Efficiency evaluation of a groundwater monitoring network using a risk-based decision-support process

Velimir V Vesselinov[1]
Kay Birdsell[1]
Paul Davis[3]
Chris Echohawk[2]

[1]Hydrology, Geochemistry, and Geology Group, Earth and Environmental Sciences
[2]Environmental Programs
Los Alamos National Laboratory, New Mexico
[3]EnviroLogic Inc, New Mexico

30845

H31F-07
AGU Fall Meeting
Quantification, Management, and Reduction of Uncertainty in Groundwater Modeling
December 13, 2006

LA-UR-06-8504

ERID 098324

Motivation

- A series of contaminant sources have the potential to impact quality of regional groundwater resources beneath the Los Alamos National Laboratory (LANL)
- Complex contaminated sites, similar to those at LANL, might require substantial time and effort for characterization and remediation
- Prioritization and well-defined goals are required to accomplish this efficiently
- These can be achieved through risk-based decision-support analysis
- We apply this approach to evaluate efficiency and effectiveness of the existing groundwater monitoring network at LANL

Risk-based decision-support analysis

- Estimate uncertainty in the model predictions incorporating current uncertainties in data and conceptual understandings
- Evaluate probability (risk) of failure at the compliance points based on uncertainty in the model predictions
- Is the risk acceptable?
  - yes: no further characterization might be needed
- Model is applied to predict risk reduction through:
  - characterization that can reduce predictive uncertainty
  - potential remedial options and related (if needed) characterization for efficient implementation
- Select action (based on the risk of failure / cost)
  - if remedy is selected no further characterization might be needed

Decision uncertainty

- **Risk of failure at the compliance points based on existing uncertainties**
- **Probability of success and cost to reduce risk of failure through characterization**
- **Probability of success and cost to reduce risk of failure through remedial activities**

Is additional characterization needed?

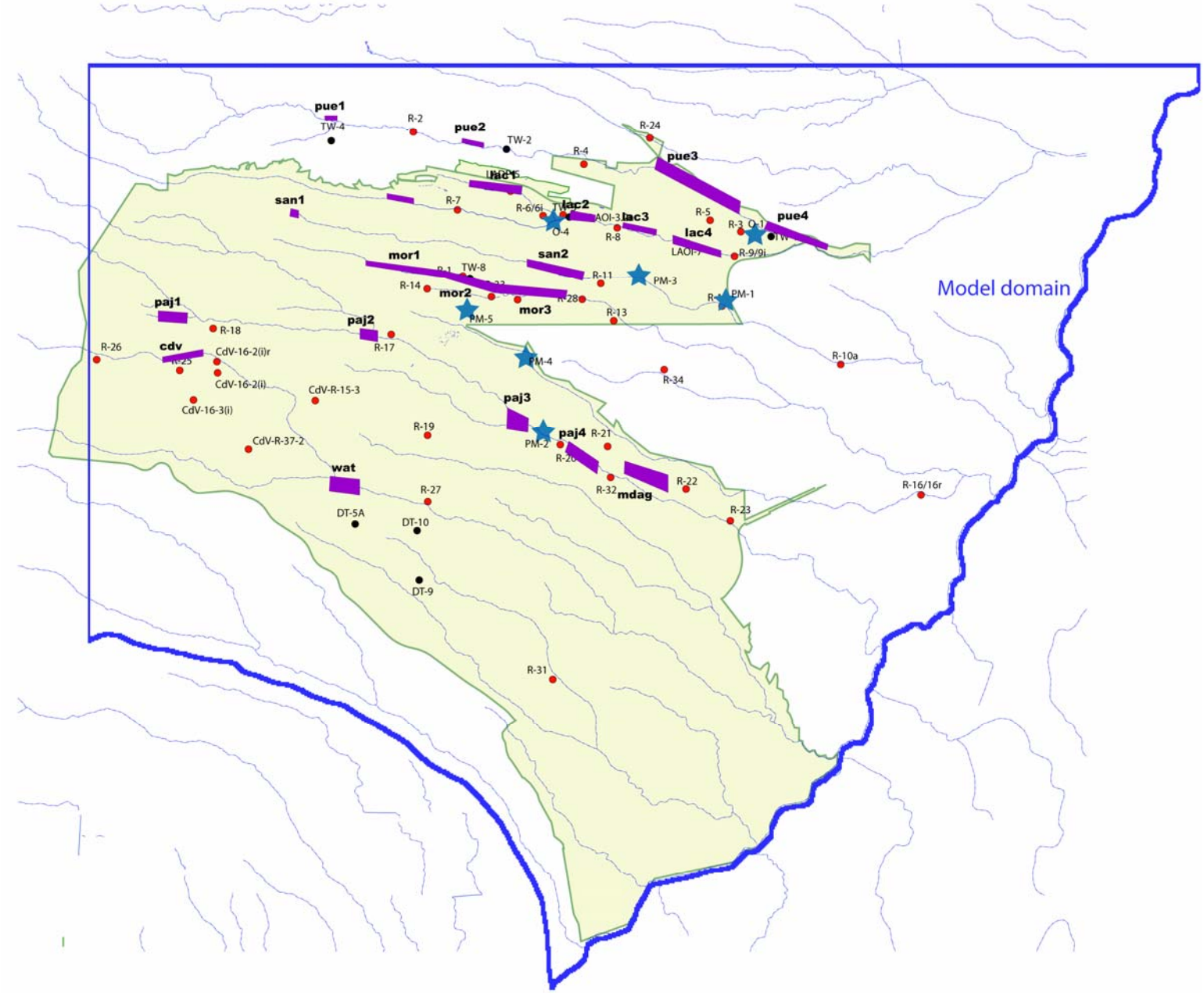
characterization = data collection, conceptual/numerical model development

- Insufficient basis for further characterization are:
  - high uncertainty in parameters/conceptualizations
  - high sensitivity of parameters/conceptualizations to model predictions
  - high uncertainty in model predictions
- High decision uncertainty which does not allow us to select an action (unacceptably high risk/cost) is a sufficient basis for further characterization
- Future characterization alternatives are ranked based on:
  - probability to make/change remedy decisions
  - probability to improve efficiency of the selected remedy(ies)
  - cost
  - execution time

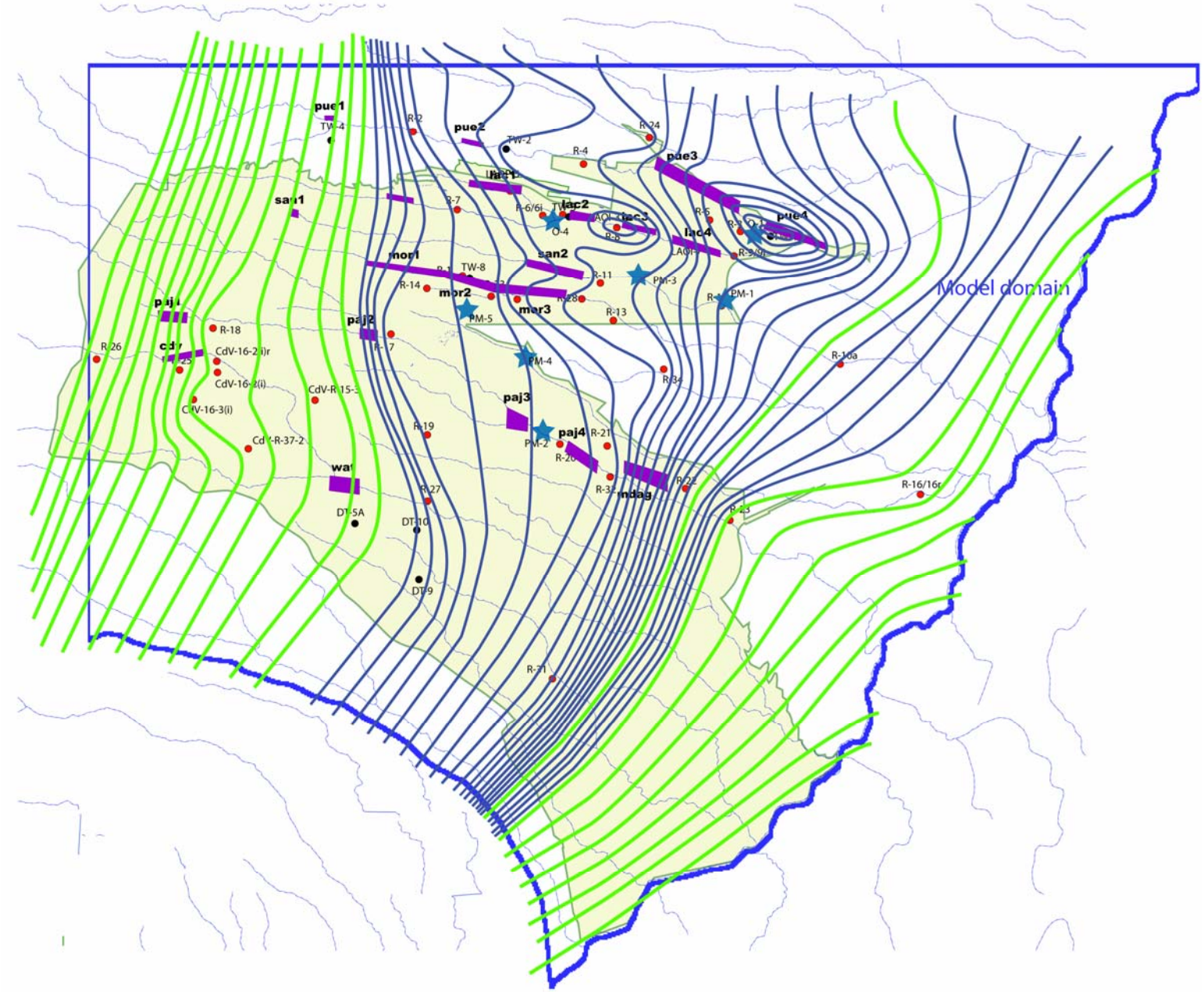
Monitoring network evaluation

- 21 potential contaminant sources
- 7 water-supply wells (i.e. max 144 pathways)
- 44 multi-screen monitoring wells
- Is the existing monitoring network capable of detecting the contaminant plumes before they reach the points of compliance at unacceptably high concentrations?
- Points of compliance
  - water-supply wells within LANL boundaries
  - offsite releases along east LANL boundary
  - springs along Rio Grande
- Probabilistic risk-based evaluation which incorporates uncertainties in the sources, model parameters and conceptualizations:
  - overall network effectiveness
  - overall network efficiency (quarterly vs. annual sampling; non-detecting and redundant wells)
  - ranking of the individual wells based on the capability to protect points of compliance

