Reduction of Water Infiltration on the BRDA of the Gardanne Alumina Refinery

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Abstract

Effective management of runoff water on a tailings storage facility is essential to prevent water infiltration into the ground and avoid any environmental impact. For nearly 130 years, the Gardanne alumina refinery operated a bauxite residue disposal area named Mange Garri, which is now a closed site. Initially designed to accommodate red mud, using the lagooning method, the site was subsequently converted into storage of dehydrated residue from 2006, following the commissioning of press-filter technology. Although a drainage system is present at the base of the storage facility allowing the collection of seepage, the change in the site's operating mode has made it possible to improve water management on the site, by significantly reducing the volume of water infiltrated. Extensive earthworks on the storage areas, combined with the construction of several spillways, enabled all run-off water to be channelled into a single collection pond. An ambitious and innovative project then made it possible to seal this pond, thus preventing water infiltration into the ground.

Keywords: Water, Bauxite residue, BRDA.

1. Introduction

The Mange Garri site is the historic Bauxite Residue Disposal Area (BRDA) from the Gardanne refinery. Located in the neighbouring municipality of Bouc-Bel-Air, the site received red mud from the early 1900s until 1966. Afterward, it was sent until 2015 to the "Fosse de Cassidaigne", a trench in the Mediterranean Sea, via a 60 km pipeline to a discharge point 7 km offshore and 320 m deep. From 2006, as part of a voluntary initiative to stop discharging red mud into the Mediterranean Sea, filter press technology was gradually deployed, with the successive commissioning of 3 filter presses. The Mange Garri site, which had been partially shut down, was converted into a storage facility for dehydrated bauxite residue.

Beyond the need to redevelop the site to accommodate the production of residue from the refinery, this reconversion was an opportunity to considerably improve water management on the BRDA, and in particular to significantly reduce water infiltration.

Although a drainage system is present at the base of the lagoons to continuously collect percolation water, the use of the lagooning method to operate a tailings storage facility inevitably leads to significant percolation in the stockpile, due to the water content of the tailings.

The storage of bauxite residue from filter presses (with a moisture content of less than 30 %) reduce significantly the amount of percolating water, if it is carried out in accordance with good engineering practice, taking particular care during both the design and operating phases to take measures to prevent water infiltration and encourage run-off.

As part of the redevelopment of the BRDA, and with the aim of improving both the geotechnical behaviour of the storage and the management of water on the site, major works have been undertaken, including the construction of spillways, the reshaping of storage areas and the sealing of the rainwater collection pond.

2. History of the BRDA

Cradle of alumina, the Gardanne refinery was the first Bayer process in the world to produce alumina in 1893. The Mange Garri site, located 2 km northwest of the factory, and whose operation has started in 1904 is therefore one of the oldest bauxite residue disposal areas. It comprises a total of seven ponds that have been successively developed and exploited on two valleys with a North-South orientation, named Valon d'Encorse and Valon de Mange Garri. These ponds are bounded by dykes made of limestone, forming dams perpendicular to the axis of the two valleys (Figure 1). Limestone materials were extracted locally through the opening of quarries. Under the bottom of the valleys where the ponds are located, the subsoil is made up of alternating banks of marly limestone, tertiary limestone and marl as well as clay over a thickness of approximately 250 m.

