorporates metabolism kinetics resulting in the net loss of the degradable portion of microorganisms.

NITROGEN AND PHOSPHORUS

In ASM1, additional nitrogen processes are necessitated by the endogenous decay-regeneration approach. In ASM1, the particulate organic nitrogen (Kjeldahl N, X_{ND}) generated from endogenous decay is converted to soluble organic nitrogen (S_{ND}) at the rate of hydrolysis of degradable particulates according to process 8. The rate of X_{ND} transformation depends on the ratio of X_{ND} to X_S. Hydrolysis of soluble degradable organic nitrogen produced from endogenous decay to ammonia is another process.

In the text, nitrogen yielded from endogenous decay of biomass is assumed to be released as ammonia.

ASM1 is not concerned with phosphorus; it is considered an inert entity in ASM1.

OTHER MINOR DIFFERENCES

ASM1 tracks nondegradable particulates in the influent (X_I) separately from those produced by endogenous decay (X_p).

ASM1 includes alkalinity transformations (S_{Alk}) for aerobic and anoxic growth.

Table 1. IWA ASM1: Process kinetics and stoichiometry for carbon oxidation, nitrification, and denitrification

Component →	i	1	2	3	4	5	6	7	8	9	10	11	12	13	Process Rate, ρ_j [$ML^{-3}T^{-1}$]
j	Process ↓	S_I	S_S	X_I	X_S	X_H	X_A	X_P	S_O	S_{NOX}	S_{NH}	S_{ND}	X_{ND}	S_{Alk}	
1	Aerobic growth of heterotrophs		$-\frac{1}{Y_H}$			1			$-\frac{1-Y_H}{Y_H}$		$-i_{NBM}$			$-\frac{i_{XB}}{14}$	$\mu_{Hm}\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{S_O}{K_{OH}+S_O}\right)X_H$
2	Anoxic growth of heterotrophs		$-\frac{1}{Y_H}$			1				$-\frac{1-Y_H}{2.86Y_H}$	$-i_{NBM}$			$\frac{1-Y_H}{14\cdot 2.86Y_H}$ $-i_{XB}/14$	$\mu_{Hm}\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{K_{OH}}{K_{OH}+S_O}\right)$ $\times\left(\frac{S_{NOX}}{K_{NOX}+S_{NOX}}\right)\eta X_H$
3	Aerobic growth of autotrophs						1		$-\frac{4.57-Y_A}{Y_A}$	$\frac{1}{Y_A}$	$-i_{NBM}-\frac{1}{Y_A}$			$-\frac{i_{XB}}{14}-\frac{1}{7Y_A}$	$\mu_{Am}\left(\frac{S_{NH}}{K_{NH}+S_{NH}}\right)\left(\frac{S_O}{K_{OA}+S_O}\right)X_A$
4	Decay of heterotrophs				$1-f_{XI}$	-1		f_{XI}					$i_{XBM}-f_{XI}$ i_{XP}		$b_H X_H$
5	Decay of autotrophs				$1-f_{XI}$		-1	f_{XI}					$i_{XBM}-f_{XI}$ i_{XP}		$b_A X_A$
6	Ammonification of soluble organic nitrogen										1	-1		$\frac{1}{14}$	$k_a S_{ND} X_H$
7	Hydrolysis of entrapped organics		1		-1										$k_h\left(\frac{X_S/X_H}{K_X+\left(X_S/X_H\right)}\right)\left[\left(\frac{S_O}{K_{OH}+S_O}\right)\right.$ $\left.+\eta\left(\frac{K_{OH}}{K_{OH}+S_O}\right)\left(\frac{S_{NOX}}{K_{NOX}+S_{NOX}}\right)\right]X_H$
8	Hydrolysis of entrapped organic nitrogen											1	-1		$\rho_7(X_{ND}/X_S)$

Anaerobic Treatment Model

The anaerobic digestion model, MantisAD, provided in GPS-X Lite is a simpler version of anaerobic digestion model no. 1 (ADM1) which is the most advanced anaerobic digestion model (requiring a plethora of data for calibration and implementation and beyond the scope of the textbook). The degradation scheme of organic material and N- transformations are as shown in Figures 1 and 2. The model (22 state variables, 13 processes plus chemical and gas exchange) assumes that the disintegration of composite particulate organic material results in the production of both slowly and readily biodegradable particulate material. This particulate material then undergoes hydrolysis resulting in the production of soluble material that is also slowly and readily biodegradable. This soluble material is then fermented to acetate and hydrogen which is subsequently converted to methane gas. Four biomass types (slowly and readily biodegradable substrate degraders, acetate utilizing methanogens, and hydrogen utilizing methanogens) mediate the steps and are subject to various pH, ammonia, and hydrogen inhibitions.

