HYDROLOGICAL BALANCE FOR FILLING THE PITS, TRANSFORMATION DAILY RAINFALL TO DAILY FLOW RATE FOR THE BASINS THAT DRAIN TO THE PITS. MODEL GR4J AND MODEL HEC-HMS

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ABSTRACT

This article presents a conceptual model for the supply of runoff information storage areas. The concepts of daily equilibrium and the simplification of rainwater transformation processes in the subsoil have been taken as reference, using tank models that take into account the temporary storage of runoff. This proposed conceptual model, used especially in open pit mining, allows any scenario to determine the evolution of the filling. In the case of a mining operation, the filling of the exploited areas seeks to restore the natural state of the area to mitigate the effects on the biosphere. The filling process requires the evaluation of the daily hydrological balance in the basins that are taxed to the storage area and the evaluation of the particular hydrological variables. Since the objective function of the model is the duration of time changes in the daily calendar of storage areas, it is necessary to define the model of rain in the future. in the model integrated in the Hec-Hms software of successive tanks..

INTRODUCTION

This article presents a conceptual model for filling a storage area, taking as a reference the daily balance, the calculations and the results for different filling scenarios, particularly in open-pit mining development projects. The objective of filling natural storage areas is to restore the natural state of the area to mitigate the effects on the biosphere of the environmental impact generated by the anthropic operations of a farm.

For the application of the methodology it is necessary the daily hydrological evaluation of the hydrological variables in the study area and particularly in the basins that are discharge at the volume to be stored. As mentioned above, the estimation of the runoff flows on a daily basis was made using the rainfall runoff models GR4J, a methodology developed in France and the integrated model of the HEC-HMS successive tank software.

The topographic limits of the areas contributing to the system are defined from the anthropic state of the zone, established according to the activities of the exploitation. In general, these drainage areas usually correspond to areas of disposal of extracted material, a disposition that defines surface drainage and the management of runoff. In the development and construction of this model, it is necessary to use records of precipitation representative of the basins that drain to the storage area, from the weighting of several pluviographic stations near the study area.

Taking into account that the conceptual model is based on the daily mass balance, it is necessary to evaluate the long-term hydrological cycle taking as a reference the values of potential evapotranspiration in the zones estimated from the daily temperature records of the seasons climatological in the area and daily precipitation.

CONCEPTUAL MODEL OF DAILY HYDROLOGICAL BALANCE

The hydrological balance for a given watershed is established from all inputs and outputs in an established control volume. Using the fundamental equation of hydrology on a daily basis, it is possible to define the balance in the control volume, as follows:

$$I - O = \frac{dV}{dt} \qquad [1]$$

Where,

I	Daily water inlets to the control volume [m³]
O	Daily water outlets to the control volume [m³]
$\frac{dV}{dt}$	Temporary change of storage in the control volume [m³/day]

$$I = P_{North\ Zone} + q_e + q_{sub} \qquad [2]$$
$$O = EVP_{North\ Zone} \qquad [3]$$

Where,

$P_{North\ Zone}$	Daily direct precipitation on the surface of the storage area [m³]
q_e	Direct runoff from the basins afferent to the storage area [m³]
q_{sub}	Underground contributions that consider infiltration and sub-surface flows. [m³]
$EVP_{North\ Zone}$	Daily direct evapotranspiration in the storage area [m³]

Other variables of the hydrological cycle corresponding to the infiltration and subsurface flow have been considered in this model in the net underground supply and direct runoff.

Equation [2] corresponds to filling scenarios without transfer of flow between adjacent storage areas, unlike equation [4] which takes into account additional inputs for discharged flows between storage zones.

$$I = P_{South\ Zone} + q_e + qsub + \Delta Q \qquad [4]$$

$$O = EVP_{South\ Zone} \qquad [5]$$

Where,

$P_{South\ Zone}$	Direct daily precipitation in the filling zone [m³]
q_e	Direct runoff from the basins afferent to the filling area [m³]
q_{sub}	Underground contributions that consider infiltration and sub-surface flows. [m³]
$EVP_{South\ Zone}$	Daily direct evapotranspiration in the filling zone [m³].
ΔQ	Flows from adjacent storage areas [m³]

The proposed model can be applied to different filling scenarios, which define the form and application of the fundamental equation of the hydrological balance described above. Figure 1 shows a general flow diagram in which the input and output variables present in the hydrological balance in the pit are graphically described.

