CASE STUDY: ANNACIS ISLAND WASTEWATER TREATMENT PLANT

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BACKGROUND OF THE WASTEWATER TREATMENT PLANT

The Annacis Island Wastewater Treatment Plant is located near Vancouver, Canada and services users in Burnaby, New Westminster, Port Moody and many other townships in the region. The plant is the largest in the Metro Vancouver area; a region that also includes the Iona Island WWTP, the Lions Gate WWTP, the Northwest Langley WWTP, and the Lulu Island WWTP.

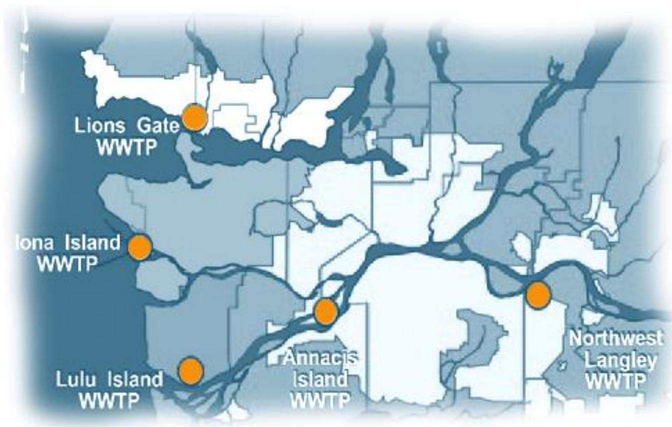


FIGURE 1: WASTEWATER TREATMENT PLANTS IN THE METRO VANCOUVER AREA[1].

Due to steadily increasing demand, the plant was recently upgraded to handle additional capacity. This upgrade was designed in five stages numbered IV to VIII. The following figure illustrates the design population for each of the stages.

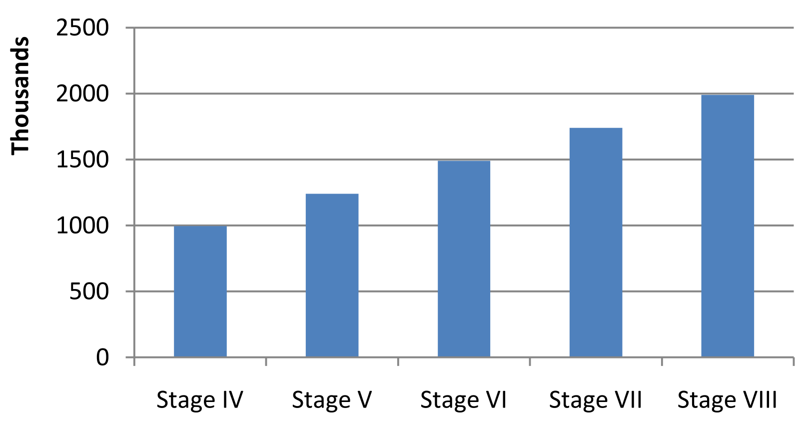


FIGURE 2: PLANT DESIGN POPULATION FOR EACH STAGE OF UPGRADE.

[1] Image provided by Metro Vancouver.

This study analyzes the approximate effectiveness of the plant during its Stage IV by constructing a rough simulation of the plant using Simgua. The plant data in this paper were generously provided by Fran Smith a graduate of Swarthmore College and an engineer at Brown and Caldwell.

ANNACIS ISLAND PLANT DESIGN

The Annacis plant contains physical, biological, and chemical treatment technologies. The facility is a large plant and is designed to handle the wastewater for 955,000 people (during Stage IV). Below is a satellite image of the plant:

FIGURE 3: SATELLITE IMAGE OF THE ANNACIS ISLAND WWTP[2].

The following is a flow sheet illustrating the wastewater treatment technologies used in the plant. This flow sheet omits the sludge handling procedures as those will not be explored in this case study.

[2] This picture and the cover image were generated using Google's *Google Earth*. They are copyrighted by Google and their partnering organizations.

Screening

- 3 bar screens to remove debris from the water.
- Width of 3.6 m; bars with spacing of 13 mm.

Aeration

- 26 aeration basins to increase the oxygen content of the water.
- Width of 6.7 m, depth of 4 m, and length of 14.3 m.

Primary Clarifiers

- 13 rectangular clarifiers to remove suspended solids and other pollutants from the water.
- Width of 13.7 m, depth of 2.74 m, length of 69.9 m.

