Methodology of Computation of Flood Wave Hydrograph in Deep Open Pits

By Stevan PROHASKA[1], Veselin DRAGIŠIĆ[1]

[1] The Faculty of Mining and Geology, Institute of Hydrogeology
University of Belgrade, Djušina 7, 11000 Belgrade; Yugoslavia

ABSTRACT

The paper presents the methodology of flood wave hydrograph computation in deep open pits. This methodology is based on spatial application of the genetic runoff formulae. The procedure for calculation of the corresponding value of heavy intensity rainfall is also given in the paper. All parameters of the accepted methodology are empirical, determined and presented for different characteristics of slope, soil and vegetation. At the end, the procedure for pump sizing is given in the case when partial flooding is allowed. The application of this methodology is illustrated by an actual example of calculating the flood wave hydrograph in deep open pits.

INTRODUCTION REMARKS

The definition of the flood wave hydrograph in deep open pits is one among very important tasks of practical hydrology. The methodology presented in this paper is based on practical application of the genetic runoff formulae. The practical application of this methodology is illustrated by an actual example of calculating the flood wave hydrograph in deep open pits for different frequency probabilities. The procedure for pump sizing, in the case when partial flooding in the pit is allowed, is also given in the paper.

COMPUTATIONAL PROCEDURE

Flood wave hydrograph

The surface runoff in deep open pits represents the genesis of a flow formation from the slopes as a function of hydrometeorological, geological and morphological conditions. In this paper the genetic runoff formula is used for the calculation of the flood wave hydrograph in deep open pits in the form:

$$Q_t = 3.33 \sum_{k=1}^{k=t} (\varphi P)_{t-k+1} f_k \tag{1}$$

Where:

- Q_t - maximum discharge in the moment t (m /s),
- P_t - sum of precipitation in the time interval from (t - Δt) to t,
- f_k - elementary catchment area between isochrones (k=1) and k,
- φ - runoff coefficient,
- Δt - time discretization period (5 minutes).

The elementary catchment area represents the unit area from which the water flows to the output profile. When determining the value of this area f_k the position of the isochrone lines must be known. The isochrone line links continuously all the points, in the catchment which have the same travel time. The total number of the elementary catchment area f is calculated as follows:

$$n = \frac{\tau_{sl}}{\Delta t} \tag{2}$$

where:

- n - the total number of the elementary catchment area f_k,
- τ_{sl} - the travel time of the surface runoff from the slope on open deep pits

The travel time of the surface runoff from the slope can be calculated using the formula:

$$\tau_{sl} = \frac{\bar{l}^{1/2}}{m_{sl}\, I_{sl}^{0.25}\, a_{sl}^{0.5}} \tag{3}$$

where:

- $\bar{l}_{sl}$ - mean length of the slope,
- I_{sl} - mean slope of the catchment in %,
- m_{sl} - coefficient depending on the roughness of the slope and the thickness of the grass cover,
- $a_{\tau,sl}$ - maximum intensity of net precipitation for the time (mm/min)

The equation (3) can be transformed into the following:

$$\tau_{sl} = \frac{\bar{l}^{0.5}}{m_{sl}\, I_{sl}^{0.25}(\bar{\psi}(\tau_{sl})\varphi P_d)^{0.5}} \tag{4}$$

or

$$\tau_{sl}(\bar{\psi}(\tau_{sl}))^{0.5} = \frac{\bar{l}^{0.5}}{m_{sl} I_{sl}^{0.25}(\varphi P_d)^{0.5}} = \theta_{sl} \tag{5}$$

where:

$\overline{\Psi}(\tau_{sl})$ - reduction curve of mean intensity,
P_d - daily sum of precipitation in mm,
θ_{sl} - hydromorphological characteristics of the slope.

