Impact of flow connectivity on the interpretation of pumping test data

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Motivation

- Pumping tests are often used for the estimation of subsurface flow parameters transmissivity **(T)** and storativity **(S)**.
- Traditional geostatistical techniques expressed in terms of two-point correlations (i.e., the covariance of flow parameters at two points is only a function of separation distance) may not be adequate to fully represent complex patterns of flow and transport in heterogeneous subsurface systems.
- To address this issue, the concept of flow connectivity has been introduced to describe how different regions of the aquifer relate to each other.
- In this study, the impact of point-to-point flow connectivity on radially convergent flow tests towards a well is investigated numerically.

Purpose

- To investigate the impact of connectivity on interpreted flow parameters (transmissivity and storativity) derived from pumping test data
- To assess whether the estimated parameters can provide insight on the connectivity of the transmissivity field. The interpretation of the pumping test data is performed using the Cooper-Jacob Method (1946)

Procedure

6 Main Sections

1. Generation of multivariate Gaussian transmissivity fields using the geostatistical library GSLIB.

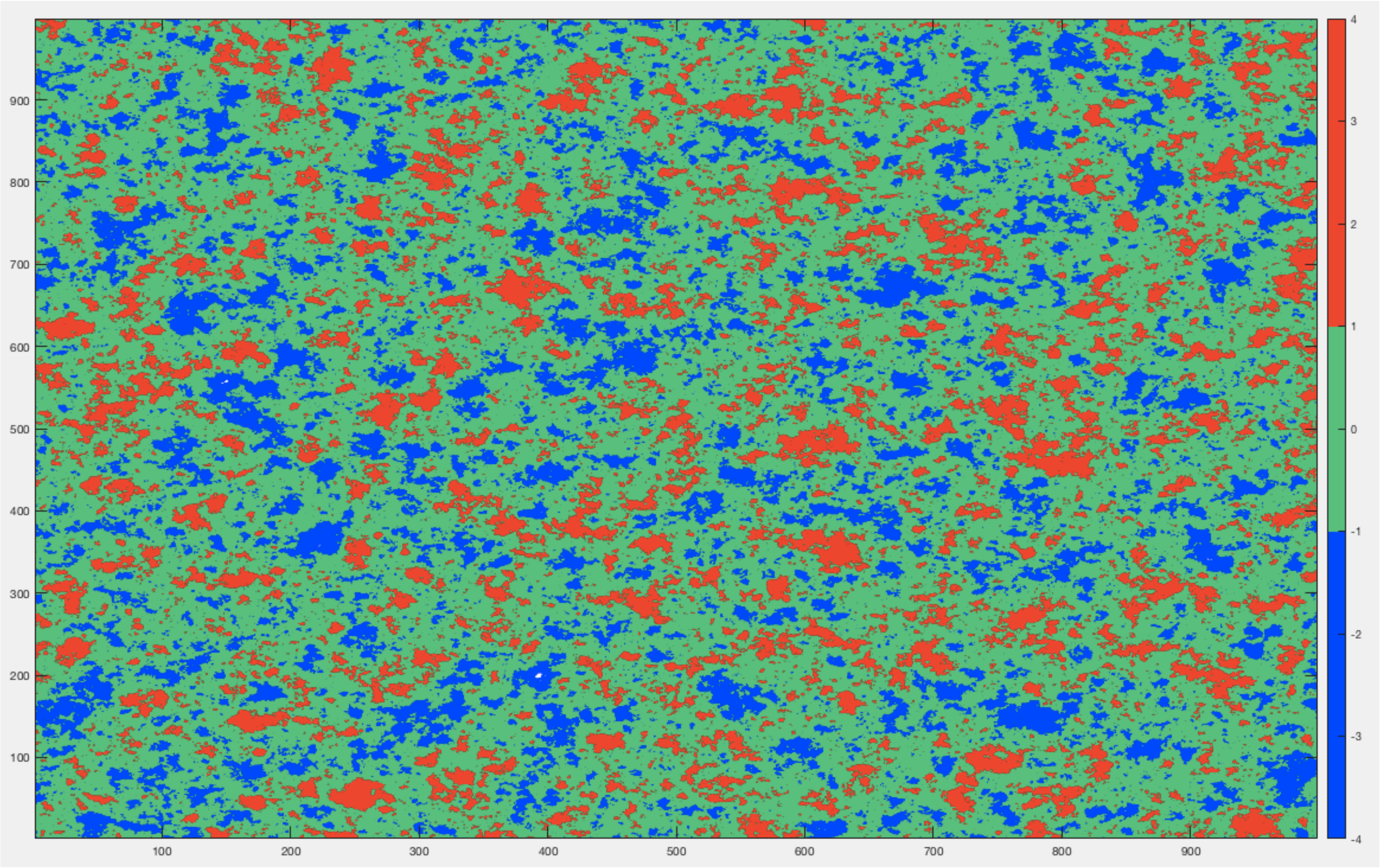
	Parameter values for ln(T) used in Gaussian Transmissivity Field Generation				
	Covariance Function Type	mean	variance	integral scale	Transmissivity at the extraction location
Unconditional	Exponential	0	1	10	Variable
Conditional	Exponential	0	1	10	**Constant**, ln(T)=0.2

2. Generation of connected high transmissivity (high-T) and connected low transmissivity (low-T) fields using the method proposed by Zinn and Harvey (2003). The statistical parameters are maintained as the Gaussian fields.

