WATER MANAGEMENT IN TROPICAL NICKEL LATERITE HEAP LEACH PROJECTS

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ABSTRACT

Water management in tropical nickel laterite projects has been discussed from the following perspectives, firstly geotechnical options to reduce water ingress into the heap leach and residue storage facility; secondly the maximization of water recycle within the process plant to minimize effluent discharge; and finally the application of dynamic water balance modeling to investigate water management strategies and to undertake surge analyses of in-process ponds. The active use of raincovers for both heap leaching and residue storage facilities is critical to minimize water ingress, particularly during high rainfall periods. RSF design is also important to ensure the stabilization of the RSF facility, which will increase in size over time, and is a major contributor to contaminated water recycle to the process plant. Careful geotechnical design is required to ensure that this facility occupies the smallest ultimate footprint area, without sacrificing geotechnical stability. Finally in-process ponds need to be sized appropriately under maximum rainfall cases in order to prevent high rainfall events leading to uncontrolled effluent disposal. Dynamic water balance modeling is discussed as a technique to undertake such an analysis, as well as analyze different water management strategies.

INTRODUCTION

One of the major challenges in nickel laterite processing in tropical climates is water management, particularly for inland situations where sulphate-containing effluent disposal is either difficult or not possible due to environmental restrictions. Currently nickel laterite heap leaching is being pursued in a number of projects including European Nickel's Çaldaĝ project in Turkey and Acoje project in the Philippines, Vale's São João do Piauí Project in Brazil and BHP Billiton's Cerro Matoso project in Colombia, many of which are located in tropical rainfall situations. From a water management perspective, nickel laterite heap leaching offers many benefits in tropical climates, particularly in the potential to recycle treated process liquors. However water ingress during heap leaching and tailings disposal can lead to excess heavy-metal-containing effluent generation, particularly during high rainfall events.

The authors have been heavily involved in the evaluation, design and on-going support of a substantial number of copper, gold and nickel heap leach projects located in tropical climatics, and are currently actively working with several clients developing tropical nickel laterite heap leach projects. The current paper examines water management strategies for nickel laterite heap leach projects from two perspectives, firstly the geotechnical perspective which is aimed at reducing rainfall ingress by methods such as the active use of raincovers and, in the case of residue storage facilities, capping and sealing; and secondly from a water management perspective, where water management strategies can be evaluated using dynamic water balances of the overall project (combining heap leaching, residue storage facility, inventories such as ponds, process plant, water treatment options and treated water recycle). This dynamic modelling approach can be a valuable water management tool during water management investigations of projects, as a range of climatic conditions can be evaluated ranging from dry year or monthly events, normal design conditions through to maximum or extreme years or events.

RAINFALL MANAGEMENT IN TROPICAL NICKEL LATERITE PROJECTS

High Rainfall Management during Heap Leaching

Tropical projects can experience very high annual rainfall, with average annual precipitations from 2,000 mm to over 4,000 mm common. Tropical storms can also be very intense, with peak rainfall of over 200 mm in a few hours. The high annual rainfall presents problems of surplus water, both in terms of water management, and making some construction activities very difficult or impossible (including operation of the stacking equipment for ore, residue and ripios stacking as well as deploying liners). Intense storms can also damage agglomerates, creating impervious surface areas and zones of channelling within the heap and otherwise impede leaching. To address these various concerns a multi-facetted approach can be integrated into the project, including:

- Raincoats (thin geomembranes used as a cover) to shed rainwater from the heap and dumps, and to protect fresh agglomerates. Examples of raincoat application are discussed by one of the current authors in [1] and [2].
- Dual-stacker methods for multi-stack heaps, using retreat methods for normal heap operations and advance stacking for the residue dump or the heap (if the agglomerates are sufficiently durable) during wet season operations, all with low ground pressure equipment [3];
- Heap stacking may need to be discontinued during high rainfall periods (and thus the design should recognize this in the agglomerator and stacker availabilities);
- Fly-ash or Portland cement stabilization of the external shell of the residue & ripios dumps for both erosion and slope stability (discussed previously). In extreme cases this may also be required in the outer shell of a multi-stack heap, possibly requiring re-handling of that portion of the ore after leaching;
- Stabilization of the underlying lift of leached ore in multi-stack operations, using combinations of reinforcing grids, waste rock, and fly-ash or Portland cement stabilization were the ripios is not sufficiently strong to support the stacking equipment; and,
- Adequate bleed neutralization capacity and water management strategies to prevent or at least minimize effluent disposal.