Trickling Filters

- 94 trickling filters to remove biological pollutants.

Biological Reactor

- 4 biological reactors to remove biological pollutants.
- Volume of 6,350 m^3 each.

Secondary Clarifiers

- 12 circular clarifiers to remove remaining suspended solids and those generated during biological treatment.
- Radius of 20 m, depth of 5.88 m.

Chlorination

- 3 chlorination facilities for disinfection of the water.
- Total volume of 10,670 m^3.

FIGURE 4: ANNACIS PLANT FLOW SHEET.

Influent data to the plant was gathered. Flow rate data was generated for average dry weather flow, and peak wet weather flow. The following water attributes were measured for average dry weather flow and maximum daily flow: Total Suspended Solid (TSS), Biochemical Oxygen Demand (BOD), and temperature[3]. This data provided wet weather and dry weather influent situations for the plant.

TABLE 1: PLANT INFLUENT CONDITIONS.

	Dry Weather	Wet Weather
Flow Rate	5.59 m^3/s	12.6 m^3/s
BOD_5	101,000 kg/d	134,000 kg/d
TSS	91,500 kg/d	171,000 kg/d
Temperature	22 ˚Celsius	12 ˚Celsius

The reader should note that even though the total magnitude of BOD_5 and TSS are higher in the wet weather scenario, concentrations of these pollutants are smaller due to the higher worst case flow rate.

DEVELOPING A SIMGUA MODEL

A Simgua model was constructed to imitate the Annacis plant. Simgua comes with a collection of components designed to simulate wastewater treatment plants. Many of the plant sections could be modeled directly using these components. Other sections of the plant (such as the trickling filters) did not have direct analogues in the included Simgua components and had to be approximated using the component toolset provided by Simgua.

[3] For readers unfamiliar with wastewater treatment, total suspended solids are the amount of particulate matter suspended in the water. Biochemical oxygen demand can be looked at as a rough measure of how much the dissolved oxygen levels in the water will be depleted. If dissolved oxygen levels fall below a certain threshold, fish and other organisms will be unable to survive. The temperature of the water affects the rate at which certain reactions take place and the total amount of dissolved oxygen that the water will be able to hold.

FIGURE 5: SAMPLE SIMGUA WWTP COMPONENTS. RESPECTIVELY A FLOCCULATOR, DISINFECTION STATION, SEDIMENTATION TANK AND AERATION BASIN.

The following is a discussion of how each section of the Annacis plant was treated when developing the Simgua model:

TABLE 2: CONVERSION FROM PLANT SECTIONS TO SIMGUA COMPONENTS.

Inflows
Simgua's WWTP components represent pollutant levels as concentrations. For BOD and TSS the units are g/m^3. Thus the pollutant data from the plant had to be converted into these units. Additionally, Simgua uses BOD_u in place of BOD_5 so this also had to be converted. A plant BOD decay constant was not available, so the Simgua default of 0.23 d^{-1} was used as an approximate. All the other water constants were left as their Simgua defaults which are designed to represent a characteristic wastewater sample. Two separate water source components were created: one for dry weather flow and one for wet weather flow. A parameter primitive was created called "Percent Wet". When Percent Wet was set to zero, dry weather flow conditions were used; and when it was set to one, wet weather conditions were used. When it was between zero and one, the two flow conditions were combined proportionally.
Screens
Three bar screen components were added to the model, and their parameters were set to mirror those of the screens in the Annacis plant.
Aeration Basins

One aeration basin was added to the model. This aeration basin was given parameters to make it equivalent in effect to the 26 aeration basins in the actual plant. This simplification allows the model to be created and modified much more quickly and easily than it would have been if 26 different basins had been created and configured. The effects of the one basin are identical to the effects of the 26 basins. The aeration basin was given a very high reaeration constant value (1,000 d^{-1}) to simulate the actions of blowers and other aeration devices.
Primary Clarifiers
One rectangular sedimentation tank was added to the model. This sedimentation tank's geometry was set to be equivalent to the 13 sedimentation tanks in the original plant. As with the aeration basins this allowed more rapid model development and modification while not changing the effects of the clarifiers. The sedimentation method was set to the time based method. This is the most accurate method available given that we know nothing about the distribution of the suspended particle sizes.
Trickling Filters
The Simgua component pack does not come with a trickling filter component. Thus this item was not included in the Simgua model.
Biological Reactor
One biological reactor component was added to the model. It was initially given a sizing equivalent to the biological reactors in the Annacis plant. The volume of the reactor was then scaled up 16 times to compensate for the lack of trickling filters in the Simgua model.
Secondary Clarifiers
One circular sedimentation tank was added to the Simgua model with parameters equivalent to the 12 secondary clarifiers in the Annacis plant.

