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Innovative heap leach pad draindown modelling using a spreadsheet model (FastDraindown)

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Abstract

Active management of residual leach solutions, which no longer have commercial value, represents both a significant financial liability and an opportunity to optimise heap leach closure. The duration and strategy of active management must be carefully planned from both technical and financial perspectives, using draindown models grounded in unsaturated matrix flow formulations.

This paper presents an innovative Excel Visual Basic for Applications (VBA) modelling approach that incorporates the key variables describing a heap leach pile, including geometry, material type and dynamic solution recirculation with time. The heap can be discretised into 1D columns (leaching cells) with variable areas, heights, hydrologic properties (i.e. saturated hydraulic conductivity, water retention curves), unsaturated hydraulic functions (i.e. Brooks & Corey 1964; van Genuchten 1980; Fredlund & Xing 1994), draindown stages and time-dependent solution recirculation strategies.

An Excel-based model provides a practical and transparent alternative to complex 2D or 3D numerical simulations. Because Excel is widely available and familiar to engineers, planners and decision-makers, models can be developed, adapted and applied without specialised software or extensive training. This approach enables rapid scenario testing, sensitivity analyses and 'what-if' evaluations at minimal cost. Its transparency also facilitates regulatory review, quality control and communication with stakeholders, reducing the risk of hidden errors and increasing confidence in the results.

The method is demonstrated through an application at an exemplary, undisclosed mine in which laboratory-obtained leach ore hydrologic properties are refined by calibrating to a large column leaching test and the field condition. The application highlights the effectiveness of the proposed method for post-closure leach pad water-balance modelling and optimisation of solution management strategies. This Excel VBA approach offers a flexible, cost-effective and reliable tool to support informed planning and decision-making during heap leach closure.

Keywords: *mine closure, leach pad, draindown, spreadsheet model*

1 Introduction

Heap leaching is a low-cost processing method widely used for deposits with large, low-grade reserves across a range of climatic conditions. Heap leach facilities vary considerably in size and geometry, and substantial solution inventories must be managed to sustain economically viable operations.

Leaching of ore is typically conducted in predefined cycles, with application rates derived from large-scale column testing. During operation, leach solution is continuously recirculated over the heap for periods ranging from several weeks to months. Once the metal-rich leach solution declines below an economic

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cut-off, irrigation is shifted to a new area of the heap and the process is repeated. The previously irrigated portion then transitions into a passive draindown phase under gravity.

Draindown is defined herein as the period during which flow rates decrease from operational levels to a residual steady-state condition. Because the hydraulic conductivity of leached ore is a nonlinear function of degree of saturation, draindown behaviour is inherently nonlinear. It is typically characterised by an initial rapid decline in flow, followed by a progressively slower reduction over time.

Draindown represents a complex process composed of actively leached areas and multiple zones undergoing different stages of drainage. This complexity is further increased in operations involving multiple lifts, which may be irrigated sequentially or repeatedly prior to closure. As a result, predicting solution fluxes during closure and post-closure periods presents a significant mathematical and practical challenge.

Management of solution inventories in a closed heap can be broadly divided into active and passive stages. During the active stage, recirculation of solution to the heap may be required to prevent pond overflow while inventory reduction measures, such as treatment and discharge, or passive and enhanced evaporation, are implemented. In the passive stage, recirculation is no longer required. Passive water management is generally achieved when total outflows from the heap, consisting of draindown and net percolation from precipitation, are less than the evaporation capacity of the solution ponds. Under these conditions, pond overflow is avoided. Where excess storage capacity is available, temporary storage combined with evaporation may reduce the duration of the active management phase.

Existing draindown assessments are commonly performed using numerical unsaturated flow models that require specialised software, detailed model development and significant computational effort. While these models provide a rigorous representation of flow processes, they are often less practical for rapid evaluation of multiple closure and water-management scenarios.

The modelling philosophy adopted in FastDraindown is consistent with several recent developments in mine-facility seepage and draindown modelling. Vega et al. (2025) demonstrated the use of multiple Hydrus-1D simulations coupled through Python to evaluate heap leach pad draindown behaviour using a pseudo-three-dimensional representation. Similarly, Noël et al. (2023) developed a pseudo-3D seepage modelling framework for mine waste facilities by combining deposition modelling with multiple Hydrus-1D simulations, illustrating how facility-scale hydraulic behaviour can be represented through a network of 1D model elements. In addition, Miskolczi et al. (2023) demonstrated the importance of coupling draindown simulations with closure water-balance models to evaluate recirculation strategies, pond management and long-term closure performance.

FastDraindown was developed as a practical intermediate solution between simplified analytical estimates and fully numerical simulations. The model combines physically based unsaturated flow calculations with a pseudo-3D representation of heap geometry, operational history and time-dependent recirculation strategies within a Microsoft Excel Visual Basic for Applications (VBA) framework. This enables rapid scenario testing, direct integration with closure water-balance evaluations, and transparent model implementation using software that is widely available to mine operators, planners and regulators. FastDraindown is intended to function as a component of an integrated closure water-balance framework. The model provides time-dependent draindown rates from the heap leach facility that can be used directly as inflows to solution ponds and closure water-balance models. Likewise, recirculation rates, evaporation-system returns or other operational management actions calculated within a water-balance model can be applied as time-dependent inflows to the heap. This interaction enables evaluation of pond sizing requirements, active solution management strategies, evaporation alternatives and the transition from active to passive closure conditions.

