Integrated Water Balance Modeling of the Alunorte Refinery

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Abstract

The alumina industry is investing in sustainable water management programs to optimize water usage, considering environmental and economic aspects. As one of the world's biggest alumina refineries, Hydro Alunorte's process involves a complex integration of water flows, involving raw water, rainwater, condensate, steam, liquor, evaporation, and water from a bauxite slurry pipeline. Most of those flows permeate the seven process lines of the three operating plants, bringing one more challenging aspect to the refinery's water management. This paper describes the development of an integrated water balance model used to assess and support a circular water management program within the alumina refinery. The model was built using flowsheets to illustrate key process areas of the refinery, and calculating average flowrates based on inputs supplied by the user; its interface also offers flexibility for the development of scenarios and sensitivity analysis, to simulate different conditions and measure the impact of critical process variables. The integrated water balance provided a clearer understanding of the refinery's current operating and process conditions, and also introduced the possibility to identify improvements in the plant's water management, with a focus on reducing water, condensate and liquor waste, loss of soda and energy, and effluent treatment costs. Several opportunities to improve the plant's water management were assessed, quantified, and categorized within two main courses of action: 1) reduction of industrial water consumption and 2) use of alternative sources. The integrated model is a powerful tool that can be used to support the identification, quantification, and development of strategies to reduce water catchment and effluent generation rates towards a more circular water management program.

Keywords: Water management, Integrated model, Circular water, Hydro Alunorte.

1. Introduction

Water is an essential natural resource for life on Earth, so its increasing consumption is a global concern. In Brazil, according to the Brazilian Water Resources Conjuncture Report, carried out by the National Water Agency (ANA) in 2021, its use occurs mainly for irrigation (50 %), human supply (25 %), industrial consumption (9 %) and others (16 %). Industrial consumption can be classified into extractive and processing; Mining is the extractive activity with the highest water consumption in Brazil. Among global water consumption, industries account for about 22 % and, according to the National Confederation of Industry, this demand is expected to increase about 400 % by 2050 [1].

Inserted in the processing context and integrated with the extractive activity of bauxite, the alumina industry requires a significant amount of water resources within its production chain. Some of the activities consuming the majority of water are steam production for the digestion process; preparation of caustic soda, flocculant, and lime solutions; residue and hydrate washing. Recognizing the importance of water as a natural resource, alumina companies across the world are investing in the development of sustainable water management programmes, aimed at intensification of recycling and reutilization of water, and therefore the reduction of non-recycled resource use [2].

As one of the world's biggest alumina refineries, Hydro Alunorte has an important role in this trend towards increased sustainability. The refinery receives bauxite from two different sources, one of them in the solid form, including moisture, and the other from a slurry pipeline. The bauxite is refined in seven process lines of the three operating plants; although mostly parallel, the seven lines have interconnection points, including some shared equipment across the plants, which adds to the complexity of the process. Involving the integration of raw water, rainwater, condensate, steam, liquor, evaporation, and water from the bauxite slurry pipeline, the water management of the refinery is achieved by the regulation of four major circuits:

- Bayer Process and condensate storage;
- Industrial water catchment and distribution;
- Bauxite pipeline receival and dewatering;
- Industrial and pluvial drainage and effluent system.

In Figure 1, a schematic of the circuits is presented, considering the main flows involved and their interconnections.

