Uncertainties in transient capture zones

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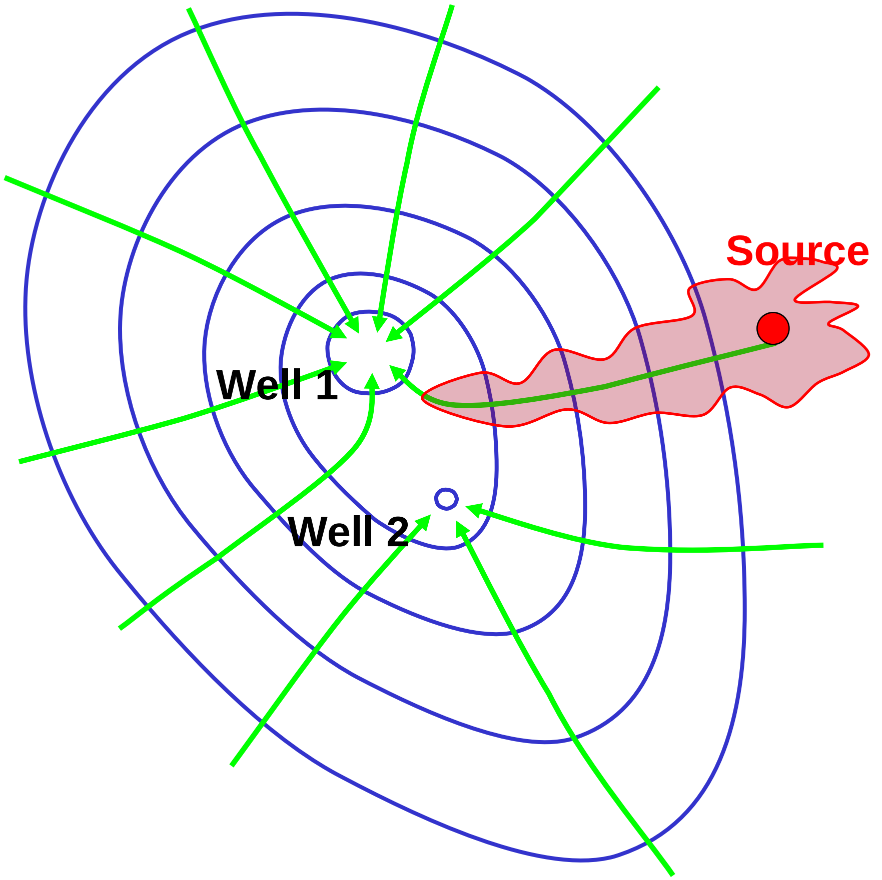
LA-UR-06-2305

CMWR XVI
Computational Methods in Water Resources
Copenhagen, Denmark, June 19-22 2006

Los Alamos NATIONAL LABORATORY EST. 1943

Capture zones



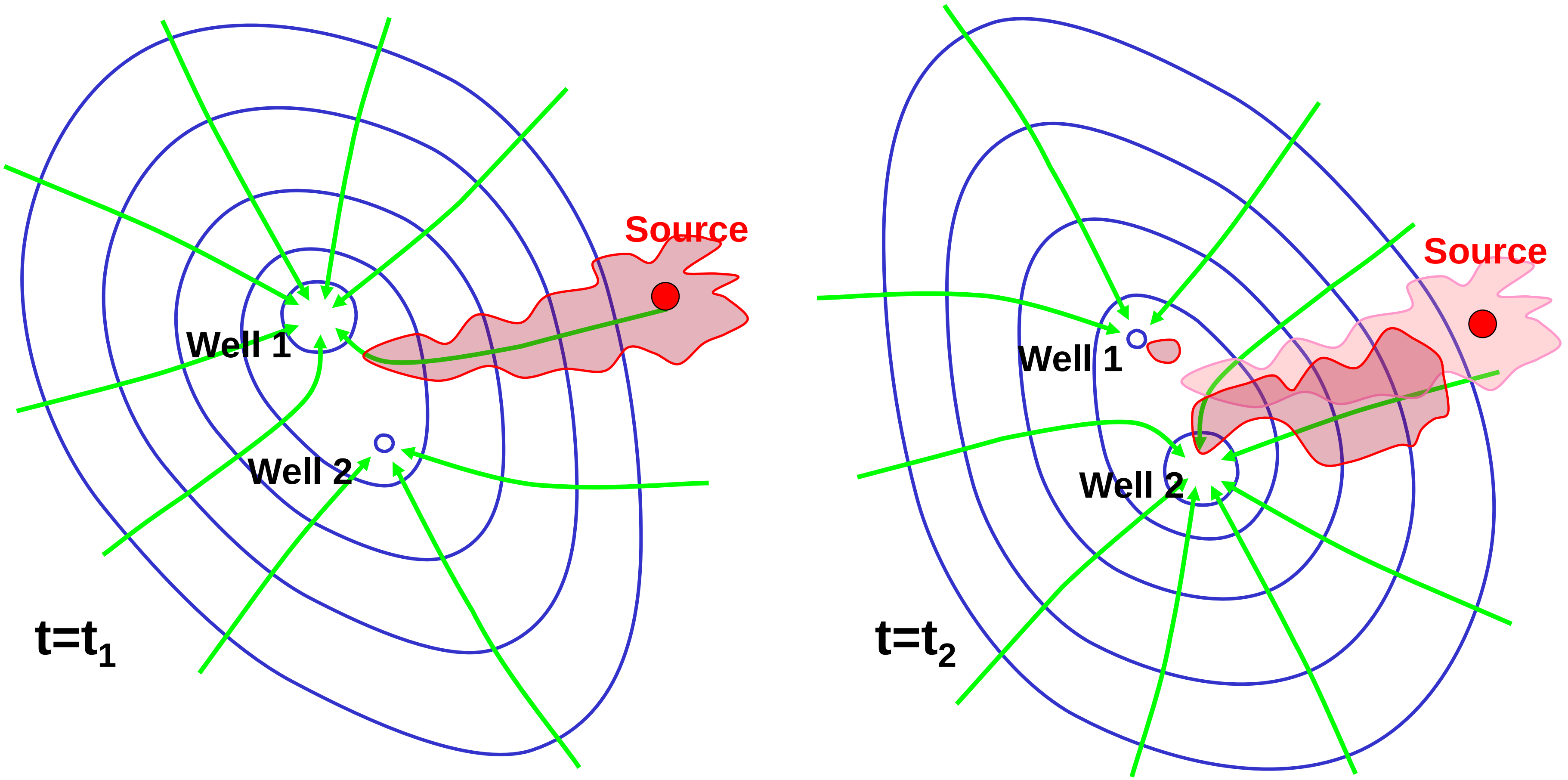
Background

- delineation of capture zones of water supply wells is important for the efficient protection of groundwater resources
- capture zones are typically estimated using models
- frequently, transients in groundwater flow and their effect on the dispersion of the potential contaminant plumes are ignored in the capture-zone analyses

Capture zone definitions:

- **Steady-state zones are delineated using (future?) steady-state flow field**
- **Transient zones are delineated using transient flow field:**
  - **transients in the flow field**
  - **transients in the contaminant releases**
    - **instantaneous releases: snapshots of the capturing associated with a given release time**
    - **continuous releases: cumulative capturing of contaminants over the release period**

Impact of transients on contaminant plume



Contaminant source is within capture zones of both wells …

… but steady-state / advective-only capture zone analyses will give us an incorrect result.

Methodology

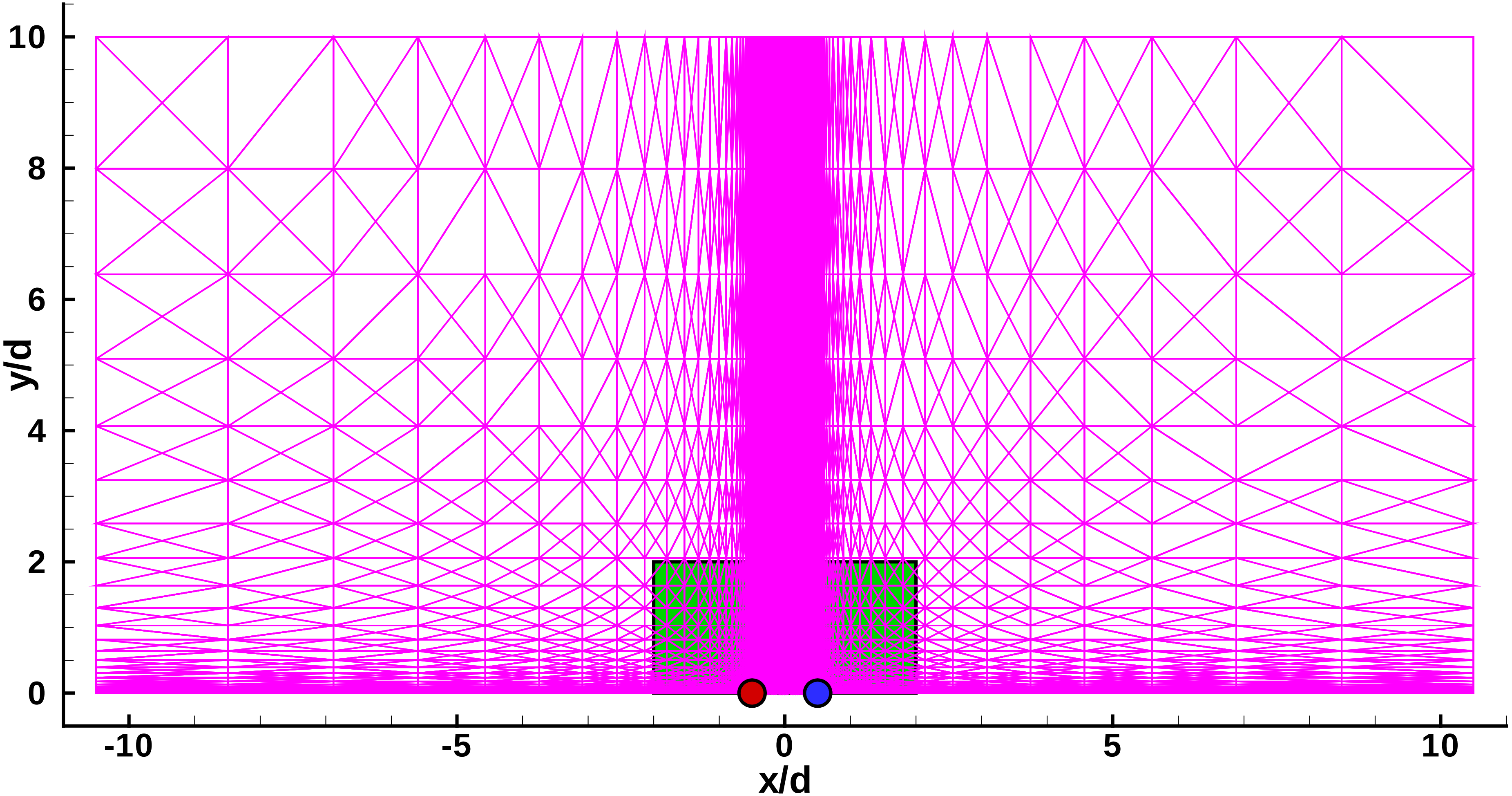
- 2D synthetic capture-zone analysis
- uniform medium
- 2 wells with temporally varying rates
- confined groundwater flow is solved numerically (for convenience); analytical solutions are available as well
- capture zones are delineated using forward particle tracking under both advective and advective-dispersive regimes
- dimensionless model parameters are derived based on analytical expressions