2 Leach pad hydraulics

Accurate prediction of heap draindown requires the addressing of several interrelated challenges, including the hydraulic properties of the heap material, heap geometry, material heterogeneity, and operational history. These factors collectively contribute to the complexity of modelling solution movement within heap leach facilities.

In practice, irrigation rates are typically limited to approximately 1 to 10% of the saturated hydraulic conductivity (Ksat), ensuring that flow remains well within the unsaturated regime. This operational constraint serves several important purposes. First, heap leach pads are constructed in multiple lifts, and the increasing overburden stress leads to compaction and particle breakage which reduce hydraulic conductivity, particularly near the base of the heap. Maintaining low application rates provides a buffer against this progressive loss of permeability. Second, heap materials are inherently heterogeneous. The presence of fines or clay-rich zones can locally reduce hydraulic conductivity well below the average value. Operating at low application rates minimises the risk of localised saturation which could otherwise lead to instability or slope failure. Finally, unsaturated flow conditions are essential for efficient leaching as they promote oxygen transport (critical in bioleaching processes) and prevent full saturation of pore spaces.

Leaching rates are typically determined through large-scale column tests conducted under controlled laboratory conditions. These tests are designed to optimise particle size distribution and irrigation rates to achieve high metal recovery within a practical leaching period.

The relationship between moisture content and matric suction is commonly described using the soil water characteristic curve (SWCC), also referred to as the water retention curve. The SWCC is a graphic expression of the relationship between the moisture content and the matric suction. It characterises how a material stores and releases water and is fundamental to understanding unsaturated flow behaviour. It is typically obtained through laboratory testing or estimated using pedotransfer functions, and then fitted using analytical models. Among the most widely used formulations are those proposed by Brooks & Corey (1964), van Genuchten (1980) and Fredlund & Xing (1994).

As matric suction increases, progressively smaller pores desaturate, and increasingly greater suction is required to remove additional water until a residual water content is reached. During irrigation, infiltrating solution initially occupies smaller pores (associated with higher suction), followed by larger pores as suction decreases. Conversely, during draindown, the largest pores drain first, followed by progressively smaller pores. The suction corresponding to the onset of drainage of the largest pores is defined as the air-entry value.

Direct measurement of unsaturated hydraulic conductivity is challenging due to the highly nonlinear and variable nature of flow in partially saturated media. Unlike saturated conditions, where flow paths are continuous, unsaturated soils contain both air and water, resulting in discontinuous pathways and strong dependence on pore structure and suction. Small changes in water content can produce large variations in conductivity, making laboratory measurements sensitive to disturbance and the reproduction of field conditions difficult. Furthermore, maintaining steady-state flow under controlled suction conditions is technically demanding. For these reasons, unsaturated hydraulic conductivity is commonly estimated indirectly from the SWCC using constitutive models.

Although different SWCC models can provide similarly good fits to laboratory data (Figure 1), the corresponding estimates of unsaturated hydraulic conductivity can vary significantly (Figure 2). For example, when using the van Genuchten (1980) formulation in combination with the Mualem approach, the pore interaction parameter (L) is commonly assumed to be 0.5. However, studies such as Schaap & Leij's (2000) have shown that this default value may lead to poor predictions, particularly under dry conditions where conductivity tends to be significantly underestimated. Their analysis suggests that alternative values (e.g. $L \approx -1$) may provide improved agreement with observed data.

Experience from field applications indicates that, despite similar SWCC fits, the resulting hydraulic conductivity functions can differ substantially among models. Based on the authors' experience, the Brooks & Corey (1964) model provides reliable predictions and has been successfully validated against field data. Notably, its predicted conductivity behaviour typically falls between that obtained from the van Genuchten (1980) formulation and the Fredlund et al. (1994) model.

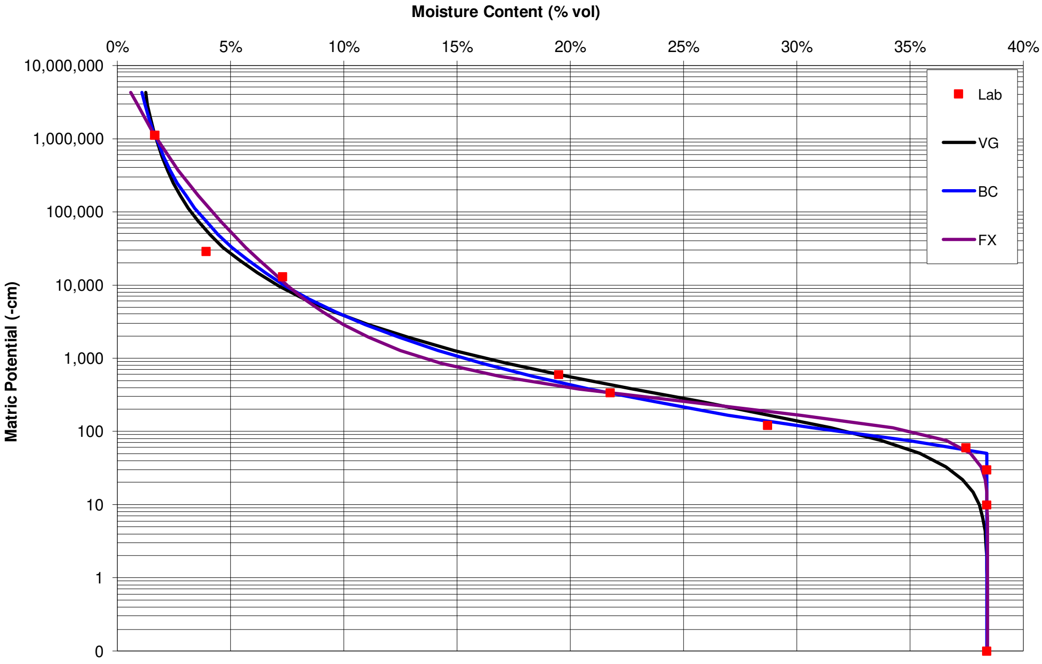

Figure 1 Exemplary soil water characteristic curve estimated by Brooks & Corey (1964) (BC), van Genuchten (1980) (VG) and Fredlund & Xing (1994) (FX) methods for heap leach materials