Sources / Compliance points / Model domain

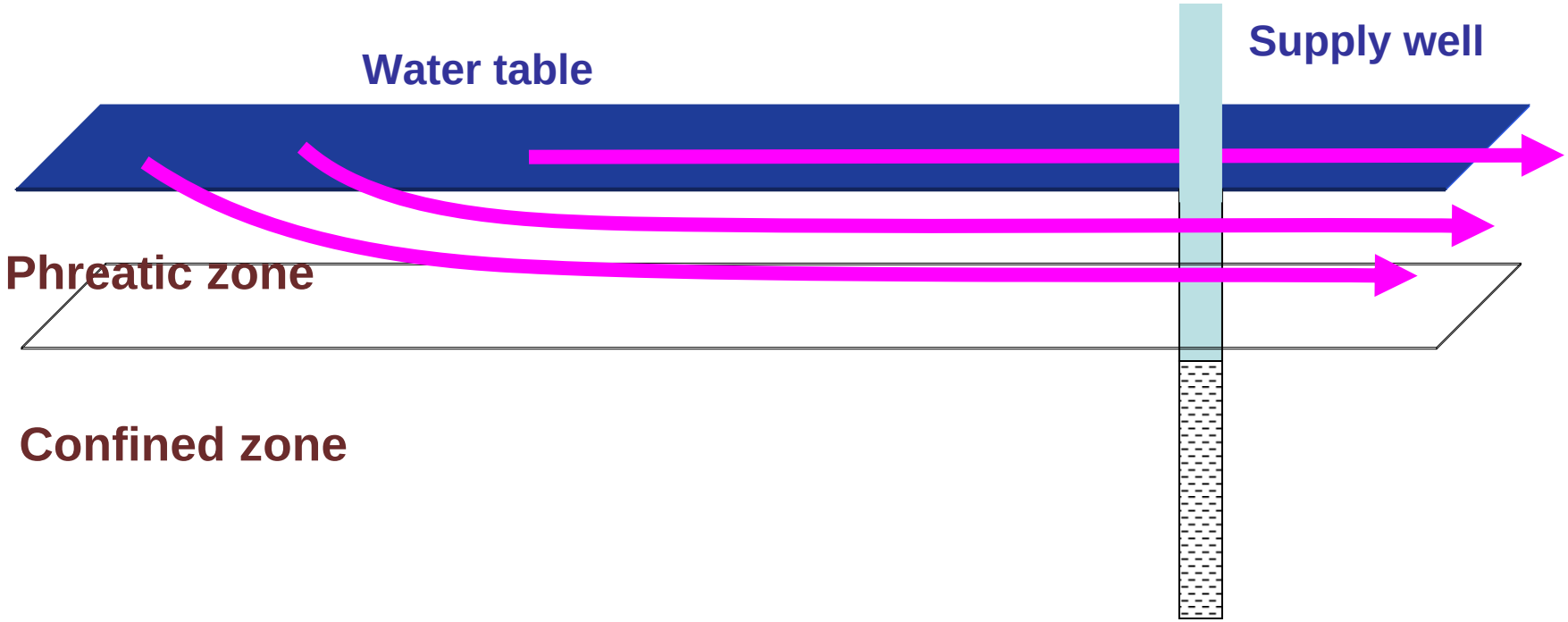


Flow structure (Model 2)



Vertical structure of regional aquifer

- strong hydraulic separation between phreatic and confined zones of the aquifer restricts propagation of the water-supply pumping drawdowns to the water-table
- hydraulic gradients in the phreatic zone are negligibly affected by the pumping
- still, pressure differences between the zone allow downward contaminant movement along filter packs and hydraulic windows



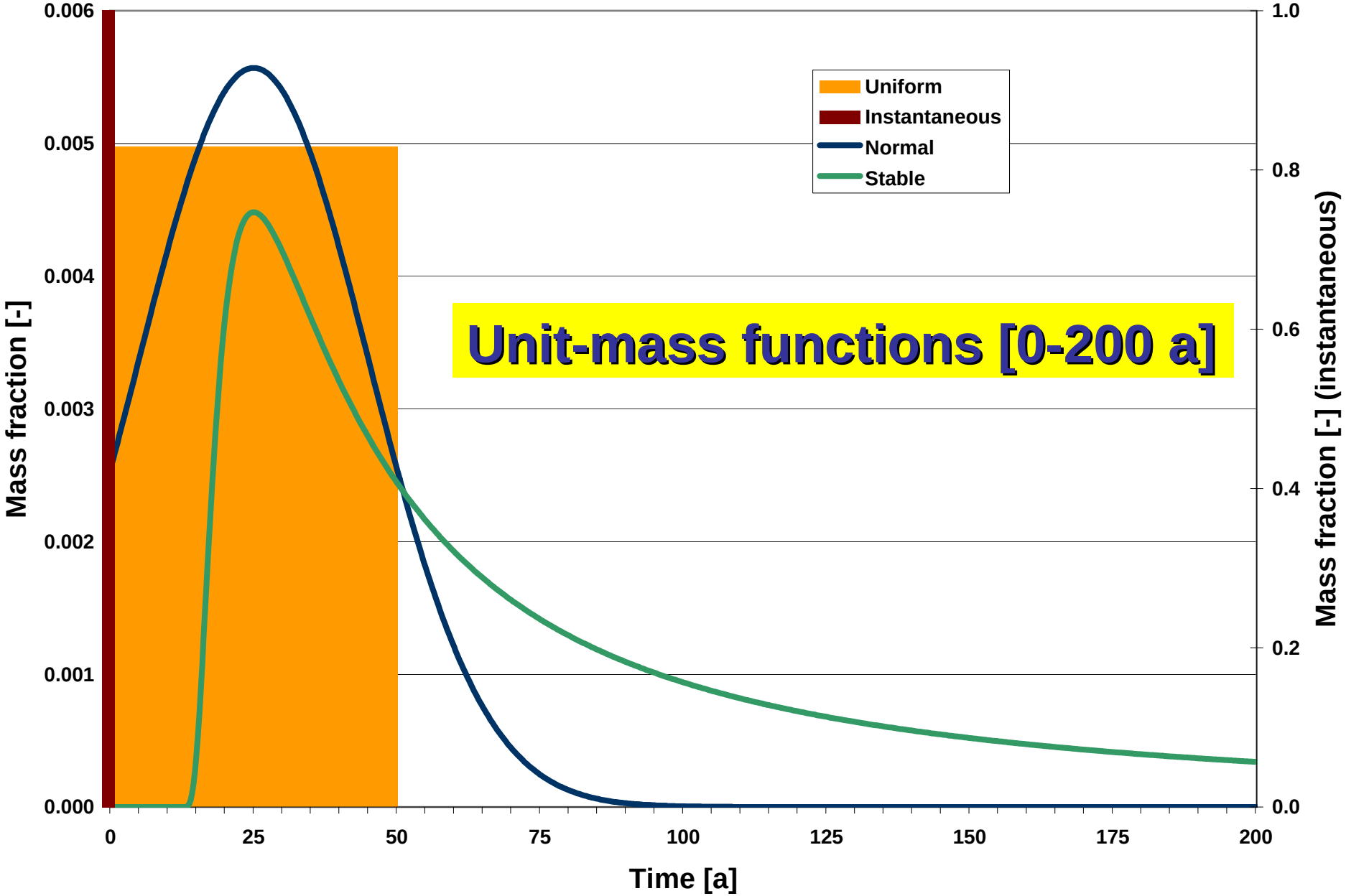
Computational model

- 3D model of the phreatic zone (thin pancake model along the water table); grid resolution 25 x 25 m^2 (700k nodes; not adequate to represent near-well flow conditions)
- Steady-state flow field assumed (water-level transients are considered negligible and currently ignored)
- Groundwater flow structure defined using water-table maps (solving only contaminant transport, no flow solution)
- No infiltration recharge (recharge impact on the water levels is explicitly defined by the imposed flow structure)
- No discharge (discharge impact on the water levels is explicitly defined by the imposed flow structure)
- No explicit water-supply pumping (existing data suggest that the pumping has negligible effect on the water-table flow directions)
- Contaminants are expected to reach the water-supply wells along the well filter packs and through hydraulic windows, and diluted due to mixing within the borehole

