# New Developments in BioWin 5.3

December 6, 2017

BioWin 5.3 contains a new Granular Sludge Sequencing Tank element to model this process, which is gaining acceptance worldwide as an effective wastewater treatment technology. BioWin 5.3 also contains an enhancement to the trickling filter element and refinements to model parameters.

Granular Sludge Sequencing Tank

A **Granular Sludge Sequencing Tank** (GSST) element is available to represent this process in BioWin configurations. The modeling approach uses BioWin's one-dimensional dynamic biofilm model to mimic the granular sludge. A one-dimensional layered solids flux model is applied for modeling settling of non-granular flocculent mixed liquor solids during unaerated/unmixed periods. These models are integrated with the general ASDM in a variable volume unit that allows various phases of operation to be specified. The GSST model has been developed to balance pragmatic design elements with mechanistic modeling rigor, to provide quick solution times, and typical process performance predictions.

GSST
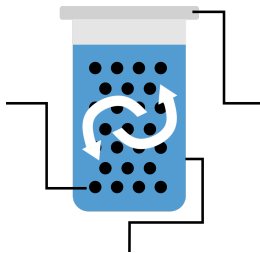
Most GSST technology implementations employ a repeated batch-fed process. The microorganisms responsible for the majority of the carbon, nitrogen and phosphorous removal grow in dense granules rather than conventional activated sludge flocs. These granules settle rapidly, eliminating the need for separate settling tanks. The granules have a layered structure that may be more aerobic on the outside and anoxic or anaerobic towards the centre. This structure allows the granular sludge to simultaneously remove carbon, nitrogen and phosphorous from the wastewater in a single reactor/settler.

Further details on the GSST element are provided in **Appendix A**.

Element Enhancement – Trickling Filter

Hydraulic loading may impact the area available for gas transfer. If the wetting rate is too low then not all of the media will be "wet" so the gas transfer area will be reduced. On the other hand, if the hydraulic loading rate gets too high then it is possible that the air spaces between the media become filled with liquid, which also will reduce the available gas transfer area. The **Hydraulic Loading Factor** attempts to account for these less-than-optimal conditions. The **Hydraulic Loading Factor** is determined by a two-sided continuous switching function.

Over an optimal range of hydraulic loading the **Hydraulic Loading Factor** is equal to or close to unity (1). The value decreases towards zero for extreme low or high loading rates. The form of the continuous switching function is defined by the **Low hydraulic loading rate switch** value and the **High hydraulic loading rate switch** value. These are the low and high hydraulic loading rates where the **Hydraulic Loading Factor** has a value of 0.5 (*i.e.* the area for gas transfer is reduced to half of the effective area). Different media types have characteristic high and low loading rates.