Disinfection
One disinfection component was added to the model with equivalent sizing to the 3 chlorination stations in the Annacis plant. Data for the reaction coefficients from the actual plant was not available so sensible defaults were used instead.

These conversions comprise the basic construction of the Simgua model of the Annacis WWTP. Since the Simgua WWTP components do not yet support sludge handling, this part of the plant was not modeled. The creation of the Simgua model proceeded smoothly and easily and should roughly approximate the performance of the actual Annacis island plant. Additional data and calibration would allow us to improve this approximation greatly, but that must wait until future work.

Below is an image of the final Simgua model:

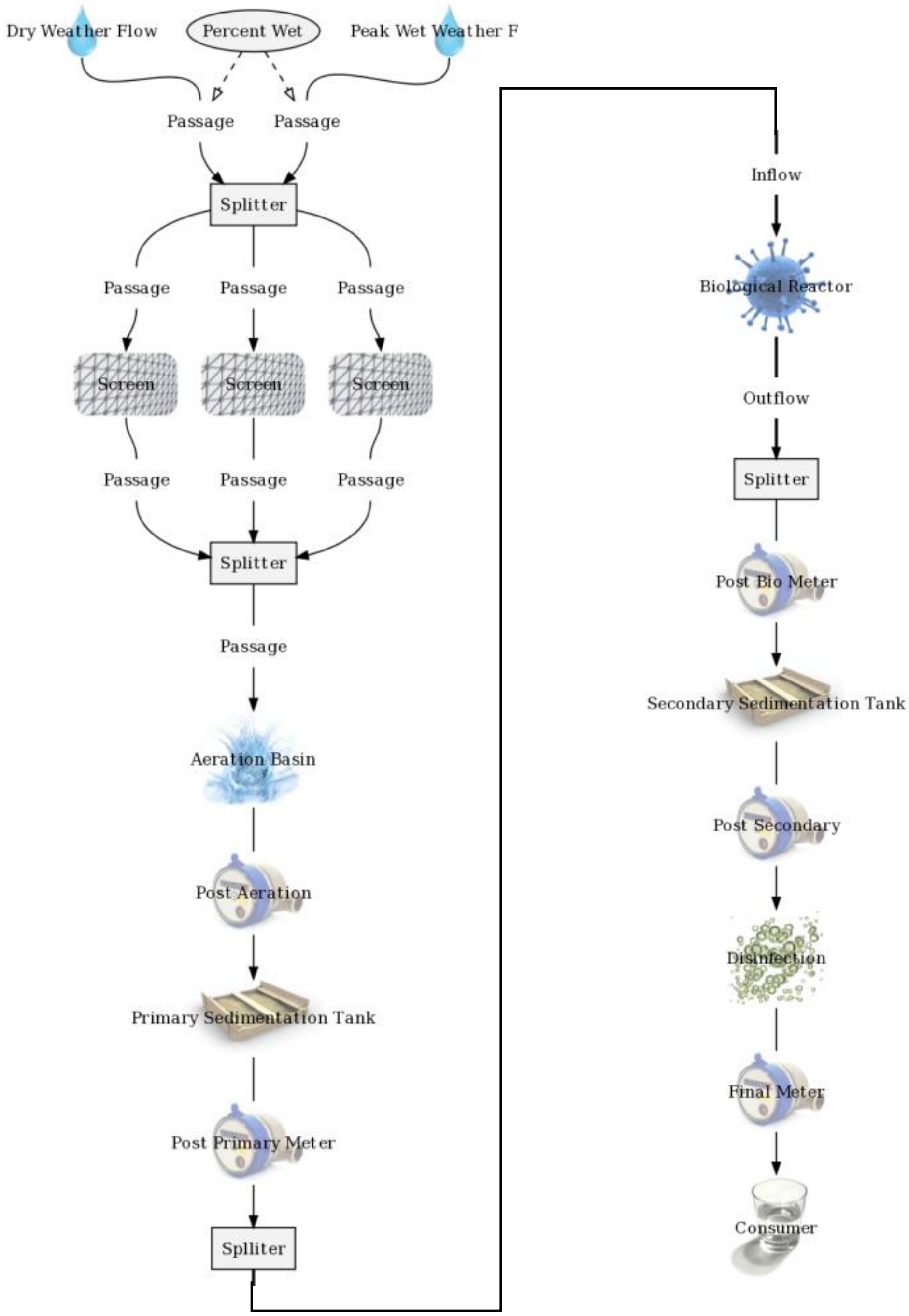


FIGURE 6: SIMGUA MODEL OF THE ANNACIS PLANT.

