Dredging of Basins for Geobags - An Innovative Solution for Sediment Management in Alumina Production

Reginaldo César[1], Giselle Lopes[2] Leonardo Braga[3] and Claudionor Pinho[4]
1, 2. Civil Maintenance Engineer
3. DRS Senior Manager
4. Infrastructure and Geotechnical Manager
Hydro Bauxite & Alumina, Barcarena, Brazil
Corresponding author: reginaldo.alvares.junior@hydro.com
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Abstract

The Bayer process, used to obtain alumina (Al_2O_3), generates large volumes of a residue characterized by high alkalinity, requiring careful management to prevent environmental impacts. At Alunorte, in Barcarena, the residue is disposed of in impermeabilized dry stacking facilities, bauxite residue disposal area (BRDA), while effluent control basins retain rainwater for treatment. Due to its fine-grained nature and susceptibility to erosion when exposed to rainfall, the material can be transported by water into the basins, settling down and reducing the available storage capacity. As a result, frequent maintenance of these basins is required. Maintaining these structures requires periodic sediment removal, traditionally carried out through mechanical cleaning. However, desilting the basins requires significant effort, in terms of removing, transporting and dispose of the sediments in the BRDA, fixing the lining system, impacting in operational downtime. Another challenge faced in tropical region is the limitation due to rainy season, meaning that maintenance can only be performed during the dry season. To overcome these challenges, a dredging system with confined disposal of underflow residues from treatment plant in Geobags was implemented, ensuring the water security of the storage facility and maintaining the available capacity in the basins. These woven-geotextile tubes retain sediments while allowing water to drain, ensuring safe and controlled deposition and performing a structural component of the stack stability. This study evaluates the performance of dredging sediments basins and disposing of the underflow in Geobags compared to the conventional mechanical method, analyzing its benefits in terms of safety, operability, and storage capacity maintenance. The methodology demonstrated operational efficiency and adequate environmental protection, standing out as a sustainable and innovative solution for bauxite residue sediments management.

Keywords: Bauxite residue, Dry stacking, Geobags, Sediment dredging, Sustainable waste disposal.

1. Introduction and Context

1.1 Climatic Characteristics

Located in Barcarena, in the northern region of Brazil, the Alunorte refinery produces alumina and operates under particularly challenging climatic conditions. Between 2021 and 2024, the average annual rainfall in the region was 2869 millimeters [1] a value significantly higher than the global average, which is around 990 millimeters per year [2].

This reflects the humid equatorial climate characteristic of the Amazon region as we can see in Figure 1. Due to the high volume of precipitation and the sensitive environmental context, Alunorte manages its filtered bauxite residue by compacting during disposal at the engineered Bauxite Residue Disposal Areas (BRDAs). The company is continuously committed to making its operations increasingly safe and more sustainable, to protect the environment and enhance reliability.

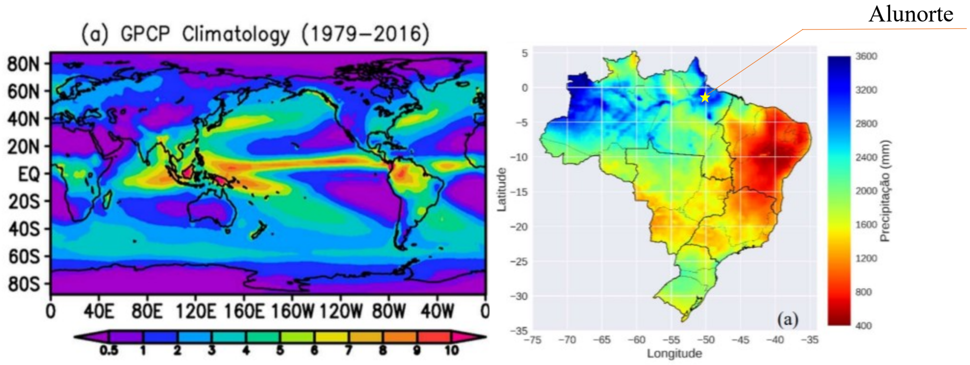

Figure 1. Global Precipitation. Left: Climatology Project (GPCP) (1979–2016) mean precipitation (mm/day) [2], Right:Historical average precipitation in Brazil in mm [1].