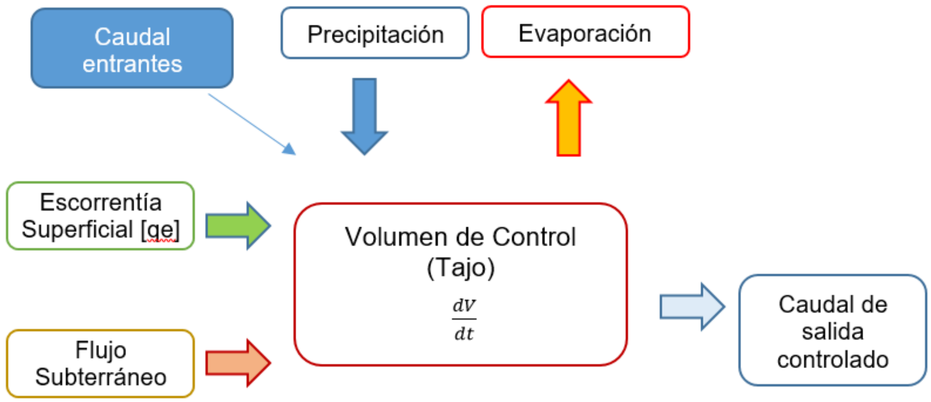

Figure 1. Flow diagram of the variables of the water balance in a control volume.

Additionally, in Figure 2, these same hydrological variables are presented, but in a basic scheme of the general location of the variables in the pit.

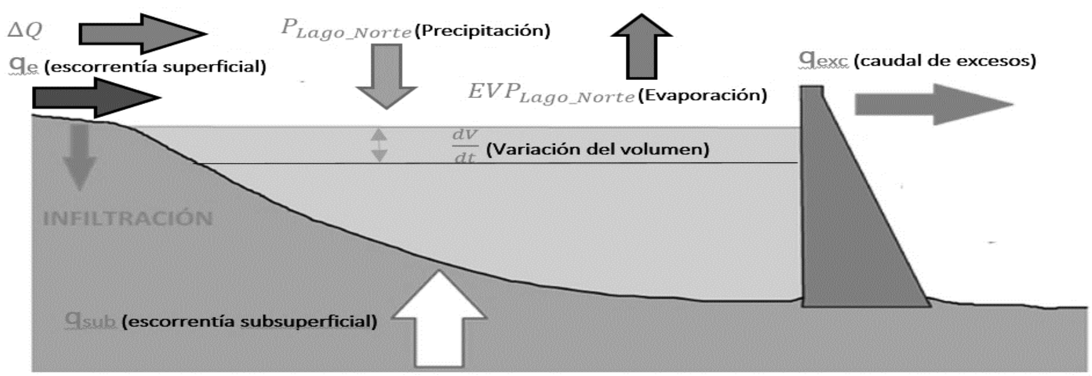

Figure 2. General outline of the hydrological balance in the pit. Filling analysis on a daily basis.

COLLECTION OF HYDROCLIMATOLOGICAL INFORMATION

In order to have the hydroclimatological information of the particular study area where the model is implanted, it is necessary to have and analyze the data of special climatological stations, common, pluviometrics and pluviografics. It is necessary to select all those stations with sufficiently long registration years. To apply the conceptual model, data on temperature, precipitation and evaporation must be available on a daily basis, for the entire period of registration of the stations. These data are the input variables for the estimation of surface runoff from the areas afferent to the storage area. It is advisable to carry out a preliminary debugging of the records, eliminating those erroneous data and identifying the missing records, to later be extended to have a sufficiently extensive base series.

GENERAL CHARACTERISTICS OF DRAINAGE BASINS

Particularly in mining excavation areas, the drainage basins that drain into the potential storage areas are surfaces whose particular topography must be established based on detailed surveys since, due to their anthropogenic characteristics, the drainages are conditioned by the disposition of the extracted sterile material. The physical parameters such as area, perimeter, average slope, compactness index and shape factor should be evaluated from the final configuration of these surfaces.