Procedure Cont'd

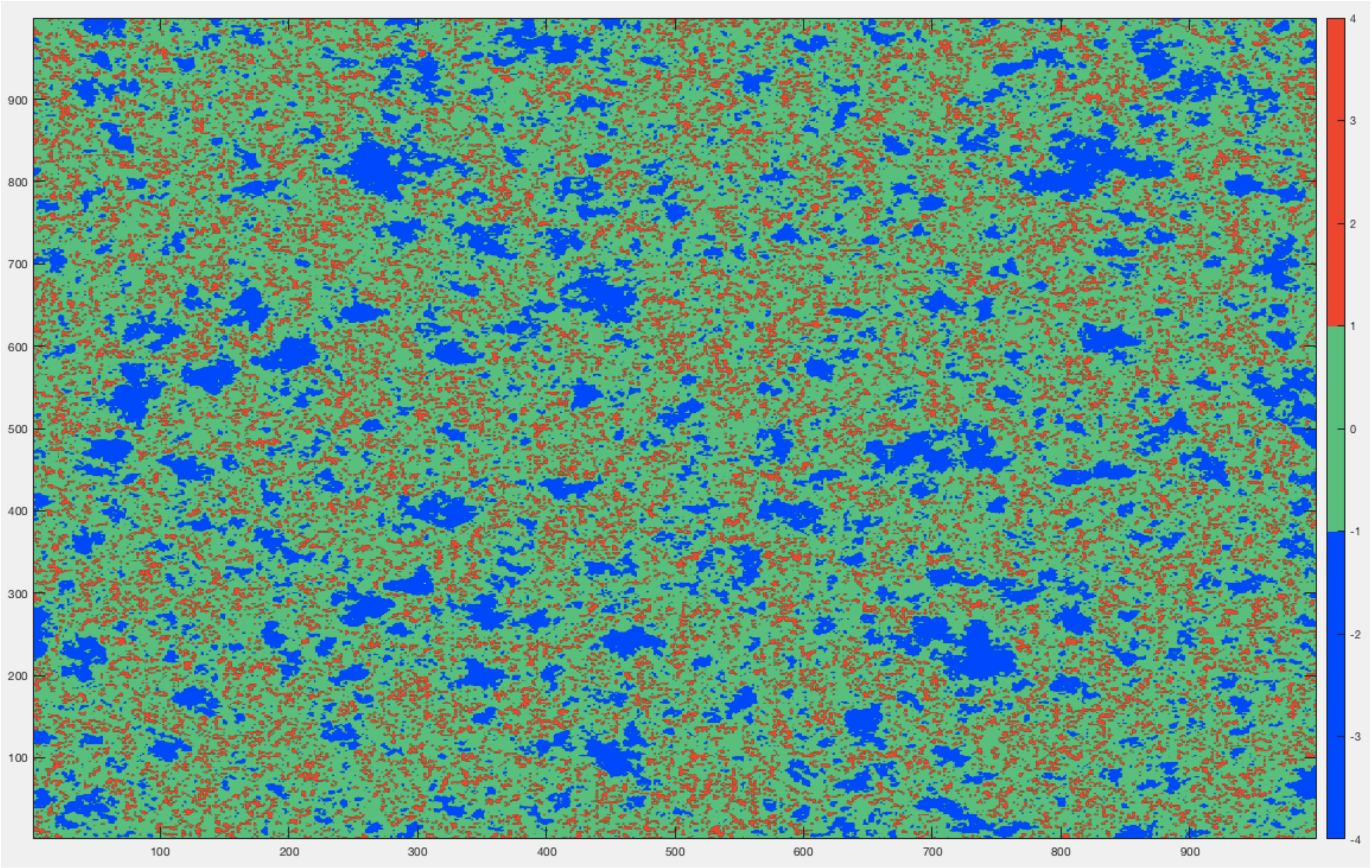
3. Pumping tests are simulated with the MODFLOW program for all fields. The aquifer is assumed to be confined. Prescribed head is imposed at the outer boundary. The pumping well is placed at the center of the domain. The drawdown vs. time graphs are generated for each field.
4. Transmissivity (T) and storativity (S) are estimated using Cooper-Jacob method. In order to investigate the impact of the location of the observation point on parameter estimation, the CJ method is applied at two different distances from the pumping well location where r/I=0.1, and r/I=0.5.
5. Connectivity scales of fields are estimated using the methodology defined in Western et al. (2001).
6. The impact of connectivity on estimated flow parameters is examined

