Numerical Simulation: a Performing Tool for Water Management in Tailings Impoundments

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Abstract
The mining industry produces very large quantities of fine-grained tailings that are generally disposed of in slurry form into dedicated impoundments. The twofold purpose of these impoundments is to contain the solids and achieve clarification of the process water for re-use. They are increasingly scrutinized with respect to their environmental performances, since they have impacts on both water availability and quality mainly through water exchanges with the aquifer, and with respect to the mechanical stability of their tailings. Currently, it is difficult to have such information through on-line measures. In this article, the authors present a simulation environment for water management in tailings impoundment. It is concluded that computer simulation is a powerful tool for an environmental standpoint as well as for assisting professionals with design and operation of tailings ponds.

Key words: simulation, tailings impoundment, water management, tailings mechanical stability, consolidation, water exchanges with the aquifer

Introduction
Mining activities provide economic benefits for many countries around the world. However, the mining industry also generates large amounts of various wastes that can have negative impacts on the environment if they are not properly managed (Benzaazoua, 2008). Among these, significant amount of fine-grained wastes referred to as tailings are produced. Disposed of in slurry form, tailings are generally discharged into dedicated impoundments which purposes are to confine the solids within their boundaries and to achieve clarification of the process water for re-use (Environment Canada, 1987). These impoundments are becoming increasingly scrutinized with respect to their influence on water resources. Indeed, tailings disposal has an impact on the fresh water consumption since in many cases it is the largest source of water losses through residual moisture in the tailings and seepage. Recycling of clarified water in the mine process is then crucial since it allows reducing the environmental impact as well as the freshwater requirements (Ritcey, 2005). Tailings ponds can also be a source of pollution through migration of pollutants with water exchanges with the hydrogeological formations. Another potential implication is the mechanical stability of tailings once the impoundment is no longer in use. Indeed, the specific geotechnical properties of many fine-grained tailings, combined with the abundant presence of water, can lead in some situations to problems of instability (Younger and Wolkersdorfer, 2004) which is of particular concern in terms of public safety and land reclamation for re-use.
Currently, it is difficult to measure on line the water transfers between a tailings pond and its surrounding aquifer as well as the tailings mechanical stability over time. To obtain such information, a quantitative understanding of the complicated interactions between water flows; solids transport, deposition and consolidation; and morphological evolution is required. Simulation tools are then necessary to evaluate the various impacts of a tailing impoundment upon its environment. Existing numerical models have only been developed for predicting solids and water transport within a tailings impoundment (Consoli and Sills, 2000) and they do not predict the water exchanges between the impoundment and its surrounding hydrogeological formations as well as tailings consolidation state. This article aims to fill this gap of numerical simulation by presenting a simulation environment for water management related to tailings impoundment in the mining industry.

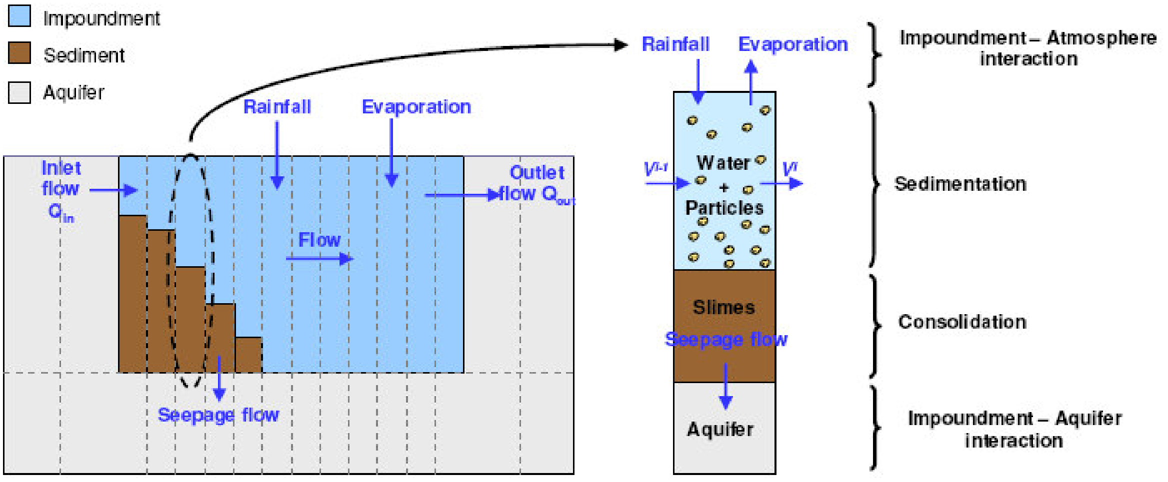
Model presentation

The model takes into account three families of governing processes that interact with one another:

- Water transport:
  - in the impoundment, process water is transported between the impoundment inlet and outlet.
  - in the surrounding aquifer, water can be exchanged depending on the properties of the groundwater flow around the impoundment.
- Solids transport: the fine particles suspended in the process water are transported and deposited at preferential locations within the impoundment, depending on local flow field, which is itself modified by particle deposition.
- Sediments consolidation: particles deposition leads to the formation of a sediment deposit undergoing self-weight consolidation, thereby modifying the topography of the impoundment and the flow field inside the impoundment.

