STOCHASTIC GEOHYDRAULIC COMPUTATION FOR OPEN-CAST MINE DEWATERING

Reichel, F., Roßbach, B. and Rösch, L.

Research Group for Open-Cast Mine Dewatering of the Institute for Lignite Mining, Großräschen and the Technical University Dresden, G.D.R.

ABSTRACT

The stochastic character of system parameters and system inputs restricts the variability of deterministic simulations of open-cast mine dewatering.

For overcoming this defect a stochastic approximation is described in this article. With this method values of the wanted results (stochastic system outputs-SSO) are computed by 1^n computer simulations.
(n = number of stochastic system parameters SSP and stochastic system inputs SSI, 1 = minimum and maximum values of SSP and SSI.)

We get the approximate function of SSO by linear interpolation between the 2^n minimum-maximum results. The probability of every discrete SSO is yielded by multiplication discrete single probabilities of SSP and SSI.

As an example for the application of this method, ground-water levels and ground-water inflow at the operating slope of an open-cast mine are determined by using 5 SSP and SSI and by using different distribution functions of SSP and SSI.

The article closes with a first estimation of the practical application possibilities of this method.

1. Stochastic parameters and inputs of geohydraulic systems

Parameters and inputs (boundary conditions) of geohydraulic systems as well a informations we got about them are, as a rule, stochastic values (SSP and SSI). There exist different reasons for the stochastic character:

1. Geologic and hydrologic values are the result of a random process.

1.1. Random process is already realized. For instance: A sedimentation process has finished, at every point of the aquifer there is a fixed value of permeability. Geological exploration, however, can only provide a random sample of all values. Statistic interpretations result in stochastic models of system parameters (BEIMS and LUCKNER /2/, STOYAN /7/, HILLE, NEUBERT and STOYAN /4/, BAMBERG and GARLING /1/ among others).

1.2. The random process is not yet realized, but from previous observations we have got stochastic data about its course. For instance: distribution functions of run-off or natural infiltration.

2. Random errors of observation. As a rule they are normally distributed with $(0, \sigma^2)$.

3. Available informations from early periods of exploration and planning cannot be considered as "true", but only as "probably". Because we have only a small number of ovserved values or other informations, a statistic interpretation is not possible. The sum of experience can although be expressed in mathematic terms by using "subjective probabilities" (MENGES /5/).

2. Deterministic computations

Despite of the stochastic character of most system parameters and inputs only deterministic calculations are used in the practice of open-cast mine dewatering (for calculations of distance between wells, well depth or pump discharge) hitherto. The reason therefore can be found above all in the high expense for stochastic calculations (Monte-Carlo simulations require a few 100 deterministic solutions). Deterministic methods however demand simplification stochastic parameter model and input model. From these models must be selected, "relevant calculation values" - as a rule it is the mean, the 1 - σ - boundary (σ - standard deviation) or maximum or minimum values.

The disadvantages of this method are obvious:

1. Loss of informations. From a lot of informations or a distribution function only one value is used.

2. No information about the sensitivity of the geohydraulic system.

3. Security can only be taken into consideration in each case for a fixed purpose of calculation.
   For instance: The calculation of (maximum) a discharge to dimensionate pumps requires the use of other values of system parameters and inputs tnan the calculation of (minimum) discharge for utilization of the pumped water.

4. Security cannot be calculated.

3. <u>Stochastic calculations</u>

In /3/, /6/ and others Monte-Carlo simulations are discribed for geohydraulic systems with stochastic and local distributed parameters. Thereby the coefficients of permeability k are regarded as lokal incorrelated or local correlated. As a result we get stochastic ground-water levels and discharges with dispersions adequate to the natural dispersion of the coefficient of permeability.

Such stochastic calculations require both a high stage of exploration and a high expense of calculation. Especially in early periods of planning these demands can hardly be realized, becaus available information usually permit only a subjective estimate of parameters and inputs and their distribution functions. Instead of local distributed parameters and inputs we should employ in these cases models with mean values. Thereby the number of random values is decreased so much, that we can use a stochastic approximation with a relatively small expense.

The approximation discribed in the following pages is based on methods of statistic design and analyses of experiments. For a maximum of n = 5 stochastic application data a computer program was developed.