Transmissivity Fields



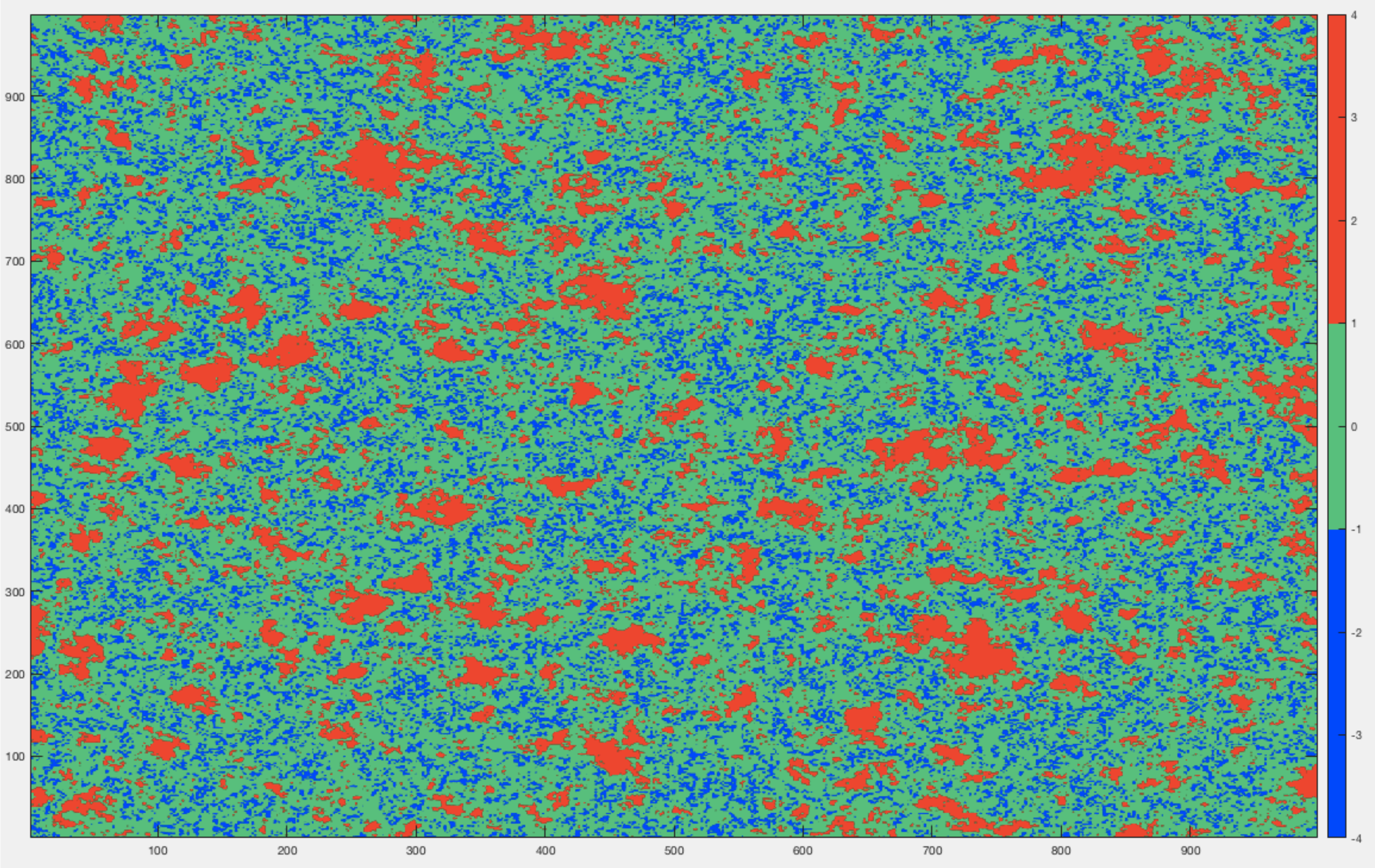
Multivariate Gaussian Field

Transmissivity Fields



High-T Connected Field (with isolated low-T clusters)

Transmissivity Fields



Low-T Connected Field (with isolated high-T clusters)

Results

Conditional realizations, r/I=0.1				
	High-T Connected (100 realizations)	Low-T Connected (100 realizations)	Gaussian (100 realizations)	Combined (300 realizations)
Average Integral Connectivity Scale	46.22	17.98	33.03	32.41
Average T	0.999	0.948	0.964	0.970
Standard Deviation of T	0.08	0.07	0.12	0.09
Average S/S_0	10.04	0.18	5.78	5.33
MAX S/S_0	34.84	4.3	49.66	49.66
MIN S/S_0	3.14E-01	2.00E-05	5.80E-04	2.00E-05
Standard Deviation of S/S_0	7.17	0.49	7.27	7.14

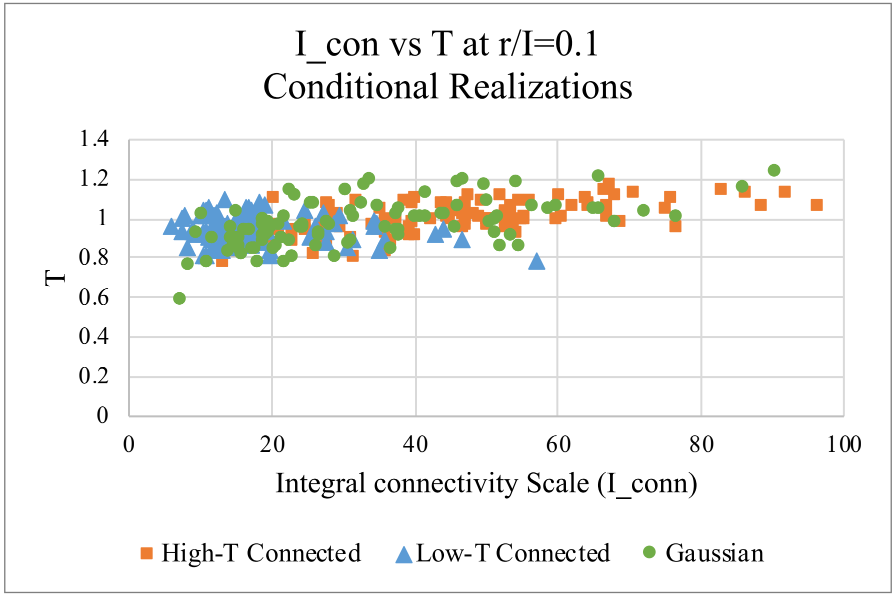
Conditional realizations, r/I=0.5				
	High-T Connected (100 realizations)	Low-T Connected (100 realizations)	Gaussian (100 realizations)	Combined (300 realizations)
Average Integral Connectivity Scale	46.22	17.98	33.03	32.41
Average T	0.998	0.953	0.968	0.973
Standard Deviation of T	0.07	0.06	0.09	0.08
Average S/S_0	2.08	0.98	2.19	1.75
MAX S/S_0	4.69	6.8	17	17
MIN S/S_0	8.81E-02	3.58E-02	1.10E-02	1.10E-02
Standard Deviation of S/S_0	1.13	1.23	2.14	1.66