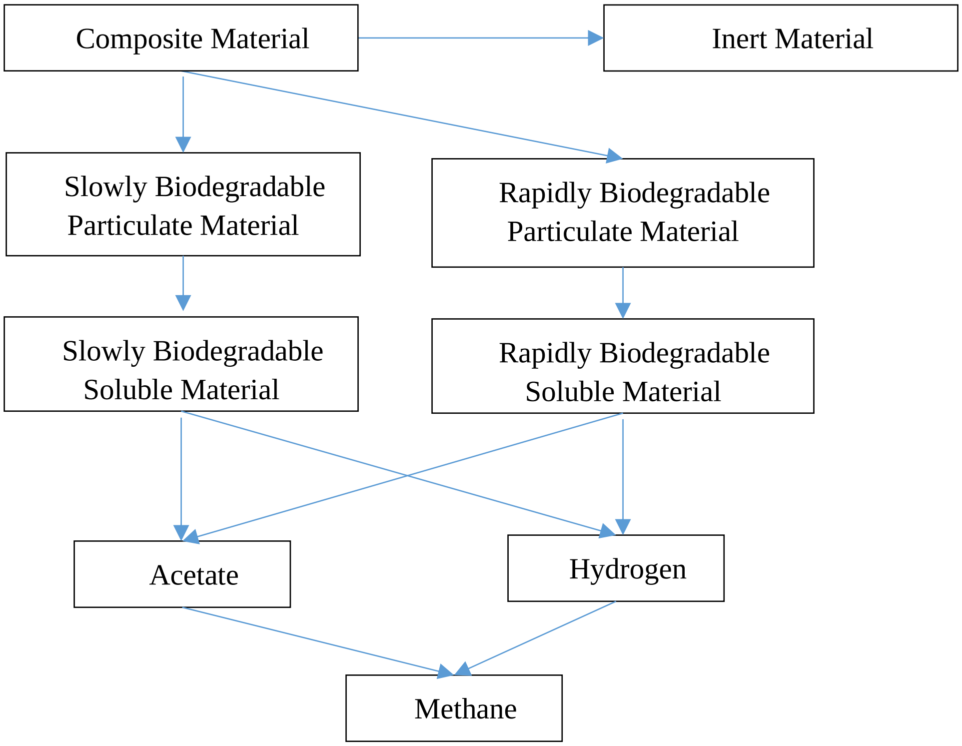


Figure 1 Anaerobic Transformation of Organic Material in Digester

The matrix describing the major metabolic phenomena in the anaerobic digestion model (MantisAD) in GPS-X Lite is given in Table 2 (see Copp et al. 2005) for comparison to the advanced anaerobic digestion model in Table 19.3. It is readily observed that the GPS-X Lite model uses concepts developed in the text but implements them differently from the model in Table 19.3. The model implemented in GPS-X Lite is geared for anaerobic digestion of solids produced in primary clarifiers and aerobic biotreatment processes and it easily integrates with these processes in an overall treatment plant model.

Definitions of parameters in the MantisAD model are given in Tables 3-5. In the model, particulate matter is separated into slowly (X_{Ss}) and rapidly (X_{Sr}) degradable particulate matter. Soluble products of hydrolysis are slowly (S_{Ss}) and rapidly (S_{Sr}) degradable substrate which are each metabolized into acetate and hydrogen. Acetoclastic and hydrogenotrophic methanogens then metabolize these products into methane. Endogenous decay renders the decayed groups of bacteria as composite particulate matter. MantisAD also provides a more detailed approach to modelling nitrogen as shown in Figure 2 and the matrix.

