Channel-Aquifer width estimation from pumping test data: a simple approach using oil reservoir techniques.

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Channel-Aquifer width estimation from pumping test data: a simple approach using oil reservoir techniques.

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1. Research Question

Can we use and/or adapt oil reservoir methodologies to assess pumping test data with linear flow patterns in channel-aquifers?

2. Introduction

- **Pumping tests** represent the standard to evaluate the hydraulic behavior of aquifers and wells through curve matching, since the historical contribution of the Theis (1935) Model for confined aquifers in uniform flow.

- **Well test analysis** in oil reservoirs became a true reservoir characterization tool with the introduction of derivative analysis by Bourdet et al. (1983). p' allows a better understanding of heterogeneous reservoirs and boundaries.

- **Linear flow** regime can be indicative of high-K fractured reservoirs or channel structures in the subsurface.

- **Aim:** to adapt the linear flow analysis in fractured reservoirs for the estimation of channel-aquifer width from pumping tests, using derivative analysis. For this purpose, we analyze pumping test data from the Spiritwood channel-aquifer, USA (Shaver and Pusc, 1992).

3. What is a Channel-Aquifer?

A long, narrow strip highly-productive aquifer in the form of buried-valley deposits, constrained by no-flow boundaries, see Fig. 1.

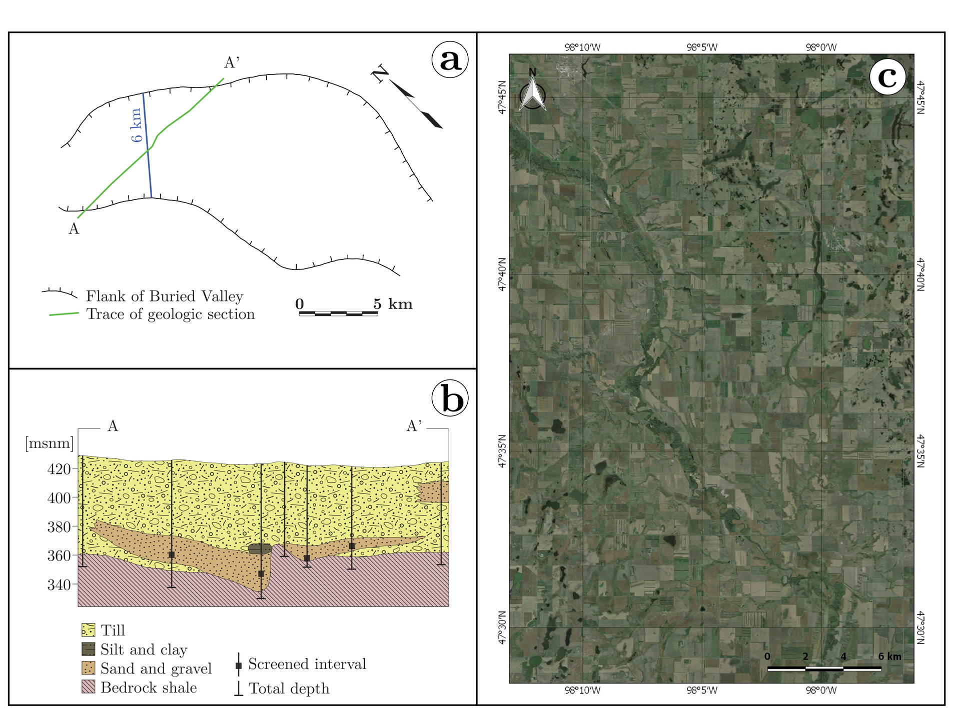

Fig 1. (a) Channel-Aquifer conceptual model and plan view of the Spiritwood channel-aquifer (North Dakota, USA), (b) hydrogeological cross-section AA' of the Spiritwood channel-aquifer, (a) and (b) after Shaver and Pusc (1992), (c) aerial view of the study area (Google Satellite).