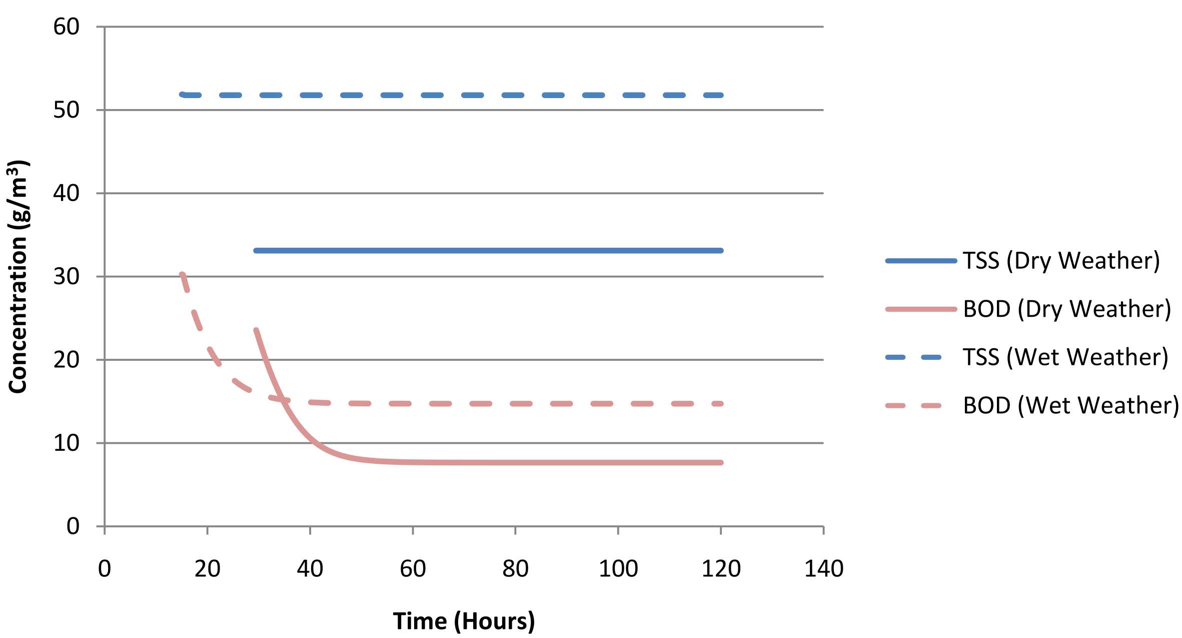
ANALYSIS OF PLANT PERFORMANCE USING THE MODEL

Once the model was created, it could be used to simulate the response of the plant to a number of different wastewater inputs or to see how the resizing or reconfiguration of the plant affected the quality of effluent water.

It is important to emphasize that the results in this section are not necessarily representative of the actual Annacis plant. We were missing important water quality parameters from the plant – such as the BOD decay constant – and had to use general values instead. Additionally, we did not model some plant components such as trickling filters. With further research, gathering of data and calibration we are confident that we could develop a very accurate model for the plant, but we were unable to carry out such additional work for this study.

STEADY STATE FLOW

The following chart illustrates the results for the effluent quality of the plant given constant dry weather flows and wet weather flows.



The reader will notice a number of interesting features in this chart. The first is the step nature of the effluent. Initially the concentrations are zero. They then instantly shoot up to positive values at 15 hours for the wet weather flow and 29.5 hours for the dry weather flow. This effect is due to the gradual filling up or "charging" of the plant. Initially all the tanks and reactors in the plant are assumed to be empty. It takes a long time for these tanks to fill up and start to overflow into the next tank. Thus, prior to charging, we have no flow out of the plant. The charging process takes less time for the wet weather flow due to its higher flow rate compared to the dry weather flow.