The current paper targets three areas particularly relevant to nickel laterite heap leaching in tropical conditions – the active use of raincovers during heap leaching, prevention of rain ingress into residue storage facilities, and water management strategies during processing.

Use of Raincovers in Heap Leaching

One of the techniques almost universally used to manage high rainfall is the application of temporary geomembrane covers or "raincoats." More specifically, a raincoat is placed over the heap, ripios or residue dump to shed rainwater from the system before it enters the process circuit. An industry review completed in 2006 and updated in 2008 [1] found 34 heap leach projects that have used or are planning to use raincoats. Among these are current installations at Pierina (Au, Peru), Philex (Au, Philippines) and four projects in planning (two commercial gold plants in Northern Mexico and nickel pilot plants in the Philippines and South America). Raincoats were first used in heap leaching in the late 1980s on gold ore heaps in Costa Rica to allow continuous wet season heap leaching in a very high-rainfall climate. The covers provided several wet season improvements including:

- Reduced surplus water and reduced water management issues;
- Less dilution of process solutions for improved metal recovery;
- Reduced reagent consumption in recirculated solutions;
- Reduced likelihood of accidental spills due to excessive storm water accumulation or excessive flows in process solution channels or piping;
- Reduced damage to the surface of the heap and ore agglomerates caused by falling raindrops (impact damage) and sheet flow (erosion);
- Reduced pond sizes and a reduction in or avoidance of the need to treat surplus water for discharge; and,
- Reduced erosion and slope instability.

Unlike semi-permanent to permanent covers used in other industries such as landfills, raincoats are generally intended for short-term wet-season use, often with dry-season removal to aid in ore placement, irrigation network maintenance, and to encourage evaporation. Thus, their design can be less robust and more operator-friendly.

Stabilization of Residue Storage Facilities (RSF) and Mitigation of Rain Ingress

Plant residue (iron filtration, bleed water neutralization and other residues) can be very difficult to manage given the generally poor geotechnical properties. In nickel heap leaching these residues will generally be filtered as part of the process circuit, improving their performance in the dump. Nevertheless, these residues will generally exhibit low shear strength, high susceptibility to static and dynamic liquefaction, low permeability and very low traffic support capabilities. Spent ore (ripios) from a dynamic heap (on/off leach pad) may also demonstrate similar behaviour, depending of course on the nature of the ore and the degree of degradation during leaching.

When raincoats are used for water control, the primary point of ingress of rain fall is the active working face of the RSF dump; that is, the area between the deployed raincoats and the active stacking operations. The amount of open area will be a function of: the rate of advance of the dump (the faster the advancement the more complex it will be to keep the rain coats very close to the active face); the thickness of each lift (thicker lifts reduce advance rates and reduce the active dump area); and the effort applied to raincoat deployment ("active" versus "passive" covers). As the reader will see later in this paper, this open area is a key input for the water balance model and one that can be, within a certain range, controlled.

Between the leading edge of the deployed raincoats and the actively stacked face, temporary measures can be used to further reduce ingress. The residue can be compacted to reduce the infiltration rate (the water may still enter the process circuit but less of it will enter the waste dump), and the dump can be sloped so that rainwater does not flow towards the active face (e.g., stacking in the up-hill direction). In fact, compacting this area, with or without a stabilizing aid such as Portland cement or fly ash can significantly improve the traffic support capacity of the residue, improving stacking operations (in a recent study the CBR was improved from 5 to 13 with the addition of 1% Portland cement by dry weight of residue.) Limiting the amount of rainwater that enters the RSF will also improve bench and global stability. Static and dynamic liquefaction of waste facilities is arguably among mining's greatest risks as discussed in [5]. Liquefaction is a function of rate of increase in stress and the degree of saturation; the use of both active raincoat systems and aggressive control measures between the leading edge of the raincoats and the active stacking face can reduce water ingress and thus the degree of saturation, significantly reducing this risk.