The numerical model takes into account the transient nature of the involved phenomena. To reduce the calculation time, a 2-dimensional configuration has been chosen (depth and main direction). Figure 1 presents the discretization scheme for the impoundment and its surroundings. The calculation domain is divided into cells. An impoundment cell is characterized by flow parameters (flow velocity, water exchange flowrate between the aquifer and the impoundment, average concentration of the suspended particles) and sediment characteristics (sediment height, void ratio). An aquifer cell is characterized by its hydraulic head. The water stage is the same in all impoundment cells.

***Figure 1** Schematic representation of the discretization of the impoundment and its environment*



The simulation consists in calculating these parameters at each time step by solving the coupled equations of water transport, solid transport and sediment consolidation. By convention, all fluxes are positive when they come inside the impoundment and negative if they go out of it.

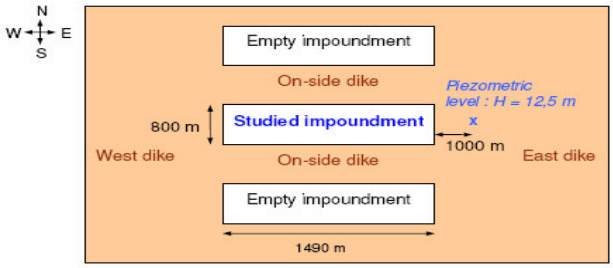
Case study

Presentation of the case study

The simulation tool was applied to an impoundment formerly used in a phosphate mine in Senegal. This impoundment is represented in Figure 2. It has an area of 119.2 ha with a depth of 38 m. It is built in a multilayer aquifer. The process water, which contains 157 g/l of suspended solids with a 4µm mean diameter, fed it with a flowrate of 1440 m^3/h. Clarified water is collected through the use of a spillway.

As shown in Figure 2, two empty impoundments border the studied impoundment. This involves a zero head on the on-side wall. Moreover, there is a draining layer of marl of 1m thick bellow the pond. Recycled water corresponds to water collected by the spillway, drained water and water infiltrated through on-side walls.

Figure 2 Top view of the studied impoundment and its surroundings



Simulation results

The filling of this impoundment was simulated over 3.25 years, i.e. 1186 days. Some results given by the simulation are presented hereinafter. They allow predicting the impoundment filling, the amount of recycled water and the water exchanges with the aquifer over time.

Figure 3 shows the evolution of the water stage with time. It should be indicated here that the first 7.5m correspond to the bottom levelling due to the presence of marl deposits. After 3.25 years, the water stage is 28.9m with a sediment outcrop over nearly 75% of the impoundment area. This simulation result is very close to what was noticed on the real impoundment, the deviation being about 1%. Evolution of the sediment deposit with time is also represented in Figure 3. Gentle sediment fronts are explained by slow settling velocity compared to the flow velocity.

As it can be seen in Figure 4, the model is able to calculate the evolution of the void ratio profile of the sediment deposit. This figure highlights the bad consolidation properties of the sediments, the void ratio being always higher than 2 and the most consolidated layer (void ratio between 2 and 5) being lower than 10m. This is due to their composition, a high clay content, and to their low particle size. These bad consolidation properties explain the low water recycling rate (Figure 5) and involve that at the end of the pond lifetime, a high amount of water is entrapped in the sediment deposit (the residual moisture being always higher than 45%) and then will not be recycled. The consolidation state of the sediment deposit is a key parameter to determine which type of rehabilitation is adapted to the site after the complete filling of the impoundment. In this case, rehabilitation will be difficult due to its instability.