The following steps are necessary:

1. Fixing of maximum and minimum values of n SSP and SSI.

2. 1^n - fold deterministic solution of the geohydraulic problem (1 = 2 minimum and maximum values of every SSP and SSI) according to design of experiments in table 1. As a result we get 2^n solutions for every output Z (ground-water levels, discharges and so on, all depending on time and place).

3. Linear interpolation between the "Minmax-Solutions" by a polynomial of 1st degree. For n = 2 the polynomial reads

$$Z = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_1 x_2$$

Figure 1 showes the graphic interpretation of this equation.

4. Discretisation of SSP and SSI and their distribution functions (figure 2).

5. Computation of all discrete values Z

6. Computation of the belongig probabilities by multiplication of discrete single probabilities (figure 2). (We suppose independenc between the SSP and SSI)

7. Computation of the discrete distribution function of Z by arranging of the amount of all solutions in classes and summation of the belongig probabilities.

4. Example

For the geohydraulic system shown in figure 3, the stochastic system outputs (SSO) ground-water levels, ground-water inflow and well discharge should be computed. Stochastic values are the SSP

- representative coefficient of permeability of the aquifer k

and the SSI

- long-time mean value of the natural infiltration VN;
- colmation of wells, quantified as additional flow length ΔL;
- number of wells, destroyed by excavation of primary stripping, quantified as distance between the wells B ;
- boundary condition H.

For the computation of the $2^5 = 32$ "minmax - solutions" a program for the one-dimensional and nonsteady ground-water flow with the values in table 2 was employed.

We want to pick up 3 values from the results:

1. ground-water level in 100 m distance of the operating slope H100 (m);
2. ground-water inflow al the operating slope Q (m^3/min 100 m);

table 1

Number of Computation	Variables				
	x_1	x_2	x_3	x_4	x_5
1	L	L	L	L	L
N = 1 2	O	L	L	L	L
3	L	O	L	L	L
N = 2 4	O	O	L	L	L
5	L	L	O	L	L
6	O	L	O	L	L
7	L	O	O	L	L
N = 3 8	O	O	O	L	L
9	L	L	L	O	L
10	O	L	L	O	L
11	L	O	L	O	L
12	O	O	L	O	L
13	L	L	O	O	L
14	O	L	O	O	L
15	L	O	O	O	L
N = 4 16	O	O	O	O	L
17	L	L	L	L	O
18	O	L	L	L	O
19	L	O	L	L	O
20	O	O	L	L	O
21	L	L	O	L	O
22	O	L	O	L	O
23	L	O	O	L	O
24	O	O	O	L	O
25	L	L	L	O	O
26	O	L	L	O	O
27	L	O	L	O	O
28	O	O	L	O	O
29	L	L	O	O	O
30	O	L	O	O	O
31	L	O	O	O	O
N = 5 32	O	O	O	O	O

O minimum

L maximum

3. well discharge of the 3d well gallery QB3

all after 3 years dewatering time.

Table 3 showes the maximum and minimum values of the 32 solutions and, for reasons of comparison, values computed with means X_1 ...... X_5 as well as mean values and standard deviations basing on different distribution functions of SSP and SSI. (The maximum and minimum values were fixed for the normal and log-normal distributions as the 3 - - boundary.)

Figure 4 shows the frequency distributions of SSP.
In this exemple all SSO have a small sensitivity with regard to the applied different distribution functions of SSP and SSI, so that the preference of a fixed distribution has no great effect on the result. The results permit statments about the probability with which extreme values of SSO required by soil mechanics or by technology will be exceeded. Soil-mechanical security also can be combuted with thes values.

5. Outlook

Stochastic geohydrological computations in open-cast mine dewatering are gaining increasing importance. This concernes above all computations in connection with the security of an open-cast mine, with the economy of dewatering, with geohydrological exploration and with territorial prognoses over a long period. Especially for the latter problem stochastic computations will have to be used in a high degree, if the different and in most cases contrary demand for security of computations should be realized in a territory with narrow realtions between water economy and mining, industry, agriculture and forestry.