In BioWin 5.3 we improved the continuous switching function of the hydraulic loading factor so that the trickling filter more accurately calculates the available area for gas transfer at extreme low or high loading rates. Our extensive testing has shown that the improved continuous switching function brings the predicted nitrification performance in line with measured data for numerous full-scale trickling filters under extreme low or high loading rates. The hydraulic loading factor plots for rock media and non-rock media/other media types are shown below:
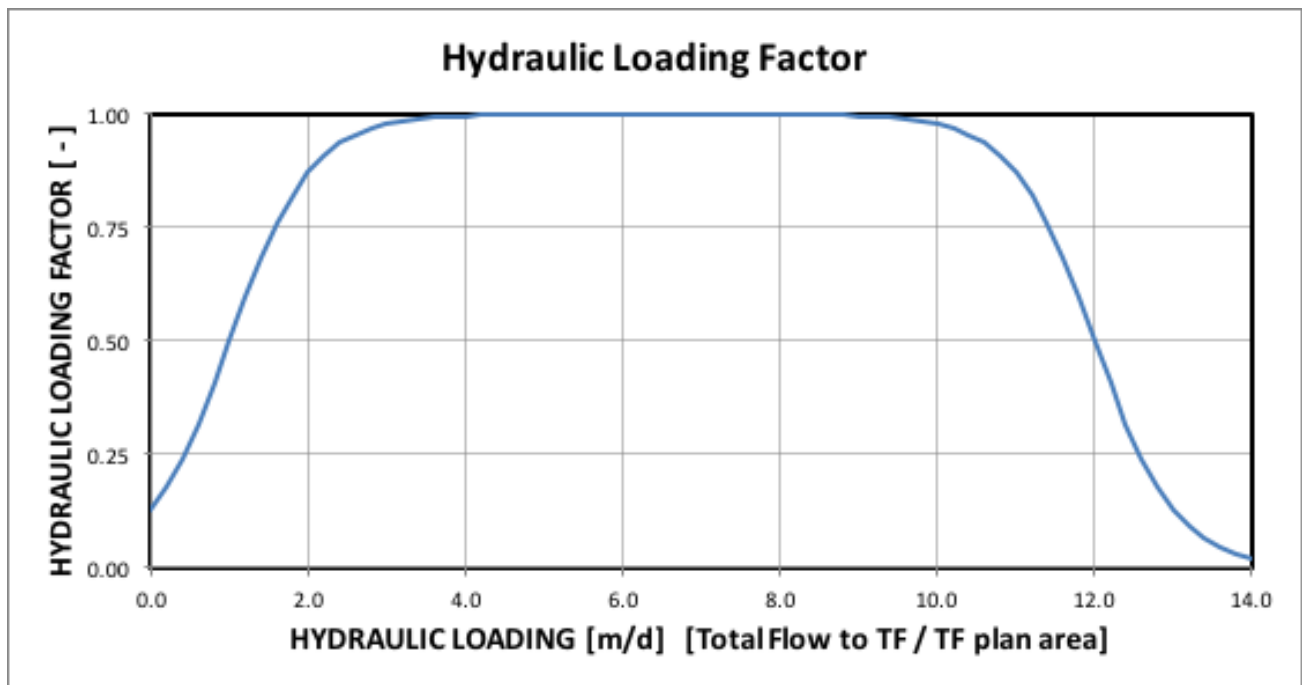
HYDRAULIC LOADING FACTOR AS A FUNCTION OF HYDRAULIC LOADING FOR ROCK MEDIA

Hydraulic Loading Factor
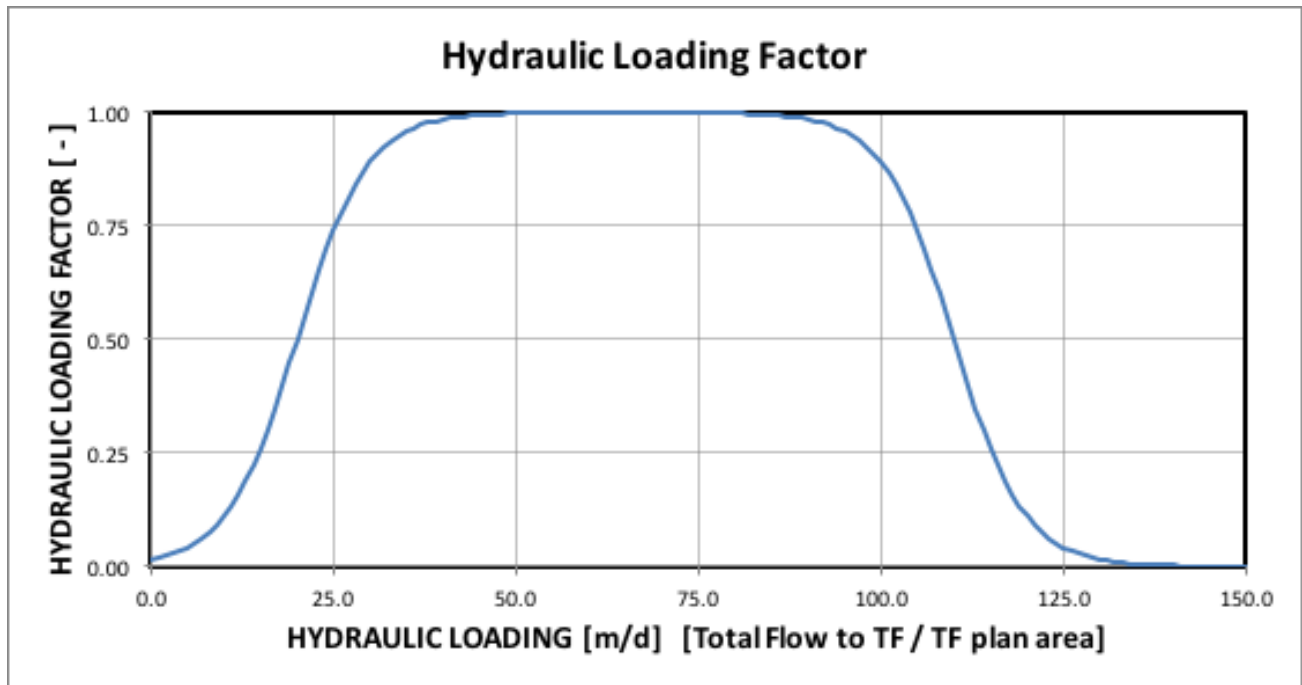
HYDRAULIC LOADING FACTOR AS A FUNCTION OF HYDRAULIC LOADING FOR NON-ROCK/OTHER MEDIA TYPES