***Figure 3** Evolution of the impoundment filling over time*

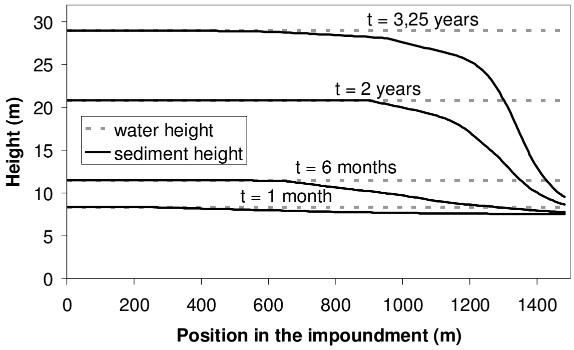


***Figure 4** Evolution of the void ratio profile in the first cell over time*

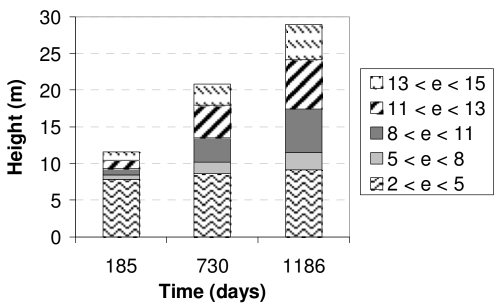


***Figure 5:** Evolution of the water recycling rate over time*

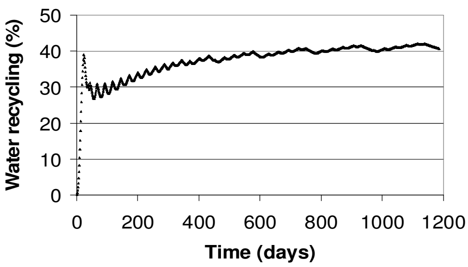
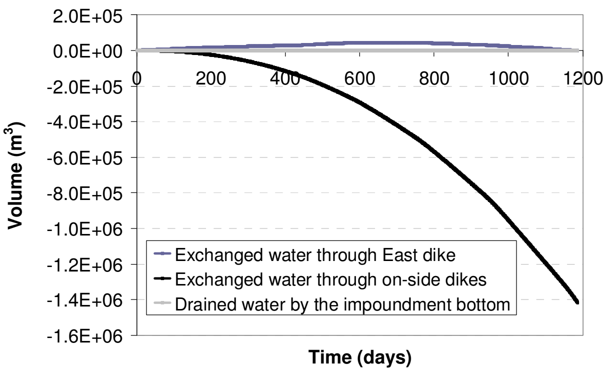


Figure 6 shows the evolution of the water volumes exchanged at the interface between the impoundment and the aquifer, these volumes being positive if they come inside the impoundment and negative if they go out of it. It can be seen that water exchanges through the impoundment bottom are very low, this being due to the clogging of the impoundment bottom by the sediment deposit. Water volumes exchanged through the East dike are also very low and their trend, firstly increasing and then decreasing, underlines the influence of the aquifer properties (hydraulic conductivity and head) on the impoundment/aquifer interactions. Moreover, a great amount of water leaks through the on-side dikes (negative water volumes) due to the presence of empty impoundments on every side so this water transfer has an influence on the water budget of the impoundment. Here, this infiltrated water is collected and its fraction in the recycled water volume represents nearly 9% at the end of the simulation time.

Figure 6 *Evolution of the water volume exchanged with the aquifer (added over time)*



Information given by this model about tailings mechanical stability and about water exchanges between a tailings pond and its surrounding aquifer cannot be obtained through on-line measures or derived from empiricism. This latter information is particularly interesting for evaluation of the impoundment impacts on the groundwater quantity and quality because it allows evaluating water recycling rate and then the withdrawals in the aquifer for the mining process and it also allows predicting tranfers of pollutants from the impoundment to the aquifer.

Conclusion

This article presents a simulation environment for water management related to tailings impoundment in the mining industry. Based on coupling between transport, deposition and consolidation processes, this numerical model is able to predict the timed evolution of a full-scale tailings pond. Information given by this simulation tool makes it a potentially valuable tool for water management. Indeed, simulation results allow predicting water exchanges between a tailings pond and its surrounding aquifer and their influence on its water budget. This model can then be used to evaluate the impacts of a tailings impoundment on water availability and quality. Beyond the benefit of the simulation tool for an environmental standpoint, it can also be useful for design, production and rehabilitation purposes since it yields numerous information including instantaneous slimes storage volume reserves, available amount of clarified water, impoundment lifetime and consolidation state of the sediment deposit.

References

Benzaazoua M. Bussière B., Demers I., Aubertin M., Fried E. and Blier A. (2008). Integrated mine tailings management by combining environmental desulphurization and cemented paste backfill: Application to mine Doyon, Quebec, Canada. Minerals Engineering 21: 330-340.

Consoli N.C. and Sills G.C. (2000). Soil formation from tailings: comparison of predictions and field measurements. Géotechnique 50 (1): 25-33.

Environment Canada - Mining, Mineral and Metallurgical Process Division (1987). Mine and Mill Wastewater Treatment. Report EPS 2/MM/3. Minister of Supply and Services Canada Catalog NO. En 49-7/2-3.

Ritcey G.M. (2005). Tailings management in gold plants. Hydrometallurgy 78: 3-20.

Younger P.L. and Wolkersdorfer C. (2004). Mining Impacts on the Fresh Water Environment: Technical and Managerial Guidelines for Catchment Scale Management. Mine Water and the Environment 23: 2-80.