The parameter θ_{sl}, which represents the runoff conditions on the open pit slope, can be defined as a function of the reduction curve, as follows:

$$\theta_{sl} = \tau_{sl}(\overline{\psi}(\tau_{sl}))^{0.5} = f(\tau_{sl}) \tag{6}$$

The runoff coefficient from the slope is function of the geological and pedological structures of the slope, vegetation and precipitation. The values of the runoff coefficient from different conditions are given in Table 2. The procedure of the method for calculating the flood wave hydrograph in open deep pits consists of the following: the definion of the hydrometeorological characteristics of the slope θ_{sl} (equation 5) and the travel time from the slope (equation 6) using the theoretical value of the

Table 1 The values of coefficient m_{sl} from the slope

Surface category	Vegetation cover		
	small or without	average	dense
Asphalt, concrete	0.50		
Compact and leveled soil surface, clayey plains	0.40	0.30	0.25
Well ploughed surface, nonploughed, paved and urban surface to 20%	0.30	0.25	0.20
Roughly ploughed surface, covered, bumped and urban surface more then 20%	0.20	0.15	0.10

maximum daily sum of precipitation for frequency probability 1%, the "adopted" runoff coefficient (Table 2) and roughness (Table 1) for real geological and pedological conditions and vegetation, as the known geomorphological characteristics of the slope (mean slope and length).

The total number of the elementary catchment areas of the genetic runoff formula is

Table 2 Surface runoff coefficient

Surface category	Characteristics of the slope	Daily sum of precipitation $P_{1\%}$ (mm)	Catchment area km^2				
			0.1	0.1-1	1-10	10-100	100
I	Asphalt, tissureless, concrete		1.0	1.0	1.0	1.0	1.0
II	Clayey, Marsh black soil calkureous	80	0.80	0.70	0.65	0.65	0.60
		81-150	0.90	0.85	0.80	0.80	0.80
		51-200	0.95	0.90	0.90	0.90	0.90
		200	0.95	0.95	0.95	0.90	0.90
III	Clays, podzoli soil,	80	0.70	0.60	0.55	0.50	0.45
	mineral foresty soil	81-100	0.80	0.75	0.70	0.65	0.65
	marsh soil	101-150	0.85	0.80	0.75	0.65	0.65
		151-200	0.85	0.85	0.80	0.70	0.70
		200	0.90	0.90	0.80	0.75	0.75
IV	Chernozem, laess,	80	0.55	0.45	0.40	0.35	0.20
	forest step soil	81-150	0.65	0.63	0.56	0.45	0.30
		151-200	0.75	0.70	0.65	0.55	0.40
		200	0.80	0.75	0.70	0.65	0.50
V	Sandy soil, desert	80	0.35	0.28	0.20	0.20	0.15
	soil, step soil	81-150	0.45	0.35	0.25	0.25	0.20
		151-200	0.55	0.45	0.40	0.35	0.30
		200	0.60	0.55	0.50	0.45	0.40
VI	Sandy, gravels, rock		0.25	0.20	0.15	0.10	0.10

determined using the equation 2 for the discretization time period Δt. The value of the elementary catchment areas f_1, f_2,..,f_k,..f_n are defined having in mind that the propagation velocity of surface runoff from the slope is constant. The total precipitation for the calculated concentration time can be obtained on the basis of the reduction curve for heavy rainfall intensity, using maximum daily sum of precipitation, as follows:

$$P = \psi(\tau)P_d \tag{7}$$

where:

P - sum of precipitation for duration of rainfall τ,
$\Psi(\tau)$ - ordinates of reduction curve for heavy rainfall.

The corresponding values of the sum of precipitation for other discrete rainfall duration, as

$(\tau_{sl}-\Delta),(\tau_{sl},-2\Delta t),...,(\tau_{sl}-(n-1)\Delta t)$, can be also defined using the equation (7). The sum of precipitation for the calculated discretization time period Δt, within the time of concentration τ_{sl}, can be determined as a direct difference of the cumulative precipitation curve, using the following system of equations:

$$\begin{aligned} P_1 &= P(\tau-(n-1)\Delta t) \\ P_2 &= P(\tau-(n-2)\Delta t)-P(\tau-(n-1)\Delta t) \\ &\vdots \\ P_{(n-1)} &= P(\tau-\Delta t)-P(\tau-2\Delta t) \\ P_n &= P(\tau)-P(\tau-\Delta t) \end{aligned} \tag{8}$$

The distribution of Δt - sum of precipitation, within the time of concentration, is defined in order to obtain the maximum possible value of the peak discharge, using the equation (1). The genetic runoff formula also defined the whole shape of the flood wave hydrograph.

Pump capacity sizing

The procedure for sizing the pump capacity for the surface flow drainage from open deep pits is based on using the so called S-curve volume hydrograph. The schematic presentation of the pump capacity sizing is shown in Fig. 1.

