MATHEMATICAL SIMULATION OF HYDRAULIC SCREEN TO DRAIN MINE AND CONSTRUCTION WORK

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ABSTRACT : The introduction of the paper specifies aspects of the hydraulic screen optimization as a drainage system for mine or construction work. The project of the screen respecting all the optimization aspects mentioned is solved by means of mathematical simulation. Stochastic models starting from methods of mathematical statistics and probability give data for the final deterministic model described by partial differential equations for physically defined relation water-rock. The conclusion of the paper contains requirements for a hardware and software of the computerized system.

RESUME : Au commencement de l'article, on spécifie les aspects du problème pour optimiser une barrière hydraulique destinée à drainer des constructions ou des ouvrages miniers. Le plan d'une barrière qui prend en considération tous les aspects en question est résolu à l'aide d'un modèle mathématique. Le modèle stochastique, dérivé par les méthodes des statistiques et du calcul de probabilité, fournit les informations nécessaires pour créer le modèle final déterministe des équations aux dérivées partielles qui décrivent le système physique eau-roche. Pour terminer, on présente les exigences de hardware et software d'un ordinateur convenable.

RESUMEN : Al comienzo del artículo se analizan los aspectos de optimización de una pantalla hidráulica, como sistema de drenaje de minas o construcciones en el subsuelo. Tenidos en cuenta todos esos aspectos, se ha resuelto un proyecto de pantalla, con ayuda de un modelo matemático. El modelo estocástico, confeccionado a partir de métodos estadísticos y probabilísticos, suministra los datos necesarios para establecer el modelo determinístico final, basado en las ecuaciones de derivadas parciales que definen las relaciones físicas roca-agua. Finalmente se señalan las exigencias del hardware y software del sistema de computación.

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INTRODUCTION

The drainage system is a very important part of a mine or construction being founded under the level of underground water. It is possible to say that in many cases the possibility of effective drainage is a limiting factor in opening a mine or realization of the construction. In the majority of cases the drainage system directly influences the way of opening or situation and technology of the construction.

The project of a concrete drainage system must start from given geological, hydrogeological and hydrological conditions, which must be respected within the whole complex together with the requirements of mining or constructional activity. This determines a wide scale of methods of isolation of mine or construction work from underground water beginning from tamponing of cracks, through injecting the failures, clay membranes, concrete walls, drainage galleries and shafts, hydraulic screens and barriers, etc., up to transferring a river bed. It is desirable to obtain optimum solution of the project and operation of a drainage system concerning, as far as possible, all the mentioned criteria. In many cases an optimum effect of drainage is obtained by the combination of several basic methods.

The paper indicates the optimization of a very frequently applied basic method of mine or construction work drainage.

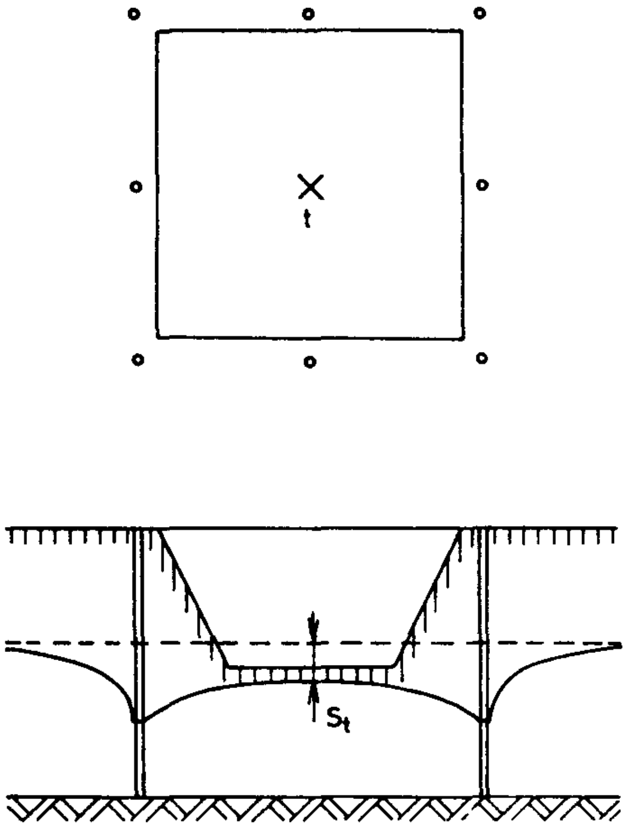
1. APPLICATION OF HYDRAULIC SCREEN FOR DRAINAGE

Hydraulic screen can be used for drainage practically under all the hydrogeological conditions: in the case of free and strained level of underground water, porous and joint permeability (in the case that the system of joints is well interconnected).