The Figure 2 shows the local hydrological regime recorded in Alunorte between the years 2021 and 2024, with a well-defined dry and wet seasons, directly influencing industrial operations – specially the management of waste generated by the Bayer process, which represents a significant portion of alumina production costs [3]. Owing to the rain regime shown in Figure 2, the more complex interventions are performed preferably during the second half of the year.

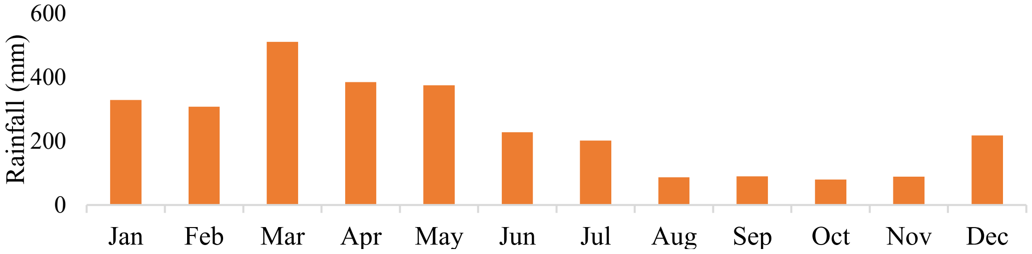

Figure 2. Recorded data from 2021 to 2024 at Hydro Alunorte in mm.

1.2 Operational Characteristics

In the context of bauxite processing, the Bayer process is widely used for alumina production, employing caustic soda under high temperatures and relatively low pressure. As a result of this process, a solid residue is generated, this residue is typically fine-grained and caustic [3].

Until 2018, Alunorte used drum filters for bauxite residue dewatering, reaching up to 64 % solids content, disposed of in the BRDA named Solid Residue Deposits 1 (DRS1) and Solid Residue Deposits 2 (DRS2) as illustrated in Figure 3. Commissioned in 2017, the filter press technology increased process efficiency, producing drier residue with 78 % solids content approximately, making it possible to employ the residue as a compacted layer that shapes the rehabilitation geometry of DRS1 and to be dry stacked in DRS2, using mechanical compaction.

For uncovered surface deposits areas, the rainwater generates a caustic effluent. This effluent is directed to control basins—lined ponds designed to temporarily store effluent composed of rainwater and bauxite residue sediments until it can be properly treated. These basins are lined with impermeable systems that promotes watertightness and the mitigating percolation to the environment.

Figure 3. Aerial view of DRS1, DRS2, and the residue cake produced by the filter press, respectively.

With a catchment area of approximately 454 hectares, the DRS is equipped with an Effluent Treatment Plant (ETP) with an average treatment rate of 3900 m^3/h, and peak capacity reaching over 14 000 m^3/h. This system plays a key role in mitigating the environmental impacts associated with water management in the industrial process [3].

The Figure 4 shows the basins of the DRS drainage system, that have a buffering volume of approximately 1.9 million cubic meters, intended for the control, temporary storage, and equalization of effluents before treatment at the dedicated station. Due to the fine particle size of the residue, the bauxite residue disposed of on the BRDAs is highly prone to erosion facilitating for sediments to be carried into the drainage systems, contributing to the silting of the basins and consequently reducing the retention capacity of these structures.

Figure 4. Aerial view of Alunorte highlighting its control basins.

To mitigate these impacts, Hydro Alunorte establishes the target of sedimentation within the basis based on biannual flood routing studies. These hydrological studies are essential for more efficient maintenance planning, ensuring that the structures remain operational even under changing environmental conditions. With this preventive approach, the company stays ahead of challenges posed by climate change and ensures compliance with legal and regulatory standards.