Water Management During Processing

The third area of water management is water management within the process plant, particularly the potential to recycle process water to minimize process plant discharge. This is particularly critical in inland projects where discharge of sulphate-containing effluent is either not possible, or needs to meet strict discharge criteria. Indeed the capability of heap-leach-based processing to enable the recycle of process solutions may allow heap leaching to be the preferred hydrometallurgical method of processing nickel laterites in tropical projects. Some of these options include-

- Use of spent process liquor for both heap leach feed liquor (barren liquor or raffinate) and heap washing;
- Use of spent process liquor for reagents preparation; and,
- Use of spent process liquor for residue washing.

Off-setting these advantages is the need to process heap leach and residue storage facility (RSF) ingresses which are generated by both rain fall and RSF consolidation. Methods for control and minimization of rainfall ingress is previously discussed; consolidation is a normal property of residue and ripios and proper predictive modelling is important in developing a reliable overall-water balance model

Because of the substantial variations in weather patterns in tropical climates, the process plant will experience substantial variations in water inputs, particularly during wet weather seasons. A substantial neutralization plant is likely to be required to treat excess process water, as well as surge control of these water inputs to allow water management control strategies to be implemented. To assist in the design of these facilities, dynamic water balance modelling can be implemented, considering a range of climatic conditions, in particular worst case, or maximum rainfall events.

DYNAMIC WATER BALANCE MODELLING

Model Development

Figure 1 presents a schematic of the processing circuit which has been developed by the authors for dynamic water balance modelling of nickel laterite heap leach projects. Key process model inputs and outputs are:

Inputs

- Heap leach ingress due to rainfall.
- RSF compaction and rain ingress.
- Rainfall addition to ponds and other storage facilities.

- Fresh water process demand which cannot employ recycled spent process liquor.

Outputs

- Liquor deportment to spent ore (ripios).
- Liquor deportment to the RSF.
- Evaporative losses.
- Neutralized discharge liquor.

Key model inputs are:

- The rainfall pattern, which generally requires daily rainfall data for 2-3 years of maximum rainfall events.
- The development of the RSF over time, in particular the maximum area of the RSF.
- Raincoat application strategy
- Heap leach and RSF rain ingress and consolidation. This can be modelled in a simplified form, or utilizing hydrological models such as the US Environmental Protection Agency's Hydrologic Evaluation of Landfill Performance (HELP).
- Process model simulation data, which will depend on the processing circuit evaluated. The authors have developed a simplified water balance correlation for the process plant which can be applied to most processing circuits, which relates steady state water usage (non-dynamic) to dynamic inputs via-

$$K_1\ HL_{ingress} + K_2\ RSF_{return} + \text{Process Plant Make-up} - \text{Discharge} = K_3$$

$HL_{ingress}$ and RSF_{return} are rainfall ingress and/or consolidation within the heap leach and RSF respectively, and are a function of the rainfall pattern, geotechnical properties and raincoat application strategy. Process Plant Make-up and Discharge reflect addition water make-up to the process plant or excess discharge water which must be treated for disposal, and are mutually exclusive outputs of the water balance.

K_1 and K_2 reflect the response of the process plant to rain ingress and/or compaction in the heap leach and RSF, and can be evaluated from steady state process modelling.

K_3 is the water demand of the process plant under a 'no rainfall' (or dry) condition which again can be determined from steady state process modelling.