Generally, the hydraulic screen presents a closed system of wells (Fig. 1) situated at the nearest possible distance from the edge or from the centre of the plan area of the drained space (further only the drained area). For the first examination of the reality of the hydraulic screen project it is possible to use the well known method of the "large diameter well" to calculate steady flow with filtering parameters being usually at the disposal from the preceding hydrogeological investigation. The equation

$$Q_c = \frac{2\pi ks \cdot m}{\ln \frac{R}{r}} \qquad (1)$$

holds true for the mean of weighed coefficient of filtration (k),



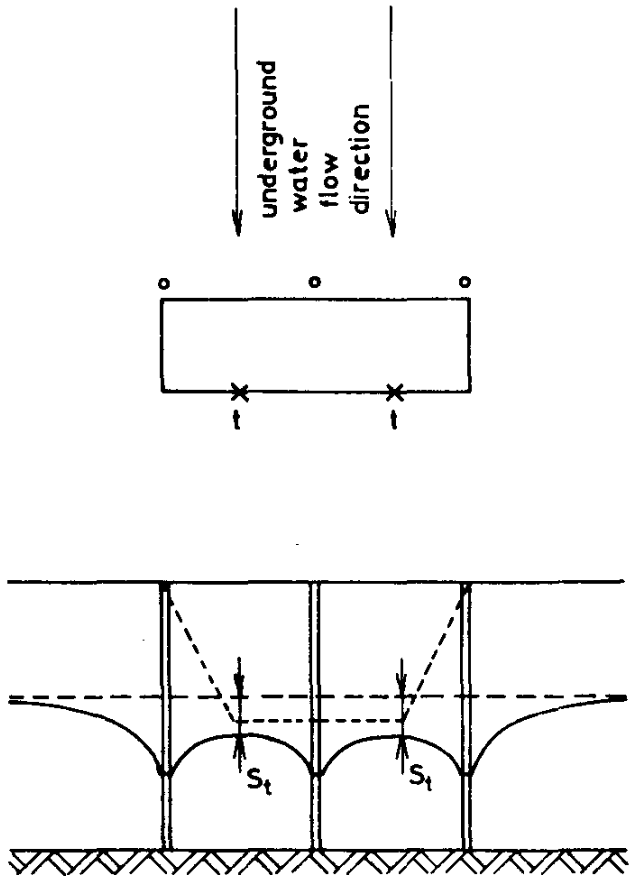


Fig. 1 **Fig. 2**

required reduction within the drained area (s), for the thickness of water-bearing stratum (m), level (H) of the free level is m = 2H-s, further for the "large diameter of the well", generally for the mean or weighed distance of the drained area center of gravity from its boundary (r) and finally for the range of the depression due to the "large diameter well" (R) drainage effect. The range of the depression is determined for orientation, e. g. from empiric relations after Kusakin

$$R = 3000\ s\ \sqrt{K} \tag{2}$$

or after Sichardt

$$R = 575\ s\ \sqrt{H\ .\ k} \tag{3}$$

Quite often it is possible to meet the non-closed hydraulic screen (fig. 2), which is suitable from the point of view of considerable savings when establishing the screen with insignificantly increased operation costs. It can be used first of all to drain areas with considerably predominating dimension in one direction. The non-closed hydraulic screen, situated along the longer side of the area being drained, usually ensures the required reduction also in the direction of the shorter dimension. In the contrary case, it is sometimes possible to close the non-closed screen at its edges in non-permeable lines ($Q = 0$). The non-closed screen can be used even in the case that the non-permeable line is situated at the longer side of the area being drained. In the case of small inflow of underground water into the area being drained, it is more convenient to prefer the non-closedscreen rather than the closed one even at the very cost of adequate extension of the non-closed screen behind the borders of the area being drained. It is evident that in all the mentioned cases the non-closed screen is situated at the side of predominating inflow of underground water. If this inflow is directed against the mining direction of the mine, the screen can be repeatedly situated in a sufficient forefield before the mining front. When mining reaches the screen, the screen is liquidated. Therefore the wells in such screens must not be equipped with steel but with such a material which can be easily extracted (ceramic casing, concrete centering, etc.).

In well permeable water-bearing strata, where large capacities are pumped with relatively flat depressions, the necessary reduction would call for non-effectively large number of wells in a hydraulic screen. This apprehension is real especially with closed hydraulic screens used to drain large areas. To obtain the required reduction even in the center part of this area, the screen is completed with a system of shallow wells, drilled and later pumped from the drainage level of the mine or from the bottom of the construction work. It is also possible to use the system of horizontal wells, eventually drainage seam or pits of small profile. The drainage seam or pit is advantageous as a supplementary drainage system even for the non-closed hydraulic screen.

A combination of a hydraulic screen with a supplementary method of drainage usually decreases the range of the depression due to the drainage of the mine or construction work. This range is especially large with small dynamic reserves of the area. If there are significant holding areas within a possible range of depression, or even a potential source of underground water pollution, it is convenient to combine hydraulic screens with hydraulic barriers. They are created by infusion wells into which water pumped from hydraulic screen is driven in. Thus the depression due to drainage of the mine or construction work is decreased. This protection can be used in many cases at the very cost of slightly increased capacities in the hydraulic screen wells.