Codes

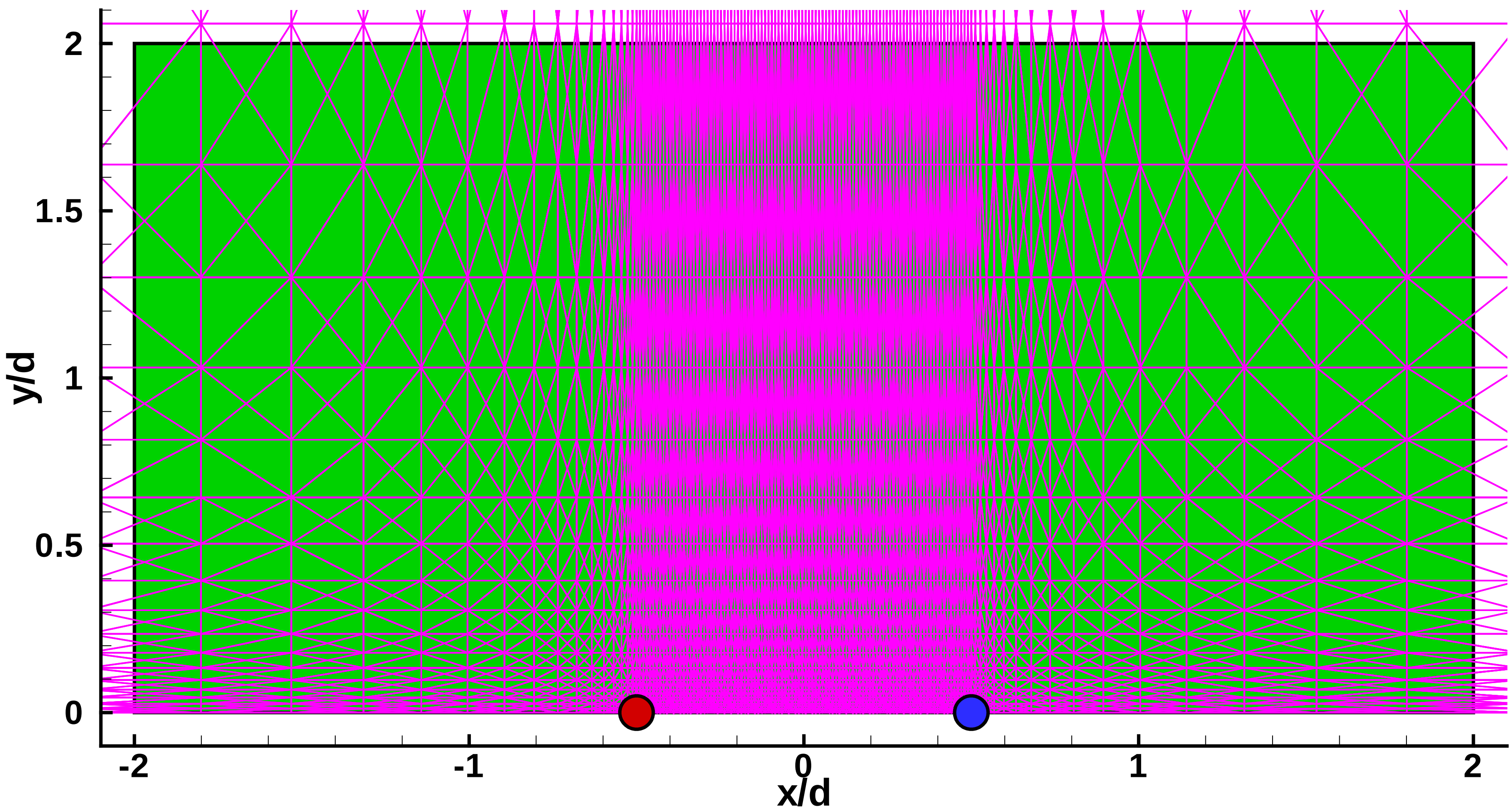
- grid-generation: LaGriT (Trease et al., 1996)
- flow simulation: FEHM (Zyvoloski et al., 2001)
- particle-tracking: FEHM (Robinson, 2002)

Model domain

dimensionless coordinates: *x/d*, *y/d*,
where *d* is the distance between wells

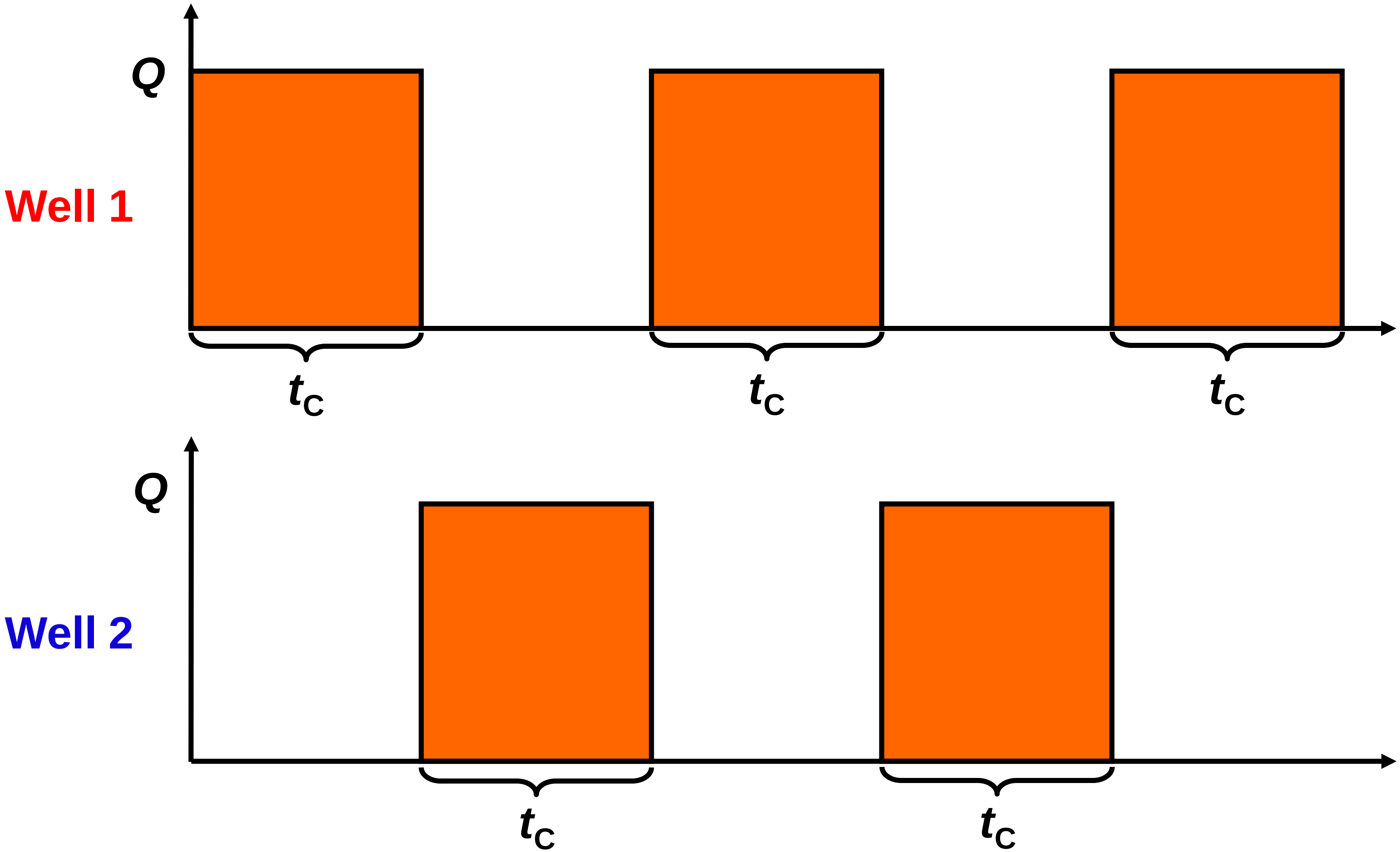


Region of capture-zone analyses



Temporal variability of pumping rates

To reduce the effect of initial conditions, 10 pumping cycles are applied before the analysis of transient capture-zone commences