In order to verify the conceptual model of filling it is necessary to define a volume in the land that allows the storage of surface runoff. It is possible that the drainage surfaces are relatively small (surfaces less than 15 km^2), dimensions that make the attenuation of runoff peaks unlikely in the presence of extreme rainfall events and therefore it is reasonable to apply a rainfall model simple runoff, for example, the rational method. On some occasions it is possible to characterize the runoff that drains to the storage areas from daily records obtained from flow meter stations.

The conceptual model uses the topographic and hydrological variables particular to the study area as input values. The Geographic Information Systems are useful to determine the characteristic curves of the storage, systems that can be fed with information taken directly in the field, “lidar” information or in some occasions with photo-restitutions.

For example, in Figure 3, typical Elevation - Surface Area curves are presented and in Figure 4 the Elevation - Volume curves necessary for modeling are presented.

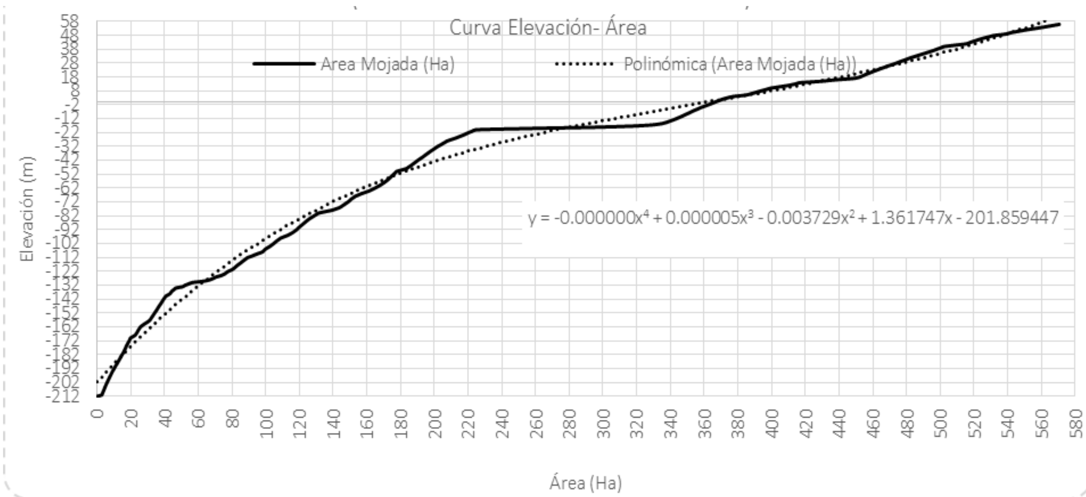

Figure 3. Elevation-Area Curve. Typical storage areas.

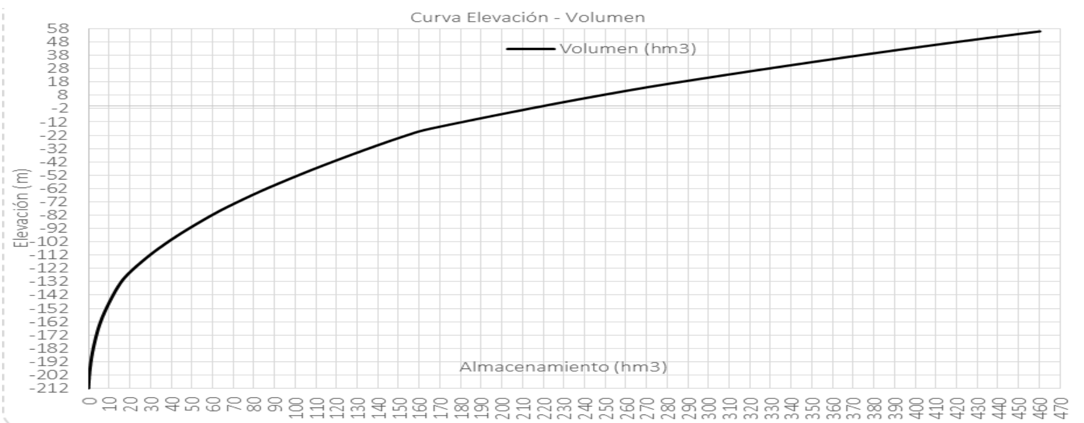

Figure 4. Elevation curve - Volume. Typical storage areas.