Similarly it is possible to combine a hydraulic screen with all the other methods of passive and active isolation of a mine or construction work from underground water.

In the conclusion of the chapter on the suitability of application of the hydraulic screen to drain mine and construction work, it is necessary to carry out an economical consideration of the screen project. A hydraulic screen, as compared with other methods of isolation of mine and construction work from underground water, under similar conditions, presents lower investment costs, but higher operation costs caused by continuous pumping of hydraulic screen. In the majority of cases the operation costs can be compensated so that water being pumped from a hydraulic screen, usually not yet polluted due to exploitation, etc., is used to improve to river flow, to supply inhabitants and industry with water, etc.

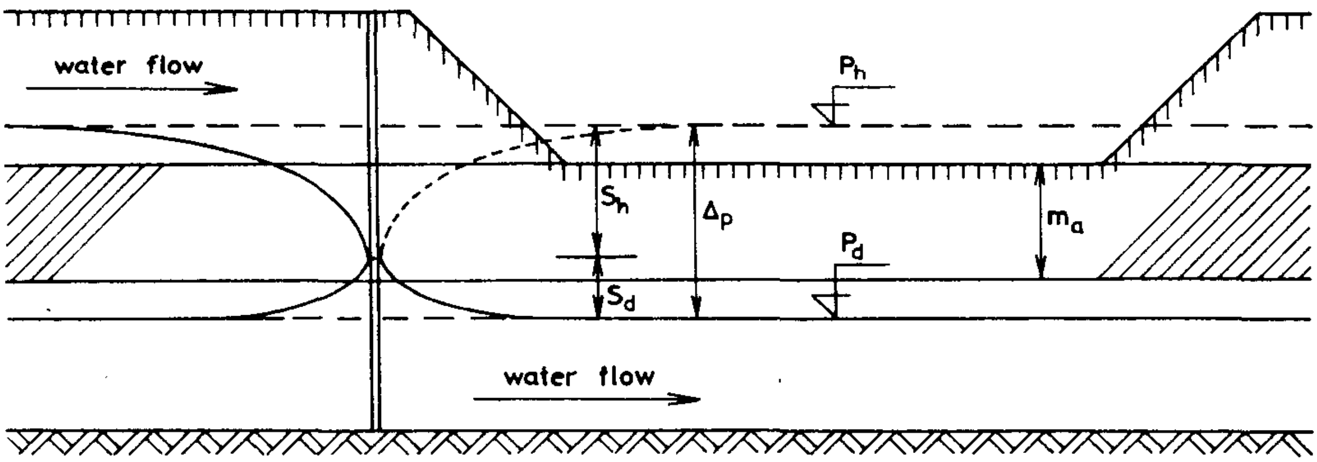


Fig. 3

Under some hydrogeological conditions there is an endeavour to use infiltration hydraulic screen (Fig. 3) for water being polluted by mining activities or else, which cannot be used for the above mentioned purposes. The principle of the infiltration hydraulic screen is in that the water from the strata disturbed by mining or construction activities is transferred due to natural draining ability of the wells into isolated lower strata, not disturbed by mining or construction activities. The condition is that the transmissibility

$$T = k \cdot m \qquad (4)$$

given by the coefficient of filtration (k) and the flow profile (m) is larger in lower strata where water is transferred to than in the upper strata being drained. Another condition is that the difference of piezometric niveau

$$\Delta p = p_h - p_d$$

of the upper (p_h) and lower (p_d) series of strata is larger than the sum of the reductions due to drainage of the upper strata (s_h) and the increase due to the resistance during infiltration of water from hydraulic screen wells into the lower strata (s_d). The following holds true

$$s_h + s_d \leq \Delta p.$$

Among others it is necessary to meet the condition that the weight of impermeable series of strata isolating the lower permeable strata from the bottom of the mine or construction ditch is larger than the upward hydrostatic pressure in the lower water-bearing strata; otherwise a fracture of isolating impermeable strata (Artesian roof) into the mine or construction work could take place. In the case of weighed specific weight (f_a) of the Artesian roof rocks of given thickness (m_a) there holds true that

$$p_d < m_a \quad f_a.$$

In the case that polluted or otherwise unusable water cannot be drained from the space of the mine or construction work by means of an infiltration hydraulic screen or similar drainage system with spontaneous drain (pit, tunnel, etc.) it is necessary to carry out a careful calculation, whether the costs for pumped hydraulic screen, i. e. investment costs and in the case of long-time drainage also operation costs, are proportional to the resulting effect of mining or constructional activity.