A key component of the water balance model is process inventories, or storage ponds. These comprise process storage ponds (such as the barren pond and PLS pond) and intermediate storage ponds to allow the buffering of liquor as a surge storage. Intermediate storage ponds include the emergency pond in the heap leach area and the RSF return water pond, which allows regulation of RSF return water from the RSF. The emergency pond also allows intermediate storage of heap leach drain down liquor during upset conditions (such as a power failure) which is particularly important for nickel laterite projects as the heap leach moisture level is as high as 35% to 45% of which 5% (by wet weight) or more can be temporary solution hold-up. For a dynamic heap with 3 million (dry) tonnes under leach, that 5% can result in over 200,000 m^3 of drainage water. For a multi-stack heap this can be considerably greater.

The other storage pond is the water pond which allows storage of run-off water from the heap and the RSF, thereby reducing the process plant's external fresh water demand. The larger the water pond, the lower the external fresh water intake during dry months.

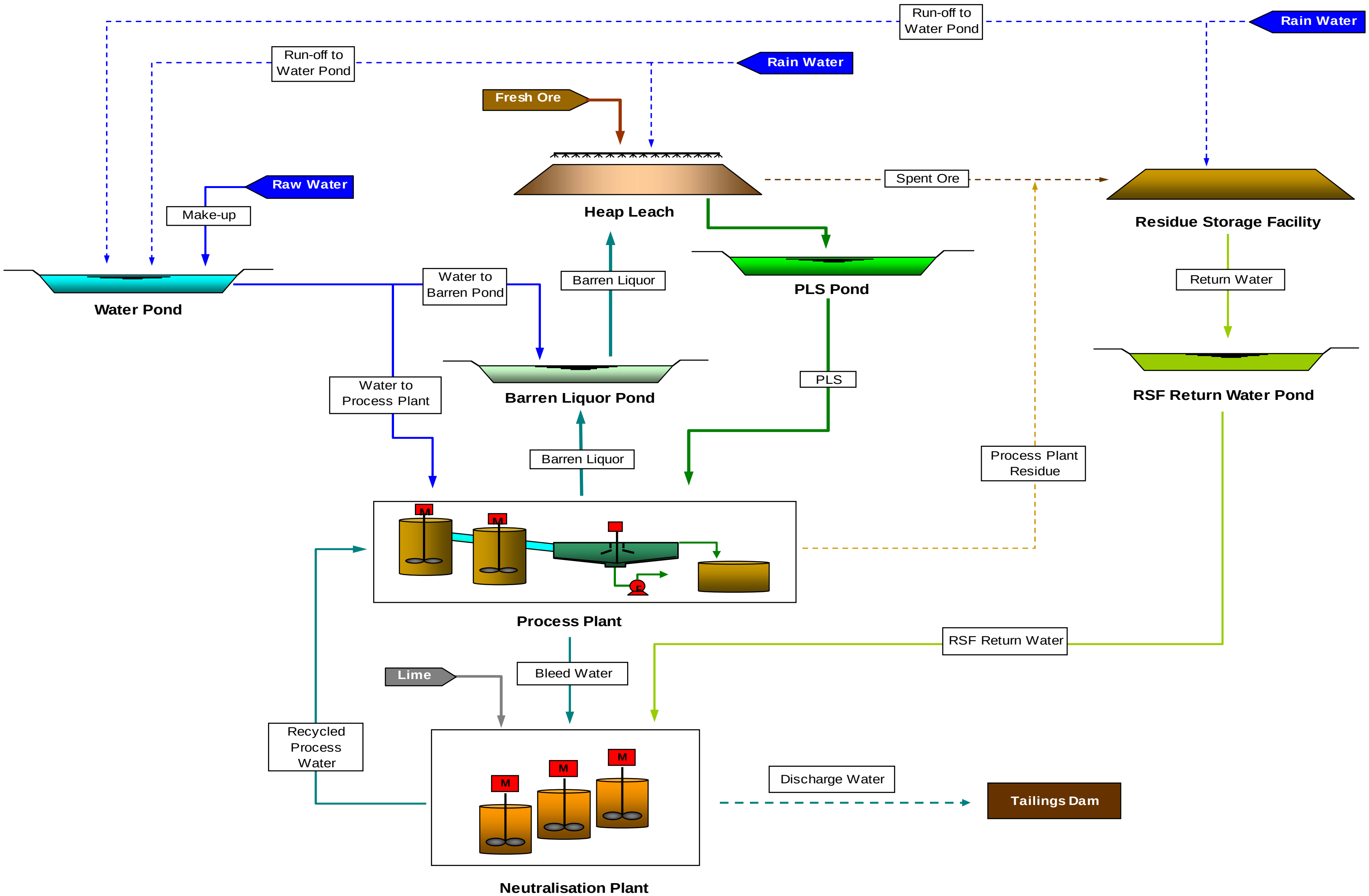


Figure 1: Schematic of Nickel Laterite Heap Leach Water Balance

Water Management Scenario