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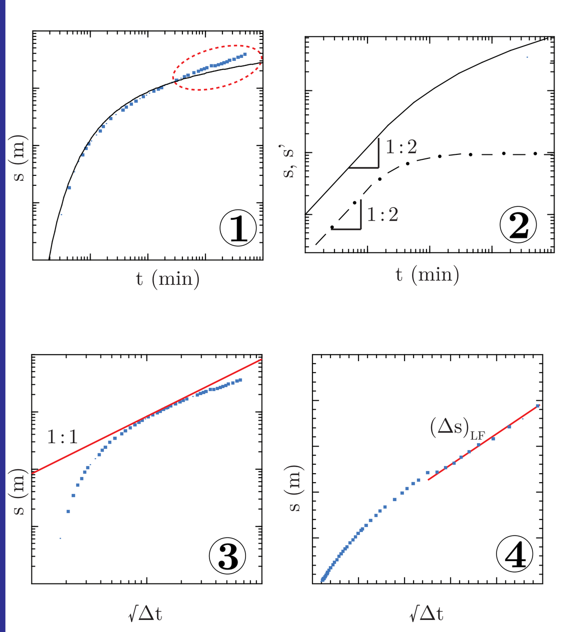
4. Methods

Dialog Box A. Channel-Aquifer diagnosis from pumping test data



CRITERIA 1
s departs from Theis model when the pumping cone reaches the boundaries.

CRITERIA 2
s and s' show a half-unit slope straight line on a Log-Log plot (Renard et al. 2009).

CRITERIA 3
s shows a unit slope straight line on a Log s-Log$\sqrt{\Delta t}$ (Gringarten, 2008).

CRITERIA 4
In the specialized plot s vs. $\sqrt{\Delta t}$, find the straight line slope $(\Delta s)_{LF}$ for eq. (3) in Dialog Box B.

Dialog Box B. Linear flow model in fractured reservoirs: adjustment for aquifers

Linear model in oil reservoirs (Alagoa and Ayoub, 1985):

$$\Delta P_{wf}(t) = \frac{\alpha_L q B \mu}{kbH}\left[2\left(\frac{\beta k t}{\emptyset_e \pi \mu c_t}\right)^{\frac{1}{2}}\right] \qquad (1)$$

Considering a *single flowing phase*, eq. (1) simplifies as:

$$\Delta h(t) = s(t) = \frac{Q}{TW_{CA}}\left[t\left(\frac{2T}{\pi S}\right)^{\frac{1}{2}}\right] \qquad (2)$$

From eq. (2) we obtain the channel- aquifer width, W_{CA}:

$$W_{CA} = \frac{Q}{T[(\Delta s)_{LF}]}\left[\left(\frac{2T}{\pi S}\right)^{\frac{1}{2}}\right] \qquad (3)$$

Where $\frac{k}{\emptyset_e \mu c_t}$ and $\frac{T}{s}$ is the hydraulic diffusivity (HD) in oil reservoirs and aquifers, respectively.

In eq. (3) $(\Delta s)_{LF}$ refers to the straight line slope in the *specialized plot* s vs. $\sqrt{\Delta t}$ (see Dialog Box A, Criteria 4)

Dialog Box C. Test Site at Spiritwood Channel-Aquifer, North Dakota

- We reinterpret an aquifer test conducted in the Spiritwood channel-aquifer (North Dakota, USA) reported in Shaver and Pusc (1992).

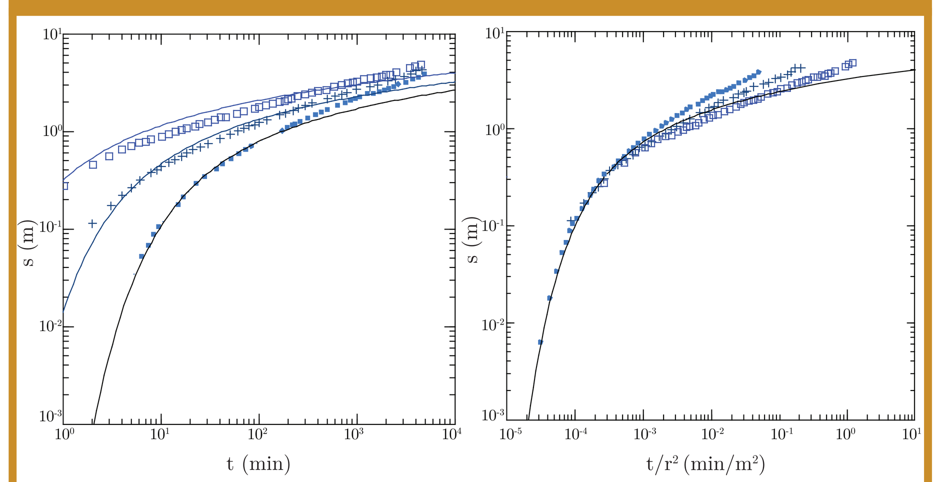
- Geology: Pleistocene buried-valley, constrained by longitudinal hydraulic barriers (Fig. 1a) of shale bedrock and till deposits (Western Glaciated Plains regions), that are aligned roughly parallel to the long axes of buried valleys.

