

Development of a Dynamic Computer Model for Water and Effluent Management at the Alunorte Refinery

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Abstract

Rainfall events are complex phenomena, as there is no dynamic pattern of occurrence since the climatic conditions have been changing over time. With high rainfall rates in recent years in the Amazon region, Hydro Alunorte has developed a dynamic computer simulator for the current configuration of water and effluent reservoirs at the refinery, allowing rigorous evaluation of storage, pumping and treatment capacity for heavy rainfall and with distributed incidence among the basins/sumps and possible interconnection/pumping arrangements between the various control basins. Legasys Storm was created in a transient regime and on Microsoft's .NET platform in C# language, which allows its use on any computer using the Windows operating system. The modeling is done using the mass conservation differential equations and the system of ordinary differential equations is numerically solved using the 4th order Runge-Kutta method. Through the simulations, it is possible to identify weak points for precipitation with a constant intensity or profile, evaluate scenarios with different pumping conditions, power failure, test operational procedures, assist in emergency strategies during heavy rain events and training in controlled environment for operations and maintenance teams.

Keywords: Heavy rainfall, Rainwater storage, Pumping system, Water and effluent, Dynamic simulator.

1. Introduction

Extreme rainfall events have emerged as one of the main consequences of climate change and global warming. These events consist of outliers of precipitation observed in each time interval. This correlation is justified by the following mechanism: with the increase in terrestrial temperature, there is a higher rate of evaporation and, consequently, there is an increase in atmospheric humidity and convective activities. Therefore, with the increase in the average temperature of the planet, there is an intensification of the hydrological cycle.

The Brazilian Amazon, in turn, has one of the highest rainfalls in the world, with an average of 2,300 mm/year. Considering a period of 30 years, from 1978 to 2007, the precipitation recorded in the Brazilian Amazon corresponded to approximately 9% of all precipitation on the solid surface of the planet [1]. It can also be noted that, considering the Brazilian Amazon, the highest rainfall rates are found in the states of Amapá and Pará.

The Hydro Alunorte is in the municipality of Barcarena, in the state of Pará, in the Amazon. The region has a well-defined seasonality of rainfall, which can be divided into two seasons: rainy (Amazonian winter), between January and June, and less rainy (Amazonian summer), between July and December.

The search for orienting tools is fundamental when working with highly complex climatic phenomena.

2. Process Modeling

With the complexity of climatic phenomena, a dynamic computer simulator was developed that allows a rigorous evaluation of Hydro Alunorte rainwater management system for different conditions of intensity and duration. Legasys Storm (LS) allows simulating scenarios with constant or profile rainfall, evaluate scenarios with different pumping conditions, test operational procedures, assist in decision making during heavy rain event and training in a controlled environment for the team of operation.

The software was developed by Hydro Alunorte's Process Engineering in partnership with Legasys, which is a technology company that studies, models, and interprets engineering and nature phenomena, creating exact solutions to problems.

Hydro Alunorte's Process Engineering department is responsible for carrying out the simulations requested by the departments responsible for the maintenance of large areas and/or equipment or by the Hydro project team. The results obtained provide orientation or recommendations for carrying out, deferring, or stopping, planned activities.

2.1 Description of the Work Domain

Hydro Alunorte has a robust management of rainwater. As can be seen in Figure 1, rainwater, from the Solid Waste Deposits (indicated by DRS1 and DRS2) or from the Refinery, can be directed to control basins and/or sumps. The system also includes treatment plants, drainage circuits, pumping stations and online monitoring instruments. This entire structure allows for operational storage, transfer, and treatment maneuvers to be carried out.

In industrial effluent treatment stations, the effluent is received in 9 (nine) control basins, which receive effluents through pipes from Solid Waste Deposits (DRS1 and DRS2) through the channel from the Refinery's drainage circuits.