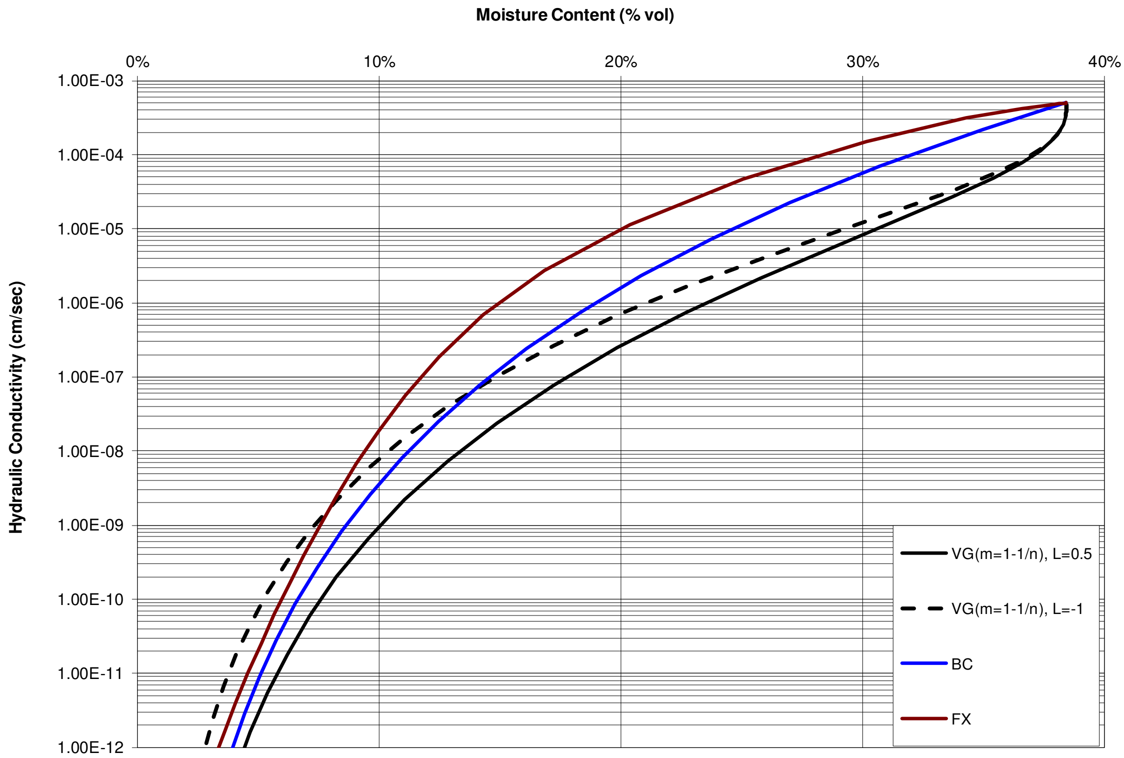

Figure 2 Exemplary unsaturated hydraulic conductivity functions estimated by Brooks & Corey (1964) (BC), van Genuchten (1986) (VG) and Fredlund et al. (1994) (FX) methods for heap leach materials

The example described in this paper uses the Brooks-Corey (BC) equation to estimate unsaturated hydraulic conductivity of the leach ore at water content θ as follows:

$$K(\theta) = K_s \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\gamma} \quad (1)$$

where:

K_s = saturated hydraulic conductivity, (L/T)

θ_s = saturated water content, dimensionless

θ_r = residual water content, dimensionless

γ = a dimensionless empirical parameter.

For facility-scale draindown calculations, the BC equation can be reformulated in terms of solution inventory within the leach pad by replacing water content with the equivalent volume of solution contained within the modelled area [Q(V)]:

$$Q(V) = AK_s \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\gamma} = AK_s \left(\frac{V - V_r}{V_s - V_r}\right)^{\gamma} \quad (2)$$

where:

A = the leach pad modelled area (L^2)

Q (V) = draindown rate from the leach pad modelled area (L^3/T)

V_s = equivalent solution volume at the saturated water content (L^3)

V_r = equivalent solution volume at the residual water content (L^3).

A large column (crib) test was conducted on representative leach ore having a P80 of 46 mm. Approximately 600 kg of ore with an initial moisture content of 0.3% was placed in a crib with an area of 1.1 m² and a height of 1.5 m. The crib was irrigated at a rate of approximately 10.8 L/hr/m² for 67 days using cyanide solution containing approximately 200 ppm cyanide (CN) and a pH of 10.27. Following termination of irrigation, draindown was monitored for 68 hours.

The BC parameters were initially derived by calibrating the model to the observed large column draindown data. Calibration quality was evaluated through comparison of observed and simulated draindown rates. As shown in Figure 3, the calibrated model reproduced the measured draindown behaviour with an R^2 value of 99.47%, indicating excellent agreement between observed and simulated results.