- Reported pumping test:
  - t = 76 hours
  - Q = 75.7 L/s
  - 3 observation wells: 8A (r=60.96 m), 8B (r=152.4m), 8C (r=304.8m)

- We follow the procedure in Dialog Box A (*diagnosis*) and Dialog Box B (*analytical estimation*)

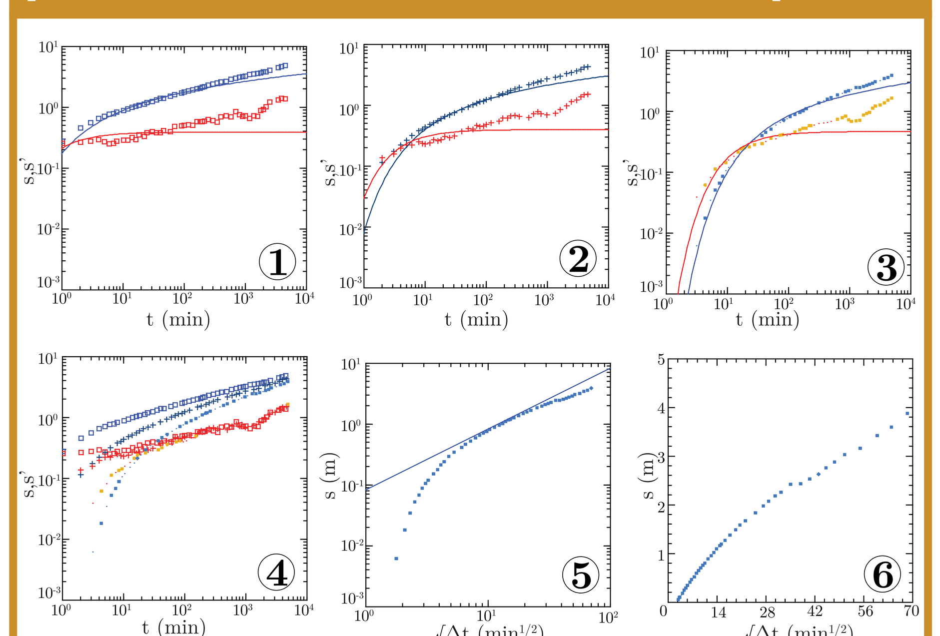
5. Results and discussion

5.1. Theis matching [criteria 1 from Dialog Box A]



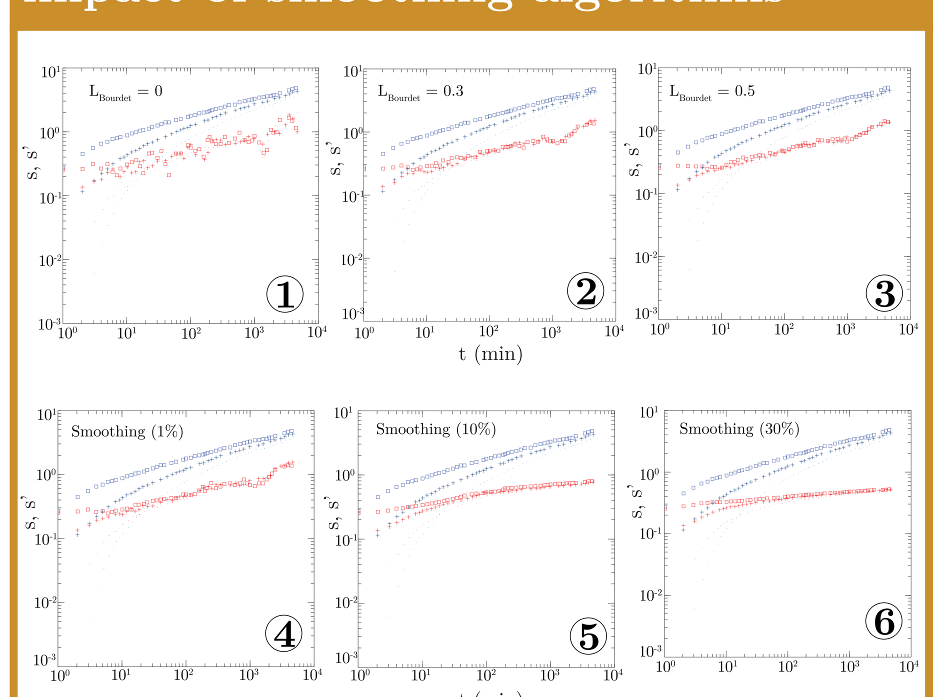
The drawdown from wells 8A, B and C departs from the Theis Model at late-times, in both single (*left*) and composite (*right*) analysis (s vs t/r^2). This effect suggests the presence of no-flow boundaries.