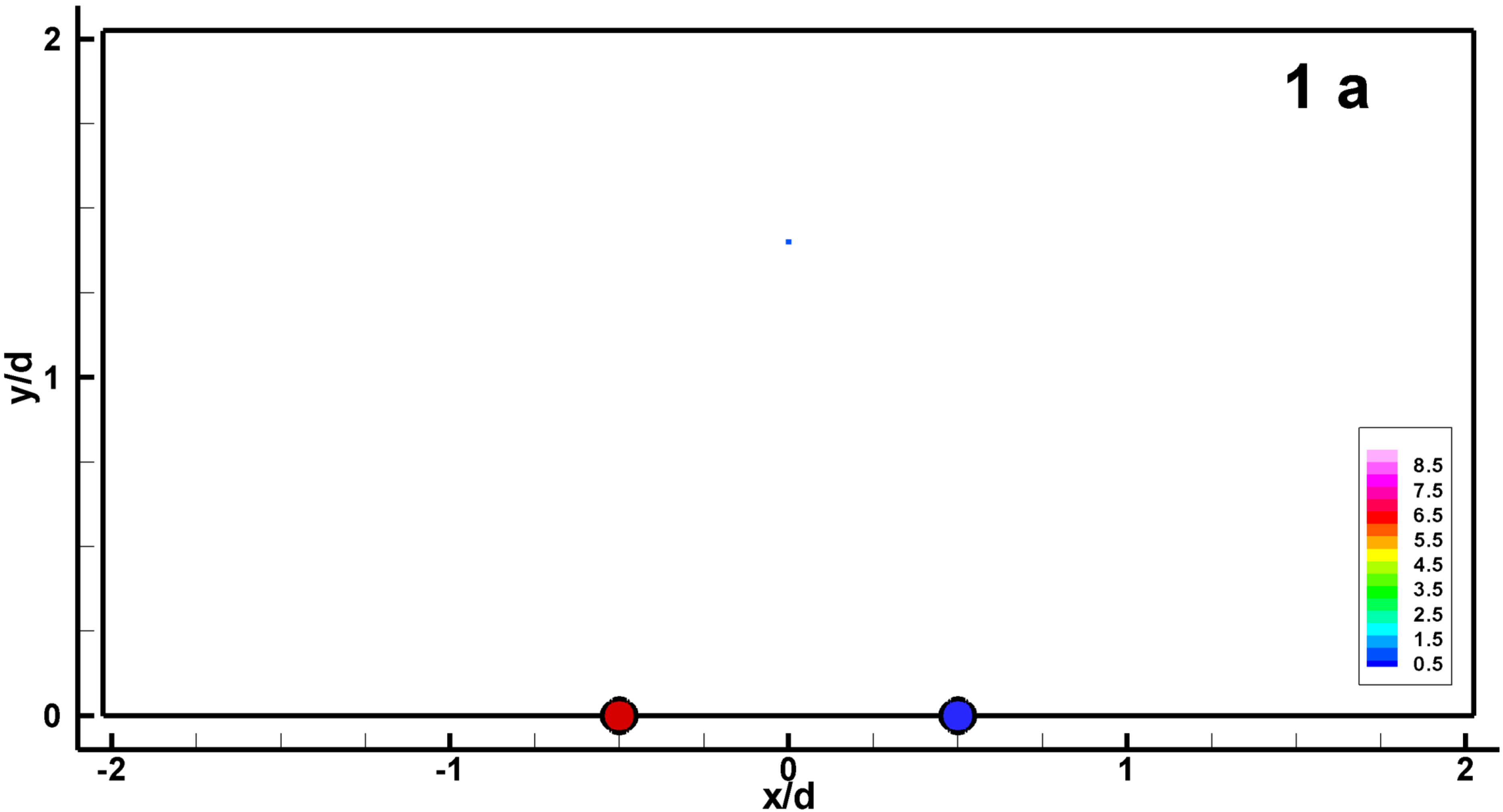


Dimensionless model parameters

- **<u>pumping rate / advective transport velocity</u>:** $Qt_C/(md^2\phi)$ [–] **obtained by comparison of quasi-steady-state advective velocity** $Q/(md\phi)$ [L/T] **and velocity required for a water particle to move distance** d **for time** t_C**, i.e.** d/t_C [L/T]
- **<u>pumping time interval</u>:** $t_C a/d^2$ [–]
- **<u>coordinates</u>:** x/d, y/d [–]
- **longitudinal / transverse <u>dispersivities</u>:** α_L/d, α_T/d [–]
- **where:**
  - k = permeability [L/T]
  - a = hydraulic diffusivity [L^2/T] ($a=k/S_S$, S_S=specific storage [L^{-1}])
  - Q = pumping rate [L^3/T]
  - t_C = pumping time interval [T]
  - d = distance between the pumping wells [L]
  - m = aquifer thickness [L]
  - ϕ = advective porosity [–]

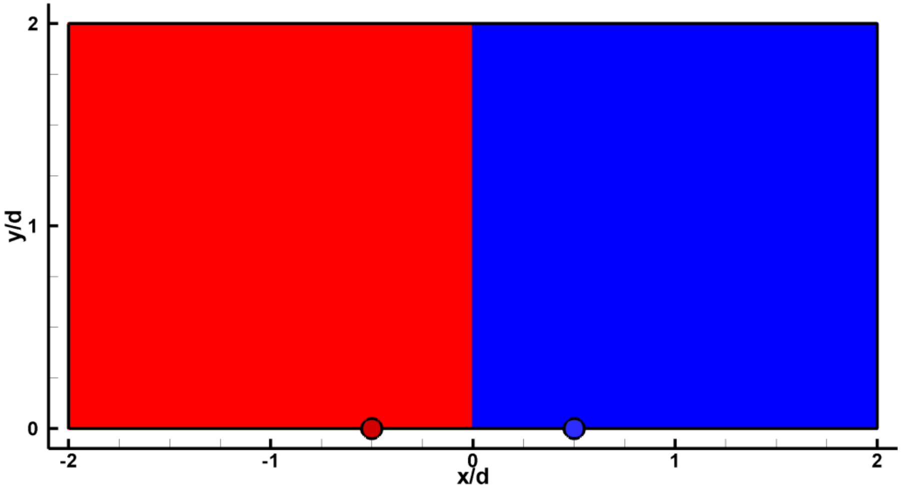
Particle-tracking simulation of impacts of transients on the contaminant plumes

m = 100 m
d = 100 m
t_C = 1000 d
Q =1 ℓ/s
a = 864 m²/d
ϕ = 0.01



Steady-state capture zones

- steady-state flow field
- instantaneous/continuous releases



LEGEND:
RED – capture zone of the left well
BLUE – capture zone of the right well

In this case, steady-state capture zones are not affected by the uncertainties in the model parameters

Transient capture zones

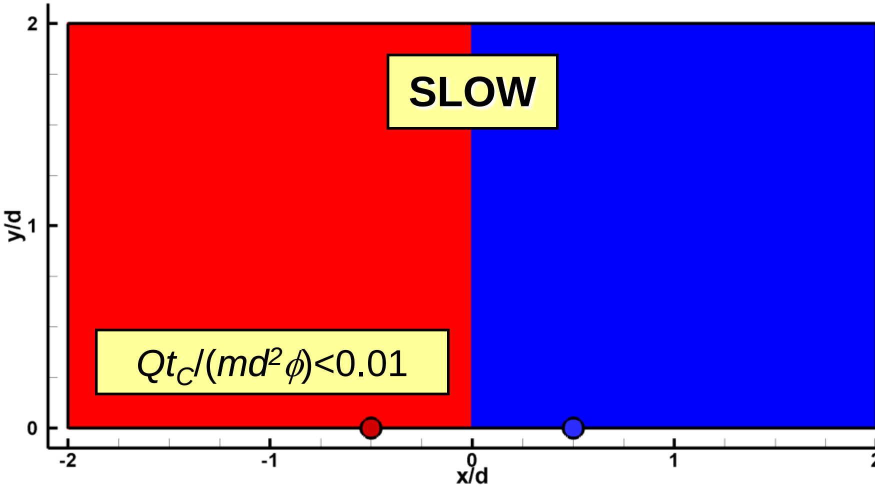
- transient flow field
- instantaneous (after 10 pumping cycles) and continuous releases

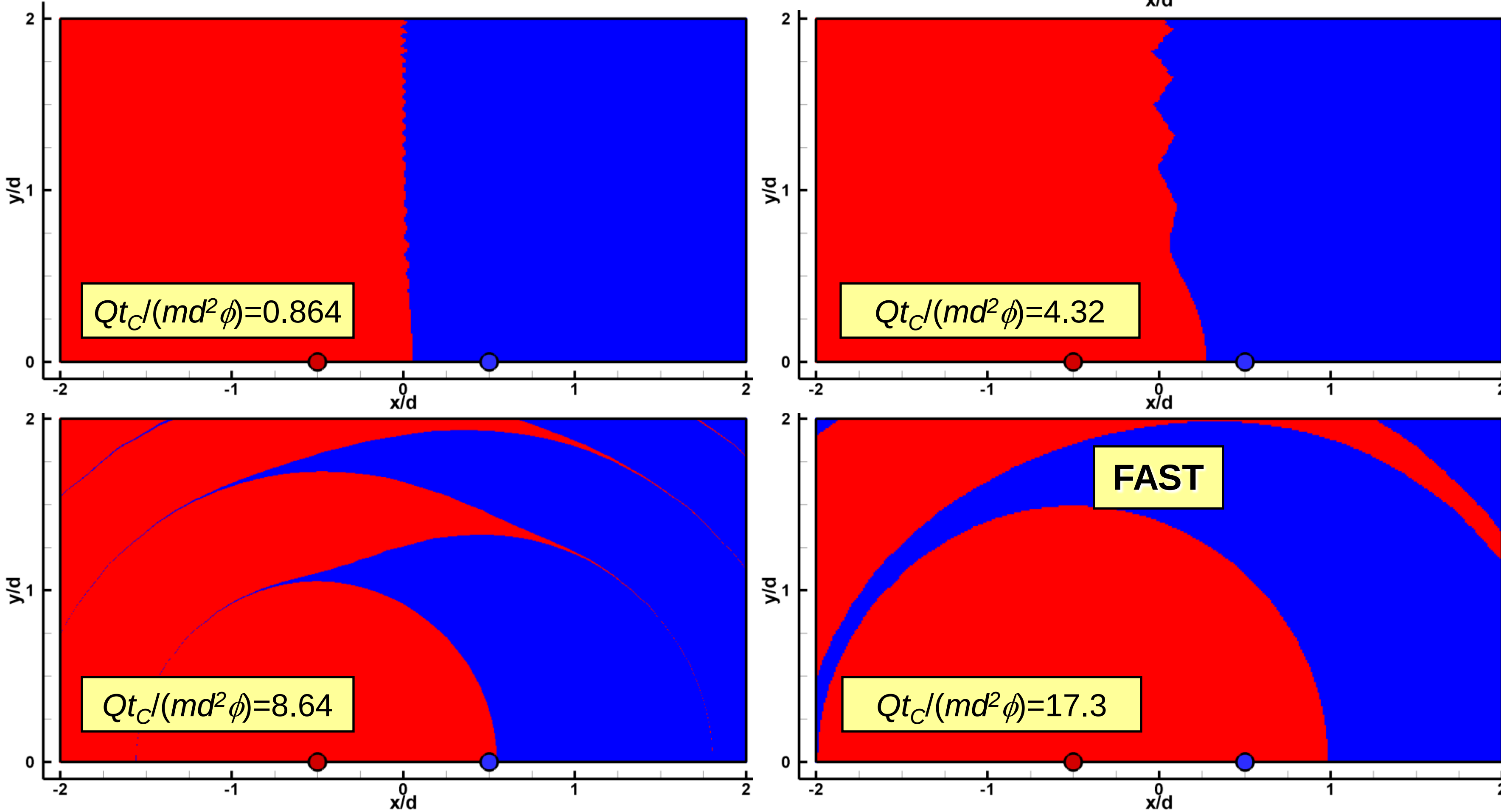
Investigated uncertainties

- transport velocity
- hydraulic diffusivity
- longitudinal/transverse dispersivities
- release times: instantaneous/continuous