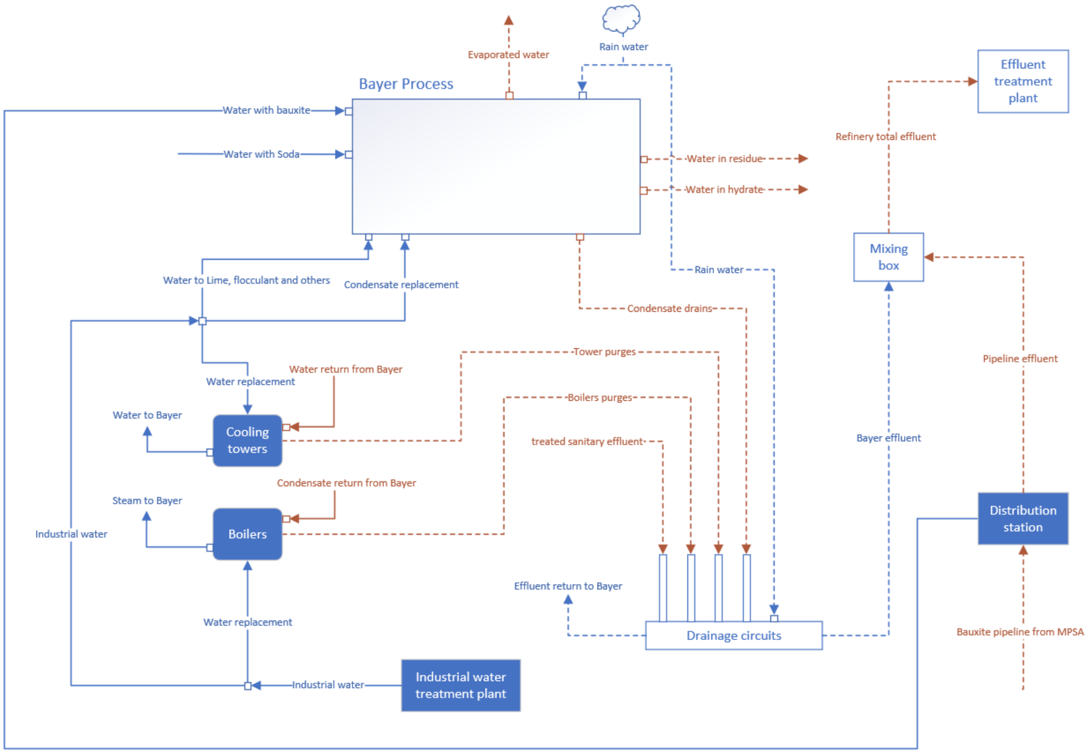

Figure 1. Hydro Alunorte integrated water balance block flow diagram.

Hydro Alunorte promotes daily monitoring meetings, in which water balance issues are discussed and actions are defined. However, as many relevant inputs and outputs are not accurately measured, and a water balance model is not available, the decision-making process is mostly based on the overall volume variation of the refinery, which results in the implementation of corrective measures that do not take into account the root cause of deviations, frequently not known.

Since these decisions impact the water catchment and effluent generation rates in all processing plants of the refinery, a better understanding and quantification of the main flowrates involved is important. In this context, the development of a water balance is an important step to optimize the decision-making process and guarantee a more sustainable water management within Hydro Alunorte.

2. Objective

This study aims to develop an integrated water balance static model to support Hydro Alunorte's decision-making process towards the refinery's water management. The modelling results are used to assess the current conditions and to propose improvements in the water management, seeking a reduction in the water catchment and effluent generation rates.

3. Methodology

The 4 main circuits of the refinery were divided into 19 subareas, based on the respective processing steps. For each subarea, a flowchart was designed, representing the water inputs and outputs, with numbered flows; a summary sheet was also created, synthesizing the key flows for the integrated water management of the whole refinery. Three groups of parallel processing lines were used as reference for the balance development, based on process similarities and equipment sharing:

- Plant 1: Lines 1, 2 and 3;
- Plant 2: Lines 4 and 5;
- Plant 3: Lines 6 and 7.

To illustrate the many different types of aqueous flowrates throughout the refinery, a codification pattern was created for the flowcharts, as depicted in Figure 2.

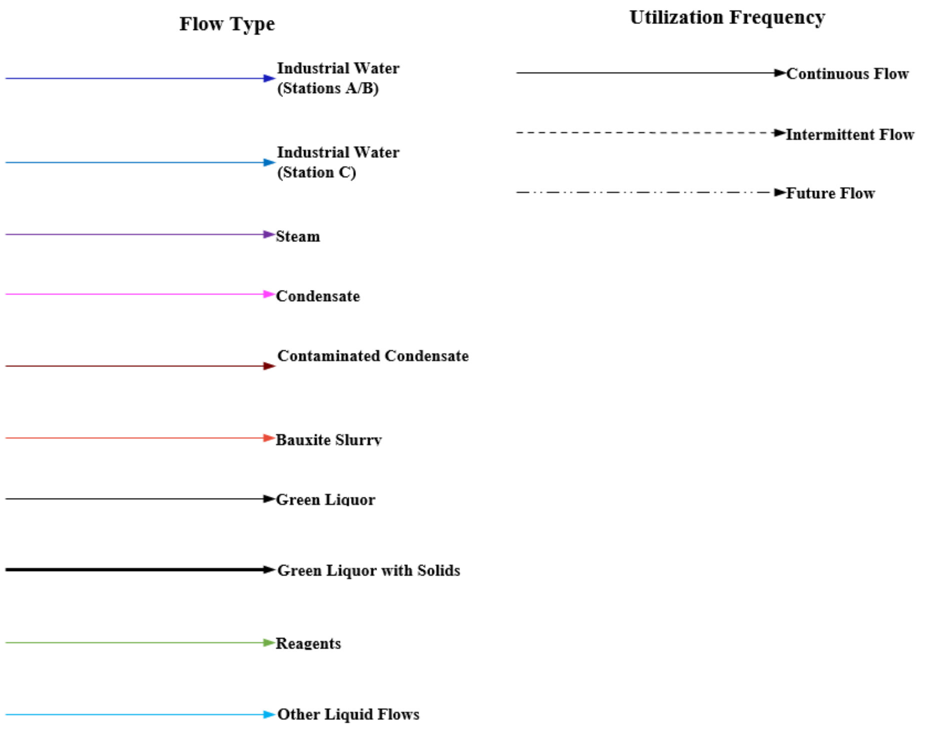

Figure 2. Flows codification pattern in the flowsheets.

Measured flows (from flowmeters, FTs) during the period between 01-Oct-2021 and 31-Dec-2021 were provided to aid the model development. The instruments (FTs) were identified in the flowchart, with the symbology depicted in Figure 3; the corresponding data were used for calibration of the base case, and also to assess the conditions of the currently installed instruments in the refinery.

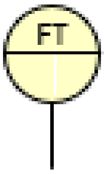

Figure 3. Flowmeters (FTs) symbology.