2. MAIN ASPECTS OF OPTIMIZATION OF THE PROJECT AND OPERATION OF HYDRAULIC SCREEN

Some aspects of a conceptional character concerning rational project and operation of a hydraulic screen have been mentioned in the foregoing chapter. All of them are directed towards one object: a necessary reduction of underground water level in the space of the mine or construction work at minimum costs with minimum affection of existing underground water regime in wider surroundings.

If this is projected onto the detail solution of a hydraulic screen, it is possible to lay out the following optimization aspects:

1. Optimum situation of the screen in predominating underground water flow direction, with regard to hydrogeological situation, respecting the boundary conditions in horizontal and vertical directions to enable to obtain maximum drainage of the space of the mine or construction work.

2. Determination of the optimum natural underground water level for which the hydraulic screen is to be dimensioned. The task is to propose maximum natural level with regard to the importance of the mine or construction work and scheduled time of drainage. Simultaneously with the course of the maximum level during individual hydrological years and during important periods of the year it is necessary to follow also minimum natural underground water level, to be able to determine the amplitude course.

3. Optimum situation of individual wells of the screen as close as possible to the centre of the drained area, in the places with the most favourable filtering parameters so that in the most unfavourable places (t) of the drained area the required reduction is obtained by superposition of the reductions due to optimum number of wells (p)

$$s_t = \sum_{i=1}^{p} s_{t,i}$$

4. A proposal of the optimum number of wells of convenient diameters to obtain balanced pumping of the screen. In no well of the screen it is permitted to exceed safety reduction which still does not permit origination of negative hydraulic effects on the skin of the well (skin-effects, obtaining critical intake rate when suffosion begins to appear) even in the case of maximum pumping of the screen to ensure required reduction with maximum proposed natural underground water level. This is closely connected with the proposal of suitable manipulation order for the operation of hydraulic screen.

5. Drainage of the mine or construction work presents mostly a large interference with existing regime of underground water in a wide surrounding. There is a question how to hold the consequences of this interference within optimum limits: to obtain a certain balance between positive and negative consequences. The starting point in the evaluation of the consequences of drainage is spreading of the depression in the space and time.

What must be taken into consideration is ageing of the screen wells, spreading of the depression to the places of expressively different hydrogeological medium as compared to that in which the mine or construction work is proposed (a change of filtering parameters, boundary conditions). One part of this prognosis is also a protection of underground water from pollution. It is necessary to consider all the water sources, potential sources of pollution, their mutual position with the possibility of displacement with regard to the direction; and to the rate of flow of underground water.

3. MATHEMATICAL SIMULATION OF THE OPTIMUM PROPOSAL OF THE PROJECT AND OPERATION OF THE HYDRAULIC SCREEN

Respecting the aspects of optimization stated in the foregoing chapter presents a complex solution of considerably wide problem which mostly exceeds the limits of the mine and construction work. It is evident that optimization cannot be solved empirically. One of the ways how to solve this problem is a mathematical simulation using the digital computers. It is very quick, mobile, when solving necessary variants of the model and considerably less expensive when we compare it to other comparable methods.

In the mathematical simulation of the hydraulic screen it is possible to speak of a stochastic simulation which is followed by deterministic simulation.

3.1 STOCHASTIC SIMULATION

Stochastic simulation solves the existing regime of underground water not affected by drainage of the mine or construction work good knowledge of which is necessary to propose the screen (Loupanec, 1969). The initial point is the time series of hydrological observations, being most of all purposeful, limited by the time interval usually of several years. An analysis of these empirical series presents a static model. From the point of view of the theory of random events, the series of hydrological observations presents a random process taking place under unchanged physical conditions within the arbitrary time. A generation of hydrological series and prognoses of hydrological characteristics within the arbitrary time presents a dynamic model. Stochastic simulation makes use of the mathematical statistics and a theory of probability. Its simulation contains always a random element (Balek, 1976; Ibbitt, 1974).

Stochastic simulation takes place in several phases on selected probability levels (e. g. $\alpha = 0.01$, i. e. 99% probability safety), on which the zero hypothesis is accepted or rejected.

3.1.1 PREPARATORY PHASE

As the statistic and probability methods call for the assumption of normality, all the hydrological series must be subjected to the coincidence test, whether they have normal or at least approximately normal distribution. Among parametric coincidence tests we can mention e. g. χ^2-test, among the non-parametric ones e. g. Kolmogorov-Smirnov test for one selection.

Extreme values of observation in empiric series are often loaded with enormous random error. An elimination of such an observation is carried out by the test of an extreme deviation. Among the parametric tests we can name e. g. Grubbs's test, among the non-parametric ones e. g. the Dixon's test.

A systematical error which usually affects all the values of observations in a hydrological series is more difficult to be identified. It is possible to use the less known method test of randomity, the test for the number of iterations (i). With the number of observations n>40 the division of the groups of observations of the same selected type (iterations) approaches the normal one with the mean μ_i and decisive deviation σ_i . The criterion of the test is the standard value

$$u_i = \frac{i - \mu_i}{\sigma_i} \tag{5}$$

An unsatisfactory test of randomity with generated series indicates an unsuitable mechanism of generation of the time series.