table 2

	x_1=k(m/s)	x_2=VN(m/s)	x_3= L(m)	x_4=B(m)	x_5=H(m)
minimum	$1 \cdot 10^{-5}$	$1 \cdot 10^{-9}$	0	200	45
maximum	$1 \cdot 10^{-4}$	$2 \cdot 10^{-8}$	200	500	50

table 3

	H100 (m)	Q(m^3/min 100m)	QB3(m^3/min)
minimum	2,54 (31)*	0,014 (32)*	0,582 (32)
maximum	5,80 (2)*	0,120 (1)*	0,041 (1)
computation with means $x_1 \ldots x_5$	4,70	0,056	0,252
$x_1 \ldots x_5$ normal distributed			
mean	4,60	0,048	0,226
standard deviation	0,30	0,009	0,047
$x_1 \ldots x_5$ uniform distributed			
mean	4,60	0,048	0,221
standard deviation	0,50	0,015	0,046
x_1 log-normal $x_2 \ldots x_5$ normal distributed			
mean	4,92	0,039	0,226
standard deviation	0,27	0,008	0,076

* Number of the computation according table 1 and 2

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List of Figures

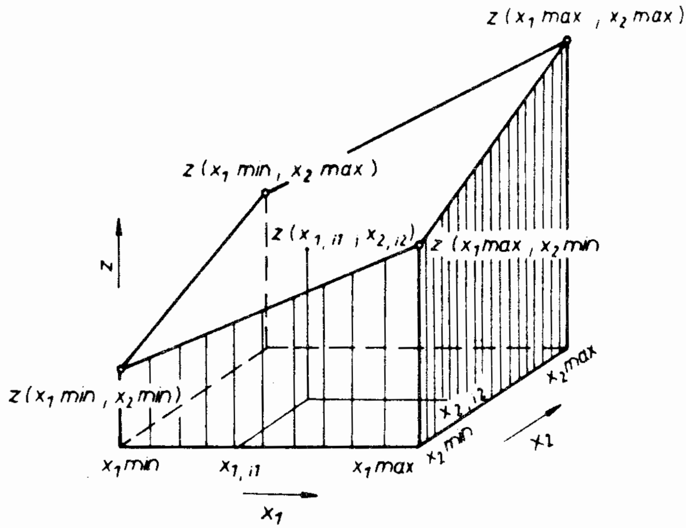
z (x1 max , x2 max)
z (x1 min , x2 max)
z (x1, i1 , x2, i2)
z (x1max , x2 min
z
z (x1 min , x2 min)
x2 max
x2, i2
x2 min
x2
x1 min
x1, i1
x1 max
x1

Fig. 1

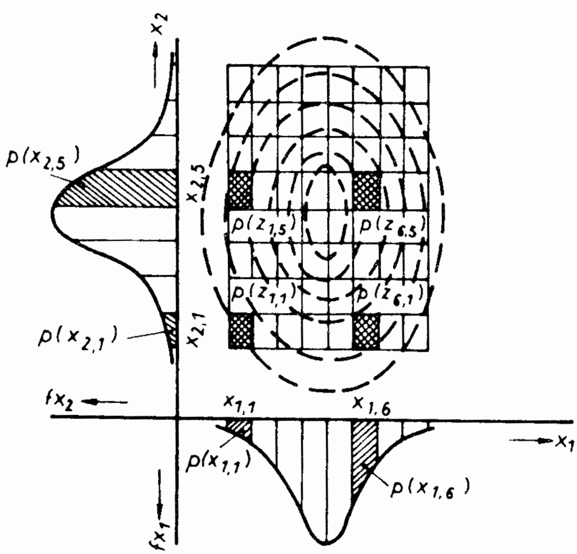
x2
p(x2,5)
x2,5
p(z1,5)
p(z6,5)
p(z1,1)
p(z6,1)
p(x2,1)
x2,1
fx2
x1,1
x1,6
x1
p(x1,1)
p(x1,6)
fx1