Uncertainties

- permeabilities for each hydrologic unit (uniform/isotropic)
- porosities for each hydrologic unit (uniform/isotropic)
- long/trans dispersivities (same for all the units)
- contaminant dilution at the water-supply wells (depending on pumping rate and near-well groundwater flow conditions)
- "capture-zone" radius of water-supply wells at the water table; radius varies from:
  - 12.5 m (controlled by the grid-size) representing "leaking filter pack", to
  - 1000 m (~radius of influence in the deep portion of the regional aquifer estimated during long-term pumping tests) assuming that the count, size and location of hydraulic windows are sufficient to sweep all the contaminants within the water-table capture zone
- temporal variability in the strength of contaminant sources (all unit-mass sources [0-200 a])
  - instantaneous (delta function) [0 a]
  - uniform distribution (step function) [0-50 a]
  - truncated normal distribution [0-200 a; peak at 25 a]
  - truncated alpha-stable Levy distribution [0-200 a; peak at 25]; "heavy" tail

Temporal variability of sources



Monte-Carlo Runs

- 1000 equally probable parameter sets
- various conceptualizations (not equally probable):
  - alternative water-table maps
  - range of radii of influence at the water-supply wells
  - range of dilution factors at the water-supply wells
- 4 different unit-mass source functions (with varying probability depending on the source)
- alternative locations of source arrival at the regional aquifer
- executed in parallel on multi-processor clusters
- results: unit-response breakthrough curves at the water-supply wells, monitoring boreholes, springs

Test for monitoring success/failure

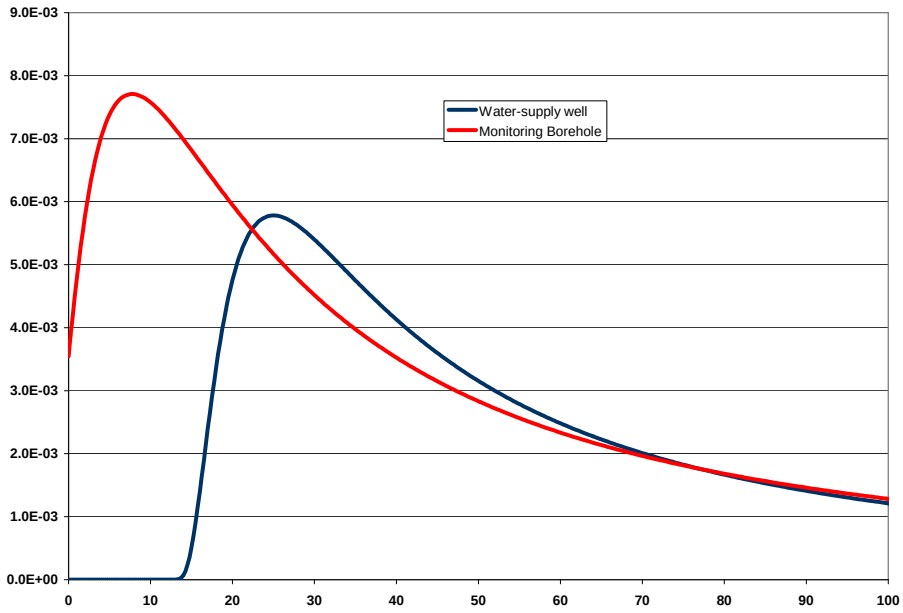
- **at any given moment in time t_i, the concentration at a water-supply well $C_W(t_i)$ is compared to the maximum concentrations already observed up to the given moment t_i at a monitoring borehole $C_{Rmax}(t_i)$**

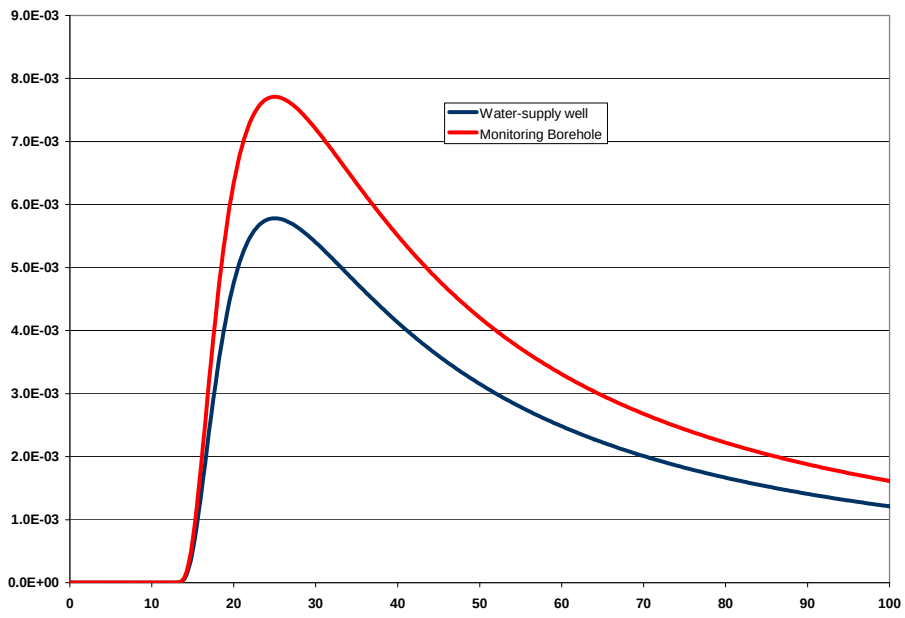
$$C_{R\max}(t_i) = \max\left[C_{R\max}(t_1), C_{R\max}(t_2), \ldots, C_{R\max}(t_i)\right]$$

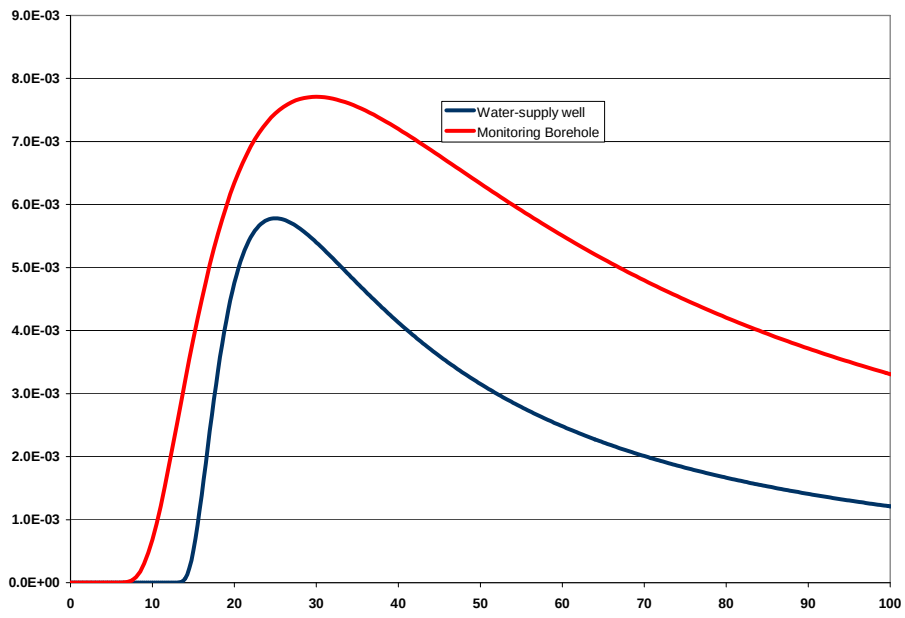
$$\mathrm{F}_{RW} = \begin{cases} 1 & \text{if } C_{R\max}(t_i) > C_W(t_i) \quad \forall i \quad \textbf{success} \\ 0 & \text{if } C_{R\max}(t_i) \le C_W(t_i) \quad \exists i \quad \textbf{failure} \end{cases}$$

- **for a given water-supply well, if there is at least one successful test, the monitoring network is providing protection; if there are only test failures, the monitoring network is not providing protection**
- **probability of detection less than 95% is considered unacceptably high risk**