The laboratory-derived BC parameters were subsequently refined through calibration against observed field operating data, including wet-up requirements, solution inventories and measured draindown behaviour. Table 1 summarises both the laboratory-derived and field-calibrated BC parameters used in the example model. The parameters presented herein are site-specific and are included solely to demonstrate application of the methodology.

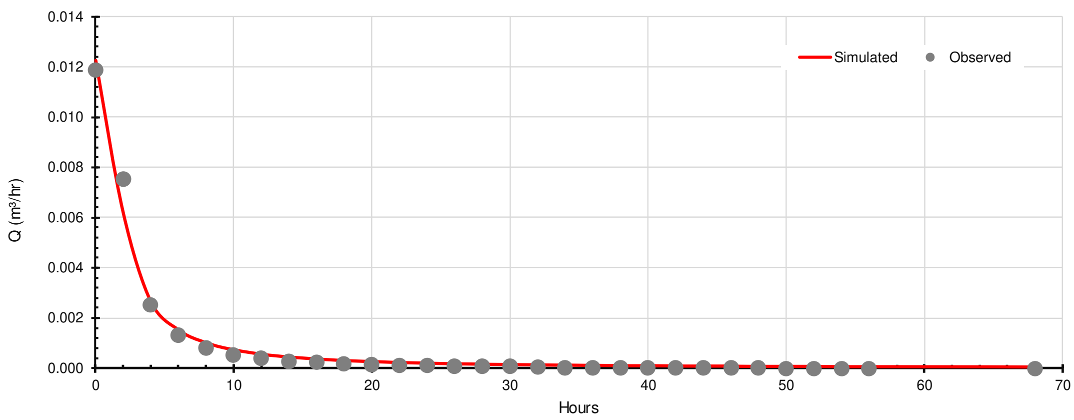

Figure 3 Observed and simulated draindown rates from the large column test (R^2 = 99.47%)

Table 1 Laboratory-derived and field-calibrated Brooks & Corey parameters and leaching water content assumptions

Parameter	Crib test	Field data
Leaching rate Ko (L/hr/m²)*	11.13	15.00
Leaching water content ϴ*	0.10	0.11
ϴr	0.07	0.07
ϴsat	0.40	0.40
ɣ	2.60	2.63
Ks (cm/s)	0.31	0.11

* Reference values used during calibration; not independent Brooks & Corey fitting parameters

[Ko is the leaching rate, L/hr/m²; ϴ is the leaching water content, dimensionless; ϴr is the residual water content, dimensionless; ϴsat is the saturated water content, dimensionless; ɣ is an empirical parameter, dimensionless; and Ks is the saturated hydraulic conductivity, cm/s]

3 Leach pad geometry

Pre-mining topography strongly influences the layout and configuration of heap leach facilities. In areas where relatively flat terrain is available, leach pads tend to have regular geometries. In contrast, operations located in complex terrain are constrained by existing topography, resulting in irregular heap configurations that conform to the available footprint (Figure 4). These conditions often produce highly variable 3D geometries characterised by abrupt changes in elevation, footprint and slope angles.

Superimposed on the external geometry, the internal structure of the heap introduces additional complexity. Heap leach pads are typically constructed in successive lifts and, in many cases, expanded in adjacent phases over time. As operations progress, it is common for heap footprints to extend beyond the original design to accommodate increased ore volumes. Consequently, larger heaps tend to exhibit increasingly complex geometries, both externally and internally.

The degree of heterogeneity represented in FastDraindown is controlled by the level of discretisation selected by the user. Different phases, lifts or operational zones may be assigned unique hydraulic properties, geometries and irrigation histories, allowing representation of large-scale heterogeneity within the facility. However, localised features such as thin stratified layers, segregation zones, compaction gradients and preferential flow pathways within individual model elements are not explicitly represented. Where such features are expected to exert a dominant influence on drainage behaviour, more detailed multidimensional analyses may be warranted.

Direct application of a unified draindown model to the entire heap would require a large-scale 3D numerical domain with fine spatial discretisation to adequately capture the nonlinear behaviour of unsaturated flow. Such an approach is computationally intensive and often impractical. Therefore, simplifications are necessary and the heap geometry is typically discretised into representative units.