1.3 Mechanized Maintenance

Since 1995, the conventional cleaning process periodically employed in the control basins was consisted of mechanical excavation and sediments removal. This process involved excavating and transporting the sedimented material, removing the existing impermeable lining system to installing a complete new one. Although effective in eliminating the sediments, this approach brought operational challenges. The basins had to be temporarily segregated of the water management system retiring them from service during maintenance.

Additionally, the resulting saturated and low-density sediment was difficult to handle as shown in Figure 5. Furthermore, this type of intervention could only be carried out during the dry season, limiting its application to the second half of the year, reducing operational flexibility throughout the year.

Figure 5. Execution of mechanized cleaning.

The material removed during mechanized maintenance is sent to the BRDA DRS1 for drying and subsequent storage. As a result, it remains exposed and, again, susceptible to erosion, promoting the return of sediments to the basins, causing rework in subsequent operational cycles.

Additionally, the low density and saturation imposes additional complexity on incorporating into the residue compaction during final disposal.

Faced with the need to optimize the cleaning process, Hydro Alunorte invested in technologies that integrate operational efficiency and environmental safety. In this context, a solution based on the integration of dredging and residue storage in Geobags within a closed system was implemented. This work aims to present a summary of this process, highlighting the operational gains, focusing on the increased safety of the disposal facility.

2. Process Methodology

2.1 Basin Dredging

The dredging process is widely recognized in the technical literature and can be carried out for various reasons, such as promoting navigability in ports, channels, and waterways; flood control; extraction of construction materials; beach widening; habitat creation; and maintenance of irrigation canals and reservoirs [4].

Dredging is also used for deepening and widening channels, mineral deposit extraction, and cleaning contaminated areas. It is classified into four main types: initial dredging, used for creating or expanding channels that have not yet reached the required depth; maintenance dredging, aimed at removing sediments accumulated due to siltation; environmental dredging, focused on removing contaminants; and mining dredging, aimed at the economic extraction of submerged mineral resources [4]. Five dredgers were specially designed and implemented at Alunorte, as exhibited in Figure 6. These dredgers were designed by Hydro in partnership with a third-party company.

The dredgers are medium-sized floating vessels, measuring 12 meters by 3.2 meters, and are remotely operated, not requiring an operator on board. They are equipped with a rotating cutterhead system and high-pressure water jets, responsible for disaggregating the sediments at the bottom of the basin. Next, an integrated pumping system suctions the sediment-water mixture out of the basin, with a capacity of up to 400 cubic meters of effluent per hour. The cutterhead system includes protective rollers that limit the depth of operation, ensuring the integrity of the impermeable high density polyethylene geomembrane at the bottom of the basin.


Figure 6. Dredgers designed for use at Alunorte.

2.2 Packaging and Dewatering in Geobags

Geobags, or geotubes, are devices made from geotextiles—permeable polymeric materials used in engineering applications such as filtration, drainage, reinforcement, and erosion control presented in Figure 7. They are commonly used for dewatering residues, such as those generated from mining, sewage treatment, and industrial effluents.

They can be manufactured from woven or nonwoven geotextiles, typically made of polypropylene or polyester. For example, needle-punched woven-geotextiles perform well in retaining fine particles, such as those found in bauxite residues [5]. The dewatering process increases the solids concentration in the dredged sediments, transforming them into a solid or semi-solid form, simplifying handling and final disposal. Additionally, this process contributes to a significant reduction in the volume of contaminated sediments requiring disposal [6].


Figure 7. Geobags used at Alunorte in the dewatering process.

Compared to traditional methods such as drying lagoons, geobags require less area offering greater control over drainage and solids retention. To enhance dewatering efficiency, the addition of flocculant polymers is commonly used, reducing the material's moisture content, making the final disposal easier.