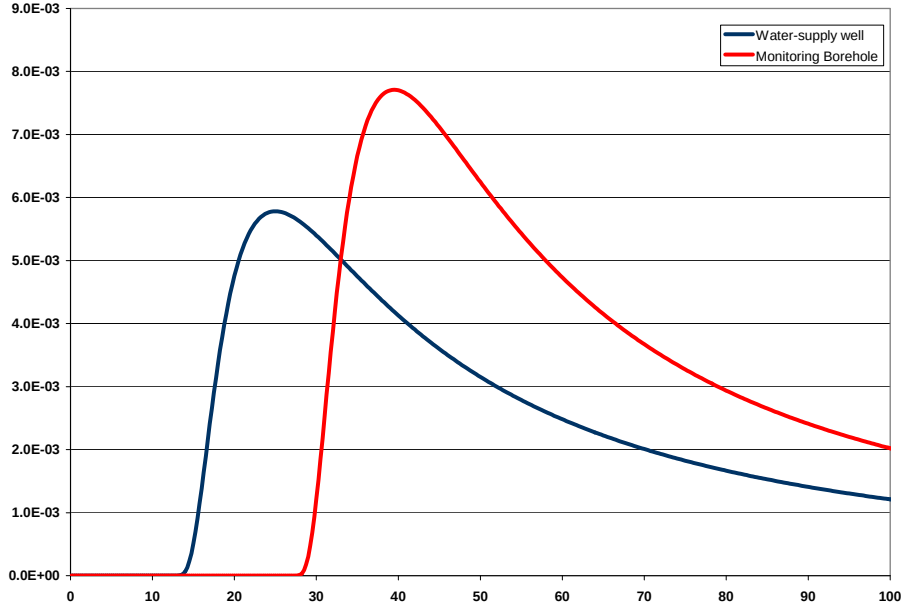
Examples of monitoring successes

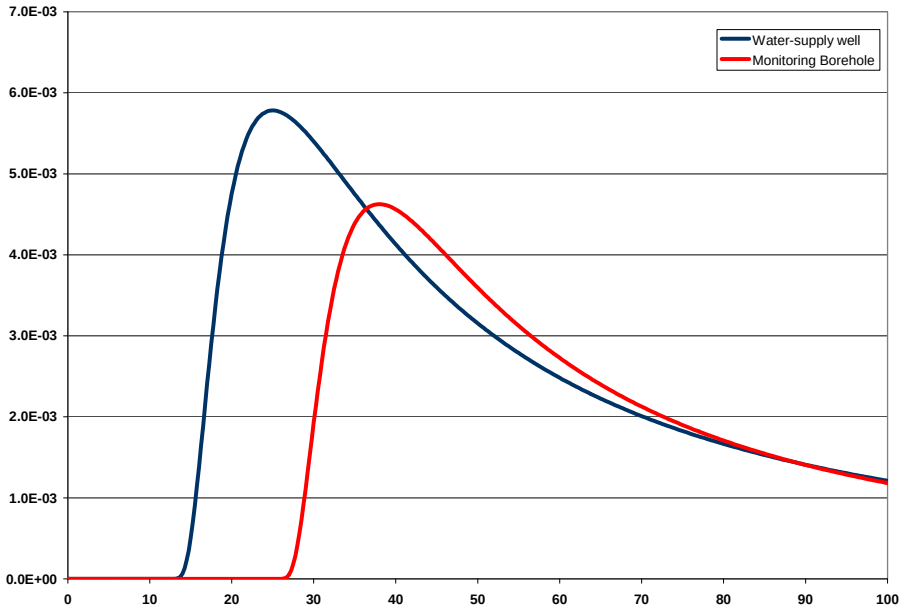


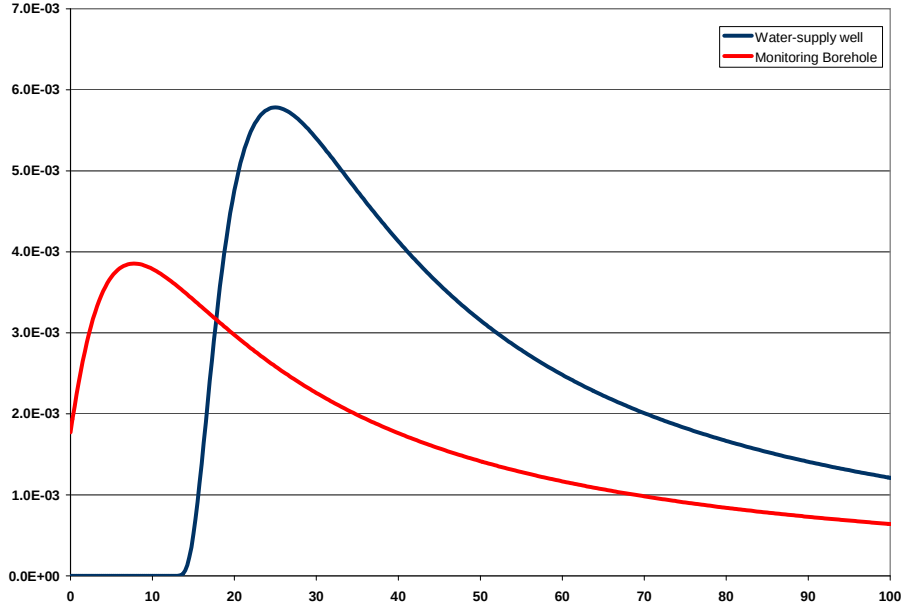


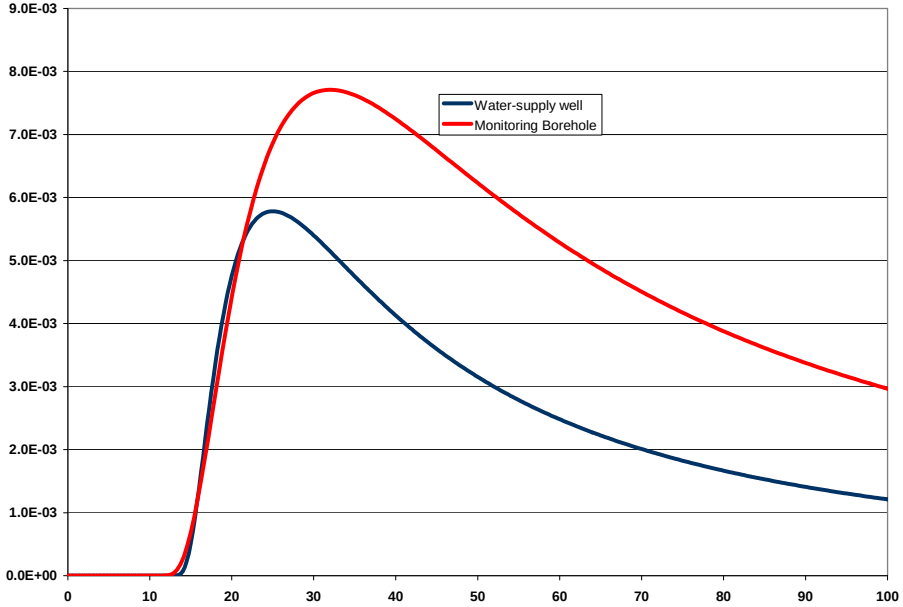


Examples of monitoring failures









Probability of network efficiency (Model 2; low dilution)

Source	O-1	O-4	PM-1	PM-2	PM-3	PM-4	PM-5	Offsite	Springs
cdv	100.0%	100.0%	99.5%	**94.4%**	97.9%	**87.4%**	**51.2%**	**76.1%**	98.1%
wat	100.0%	100.0%	99.9%	**60.0%**	99.5%	96.7%	99.9%	**67.9%**	**75.1%**
paj1	100.0%	100.0%	100.0%	99.7%	100.0%	99.2%	**81.5%**	**87.5%**	99.5%
paj2	100.0%	100.0%	100.0%	99.8%	100.0%	99.4%	**64.1%**	**88.8%**	99.8%
paj3	99.7%	99.4%	**76.8%**	**0.0%**	**83.1%**	**69.6%**	99.9%	**24.6%**	**61.7%**
paj4	100.0%	100.0%	100.0%	**26.4%**	100.0%	99.2%	100.0%	**4.4%**	**88.8%**
mdag	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	100.0%	95.9%	98.6%
mor1	100.0%	99.7%	99.7%	100.0%	100.0%	100.0%	**8.7%**	**83.7%**	98.9%
mor2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**35.4%**	**90.8%**	99.7%
mor3	99.8%	99.8%	99.2%	100.0%	**92.8%**	98.6%	100.0%	**82.8%**	98.6%
san1	100.0%	95.7%	99.8%	100.0%	99.8%	100.0%	**40.5%**	**70.8%**	95.1%
san2	100.0%	**19.1%**	96.4%	100.0%	**51.6%**	98.6%	100.0%	**64.3%**	**94.1%**
lac1	98.4%	99.5%	99.5%	100.0%	99.9%	100.0%	**92.2%**	**57.1%**	**90.8%**
lac2	95.5%	**0.0%**	**93.9%**	100.0%	**55.7%**	100.0%	100.0%	**29.0%**	**79.4%**
lac3	**86.3%**	98.4%	**79.4%**	100.0%	**30.5%**	99.9%	100.0%	**55.9%**	**88.1%**
lac4	**77.2%**	100.0%	**69.5%**	100.0%	**88.0%**	100.0%	100.0%	**64.2%**	**90.6%**
dp	99.2%	**40.5%**	99.7%	100.0%	99.6%	100.0%	100.0%	**40.5%**	**82.7%**
pue1	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**60.8%**	**92.2%**
pue2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**60.4%**	**93.7%**
pue3	**67.6%**	99.8%	97.9%	100.0%	99.4%	100.0%	100.0%	**68.2%**	**92.1%**
pue4	**0.0%**	100.0%	**76.7%**	100.0%	99.8%	100.0%	100.0%	**10.4%**	**26.1%**

Probability of network efficiency (Model 3; low dilution)

Source	O-1	O-4	PM-1	PM-2	PM-3	PM-4	PM-5	Offsite	Springs
cdv	100.0%	100.0%	99.8%	97.5%	99.8%	96.9%	**87.3%**	**58.2%**	**91.2%**
wat	100.0%	100.0%	100.0%	**83.2%**	100.0%	99.5%	100.0%	**60.8%**	**81.0%**
paj1	100.0%	100.0%	99.7%	99.9%	100.0%	99.8%	**93.4%**	**67.5%**	**93.3%**
paj2	100.0%	100.0%	99.9%	99.8%	100.0%	100.0%	**94.4%**	**66.2%**	**93.8%**
paj3	100.0%	100.0%	99.5%	**0.1%**	100.0%	97.9%	100.0%	**1.6%**	**67.0%**
paj4	100.0%	100.0%	100.0%	99.1%	100.0%	99.4%	100.0%	**30.7%**	**92.1%**
mdag	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	100.0%	95.7%	99.4%
mor1	100.0%	99.9%	99.9%	100.0%	100.0%	100.0%	99.9%	**76.4%**	96.1%
mor2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	**86.7%**	98.7%
mor3	100.0%	100.0%	99.0%	100.0%	99.9%	100.0%	100.0%	**62.0%**	**89.5%**
san1	100.0%	99.7%	100.0%	100.0%	100.0%	100.0%	97.4%	**58.7%**	**89.8%**
san2	100.0%	**76.4%**	97.1%	100.0%	**87.5%**	100.0%	100.0%	**56.2%**	**88.6%**
lac1	99.9%	100.0%	99.9%	100.0%	99.9%	100.0%	99.8%	**52.8%**	**88.6%**
lac2	100.0%	**67.7%**	98.1%	100.0%	**84.4%**	100.0%	100.0%	**32.8%**	**79.4%**
lac3	98.6%	99.8%	**94.8%**	100.0%	**60.4%**	100.0%	100.0%	**51.0%**	**83.7%**
lac4	**93.9%**	100.0%	**91.1%**	100.0%	98.3%	100.0%	100.0%	**51.2%**	**83.4%**
dp	100.0%	96.7%	100.0%	100.0%	99.9%	100.0%	100.0%	**38.6%**	**81.5%**
pue1	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**57.7%**	**89.0%**
pue2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**59.4%**	**92.9%**
pue3	96.2%	100.0%	99.8%	100.0%	100.0%	100.0%	100.0%	**68.7%**	**91.9%**
pue4	**46.4%**	100.0%	96.5%	100.0%	100.0%	100.0%	100.0%	**5.3%**	**29.3%**