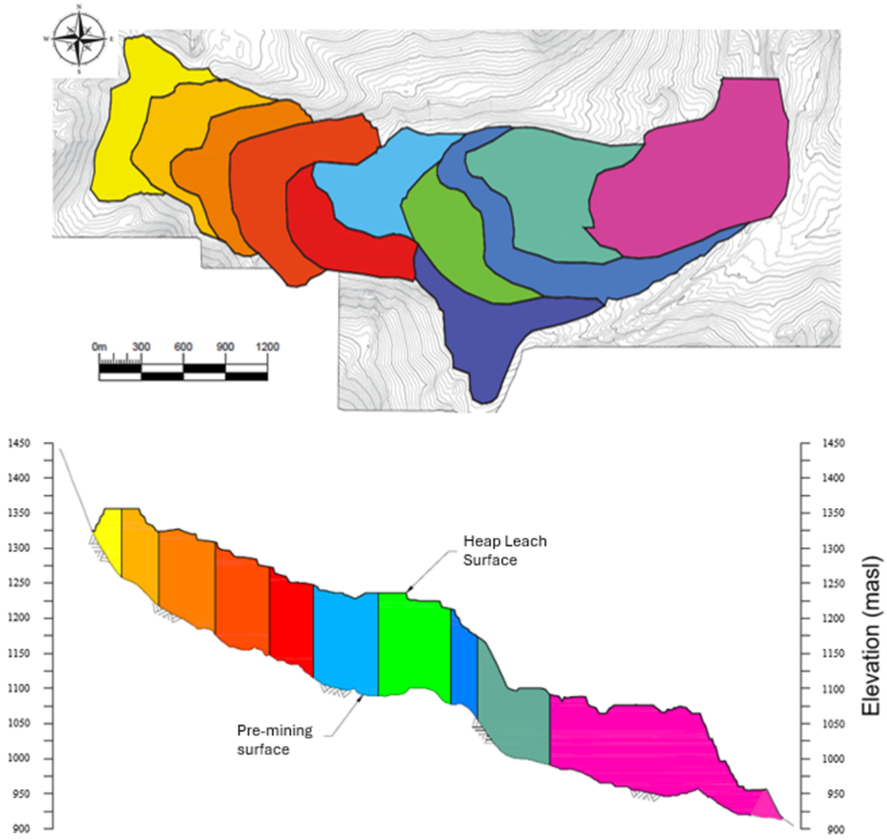

Figure 4 Heap leach pile in plan view (top) and elevation profile (bottom) at an exemplary, undisclosed mine. Each colour represents a different operational phase

4 Modelling approach

Heap leach pad draindown can be simulated using either simplified empirical approaches or fully coupled numerical models of unsaturated flow. While conventional 2D and 3D numerical models are robust and physically rigorous, they typically require substantial computational resources and long run times. This limits their practicality for iterative design evaluations and operational decision-making.

To address these limitations, an alternative approach has been developed that combines simplified 1D empirical modelling within a Microsoft Excel 365 macro-enabled environment. This approach enables a pseudo-3D representation of the heap by discretising it into multiple 1D elements, significantly reducing computational demand while retaining the key physical behaviour.

Operational history has a significant influence on the saturation state of the heap at the end of leaching. During active operations, irrigation is applied sequentially across different phases of the leach pad according to a predefined schedule. The total irrigation rate is typically constrained by pumping capacity and power infrastructure and remains relatively constant. Depending on the size of individual phases, multiple irrigation cycles may be required, and overlapping cycles can result in portions of the heap being irrigated more than once. Consequently, at the time of closure, different regions of the heap may have experienced irrigation at widely different times, ranging from recent application to several months or even years prior, resulting in spatially variable saturation conditions. FastDraindown has the capability to replicate the complexities associated with the operational history with user-defined parameters that are defined based on site-specific conditions.

The modelling framework begins by subdividing the leach pad into operational phases. Each phase is further discretised vertically into lifts (layers), with corresponding plan areas assigned to each lift. Table 2 presents an example of this discretisation for a representative heap leach facility, assuming a uniform lift height of

13 m. The total footprint and volume of the facility are approximately 5.6 million m² and 442.2 million m³, respectively. Assuming an average dry density of 1.63 g/cm³, the total mass of ore within the facility is approximately 720.8 million tonnes.

In this example, the heap is discretised into 11 phases and 12 lifts, resulting in a total of 132 1D model elements (Table 2). Each element represents a vertical column with independent draindown behaviour. The overall draindown response of the facility is obtained by summing the contributions from all 1D elements.

The operational history of the heap is incorporated into the model through the specification of a final irrigation schedule, defined as the last complete cycle of irrigation applied to each phase of the leach pad. This approach enables quantification of the elapsed time since the last active irrigation at any given location within the heap.

By establishing this temporal reference, the model can estimate the corresponding moisture content distribution at the start of the simulation. This, in turn, allows calculation of the initial solution inventory and its evolution over subsequent timesteps. A key assumption of the approach is that model time begins immediately following completion of the final irrigation cycle and progresses forward from that point.

For the demonstrative example used in this paper, several user-defined operational assumptions are adopted. The maximum irrigation grid is assumed to have a fixed area of 280,000 m² with a nominal leaching rate of 16 $L/hr^{-1}/m^{-2}$. Each irrigation cycle is assumed to last 60 days, followed by an average of 30 days being required for system relocation and set-up between cycles. Based on these assumptions, Table 3 and Figure 5 present the irrigation cycles, the estimated leaching durations and the timing of the final irrigation for each phase.

Table 2 Leach pad discretisation based on column height

	Footprint area of each phase (m^2)										
Column height (m)	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4a**	**Phase 4b**	**Phase 5a**	**Phase 5b**	**Phase 6**	**Phase 7**	**Phase 8**	**Phase 9**
13	27,665	37,518	44,220	0	31,979	24,728	3,158	64,219	110,730	104,511	208,267
26	30,086	37,815	29,395	0	30,881	23,304	7,474	64,099	55,700	59,200	110,242
39	51,414	31,870	22,322	0	28,170	22,999	8,866	96,106	54,400	50,280	112,948
52	31,514	42,120	19,432	0	30,285	22,803	12,162	94,436	54,415	42,481	104,714
65	25,952	51,241	17,292	0	28,719	21,612	11,984	111,315	48,631	52,241	98,500
78	25,428	61,454	16,847	82	27,267	27,831	14,997	88,588	49,693	42,577	89,700
91	41,346	77,957	40,983	5,510	22,139	29,787	16,066	82,238	47,070	41,055	85,200
104	83,896	52,794	33,738	20,023	23,897	28,544	30,779	64,079	62,100	50,807	100,056
117	74,558	53,224	38,557	25,248	18,663	21,534	47,303	47,255	76,000	48,236	98,976
130	49,281	78,051	24,558	25,953	16,743	18,009	23,310	48,359	118,964	81,151	28,999
143	26,705	82,195	26,155	60,520	8,567	17,622	12,947	4,227	99,677	56,175	9,630
156	26,496	33,894	15,156	73,279	123	2,057	2,330	0	0	466	0
Footprint area, m^2 =	494,341	640,133	328,655	210,615	267,433	260,830	191,376	764,921	777,380	629,179	1,047,232