Based on the flow relationships between the subareas, an Excel model was built to calculate the water balance, integrated with the flowcharts. This tool showcases all flows of water, solution, vapors and condensates, or any other flows that may contribute to the water balance of the plant, performing a static simulation of the balance to determine average mass flowrates.

The model allows the creation of different scenarios in which input data are changed to predict the impact on all flows. The base case scenario presents the current nominal operation of the refinery (6.3 million tons of alumina per year), based on assumptions established by Hydro Alunorte technical team and reference documents for each area, such as process flowcharts and expansion project criteria. This scenario is used as main reference for the assessment of the current water management conditions and identification of possible improvements presented in this paper.

4. Results and Discussion

4.1 Current Conditions Assessment

4.1.1 Bayer Process and Condensate Storage

One of the main points of attention in the Bayer Process and Condensate Storage circuit is the excess condensate disposal, which occurs continuously. The initial assumption of Hydro Alunorte's technical team was that the main cause of this issue was condensate contamination, which occurs frequently. It is noteworthy that, in the current operation, there is no direct measurement of this waste. Although the flow can be obtained indirectly through the FTs that measure the inputs and outputs of the condensate storage area, the calculation is intrinsically linked to an accumulation of measurement errors at each point, providing a relatively unreliable result. The lack of a direct measurement also prevents a quantification of the instantaneous discharge flow in cases of varying levels in the tanks.

The water balance model confirmed an imbalance in the condensate tanks, in nominal conditions, providing the quantification of the average excess disposal rate, which corresponds to 33 % of the total available condensate. A conservative scenario was also built to simulate an extreme condition with the highest condensate contamination rate observed in all operating data provided by Hydro Alunorte. Even in this situation, a high excess rate is observed, corresponding to 25 % of the total available. Therefore, contradicting the technical team's initial hypothesis, the modelling results indicate that condensate contamination is in fact not the main disposal cause.

To understand the root causes of the condensate tanks imbalance, its main consumers were assessed. The base case showcases that there are significant substitution rates of condensate consumption by industrial water consumption, in some areas, which is probably a consequence of the higher quality of the latter. As an example, the model indicated that 33 % of the hydrate washing, ideally designed to be provided by condensate, is actually made with industrial water; if hydrate washing were entirely carried out with condensate, total condensate waste would be reduced from 33 % to 24 % of the total available. Besides condensate disposal, this substitution also results in higher water catchment rates, further discussed in section 4.1.1.

4.1.2 Industrial Water Catchment and Distribution

Industrial water (new and clean water for the process) comes from water wells, slurry dewatering and water batches from the pipeline. After proper capture, there are three treatment stations: stations A and B, which treat water from wells, and station C, which treats water from the pipeline and dewatering.

For the treatment stations A and B, that treat water captured from the wells, the main consumers are presented in Figure 4, with relative consumption rates quantified according to the model base case. The treatment station C assessment is provided in section 4.1.3.

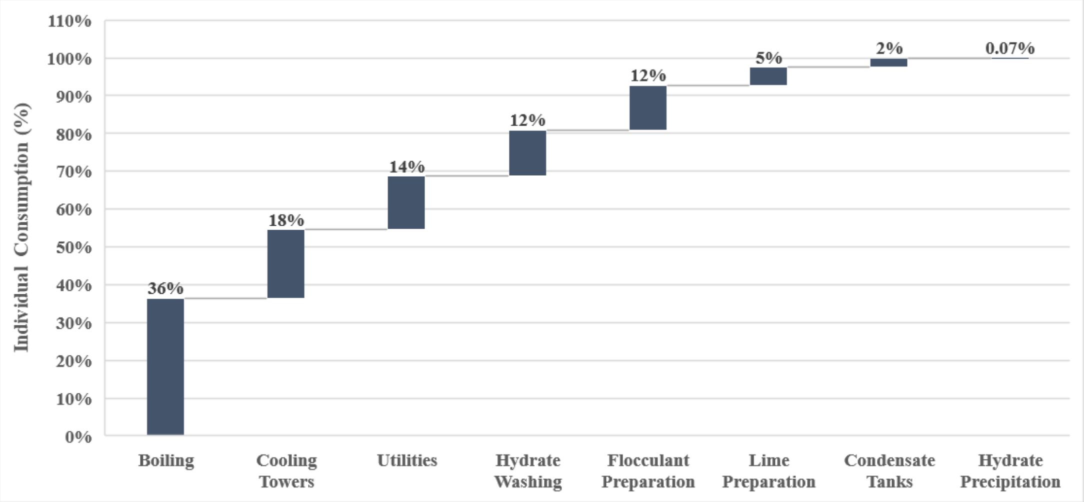

Figure 4. Water consumption for treatment stations A and B.

As illustrated, the boiling area is the most representative in terms of new water consumption. As only a portion of the steam used in the consuming areas returns as condensate, part of the make-up is used to supply the remaining demand for the generation of live steam, corresponding to 47 % of industrial water consumption in the area. Possible efficiency gains in this condensate return can result in a significant reduction in freshwater consumption. The remainder of consumption in the area is dedicated to replacing demineralization losses (4 %), losses to the atmosphere (4 %), blowdown generation (10 %) and direct steam (34 %) in the boilers.