Impact of transport velocities

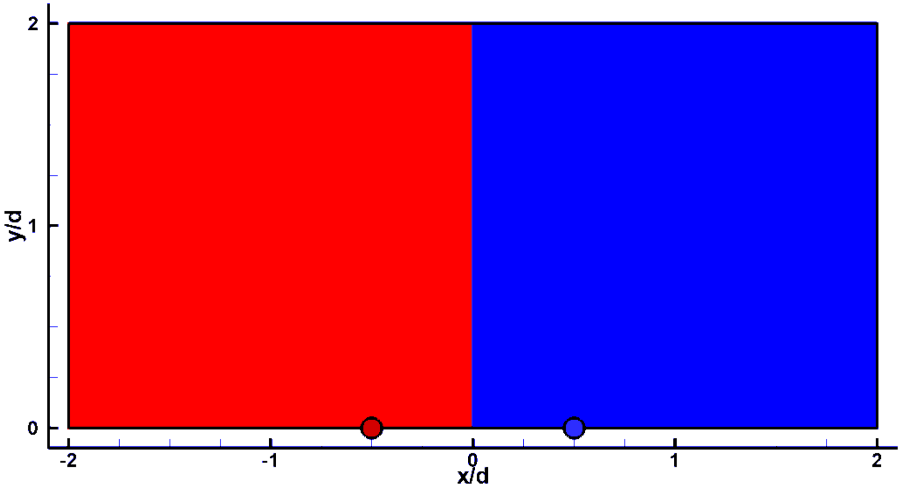
The slower the transport velocities, the higher the number of capture-zone fingers



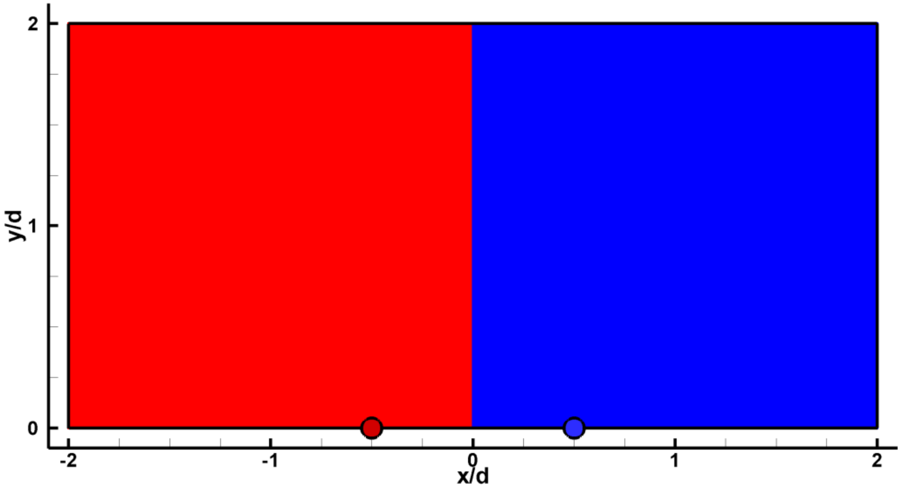


Steady-state vs transient capture zones

steady-state



$Qt_C/(md^2\phi)$<0.01
t_Ca/d^2=86.4



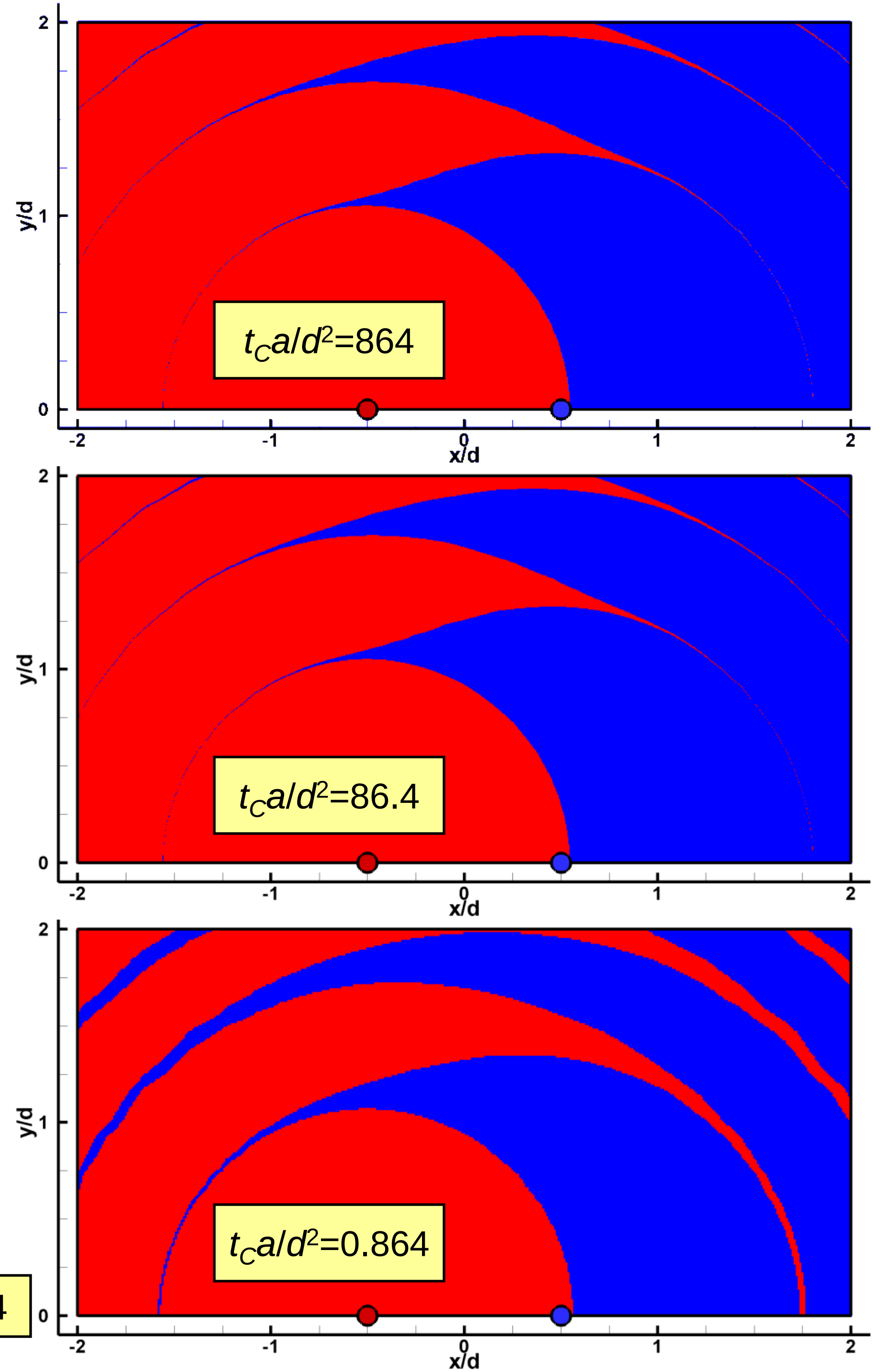
<u>Transient</u> capture zones obtained for the case of very low transport velocities and <u>steady-state</u> capture zones are equivalent