Table 3 Leach pad leaching durations of each phase for the exemplary, undisclosed heap leach pile

Phase	Leaching start date	Number of irrigation cycles	Leaching end date	Rinsing duration, days
Phase 1	04/15/2021	2	10/12/2021	180
Phase 2	11/11/2021	3	08/08/2022	270
Phase 3	08/08/2022	2	02/04/2023	180
Phase 4a	02/04/2023	1	05/05/2023	90
Phase 4b	05/05/2023	1	08/03/2023	90
Phase 5a	08/03/2023	1	11/01/2023	90
Phase 5b	11/01/2023	1	01/30/2024	90
Phase 6	10/18/2031	3	07/14/2032	270
Phase 7	07/14/2032	3	04/10/2033	270
Phase 8	04/10/2033	3	01/05/2034	270
Phase 9	01/05/2034	4	12/31/2034	360

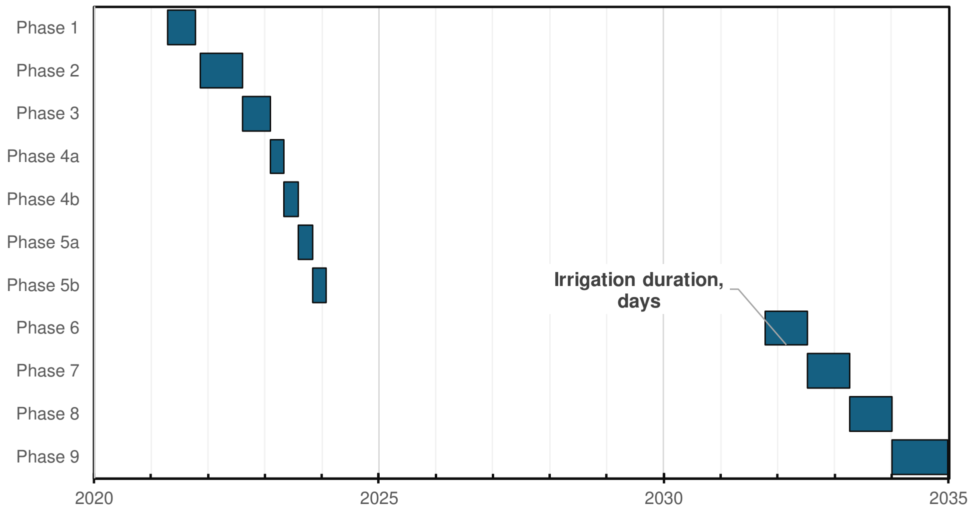

Figure 5 Last active irrigation schedules by phases for the exemplary, undisclosed heap leach pile

The irrigation grid area, irrigation cycle duration, relocation period and application rate used in this example are site-specific operational inputs derived from the facility's mining and leaching plan. These values are not fixed model assumptions. FastDraindown allows users to define these parameters according to site-specific operating practices, enabling evaluation of alternative irrigation strategies and closure scenarios. Changes in these operational inputs affect the timing and distribution of moisture within the heap and are therefore reflected in the predicted draindown response.

Figure 6 illustrates the conceptual 1D model used to represent each heap column. Each column, with area (A) and height (H), is treated as a single element. The initial water content is determined from the irrigation rate and the soil unsaturated hydraulic conductivity function.

The model allows any time-dependent inflow at the top of the column, denoted as $Q_{in} = Q(t)$. This inflow can represent recirculation of draindown solution, meteoric infiltration or droplet fall-back from forced evaporators installed on the pad surface. The outflow, denoted as $Q_{out} = K(\theta) * A$, is defined as the unsaturated hydraulic conductivity multiplied by the column area (A).

When the outflow exceeds the inflow, the water storage in the column, represented by its average water content, declines over time. As the water content decreases, the unsaturated hydraulic conductivity also decreases, producing the characteristic decaying shape of the draindown curve (Figure 7). Taller columns require longer drainage times, resulting in a flatter draindown curve, whereas shorter columns drain more quickly.

Parameter definitions:

Q_{in} is the time-dependent inflow, denoted as Q(t), to the top of heap column, L^3/T.

Q_{out} is the outflow, or draindown, from the column, L^3/T.

θ_0 is the initial water content of the heap column, dimensionless.

$\Delta\theta$ is the change in water content of the heap column, dimensionless.

$K(\theta)$ is the unsaturated hydraulic conductivity, L/T.

A is the cross-sectional area of the heap column, L^2.

H is the heap column height, L.