Probabilities of monitoring wells to provide protection of the water-supply wells (>50%; Model 3; low dilution case)

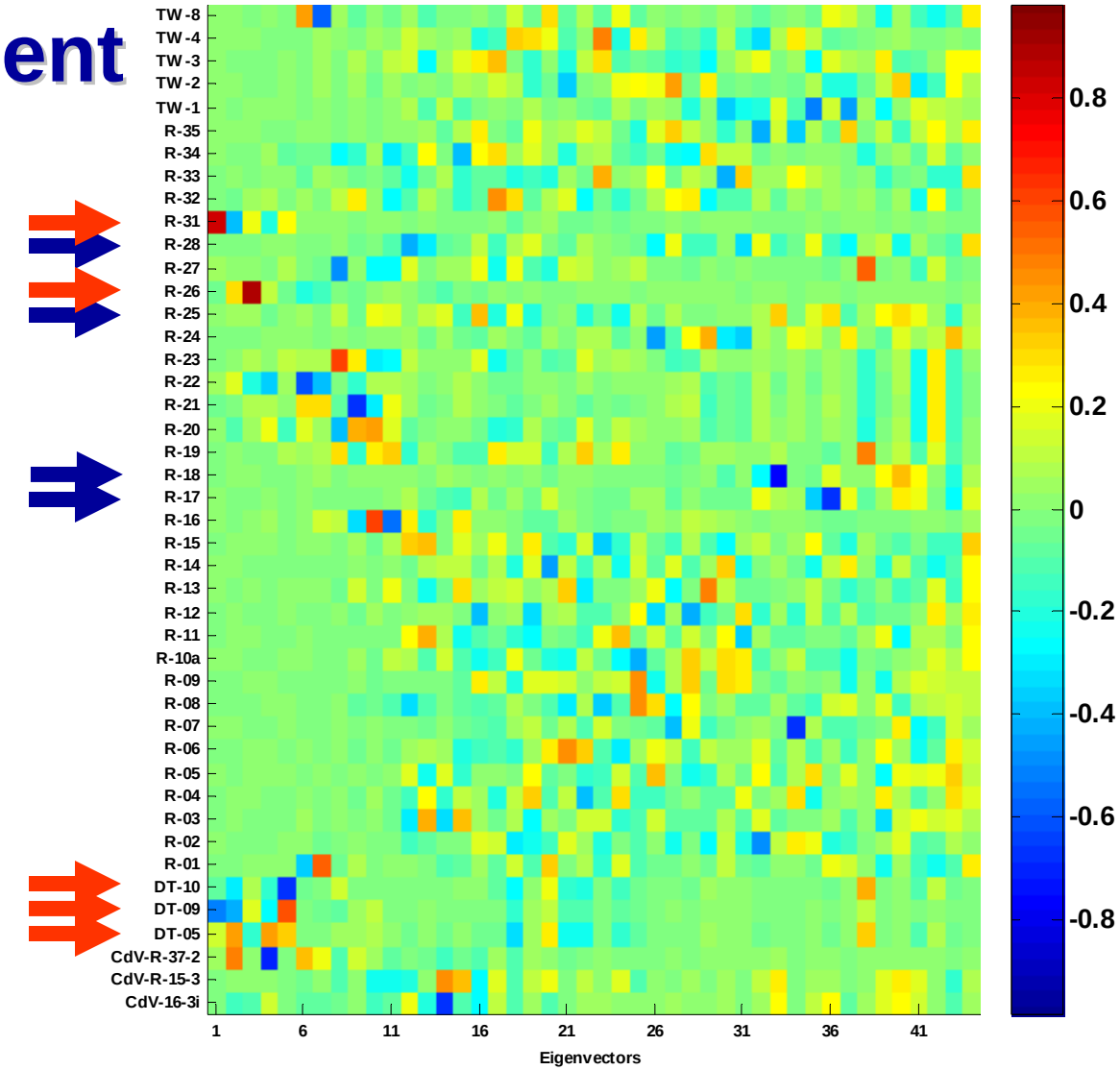
Well	cdv	wat	paj1	paj2	paj3	paj4	mdag	mor1	mor2	mor3	san1	san2	lac1	lac2	lac3	lac4	dp	pue1	pue2	pue3	pue4
CdV-16-3i	9.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CdV-R-15-3	17.2%	0.0%	7.8%	1.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CdV-R-37-2	2.4%	0.1%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-05	0.2%	14.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-09	0.1%	6.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-10	0.3%	22.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-01	**55.3%**	0.0%	**61.0%**	**50.2%**	0.0%	0.0%	0.0%	**72.3%**	**70.6%**	34.3%	**56.1%**	4.8%	17.0%	0.2%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%
R-02	0.2%	0.0%	0.8%	0.5%	0.0%	0.0%	0.0%	5.5%	0.4%	0.0%	20.0%	0.1%	25.5%	0.0%	0.0%	0.0%	6.8%	23.5%	11.1%	0.0%	0.0%
R-03	1.3%	0.3%	1.1%	0.9%	0.3%	0.0%	0.0%	1.8%	1.9%	1.8%	1.7%	2.1%	2.0%	2.8%	5.5%	8.0%	3.0%	0.9%	1.7%	10.9%	5.9%
R-04	12.2%	0.0%	15.4%	11.5%	0.2%	0.0%	0.0%	37.6%	31.7%	24.8%	33.0%	28.2%	28.8%	42.2%	4.5%	1.5%	39.0%	18.3%	25.4%	7.2%	0.1%
R-05	14.0%	1.0%	13.1%	11.6%	1.8%	0.1%	0.1%	21.1%	18.6%	17.8%	20.5%	19.4%	22.4%	29.8%	39.0%	32.6%	28.7%	14.5%	20.0%	40.0%	7.0%
R-06	6.3%	0.0%	10.2%	7.4%	0.1%	0.0%	0.0%	30.5%	24.9%	18.8%	28.4%	20.3%	19.4%	17.8%	0.4%	0.2%	29.6%	10.3%	15.0%	0.7%	0.0%
R-07	1.6%	0.0%	4.9%	1.6%	0.0%	0.0%	0.0%	26.3%	3.5%	0.4%	49.8%	0.5%	36.6%	0.1%	0.0%	0.0%	29.1%	3.7%	7.4%	0.0%	0.0%
R-08	7.5%	0.5%	7.7%	6.1%	0.5%	0.1%	0.0%	13.7%	13.6%	15.9%	5.2%	20.5%	2.8%	24.8%	6.8%	1.2%	4.7%	1.5%	2.2%	3.2%	0.1%
R-09	26.9%	3.4%	25.1%	21.5%	4.9%	0.2%	0.1%	20.5%	22.3%	28.3%	11.9%	22.6%	14.5%	15.8%	20.4%	20.8%	16.4%	7.5%	11.6%	26.0%	11.4%
R-10a	27.7%	6.0%	27.9%	25.2%	6.3%	0.4%	0.1%	23.8%	25.3%	30.8%	12.0%	23.1%	8.8%	11.6%	9.0%	9.2%	9.2%	4.1%	6.7%	11.5%	7.5%
R-11	34.7%	2.5%	34.7%	31.5%	2.4%	0.2%	0.1%	31.3%	34.1%	40.7%	16.4%	47.3%	3.3%	15.2%	3.6%	0.7%	2.7%	0.6%	0.9%	1.4%	0.0%
R-12	**67.9%**	25.2%	**66.1%**	**63.8%**	27.3%	1.6%	0.1%	**62.5%**	**62.7%**	**64.1%**	41.2%	**53.9%**	20.7%	40.6%	30.1%	17.6%	20.6%	9.9%	14.6%	18.5%	3.9%
R-13	39.2%	16.1%	35.2%	33.8%	17.9%	0.8%	0.1%	28.2%	30.4%	38.8%	12.6%	22.1%	1.6%	3.8%	2.2%	0.6%	0.5%	0.2%	0.5%	0.9%	0.0%
R-14	36.0%	0.0%	41.3%	31.5%	0.0%	0.0%	0.0%	**65.0%**	40.4%	7.6%	36.8%	0.4%	7.7%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
R-15	**71.4%**	3.4%	**69.7%**	**68.0%**	1.7%	0.2%	0.1%	**69.1%**	**69.2%**	**66.7%**	46.9%	29.5%	12.3%	2.2%	0.1%	0.0%	1.3%	0.3%	0.2%	0.1%	0.0%
R-16	8.1%	1.6%	7.6%	8.8%	1.6%	0.1%	0.1%	6.8%	6.9%	9.2%	4.4%	6.5%	1.7%	2.4%	1.8%	1.3%	1.2%	0.8%	1.7%	1.6%	1.3%
R-17	**71.3%**	0.4%	**65.3%**	**70.0%**	0.0%	0.0%	0.0%	13.0%	3.8%	0.9%	3.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-18	41.2%	0.0%	**71.3%**	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-19	9.6%	31.2%	4.1%	2.9%	2.5%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-20	9.8%	34.3%	5.3%	4.4%	33.2%	10.6%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-21	0.7%	21.2%	0.5%	0.3%	15.1%	11.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-22	6.2%	24.5%	4.3%	3.6%	19.3%	10.5%	0.5%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
R-23	16.8%	34.9%	11.5%	9.0%	32.2%	8.2%	0.5%	1.3%	0.8%	0.9%	0.0%	0.3%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%
R-24	0.1%	0.0%	0.4%	0.2%	0.0%	0.0%	0.0%	1.3%	0.6%	0.5%	1.4%	0.9%	2.9%	4.9%	1.7%	0.3%	7.6%	1.2%	3.4%	27.4%	0.0%
R-25	13.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-26	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-27	0.5%	37.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-28	**63.2%**	4.6%	**61.4%**	**60.4%**	2.6%	0.2%	0.1%	**57.7%**	**59.1%**	**64.2%**	35.2%	**53.1%**	5.5%	8.1%	0.5%	0.1%	2.2%	0.3%	0.5%	0.2%	0.0%
R-31	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-32	0.6%	25.1%	0.6%	0.2%	10.9%	10.1%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-33	**69.1%**	0.3%	**69.8%**	**65.5%**	0.2%	0.1%	0.0%	**71.2%**	**69.9%**	**60.8%**	45.5%	9.1%	7.4%	0.4%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%
R-34	8.9%	11.8%	6.4%	4.3%	21.1%	0.2%	0.0%	1.0%	0.9%	0.9%	0.1%	0.6%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%
R-35	7.4%	1.1%	8.4%	7.0%	1.2%	0.0%	0.0%	6.5%	8.4%	14.5%	3.5%	16.9%	1.4%	7.9%	6.1%	0.3%	1.6%	0.9%	1.3%	1.5%	0.0%
TW-1	0.0%	0.0%	0.2%	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.3%	0.2%	0.2%	0.1%	0.3%	0.4%	0.8%	0.2%	0.1%	0.1%	1.0%	17.4%
TW-2	3.3%	0.0%	7.1%	3.3%	0.0%	0.0%	0.0%	26.6%	9.2%	3.7%	48.9%	6.0%	36.4%	3.2%	0.0%	0.0%	40.2%	23.0%	30.2%	0.1%	0.0%
TW-3	15.8%	0.4%	18.5%	16.4%	0.4%	0.1%	0.0%	37.5%	34.4%	28.7%	30.8%	33.3%	17.4%	38.1%	3.6%	1.4%	20.9%	7.3%	12.0%	3.8%	0.1%
TW-4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
TW-8	**55.9%**	0.1%	**63.0%**	**51.7%**	0.0%	0.0%	0.0%	**72.3%**	**70.6%**	38.3%	**56.0%**	5.6%	15.0%	0.1%	0.0%	0.0%	0.4%	0.1%	0.0%	0.0%	0.0%