Impact of hydraulic diffusivity

- ❖ faster propagation of pressures
  - ❖ confined conditions

The lower the hydraulic diffusivity, the wider the capture-zone fingers

- ❖ slower propagation of pressures
  - ❖ unconfined conditions



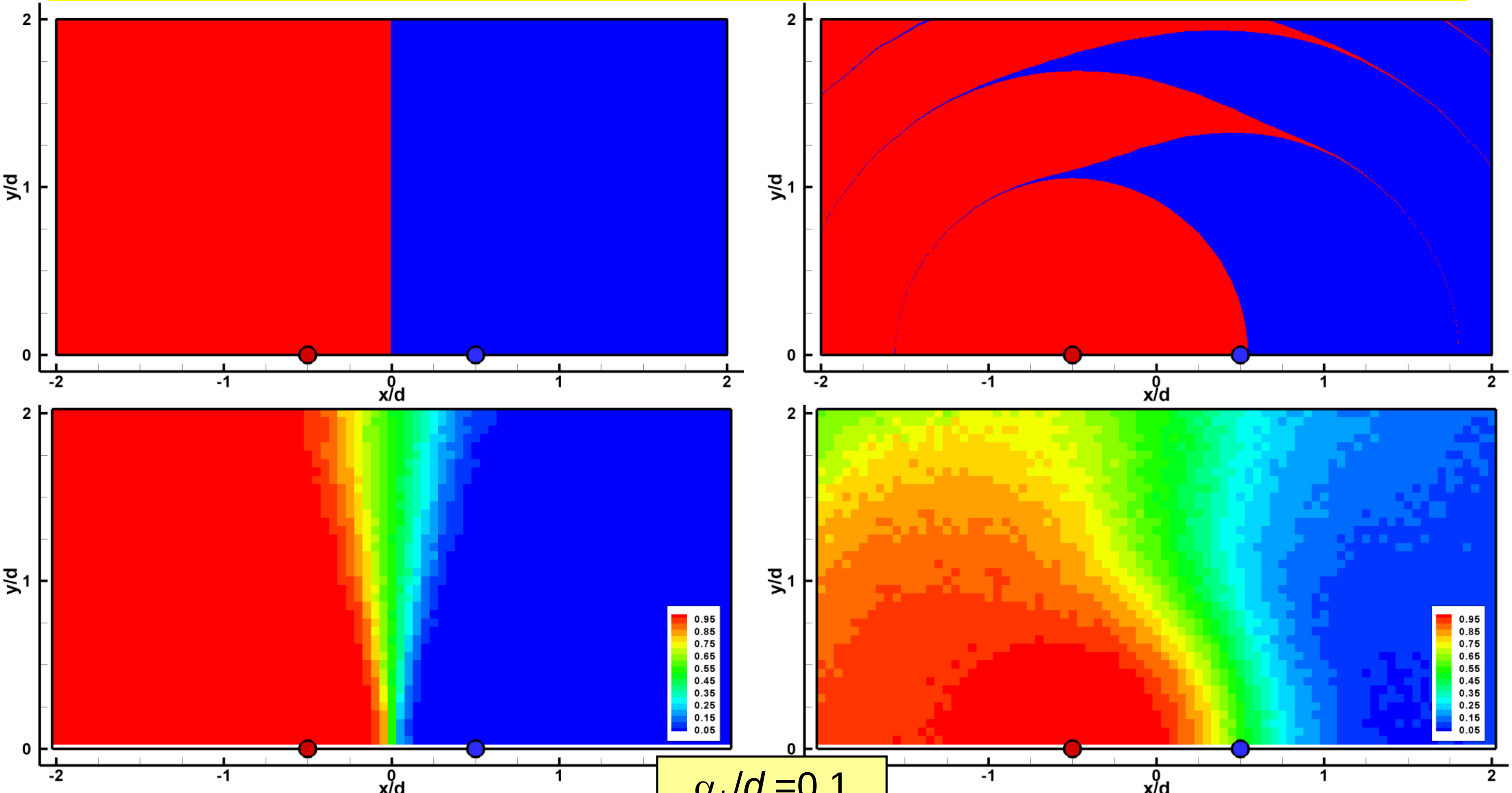
$Qt_C/(md^2\phi)$=8.64

$Qt_C/(md^2\phi)<0.01$
$t_C a/d^2=86.4$

Impact of dispersion

$Qt_C/(md^2\phi)=8.64$
$t_C a/d^2=86.4$

Low velocity (Steady-state) — High velocity

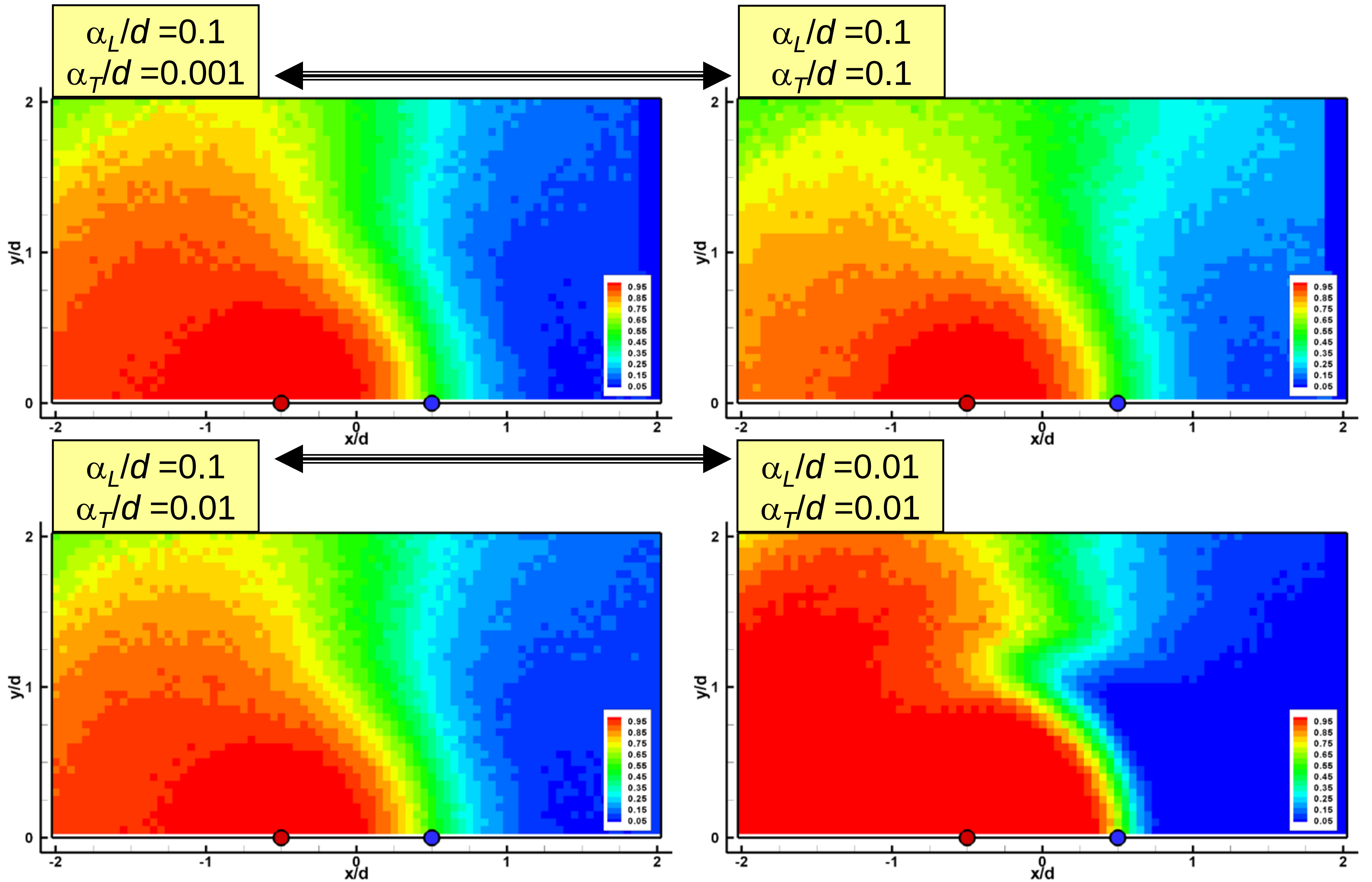


$\alpha_L/d=0.1$
$\alpha_T/d=0.01$

LEGEND:

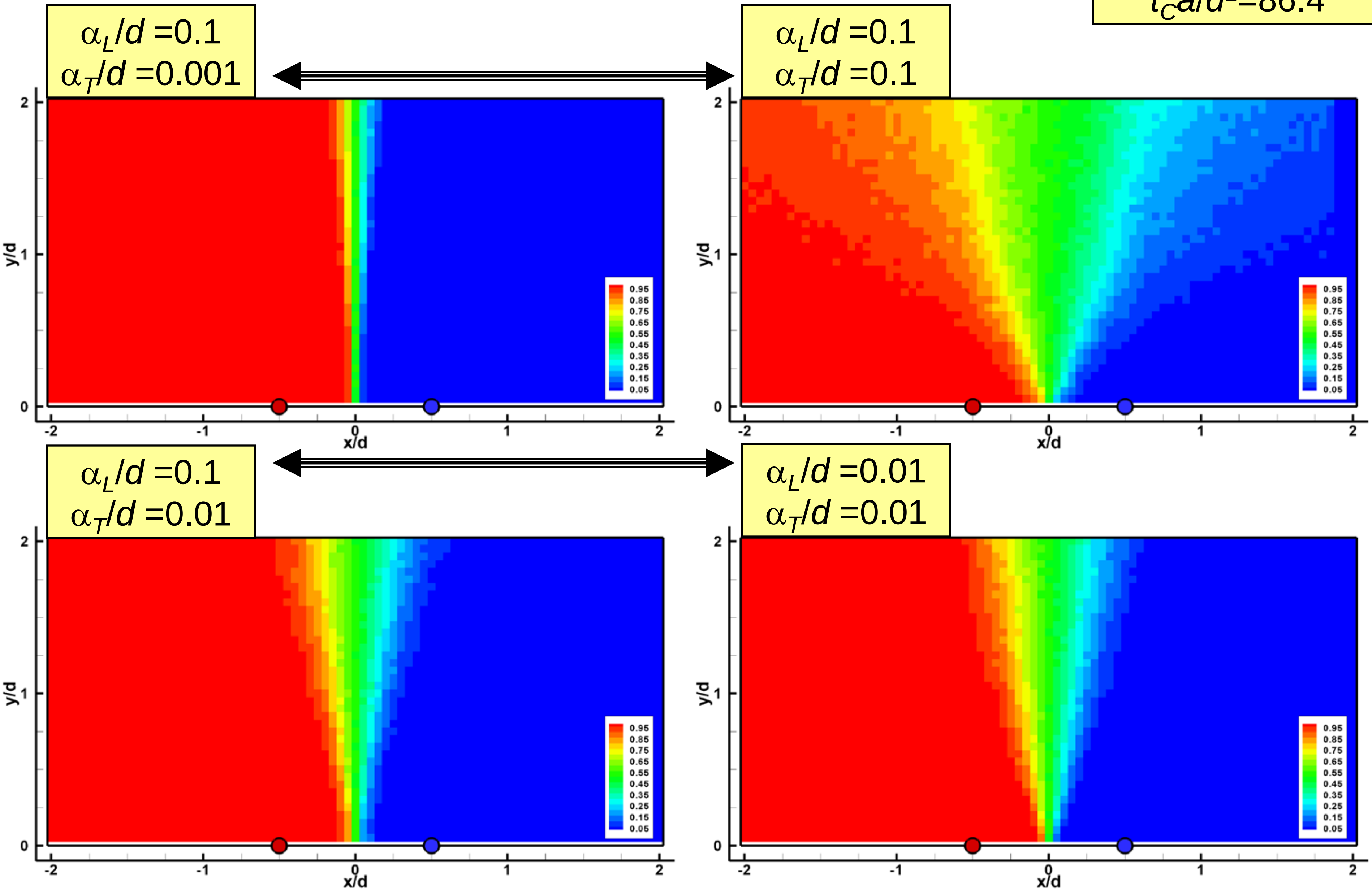
Color range between RED and BLUE represents the capturing percentage

In the high velocity transient case, α_L is important, while α_T has a minor effect on the estimates



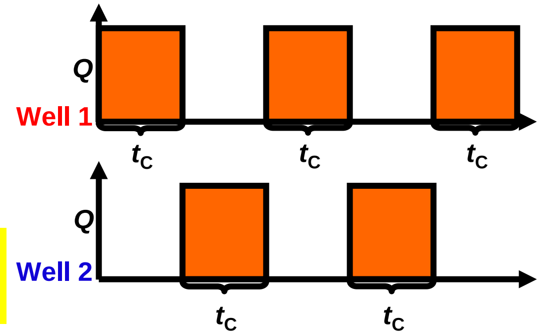
In the low-velocity transient (steady-state) case, α_T is important, while α_L has a minor effect on the esti