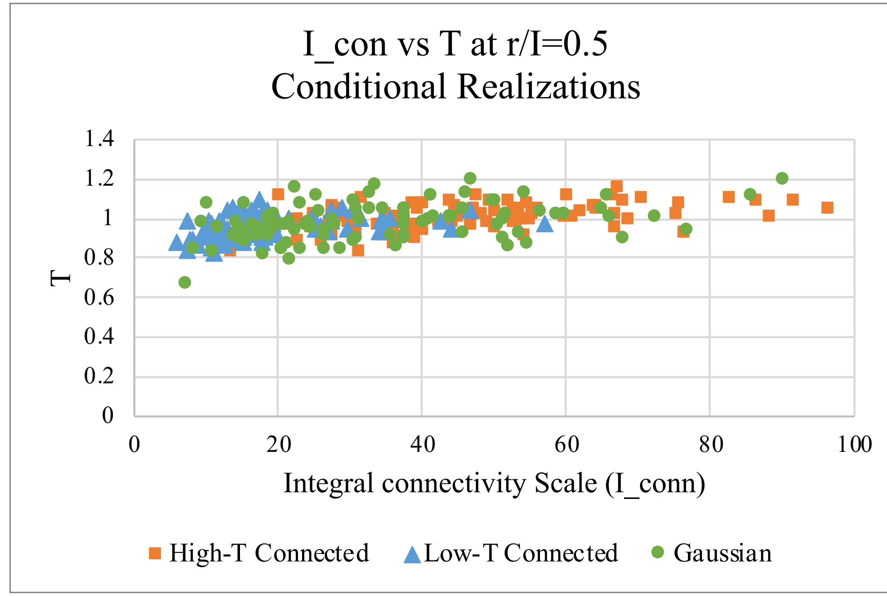
Results

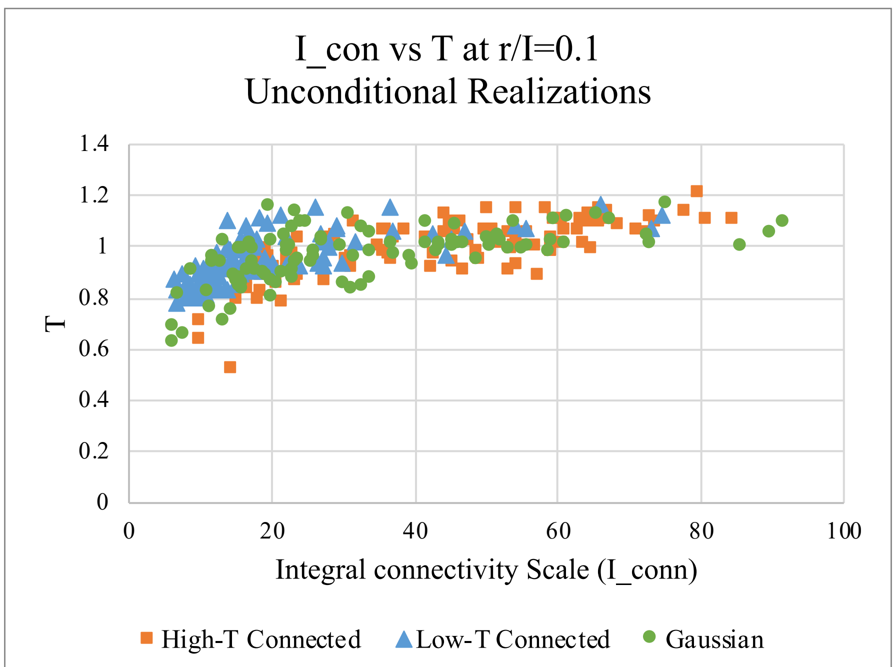
Unconditional realizations, r/I=0.1				
	High-T Connected (100 realizations)	Low-T Connected (100 realizations)	Gaussian (100 realizations)	Combined (300 realizations)
Average Integral Connectivity Scale	43.93	19.88	33.48	32.43
Average T	0.988	0.953	0.963	0.968
Standard Deviation of T	0.11	0.09	0.11	0.11
Average S/S_0	5.28	14.60	16.22	12.03
MAX S/S_0	30.78	526.50	462.37	526.50
MIN S/S_0	1.62E-11	3.46E-05	1.08E-15	1.08E-15
Standard Deviation of S/S_0	6.83	57.83	54.42	46.11