Fig. 2

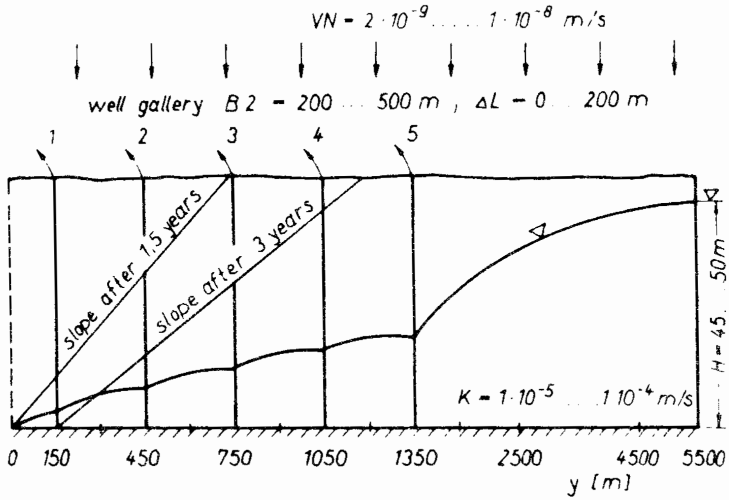
VN = 2 · 10⁻⁹ ..... 1 · 10⁻⁸ m/s
well gallery B 2 = 200 ... 500 m , ΔL = 0 ... 200 m
1
2
3
4
5
slope after 1,5 years
slope after 3 years
H = 45 ... 50m
K = 1 · 10⁻⁵ ... 1 10⁻⁴ m/s
0
150
450
750
1050
1350
2500
4500
5500
y [m]

Fig. 3

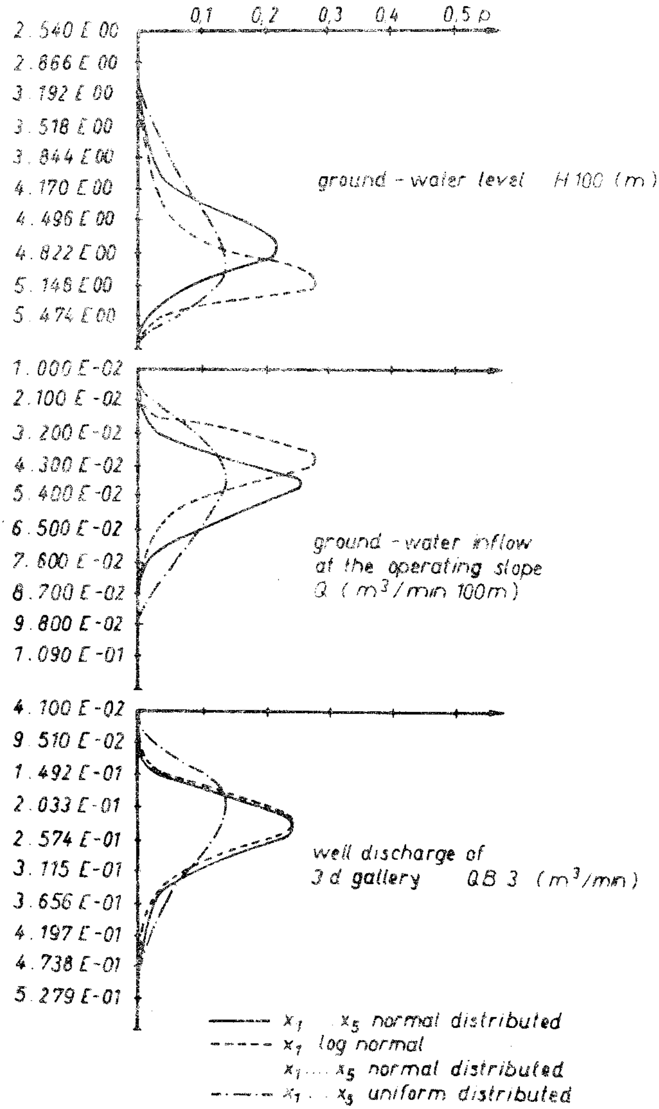
0,1 0,2 0,3 0,4 0,5 p
2.540 E 00
2.866 E 00
3.192 E 00
3.518 E 00
3.844 E 00
4.170 E 00
4.496 E 00
4.822 E 00
5.148 E 00
5.474 E 00
ground - water level H 100 (m)
1.000 E-02
2.100 E-02
3.200 E-02
4.300 E-02
5.400 E-02
6.500 E-02
7.600 E-02
8.700 E-02
9.800 E-02
1.090 E-01
ground - water inflow
at the operating slope
Q (m³/min 100m)
4.100 E-02
9.510 E-02
1.492 E-01
2.033 E-01
2.574 E-01
3.115 E-01
3.656 E-01
4.197 E-01
4.738 E-01
5.279 E-01
well discharge of
3 d gallery QB 3 (m³/min)
x1 ... x5 normal distributed
x1 log normal
x1 .... x5 normal distributed
x1 ... x5 uniform distributed

Fig 4