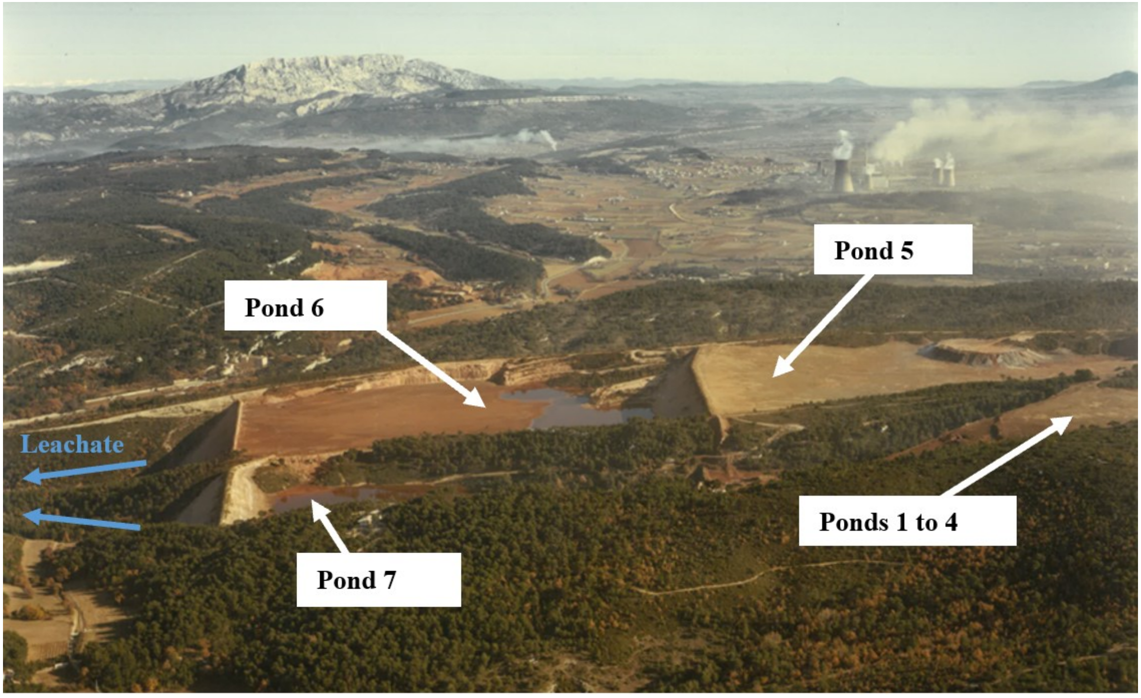

Figure 1. Aerial view of the Mange Garri BRDA around 1970.

The first six ponds were used to store the bauxite residue by lagooning before using the pipeline to the sea. The pond 7 was built to be able to occasionally store the red mud, during maintenance shutdowns on the pipeline.

A drainage and collection system for percolating water has historically been installed at the base of the ponds, allowing leachate to be directed downstream to a pumping station.
This drainage system fulfills 2 objectives:

- continuously collect percolating water from the site
- drain the soils at the foot of the dam, to evacuate rainwater, thus preventing saturation of the foundation soils

In 1966, when the storage of red mud was stopped in favour of sending it out to sea, the ponds 1 to 6 were partially revegetated. It was only from the beginning of the 2000s, in a context of gradual reduction in the volume of red mud discharged into the sea, that the site was operated again, firstly by developing small lagoons in pond 6, then by 2006, storing residue from the first filter press operation installed in the refinery.

In 2013 and 2014, with the construction of 2 additional filter presses on the Mange Garri site it was possible to completely stop discharging red mud into the sea by the end of 2015. As a result, the entire bauxite residue production has been stored on the Mange Garri site between 2016 and 2022, on ponds 5 and 6. Pond 7 was still used as a back-up to the pumping to sea, for industrial wastewater management at the Gardanne plant.

The transformation of the Gardanne refinery in 2021 and 2022, aimed at replacing bauxite feed with hydrate, resulted in the permanent cessation of bauxite residue production. Operations at the Mange Garri BRDA came to an end on 8 October 2022, approximately 130 years after receiving the first tonnes of residue.

3. BRDA Development Works

As part of the reuse of the Mange Garri site, to enable the storage of dehydrated bauxite residue, the development work is aiming at avoiding water infiltration, by channelling the runoff towards a sealed pond. To this end, a first phase of work consisted of the construction of structures and the reshaping of storage surfaces, to allow the runoff water to converge towards a rainwater pond. Following this, an ambitious project was undertaken to seal the rainwater collection pond effectively.