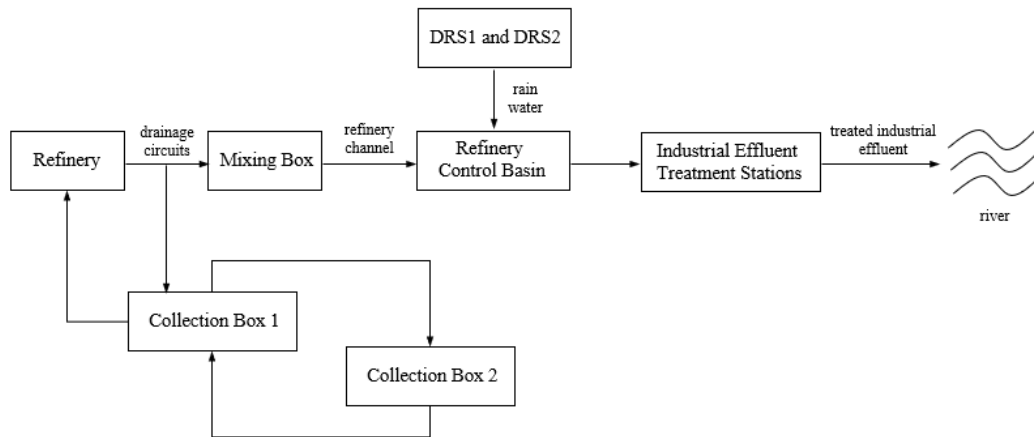


Figure 1. Simplified scheme of the flow of rainwater and effluent for treatment.

The drainage circuits receive, in addition to rainwater that falls on the Refinery, also water stemming from purging of the cooling towers and tanks, floor washing as well as condensate.

2.2 Simulator Development

The LS simulator was developed in .NET framework 4.5 in C# language, which allows its use on any computer that uses the Windows operating system, without the need to install any additional

packages or external licenses. LS has a graphical interface, depicted in Figure 2, and developed using Windows Forms and which allows for an interactive and intuitive use.

In addition to the management system flowchart window, the simulator presents interactive panels on its main screen with:

1. Simulation Control Panel
2. Menu Panel with:
 - a. Menu: with functionality to save and load simulations
 - b. Flowsheet: to open the flowchart window
 - c. Refinery: configuration menu of data related to the Refinery
 - d. Reservoirs: menu of control basins and sumps, with access to the configuration menu of each reservoir, inlet and outlet currents and level graph
 - e. Rainfall: menu for defining the rain to be simulated.
3. Time Control Panel: allowing you to speed up or slow down the simulation resolution and set a time for the simulation to pause
4. Results Panel: showing important information such as instantaneous intensity, accumulated precipitation, volume treated in the treatment plants and the volume available in the three areas (Refinery, Solid Waste Deposit – DRS1 and DRS2).

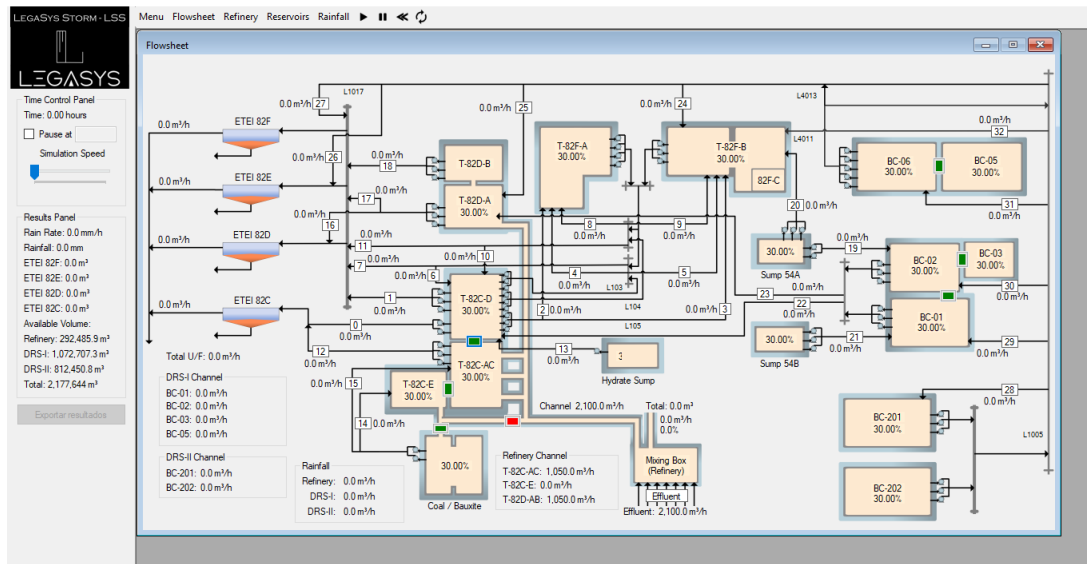


Figure 2. Simulator home screen.

