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Data Analysis in Experimental Network Design for Groundwater Basin: A Case Study.

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1. Introduction. The identification of aquifer structure, boundary and initial conditions and parameters has to proceed any problem of groundwater prediction and management. The reliability of this identification holds the key to the prediction and management problems. Problem of experiment network design plays an important role in identification of aquifer boundary conditions and parameters. The present work is attempting to reveal the data structure which serves as a basis in solving network design to decrease the uncertainty of estimated parameters.

2. Methodology. In the present literature, two main inverse methods are classified: indirect and direct. In the direct method the most common criterion is the output least squares. The parameter values are to be found such that minimize the mean square error between the observed and simulated state variables (groundwater head, concentration etc.). In this procedure the estimated parameter values are determine successively in such a manner that the objective function decreases and reaches minimum in respect to the estimated parameter values. In the direct method the parameters are estimated directly by solving the system of simultaneous equations when the head values are given in all numerical mesh nodes. To avoid the nonuniqueness and instability, the information on parameterization and upper and lower limits should be included. In contrast to these two methods, the geostatistic method may use only prior information of parameters. Thus, the parameter and state variable data are the essential parts of the parameter identification. One of the methods of optimization of network design to improve the parameter estimation is the decreasing the variance of estimation error of parameters by kriging. The details of geostatistic kriging may be referred to Ghislain de Marsily (1987). There are three cases of kriging: stationary, intrinsic and nonstationarity cases. In the first case the random function Z is said to be second-order stationary if the mathematical expectation is a constant and the function of covariance only depends on the distance between considered points. This is the hypothesis of the second-order stationarity. The second case is: the hypothesis of second-order stationarity with a finite variance is not satisfied by the data. Therefore, a less stringent hypothesis named the "intrinsic hypothesis" should be developed to make the estimation possible. The third case deals with problems when the mathematical expectation of Z is not a constant and variogram cannot be determined from data. In practice the second case is widely used and the third case is often simplified to be applicable by the "intrinsic hypothesis". The results of deriving kriging for the second case are as follows. The estimation of an unknown quantity Z^*_0 of a random by weighted sum of all the available measurements is:

$Z^*_0 = \sum_{i=1}^{n} \lambda^i_0 Z_i$ ... (1), where λ^i_0 are determined by solving the following system of $n+1$ linear equations:

$\sum_{j=1}^{n} \lambda^j_0 \gamma(x_i - x_j) + \mu = \gamma(x_i - x_0),\ i=1,...,n,\ \sum_{i=1}^{n} \lambda^i_0 = 1$ ... (2) where λ^i_0: weight values determined from chosen variogram, μ: new unknown. The variance (or square of standard deviation) of estimation error is:

$$\sigma^2 = var(Z^*_0 - Z_0) = \sum_{i=1}^{n} \lambda^i_0 \gamma(x_i - x_0) + \mu \text{ ... (3)}$$

To improve the reliability of the estimated parameter, the covariance must be decreased which is equivalent to increase of observation points around the estimated point. The more number of the data and the less distances from them to the estimated point are, the less variance of estimation error is.

3. Network Design for North-West Region of Northern Kanto Basin.

The location of the study area is shown in Fig. 1. The basin consists of unconfined and two confined aquifers A and B. This work deals with confined aquifers, which are the main productive aquifers.

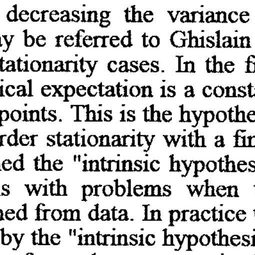

Fig.1 Location of Study Area

Water Level Monitoring. The mean quadratic increment of the head between data points and their chosen variogram forms are shown in Fig.2. Kriging with moving neighborhood was used to estimate head of aquifer A and B. Figure 3 shows the variance of kriged head in aquifer A in 1983 (that of aquifer B is not shown), which are used as initial water levels in parameter identification. The data are not equally distributed over the modelled area and the large values of variance are in the peripheral region. The similar results are related to head of aquifer B. Figure 4 shows the variation of standard deviation of head with the averaged distance from the data points to the estimated point. The minimum values are 5.0 m and 4.5 m for aquifer A and B, respectively. Therefore, to have more reliable initial water level to carry out inverse problem, additional water level observation wells should be located.