The consumption at the cooling towers is also noteworthy. In this area, the water usage is necessary to supply the losses due to evaporation and carry-over in the cooling towers and, therefore, any opportunity for reduction would be linked to the search for a possible gain in efficiency to reduce these losses.

Overall utilities consumption represents, together, the third largest demand for new water. The distribution of this consumption is the following: make-up of compressor cooling towers (42 %), make-up of a tank in the calcining area (39 %), service water (14 %), instrument purge (3 %) and non-condensable gas towers (2 %). A review of the operation of the refinery's utilities system can help to understand in more detail the efficiency of these systems, with the identification of possible improvement opportunities to reduce consumption. The focus should be on the make-up of compressor cooling towers and the make-up of the calcining area tank, which together represent 81 % of the demand of all utilities systems.

Finally, the graph also demonstrates the relevance of hydrate washing for freshwater consumption. As explained in section 4.1.1, this consumption takes place through an operational process that results in the use of industrial water for hydrate washing, to the detriment of condensate.

Boiling, cooling towers, hydrate washing and the utilities system (services, instruments and general make-ups) are responsible for the combined rate of 81 % of the entire fresh water demand of the plant. Thus, a possible reduction in the rate of water abstraction from wells is directly linked to the understanding and identification of opportunities for improvement in the operation of these areas.

4.1.3 Bauxite Pipeline Receival and Dewatering

On average, 3 batches per day of slurry are received in 2 tanks with 50 % (±2 %) of moisture. After dewatering, the remaining water is directed to treatment station C. The same occurs with the water batches coming from the pipeline, which are not regular, with an average duration of 2 hours per day. Hydro Alunorte provided data that illustrate the monthly behavior of these batches during two years of operation. These data were used as reference for the model, through the insertion of an input that estimate the continuous flowrates of the batches depending on the production rate of the refinery.

Since this water has a lower quality than the wells, due to the high concentration of suspended solids even after treatment in station C, it is only distributed to specific consumption points. As a consequence, the model quantified an excess of 65 %, which is continuously discarded as part of the plant’s nominal operation (nominal conditions).

4.1.4 Industrial and Pluvial Drainage and Effluent System

The drainage circuits (DCs) are characterized by collection points, diversion boxes and a set of channels responsible for the segregation of the effluents generated in the plant. There are a total of 9 circuits. The final destination can be the effluent treatment area, or even the return to be reprocessed in the refinery, if the conductivity is greater than 3500 µS, indicating contamination. The only point where the flow is measured in this circuit is at the return of contaminated effluent. Thus, there is a lag in monitoring of the total effluent generated in the plant and also the amount directed to each of the drainage circuits.

Regarding the industrial effluent, the quantification of flows from the refinery's continuous discharge sources are presented in Figure 5, calculated in the model base case conditions.

The pipeline water discharge is the biggest source of effluent generation. As explained in section 4.1.3, the limited use of water from the pipeline is due to the low quality of this liquid stream which can be harmful to most potential consumers in the plant.

Industrial drainage disposal is also highly relevant for the effluent generation. The total flow of industrial drainage available is a sum of the contribution of sealing water, service, instrument purge and general plant make-up water. Any surplus not consumed by the process is discarded by the sump pumps available in each area.

Another major contributor to the refinery's effluent generation is the condensate tank area, due to the high rate of condensate disposal, as explained in section 4.1.1.

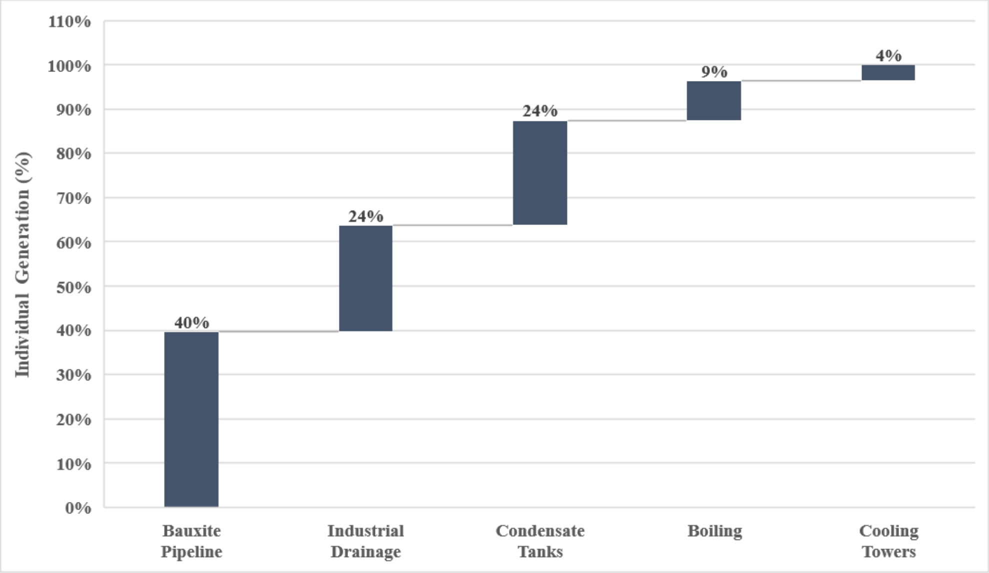

Figure 5. Industrial effluent contributors.