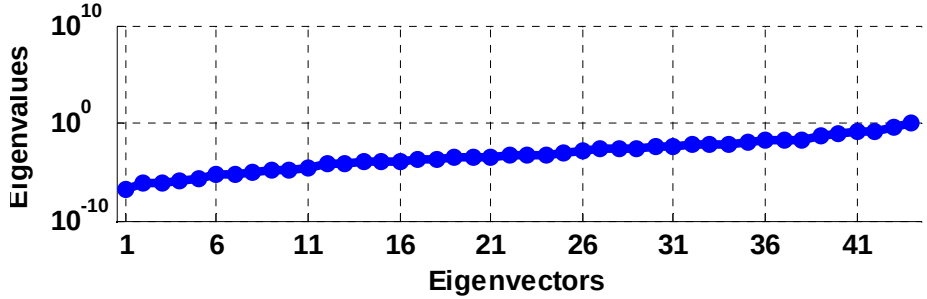
Principle-component analysis

Analyzed is a covariance matrix representing the relationships between probabilities of individual monitoring wells to provide protection of water-supply wells from various sources

Some of the wells demonstrate unique and important detection capabilities (blue arrows)

Some of the wells demonstrate redundant and unimportant detection capabilities (red arrows)





Conclusions

- conceptual uncertainties have major impact on our results; the most important are dilution at the water-supply wells and size of capture zones
- uncertainties in the temporal variability of source strength seem to be irrelevant; no further characterization might be needed
- existing monitoring network appears to be effective for 15% (3) of the sources and 14% (1) of the water-supply wells regardless of source, conceptual and parametric uncertainties; no further characterization might be needed for about 75% (109 from 144) of the pathways
- about 25% of the monitoring wells are not detecting plumes or are redundant
- annual and quarterly sampling at monitoring wells produce similar results in terms of protection
- risk-based decision-support analysis can help prioritize site activities regardless of the stage of characterization

Contact

Velimir V Vesselinov
vvv@lanl.gov

http://www.ees.lanl.gov/staff/monty

Unit-mass sources

- unit-mass sources allow us to estimate the total contaminant mass at the source required to cause unacceptable concentrations (exceedance MCL's and HI) at the compliance points
- applied set of unit-mass sources allows us to estimate how well we might need to characterize the temporal variability of the source strengths of each source
- comparing results obtained using different source types we can contemplate what characteristics of the contaminant detection/capturing are impacting our results:
  - first arrival time
  - peak arrival time
  - late-time tails
  - total mass

“No further characterization” examples

- **No further characterization needed if:**
  - **High uncertainty in the source mass and its temporal variability … but even the worst-case scenarios cannot produce unacceptable levels of contamination at the points of compliance**
  - **High uncertainty in the predicted contaminant travel times … but an efficient monitoring network provides sufficient early warning time to apply remedies before contaminants can reach the points of compliance**
  - **Pump-and-treat at the wellheads is the only possible remedial option**

Probability of network efficiency (Model 2; high dilution)

Source	O-1	O-4	PM-1	PM-2	PM-3	PM-4	PM-5	Offsite	Springs
cdv	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	99.1%	**80.6%**	99.3%
wat	100.0%	100.0%	100.0%	96.9%	100.0%	99.8%	100.0%	**77.0%**	**81.9%**
paj1	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**91.1%**	99.9%
paj2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**88.5%**	**91.4%**	99.9%
paj3	100.0%	100.0%	96.5%	**11.5%**	97.5%	**94.9%**	100.0%	**30.4%**	**65.8%**
paj4	100.0%	100.0%	100.0%	**85.4%**	100.0%	99.8%	100.0%	**7.0%**	96.5%
mdag	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	95.9%	99.4%
mor1	100.0%	100.0%	99.7%	100.0%	100.0%	100.0%	**41.2%**	**89.0%**	99.5%
mor2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**93.9%**	96.0%	100.0%
mor3	99.8%	99.9%	99.7%	100.0%	99.5%	99.7%	100.0%	**89.1%**	99.5%
san1	100.0%	99.2%	99.9%	100.0%	99.8%	100.0%	**57.0%**	**71.4%**	96.1%
san2	100.0%	**59.9%**	100.0%	100.0%	97.5%	100.0%	100.0%	**69.5%**	96.1%
lac1	98.8%	99.8%	99.7%	100.0%	99.9%	100.0%	**94.7%**	**61.6%**	**92.2%**
lac2	100.0%	**85.2%**	100.0%	100.0%	100.0%	100.0%	100.0%	**32.1%**	**79.8%**
lac3	99.2%	100.0%	96.1%	100.0%	**65.5%**	100.0%	100.0%	**65.1%**	**93.0%**
lac4	97.1%	100.0%	**89.0%**	100.0%	95.9%	100.0%	100.0%	**74.9%**	95.1%
dp	99.6%	**75.5%**	100.0%	100.0%	99.8%	100.0%	100.0%	**46.1%**	**86.3%**
pue1	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**64.7%**	**94.1%**
pue2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**75.1%**	98.1%
pue3	**89.4%**	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	**70.2%**	**92.1%**
pue4	**43.7%**	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**12.6%**	**29.8%**
all	96.5%	96.2%	99.1%	**94.9%**	97.9%	99.7%	**94.0%**	**66.2%**	**90.2%**

Probability of network efficiency (Model 3; high dilution)

Source	O-1	O-4	PM-1	PM-2	PM-3	PM-4	PM-5	Offsite	Springs
cdv	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	**58.2%**	**91.2%**
wat	100.0%	100.0%	100.0%	99.2%	100.0%	99.9%	100.0%	**60.8%**	**81.0%**
paj1	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**67.5%**	**93.3%**
paj2	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	96.8%	**66.2%**	**93.8%**
paj3	100.0%	100.0%	100.0%	**4.0%**	100.0%	99.0%	100.0%	**1.6%**	**67.0%**
paj4	100.0%	100.0%	100.0%	100.0%	100.0%	99.7%	100.0%	**30.7%**	**92.1%**
mdag	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	95.7%	99.4%
mor1	100.0%	99.9%	99.9%	100.0%	100.0%	100.0%	100.0%	**76.4%**	96.1%
mor2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**86.7%**	98.7%
mor3	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**62.0%**	**89.5%**
san1	100.0%	99.8%	100.0%	100.0%	100.0%	100.0%	99.2%	**58.7%**	**89.8%**
san2	100.0%	**86.1%**	99.7%	100.0%	97.8%	100.0%	100.0%	**56.2%**	**88.6%**
lac1	99.9%	100.0%	99.9%	100.0%	99.9%	100.0%	99.9%	**52.8%**	**88.6%**
lac2	100.0%	**93.7%**	100.0%	100.0%	99.6%	100.0%	100.0%	**32.8%**	**79.4%**
lac3	99.9%	100.0%	98.9%	100.0%	**76.0%**	100.0%	100.0%	**51.0%**	**83.7%**
lac4	97.3%	100.0%	**93.2%**	100.0%	98.9%	100.0%	100.0%	**51.2%**	**83.4%**
dp	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	**38.6%**	**81.5%**
pue1	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**57.7%**	**89.0%**
pue2	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**59.4%**	**92.9%**
pue3	98.8%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%	**68.7%**	**91.9%**
pue4	98.5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**5.3%**	**29.3%**

