Solute concentration at a pumping well in non-Gaussian random aquifers under time-varying operational schedules

H31C-1372

Arianna Libera [a], Felipe P. J. de Barros [a,*], Monica Riva [b,c], Alberto Guadagnini [b,c]

[a]Sonny Astani Dept. of Civil and Environmental Eng., USC, USA. [b]Dept. Civil and Environmental Eng., Politecnico di Milano, Italy. [c] Dept. Hydrology and Atmospheric Sci., University of Arizona, USA.

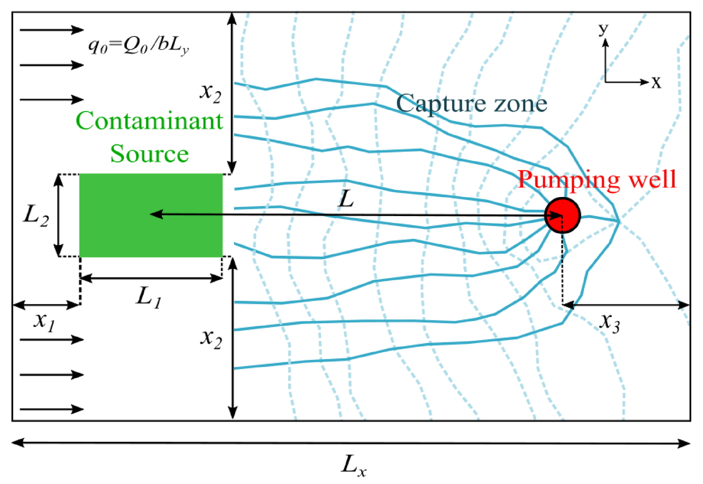
* fbarros@usc.edu

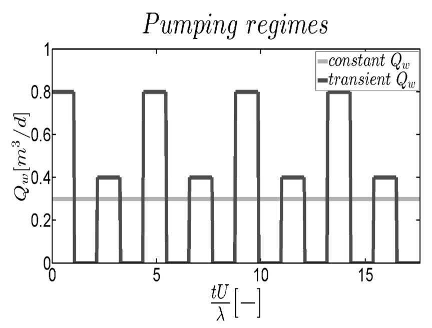
I. Motivation

- It is common for water agencies to schedule groundwater extraction through a temporal sequence of pumping rates to maximize the benefits to anthropogenic activities and minimize the environmental footprint of the withdrawal operations.
- The temporal variability in pumping rates and aquifer heterogeneity affect dilution rates of contaminant plumes and chemical concentration breakthrough curves (BTCs) at the well.
- Contaminant transport under steady-state pumping is widely studied but the manner in which a given time-varying pumping schedule affects contaminant plume behavior is tackled only marginally (e.g. [1]).
- Most studies focus on the impact of Gaussian random hydraulic conductivity (K) fields on transport.
- We systematically analyze the significance of the random space function (RSF) model characterizing K in the presence of distinct pumping operations on the uncertainty of the concentration BTC at the operating well.
- We juxtapose Monte Carlo based numerical results associated with two models: (a) a recently proposed Generalized Sub-Gaussian model which allows capturing non-Gaussian statistical scaling features of RSFs such as hydraulic conductivity, and (*b*) the commonly used Gaussian field approximation.
- Our novel results include an appraisal of the coupled effect of (*a*) the model employed to depict the random spatial variability of K and (*b*) transient flow regime, as induced by a temporally varying pumping schedule, on the concentration BTC at the operating well.
- Results contribute to determine conditions under which any of these two key factors prevails on the other.

II. Problem Set-Up & Methodology

- Instantaneous contaminant release in a 2D confined aquifer characterized by heterogeneous and isotropic hydraulic conductivity (K) field.
- Analysis of Gaussian and non-Gaussian hydraulic conductivity fields ($Y(x) = \ln(K)$).
- Contaminant concentration (C) measured at the pumping well, subject to a constant or transient pumping regime [$Q_w(t)$]. The same volume of water is extracted with the two pumping strategies.





Groundwater flow and contaminant transport are respectively solved numerically through MODFLOW and MT3DMS within the Monte Carlo framework. More details, see Ref. [1].