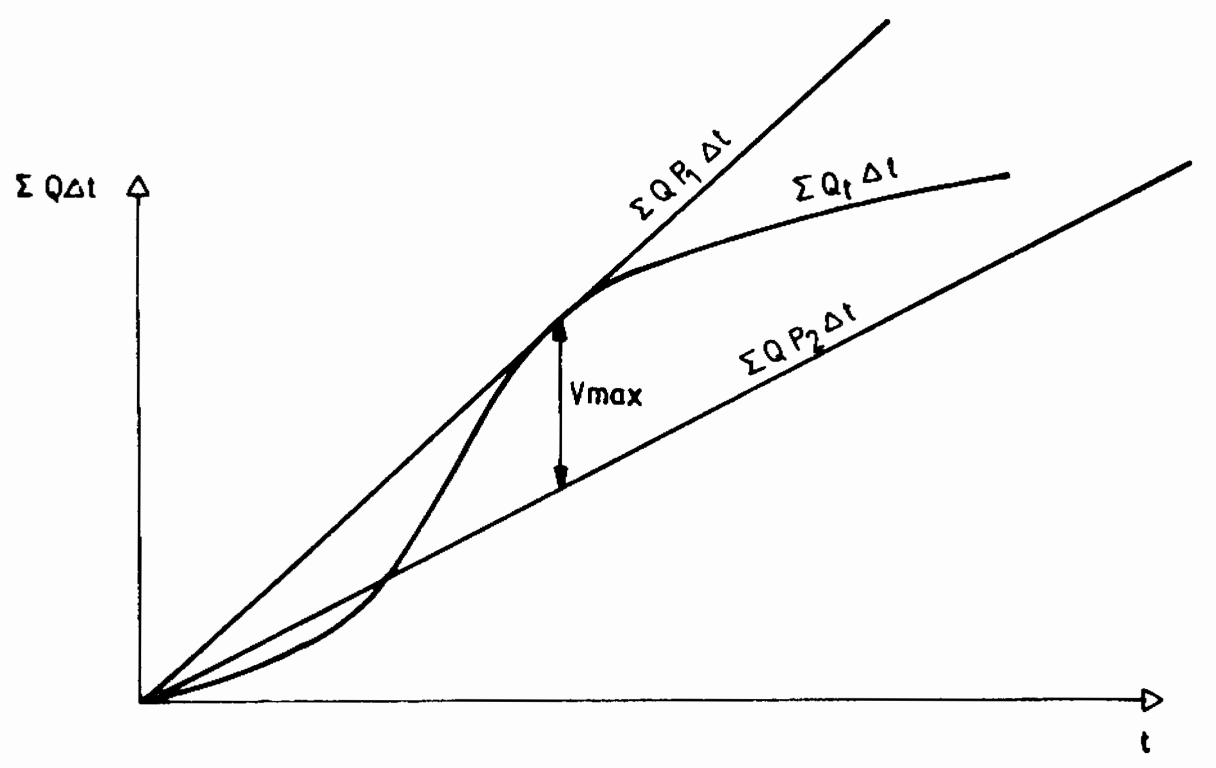

Figure 1

$\sum Q\Delta t$ represents the volume of surface flow in open pit as a function of time t. Generally represents the volume of the water to be drained by the pump capacity P. Consequently, (Fig. 1) the line $\sum QP_1\Delta t$ shows that the pump 1 will drain the whole open pit with-out flooding. The line $\sum QP_2\Delta t$ indicates that the open pit will be flooded up to maximum value of flooding water V_{max}. The value of V_{max}, obtained as can be calculated for different flood hydrograph frequency probabilities and different capacity of pump P.

$$V_{max} = (\sum Q\Delta t - \sum QP\Delta t) \tag{9}$$

Having in mind the volume curve of the open deep pit (Fig. 2) and the fact that in special cases control flood could be allowed, for example to the volume V_o, the sizing of the pump capacity can be determined as follows:

$$V_{max} = V_0 = \max(\sum Q\Delta t - \sum QP_2\Delta t) \tag{10}$$

$$QP_2 = f(V_0, \sum Q\Delta t) = \frac{\sum Q_0\Delta t}{T_0} \tag{11}$$

All variables and schematic procedures for sizing the pump capacity for drainage of a open deep pits are given in Fig. 2.

