Analysis of the joint impact of dose-response models and permeability heterogeneity on aquifer resilience loss due to Bisphenol A contamination

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Emerging contaminants draw attention due to endocrine-related health effects

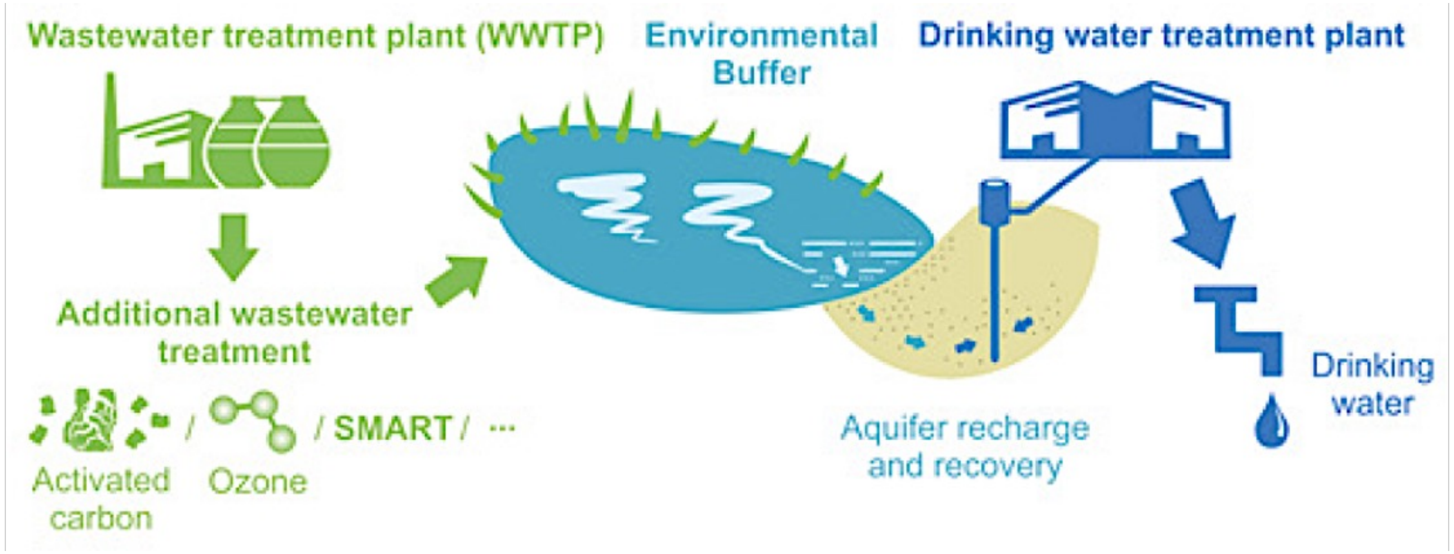


Diagram of Indirect Potable Reuse (Lukat et al., 2017)

Examples of Emerging Contaminants

(http://wmrc.illinois.edu, https://undark.org, and https://www.motherearthliving.com)

Bisphenol A (BPA) has multiple types of adverse health effects to different subpopulation groups

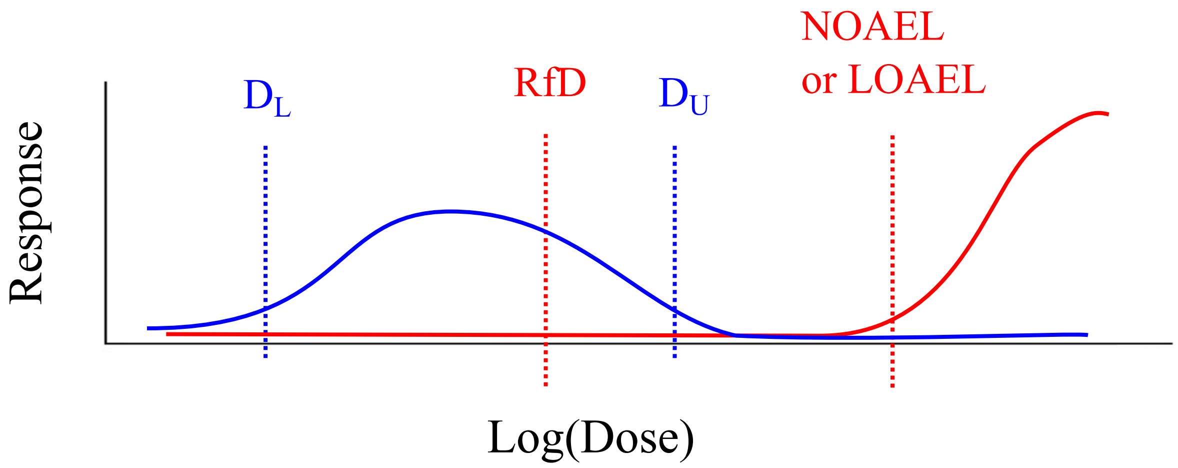
1. General Toxicity of BPA (USEPA, 2010)