$Qt_C/(md^2\phi)<0.01$
$t_C a/d^2=86.4$

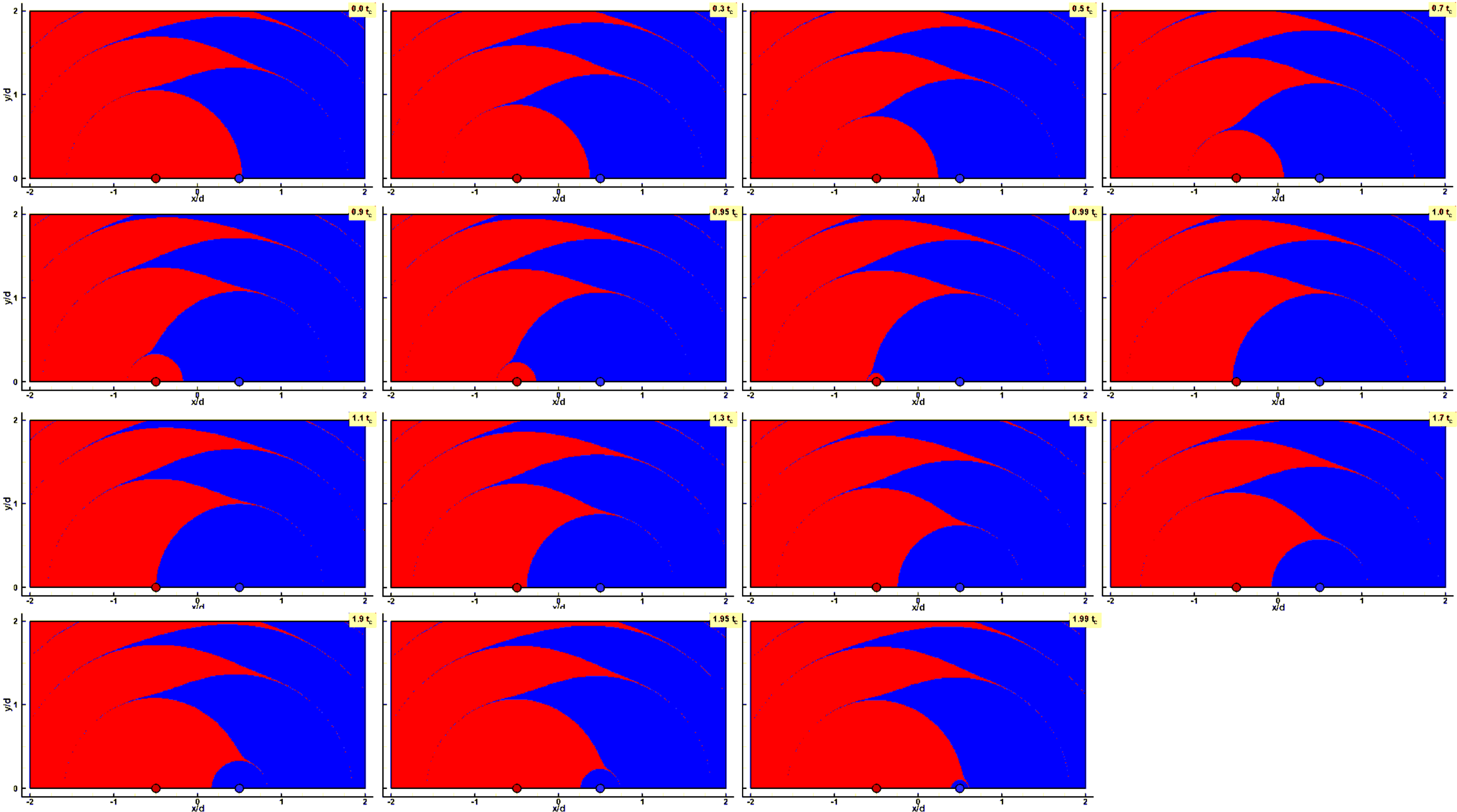


Transient capture zones: Impact of release times

$Qt_C/(md^2\phi)=8.64$
$t_Ca/d^2=86.4$



Capture zones change with the release time



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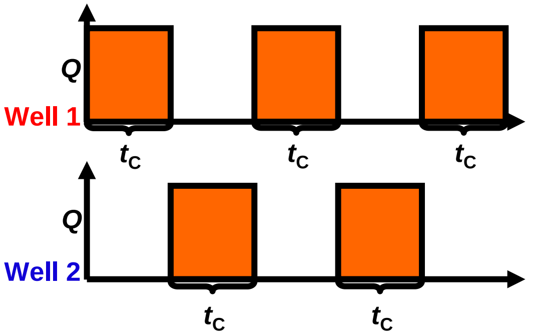
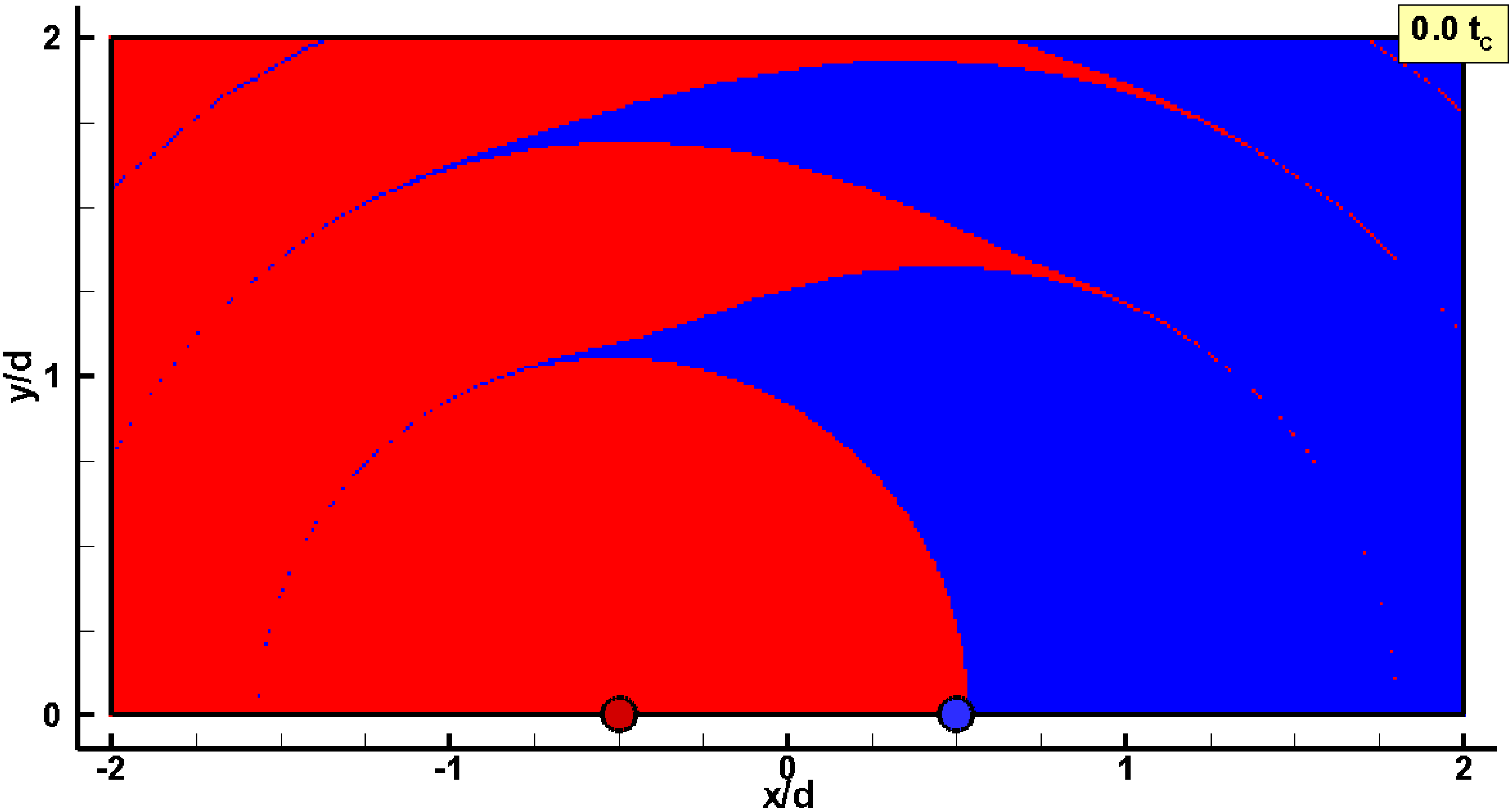