3.1 Construction of Spillways

Historically, the different tailings lagoons were designed to be hydraulically separated from each other. Each pond featured a classic lagoon profile, with a dam on one side, where the red mud was discharged, and a low point on the other, where the water could evaporate or be pumped to the plant. Consequently, there was no connection between ponds 5 and 6 and pond 7.

The first challenge was to ensure that surface water from the entire site could runoff to a single point. To accomplish this, concrete spillways were constructed to channel runoff water from the upstream areas of the site to flow downstream. As part of this project, two main structures were built. The first spillway, built in 2009, was connecting ponds 6 and 7, while the second, built in 2017, was connecting ponds 5 and 7.

The construction of these structures was a prerequisite for larger-scale works, consisting of re-profiling all the storage areas in order to channel the water towards these spillways.

3.2 Reshaping of Storage Areas

The earthworks of the tailings ponds were possible using the bauxite residue produced by the filter presses. Indeed, the bauxite residue which has low permeability (10^{-8} m/s) allows water runoff. Firstly, a reshaping of pond 6 was initiated between 2013 and 2016, followed by a reshaping of pond 5 from 2017 to 2018. The initial south-facing slope has been reversed to the north, so that surface water flows directly into the spillways created beforehand. To achieve a slope of 3 to 5 % towards the north, 550 000 m^3 of tailings were stored on pond 6 and 300 000 m^3 on pond 5. Once this reshaping was completed, the storage of bauxite residue has continued from 2018 on pond 6, by operating storage compartments.

The method of storage also plays a key role in reducing water infiltration. Indeed, although the storage profile ultimately encourages runoff, it is crucial to ensure that the same level of care is maintained throughout the operations to prevent water from stagnating and infiltrating. The following measures have been implemented:

- The creation of a drainage network at the base of the storage compartments (Figure 2) allowed water runoff, particularly during storms, preventing infiltration and allowing easier operations.
- Implementation of drainage shafts within the storage compartments maintained effective drainage until final filling level of the compartments was achieved. The purpose of these structures is also to continue drainage once the landfill has been completed. This improves the geotechnical behaviour of the storage facility and helps to drain residual impregnation water.
- During the unloading of bauxite residue into the storage compartments using dump trucks, the residue was spread daily with a bulldozer to achieve a layer of approximately 40 cm, thereby promoting water runoff.
- Slopes of around 3 to 5 % in the operating compartments were adopted to encourage runoff and to limit erosion phenomena.
- A set of ditches was implemented on the surface of ponds 5 and pond 6.

Monitoring the evolution of the water saturation level within the residue storage areas was carried out using piezometers located in ponds 5 and 6which showed a significant decrease in water level since 2015 (Figure 3) thus demonstrating the effectiveness of the work undertaken.