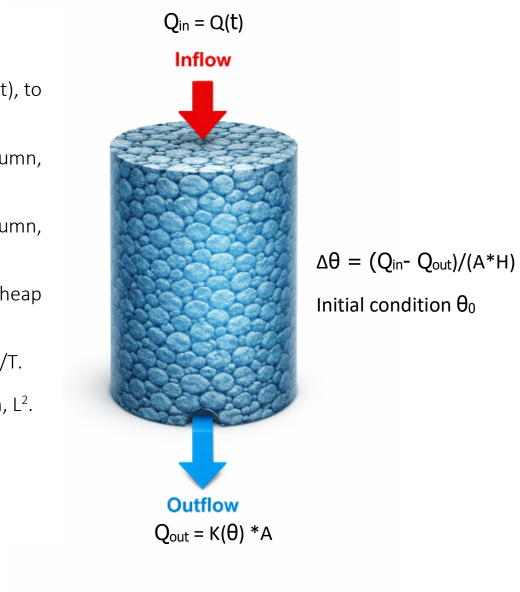

Figure 6 1D conceptual draindown model

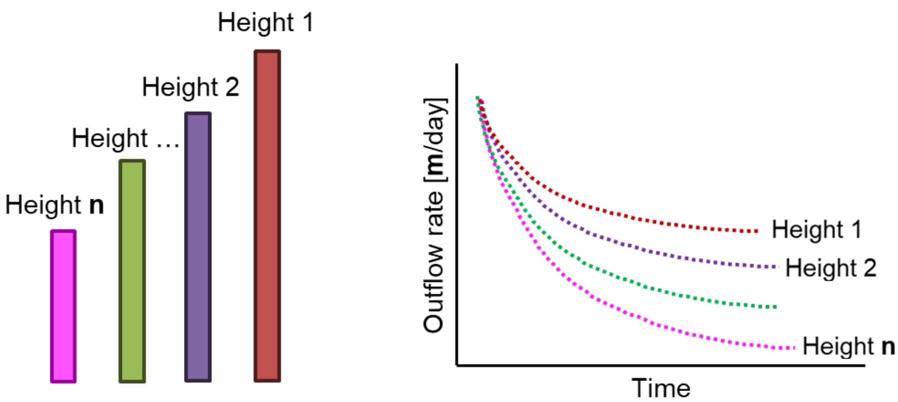

Figure 7 1D draindown curves for various heights under the same leaching cycle. The outflow rate is specific draindown [L/T] from the heap leach for different vertical column heights.

As illustrated in Figure 7, FastDraindown represents the heap as a collection of independent 1D columns and assumes that vertical unsaturated flow is the dominant mechanism governing draindown. Consequently, the model does not explicitly simulate lateral flow, perched water zones, preferential flow pathways or other localised 3D processes that may occur within a heap leach facility. These processes can influence local moisture distributions and drainage patterns, particularly in highly heterogeneous materials or complex geometries. Nevertheless, the objective of the model is to estimate facility-scale draindown behaviour and support closure water-balance evaluations rather than to reproduce detailed internal flow fields. For applications where detailed characterisation of local flow processes is required, more sophisticated multidimensional numerical models may be warranted.

5 Modelling results example

Draindown simulations for the entire leach facility over the full operational period were conducted using a Microsoft Excel 365® macro-enabled workbook, FastDraindown. The required inputs for the model are:

1. facility geometry, as defined in Table 2
2. final irrigation schedules for all phases, as defined in Table 3
3. facility identification mapping, where each combination of phase and cycle is assigned a unique identifier, and may have distinct hydrologic properties and inflow time series
4. field-calibrated Brooks & Corey parameters as in Table 1
5. for simple demonstration purposes, no recirculation is assumed, i.e. Q_{in}=0.

The model is designed for user convenience. Input and output units can be freely selected according to user preference, and simulations can be executed with a single click to run the VBA code. The model employs an adaptive timestepping scheme, using smaller timesteps when the draindown curve is steep and progressively larger steps as the curve flattens, ensuring computational efficiency without sacrificing accuracy.

Figure 8 presents the simulated total draindown of the entire heap over the operational period. Independently presented draindown curves for phases 2, 5a and 8 illustrate the effect of multiple irrigation cycles within a phase. Due to the high permeability of the site's leach ore, draindown occurs rapidly, with most water exiting the heap shortly after irrigation ceases.

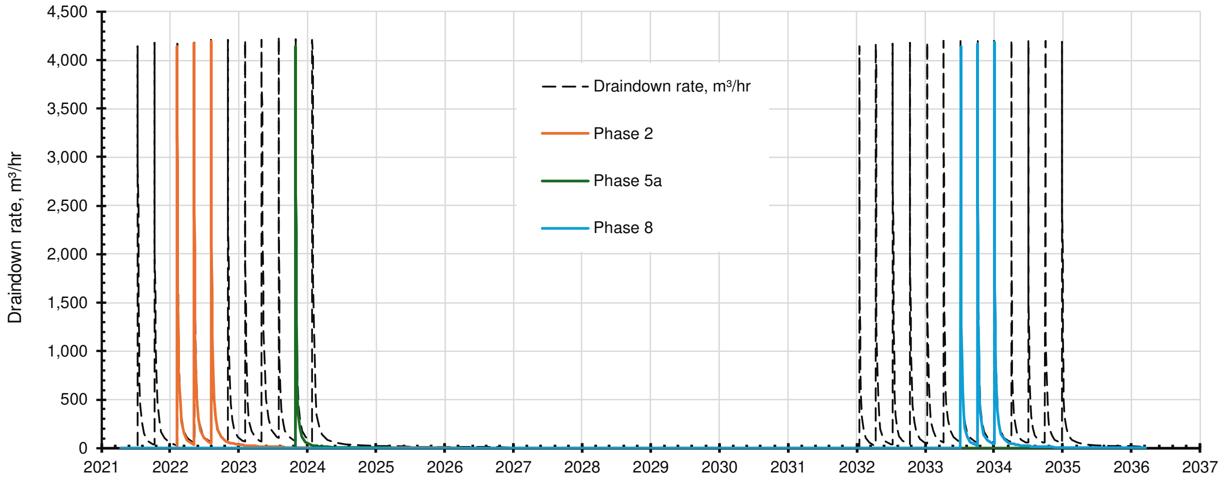

Figure 8 Simulated draindown curves for all phases and during all operation times

As indicated in Table 3 and Figure 5, the final leaching on phase 9 is completed in December 2034. Figure 9 shows the total draindown following cessation of leaching, along with the draindown curves of 3 user-selected individual phases (phases 7, 8 and 9). Due to the high permeability of the ore, draindown from phases 7 and 8 occurs rapidly and contributes minimally to the total. Consequently, the overall draindown is dominated by the last active phase, Phase 9.