The second feature of this chart that should be discussed is the decline in BOD concentration immediately after charging. This effect is caused by the continuously stirred tank reactor that is used to model the biological reactor. As this reactor is initially charged and overflowed, the water flowing out of it contains influent that has not remained in the plant very long. As the simulation progresses, the average age of the water in the reactor increases. As the water ages, the BOD also decays. Therefore, the BOD levels in the effluent steadily decline before asymptoting to a steady state value as the simulation progresses. In our further analyses we will disregard the initial charging and biological reactor stabilization effects and will instead start our analysis once steady state flow conditions have been reached.

MODEL RESPONSE TO RAIN EVENTS

One way the model was tested was to simulate different rain events. These events were created by first obtaining steady state dry weather flow. The inflow was then switched to pure wet weather flow conditions for a fixed period of time before being switched back to dry weather flow conditions. Three different scenarios were modeled: one with a half hour rain event, one with a four hour rain event, and one with a fifteen hour rain event.

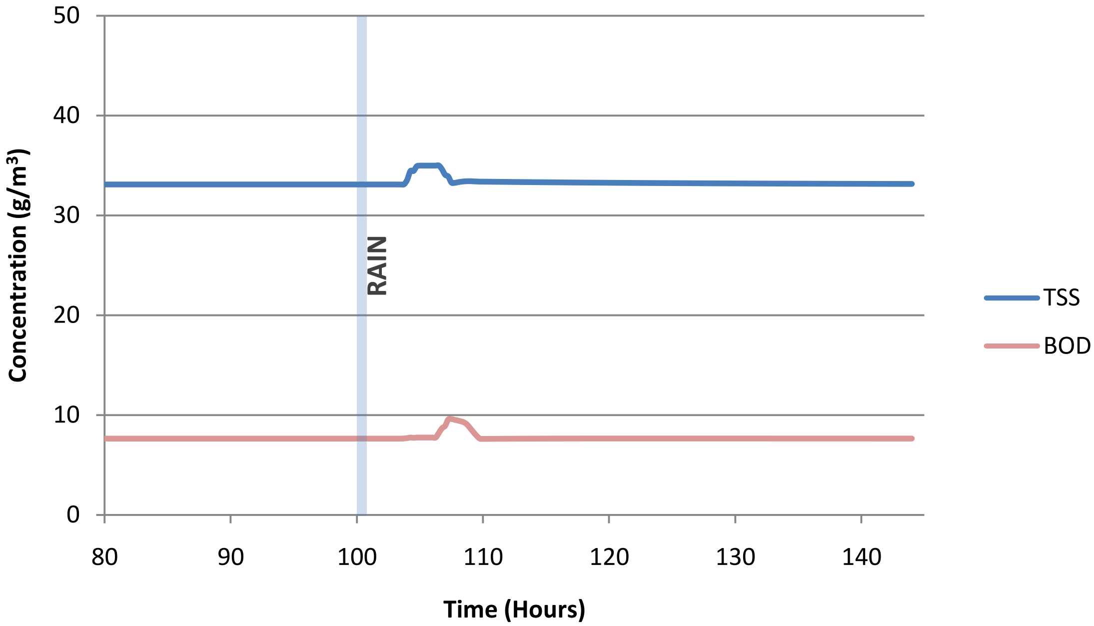


FIGURE 7: HALF HOUR RAIN EVENT.