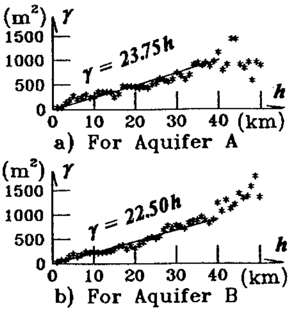

Fig.2 Variogram of Head Kriging

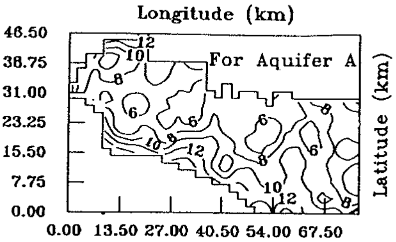

Fig.3 Standard Deviation of Estimated Head (m)

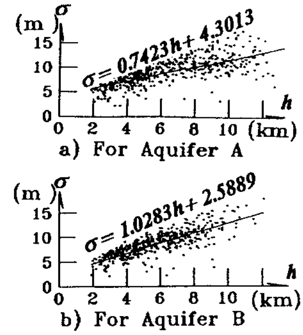

Fig.4 Relation Between σ of Estimated Head and Distance to Data Point

Transmissivity. The variogram data and used variogram form for log-transmissivity (log-T) kriging are presented in Fig.5. Numbers of available transmissivity values of aquifer A and B are 88 and 59, respectively. However, they are not equally distributed which results in large variation of their log-normal covariance. The kriged transmissivity values may be used as the model parameters' values or as the prior information of parameters to ensure the uniqueness and stability of the inverse analysis. The standard deviation of log-T of aquifer A is shown in Fig.6 (that of aquifer B is not shown). The minimum values are 1.35 and 1.3 for aquifer A and B. For the area far from data points the deviation increased. Figure 7 presents the relationship between the mean distance from data points to the estimated points and the deviation of estimated log-T. From Fig. 7 it follows that the uncertainty of transmissivity rapidly increases with the increase of distance to data point.

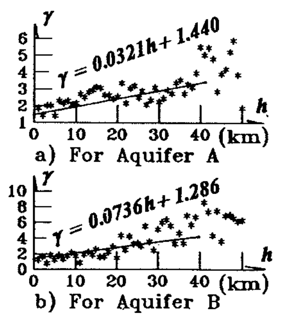

Fig.5 Variogram of Log-Transmissivity Kriging

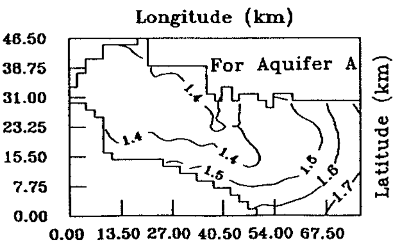

Fig.6 Standard Deviation of Estimated Log-Transmissivity

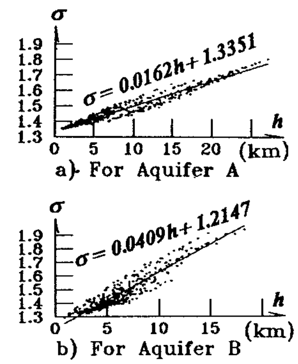

Fig.7 Relation Between σ of Estimated Log-T and Distance to Data Point

4. Conclusions. From this study it follows that: i) water level of aquifers of the study area may be considered as random field with the intrinsic hypothesis, ii) standard deviation of estimated head fluctuated with a large magnitude around the best fit line, iii) the standard deviation of log-T closely gathered around its best fit line, however it may not be less than 1.3 for very near distance and, iv) the results may serve as the basis for the optimal network design of additional water level observation wells and pumping tests.

References

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