To optimize the flocculation process, bench-scale tests such as the Jar test are conducted to determine the ideal flocculant dosage. This test accurately identifies the flocculation start point and evaluates the strength of the formed flocs under high agitation, ensuring their stability and a more cost-effective operation [7]. Floc samples that maintain integrity for at least one minute under high-speed mixing are considered resistant and effective. This condition simulates the agitation caused by the static mixer and the residence time of the effluent in the pipeline, as illustrated in Figure 8.

Figure 8. Use of Jar test to determine dosage and flocculation stability.

High molecular weight cationic polymers are used to promote immediate flocculation, resulting in large, cohesive, and dense flocs [7]. The application of these flocculants in thickeners and effluent treatment leads to higher sedimentation rates, even at low concentrations. The mixing occurs directly within the pipeline through which the effluent flows, with the turbulent flow regime itself responsible for floc homogenization and the resulting separation of suspended solids.

After the polymer is added, the dredged material is pumped under pressure into the Geobags, where the formed flocs — larger than the geotextile mesh — are retained, allowing mostly water to pass through. The filling process can be carried out continuously; however, the filling up in cycles tends to optimize the effective volume usage of the geotextile tubes. The choice between these approaches depends on variables such as the solids flow rate, the permeability characteristics of the soil/geotextile system, and the material's consolidation coefficient, all of which directly influence the drying efficiency.

The operation is generally conducted with three geobags operating in an alternating cycle, allowing pauses between cycles for dewatering and consolidation of the solids as in Figure 9. As water drains and the material volume decreases, new filling cycles are initiated until the geobags reach their maximum capacity.

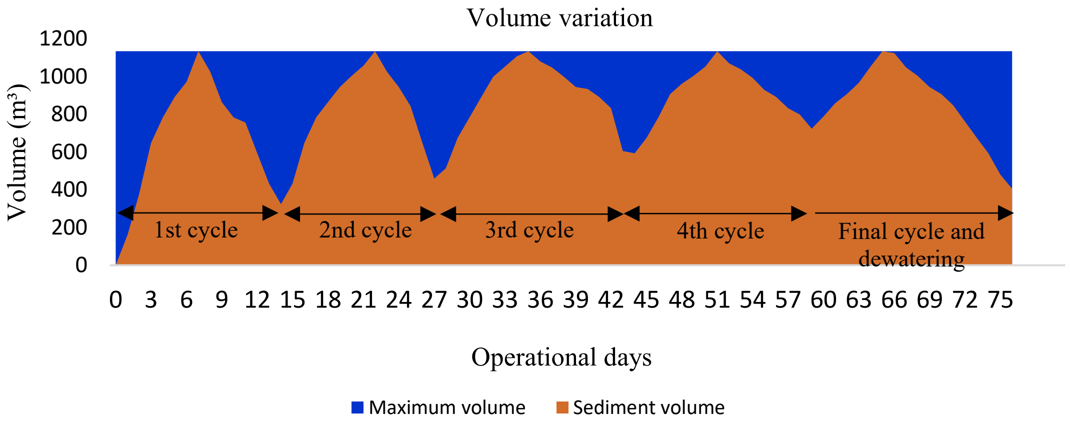

Figure 9. Cyclic filling operation of the geobags.

Afterwards, they remain in the drying phase, achieving approximately 70 % solids content, which significantly increases the density of the retained material. For the material managed at Hydro Alunorte, the loading and dewatering cycle time is 14 days, while the total operation lasts 75 days.

The dredging methodology combined with the geobag system was implemented in two basins, aiming to remove the silted material and transfer it to DRS1 with a final solids concentration of around 70 %. Operations began in January 2024, with the gradual mobilization of five dredgers, arranged to ensure operational availability and meet monthly production targets.

The adoption of the new methodology has allowed the establishment of a structured operational flow presented in Figure 10, with data showing progressive improvement over time, reflecting the process learning curve.