Criteria of all the mentioned tests are compared at the selected level of importance with their critical values, tabulated in every statistics textbook (e. g. Nosek, 1972; Raisenauer, 1970).

3.1.2 DETERMINATION OF STATISTIC PARAMETERS OF THE SERIES

This phase is used to ascertain, except for the parameters currently used in parametric tests (extreme amplitude, mean, decisive deviation, median) also chronological trends of observations, empiric frequency and distribution line or even the line of repetition and also the determination of quantities, variation range, coefficient of variation (C_v) and a coefficient of assymetry (C_s).

Some statistical characteristics are used when preparing the balance equations, first of all when specifying their terms in the arbitrary convenient time period. The left side of this equation separates the underground drain determining dynamic reserves of the area where the mine or construction work is situated. This dotation must be taken into calculation when draining (Dub, 1969).

3.1.3 SERIES TRANSFORMATION

Hydrological series are often discrete (rain, irregular water consumption). For the analysis with continuous series it is recommended to carry out a convenient transformation of discrete series. The transformation of the series can suitably emphasize its dynamics. When simulating infiltration of the rain water to the underground water level, it is necessary to cumulate the rain water (a transformation of the original series by gliding totals) within a certain period to enable the process of infiltration. The series are frequently smoothed due to transformation (e. g. gliding totals) or some observations are emphasized (e. g. weighed mean).

Transformation mechanisms may be very complicated. If several series take part in the transformation process (first of all at the input), we speak about superposition. Both procedures are often taken in the process of series generation (Grushevskij, 1973).

3.1.4 CORRELATION AND REGRESSION ANALYSIS OF THE SERIES

While correlation determines the degree of dependence of variables (e. g. by correlation coefficient R), regression describes this dependence by the function of an approximation.

A practical application distinguishes twice and more multiple correlation and regression analysis.

The T-test with twice-multiple analysis is satisfactory to evaluate the coefficient of correlation (R_{yx}) between one dependently (y) and one independently (x) variable.

$$t = \frac{R_{yx}}{\sqrt{1 - R^2_{yx}}} \cdot \nu \qquad (6)$$

where $\nu = n-2$ is the number of degrees of freedom for n observations. A regression relation between both variables can be generally written in the term of the sum of arbitrary known funotions $\varphi_j(x)$ and unknown parameters b_j.

$$y = \sum_{j=0}^{p} b_j \ \varphi_j(x) \qquad (7)$$

The coefficient of correlation $(R_{yx_{1,2\ldots p}})$ between dependently variable (y) and independently variables $(x_1, x_2, \ldots x_p)$ is evaluated by means of the F-test.

$$F = \frac{R^2 yx_{1,2\ldots p}}{1-R^2 yx_{1,2\ldots p}} \cdot \frac{\nu_2}{\nu_1} \qquad (8)$$

where $\nu_1 = p$ and $\nu_2 = n-p-1$ are the degrees of freedom for n observations. A regression relation between these variables can be generally written in the term of the sum of arbitrary known funotions of independently variables $\varphi_j(x_1, x_2 \ldots x_p)$ and unknown parameters b_j.

$$y = \sum_{j=0}^{p} b_j \ \varphi_j(x_1, x_2 \ldots x_p) \qquad (9)$$

If the variable on the left side of the equation (9) is substituted by the group of variables $y_1, y_2 \ldots y_l$, the multivariation analysis also called the canonical analysis is obtained. For the evaluation of the coefficient of the canonic correlation $Ry_{1,2\ldots l}\, x_{1,2\ldots p}$, F-test of the following form is used:

$$F = \frac{R^2 y_{1,2\ldots l}\, x_{1,2\ldots p}}{1-R^2 y_{1,2\ldots l}\, x_{1,2\ldots p}} \cdot \frac{\nu_2}{\nu_1} \qquad (10)$$

where $\nu_1 = p$ and $\nu_2 = n-p-l$ are the degrees of freedom for n observations under the condition that $l \leq p$. The general canonic regression relation can be written in the form similar to equation (9)

$$\sum_{k=0}^{l} c_k \cdot \varphi_k (y_1, y_2 \ldots y_l) = \sum_{j=0}^{p} b_j \cdot \varphi_j (x_1, x_2 \ldots x_p) \quad (11)$$

The results of the dispersion analysis for the evaluation of the coefficient of correlation are evaluated at a selected level of importance, and for given degrees of freedom with critical values of Student's division (T-test) or Fischer-Snedecor division (F-test).

The correlation and regression analyses are widely applied during simulation of the drainage system of a mine or construction work. Individual types mentioned above of the analyses are used according to the number of variables (time series of observed hydrological events), which are at the disposal.