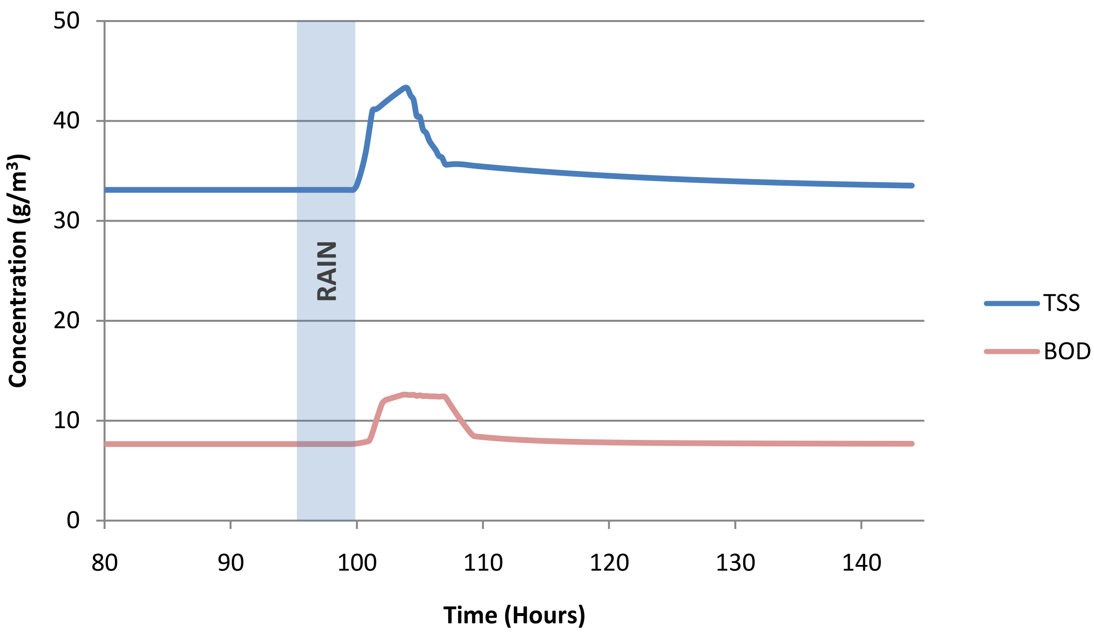


FIGURE 8: FOUR HOUR RAIN EVENT.

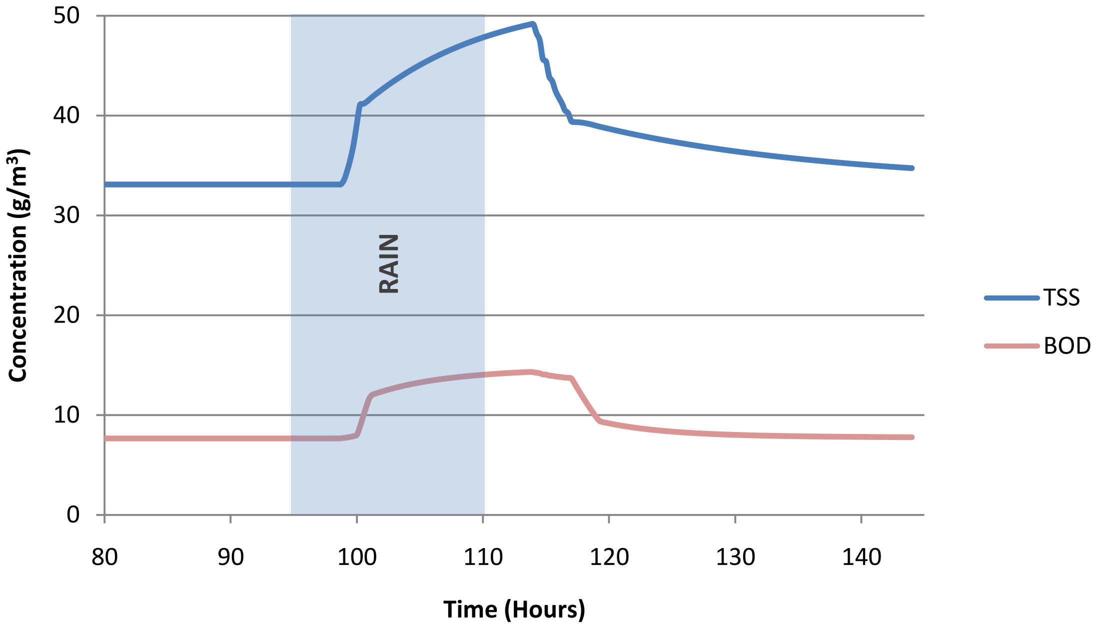


FIGURE 9: FIFTEEN HOUR RAIN EVENT.

These figures illustrate a number of important aspects of the plant. For instance, it takes approximately five to eight hours before the effects of a change in influent appear in the effluent from the plant. Also the shapes of the resultant "bumps" in effluent pollutant levels are quite peculiar and deserve further study.

In the fifteen hour rain event – where these bumps are most pronounced – we can see four distinct curves as part of the TSS response, and five distinct curves as part of the BOD response. For the TSS case, the TSS levels initially increase at a very rapid pace for about an hour and a half, the levels then keep increasing at a slower pace for another thirteen hours. Thereafter, the levels decline sharply before declining much more slowly and asymptotically approaching the dry weather flow steady state. The reason for each of these different curve shapes is not immediately clear, which proves just how valuable a simulation can be when dealing with complex systems. It reveals behaviors and properties of the system that would not be visible if one was just studying the equations and parameters of the system on paper.