Animation of transient capture zones at different release times

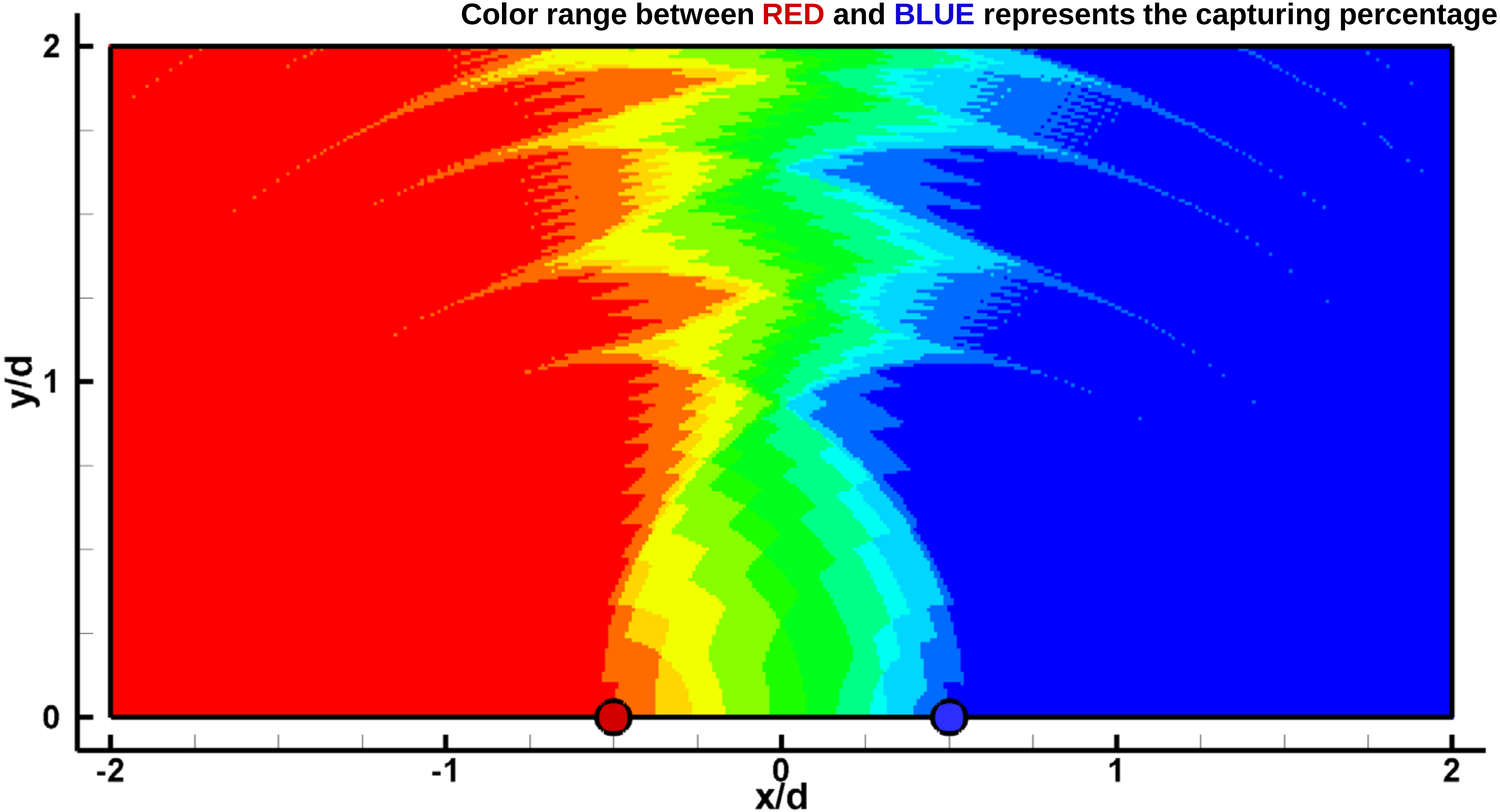


Transient capture zones: Continuous releases

$Qt_C/(md^2\phi)=8.64$
$t_Ca/d^2=86.4$

Smearing of the capture zones due to continuous releases

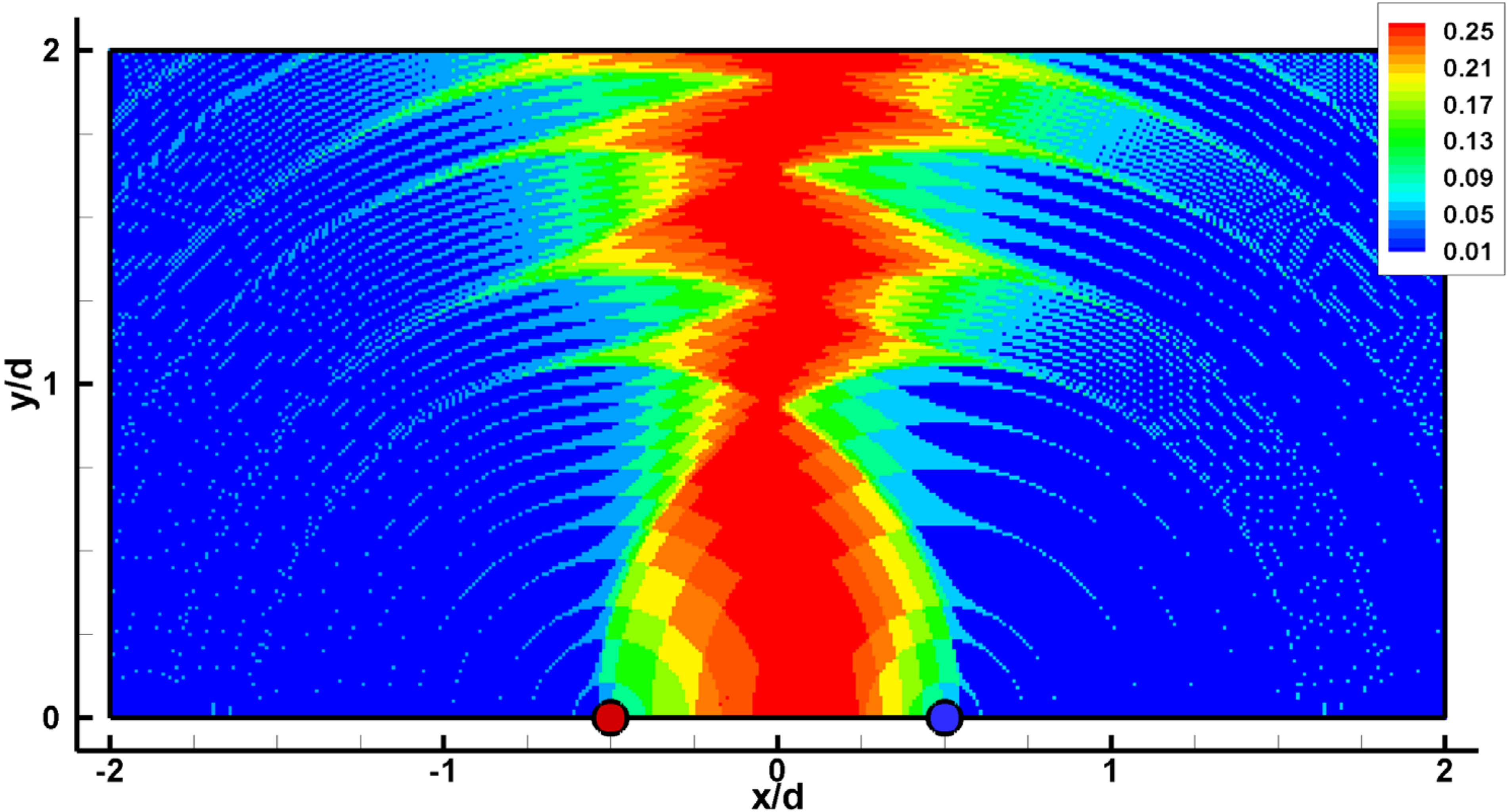
LEGEND:
Color range between RED and BLUE represents the capturing percentage