The use of dynamic water balancing is considered using the following hypothetical scenario, which represents a typical nickel laterite heap leaching project:

Heap Leach Parameters

- 750,000 m^2 total area (dynamic heap)
- 20% uncovered area, including stacking modules (this value can be increased or decreased depending up the degree of management invested, and will typically decrease with time as the operators gain experience with raincoats).

RSF Parameters (plant residue & ripios)

- Type of residue storage – dry stacking.
- 2,000,000 m^2 (note that the RSF area will increase with time on a project, the current scenario considers a maximum area where multiple benching is underway).
- 10% uncovered area (as with the heap, this number can be higher or lower depending on design and operational factors.
- 4% moisture loss (absolute) due to residue consolidation (this is a property of the materials, the amount of water in the ripios and residue when placed, the lift thickness and total depth of the dump, the rate-of-rise, and the amount of water ingress allowed).

Rainfall Pattern

- 2,600 mm/yr based on the rainfall pattern shown in Figure 2 (represents a South American tropical location).

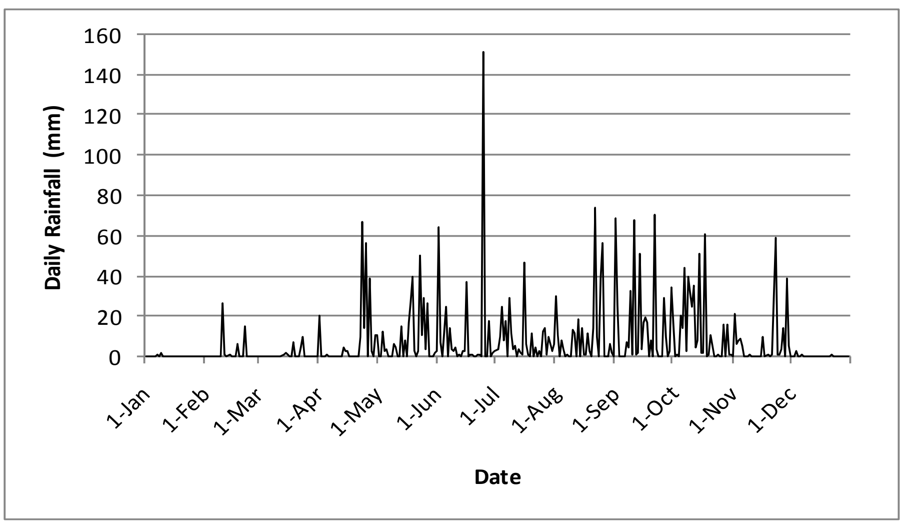
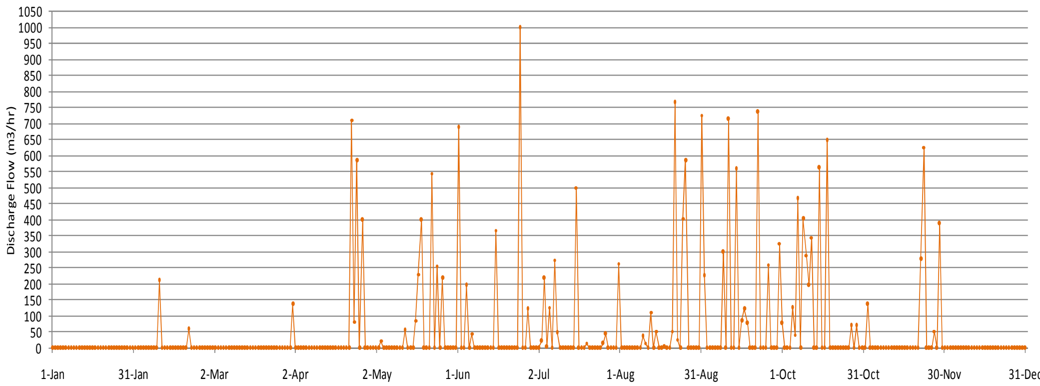