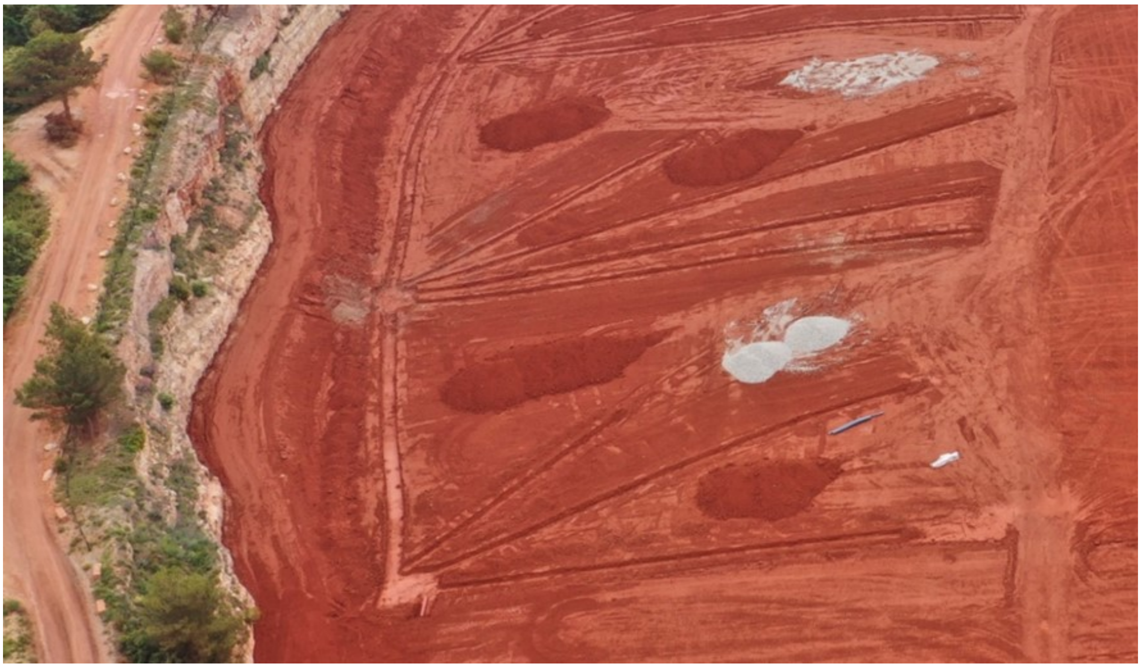

Figure 2. Implementation of a drainage network at the base of a storage compartment.

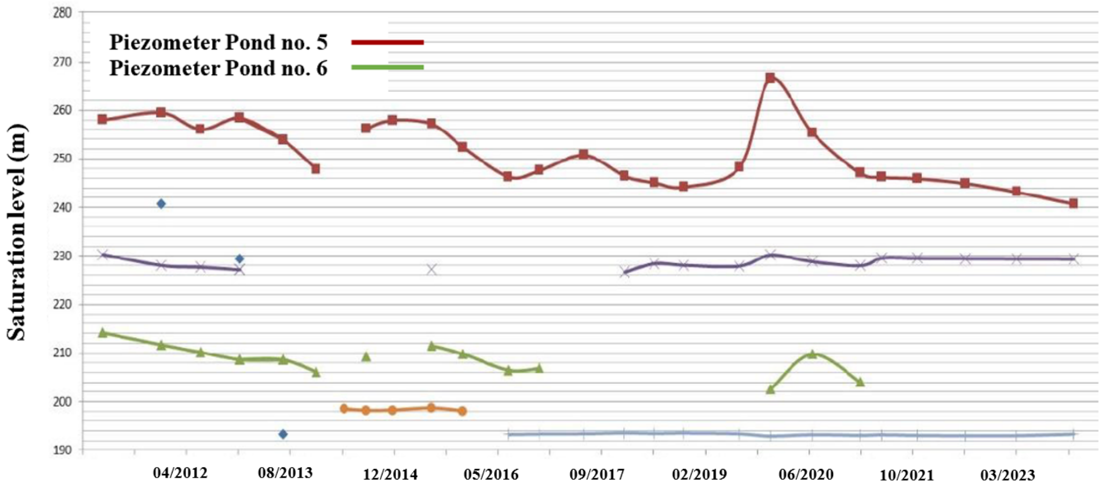

Figure 3. Evolution of the saturation level in ponds 5 and 6.

3.3 Sealing of the Rainwater Collection Pond

In 2016, the authorities required ALTEO to build a sealed rainwater collection pond on the site with a capacity of 110 000 m^3 to store the volume of a 10-year rainfall. The development of the surroundings of this pond also had to accommodate the storage of 304 000 m^3 volume corresponding to a 100-year rainfall event.

All the aforementioned work allowed for the redirection of all runoffs from the storage areas to a single point into pond 7. Initially designed to receive red mud during shutdown maintenance on the pipeline out to sea, this pond was built downstream of the others, making it an ideal location for collecting rainwater. In order to meet the requirements of the authorities, pond 7 had to be sealed. However, since its creation, the pond had always been kept filled with water resulting in the base soils of the pond being very wet and offering almost zero bearing capacity (Figures 4 and 5). The main challenge of this project was to allow the movement of machinery to install a waterproof membrane.

Figure 4. Digging test with a long reach excavator.

Figure 5. Overall view of pond 7 at the start of the works.