As FastDraindown is intended primarily as a practical engineering tool for facility-scale draindown estimation, detailed sensitivity and uncertainty analyses were not included in the example presented herein. Nevertheless, users can readily evaluate parameter sensitivity by varying hydraulic properties, heap geometry, irrigation schedules and operational assumptions, and by examining the resulting effects on predicted draindown behaviour. Furthermore, the spreadsheet-based framework can be readily coupled with probabilistic analysis tools, such as @RISK or Crystal Ball, to support stochastic evaluations where uncertainty quantification is required.

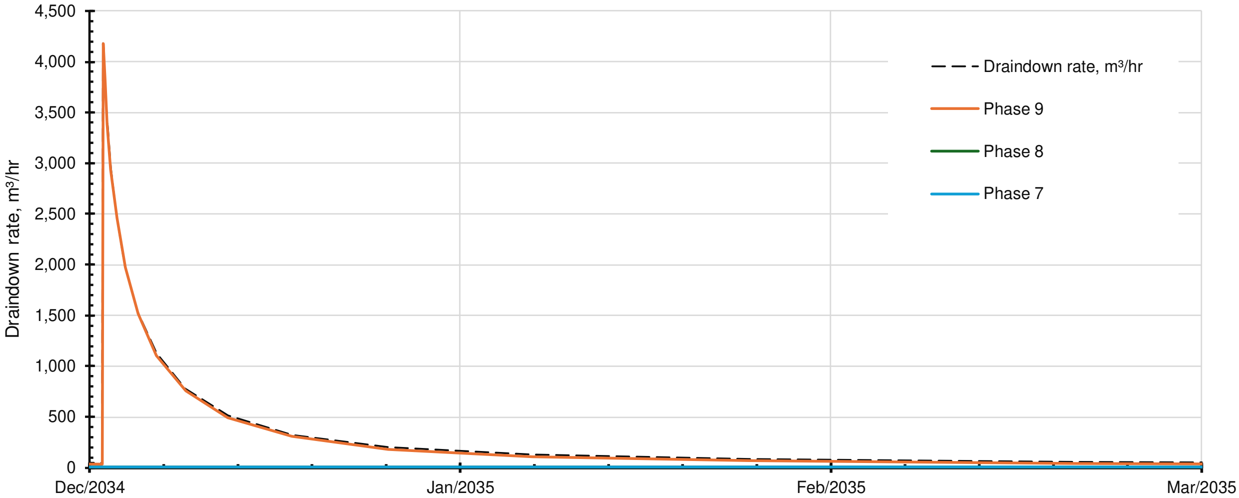

Figure 9 Simulated draindown curves for all phases post final leaching

6 Conclusion

The FastDraindown workbook has been developed to simulate draindown from an entire heap leach pad during both operational and post-closure periods. The results generated by FastDraindown can be used to inform site-wide closure water-balance models, enabling rapid scenario testing, sensitivity analyses and alternative evaluations at minimal cost.

The model calculates downward fluxes using unsaturated matrix flow equations and updates column saturation over time through a forward difference water-balance approach. It provides a practical intermediate solution between overly simplistic analytical models and computationally intensive numerical simulations. Compared with other analytical approaches, FastDraindown offers enhanced capabilities for data management, flexible representation of leach pad geometry, a user-friendly interface and fast simulation performance.

Implemented in Microsoft Excel 365®, FastDraindown leverages widely available and familiar software, allowing engineers, planners and decision-makers to develop, adapt and apply the model without specialised tools or extensive training. The transparency of the spreadsheet-based framework also facilitates regulatory review, quality control and communication with stakeholders, reducing the risk of hidden errors and increasing confidence in the results.

FastDraindown introduces a practical pseudo-3D facility-scale draindown modelling framework that combines physically based unsaturated flow calculations, operational history and closure water-management considerations within a transparent Microsoft Excel Visual Basic for Applications (VBA) environment. FastDraindown is intended as a practical facility-scale engineering tool that bridges the gap between single-element analytical approaches and computationally intensive multidimensional numerical models. Its principal strengths include computational efficiency, flexibility, transparency and implementation within a widely available Microsoft Excel VBA environment that facilitates scenario evaluation, peer review and regulatory review. The model can be readily coupled with pond water-balance simulations, allowing 2-way interaction between draindown predictions and closure water-management strategies, and can be used in deterministic or stochastic analyses through commercially available Excel add-ins. The current methodology assumes that vertical unsaturated matrix flow is the dominant drainage mechanism and therefore does not explicitly represent multidimensional flow processes, preferential flow pathways, perched water conditions or detailed small-scale heterogeneity within individual model elements. Future developments may focus on tighter integration with pond water-balance simulations and implementation of native stochastic input capabilities within the FastDraindown framework.

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