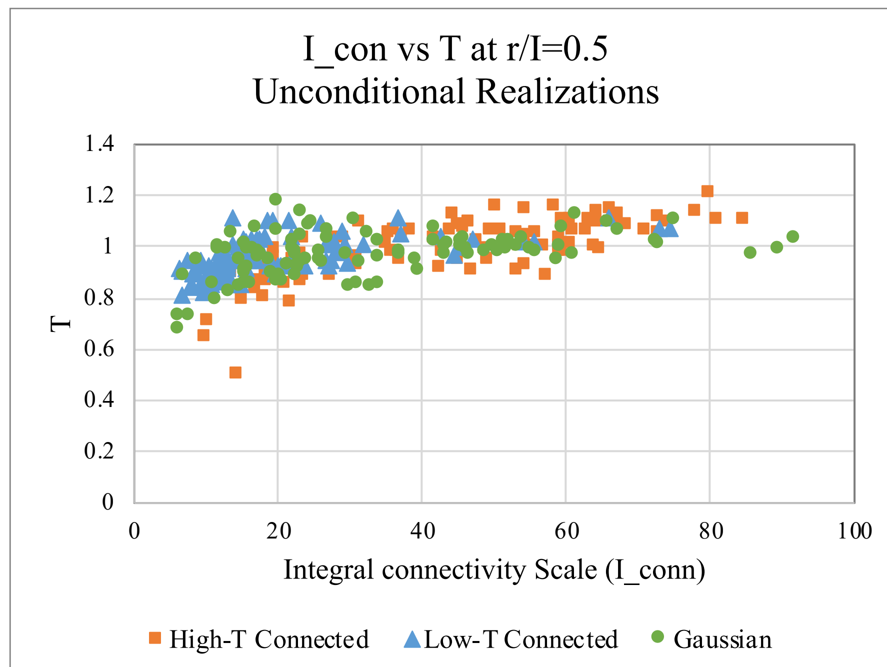
Unconditional realizations, r/I=0.5				
	High-T Connected (100 realizations)	Low-T Connected (100 realizations)	Gaussian (100 realizations)	Combined (300 realizations)
Average Integral Connectivity Scale	43.93	19.88	33.48	32.43
Average T	0.989	0.957	0.968	0.972
Standard Deviation of T	0.11	0.07	0.09	0.09
Average S/S_0	1.69	2.11	2.19	2.00
MAX S/S_0	5.00	35.53	25.75	35.53
MIN S/S_0	1.55E-04	1.88E-02	3.11E-04	1.55E-04
Standard Deviation of S/S_0	1.25	4.26	3.46	3.25

Results

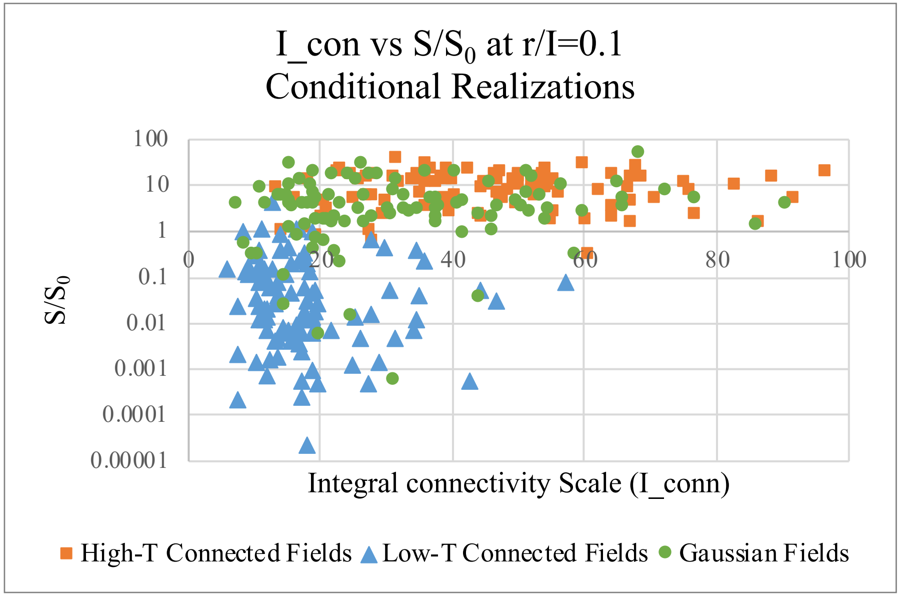

I_con vs T at r/I=0.1
Conditional Realizations
T
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Integral connectivity Scale (I_conn)
High-T Connected
Low-T Connected
Gaussian