III. Geostatistical models

Gaussian $Y(\underline{x}) = \ln(K)$ **Sub-Gaussian** $Y(\underline{x}) = \ln(K)$

$Y_G(x) = G(x)$, $\alpha \to 2$

$Y_{SG}(x) = U(x)G(x)$, α=1.2 α=1.5 α=1.8

For more details, see Ref. [2]

$G(x)$: stationary Gaussian function (truncated fractional Brownian motion and characterized by truncated power variogram)

Subordinator $U(x)$: function, independent of $G(x)$, of i.i.d. non-negative values at points x, lognormally distributed according to $\ln N(0,(2-\alpha)^2)$

Covariance model, variance and integral scale

$$C_G(s) = C(s,\lambda_u) - C(s,\lambda_l)$$

$$C(s,\lambda_m) = \frac{A\lambda_m^{2H}}{2H}\left[\exp\left(-\frac{s}{\lambda_m}\right) - \left(\frac{s}{\lambda_m}\right)^{2H}\Gamma\left(1-2H,\frac{s}{\lambda_m}\right)\right], \quad m = l,u$$

$$\sigma_G^2 = \frac{A}{2H}(\lambda_u^{2H} - \lambda_l^{2H})$$

$$I_G = \frac{2H}{1+2H}\frac{\lambda_u^{1+2H} - \lambda_l^{1+2H}}{\lambda_u^{2H} - \lambda_l^{2H}}$$

$$C_{SG} = \sigma_{SG}^2 - \gamma_{SG} = e^{(2-\alpha)^2} C_G$$

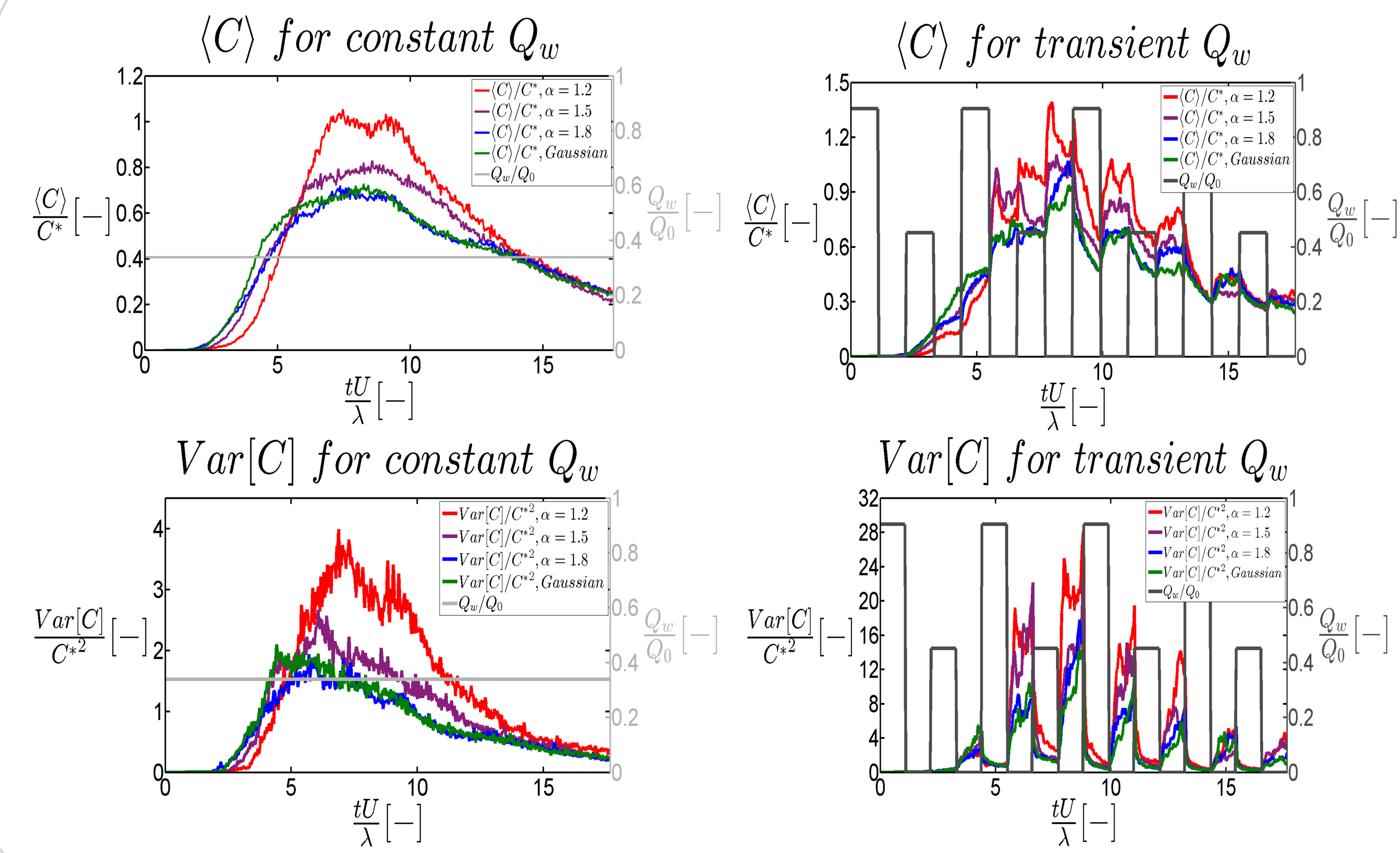
$$\sigma_{SG}^2 = e^{2(2-\alpha)^2}\sigma_G^2$$

