Sensitivity analysis of VSAFT2 apply on aquifer hydraulic conductivity inverse estimation

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Introduction

• The issue of remediation of groundwater contamination
• Accurate and efficient remediation
• The understanding of hydrogeological conditions at sites
• The hydraulic tomography surveys (HTS) (Yeh et al., 2000)
Algorithm: SSLE

Sequential successive linear estimator (Yeh et al., 2000)

\[ Y_{c}^{r+1}(x_0) = Y_{c}^{r}(x_0) + \omega_{j_0}^{(r)} \left[ \phi_{j}^{(*)}(x_j) - \phi_{j}^{(r)}(x_j) \right] \]

- \( Y_{c}^{r+1} \): estimate of the conditional mean of lnK at iteration \( r+1 \)
- \( Y_{c}^{r} \): estimate of the conditional mean of lnK at iteration \( r \)
- \( \omega_{j_0}^{(r)} \): weighting coefficient
- \( r \): iteration index
- \( \phi_{j}^{(*)} \): the simulated head at location \( j \)
- \( \phi_{j}^{(r)} \): the observed head at location \( j \) of the solution to at iteration \( r \)
Model: VSAFT2

Variably Saturated Flow and Transport utilizing the Modified Method of Characteristics, in 2D (Yeh et al.)

Homo/hetero
K mean
Correlation length
Boundary condition
Initial condition
Wells location
Pumping rate
Hard data
Criteria
...

Conceptual model
Homogeneous

Heterogeneous
Cross-hole pumping test

Conceptual model

1
2
3
4
5
Heterogeneous Cross-hole pumping test
Inverse

VSAFT2

SSLE

Estimation K field

K

12.00
11.50
11.00
10.50
10.00
9.50
9.00
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0 2 4 6 8 10

0 2 4 6 8 10

0 2 4 6 8 10
Mean absolute error = \( \frac{1}{n} \sum_{i=1}^{n} |\hat{f}_i - f_i| \)

Root Mean square error = \( \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\hat{f}_i - f_i)^2} \)
Objective

Variance $\ln(K)$  ↔  Correlation length

Random seed
Variance $\ln(K)=0.5$

Variance $\ln(K)=1.0$

Variance $\ln(K)=1.5$

Variance $\ln(K)=2.0$
Results and Discussion

Mean absolute errors

\[ error = \frac{1}{n} \sum_{i=1}^{n} |\hat{f}_i - f_i| \]

RMS errors

\[ error = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\hat{f}_i - f_i)^2} \]
Error against correlation length

Mean absolute errors

\[
\text{error} = \frac{1}{n} \sum_{i=1}^{n} |\hat{f}_i - f_i|
\]

RMS errors

\[
\text{error} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\hat{f}_i - f_i)^2}
\]
RMS Errors

Error against Variance

Correlation length=5

Correlation length=10

Correlation length=20
RMS Errors

Error against Variance

Random Seed A

Random Seed B

Random Seed C

Random Seed D

Random Seed E

Random Seed F

correlation length = 5
Random Seed C
Variance=0.5
Correlation length=5

Random Seed C
Variance=2.0
Correlation length=5
Random Seed C
Variance=0.5

Random Seed A
Correlation length=5
Variance=2.0

Variance=1.0

Variance=1.5

Variance=2.0
RMS Errors

Error against Correlation length

Variance ln(K)=0.5

Variance ln(K)=1.0

Variance ln(K)=1.5

Variance ln(K)=2.0
RMS Errors

Error against Correlation length

Random Seed A

Random Seed B

Random Seed C

Variance $\ln(K)=2$

Random Seed D

Random Seed E

Random Seed F
Random Seed C
Variance=2.0
Correlation length=10

Random Seed C
Variance=2.0
Correlation length=20
Random Seed F
Variance=2.0
Correlation length=10

Random Seed F
Variance=2.0
Correlation length=20
Mean Absolute Errors vs Error against Variance

- Correlation length = 5
- Correlation length = 10
- Correlation length = 20
Mean Absolute Errors

Error against Variance

Random Seed A

Random Seed B

Random Seed C

Random Seed D

Random Seed E

Random Seed F
Mean Absolute Errors

RMS Errors
Mean Absolute Errors

Error against Correlation length

Variance ln(K)=0.5

Variance ln(K)=1.0

Variance ln(K)=1.5

Variance ln(K)=2.0
Mean Absolute Errors

Error against Correlation length

Random Seed A

Random Seed B

Random Seed C

Random Seed D

Random Seed E

Random Seed F
Conclusion

1. The mean absolute errors and the root mean square errors have the same trend.
2. The larger the correlation length, the less the errors.
3. The less the variance $\ln(K)$, the less the errors.
4. The larger the variance $\ln(K)$, the better the estimate results in the low K zone.
Future works

- The density of observation wells
- The minimum stress event
- Hard data or not
- Calculate mean K by hard data
- Different input water level
- Change RMSE to NRMSE

Normalized root mean square error

$$NRMSE = \frac{\sum_{i=1}^{n}(f_i - \hat{f}_i)^2}{n f_i^2}$$
Thanks for listening😊