Noncarcinogenic, weakly estrogenic chemical (developmental and reproductive adverse effects)

2. Two types of health effects from BPA

Adverse health effects	**Systemic effects**	**Endocrine-related effects**
References	NTP (1982) and USEPA (1988)	Recent studies and NTP (2008)
End points	Reduced body weight or reduced organ weight	Neural and behavioral alterations or lesions in the prostate
Target	General (Adults and children)	Fetuses, infants, and children
Exposure duration	Chronic toxicity (> 1 year)	Specific time window (pregnancy, infancy)
Dose-response relationship	**Monotonic dose-response**	**Non-monotonic dose-response**
Benchmark dose type	Threshold level	Low dose range

Needs to consider different health models of BPA in health risk assessment for groundwater contamination



Systemic effects
Monotonic Dose Response (MDR)

$$\xi(t) = \begin{cases} 0, & ADD(t) \geq \text{RfD} \\ 1, & \text{otherwise} \end{cases}$$

Endocrine-related effects
Non-monotonic Dose Response (NMDR)

$$\xi(t) = \begin{cases} 0, & D_L < ADD(t) < D_U \\ 1, & \text{otherwise} \end{cases}$$

Loss of Aquifer Resilience, R_L
(Bocchini et al., 2014)

- Period when an aquifer is not reliable as a potable water source due to potential health risks from emerging contaminants

$$R_L = \int_{t_0}^{t_0+t_f} \{1 - \xi(t)\}\, dt$$

Challenges in subsurface hydrology

- **No full characterization** under practical limits
- **Multi-scale spatial heterogeneity** of an attribute of interest in subsurface systems
- **Too many factors** affect an attribute of interest

e.g., in groundwater systems

$K(\boldsymbol{x})$; **hydraulic conductivity**

$q(\boldsymbol{x}, t)$; **groundwater flow**

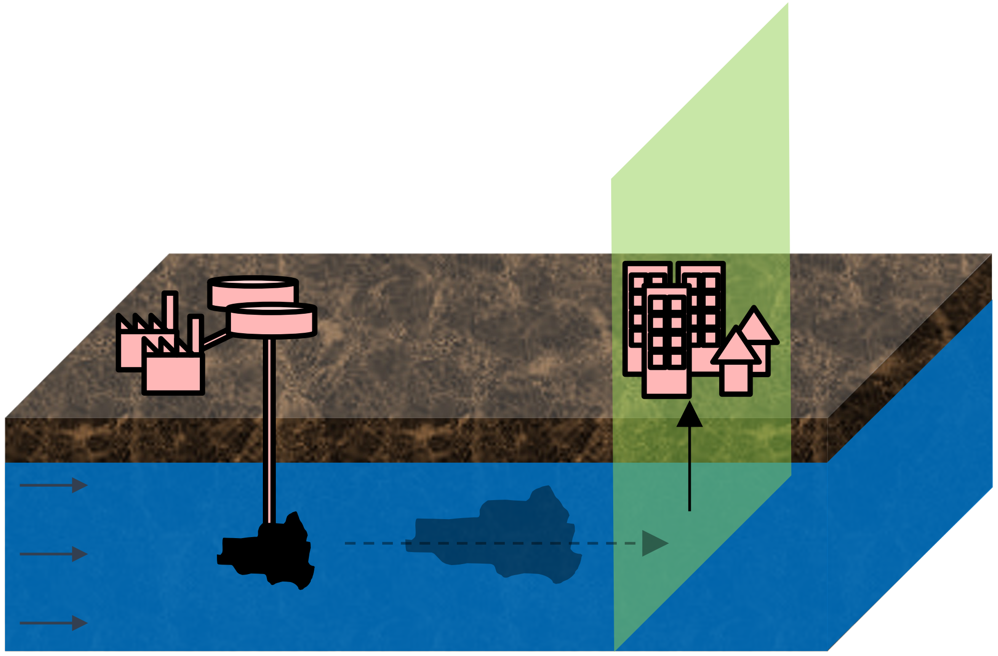
$c(\boldsymbol{x}, t)$; **contaminant concentration**