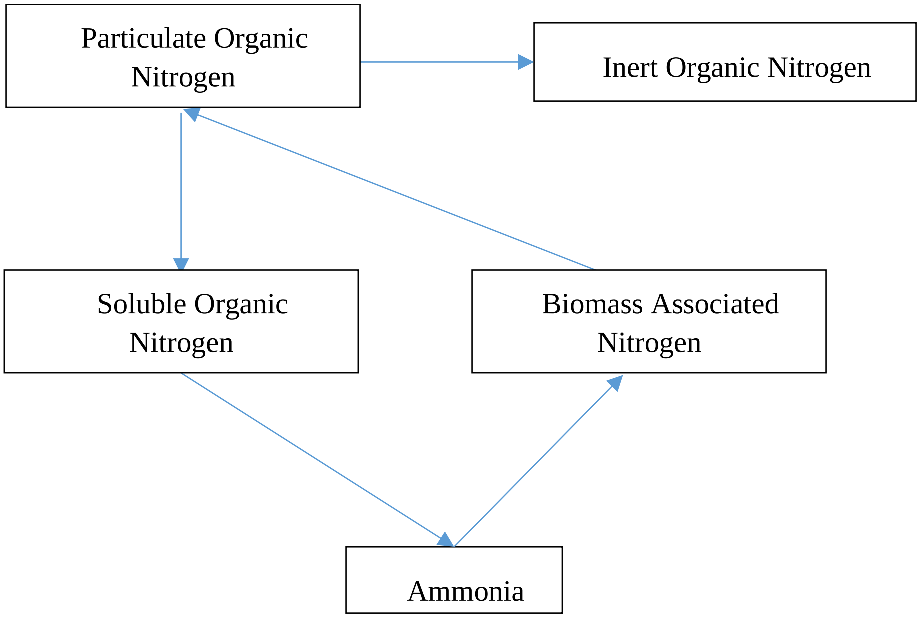


Figure 2 Anaerobic Transformation of Nitrogen in Digester

Table 2 MantisAD anaerobic digester model

Component → i		1	2	3	4	5	6	7	8	9	10	11	12	13	14
j	Process ↓	X_I	S_I	X_{bs}	X_{br}	X_{Ac}	X_{H2}	X_C	X_{sb}	X_{rb}	S_{sb}	S_{rb}	S_{Ac}	S_{H2}	S_{CH4}
1	Disintegration	Y_{X_I}	Y_{S_I}					-1	Y_{sb}	$1 - Y_{X_I} - Y_{S_I} - Y_{Sb}$					
2	Hydrolysis of readily hydrolysable material									-1		1			
3	Hydrolysis of slowly hydrolysable material								-1		1				
4	Uptake of readily biodegradable substrate				Y_{br}							-1	$Y_{Acrb}(1 - Y_{br)}$	$(1 - Y_{Acrb})(1 - Y_{br})$	
5	Uptake of slowly biodegradable substrate			Y_{bs}							-1		$Y_{Acsb}(1 - Y_{bs)}$	$(1 - Y_{Acsb})(1 - Y_{bs})$	
6	Uptake of acetate					Y_{Ac}							-1		$1 - Y_{Ac}$
7	Uptake of Hydrogen						Y_{H2}							-1	$1 - Y_{H2}$
8	Organic nitrogen hydrolysis														
9	Ammonification														
10	Endogenous decay of slow degraders			–1				1							
11	Endogenous decay of rapid degraders				-1			1							
12	Endogenous decay of hydrogenotrophic methanogens					-1		1							
13	Endogenous decay of acetoclastic methanogens						-1	1							

Table2 continued.