Default Parameter Changes

Biofilm Attachment / Detachment Rates

Particulate attachment and detachment rates have a major role in establishing biofilm thickness, dynamics, and system activity, similar to SRT in activated sludge. The biofilm model is employed in the media bioreactors, trickling filters, submerged aerated filters and granular sludge sequencing tank in BioWin. EnviroSim performed numerous model calibrations of these types of systems to measured BOD, ammonia, NO_X and biofilm growth profiles from full-scale and pilot-scale plants. Through this extensive testing, we have revised the default biofilm attachment and detachment rates to **8 g/(m^{2}d)** and **8,000 g/(m^{3}d)**, respectively. [The former respective attachment and detachment rates were 80 g/(m^{2}d) and 80,000 g/(m^{3}d), respectively].

OHO Dissolved Oxygen Half Saturation Coefficient

The ordinary heterotroph organism (OHO) dissolved oxygen (DO) half-saturation coefficient (K_{DO}) is used in several OHO rate expressions (*e.g.* growth, decay) to switch off aerobic OHO activity under low DO conditions, and turn on anoxic processes in the presence of NO_X. In previous versions of BioWin, the default value for this parameter was 0.05 mg O_2/L. This meant that anoxic processes only would be turned on in the model under very low DO conditions, and BioWin was conservative in nitrogen removal predictions by default. This value was selected based on observations of laboratory and pilot-scale systems that typically had shallow liquid depths (relative to full-scale systems), vigorous mixing and/or high air flow rates – all of which combined to yield small sludge flocs and very little evidence of denitrification even at relatively low DO levels.

However, in full-scale systems, lower levels of mixing intensity as well as other non-idealities often result in some degree of denitrification occurring at low DO levels. To reflect this with its default parameter set, *in BioWin 5.3 the default OHO K_{DO} has been increased from 0.05 mgO$_2$/L to 0.15 mgO$_2$/L*. Obviously, the user can adjust this parameter to best fit observed process behavior, however, BioWin 5.3 will be somewhat less conservative in its predictions than previous versions for nitrogen removal if there are low DO zones incorporated in the process flowsheet.

Further details on all new features in BioWin 5.3 can be found in the Help manual.

Usability Feature

Multiply a Column by a Factor

Users may now multiply a column of values by a factor. This is done by right clicking on the "Value" column and selecting "Multiply column" from the pop-up window. In the example below, the initial state variable concentrations in a variable volume bioreactor are multiplied by a factor of 2 to increase the starting concentrations in the mixed liquor.