→ Environmental performance metrics

e.g., health risk, reliability, & resilience

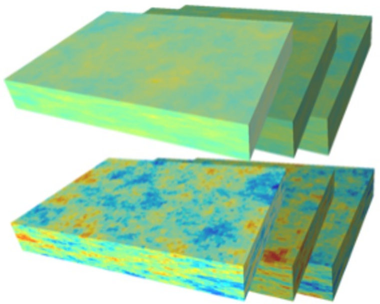
< https://www.clactonandfrintongazette.co.uk/ >

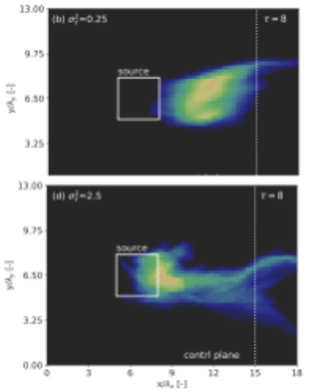
How does the uncertainty in hydraulic conductivity manifest in the aquifer resilience loss against BPA contamination in groundwater?



Hydraulic Conductivity → Flow & Transport → Environmental Assessment → Statistics of R_L

Hydraulic Conductivity	Flow & Transport	Environmental Assessment	Statistics of R_L
$K^i(\boldsymbol{x})$	$q^i(\boldsymbol{x},t)$	$ADD^i(t)$	
$\sigma_Y^2=\{0.25, 2.5\}$ where $Y=\log K$	$C^i(\boldsymbol{x},t)$	$\xi^i(t)$	
$i=1,2,\ldots,500$	$C_F^i(t)$	**MDR** / **NMDR**	
		R_L^i	

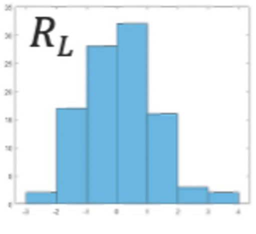




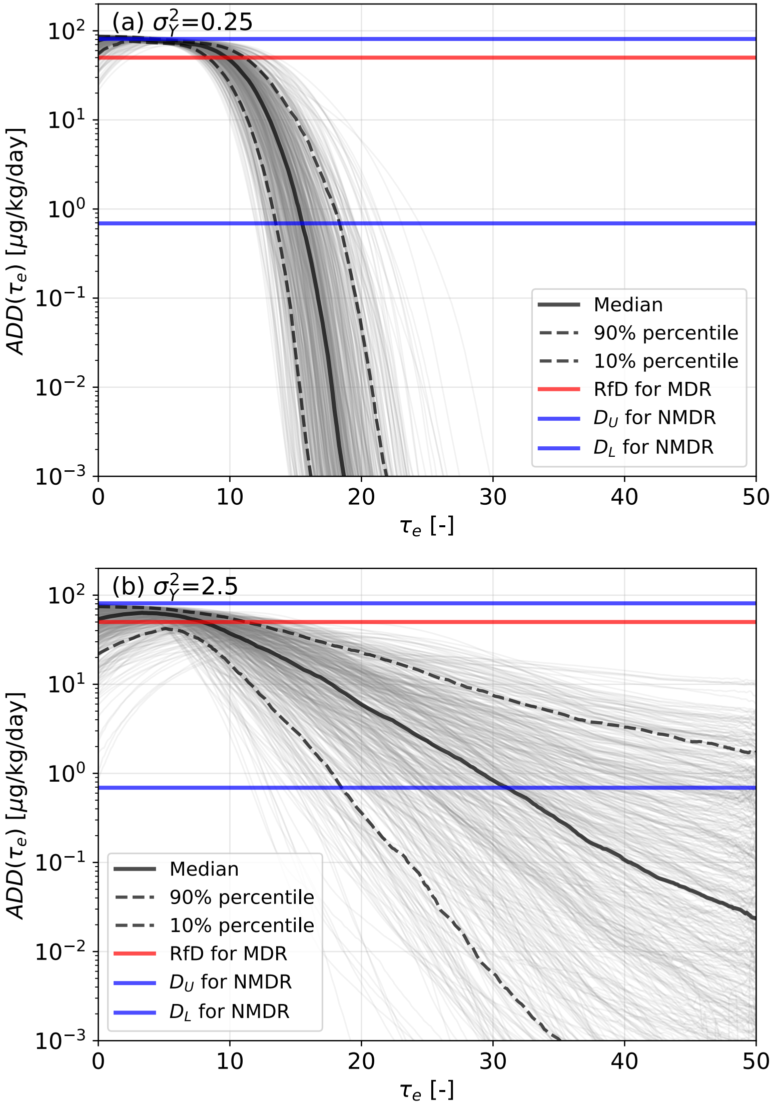
$$ADD(t)=\frac{C_F(t;x_{CP})\times IR\times ED}{BW\times AT}$$