Component → i		15	16	17	18	19	20	21	**Process Rate**
j	Process ↓	S_{IC}	S_{IN}	X_{Nb}	X_{NI}	adS_{NI}	adS_{Nd}	adX_{Nd}	ρ_j [ML^{-3}T^{-1}]
1	Disintegration	$C_{Xc} - Y_{S_I}C_{S_I} - Y_{X_I}C_{X_I} - Y_{sb}C_{Xsb} - (1 - Y_{X_I} - Y_{S_I} - Y_{sb})C_{Xrb}$			$Y_{X_I}Y_{X_{NI}}$	$Y_{S_I}Y_{S_{NI}}$	$-Y_{X_I}Y_{X_{NI}} - Y_{S_I}Y_{S_{NI}}$		$K_{dis}X_C$
2	Hydrolysis of readily hydrolysable organics	$C_{Xrb} - C_{Srb}$							$K_{hydrh}X_{rb}$
3	Hydrolysis of slowly hydrolysable organics	$C_{Xsb} - C_{Ssb}$							$K_{hydsh}X_{sb}$
4	Uptake of readily biodegradable substrate	$C_{Srb} - Y_{br}C_{bio} - Y_{Acrb}(1 - Y_{br})C_{SAc}$	$-Y_{br}Y_{NXB}$	$Y_{br}Y_{NXB}$					$\frac{\mu_{Xbr}S_{rb}}{K_{Srb} + S_{rb}}X_{br}\nu_4$
5	Uptake of slowly biodegradable substrate	$C_{Ssb} - Y_{bs}C_{bio} - Y_{Acsb}(1 - Y_{bs})C_{SAc}$	$-Y_{bs}Y_{NXB}$	$Y_{bs}Y_{NXB}$					$\frac{\mu_{Xbs}S_{sb}}{K_{Ssb} + S_{sb}}X_{bs}\nu_5$
6	Uptake of acetate	$C_{SAc} - Y_{Ac}C_{bio} - (1 - Y_{Ac})C_{SCH4}$	$-Y_{Ac}Y_{NXB}$	$Y_{Ac}Y_{NXB}$					$\frac{\mu_{XAc}S_{Ac}}{K_{SAc} + S_{Ac}}X_{Ac}\nu_6$
7	Uptake of Hydrogen	$-Y_{H2}C_{bio} - (1 - Y_{H2})C_{SCH4}$	$-Y_{H2}Y_{NXB}$	$Y_{H2}Y_{NXB}$					$\frac{\mu_{XH2}S_{H2}}{K_{SH2} + S_{H2}}X_{H2}\nu_7$
8	Organic nitrogen hydrolysis						1	-1	$K_{dis}adX_{Nd}$
9	Ammonification		1				-1		$\left(K_{hydrb}X_{rb} + K_{hydsb}X_{sb}\right)\frac{adS_{Nd}}{X_{rb}+X_{sb}}$
10	Endogenous de-cay of slow degraders	$C_{bio} - C_{Xc}$		$-Y_{NXB}$				Y_{NXB}	b_hX_{bs}
11	Endogenous decay of rapid degraders	$C_{bio} - C_{Xc}$		$-Y_{NXB}$				Y_{NXB}	b_hX_{br}
12	Endogenous decay of hydrogenotrophic methanogens	$C_{bio} - C_{Xc}$		$-Y_{NXB}$				Y_{NXB}	b_hX_{Ac}
13	Endogenous decay of acetoclastic methanogens	$C_{bio} - C_{Xc}$		$-Y_{NXB}$				Y_{NXB}	b_hX_{H2}

Notes on Table 2.

Soluble CO_2 and inert inorganic solids are also state variables tracked by MantisAD but they are not listed in the table due to space limitations.

Rates 4-7 include inhibition terms (ν_i) that are function of pH, unionized ammonia, and hydrogen; see Copp et al. (2005) for details.

The model calculates pH and gas transfer from the liquid phase to the gaseous phase. Thus, the initially soluble methane (S_{CH4}) produced leaves in both the gas exiting the reactor as well as the liquid effluent. Carbon dioxide and hydrogen also exit by both routes.

Table 3 State Variables in MantisAD

Variable	Symbol	Units
Inert inorganic suspended solids	X_{II}	mg/L
Inert organic suspended solids	X_I	mg COD/L
Inert soluble COD	S_I	mg COD/L
Biomass growing on slowly biodegradable material	X_{bs}	mg COD/L
Biomass growing on readily biodegradable material	X_{br}	mg COD/L
Acetate degraders	X_{Ac}	mg COD/L
Hydrogen degraders	X_{H2}	mg COD/L
Composite material	X_C	mg COD/L
Slowly hydrolysable particulate material	X_{sb}	mg COD/L
Readily hydrolysable particulate material	X_{rb}	mg COD/L
Slowly biodegradable soluble material	S_{sb}	mg COD/L
Readily biodegradable soluble material	S_{rb}	mg COD/L
Acetate	S_{Ac}	mg COD/L
Hydrogen	S_{H2}	mg COD/L
Methane	S_{CH4}	mg COD/L
Ammonia	S_{IN}	mg N/L
Biomass associated nitrogen	X_{Nb}	mg N/L
Inert organic particulate nitrogen	X_{NI}	mg N/L
Inert organic soluble nitrogen	adS_{NI}	mg N/L
Organically bound soluble nitrogen	adS_{Nd}	mg N/L
Organically bound particulate nitrogen	adX_{Nd}	mg N/L
Inorganic carbon	S_{IC}	mole/L