$$I_{SG} = e^{-(2-\alpha)^2} I_G$$

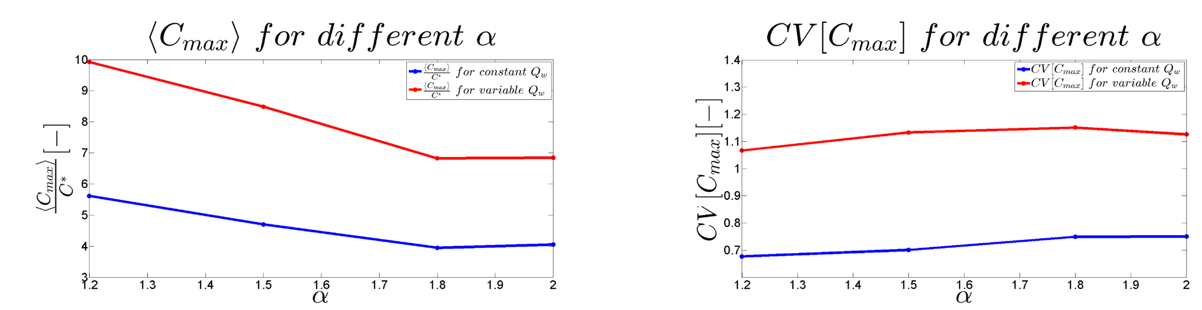
In our study: $\langle Y_G \rangle = \langle Y_{SG} \rangle$ $\quad {\sigma^2}_G = {\sigma^2}_{SG}$ $\quad I_G = I_{SG}$