After we have learned the plant's response to the rain event, we can explain the four separate curves for the TSS effluent response using the following table:

TABLE 3: TSS POLLUTANT CONCENTRATIONS IN AND INFLUENT FLOW RATE.

	Low Flow Rate	High Flow Rate
Low TSS Concentration	Best Case	Wet Weather Flow
High TSS Concentration	Dry Weather Flow	Worst Case

As we can see, there are four combinations of pollutant concentrations and flow rates in this table. The wet weather flow is represented by the high flow rate and low TSS concentration cell. The dry weather flow is represented by the low flow rate and high TSS concentration cell. The reader might expect that we stay in one of these two cells throughout the simulation. Something else occurs, however, when we switch from dry weather flow conditions to wet weather flow conditions. The water that is already in the plant when we first do the switch contains the high, dry weather TSS concentration. This water is then pushed through the plant with the high, wet weather flow rate. Therefore, we are moved to our "Worst Case" cell in the above table. Due to the continuously stirred tank reactor that is used to model the Biological Reactor, we do not immediately jump to this cell's steady-state effluent value, instead we asymptotically approach it. The four curves that construct the TSS response to the rain events are simply the asymptotic approaches to the steady state values of the four flow conditions illustrated in the above table.

DESIGN OF REACTORS

We can also use our model to determine the optimal design of the plant given specified inputs and desired effluent quality or standards. For instance we can experiment with the sizing of reactors and measure the resulting effluent properties. The following chart illustrates this experimentation for a range of biological reactor sizes and for both dry weather and wet weather conditions.

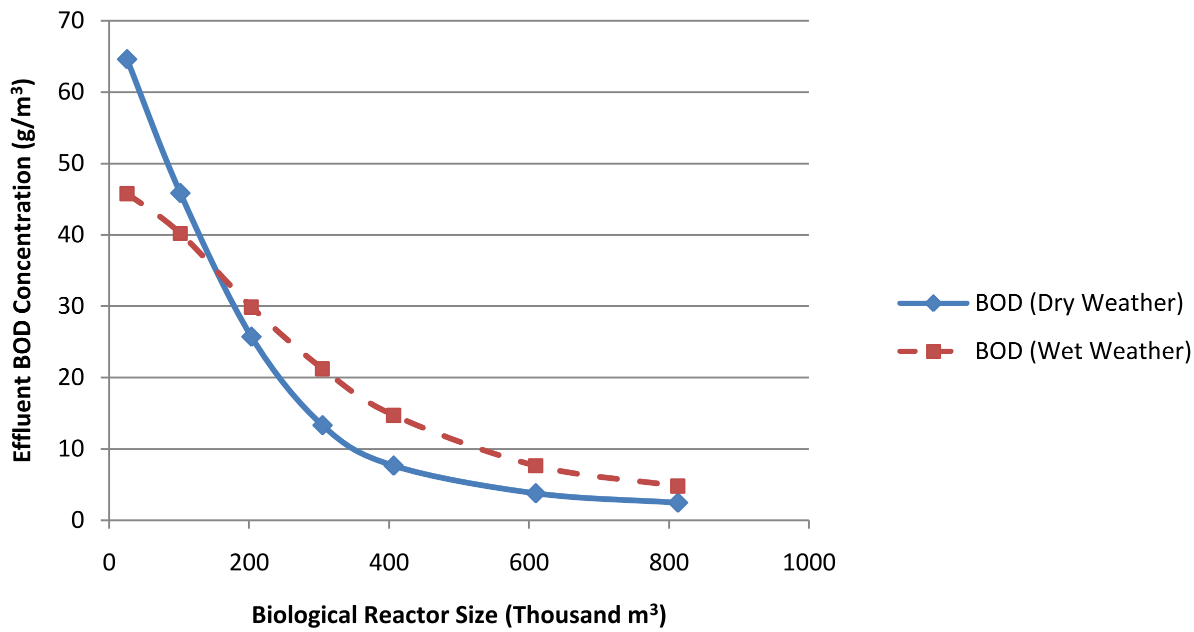


FIGURE 10: BOD REMOVAL VERSUS BIOLOGICAL REACTOR SIZE.