When using the MantisAD model together with ASM1 model, the phosphorus is considered an inert entity in MantisAD and its reactions are disabled.

Table 4 Stoichiometry Constants in MantisAD

Parameter	Symbol	Unit
Readily biodegradable biomass yield	Y_{br}	g COD/g COD
Slowly biodegradable biomass yield	Y_{bs}	g COD/g COD
Acetate degraders biomass yield	Y_{Ac}	g COD/g COD
Hydrogen degraders biomass yield	Y_{H2}	g COD/g COD
Yield of particulate inert material from composite material	Y_{X_I}	g COD/g COD
Yield of soluble inert material from composite material	Y_{S_I}	g COD/g COD
Yield of slowly biodegradable material from composite material	Y_{sb}	g COD/g COD
Acetate yield from readily biodegradable substrate	Y_{Acrb}	g COD/g COD
Acetate yield from slowly biodegradable substrate	Y_{Acsb}	g COD/g COD
Fraction of hydrolysed nitrogen becoming particulate inert nitrogen	$Y_{X_{NI}}$	g N/g N
Fraction of hydrolysed nitrogen becoming soluble inert nitrogen	$Y_{S_{NI}}$	g N/g N
Fraction of ammonia becoming associated with the biomass	Y_{NXB}	g N/g N
Composites carbon content	C_{Xc}	mole C/g COD
Soluble inerts carbon content	C_{S_I}	mole C/g COD
Particulate inerts carbon content	C_{X_I}	mole C/g COD
Readily hydrolysable particulate material carbon content	C_{Xrb}	mole C/g COD
Slowly hydrolysable particulate material carbon content	C_{Xsb}	mole C/g COD
Soluble readily biodegradable carbon content	C_{Srb}	mole C/g COD
Particulate slowly biodegradable carbon content	C_{Ssb}	mole C/g COD
Acetate carbon content	C_{SAc}	mole C/g COD
Methane carbon content	C_{SCH4}	mole C/g COD
Biomass carbon content	C_{bio}	mole C/g COD

Table 5 Kinetic Constant in MantisAD

Parameter	Symbol	Unit
Rate of disintegration	K_{dis}	1/d
Hydrolysis rate of readily biodegradable particulate material	K_{hydrb}	1/d
Hydrolysis rate of readily biodegradable soluble material	K_{hydsb}	1/d
Readily biodegradable substrate uptake rate	μ_{Xbr}	1/d
Slowly biodegradable substrate uptake rate	μ_{Xbs}	1/d
Acetate degraders growth rate	μ_{XAc}	1/d
Hydrogen degraders growth rate	μ_{XH2}	1/d
Biomass decay rate	b_h	1/d
Half saturation coefficient for readily biodegradable substrate uptake	K_{Srb}	mg COD/L
Half saturation coefficient for slowly biodegradable substrate uptake	K_{Ssb}	mg COD/L
Half saturation coefficient for acetate uptake	K_{SAc}	mg COD/L
Half saturation coefficient for hydrogen uptake	K_{SH2}	mg COD/L

References

Copp, JB, E Belia, S Snowling, and O Schraa (2005), "Anaerobic digestion: a new model for plat-wide wastewater treatment process modeling," *Water Sci Technol*, 52, 10-11, 1-11.

Droste RL and RL Gehr (2018), *Theory and Practice of Water and Wastewater Treatment*, 2nd ed., John Wiley & Sons, New York.

Henze, M, CPL Grady, Jr, W Gujer, GvR Marais, and T Matsuo (1987), *Activated Sludge Model No.1. IAWQ Scientific and Technical Report No. 1*, IWA Publishing, London, England.