Multiply column

Multiply column

Multiply column number 2 Value

by 2

OK Cancel

Appendix A - Granular Sludge Sequencing Tank

Model Description

In the modeling approach, the granular sludge mass is represented by a biofilm with a calculated surface area and film thickness. The biofilm thickness is assumed to be equivalent to the "average" granule radius. The model does not predict new granule "formation" or consider a granule size distribution, but the diameter of granules may change dynamically depending on loading. The dynamic mixed-culture biofilm model used in the approach includes the following aspects:

- A boundary layer at the biofilm surface as a diffusion resistance for mass transfer of solutes.
- Diffusion of soluble, particulate and dissolved gaseous components within the biofilm.
- Exchange of particulates between the film surface and the bulk liquid due to detachment (erosion) and attachment (impingement).
- Growth (and decay) of different biomass species within the biofilm.

In general, the GSST flowsheet element in which the models are implemented incorporates the following features to capture typical operational aspects of GSSTs and the resulting process performance:

- Each cycle in the GSST has a mixing phase followed by a settling phase. Aeration may be switched on and off during the mixing phase (based on DO setpoint or air flowrate).
- During the mixing phase, the granules are assumed to be completely mixed within the bulk liquid.
- When settling begins, the granules **_instantaneously_** settle to the bottom of the tank and occupy a percentage of the reactor volume. The volume of the granules themselves is based on granular biofilm volume. However, the volume occupied by the granules is larger because volume is reserved for voidage between the granules.
- The GSST uses a variable volume one-dimensional solids flux model to simulate settling of mixed liquor (non-granular) solids. The bulk liquid above the volume of settled granules is divided into "n" equal-depth layers during settling (n = 10 in the default GSST implementation).
- The GSST typically is fed at or near the end of the settling phase. The feed enters the bottom of the tank where the settled granules are located and flows through the voidage volume across the surface of the settled granules. The voidage volume is considered to be completely mixed, rather than plug or semi-plug flow. As the feed flows into the bottom of the unit, liquid is displaced upward, through the layers above the granule volume. At the top of the GSST, liquid can overflow or be decanted as treated effluent.
- Waste activated sludge (WAS) is removed from the bottom layer of the settled mixed liquor solids; the granules are not removed in the waste flow. However, granular mass and composition is not static because there is attachment to and detachment from the granule surface continuously during the mixed phase.
- The user has the option to incorporate a small decant event prior to commencing a mix/react phase to drop the liquid level in the GSST. This provides some freeboard to avoid spillage of mixed reactor contents when aeration commences. The decant is removed from the top layer of the bulk liquid.
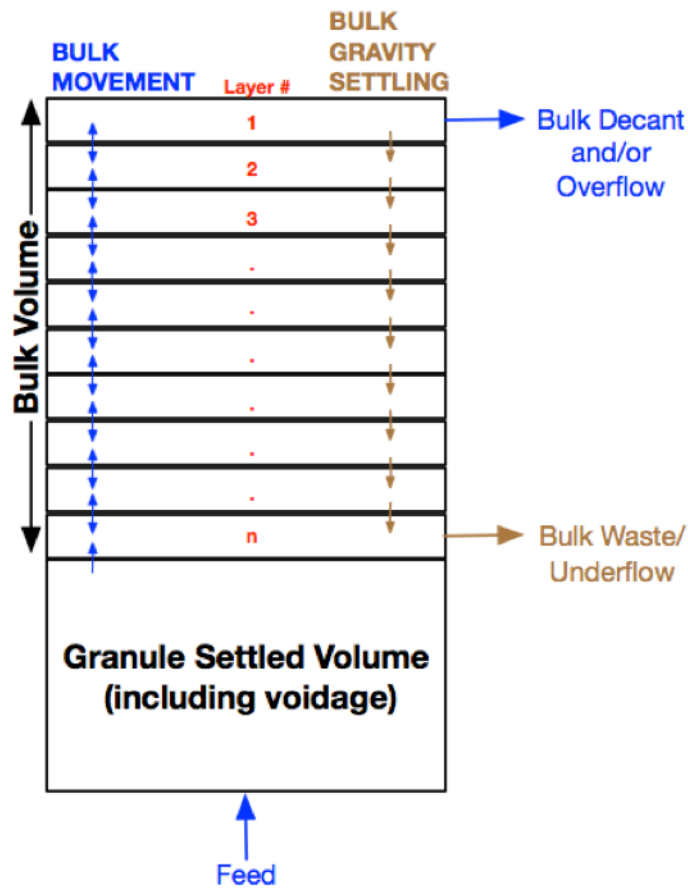
Flow schematic of the GSST in settle mode