Transient capture zones: Continuous releases

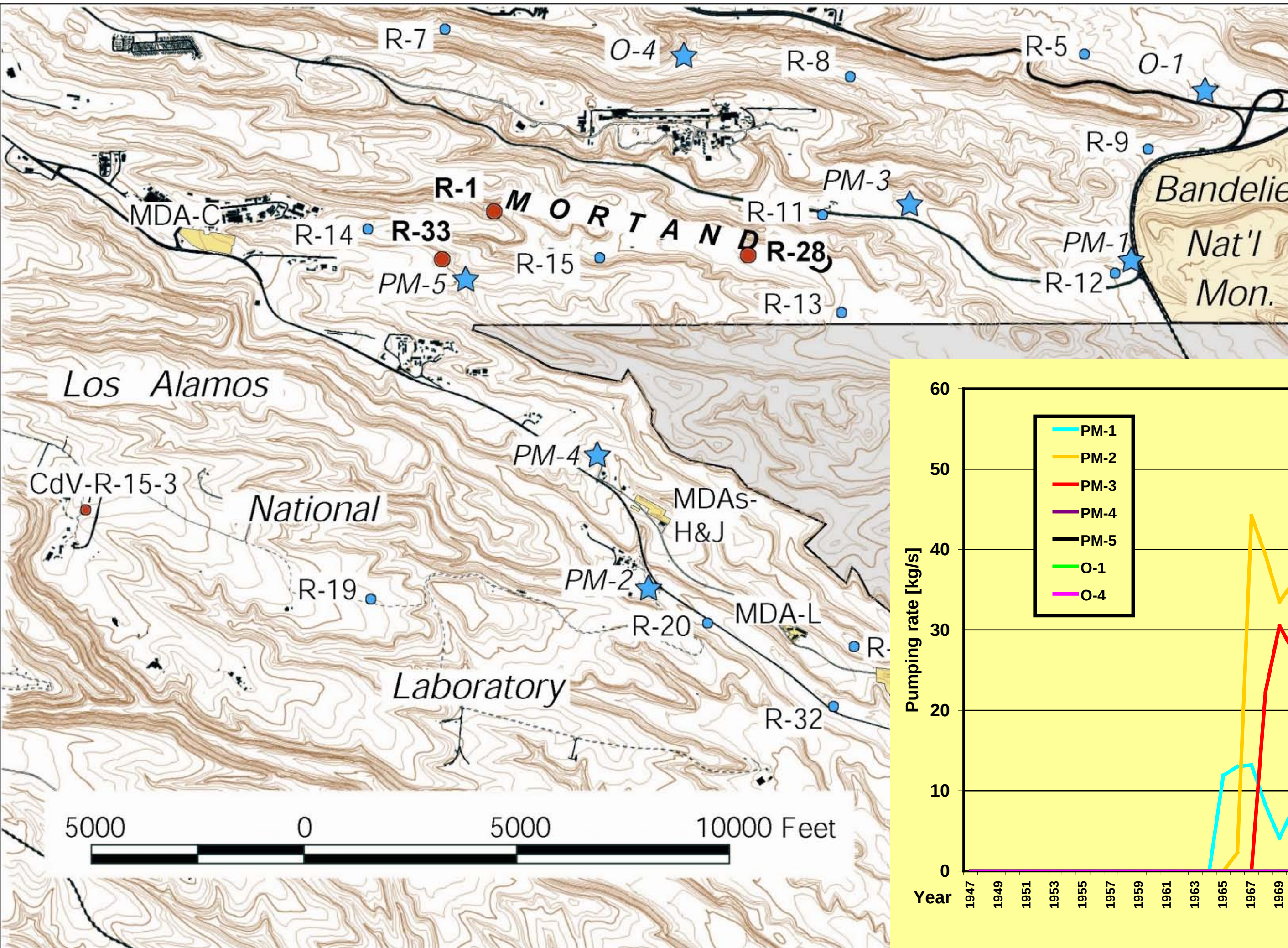
$Qt_C/(md^2\phi)=8.64$
$t_Ca/d^2=86.4$

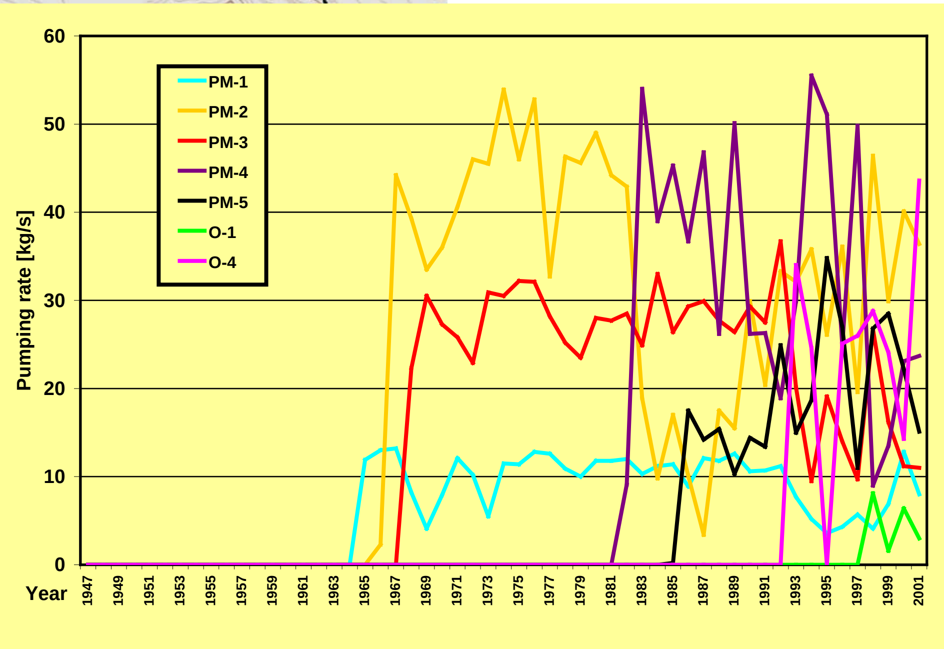
Variance in the capture-zone estimation due to continuous releases



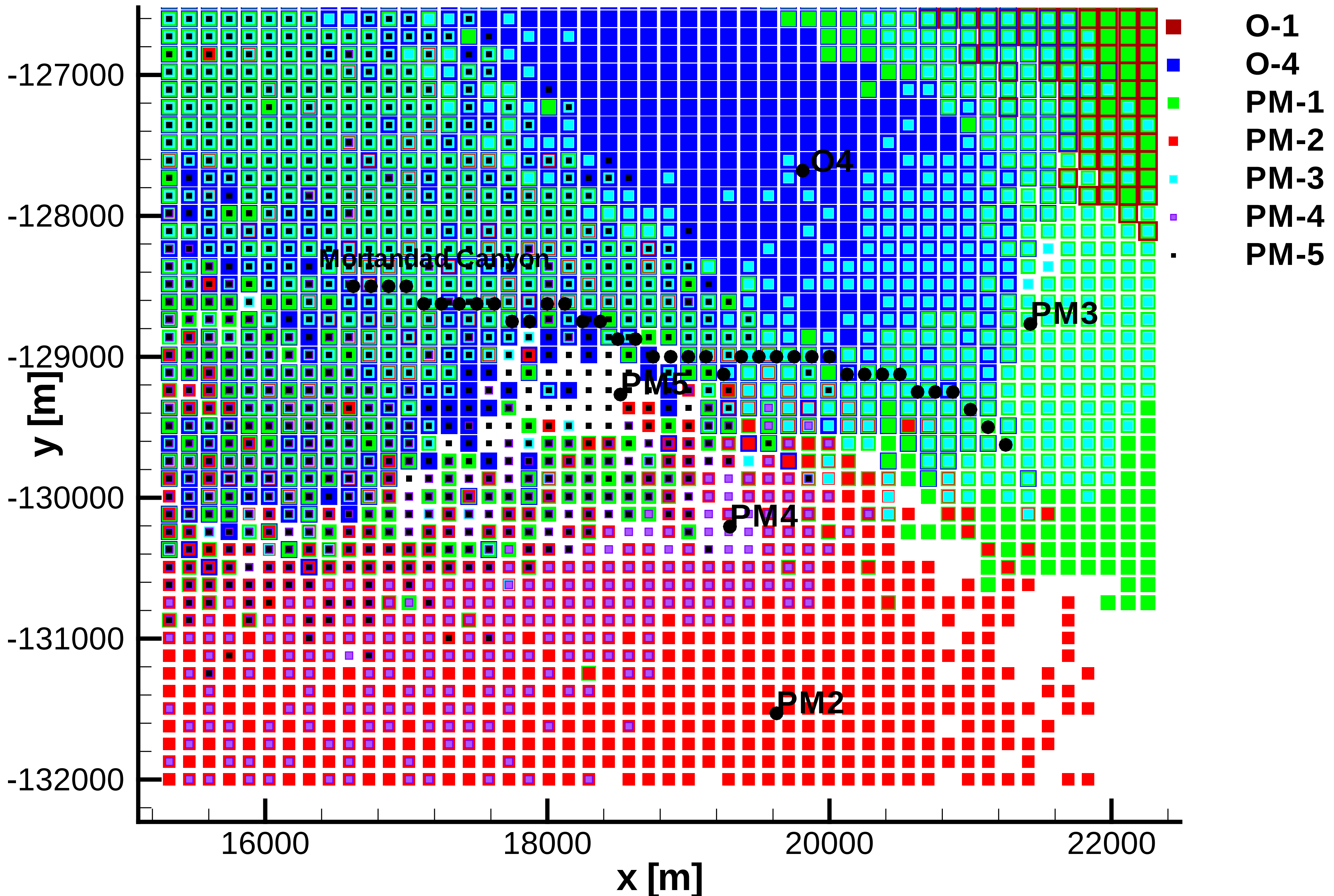
Los Alamos Nat'l Lab (LANL) case study

- **multiple water-supply wells with variable pumping rates**
- **multiple contaminant sources in their vicinity with uncertain and variable release history**
- **unknown contaminant fate in the saturated and unsaturated zones**
- **capture-zone predictions are made using complex 3D UZ/SZ models**

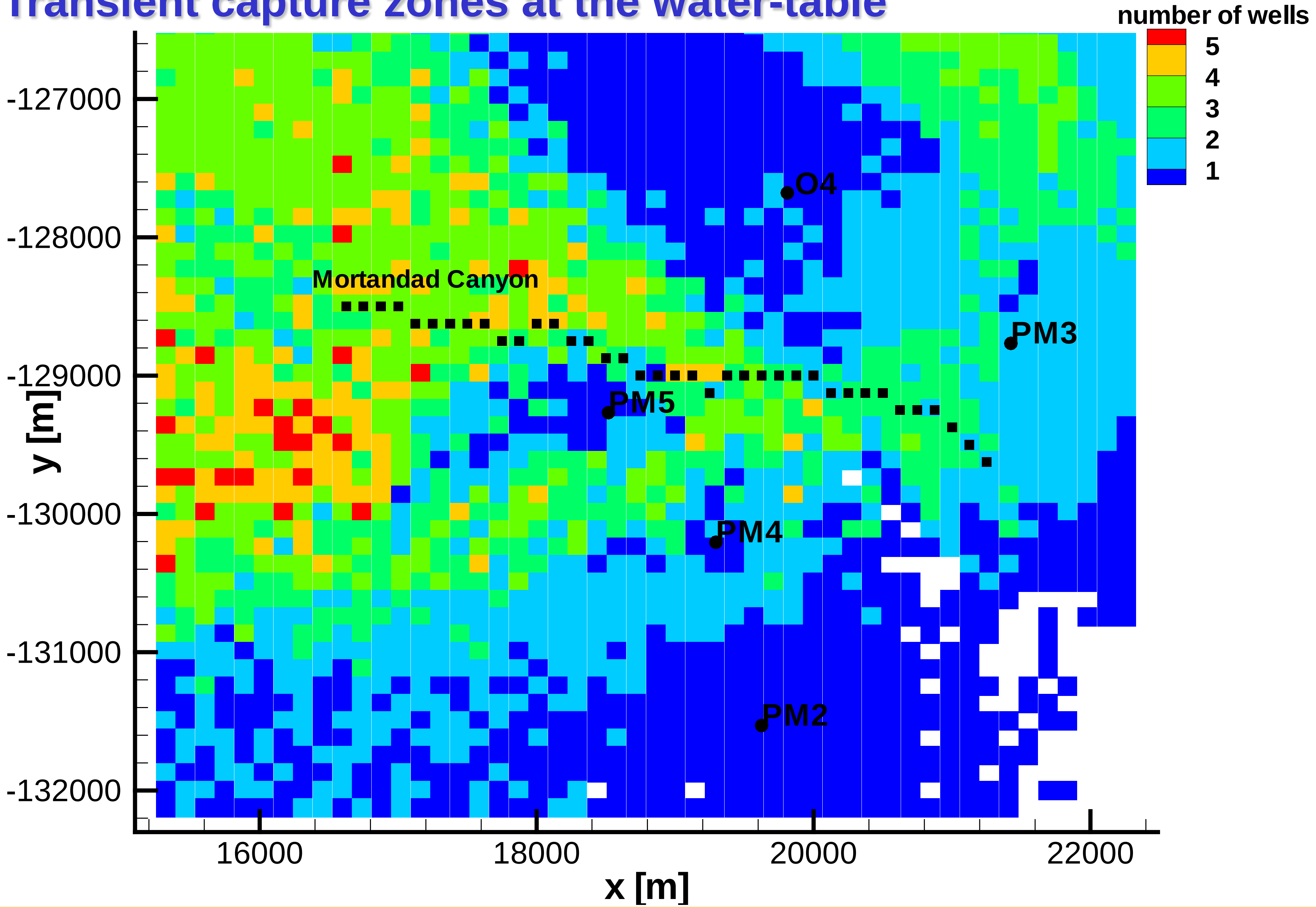




Transient capture zones at the water-table



Transient capture zones at the water-table



Number of wells capturing contamination from each location

Findings/Conclusions

- **Transients are important to consider in capture zone analyses**
- **Significance of transients for capture-zone analyses depends on**
  - **amplitude/frequency of the transients in the groundwater flow and transport (well pumping/contaminant releases),**
  - **rate of propagation of contaminants (pore velocities)**
  - **contaminant dispersion (dispersivities)**
  - **rate of propagation of hydraulic pressures (hydraulic diffusion)**
- **Uncertainties in the transient capture zone estimates depend predominantly on:**
  - **transport velocities**
  - **longitudinal dispersivity in the case of high transport velocities, and transverse dispersivity in the case of low transport velocities**
  - **release times**
- **Transient capture zones can be effectively delineated even for very complex models through parallelization**