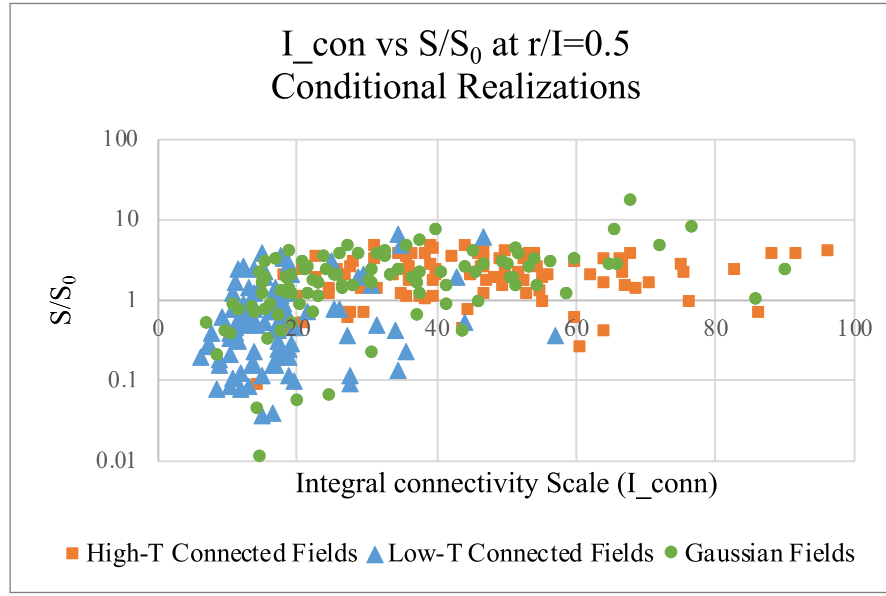

I_con vs T at r/I=0.5
Conditional Realizations
T
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Integral connectivity Scale (I_conn)
High-T Connected
Low-T Connected
Gaussian

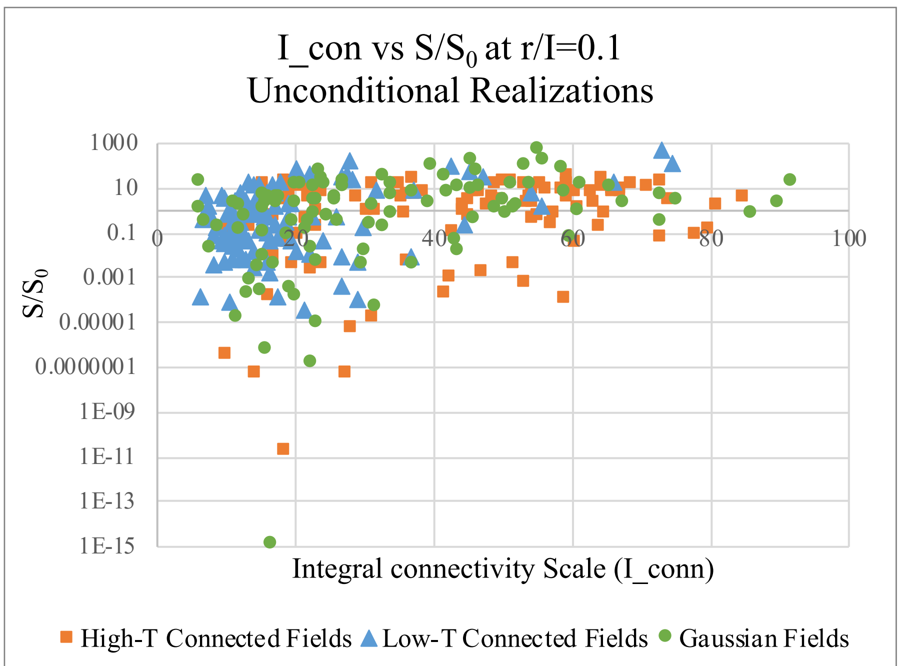

I_con vs T at r/I=0.1
Unconditional Realizations
T
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Integral connectivity Scale (I_conn)
High-T Connected
Low-T Connected
Gaussian

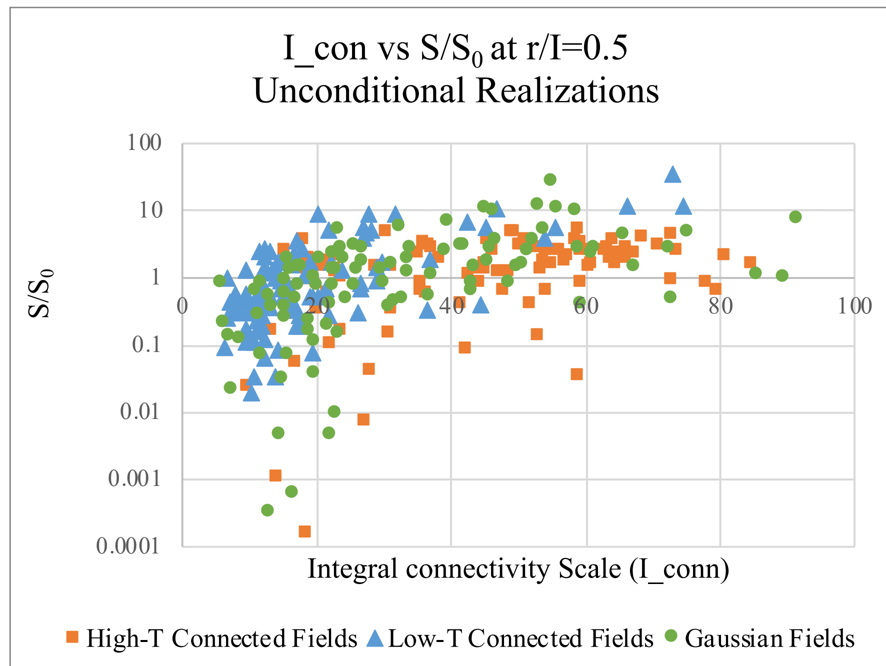

I_con vs T at r/I=0.5
Unconditional Realizations
T
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Integral connectivity Scale (I_conn)
High-T Connected
Low-T Connected
Gaussian