Pipeline effluent, industrial drainage and condensate disposal are responsible for the combined contribution of 87 % of all refinery effluent. Thus, a possible reduction in effluent generation is directly linked to understanding and identifying opportunities for improvements in the operation of these process units.

In addition to the generating sources, the steady-state modeling also allowed the quantification of industrial effluent destined for each of the DCs, as shown in Figure 6.

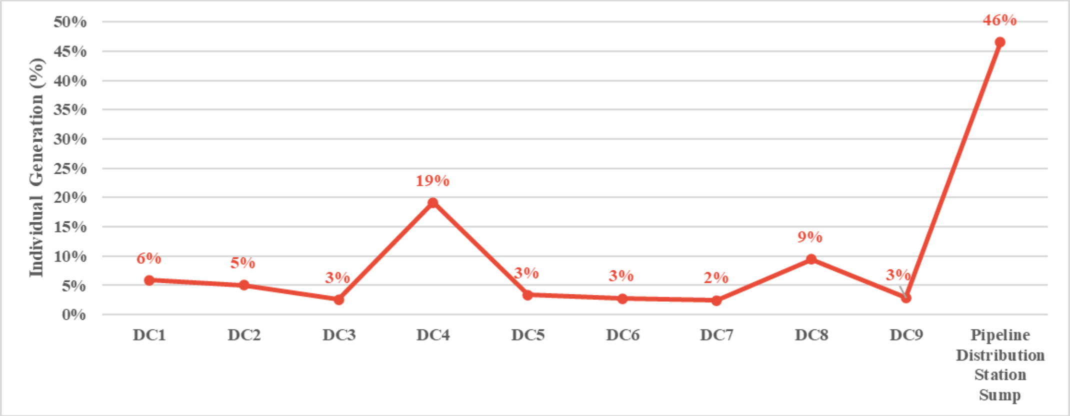

Figure 6. Industrial effluent distribution in Drainage Circuits (DCs).

To assess the pluvial contribution, average precipitation rates per month were included as inputs for the model. As in the case of industrial drainage, part of the captured water can be incorporated into the process, and the rest is destined for the drainage circuits of the corresponding areas, forming the pluvial effluent. In Figure 7, the average rainwater flowrates to be treated in each DC over a year are presented.

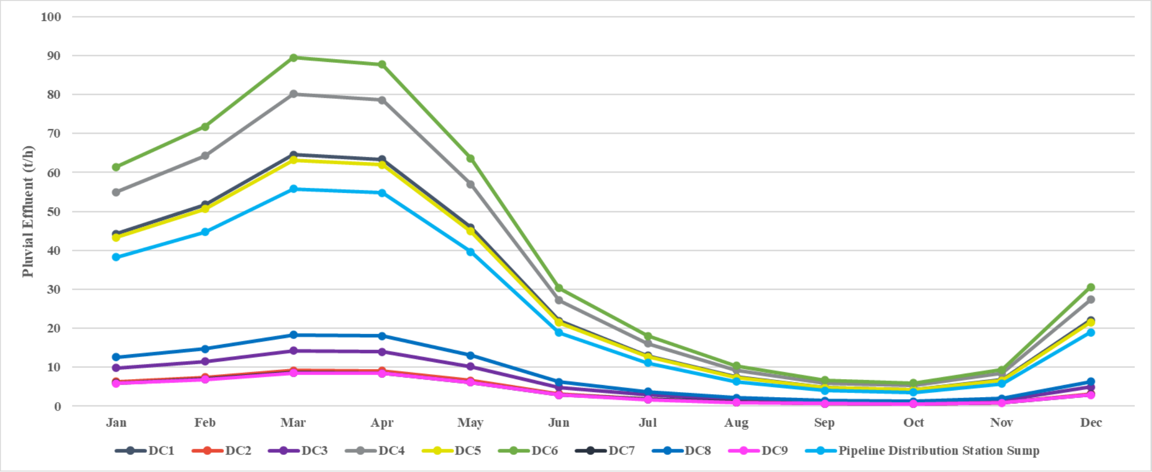

Figure 7. Pluvial effluent distribution in Drainage Circuits (DCs).

4.2 Possible Improvements

4.2.1 Flowrate Monitoring

The monitoring of the flows of main relevance to the water balance is fundamental for a correct regulation of the system, providing the numerical basis for the implementation of corrective actions in the case of deviations. A typical flowchart illustrating the sequential steps involved in decision-making is shown in Figure 8.

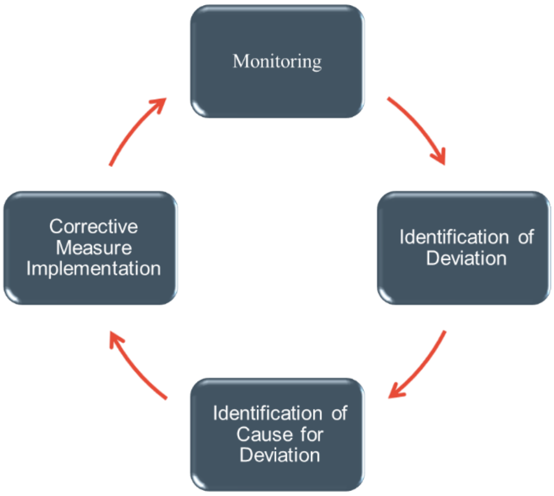

Figure 8. Water Balance Monitoring and Control Flowchart.