5.2. Diagnostic and specialized plots [criteria 2-4 from Dialog Box B]



Graphs 1-4: s and s' shows a pseudoparallel behavior and slopes of ~1/2, suggesting a linear flow pattern from 400 min ≤ t ≤ 4,200 min. Linear regime was checked in *graph 5* (unit slope straight line in Log(s)-Log$\sqrt{t}$). Specialized plot (*graph 6*) was used to calculate $(\Delta s)_{LF}$.

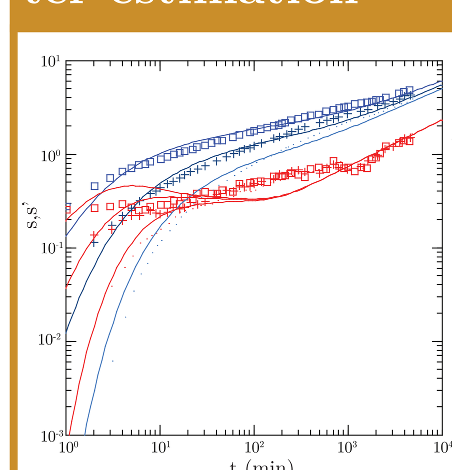
5.3. Noise in the derivative signal: impact of smoothing algorithms

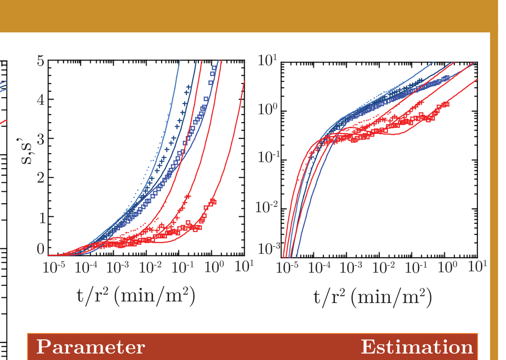


Upper: Bourdet's differentiation interval (L) algorithm (0≤L≤ 0.5).

Lower: sliding window algorithm (1, 10, 30%). As noted, Bourdet's L ≤ 0.3 (*graph 2*) is sufficient to smooth the signal. Oversmoothing can affect the flow regime diagnosis (*graphs 5 and 6*).

5.4. Matching analysis and parameter estimation





Parameter	Estimation
Transmissivity, T	2062 [m^2/d]
Hydraulic conductivity, k_h	50 [m/d]
Storage coefficient, S	1.3×10^{-5} [-]
Aquitard leakage factor, 1/B'	0.16 [m^{-1}]
Aquitard conductivity, k_y	0.8 [m/d]
Slope, $(\Delta s)_{LF}$ (*specialized plot*)	1.77 [$\frac{m}{\sqrt{d}}$]
Channel-aquifer width, W_{CA} (eq. 3)	~3340 [m]

- Eq. (3) allowed us to estimate the W_{CA} in the order of ~3340 m. Shaver and Pusc (1992) reported a width of 6000 m (see Fig. 1a).

- The Moench (1985) Model for unsteady flow was used for the matching analysis. The adjustment was improved by replacing the constant-head source boundary with no-flow boundaries.

- We use the image well theory to simulate the distance between the pumping well and the boundaries. After a trial-and-error procedure, the best matching (with a sum of squared residuals, |RSS| = 0.03 m) was achieved by simulating a distance of 1800 m from each side of the well, or a channel width of 3600 m, which is consistent with the previous finding.

- Hydraulic parameters can be read from the above table.

6. Conclusions

- A simple method for the assessment of linear flow patterns from pumping test data is presented, with a particular focus on the channel-aquifer width estimation.

- The current workflow was adapted from the oil reservoir engineering.

- Further research is needed in order to fully understand linear flow geometries considering a wide range of hydraulic, geologic and hydrogeologic settings.

7. References

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Nomenclature

B Oil formation factor
H Reservoir thickness
h Hydraulic head
K Permeability
P Pressure
p' Pressure derivative
P_{wf} Well flowing pressure
Q Groundwater flow rate
q Oil flow rate
r Radial distance
s Drawdown
s' Drawdown derivative ($s' = \partial s/\partial \ln(t)$)
T Aquifer transmissivity
t Elapsed time
W_{CA} Channel-aquifer width

Greek
Δ Change, drop
α_L, β Unit conversion factors

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