The BioWin user working with wastewater treatment plants employing GSST technology will be able to obtain answers for the following questions:

- How much granular sludge mass and granular sludge surface area is required to achieve a specific process objective?
- How much active biomass will the granular sludge contain?
- What will the average diameter of the granules be (in mm) depending on substrate loading, solids exchange between the granules and the bulk liquid, EPS strength coefficients and the effect of gas (N_2, CH_4, CO_2) generation inside the granules?
- How will soluble and particulate components be distributed inside the granules?
- Will different growth regimes (*e.g.* aerobic, anoxic, anaerobic) exist over the granule radius?
- How will the reaction rates for the biological processes (growth and decay of heterotrophic and autotrophic biomass, fermentation, *etc.*) be distributed within the granules?
- Will pH effects and precipitation reactions within the granules significantly change porosity, density and conversion rates?

GSST parameters

This section describes the rationale behind some of the "default" settings that exist within the GSST element when it is first placed on the drawing board. It is important to note that these are not intended to serve as strict design guidelines, but rather, reasonable starting points.

Dimensions tab
The GSST usually is 16 to 24 feet (4.9 to 7.3 m) deep. When the GSST element is placed onto the drawing board, the default depth is 6 m.

Granules tab
The formation of the granules is not modelled; the GSST initially contains a user-input **_estimated_** volume of granular sludge. The user also specifies estimates for the initial granule diameter (D) and a voidage factor (ε) for settled granules, as follows:

- Estimated granule diameter (D) [mm]. This sets the initial diameter of the granules at the beginning of a simulation from seed conditions. The actual diameter is a simulated output and will change from the initial estimate over the duration of a simulation.
- Estimated granule settled volume fraction (FG) of reactor volume (Vt). This sets the initial estimate of the reactor volume occupied by both the granules and the intergranular voidage when granules are settled on the bottom of the reactor at the beginning of a simulation from seed conditions. The actual settled volume is a simulated output and will change from the original estimate over the duration of a simulation.
- Voidage (of settled granules) (E). This sets the percentage of the granule settled volume occupied by voidage. Although the granule diameter and settled volume parameters are simulated and may change over the course of a simulation, the voidage percent is assumed to remain constant over the duration of a simulation.
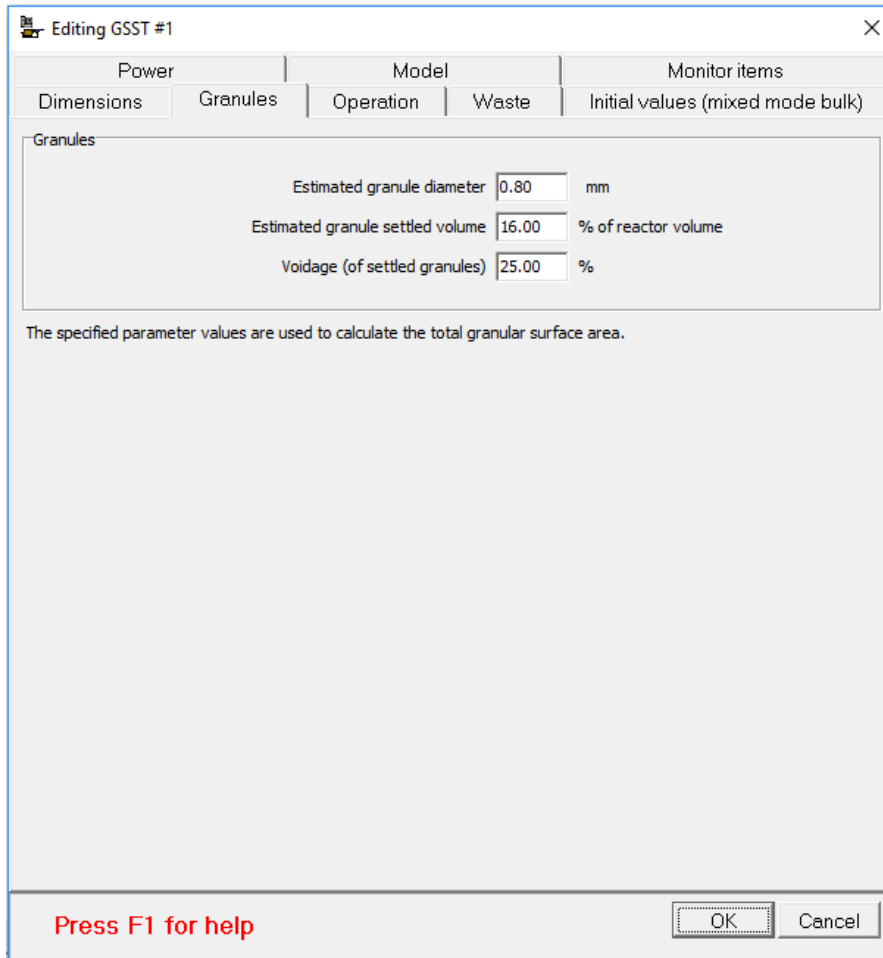
The granules tab of a GSST

These user-defined parameters are used to calculate the base granular surface area. The base granular surface area and the user-specified voidage fraction are held constant throughout a dynamic simulation. The GSST model dynamically calculates the granular diameter depending on a number of factors, such as substrate loading and solids exchange between the granules and the bulk liquid. The granular settled volume fraction of the reactor volume changes proportionally to the model-calculated granular surface area.