POSSIBLE FILLING SCENARIOS IN MINING EXPLOITATION ZONES.

The mining areas have important areas of potential storage due to the activities of the extraction and disposal of material. Due to the complexity of the mining plans, anthropic effects turn out to be the starting point of different analyzes for the filling of potential storage areas. Some scenarios and possible special conditions in areas of mining extraction, for the use of the proposed filling model are presented below:

- **Filling of storage areas with surface runoff from drainage basins that drain naturally.**

This scenario corresponds to those areas that drain naturally to the storage area. In order to analyze this topology, the natural divisions, the soil conditions, and their vegetation cover must be determined, which will determine the runoff volumes and the infiltration volumes.

- **Filling of storage areas with surface runoff from basins whose main drainage must be modified.**

This scenario corresponds to conditions in which we want to accelerate the process of filling the potential storage areas from the runoff of basins that do not drain directly to these areas. It is necessary to design run-off canalization works and structures that allow the transport of water, such as channels, ditches or ditches. The topographic conditions of the sections through which the water will be transported must be analyzed and the hydraulic variables analyzed in order to select those that efficiently allow the runoff to be transported to the storage area.

- **Filling of storage areas with surface runoff and diversion of flow from adjacent storage areas.**

Due to the great variability of extraction processes in mining areas, it is possible to find potential storage areas divided into two or more independent zones intercommunicated by hydraulic structures, which allows the filling of these zones in different stages according to the mining plans. This last scenario, of many other possible, corresponds to the filling of storage areas with volumes of water coming from adjacent storage areas. In this particular case it is necessary to define the overflow levels between storage areas in order to quantify the volumes transferred and estimate the filling times of each zone to define the dates of operation of the storage systems.

RAINFALL MODELS. METHOD GR4J.

The GR4J model is an aggregate rainfall-runoff model with 4 parameters and daily resolution (Perrin et al, 2003) and is an alternative to traditional long-term models. It is a model based on the representation of soil retention from two tanks and two unit hydrographs. The variables used for the estimation of runoff are: x1, maximum capacity of the production tank [mm], x2, coefficient of exchange of groundwater [mm] x3, maximum capacity for transit in channels [mm] x4 and time base of the unit hydrograph UH1 [days].

These parameters are experimental values that can be calibrated for a particular study area from records of surface runoff in the drainage basins.

In the particular case of the mining exploitation areas, temporary storage pools for runoff allow the deposition of sediments. These pools located at the end of the basins that drain into the potential storage areas are a point of control of them. Because it is necessary to monitor the conditions of the discharges of these pools, it is normal to find limnimetric and limnigraphic stations at the entrance. These stations have useful registers that allow the calibration of parameters X1, X2, X3 and X4 of the GR4J model and of other aggregate models. Due to the complexity of these areas, it is necessary to carry out the calibrations from daily runoff records.

CALIBRATION OF THE PARAMETERS OF MODEL GR4J.

As mentioned in the previous section, for the determination of the parameters X1, X2, X3 and X4 corresponding to the soil coefficients of the GR4J model, it is possible to use the available field information in a sediment pool. A calibration method considers the daily flow duration curve recorded in a pool that must be compared with the daily flow duration curves generated with the runoff values determined with the GR4J model from seed values of X1, X2, X3 and X4 the smallest error must be obtained between the curves compared. To estimate the calibration parameters, it is also necessary to minimize the error between the duration curves trying to maintain the average of the historical series and the average of the generated values.

It is also possible to perform a base calibration using daily information from a nearby limnimetric station.

Table 1 shows an example of the estimation of the parameters of the GR4J model. For this simulation, the parameters X1, X2, X3 and X4 were calibrated trying to preserve the mean and the deviation of the historical series and the series generated with GR4J. Likewise, it was sought that the duration curves were similar, that is, maintaining the minimum trend and the same configuration. Figure 5 shows the flow duration curves obtained.

To evaluate the quality of the calibration of the resulting parameters, it is recommended to analyze and review the statistical parameters of the flow duration curves, as presented in Table 2.