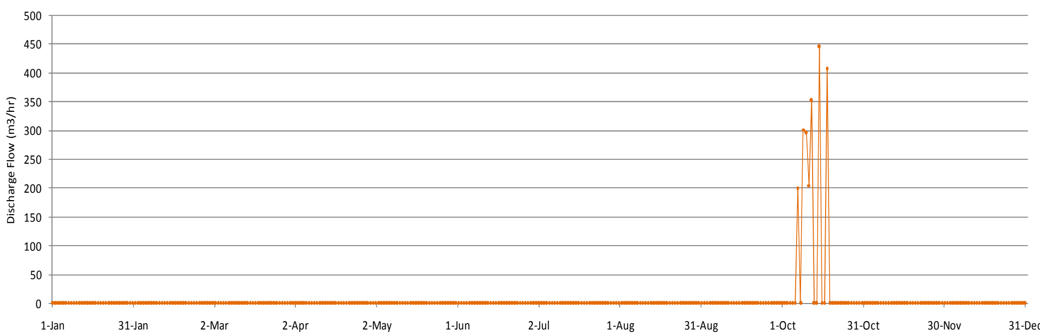
Figure 2: Daily Rainfall Pattern

Model Results

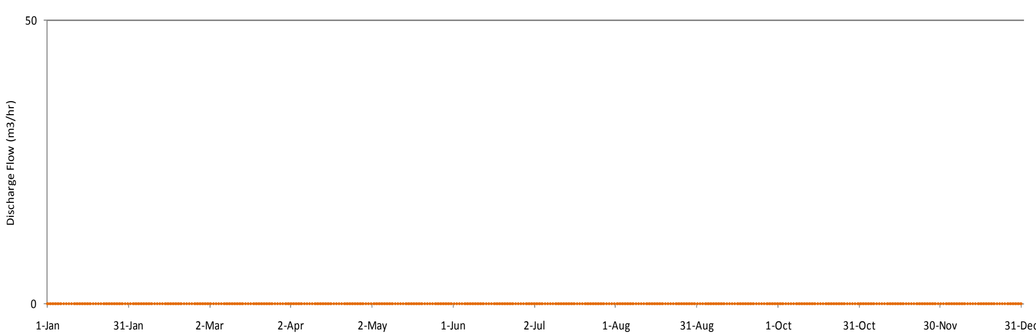
Figure 3 presents the water balance modeling results for different RSF return water pond sizing, ranging from no RSF return water pond (direct feeding of RSF return water to the process plant) to a relatively small pond (100,000 m^3), and to a pond sized to eliminate process pond discharge (250,000 m^3 in this example). With no surge control (Case 1), substantial periodic discharge of neutralized plant effluent occurs. An RSF return water pond can either reduce the frequency of discharge effluent (Case 2 – 100,000 m^3 pond), or eliminate effluent discharge if the RSF return water pond is sufficiently large (Case 3 – 250,000 m^3 pond).



Case 1 – No RSF Return Water Pond



Case 2 – Small RSF Return Water Pond (100,000 m^3)



Case 3 – Substantial RSF Return Water Pond (250,000 m^3)