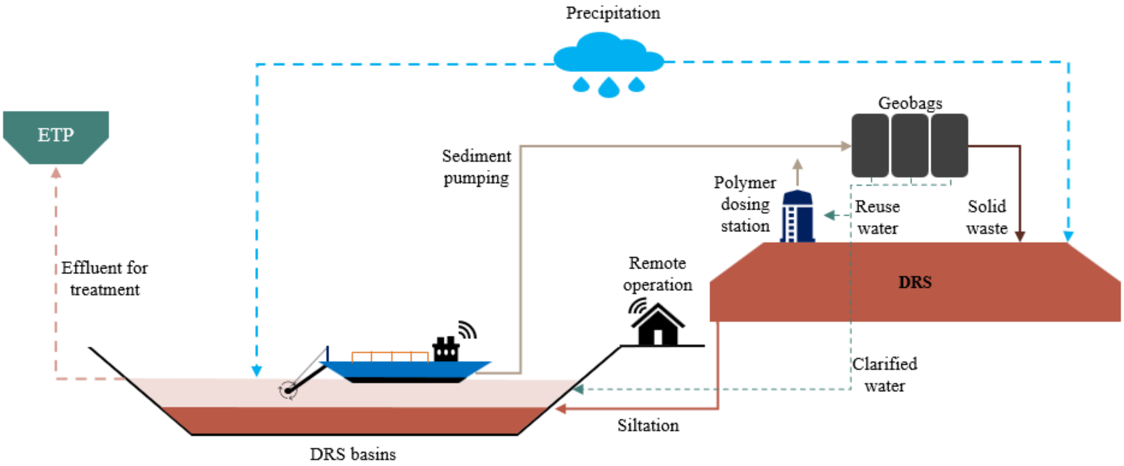

Figure 10. Process flowchart for dredging and geobag filling operations.

3. Results

3.1 Operation History

The dredging operation was gradually implemented, with the progressive deployment of dredgers according to the mobilization plan established in the contract. This strategy enabled the development of an operational learning curve, allowing continuous adjustments and efficiency gains as new units were integrated into the system, directly reflecting an increase in productivity.

In the operation history, approximately 1.2 million cubic meters of effluent were pumped from the basins to the Geobags. After the dewatering process, the clarified water was returned to the basins while the solids remained retained in the Geobags, resulting in about 91 078 m^3 of material, as illustrated in Figure 11.

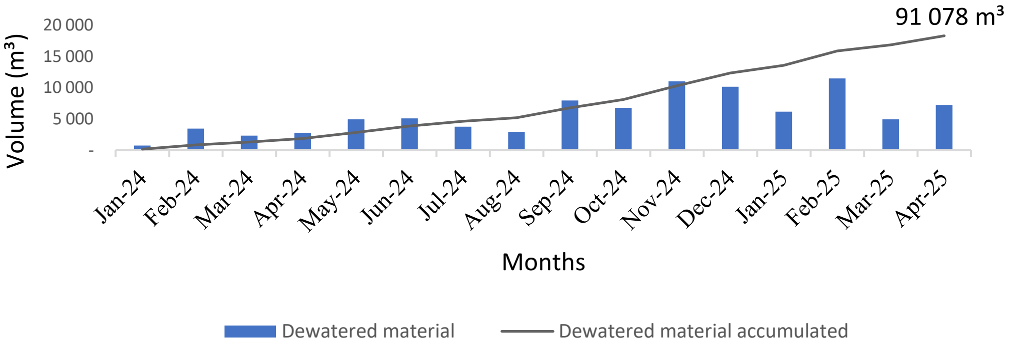

Figure 11. Volume of dewatered material.

3.2 Material Characteristics

The operation data presented in Figure 11 reflect the amount of material confined in the Geobags. However, the physical properties of the material found in the basins, the pipeline, and the Geobags show differences, resulting in variations in density, volume, and solids content. Considering that the parameters of the effluent transported through the pipeline are influenced by factors such as the degree of consolidation, polymer concentration, variations in suction power, and water levels during operation, this study will focus the analysis on the data obtained from the basins and the Geobags, allowing for a more representative and feasible comparison presented on Table 1.