For the dynamic modeling in question, a system of ordinary differential equations was used, based on the differential equation of conservation of mass (Equation (1)). Equation 1 is added to the ODE system for each reservoir that was simulated. Therefore, the model was built with a total of 17 differential equations.

$$\frac{d(\rho V)}{dt} = \sum \rho F_i^{in} - \sum \rho F_i^{out} + \rho F_{rain} \quad (1)$$

Where:

- ρ Mass density, kg/m³
- V Volume, m³
- t Time, h
- F_i^{in} Inlet volumetric flow, m³/h
- F_i^{out} Output volumetric flow, m³/h
- F_{rain} Rainfall volumetric flow, m³/h

The rainfall volumetric flow is calculated by Equation (2) and is a function of the rainfall intensity and catchment area.

$$F_{\text{rain}} = A_{\text{catch}} i_{\text{rain}} \quad (2)$$

Where:

A_{catch} catchment area, m²

i_{rain} rainfall intensity, m/h

The ODE system is solved by 4th order Runge-Kutta method, which is a traditional method used in engineering problems. The fact that it does not use higher-order derivatives greatly contributes to the popularity of the method compared to the others [2].

3. Case Studies

The shutdown of large areas or equipment for maintenance during the Amazonian summer, called the summer plan, is very important to ensure a more robust area during the next Amazonian winter. However, in the summer plan, there are monthly rainfall with considerable volumes (between 160 millimeters and 230 millimeters) and because of this it is important to have a good alignment between the areas of process, operation, and maintenance to evaluate these shutdowns.

The LS simulator allows to develop a strategy based on the expected rainfall for the period (daily, weekly, or monthly) and the current level and pumping conditions of the control basins. With the simulation, we can get an idea of the final levels and available volume of the basins, in addition to the total volume treated per treatment plant. With this output data, we can minimize the risks of overloading the control basins from a predictive assessment.

3.1 Case Study 1

Use the simulator as a training tool for the operation, maintenance, process, and other areas of the refinery. Show, for example, the importance of increasing or decreasing the pumping rate of basins for level control. As the simulator is dynamic, it provides us with a clear and didactic visualization. As an example, we have the monitoring of the pumping and level of the control basin of the T-82D-A, as shown in Figure 3. From the moment it starts to rain (constant rain), the level starts to rise, and the pumps are off (flow rate of each pump of 1,000 m³/h). With the entry of the first bomb the level continues to rise. With the inlet of the second pump the level starts to rise slowly and from the inlet of the third pump the level starts to decrease.

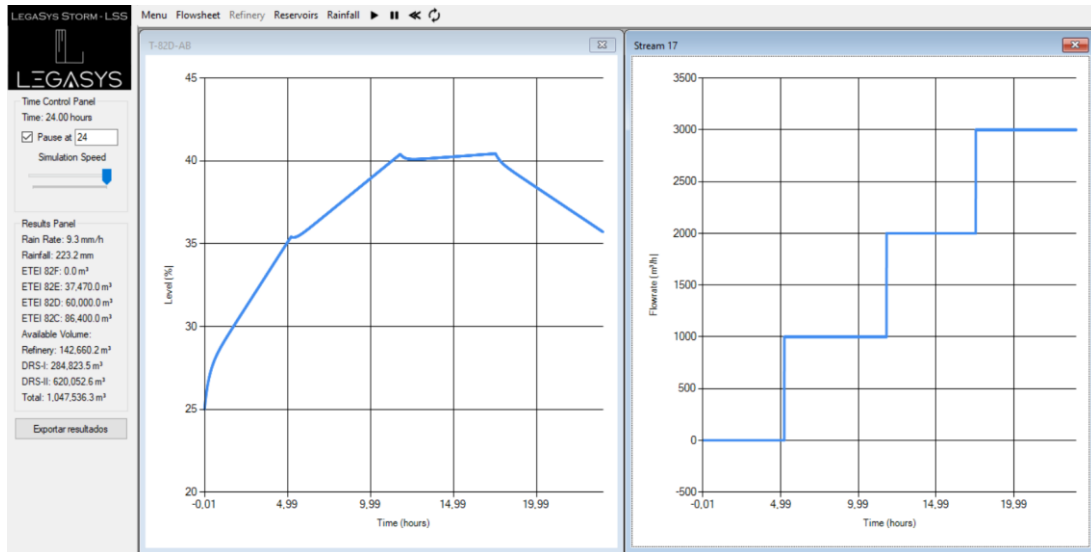


Figure 3. Case study 1 simulation result screen.

The objective is to show the importance of decision making based on a guiding tool.