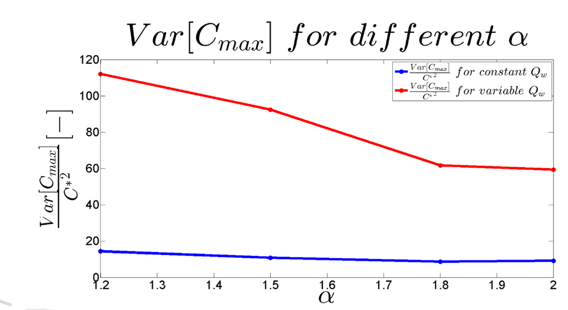
IV. Numerical Results

a. Concentration mean and variance at the well



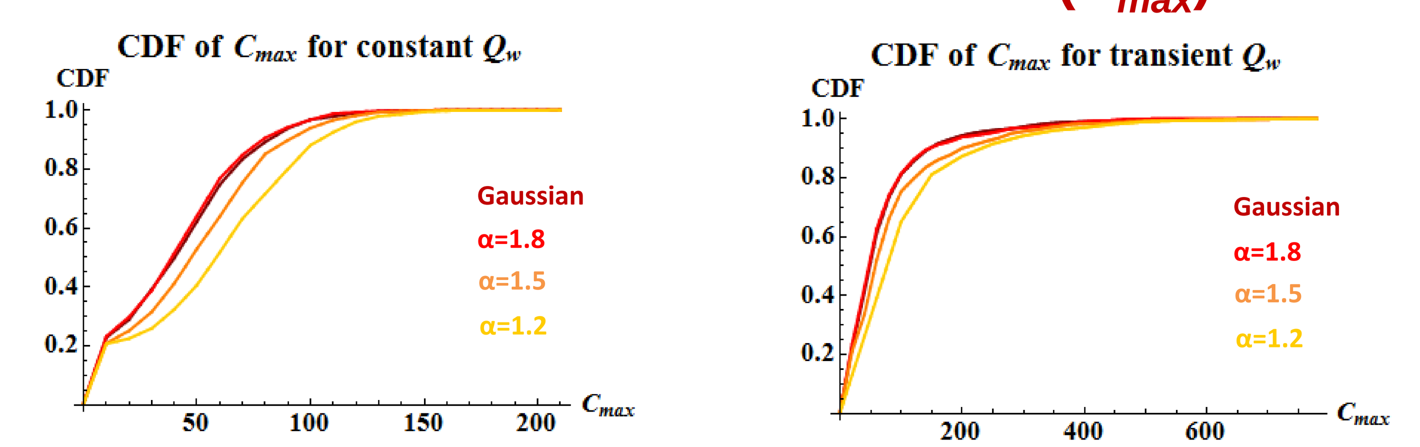
b. Statistics of C_{max} vs α



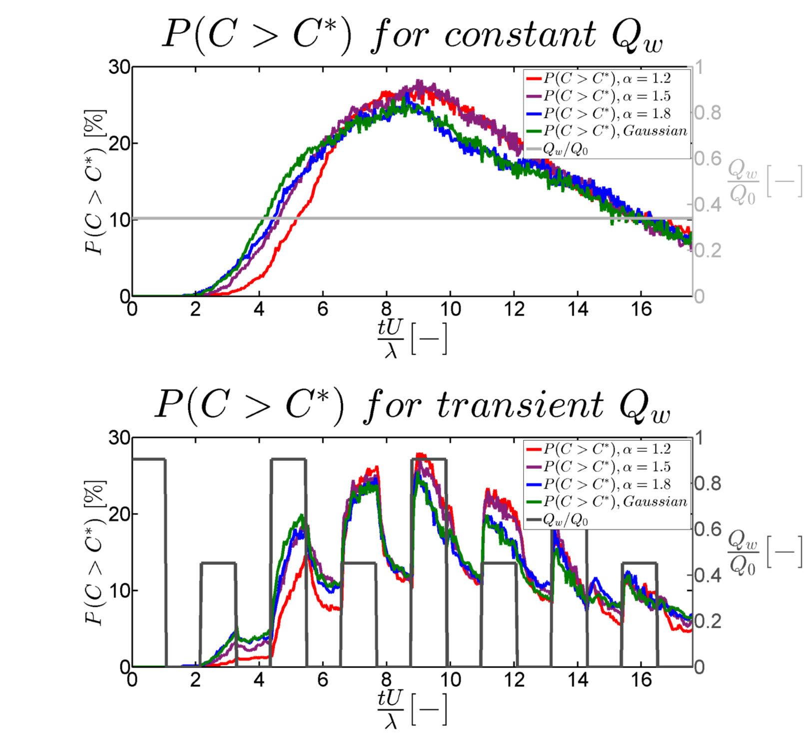


C_{max}: Maximum concentration
$\langle C_{max} \rangle$: Mean of C_{max}
$Var[C_{max}]$: Variance of C_{max}
$CV[C_{max}]$: Coeff. of Variation of C_{max}

c. CDF of the maximum concentration (C_{max})



d. Probabilistic Risk Analysis



V. Conclusions Remarks

✓$\langle C \rangle$ and $Var[C]$ increase for Sub-Gaussian $Y(\boldsymbol{x})$ (especially when Q varies with time)
✓$\langle C \rangle$ and $Var[C]$ tend to increase for Gaussian $Y(\boldsymbol{x})$ for small times. The opposite occurs at large times
✓$\langle C_{max} \rangle$ and $Var[C_{max}]$ increase for Sub-Gaussian $Y(\boldsymbol{x})$
✓$\langle C_{max} \rangle$ and $Var[C_{max}]$ increase under variable pumping
✓Variable pumping enhances the differences between $\langle C_{max} \rangle$ and $Var[C_{max}]$ of Gaussian and non-Gaussian $Y(\boldsymbol{x})$
✓The CDF of C_{max} has different slopes for different α values and for different pumping schemes (constant or transient)
✓The range of C_{max} values increases under variable pumping
✓Risk of concentration exceedance increases for Sub-Gaussian $Y(\boldsymbol{x})$

References

[1] Libera, A., de Barros, F. P. J., Guadagnini, A. Influence of pumping operational schedule on solute concentrations at a well in randomly heterogeneous aquifers. J. Hydrol., In press.

[2] Riva, M., Neuman, S. P., Guadagnini, A., 2015. New scaling model for variables and increments with heavy-tailed distributions. Water Resour. Res., 51, 4623-4634. doi:10.1002/2015WR016998.