Table 1. Average parameters considered in DRS operations.

Parameter	**Basins**	**Geobags**
Density (g/cm^3)	1.32	1.49
Moisture (%)	68.3	34.4
Dry density (g/cm^3)	0.78	1.11

The variation in operational parameters is considered in the cleaning calculations, given the impact of material consolidation on the different volumes involved. For this purpose, a bulking factor is applied, determined by the ratio between the dry densities of the materials in different consolidation states defined by Equation 1. This approach enables a more accurate estimation of the actual volume removed from the basin, aligning with the main objective of the project: to ensure the full availability of basin capacity for the temporary storage of stormwater.

$$BF = \gamma_{dG}/\gamma_{db} = 1.42 \tag{1}$$

where:

BF	Bulking Factor
γ_{dG}	Dry density of the fill material inside the geobags
γ_{db}	Dry density of the basin material

Thus, it is verified that the volume of material present in the basins is approximately 40 % greater than the volume generated in the Geobags. Therefore, the 91 078 m^3 of material retained in the Geobags corresponds to the cleaning of 128 739 m^3, which represents about 7 % of the total volume of the buffer capacity of DRS1 and DRS2.

Another relevant aspect is the positive balance observed in the cleaning process. If adopted, the conventional mechanized method would have sent the 128 739 m^3 of material with low consolidation rates to the DRS1. In the new scenario adopting dredging, a gain of 37 661 m^3 was achieved in consolidation efficiency demonstrating a reduction in the final volume of material to be disposed of in the BRDA, as shown in Figure 12.

Figure 12. Final condition of the dewatered Geobag.

An important environmental and operational benefit is also highlighted: the significant reduction in solid waste generation associated with the removal of the geomembrane. Under the conventional method, replacing the impermeable liner would result in the production of waste material and incurring insubstantial costs related to its replacement.

In 2024, 86 800 m³ of material were removed from the basins with dredging. To validate the effectiveness of the method, a comparison was made with the conventional approach, based on historical data from previous operations. The results of this analysis are presented in the Table 2 below.

Table 2. Unit comparison of the methods.

Cleaning Process	**Mechanized maintenance**	**Dredge**
Cleaning period	Apply only during dry season	Apply in dry and rainy seasons
Number of people	97	40
Number of equipment	33	8
Diesel consumption	1.98 L/m^3	1.85 L/m^3
CO_2 emission	5.14 kg/m^3	4.18 kg/m^3
Volume of material sent to final disposal	95 521 m^3	61 434 m^3
Solids content	55 %	74.4 %

4. Final Considerations

When comparing the operational, environmental, and safety gains provided by the new method, a significant improvement is observed in the indicators directly related to sustainable development and the reduction of human exposure to risk. The decrease in the number of trucks required for conventional cleaning reduces the presence of personnel within the disposal area and contributes to lower diesel consumption and, consequently, reduced CO_2 emissions.

One of the key advantages of this approach is the ability to carry out maintenance year-round, without relying exclusively on the dry season. This operational flexibility allows for more efficient control of sedimentation levels, in line with pre-established targets, and makes the process better equipped to handle the impacts of climate change, that could hinder the feasibility of traditional mechanized interventions.

Additionally, the waste generated after the dredging and dewatering process has a higher density, which facilitates mechanical compaction at the disposal site, contributing to the stability of the deposit and improving bonding between the deposited layers. The lower moisture content reduces both the risk of fine particle dispersion, and the amount of water adhered to the waste, aligning with best practices for safety and environmental control.

This approach is in line with global practices with the periodic review and continuous improvement of tailings management technologies and strategies, with the goal of minimizing risks and optimizing environmental outcomes, thereby enhancing the resilience of the operation to climate change and enabling adaptive management. In this way, Hydro Alunorte continues to improve the waste management initiatives contributing to a more sustainable operation.

5. References

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