Table 1- Initial and calibrated values of parameters X1, X2, X3 and X4 - Model GR4J

Variable	Initial Values Assumptions	Values of the Calibration
X1[mm]	1226.70	800
X2[mm]	1.27	0.80
X3[mm]	225.06	18.00
X4[days]	1.16	10.90
So/R1	0.40	0.00
Ro/X3	0.40	0.00

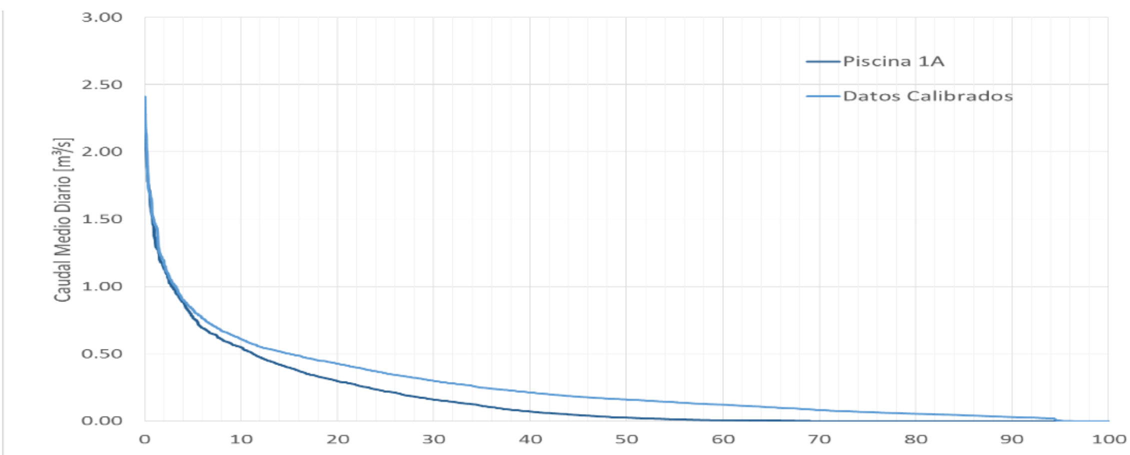

Figure 5. Duration Curves of the Daily Flow Registers and the Study Basin.

As an additional recommendation, it should be checked that the correlation coefficient (R^2) between the duration curves is very close to the unit, since this shows that the estimated results adjust quite well to the historical records of flows. Therefore it is possible use the parameters to estimate the runoff of the other basins that possibly drain into the storage area.

Table 2 - Statistical parameters of the optimization of variables X1, X2, X3 and X4.

Variable	Modeling GR4J	Records	Percentage Error [%]
Deviation [m³/s]	0.294	0.295	0.29
Peak flow [m³/s]	2.41	2.23	7.92
Coefficient correlation between the curves of duration [R^2]	0.977		-

Figure 6 shows an example of the results of the direct runoff generated on a daily basis with the GR4J model from the calibrated parameters X1, X2, X3 and X4.

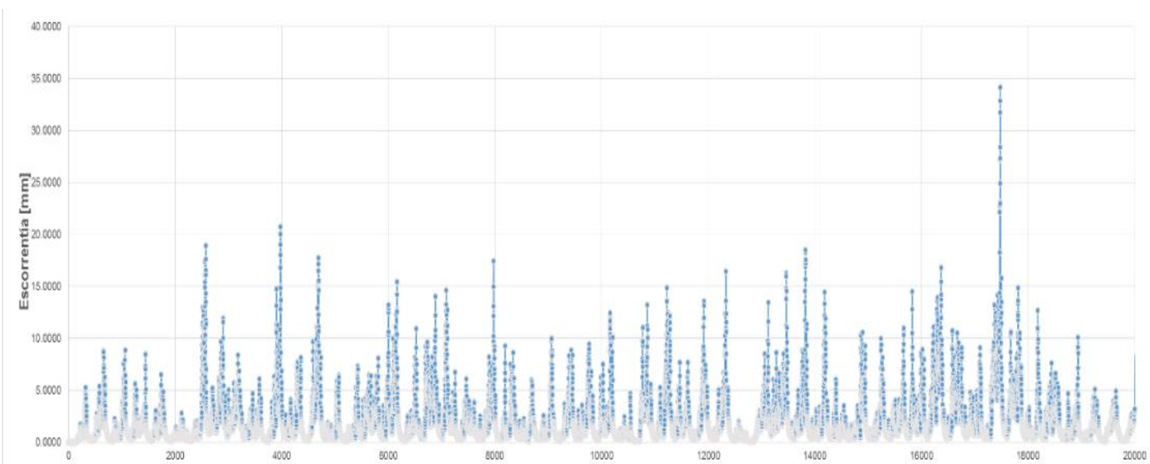

Figure 6. Daily runoff of the multi-year level basin. Model GR4J.