3.2 Case Study 2

A simulated case was the shutdown for maintenance of the DRS2 pumping stations, that is, the control basins (BC201 and BC202) would only receive rainwater and all pumping would be unavailable. Maintenance would last 6 hours, and rain forecast for the day would be 140 millimeters. From this, the simulator would help to predict the final levels of these basins in the adopted period, as shown in Figure 4.

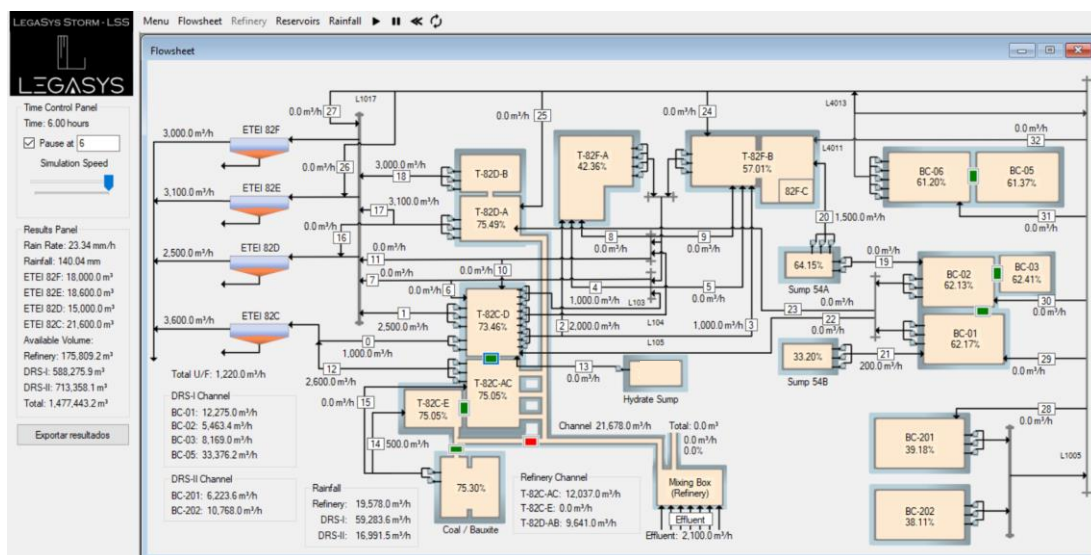


Figure 4. Case study 2 simulation result screen.

With the simulation it is possible to visualize the configuration of all areas, in addition to the focal point of the study.

3.3 Case Study 3

An example of a strategy adopted was to simulate the isolation of control basins BC6 (located in DRS1) and BC201 (located in DRS2), from the other basins and channels, to use the volume of rainwater stored exclusively for the supply of water trucks (watering of roads) and the pumping of these basins would only occur in extreme need. According to the rain forecast for the month of July, the volume would be 130 millimeters. From this, the simulator helps to predict the levels of the basins and the necessary flow of pumping and treatment in the adopted period, as shown in Figure 5.

Input data are initial levels of control of basins and reservoirs, precipitation (constant intensity or peaked profile) and duration. Thus, the output data are the final levels of basins and control wells, pumping flow and necessary treatment, in addition to other process information.