Probabilities monitoring wells to provide protection of the water-supply wells (Model 3; high dilution case)

Well	cdv	wat	paj1	paj2	paj3	paj4	mdag	mor1	mor2	mor3	san1	san2	lac1	lac2	lac3	lac4	dp	pue1	pue2	pue3	pue4
CdV-16-3i	**56.8%**	0.0%	25.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CdV-R-15-3	**66.7%**	1.2%	36.5%	17.1%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CdV-R-37-2	7.2%	2.1%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-05	0.4%	26.7%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-09	0.1%	8.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-10	0.5%	31.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-01	**57.8%**	0.0%	**64.0%**	**52.9%**	0.0%	0.0%	0.0%	**72.3%**	**70.6%**	36.7%	**56.8%**	5.0%	17.4%	0.2%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%
R-02	0.2%	0.0%	0.8%	0.5%	0.0%	0.0%	0.0%	5.8%	0.4%	0.0%	20.6%	0.1%	26.2%	0.0%	0.0%	0.0%	7.3%	23.5%	11.5%	0.0%	0.0%
R-03	19.6%	2.5%	19.9%	16.1%	3.6%	0.1%	0.1%	20.3%	19.2%	20.7%	12.5%	19.2%	17.6%	21.4%	28.7%	27.5%	21.9%	9.1%	14.5%	34.4%	16.4%
R-04	27.2%	0.4%	31.8%	25.1%	0.6%	0.1%	0.1%	**56.4%**	**50.7%**	40.8%	48.0%	43.6%	35.8%	48.9%	8.7%	2.6%	39.7%	23.5%	29.9%	12.8%	0.1%
R-05	26.5%	2.5%	25.7%	22.3%	3.5%	0.2%	0.1%	36.4%	33.1%	32.8%	30.9%	32.8%	30.7%	41.8%	42.6%	33.5%	36.4%	19.8%	26.4%	40.0%	9.8%
R-06	15.5%	0.1%	21.1%	14.2%	0.2%	0.1%	0.1%	**55.1%**	45.5%	32.3%	48.9%	39.1%	33.9%	30.9%	0.6%	0.3%	39.6%	17.8%	25.9%	1.5%	0.0%
R-07	1.7%	0.0%	5.1%	1.6%	0.0%	0.0%	0.0%	29.8%	4.1%	0.4%	**51.6%**	0.5%	36.7%	0.1%	0.0%	0.0%	30.2%	3.9%	7.7%	0.0%	0.0%
R-08	15.5%	1.9%	17.1%	14.2%	2.2%	0.1%	0.0%	27.1%	26.3%	29.8%	11.2%	38.0%	8.8%	37.6%	17.5%	3.6%	12.2%	4.8%	6.5%	8.5%	0.3%
R-09	29.6%	3.7%	28.6%	23.5%	5.6%	0.2%	0.1%	23.3%	25.0%	31.1%	12.3%	25.3%	15.0%	17.1%	22.7%	21.7%	17.0%	7.7%	11.9%	27.2%	11.6%
R-10a	**57.1%**	17.0%	**57.3%**	**52.9%**	18.0%	1.2%	0.2%	**53.5%**	**53.1%**	**54.6%**	33.8%	44.6%	24.5%	29.8%	19.8%	12.9%	22.4%	13.0%	18.8%	19.9%	10.9%
R-11	**57.0%**	7.0%	**57.8%**	**52.6%**	6.7%	0.2%	0.1%	**53.8%**	**55.5%**	**61.0%**	25.9%	**58.6%**	6.8%	28.1%	10.7%	2.1%	6.0%	1.6%	2.3%	5.0%	0.1%
R-12	**68.6%**	27.1%	**67.2%**	**64.6%**	31.4%	1.7%	0.1%	**63.3%**	**63.2%**	**64.4%**	41.7%	**54.1%**	21.0%	41.1%	30.9%	17.8%	20.9%	10.0%	14.8%	18.8%	4.0%
R-13	**63.7%**	29.4%	**61.2%**	**57.4%**	32.4%	1.6%	0.1%	**52.4%**	**53.6%**	**58.7%**	25.9%	41.9%	5.9%	12.2%	8.2%	2.2%	3.1%	0.9%	1.8%	3.6%	0.1%
R-14	**55.4%**	0.0%	**62.3%**	**51.0%**	0.0%	0.0%	0.0%	**72.3%**	**59.6%**	18.1%	**51.3%**	0.9%	13.1%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%
R-15	**74.3%**	3.9%	**72.6%**	**70.0%**	2.1%	0.2%	0.1%	**70.9%**	**70.5%**	**67.4%**	49.1%	34.4%	13.0%	2.6%	0.1%	0.0%	1.5%	0.3%	0.2%	0.1%	0.0%
R-16	16.0%	2.2%	15.5%	15.9%	2.8%	0.2%	0.1%	13.8%	13.1%	14.8%	6.4%	11.4%	2.8%	3.8%	3.6%	2.0%	2.1%	1.0%	2.2%	2.6%	1.8%
R-17	**75.1%**	0.6%	**72.8%**	**70.5%**	0.0%	0.0%	0.0%	23.3%	7.7%	1.1%	6.3%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-18	**64.6%**	0.0%	**72.9%**	0.3%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-19	23.0%	39.6%	13.2%	10.0%	5.1%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-20	20.4%	38.3%	11.9%	10.0%	40.9%	11.5%	0.2%	0.1%	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-21	11.7%	37.1%	7.5%	5.6%	37.5%	11.7%	0.5%	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-22	15.4%	37.3%	11.7%	8.7%	38.0%	11.4%	0.5%	0.9%	1.1%	0.4%	0.3%	0.5%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
R-23	19.8%	37.2%	13.3%	10.0%	39.5%	8.3%	0.5%	1.8%	1.0%	0.9%	0.1%	0.4%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%
R-24	15.4%	0.8%	17.4%	14.1%	0.7%	0.1%	0.1%	39.9%	35.1%	25.0%	34.2%	32.8%	33.3%	42.7%	32.7%	13.6%	38.0%	22.1%	28.4%	38.7%	1.5%
R-25	**73.4%**	0.0%	32.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-26	2.5%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-27	2.2%	40.4%	0.4%	0.4%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-28	**70.7%**	5.4%	**70.0%**	**67.2%**	3.6%	0.2%	0.1%	**65.0%**	**66.0%**	**67.3%**	38.6%	**57.0%**	6.1%	9.6%	0.9%	0.2%	2.7%	0.3%	0.5%	0.4%	0.0%
R-31	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-32	5.1%	37.9%	3.3%	2.6%	26.3%	11.6%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-33	**70.9%**	0.3%	**71.7%**	**67.2%**	0.2%	0.1%	0.0%	**71.9%**	**70.6%**	**62.1%**	45.9%	9.7%	7.5%	0.4%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%
R-34	11.2%	14.3%	7.9%	5.3%	26.5%	0.2%	0.1%	1.2%	1.0%	1.1%	0.1%	0.6%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%
R-35	**63.1%**	15.5%	**63.3%**	**58.6%**	17.0%	0.4%	0.1%	**59.0%**	**58.7%**	**62.4%**	34.5%	**57.0%**	17.4%	48.2%	41.1%	6.9%	19.4%	8.2%	12.4%	15.8%	0.8%
TW-1	21.8%	3.7%	19.9%	17.0%	4.6%	0.1%	0.1%	17.9%	18.9%	23.2%	8.0%	19.4%	8.2%	11.2%	15.3%	15.4%	10.8%	4.5%	7.7%	23.3%	26.9%
TW-2	5.0%	0.0%	11.0%	4.8%	0.0%	0.0%	0.0%	40.0%	15.7%	6.0%	**54.1%**	10.4%	36.8%	4.8%	0.1%	0.0%	40.3%	23.6%	30.2%	0.2%	0.0%
TW-3	33.1%	0.8%	38.0%	32.0%	1.0%	0.1%	0.1%	**62.8%**	**58.6%**	**50.3%**	44.9%	**52.1%**	25.2%	49.8%	7.0%	2.8%	31.4%	11.1%	17.8%	7.5%	0.1%
TW-4	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	1.0%	0.1%	0.0%	4.5%	0.0%	5.9%	0.0%	0.0%	0.0%	0.5%	16.4%	0.4%	0.0%	0.0%
TW-8	**57.5%**	0.1%	**65.0%**	**53.1%**	0.0%	0.0%	0.0%	**72.3%**	**70.6%**	39.8%	**56.3%**	5.7%	15.1%	0.1%	0.0%	0.0%	0.4%	0.1%	0.0%	0.0%	0.0%

Probabilities monitoring wells to provide protection against offsite releases (Model 3)