Results

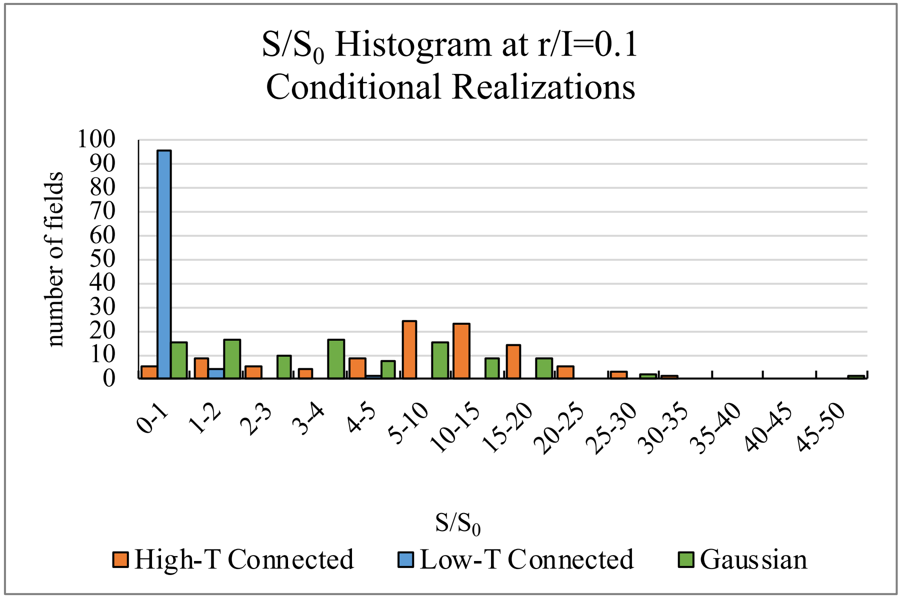

I_con vs S/S0 at r/I=0.1
Conditional Realizations
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0
20
40
60
80
100
S/S0
Integral connectivity Scale (I_conn)
High-T Connected Fields
Low-T Connected Fields
Gaussian Fields


I_con vs S/S0 at r/I=0.5
Conditional Realizations
100
10
1
0.1
0.01
0
20
40
60
80
100
S/S0
Integral connectivity Scale (I_conn)
High-T Connected Fields
Low-T Connected Fields
Gaussian Fields

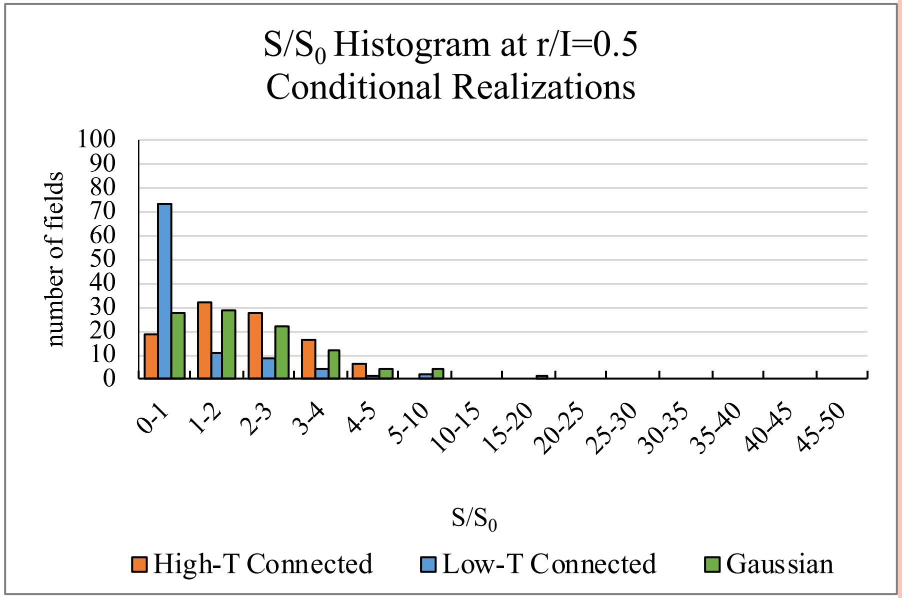

I_con vs S/S0 at r/I=0.1
Unconditional Realizations
1000
10
0.1
0.001
0.00001
0.0000001
1E-09
1E-11
1E-13
1E-15
0
20
40
60
80
100
S/S0
Integral connectivity Scale (I_conn)
High-T Connected Fields
Low-T Connected Fields
Gaussian Fields


I_con vs S/S0 at r/I=0.5
Unconditional Realizations
100
10
1
0.1
0.01
0.001
0.0001
0
20
40
60
80
100
S/S0
Integral connectivity Scale (I_conn)
High-T Connected Fields
Low-T Connected Fields
Gaussian Fields