As is expected, the level of BOD in the effluent decreases asymptotically with the size of the biological reactor. Less expected, however, is the relationship between the dry and wet weather flow conditions. A priori, one would assume that that the wet weather BOD levels would consistently be above or below the dry weather levels. Instead the plant exhibits an interesting relationship where wet weather levels are initially below the dry weather levels. At a reactor size of about 175,000 m^3 they switch places and the dry weather BOD levels remain below the wet weather BOD levels for the remainder of the sample space. Both BOD levels approach zero, however, as the reactor grows in size. Again, this is an example of non-intuitive behavior that would be very difficult to predict without the aid of a simulation.

EQUIPMENT FAILURE OR MAINTENANCE

We can also use our model to predict how the plant will respond to a removal of capacity. For instance, one of our biological reactors or sedimentation tanks might be taken off-line due to equipment failure or prescheduled maintenance. In the following example, we assume that we lose 25%

of our biological reactor capacity due to failure. We model this failure as a linear reduction in capacity from a total of 100% to 75% over a period of eight hours. Following this drainage period, the reactor capacity stays at 75% for another sixteen hours after which it is restored to full capacity. The following chart illustrates the response of the Annacis plant model to this failure:

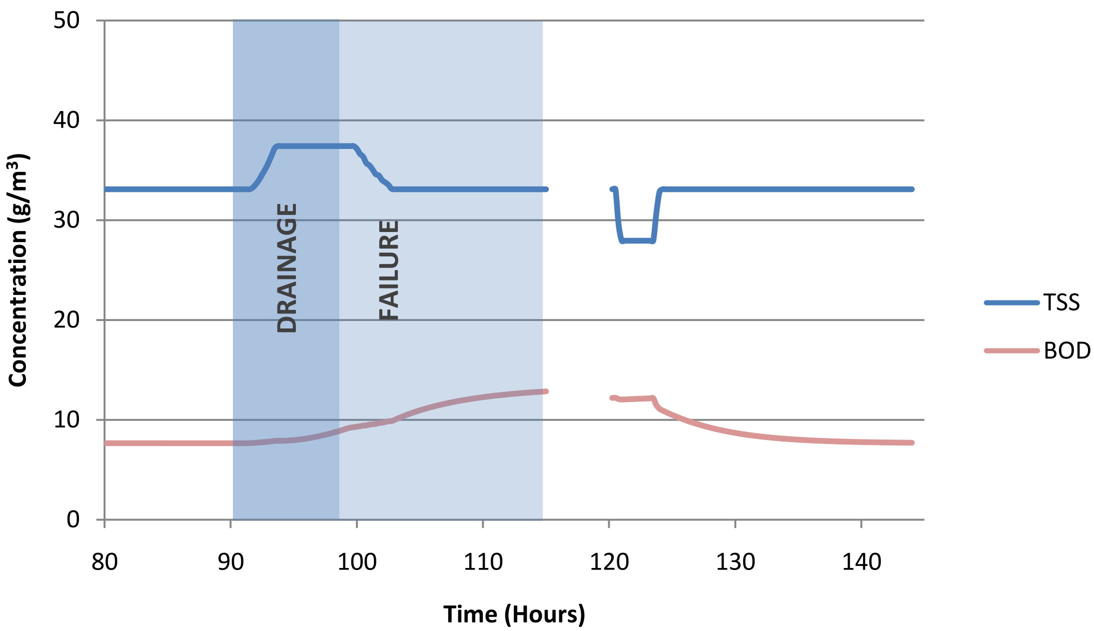


FIGURE 11: EFFLUENT QUALITY IN RESPONSE TO A 25% REDUCTION IN BIOLOGICAL REACTOR SIZE.

Clearly the plant's response to this failure is quite complex again illustrating the utility of using a full time-based simulation to model wastewater treatment plants.

DISCUSSION AND CONCLUSIONS

The Annacis plant model illustrates the usefulness of the Simgua wastewater treatment components to construct and simulate an actual WWTP. A Simgua model was constructed and configured easily. The resulting model was used to predict plant response to a number of different rain events. In our trial runs we observed a number of phenomena that would be extremely hard to predict without the time-based simulation environment provided by Simgua. Although these results cannot be used to precisely predict the actual response of the Annacis plant, with some additional calibration and data gathering they could quickly become much more applicable.

In future work we would be particular interested in learning what the standard constants for the water – such as the BOD decay constant – were at the plant and in determining the particle size distribution for the suspended solids in the water. The latter would greatly increase the accuracy of our sedimentation tank simulations for we would then be able to use full physical simulations. This information would result in a more faithful model of our target plant and would be valuable for design or operational simulation tasks.