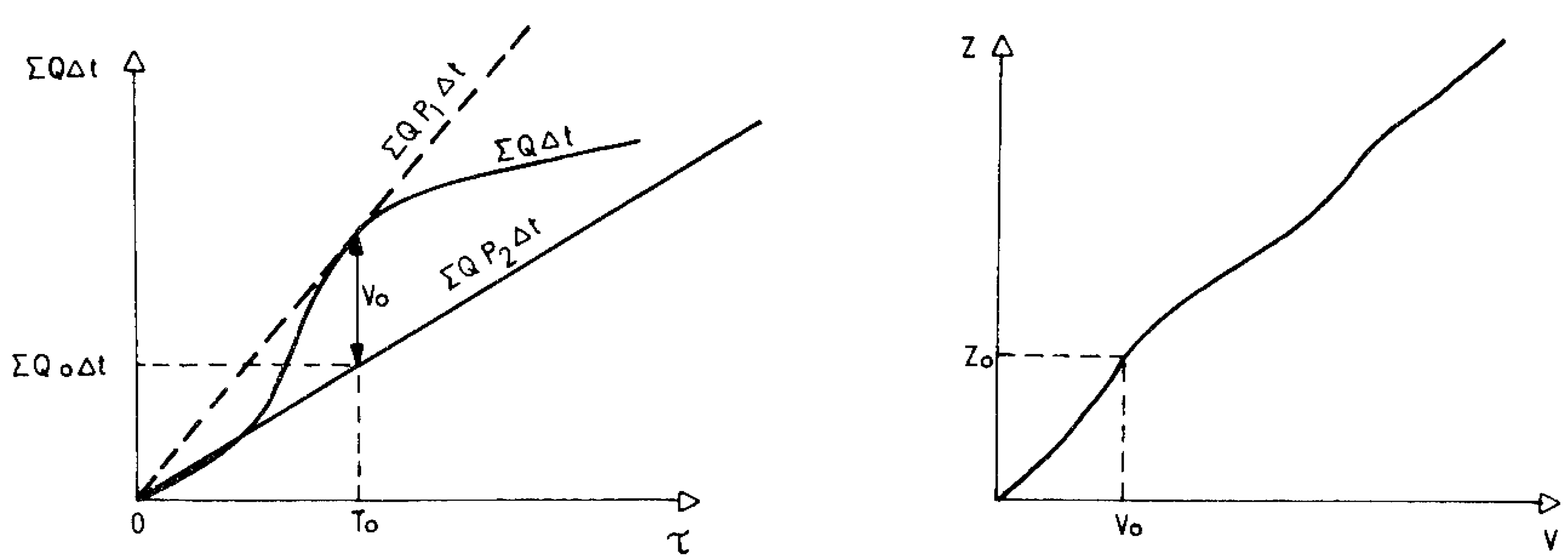

Figure 2

THE APPLICATION

The presented methodology for calculating the flood wave hydrograph is applied for the Majdanpek open pit. All relevant data for pluviographic regime were used for meteorological station Veliko Gradište. The numerical characteristics of heavy rainfall are defined using the data for the long time series. The data served for computing all types of reduction curves: $\psi(\tau)$ and $\bar{\psi}(\tau)$, are shown in Fig. 3, as the distribution probability function of maximum daily precipitation.

The defined relationship between hydromorhological characteristics of the slope θ_{sl} and the time of concentration (equation 6) is presented in Fig. 4.

On the base on geomorphological and pedological characteristics of the Najdanpek open pit the following parameters are chosen:

- the coefficient of roughness of the slope (Table 1),
- the runoff coefficient (Table 2)

for calculating the hydromprphological characteristics of the slope, which is equal to:

$\theta_{sl} = 2.31$

According to graphical presentation given on Fig. 4, the corresponding value of the time concentration is:

$\tau_{sl} = 15$ minutes

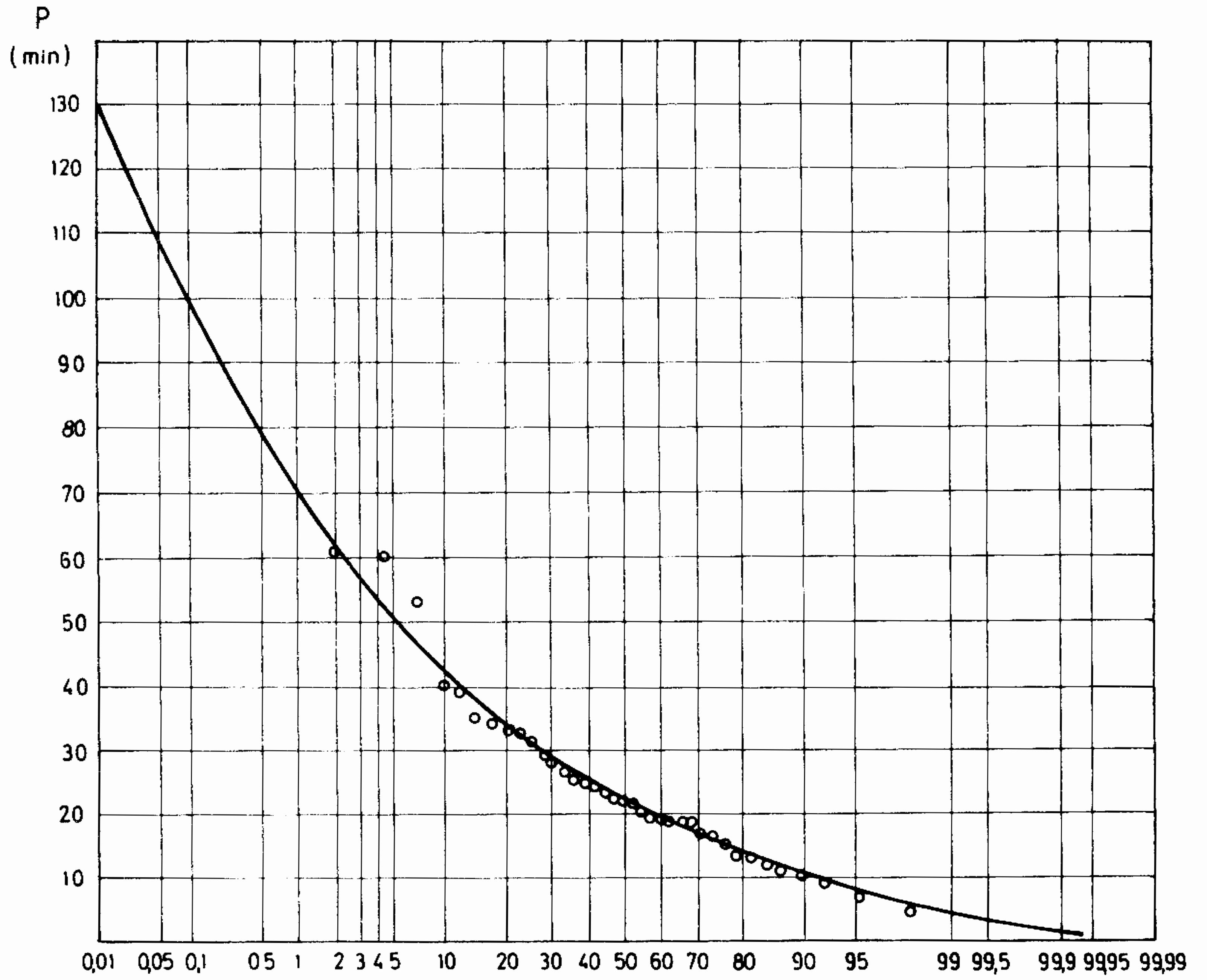

Figure 3. Distribution function of maximum daily sum of precipitation

Since the discreditation period of time is equal $\Delta t = 5$ minutes, the total number of the elementary catchment area is:

$n = 15/3 = 3$

Based on different distribution of discrete values of rainfall (P_1, P_2, P_3 and P_4) within the time of concentration, two computed flood wave hydrograph were obtained. The graphical presentation of the computed hydrographs is given in Fig. 5.

The cumulative volume curve of 100 - years flood in Majdanpek open pit is presented Fig. 6. The straight lines present the constant work of the pump. Capacity of the pump:

$QP_0 = 60.83 \ m^3/s$

is provided the total drainage of open pit for 100 years flood. In the case that the capacity of pump would be:

$$QP_1 = 26.67 \quad m^3/s$$

(second line)
the open pit will be flooded to the depth of 0.5 m and for the pump capacity of:

$$QP_2 = 3.33 \; m^3/s$$

the depth of water in the pit will be 1 m.