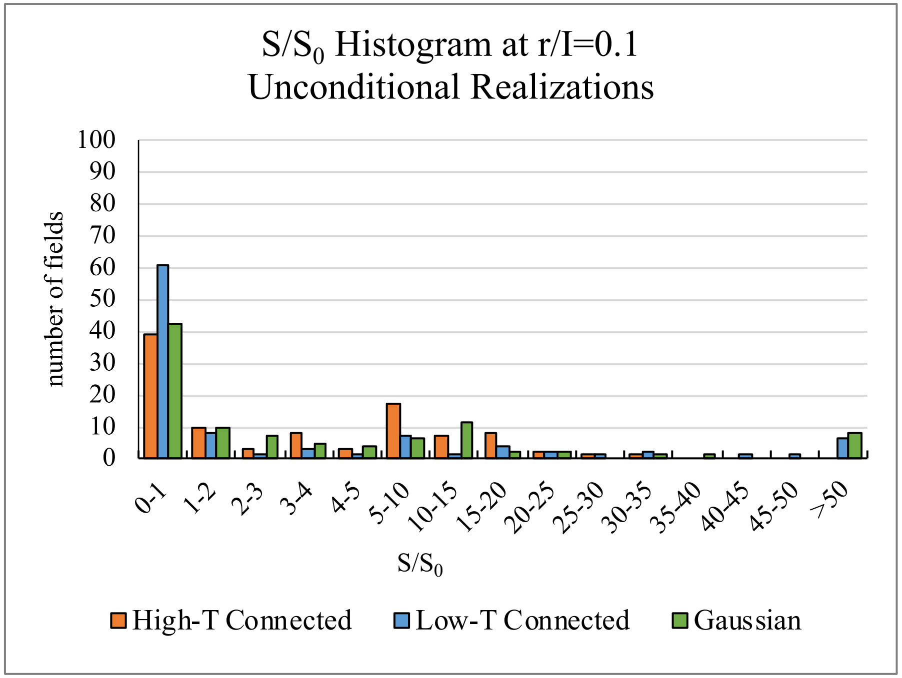
Results



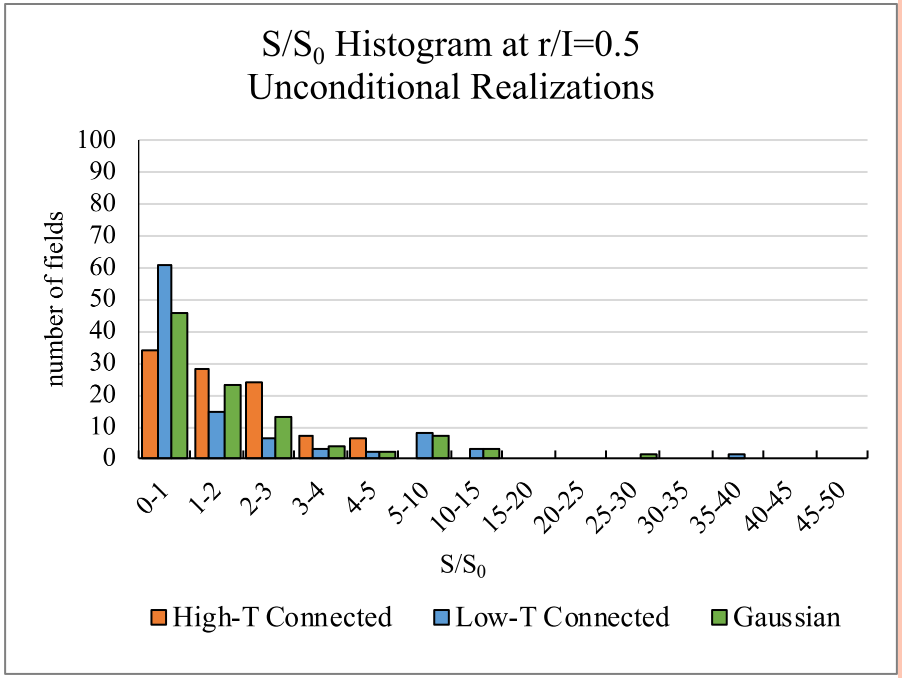
S/S0 Histogram at r/I=0.1
Conditional Realizations
number of fields
100
90
80
70
60
50
40
30
20
10
0
0-1
1-2
2-3
3-4
4-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
S/S0
High-T Connected
Low-T Connected
Gaussian



S/S0 Histogram at r/I=0.5
Conditional Realizations
number of fields
100
90
80
70
60
50
40
30
20
10
0
0-1
1-2
2-3
3-4
4-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
S/S0
High-T Connected
Low-T Connected
Gaussian



S/S0 Histogram at r/I=0.1
Unconditional Realizations
number of fields
100
90
80
70
60
50
40
30
20
10
0
0-1
1-2
2-3
3-4
4-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
>50
S/S0
High-T Connected
Low-T Connected
Gaussian



S/S0 Histogram at r/I=0.5
Unconditional Realizations
number of fields
100
90
80
70
60
50
40
30
20
10
0
0-1
1-2
2-3
3-4
4-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
S/S0
High-T Connected
Low-T Connected
Gaussian

Key Findings

- Estimated transmissivities are close to the geometric mean of transmissivity for all sets of realizations. This finding is in line with previous research (Meier et al., 1998. Sanchez-Vila et al., 1999.)
- The impact of connectivity on transmissivities estimated using Cooper-Jacob method is negligible.
- The estimated storativity using the Cooper-Jacob method is sensitive to the aquifer connectivity (histograms of S/S_0). For low connecitivty, the computed S/S_0 is systematically lower than 1. On the other hand for high connectivity, the estimated S/S_0 is can be significantly greater than 1.
- For observation wells located close to the pumping well, larger variability in the calculated S/S_0 is observed.
- Calculated S/S_0 for unconditional realizations have larger variability than that of conditional realizations.
- Estimated storativity (S) using Cooper-Jacob method is mildly correlated with the integral connectivity scale. However, this correlation is not sufficient to estimate the level of connectivity accurately.

References

- Cooper, H. and Jacob, C., 1946. A generalized graphical method for evaluating formation constants and summarizing well-field history. *Transactions, American Geophysical Union*, 27(4), p.526.
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