An effective monitoring and control system requires proper functioning of each of the steps listed in the flowchart. Possible deficiencies in any of the steps can result in inefficient corrective actions, which can generate disturbances or other knock-on effects in other areas of the water balance unrelated to the original deviation.

The main reference used for monitoring and identification of deviations is data from flow meters (FTs). Currently, due to limitations in the quantity of measurement instruments, many important flows are only accounted for through indirect calculations from other measured flows. Calculations of this type are intrinsically linked to an accumulation of measurement errors at each point, returning a result of low reliability. Therefore, the main recommendations to improve the quality of monitoring and identification of deviations is the addition of new FTs in key flows, such as condensate disposal, industrial water consumers and effluent from the drainage systems.

The root cause for deviation identification is a critical step in the current operation of Hydro Alunorte since the data and tools available are often insufficient to provide a correct assessment. The developed integrated water balance model can be of great value at this stage since it presents the cause-and-effect relationships between all the main aqueous flows of the refinery. It is recommended to use the model whenever deviations are identified in the operation, either as a tool for visualization of the flow interconnections, or as a simulator, through the construction of static scenarios representing the occurrence of possible imbalances.

As for the step of implementing corrective measures, it is extremely dependent on the success of the previous steps of monitoring, identifying the deviation and identifying the cause. Even greater effectiveness can be achieved by simulating the intended action before its actual implementation, through the static model. After implementing any corrective measure, the loop should be closed by continuing to monitor and measure performance.

4.2.2 Water Catchment and Disposal Rates

The rate of capturing new water from the wells and the disposal of excess water flows to the effluent system are directly linked. A reduction in the capture rates can be achieved by reducing consumption at the destination locations (refer to section 4.1.2) or by using alternative sources of water (refer to section 4.1.3). In both cases, this reduction would also impact the refinery's effluent generation rate, as illustrated in the interconnection flowchart shown in Figure 9.

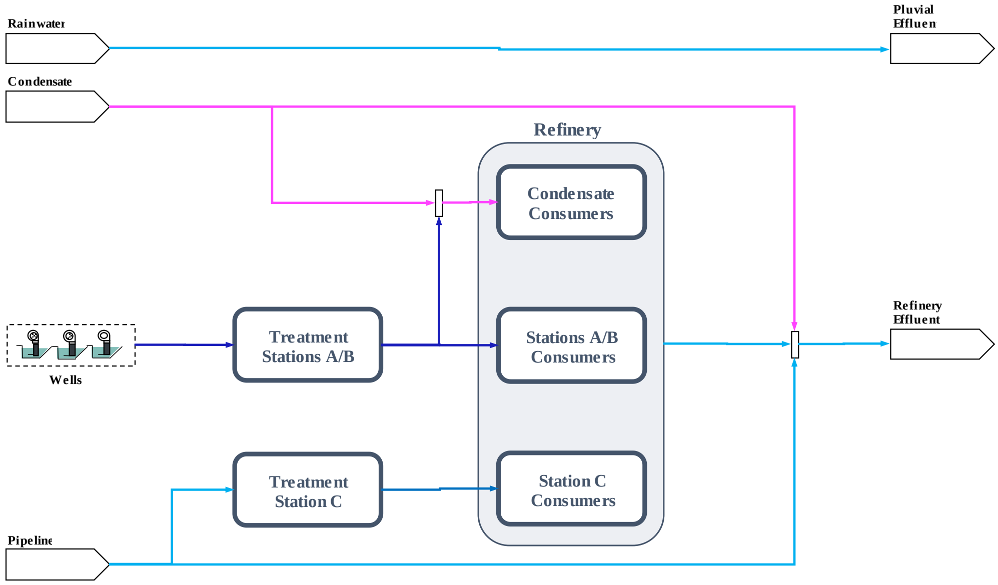

Figure 9. Water catchment and disposal flowchart.

4.2.2.1 Reduction of Industrial Water Consumption

As illustrated in Figure 9, part of the new water captured in the wells is sent, after treatment, to specific consumers of treatment stations A and B, and another part is used as a make-up for condensate consumers. Therefore, two options are possible to reduce the consumption of new water: 1) reduction of demand from consumers of stations A and B (Figure 10), or 2) reduction of make-up for condensate consumers (Figure 11).