A second challenge was to guarantee the integrity of the membrane once the pond was filled with water, due to the compressible nature of the soil. To meet these constraints, a system consisting of several layers was implemented over the entire surface area of the pond (4.5 ha):

- Firstly, a trafficability geogrid, covered with 70 cm of bauxite residue, was required to increase the bearing capacity of the soil and allow access with earthmoving machinery.
- A reinforcement geogrid covered with 30 cm of bauxite residue made it possible to strengthen the basin.
- The complex {Bentonite geosynthetic + HDPE (high density polyethylene) membrane} forming a passive and active safety barrier was then installed.
- Finally, a geotextile and a 30-centimeter layer of gravel were laid to protect and ballast the membrane.

Figure 6 shows a detailed cross-section of this system.

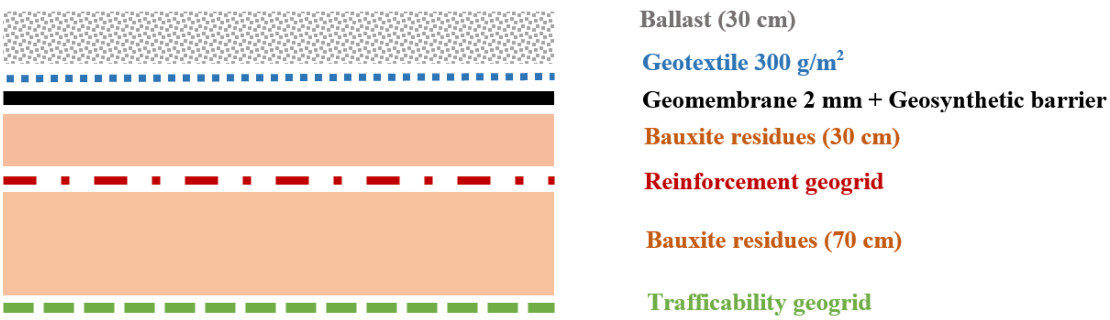

Figure 6. Detailed cross-section of the system implemented at the bottom of the pond.

The commencement of the work, however, was dependent on emptying the pond, which had accumulated a high inventory of water due to several consecutive rainy episodes. 90 000 m³ of water had to be pumped back to the plant in the space of 4 months to eliminate this accumulation of water. Due to the length of time required to construct the different layers detailed above, and in order to protect the site, water management during the works required the creation of temporary dams to retain water upstream of the spillways.

In summary, more than 2 years of studies, 1 year of pre-works and 6 months of construction work were necessary to carry out this monumental project, which involved 30 people. Figure 7, which shows the progress of the works, gives an idea of the scale of the project.

Figure 7. Overview of the rainwater collection pond sealing project.

4. Impact on the Reduction of Water Infiltration

All the measures described below have helped to prevent the infiltration of water into the ground:

- Earthworking of the storage areas reduced percolation into the ground by promoting water runoff towards the rainwater collection pond using the new constructed spillways.
- The use of appropriate operating techniques within the storage compartments has maximised run-off.
- The sealing of pond 7 has eliminated the water infiltration historically present in this area.

In just a few years, water infiltration has been considerably reduced. This improvement was observed by monitoring the flow rate of percolation water collected downstream of the BRDA (Figure 8). This reduction was recorded continuously for several years.