Operation tab
The major operational settings of the GSST are the cycle settings. The Operation tab of the GSST is shown below. Note the cycle length, settling and decant periods correspond to the default settings observed when you drop a GSST element onto the drawing board.
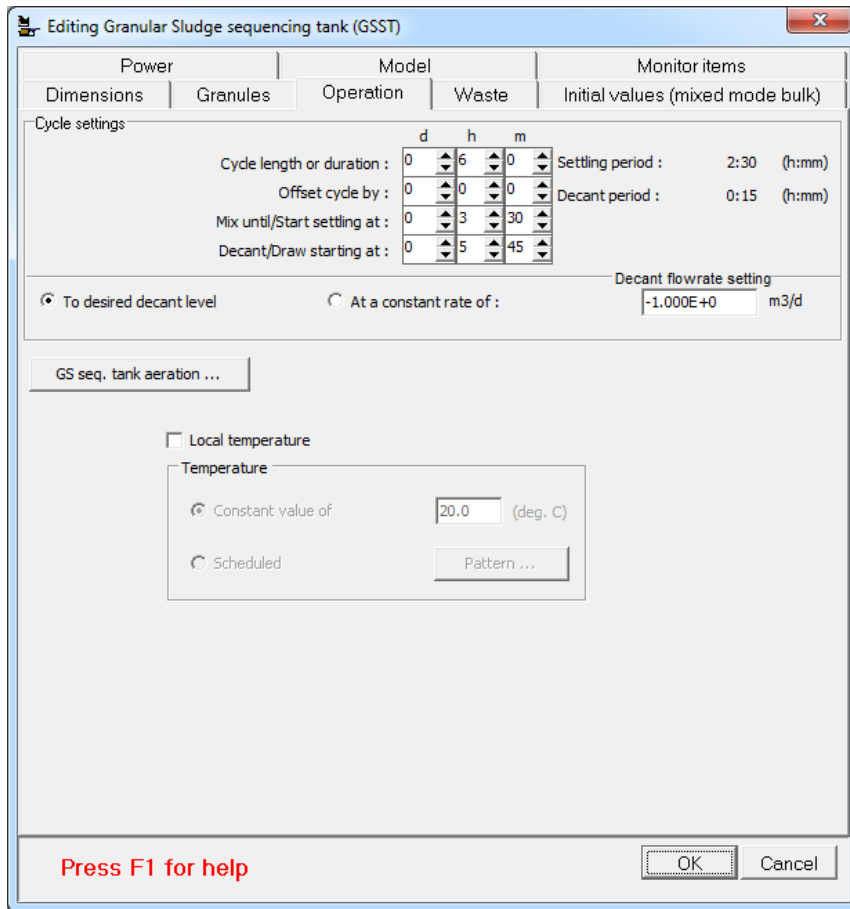
The figure below is an alternative illustration of the operational cycle of the GSST element when it is dropped onto the drawing board.
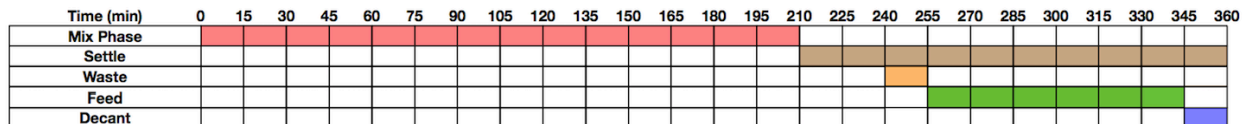
The user may specify the aeration settings in the GSST using a DO set-point or air flow rate at a constant value or following a defined pattern. The react/mix phase in the GSST element sets the maximum time span for aeration.

Waste tab
Typically thickened mixed liquor is removed from the GSST partway into the settling period, before the GSST is fed. Granules are never wasted from the GSST, only bulk mixed liquor. If wasting occurs at some point in the settling period, it is removed from the bottom settling layer.

Initial values tab
The user may set up the initial settings of the bulk mixed liquor concentrations and liquid hold-up in the GSST element.

Power options

The user may enter power specifications for mechanical mixing in the GSST. Power can be specified on a power per unit volume basis or on a fixed basis at a constant value or in a pattern.

Model tab

When a GSST element is placed onto the drawing board, local biofilm, kinetic, diffuser and settling parameters are applied, as shown below.

This is done to allow certain parameter values in the GSST to differ from BioWin's global defaults. The reasoning for adjusting these particular parameter values is described below. The user may adjust any of the model parameter values to calibrate a GSST model to measured data. The default settings are provided as a means to achieve typical process performance, but are not intended to serve as strict design guidelines.

- Under the **Granule model options** section on the **Model** tab, the **number of internal layers (through granule)** setting is specified as three. Increasing the number of layers may impact gradients of dissolved oxygen, substrates and biomass species throughout the granules. However, the biofilm model is computationally intensive, so increasing the number of layers increases simulation time. Assuming three layers appears to provide a good balance of these factors in calibrating GSST models to full-scale and pilot-scale systems.
- The **Boundary layer thickness** is specified as 50 micrometers. This thickness appears suitable for calibrating GSST models with respect to the observed removal of nitrogen and phosphorous.