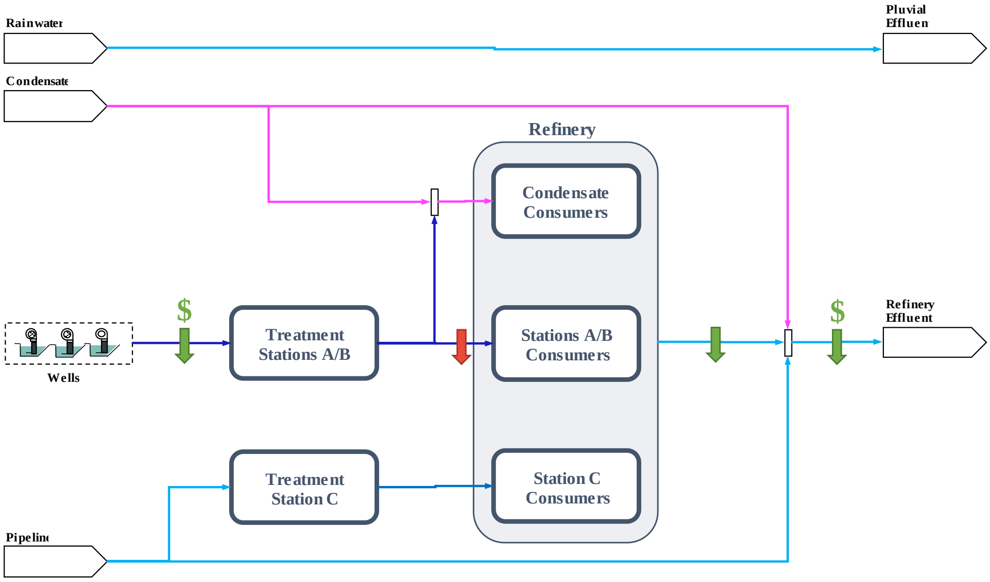

Figure 10. Impacts of decreased demand of stations A and B consumers.

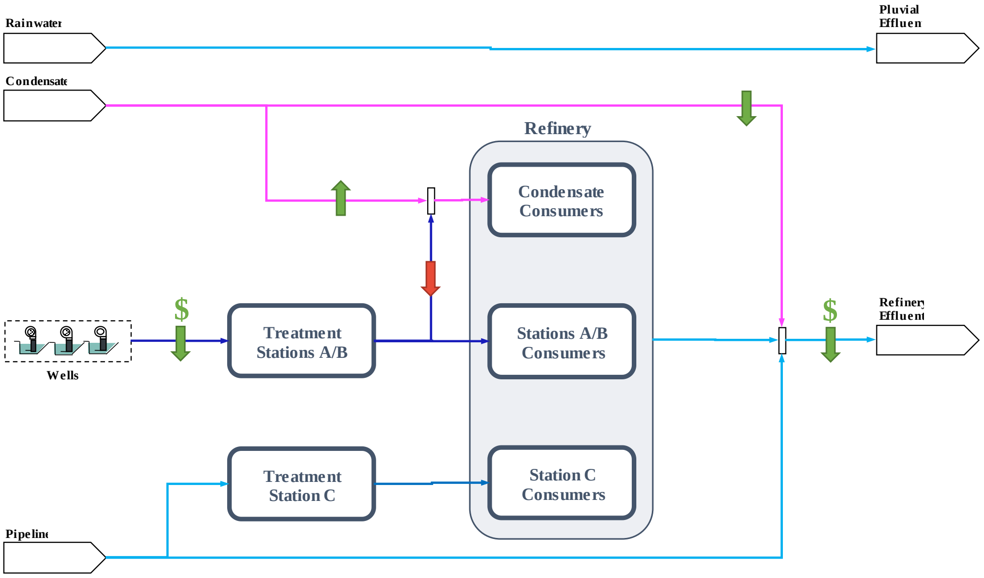

Figure 11. Impacts of make-up for condensate consumers reduction.

A simulation in the model indicates that the reduction in the demand of stations A and B consumers could reduce up to 43 % of the water catchment and 22 % of the effluent generation. The main actions that could be implemented to achieve this reduction are:

- Boiling: reduction of direct steam rate and losses in demineralization, to atmosphere and by blowdown;
- Cooling towers: improve tower efficiency, reducing evaporation losses and blowdowns. Identification and reduction of losses in the closed circuit of cooling water used for this sealing;
- Utilities System: improve efficiency in compressor cooling towers, reducing evaporative losses and blowdowns.

The same simulation was made the opportunity to reduce the consumption of make-up water for consumers of condensate , showcasing a possible reduction of up to 35 % of the water catchment and 18 % of the effluent generation. This goal could be achieved through the following actions:

- Hydrate washing: limitation of the operational maneuver that promotes the ingress of industrial water in the condensate tank;
- Boiling: increase condensate return efficiency;
- Utilities system: verification of the possibility of using the existing condensate line for tank make-up in calcining area, in detriment of the industrial water line.

4.2.2.1 Alternative Water Sources Utilization

It is noteworthy that, despite reducing the general treated water volume, the use of alternative sources or water requires an additional treatment cost, since the existing treatment station C would need to be expanded and its process adapted to adequately treat the new flows, implying in a transfer of costs. Therefore, the industrial water consumption reduction improvements explained in section 4.2.2.1 should be prioritized, since they have a direct impact on capture and disposal rates through an increase in efficiency, without the need for additional treatment costs.

The main alternative water sources identified are the bauxite pipeline (Figure 12) and rainwater (Figure 13).