The correlation analysis is used to ascertain the genesis of underground water in the given area, its origin, e. g. rain water infiltration or surface water or underground in-flow, the position and direction of which is defined. Similarly the correlation is used to specify the border conditions in a horizontal direction: determination of impermeable line (Q=0), constant level (H=const.) and an unlimited water-bearing stratum. The border conditions in a vertical direction can be determined by the correlation of levels of underground water in observed wells made in various water-bearing strata.

The regression analysis can follow the correlation analysis in those cases where the correlations indicate a dependence between hydrological effects at selected level of importance. The regression is used to ascertain the proportion of individual factors (climatic, hydrologic, hydrogeologic) to the genesis of underground water in the given area. Quantification of underground water infiltration with regard to the border conditions in horizontal and vertical directions is carried out similarly. On the ground of proved important dependence of short-time observed level of underground water on long-time observed affecting factors the time series of variation of underground water level is generated, eventually a prognosis of long-time characteristics of this variation is carried out. A natural underground water level in the place of pumping is areally interpolated by the regression by means of not-affected wells in wider surroundings of the mine or construction work.

In the correlation analysis it is possible to use with an advantage the method of the so called serial correlations which is essentially the principle of autocorrelation applied to more variables.

The time lag between mutually affecting hydrological effects (e. g. a retardation which shows itself in the proportion of rain water on the dotation of underground water) is determined from the phase shift (k) for an infiltration cycle

$$y_i = f\ (x_{i+k})$$

where the correlation coefficient is the largest. In this way it is easy to determine the rate of natural infiltration of underground water in horizontal and vertical directions (Chow, 1964; Draper, 1966; Malevanyj, 1972; Matalas, 1964; Rektorys et al., 1963).

3.1.5 APPROXIMATION OF EMPIRIC DISTRIBUTION LINE

Chapter 2 emphasizes the importance of maximum natural level of underground water for the optimum proposal of the project and operation of the hydraulic screen. If long-time observed significantly affecting factors of underground water are not at the disposal for the prognosis of this level for the whole time of operation of the screen, it is not possible to use the prognosis by means of regression as stated in par. 3.1.4. It is, however, possible to use an approximation of empiric distribution line of short-time observation of underground water by suitable division (e. g. log-normal, Gumbel's, binomic, triparametric Γ). The long-time characteristics of underground water level is extrapolated by means of the mass curve with suitable division. The period of short-time pumping tests to ascertain the filtering parameters is classified also on the ground of this curve. Until now the best satisfaction in the case of underground water is given the mass curve approximation.

$$y = \int_{x_0}^{+\infty} \varphi(x)dx \tag{12}$$

Pearson's classification of the 3rd type

$$\varphi(x) = \frac{(x-x_0)^{\frac{a}{d}}\ e^{-\frac{x-x_0}{d}}}{d^{(\frac{a}{d}+1)}\,\Gamma(\frac{a}{d}+1)} \tag{13}$$

for optimum parameters a, d (Aleksejev, 1960; Hátle, 1972).

With regard to the extent of the paper it is not possible to specify some other methods used in stochastic simulation, such as harmonic analysis, trend analysis, discrimination and vice versa cluster analysis, factor analysis and some methods of the theory of games. They are, anyway, used in hydrology up to now very seldom. Their wider application is restricted first of all by relatively short empiric series of observations and insufficient number of observed variables (Satran, 1973; Vilkas, 1973).

3.2 DETERMINISTIC SIMULATION

A deterministic model in hydrology starts from physically defined relations water - rock described by partial differential equations. These, in general term, include anisotrophy, space assymetry of flow, infiltration from the surface or from the neighbouring water-bearing strata and other influences including incomplete wells, dip and non-linear course of the strata and bedrock. The solution of these differential equations (by the analytic-conform method, the method of nets or the method of final elements) is laborious, but with regard to more and more effective computers, it is feasible. Another situation is in collection of input data (parameters) for these generally formulated differential equations. The deterministic model takes the data, except for the stochastic model, first of all from hydrologic investigation and pumping tests. Current means of investigation, technology of drilling and pumping, are not at the level which would be required by a generally formulated mathematical apparatus (Hálek, 1973).

These reasons represent the usual limits of the deterministic model, which is simplified to be adequate to the quality of input parameters. These are usually made gradually more precise by verification of the mathematical model so that it gives the best corresponding to the given natural conditions. Such a method of simulation corresponds well also to the optimization of the hydraulic screen used to drain the mine or construction work.