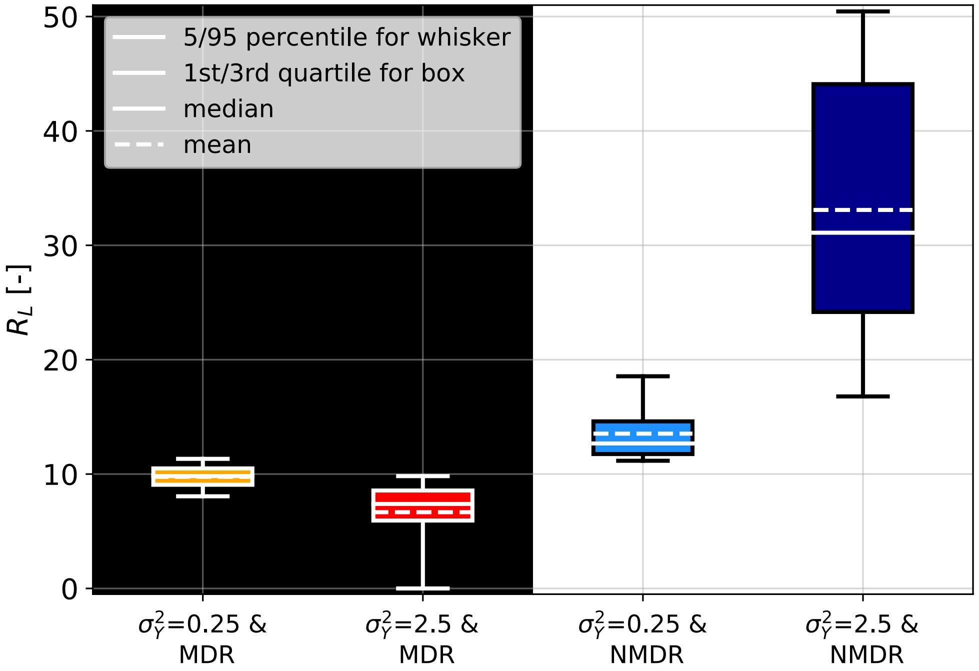
$$\xi(t)=\begin{cases}0, & ADD(t)\geq \text{RfD}\\ 1, & \text{otherwise}\end{cases}$$

$$\xi(t)=\begin{cases}0, & D_L<ADD(t)<D_U\\ 1, & \text{otherwise}\end{cases}$$



Dispersion under heterogeneity brings opposite impacts on aquifer resilience depending on health effects





Im et al., 2020, *Science of the Total Environment*, 727: 138363

Conclusion

- Investigate how the uncertainty in hydraulic conductivity manifests in the aquifer resilience loss against BPA contamination in groundwater
- Find the aquifer resilience loss and its uncertainty changes in the opposite way depending on the types of health effects along the heterogeneity level
- Emphasize the importance of the types of health effects (i.e., vulnerable subpopulations) in the groundwater management against emerging contaminants