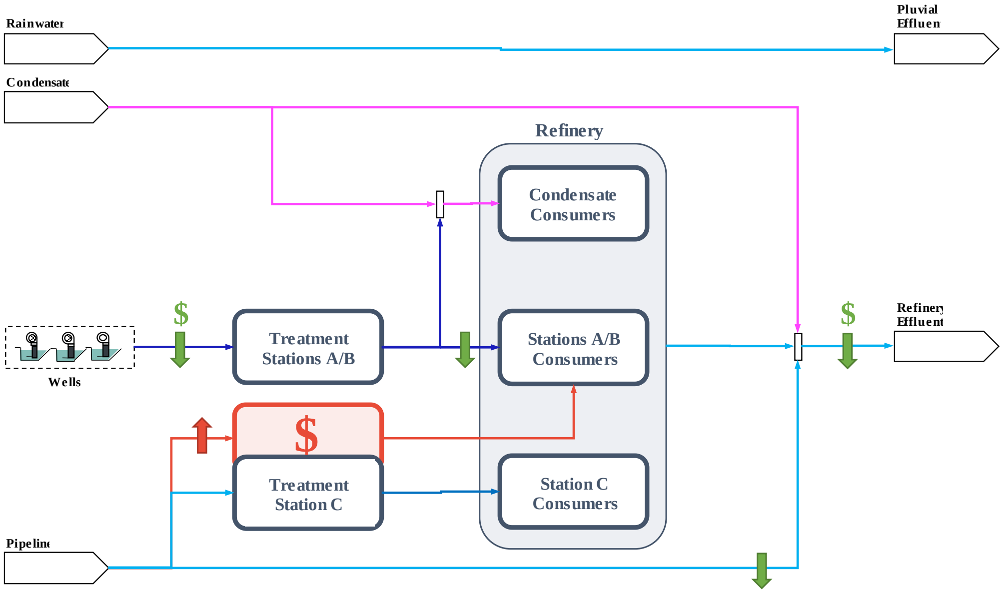

Figure 12. Impacts of increased bauxite pipeline water utilization as alternative source.

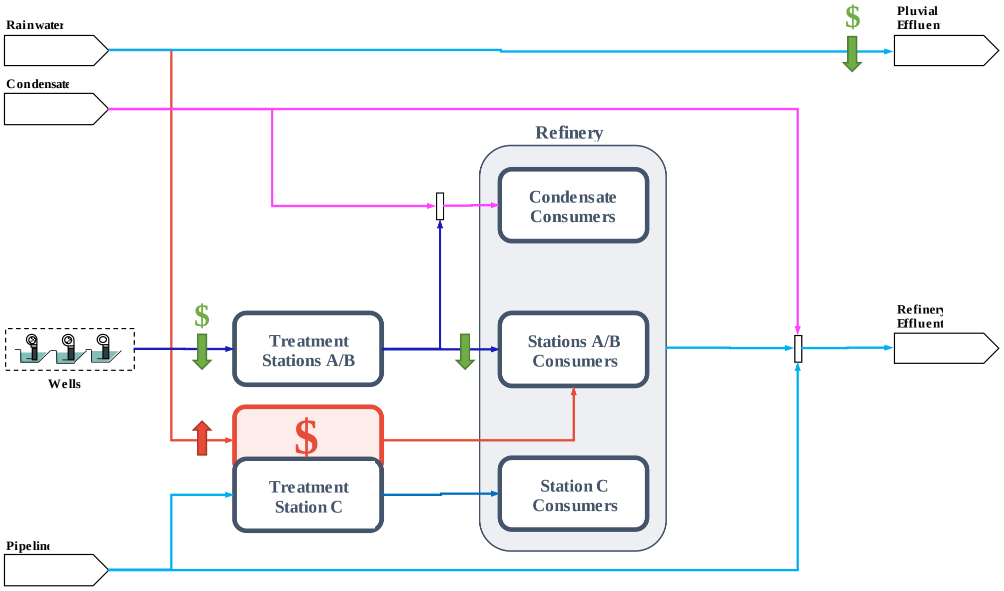

Figure 13. Impacts of rainwater utilization as alternative source.

As discussed in section 4.1.3, Hydro Alunorte currently discards 65 % of the water coming from the pipeline. If the totality of the available water could be treated and consumed, a potential reduction of 78 % of the water catchment and 40 % of the effluent generation could be achieved. These potential savings should be contrasted with the costs required for a possible expansion and adaption of treatment station C.

Regarding rainwater, in the current operation, the final destination of all rainwater is disposal, even if part of it passes through the process first. A possible treatment and distribution of this flowrate would imply in variable reduction of water catchment and effluent generation reduction rates, subject to rainwater availability throughout the year.

5. Conclusions

The integrated water balance modeling of the Alunorte refinery provided relevant information towards the water management. The steady-state model is a powerful tool to quantify important flows and to aid decision-making process for water regulation within the refinery. The base case developed was used as reference for the assessment of the current conditions and for improvements proposal.

The current conditions assessment resulted in the identification of gaps in the decision-making process, many times caused by the lack of data availability. Possible root causes for some important imbalances were also identified, such as the condensate storage. Finally, the stratification of industrial water consumption and effluent generation was also provided, allowing the determination and quantification of the main contributing areas.

Among the two main improvement opportunities to reduce water catchment and effluent generation rates, it is highlighted that the reduction of industrial water consumption should be considered as a priority instead of the possibility of using alternative sources. The reduction in consumption is presented as a direct solution, resulting in the reduction of the total volume of treated water in the plant. The use of alternative sources would represent a redirection of flows, which, despite also reducing the total amount treated, would require an extra investment to treat an additional flow, resulting in a transfer of costs.

6. References

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