For illustration let us state an example of such a simplified simulation on the ground of linearized differential Businesq equation of axially symmetrical non-stabilised flow of underground water towards a complete well

$$a\left(\frac{\partial^2 U}{\partial r^2} + \frac{1}{r}\,\frac{\partial U}{\partial r}\right) = \frac{\partial U}{\partial t} \qquad (14)$$

for the function of potential (U), coefficient of pressure conductivity (a), coefficient of filtration (k) and the distance of given point from the centre of the well (r). The condition of the described flow is isotropic, horizontal water-bearing stratum. The solution of the equation (14) by e. g. analytic-conform method leads, under certain assumptions, to the equation simulating an independently pumped well in an unlimited water-bearing stratum with constant consumption (Q) in the time (t).

$$U = \frac{Q}{4\pi k} \quad W(x) \tag{15}$$

for

$$x = \frac{r^2}{4at} \tag{16}$$

where $W(x)$ is the integral-exponential function $-E_1(-x)$.

Using the principle of superposition of partial effects from the individual wells, it is possible to simulate

a) cooperation of individual wells in the screen
b) respecting the line border conditions by means of the method of a conform transformation (reflection of wells)
c) a volume of the consumption of underground water from the individual wells of the screen in the given time at prescribed reductions in the wells and that even in the case that pumping does not start in the whole screen simultaneously, but in the arbitrary wells in the arbitrary time.
d) a reduction of the underground water level in an arbitrary point of the mine or construction work and its surroundings with an arbitrary consumption (constant in time) from the individual wells in the screen and that even in the case of interrupted pumping in an arbitrary well.

These possibilities of deterministic simulation enable, when respecting the proposed natural underground water level and on the other hand a safety reduction, to maintain fully the aspects of the optimization of the project and operation of hydraulic screen (Bánský, 1976; Kazda, 1976; Loupanec, 1978).

3.3 PROPOSAL OF NATURAL UNDERGROUND WATER LEVEL FOR DIMENSIONING THE SCREEN

Par. 3.1 determines, by means of the stochastic simulation, the maximum and minimum natural underground water level and thus also the amplitude of its variation. Its long-time prognosis is known, as well as the course during individual hydrological years and also characteristic periods (wet, dry).

If the amplitude of the underground water level variation is small, the screen is dimensed for long-time maximum level which can be proportionally decreased if it is possible to flood a part of the mine or construction work.

On the contrary, if the amplitude of underground water level variations is high, heavy-duty pumps being dimensed for maximum natural level would pump only small quantities during the time when the level is low and therefore they would work non-effectively. The optimum solution of the screen operation in this situation calls for the consideration of three variants:

1. If the conditions allow, first of all the number of the screen wells and their mutual position, the safety reduction and also the range of the depression, the screen is dimensed for natural level, reduced as compared to the maximum level by the same amount which it is possible to reduce the level under the bottom of the mine or construction work by. Using this variant, the amount pumped from the screen is approximately constant even during the period of low natural level, when the level is reduced under the level required by mining or constructional activity. An eventual increase of natural level above the proposed one is then safely retained in the retention space under the mine or construction work. This variant of the optimization of the screen operation is advantageous in the case of frequent, intensive variation of natural level of underground water. It is possible to use a stochastic prognosis of this variation and to control pumping in the screen in advance so that the retention space under the mine or construction work is maintained in the required size only during the necessary time.

2. If the dislocation of wells allows, it is possible to interrupt pumping in some wells during the period of low natural level. The remaining wells may be pumped at constant capacity. This variant of the optimization of the screen operation assumes lower permeability of the drained horizon, in which depressions with higher curvature are realized.

3. If the conditions do not allow to apply the first or the second variant, it is necessary to install except for heavy-duty pumps for pumping during the periods with high natural levels, also the small-capacity pumps for low levels. With the low suction heights of the used pumps and considerable reductions, it will be in most cases an installation of the pumps in the wells which must be proposed as wide-profile wells.

3.4 SAFETY REDUCTION OF THE LEVEL IN PUMPED SCREEN WELLS
During no variant of the optimum operation stated in par. 3.3 the reduction in the screen wells may reach critical reduction during which negative hydraulic effects begin to appear on the skin of the well. A real intake rate is evaluated first of all

$$v_s = \frac{Q}{2\pi r \cdot h \cdot p_f \cdot a} \tag{17}$$

for capacity (Q), well radius (r), effective length of a filter (h), relative number (p_f) and safety coefficient (a) which depends first of all on the age of the well. The relative number describes the flow profile at a correct selection of perforation and strew-round, this number will be identical with the effective porosity of the water-bearing stratum (μ). In this case the skin effect will be the smallest. The real intake rate must not exceed the critical rate during which suffosion takes place.

4. A HARDWARE AND SOFTWARE FOR MATHEMATICAL SIMULATION OF THE HYDRAULIC SCREEN

The mathematical simulation of the optimum project and operation of the hydraulic screen calls not only for a powerfull computer, but also for an effectively arranged programme system.