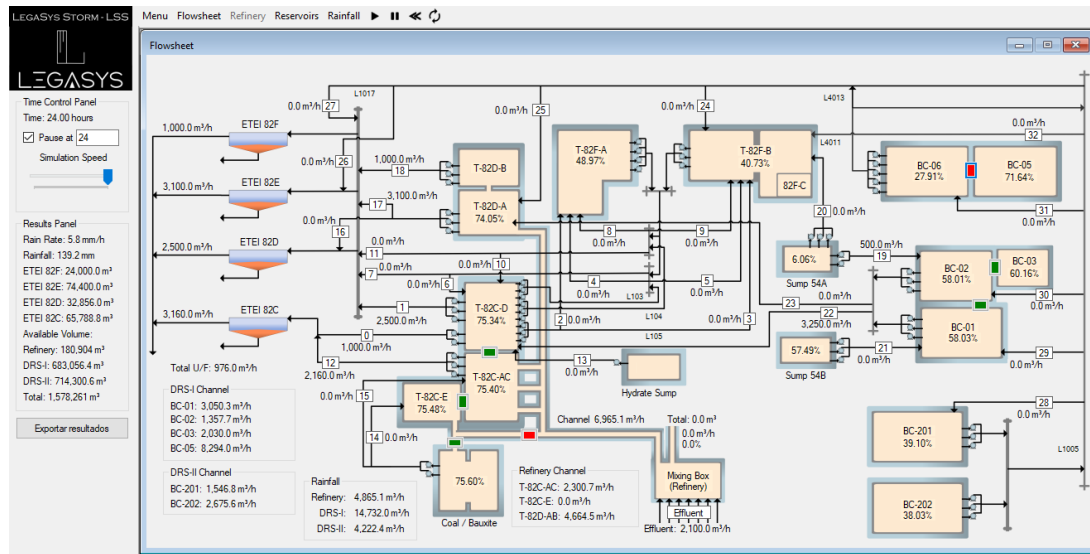


Figure 5. Case study 3 simulation result screen.

It's possible to visualize the final levels of the control basins and sumps, the necessary pumping, and the required treatment flow.

4. Results and Discussion

Through the simulations, it is possible to evaluate scenarios with constant or profile rainfall, scenarios with different pumping conditions, test operational procedures, assist in decision making during heavy rain events and training in a controlled environment for the operation team.

Figure 3 shows the simulation result for case study 1. The software was used as a training tool. The control basin used was the T-82D-A to show the importance of deciding at the right time to reduce the level with increasing pumping. In the simulated case, 3 flow elevation moments with 1,000 m³/h were used for each moment. Table 1 shows a summary of the simulation results.

Table 1. Simulation summary for the case study 1.

Data	Inputs	Outputs
Precipitation volume	223.2 millimeters	-
Duration of precipitation	24 hours	-
Starting level of the T-82D-A	25%	-
Level after pump 1 inlet (total of 1,000 m ³ /h)	-	35.26%
Level after pump 2 inlet (total of 2,000 m ³ /h)	-	40.18%
Level after pump 3 inlet (total of 3,000 m ³ /h)	-	40.09%
Final level of the T-82D-A	-	35.24%

The final level of the basin is directly related to the pumping flow. The ramp made for starting the pumps is enough for the reduction in the volume of rainwater in the T-82D-A basin to begin to be noticed.

Figure 4 shows the simulation result for case study 2. The software was used to assess the final levels of the DRS2 control basins (BC201 and BC202) after the pumping stations were shut down for maintenance for 6 hours. Table 2 shows a summary of the simulation results.

Table 2. Simulation summary for the case study 2.

Data	Inputs	Outputs
Precipitation volume	140.04 millimeters	-
Duration of precipitation	6 hours	-
BC201 level	25%	39.18%
BC202 level	25%	38.11%
BC201 pumping	OFF	-
BC202 pumping	OFF	-

The final levels of the DRS2 control basins (BC201 and BC202) varied between 13.11% and 14.18% based on the initial level.

A decision-making or risk assessment needs a guiding tool that reflects the reality of the area.

Figure 5 shows the simulation result for case study 3 for a rainfall of 139.2 millimeters with constant intensity for 24 hours. Precipitation occurring in a single day and above the forecast for the month of July. With the simulated results, BC6 (located in DRS1) presented a final level of 27.91% and BC201 (located in DRS2) a final level of 39.10%, with authorization to carry out the planned activity. Table 3 shows a summary of the simulation results.

Table 3. Simulation summary for the case study 3.

Data	Inputs	Outputs
Precipitation volume	139.2 millimeters	-
Duration of precipitation	24 hours	-
BC6 level	25%	27.91%
BC6 pumping	OFF	-
BC6 isolation	ON	-
BC201 level	25%	39.10%
BC201 pumping	OFF	-
BC201 isolation	ON	-

The final levels of the other control basins and sumps ranged from 6.06% to 75.48%.

The simulator seeks to equalize all basin levels to ensure process safety during scheduled maintenance.

5. Conclusions

The development of the dynamic computer simulator serves to evaluate the capacity of storage, pumping and treatment of effluents of Hydro Alunorte. One of the main objectives of the tool is to equate all the complexity of the water management system in a software that presents an intuitive, interactive interface, rich in information and that can represent rain events with constant intensity or with a profile containing peaks.

Considering the climate changes observed in recent years, the forecast of atypical rainfall intensification, its direct influence on the industrial scope and the fragility in the forecast of these occurrences, it is essential to evaluate ways to minimize the effect of these events and mitigate possible impacts. The use of computational models to evaluate scenarios is one of the safest and most modern viable techniques for this type of complexity.

6. References

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