RESULTS ANALYSIS - FILLING THE STORAGE AREA

From the estimated values of daily surface runoff that reaches the storage area and together with the estimation of the daily precipitation, the real evapotranspiration, the underground flow and the other hydrological variables for the storage area it is possible to carry out the mass balance, determining the change of the level in time. Based on the characteristic curves of the filling zone, it is possible to graph and estimate filling times, with the purpose of predicting water levels for different dates.

These graphs in turn allow decision making in the areas of influence of the storage area and particularly establish action plans in mining extraction areas, which are conditioned to the mining plans. Figure 7 shows a typical filling curve.

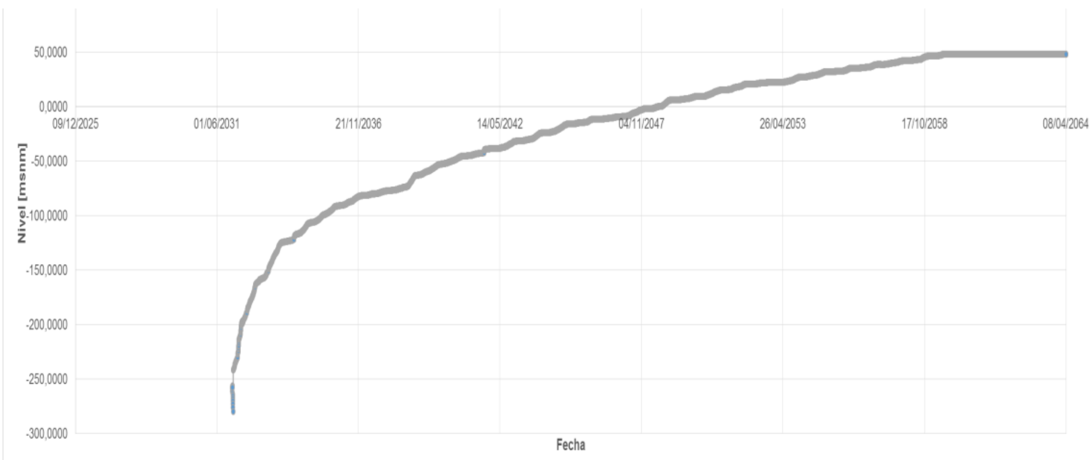

Figure 7. Typical filling curve for a natural storage area.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the different studies, methodologies used and analyzes carried out to fill the storage areas, the following conclusions and recommendations are presented:

The daily precipitation values for the different basins must be obtained from the available historical series of stations existing in the project area, whose data must be verified.

It is recommended that the historical series of daily rainfall extend over 50 years.

Due to the difficulty of estimating the different parameters of the soil in the basins that drain to the potential storage areas, it is proposed to transform the rain to runoff from the model of two tanks of the GR4J method, a form that allows the calibration of the parameters necessary to perform the modeling. It is possible to perform the calibration of this model from the historical records of daily runoff collected in one of the basins that drain the area of. Because of its simplicity, the GR4J model does not explicitly consider the conditions of non-stationary flow, derived mainly from the processes performed once the water infiltrates or percolates. That is, an aggregate (point) and permanent model has been used.

Part of the calibration of the GR4J model requires ensuring that the statistical parameters corresponding to the mean and standard deviation of the data generated with the model and of the records available in the instrumented basin are similar. Likewise, it must be guaranteed that the duration curves obtained in the different basins have the same frequency of occurrence of the minimum flows of the historical records.

The hydrological balance proposed in these studies considers, on a daily basis, the inputs and outputs of the system in order to evaluate the filling times. The underground contributions in the balance model were assumed as known values.

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