The hardware input must at least digitize the analog registered data on hydrological observations and pumping tests. More advantageous is direct storing of these automatically scanned informations in the input medium of the computer, either decentralized or remote transfer into registering centre. In the case of the 3rd generation computer we can assume a satisfactory operation speed, a capacity of the internal memory of approx. 500 KB, a mobile external memory, a strong operation system allowing the multiprogramming or even the time sharing. The real time data processing can be used only in the case of peak solution of drainage optimization, when pumping in the hydraulic screen is controlled automatically by the computer through servomotors of the pump valves. In any case it is necessary to provide the computer with a graphical output, the best one would be a plotter or a digigraph in off-line regime.

A part of the software should be a data base of the time series, which must enable storage of practically arbitrary number of series, their precise identification and a direct access during the manipulation, actualization and effective checking of the series. The system of programmes for the actual mathematical simulation must solve all the tasks described in the chapter No 3. It will take still a certain time untill this system will operate automatically with minimum intervention of an operator. Today we find sufficient when the individual phases of the model are processed by independent subsystems (main programme + sub-routines, common for the whole system). A unit-built system is advantageous during the actualization, expansion or mutual interconnection of the subsystems. It is desirable that the programme systems enable, except for the tabular output, also a graphical output - drawing schemes, maps or block schemes (Loupanec, 1978).

CONCLUSION

In the conclusion of the paper on mathematical simulation of the optimum project and operation of the hydraulic screen for drainage of mine or construction work it is necessary to point out the necessity of the optimization. The optimization can save considerably high investment costs and first of all the long-time operation costs. The problem of no less importance is also a preventive solution of underground water protection with regard to the mine or construction work. The mathematical simulation using the computers presents an effective means of this optimization. On the other hand it is necessary to realize that the process of optimization starts from the natural conditions, the intricacy and variability of which is sometimes very difficult to be schematized mathematically at the required level. It will be therefore necessary to correct, in some cases, the mathematical model empirically. The endeavour is, with the development of hydrogeological investigation, the technology of drilling and pumping and with future development of measuring techniques, computer hardware and software, together with gradual precisioning of the mathematical simulation, to reduce those empiric interventions and on the contrary to increase the number of drainage systems controlled by the computer in the real time.

BIBLIOGRAPHY

ALEKSEJEV, G. A. 1960. Grafoanalitičeskije sposoby opredelenija i privedenija k dlitelnomu periodu nabljudenij parametrov krivych raspredelenija. In: Trudy GGI, vyp. 73., Leningrad

BALEK, J. 1976. Některé stochastické modely pro potřeby čsl. výzkumu a praxe. In: Vodohospodářský časopis, roč. 24, č. 4., Bratislava

BÁNSKÝ, V.; KOVAŘÍK, K. 1976. Použití metody konečných prvků v hydrogeologii. In: Sborník "Semináře o využití mat. modelování v hydrogeologii v rezortu ČGÚ". Praha

DRAPER, N. R.; SMITH, H. 1966. Applied regression analysis. New York

DUB, O.; NĚMEC, J. a kol. 1969. Hydrogeologie. Praha

GRUSHEVSKIJ, M. S. 1973. Voprosy matematičeskogo modelirovanija gidrogeologičeskich processov. Leningrad

HÁTLE, J.; LIKEŠ, J. 1972. Základy počtu pravděpodobnosti a matematické statistiky. Praha

HÁLEK, V.; ŠVEC, J. 1973. Hydraulika podzemních vod. Praha

CHOW, V. T. 1964. A handbook of Applied Hydrology. New York

IBBIT, R. P. 1974. Representative Data Sets for Testing of Mat. Models. UNESCO SC 74/WSS. Paris

KAZDA, I. 1976. Systém programů pro řešení potenciálního filtračního proudění. In: Sborník "Semináře o využití mat. modelování v hydrogeologii v rezortu ČGÚ. Praha

LOUPANEC, M. 1969. Řešení otázek režimu podzemních vod v okolí ložisek pomocí počítače. In: Sborník Sympozia "Hornická Příbram ve vědě a technice". Příbram

LOUPANEC, M.; MAŠEK, F. 1978. Modelování jímacích systémů s využitím hydrogeologických programů. In: Geologický průzkum, v tisku. Praha

LOUPANEC, M. 1978. Racionalizacija režimnych nabljudenij v gidrogeologii. In: Sborník symposia "Geotechnika 1978". Brno

MALEVANYJ, G. G.; PIRJATIN, V. D. 1972. Sposob naimenšich kvadratov v gidrogeologičeskich issledovanijach i razčetach. Charkov

MATALAS, N. C.; JACOBS, B. 1964. A Correlation Procedure for Augmenting Hydrologic Data. Statistical Study in Hydrology. New York

NOSEK, M. 1972. Metody v klimatologii. Praha

RAISENAUER, R. 1970. Metody matematické statistiky. Praha

REKTORYS, K. a kol. 1963. Přehled užité matematiky. Praha

SATRAN, V.; SOUKUP, B. 1973. Použití matematických metod v geologii. Praha

VILKAS, E. 1973. Uspechi teorii igr. Vilnius