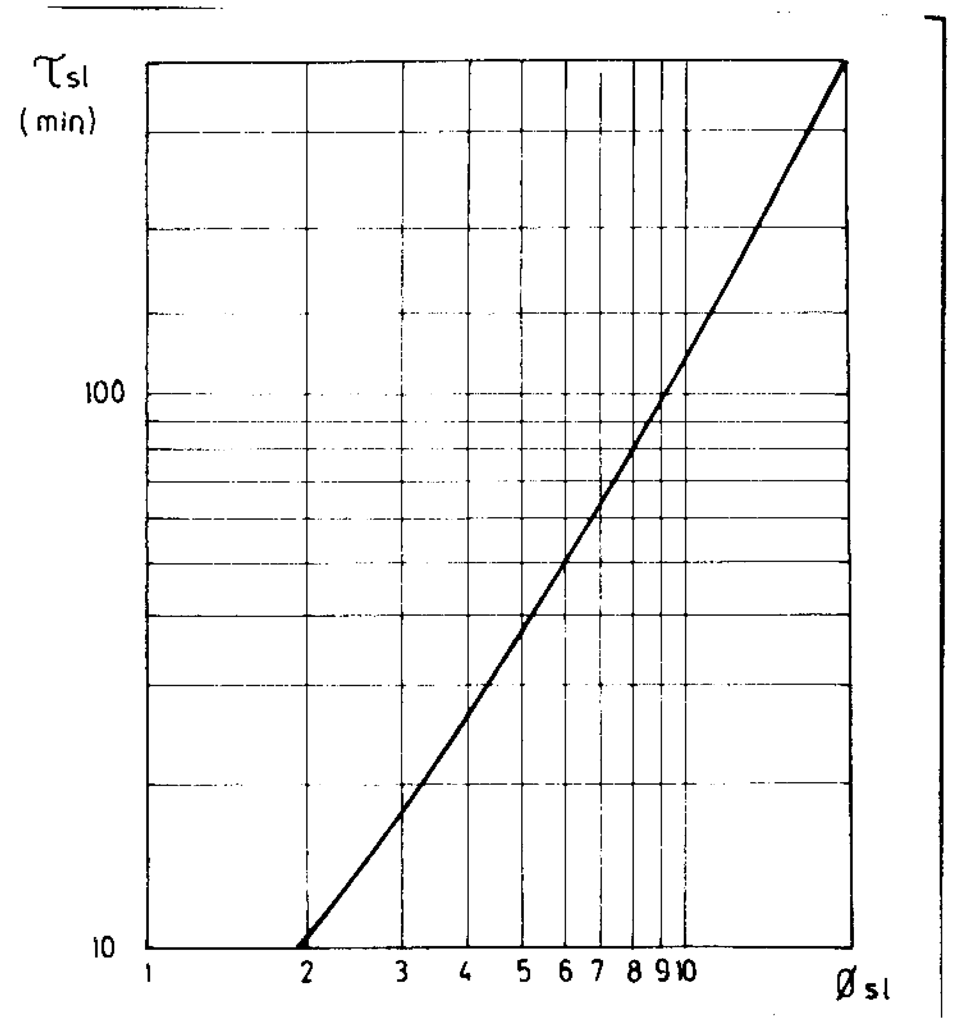

Figure 4. Relationship

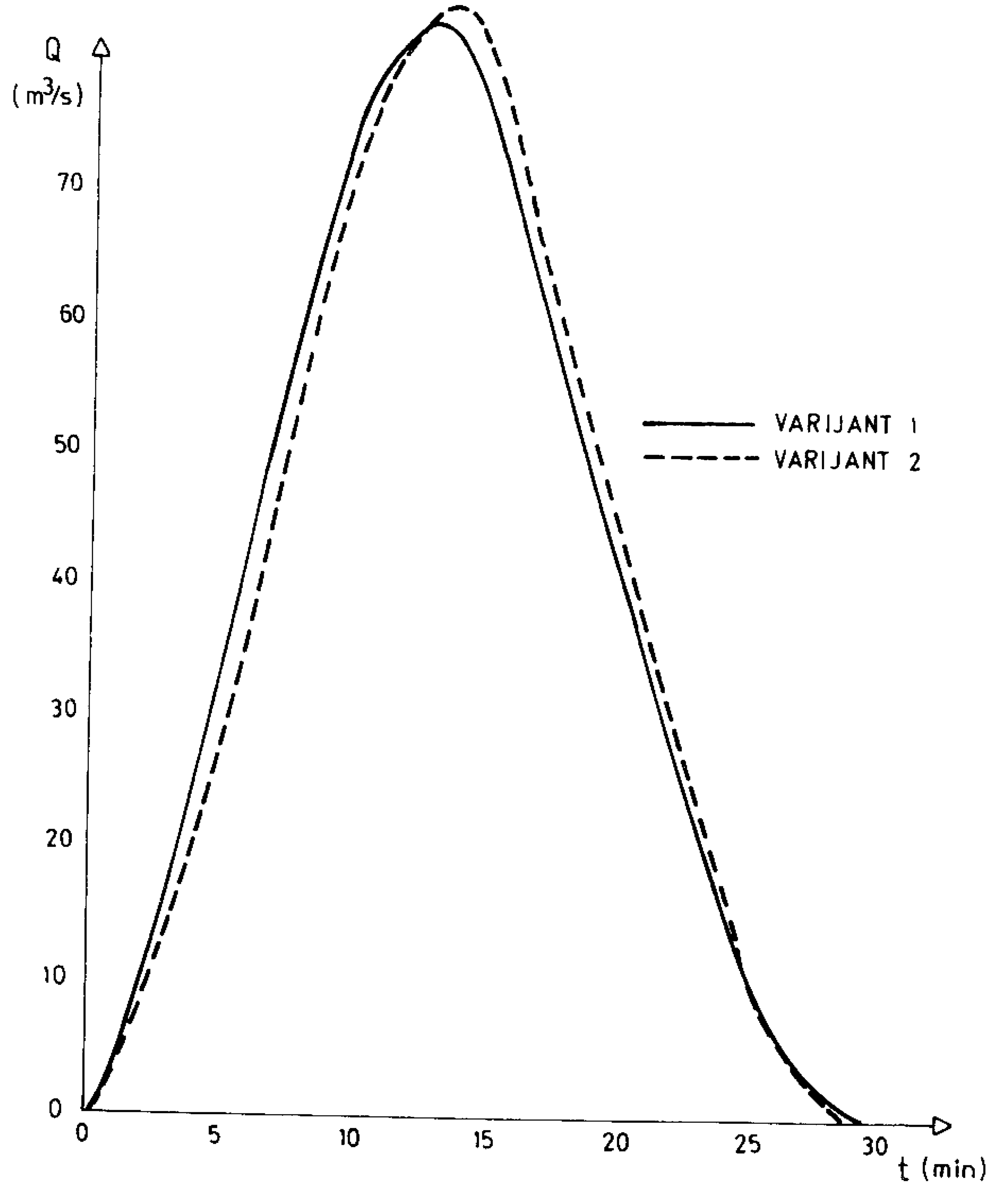

Figure 5. 100 - years flood hydrograph for open pit Majdanpek

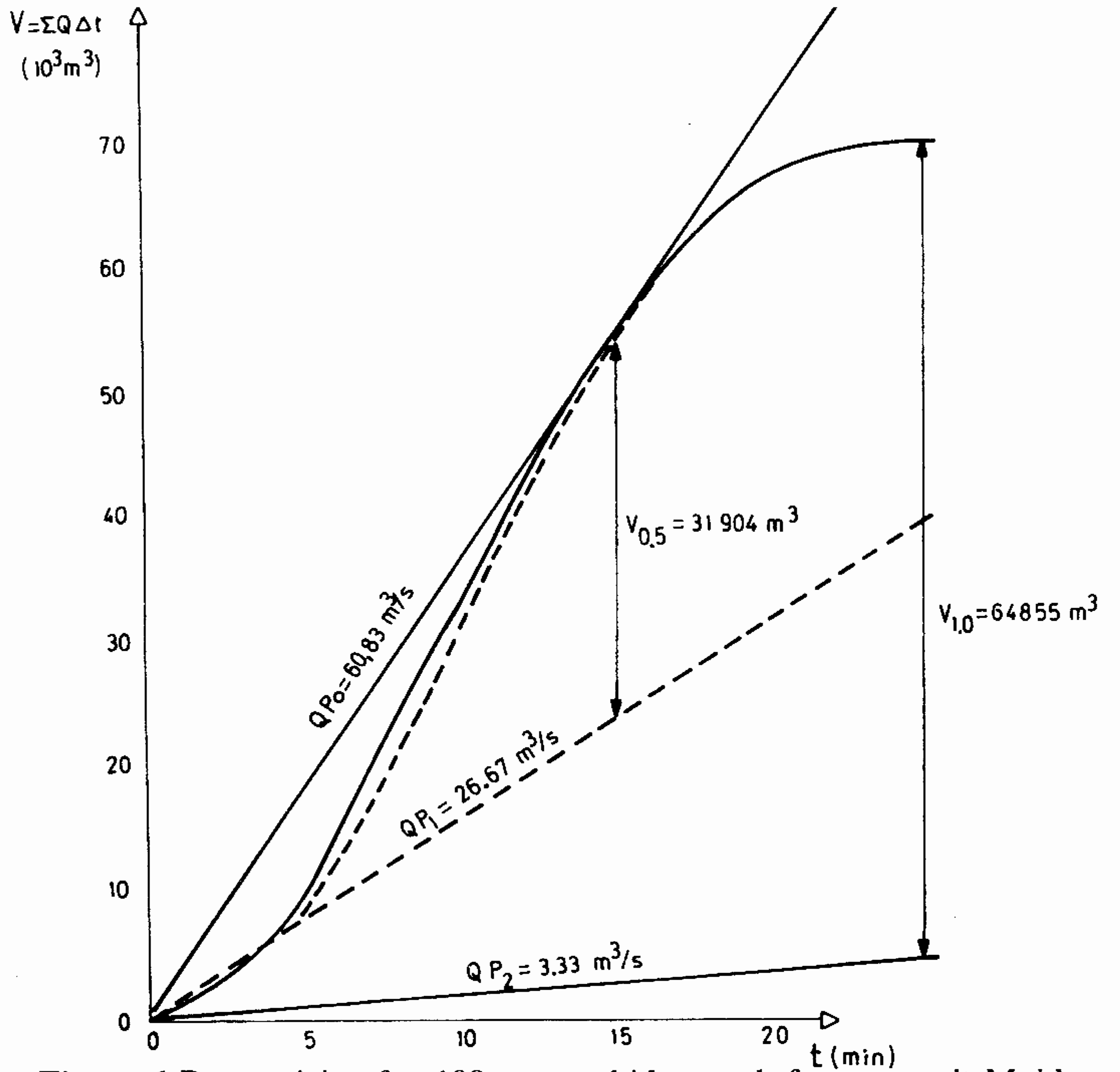

Figure 6.Pump sizing for 100 - years hidrograph for open pit Majdanpek

CONCLUDING REMARKS

The procedure presented in this paper and applied to the computation of the flood wave hydrograph in the real open pit, represents one of the methods that can be used for solving practical problems in open mines. The computation procedure also defines the way of the pump sizing depending on the allowed depth of flooding. The presented results, obtained for the open pit Majdanpek, show that this method can be widely used in actual practice.

REFERENCES

1. Klibašev K.P., Goroškov I.F. (1970) : Gidrologičeskie rasčety. Gidrometeoizdat, Leningrad.
2. Gosudarstveny komitet SSSR po gidrometeorologii i kontrolyu prirodnoy sredy,(1984) : Posobye po opredeleniyu rasčotnyh gidrologičeskih karakteristik. Gidrometeoizdat, Leningrad.
3. Prohaska S., Petković T., Dragišić V. (1987) : Uporedna analiza dva postupka za odredjivanje merodavnih intenziteta kiša za područje Majdanpeka. IX Jugoslovenski simpozijum o hidrogeologiji i inžinjerskoj geologiji, Priština.
4. Prohaska S., Petković T., Dragišić V (1987) : Proračun hidrograma površinskog oticaja na otvorenim rudnim kopovima. XI Jugoslovenski simpozijum o hidrogeologiji i inžinjerskoj geologiji, Priština.