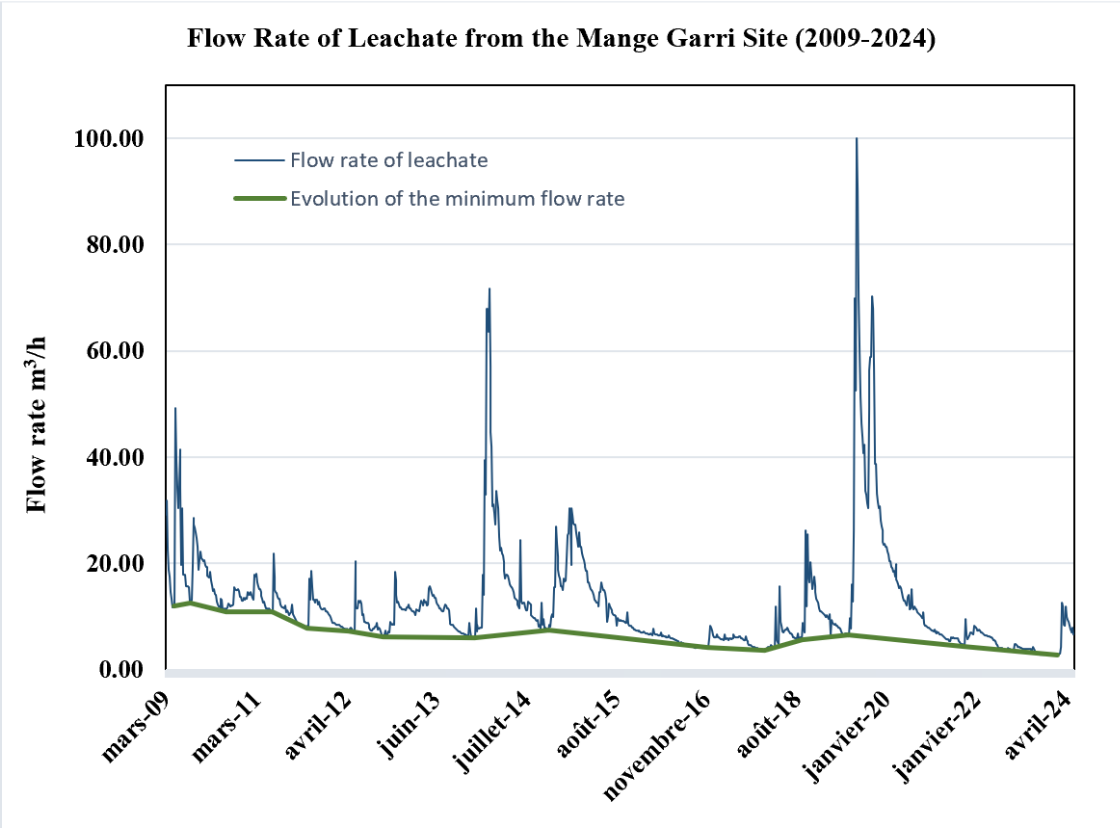

Figure 8. Flow rate of leachate from the Mange Garri BRDA (2009-2024).

We have observed a progressive decrease in the minimum levels recorded between two rainy events. Prior to 2016, the minimum flow rate was 6 m^3/h. After 2016, the minimum flow rate dropped to 4 m^3/h, and in February 2024 has reduced below 3 m^3/h, best performance achieved so far. Even if percolation is a slow and complex phenomenon to analyse, the result of this monitoring shows a significant improvement with a continuous downward trend.

As mentioned above, it is important to note that the flow peaks recorded correspond to occasional increases following rainfall events. These are not representative of the flow of percolation water. Indeed, during these rainfall events, the drainage system continues to evacuate water from the tailings storage ponds but also evacuates water downstream of the dams, thus preventing saturation of the soil.

5. Conclusions

After more than 10 years of project work, the configuration of the Mange Garri BRDA achieved the objective initially set, by allowing optimized water management that prevents runoff water from infiltrating into the ground. Although the reduction in the volume of percolation water following these works may be slow due to the low permeability of the residue, the measured leachate flow rate dowstream shows encouraging results.

On October 8, 2022, operations at the BRDA came to a definitive halt, as part of the transformation of the Gardanne refinery, aimed at replacing bauxite feed with hydrate. Following this, a compost cover was implemented over the entire site. Initially intended to eliminate the risk of dust emissions, it also prevents rainwater from coming into contact with bauxite residue, as demonstrated by the color of the water in pond 7, visible in the foreground of Figure 9.

Even if the BRDA development works was initially intended to support operations at the Mange Garri site, it has nevertheless helped to initiate its rehabilitation.

Figure 9. Aerial view of the BRDA in June 2023.