- **Local biofilm parameters** are used to specify thin and thick biofilm limits lower than the BioWin defaults, and maximum biofilm concentrations of particulate organics greater than the BioWin defaults.

    o The granular sludge mass is represented by a biofilm with a calculated surface area and film thickness. The biofilm thickness is assumed to be equivalent to the "average" granule radius. The granular diameter is therefore equivalent to two times the biofilm thickness. When the GSST element is placed onto the drawing board, the thin and thick film limits are set at 0.3 mm and 0.75 mm, respectively. This favors the development of granular diameters between 0.6 mm and 1.5 mm.

    o The concentration of organic particulate state variables may be higher in granules than in conventional biofilms growing in IFAS and MBBR systems. The user may easily increase the maximum biofilm concentrations of particulate organics by right-clicking on the value column, selecting "Multiply column (Part. organics only)", and then specifying a factor. When the GSST element is placed onto the drawing board, the specified maximum biofilm concentrations of particulate organics are 5 times the default values.

- **Local kinetic parameters** are used to set the OHO dissolved oxygen half saturation parameter on the **Switches** tab to 0.25 mgO_2/L. This allows for more simultaneous nitrification/denitrification than is typically observed in well-mixed well-aerated conventional activated sludge reactors. The user may adjust this parameter to calibrate the GSST model to match measured effluent ammonia, nitrate and nitrite concentrations.

- **Local diffuser parameters** are used to modify the K1 parameter. The K1 parameter value has been decreased to 1.0 to achieve reasonable SOTE performance at a GSST depth of 6 m.

- **Local settling parameters** are set to adjust the maximum Vesilind settling velocity (Vo), Vesilind hindered zone settling parameter (K) and Maximum compactability constant parameter values to reflect the rapid settling observed in GSSTs. The Vo value is 340 m/d and the K value is 0.18 L/g. To avoid losing a significant mass of bulk suspended solids, the settling velocity of the interface must be greater than the upflow velocity when the influent flow is introduced in the bottom of the GSST, and these parameter values should achieve that for most cases. However, they may require further adjustment if the simulated GSST effluent solids are undesirably high. The maximum compactability constant is locally increased to 30,000 mg/L to reflect the high compactability of solids observed in GSSTs. Note that all of the settling parameter adjustments are for the Modified Vesilind approach of BioWin. As such, the Modified Vesilind settling model must be used with the GSST element.
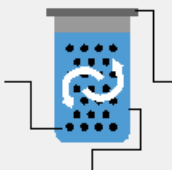
Flyby panes

Flyby panes report the following values for the GSST; note that the user is given an indication of what parameters are set locally by red text.

Physical parameters (bottom left):

Name: GSST #1		Type: Granular sludge sequencing tank (GSST)
Volume:	10000.00	m3
Area:	1666.67	m2
Depth:	6.00	m
Diffuser coverage:	10.00	%
Number of diffusers:	4065	
Diffuser unit area:	0.0410	m2
Granular sludge		
Granular surface area	3000000	m2
Estimated diameter	0.80	mm
Estimated settled volume	16.0	% of reactor
Voidage	25.0	% of settled volume

Performance parameters (bottom right):

		Centre	Surface	Bulk	
	Ammonia N	31.93	31.93	7.09	mgN/L
Granule diameter 0.82 mm	Nitrate N	0	0	4.38	mgN/L
Net TSS Conc 6.97 kg/m3	Nitrite N	0	0	0.03	mgN/L
Granule TSS mass 52963 kg	Soluble PO4-P	27.41	27.39	6.38	mgP/L
% TSS in granules 79 %					
Granule settled volume 1641.93 m3	Volatile suspended solids	33083	32915	1148	mg/L
Granule settled volume % of total volume 16.42 %	Total suspended solids	43224	42118	1698	mg/L
	Dissolved O2	0	0	1.38	mg/L
OUR - Total 8.15 mgO/L/hr			pH	7.05	
Air flow rate 2242.90 m3/hr (20C, 1 atm)					
OTR 81.52 kg/hr					

Local kinetic parameters
Local biofilm parameters
Local diffuser parameters   Local settling parameters