Figure 3: Process Plant Discharge Water Simulation

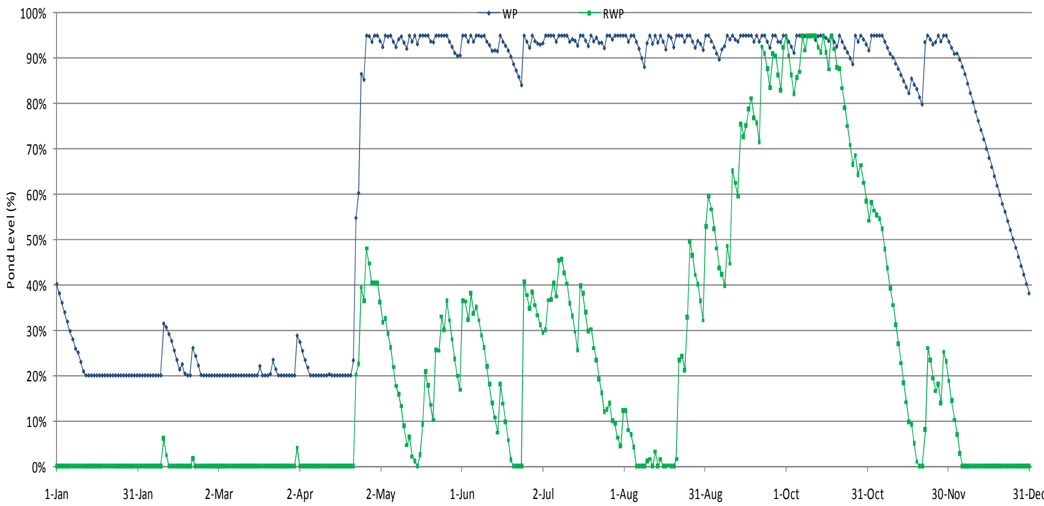


Figure 4: Pond Inventory Levels – Case 2

The impact of rainfall ingress can also be seen by an examination of pond inventory levels in the water management model. For the illustrated example, inventory levels for both the RSF return water pond and water pond (sized at 500,000 m3) are illustrated in Figure 4 for Case 2. The RSF return water pond levels (shown in green) allow regulation of pond discharge flows to prevent process plant effluent discharge until rainfall levels fill the pond, in which case effluent discharge occurs. The water pond (shown in blue) which received heap leach and RSF run-off allows operation of the process plant for 8 months of the year without additional fresh water make-up.

The above example illustrates some of the trade-offs between larger pond capacities (additional capital costs and larger footprint areas) and water management regulation. However, in certain locations, effluent discharge may not be possible, in which case sufficient pond volumes must be allowed for to prevent this occurrence. This also implies the application of the geotechnical methods discussed in the previous section to minimize water ingress. The example focused on above is a wet year example. Alternative dry year events can also be readily simulated, in this case focusing on the sizing and utilization of the water pond.

The above example is also based on dry-stacking of the residue. An alternative analysis can be conducted with a tailings dam fed with residue slurry. However, the lack of stability of slurry based tailings facilities in tropical climates, coupled with high rainfall ingress to the dam make this a difficult proposition in high rainfall conditions where water management is critical.

CONCLUSIONS

Heap leaching of nickel laterites is being pursued by a number of projects due to the potential for low capital cost processing, many of which are in tropical climatic conditions and therefore require careful water management design to reduce or eliminate effluent disposal due to high rainfall events. The current paper discussed water management in tropical nickel laterite heap leach projects from the following perspectives:

- The active use of raincovers to minimize water ingress into the heap leach and residue storage facility (RSF);
- Stabilization of the RSF to prevent failure under high rainfall operations;
- Process design to maximize water recycle within the processing facility thereby reducing water intake and effluent disposal;
- The need for a carefully designed neutralization facility to cope with varying quantities of spent process liquor; and,
- The need for dynamic water balance modelling under both dry and maximum rainfall conditions to evaluate water management strategies, and to undertake a surge analysis of in-process ponds. Operational calibration of this model has also proven valuable in copper and gold tropical operations and will likely do so in nickel laterite heap leaching.

Dynamic water balance modelling needs to be undertaken on daily rainfall data in order to evaluate the impact of high rainfall events on the process design. With careful evaluation of in-process ponds, it is possible to regulate the impact of such events, and possibly reduce the need for effluent disposal in conjunction with the other measures discussed. This can be critical for projects where effluent disposal is difficult or not possibly, such as inland projects.

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