Well	cdv	wat	paj1	paj2	paj3	paj4	mdag	mor1	mor2	mor3	san1	san2	lac1	lac2	lac3	lac4	dp	pue1	pue2	pue3	pue4
CdV-16-3i	9.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CdV-R-15-3	17.2%	0.0%	7.8%	1.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CdV-R-37-2	2.4%	0.1%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-05	0.2%	14.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-09	0.1%	6.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-10	0.3%	22.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-01	**55.3%**	0.0%	**61.0%**	**50.2%**	0.0%	0.0%	0.0%	**72.3%**	**70.6%**	34.3%	**56.1%**	4.8%	17.0%	0.2%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%
R-02	0.2%	0.0%	0.8%	0.5%	0.0%	0.0%	0.0%	5.5%	0.4%	0.0%	20.0%	0.1%	25.5%	0.0%	0.0%	0.0%	6.8%	23.5%	11.1%	0.0%	0.0%
R-03	1.3%	0.3%	1.1%	0.9%	0.3%	0.0%	0.0%	1.8%	1.9%	1.8%	1.7%	2.1%	2.0%	2.8%	5.5%	8.0%	3.0%	0.9%	1.7%	10.9%	5.9%
R-04	12.2%	0.0%	15.4%	11.5%	0.2%	0.0%	0.0%	37.6%	31.7%	24.8%	33.0%	28.2%	28.8%	42.2%	4.5%	1.5%	39.0%	18.3%	25.4%	7.2%	0.1%
R-05	14.0%	1.0%	13.1%	11.6%	1.8%	0.1%	0.1%	21.1%	18.6%	17.8%	20.5%	19.4%	22.4%	29.8%	39.0%	32.6%	28.7%	14.5%	20.0%	40.0%	7.0%
R-06	6.3%	0.0%	10.2%	7.4%	0.1%	0.0%	0.0%	30.5%	24.9%	18.8%	28.4%	20.3%	19.4%	17.8%	0.4%	0.2%	29.6%	10.3%	15.0%	0.7%	0.0%
R-07	1.6%	0.0%	4.9%	1.6%	0.0%	0.0%	0.0%	26.3%	3.5%	0.4%	49.8%	0.5%	36.6%	0.1%	0.0%	0.0%	29.1%	3.7%	7.4%	0.0%	0.0%
R-08	7.5%	0.5%	7.7%	6.1%	0.5%	0.1%	0.0%	13.7%	13.6%	15.9%	5.2%	20.5%	2.8%	24.8%	6.8%	1.2%	4.7%	1.5%	2.2%	3.2%	0.1%
R-09	26.9%	3.4%	25.1%	21.5%	4.9%	0.2%	0.1%	20.5%	22.3%	28.3%	11.9%	22.6%	14.5%	15.8%	20.4%	20.8%	16.4%	7.5%	11.6%	26.0%	11.4%
R-10a	27.7%	6.0%	27.9%	25.2%	6.3%	0.4%	0.1%	23.8%	25.3%	30.8%	12.0%	23.1%	8.8%	11.6%	9.0%	9.2%	9.2%	4.1%	6.7%	11.5%	7.5%
R-11	34.7%	2.5%	34.7%	31.5%	2.4%	0.2%	0.1%	31.3%	34.1%	40.7%	16.4%	47.3%	3.3%	15.2%	3.6%	0.7%	2.7%	0.6%	0.9%	1.4%	0.0%
R-12	**67.9%**	25.2%	**66.1%**	**63.8%**	27.3%	1.6%	0.1%	**62.5%**	**62.7%**	**64.1%**	41.2%	**53.9%**	20.7%	40.6%	30.1%	17.6%	20.6%	9.9%	14.6%	18.5%	3.9%
R-13	39.2%	16.1%	35.2%	33.8%	17.9%	0.8%	0.1%	28.2%	30.4%	38.8%	12.6%	22.1%	1.6%	3.8%	2.2%	0.6%	0.5%	0.2%	0.5%	0.9%	0.0%
R-14	36.0%	0.0%	41.3%	31.5%	0.0%	0.0%	0.0%	**65.0%**	40.4%	7.6%	36.8%	0.4%	7.7%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
R-15	**71.4%**	3.4%	**69.7%**	**68.0%**	1.7%	0.2%	0.1%	**69.1%**	**69.2%**	**66.7%**	46.9%	29.5%	12.3%	2.2%	0.1%	0.0%	1.3%	0.3%	0.2%	0.1%	0.0%
R-16	8.1%	1.6%	7.6%	8.8%	1.6%	0.1%	0.1%	6.8%	6.9%	9.2%	4.4%	6.5%	1.7%	2.4%	1.8%	1.3%	1.2%	0.8%	1.7%	1.6%	1.3%
R-17	**71.3%**	0.4%	**65.3%**	**70.0%**	0.0%	0.0%	0.0%	13.0%	3.8%	0.9%	3.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-18	41.2%	0.0%	**71.3%**	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-19	9.6%	31.2%	4.1%	2.9%	2.5%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-20	9.8%	34.3%	5.3%	4.4%	33.2%	10.6%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-21	0.7%	21.2%	0.5%	0.3%	15.1%	11.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-22	6.2%	24.5%	4.3%	3.6%	19.3%	10.5%	0.5%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
R-23	16.8%	34.9%	11.5%	9.0%	32.2%	8.2%	0.5%	1.3%	0.8%	0.9%	0.0%	0.3%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%
R-24	0.1%	0.0%	0.4%	0.2%	0.0%	0.0%	0.0%	1.3%	0.6%	0.5%	1.4%	0.9%	2.9%	4.9%	1.7%	0.3%	7.6%	1.2%	3.4%	27.4%	0.0%
R-25	13.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-26	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-27	0.5%	37.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-28	**63.2%**	4.6%	**61.4%**	**60.4%**	2.6%	0.2%	0.1%	**57.7%**	**59.1%**	**64.2%**	35.2%	**53.1%**	5.5%	8.1%	0.5%	0.1%	2.2%	0.3%	0.5%	0.2%	0.0%
R-31	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-32	0.6%	25.1%	0.6%	0.2%	10.9%	10.1%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-33	**69.1%**	0.3%	**69.8%**	**65.5%**	0.2%	0.1%	0.0%	**71.2%**	**69.9%**	**60.8%**	45.5%	9.1%	7.4%	0.4%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%
R-34	8.9%	11.8%	6.4%	4.3%	21.1%	0.2%	0.0%	1.0%	0.9%	0.9%	0.1%	0.6%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%
R-35	7.4%	1.1%	8.4%	7.0%	1.2%	0.0%	0.0%	6.5%	8.4%	14.5%	3.5%	16.9%	1.4%	7.9%	6.1%	0.3%	1.6%	0.9%	1.3%	1.5%	0.0%
TW-1	0.0%	0.0%	0.2%	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.3%	0.2%	0.2%	0.1%	0.3%	0.4%	0.8%	0.2%	0.1%	0.1%	1.0%	17.4%
TW-2	3.3%	0.0%	7.1%	3.3%	0.0%	0.0%	0.0%	26.6%	9.2%	3.7%	48.9%	6.0%	36.4%	3.2%	0.0%	0.0%	40.2%	23.0%	30.2%	0.1%	0.0%
TW-3	15.8%	0.4%	18.5%	16.4%	0.4%	0.1%	0.0%	37.5%	34.4%	28.7%	30.8%	33.3%	17.4%	38.1%	3.6%	1.4%	20.9%	7.3%	12.0%	3.8%	0.1%
TW-4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
TW-8	**55.9%**	0.1%	**63.0%**	**51.7%**	0.0%	0.0%	0.0%	**72.3%**	**70.6%**	38.3%	**56.0%**	5.6%	15.0%	0.1%	0.0%	0.0%	0.4%	0.1%	0.0%	0.0%	0.0%

Probabilities monitoring wells to provide protection of the White-Rock Canyon springs (Model 3)

Well	cdv	wat	paj1	paj2	paj3	paj4	mdag	mor1	mor2	mor3	san1	san2	lac1	lac2	lac3	lac4	dp	pue1	pue2	pue3	pue4
CdV-16-3i	2.2%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CdV-R-15-3	3.8%	0.0%	2.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CdV-R-37-2	0.5%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-05	0.1%	7.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-09	0.0%	4.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DT-10	0.1%	15.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-01	21.3%	0.0%	24.3%	19.5%	0.0%	0.0%	0.0%	**33.0%**	**33.9%**	20.4%	19.4%	5.6%	7.6%	0.3%	0.0%	0.0%	0.3%	0.0%	0.1%	0.1%	0.0%
R-02	0.0%	0.0%	0.3%	0.2%	0.0%	0.0%	0.0%	3.4%	0.6%	0.1%	6.3%	0.0%	10.5%	0.0%	0.0%	0.0%	5.5%	15.0%	5.5%	0.0%	0.0%
R-03	0.2%	0.1%	0.2%	0.2%	0.1%	0.0%	0.0%	0.4%	0.3%	0.4%	0.2%	0.5%	0.3%	0.6%	0.9%	2.3%	0.5%	0.1%	0.3%	3.1%	4.0%
R-04	6.0%	0.5%	7.0%	6.0%	0.6%	0.0%	0.0%	14.2%	11.4%	10.4%	9.2%	15.0%	9.9%	21.1%	6.6%	4.3%	22.5%	6.6%	10.0%	8.8%	0.4%
R-05	10.4%	1.5%	11.4%	9.9%	2.7%	0.0%	0.0%	15.7%	14.3%	15.0%	10.8%	17.6%	11.5%	18.8%	29.7%	**35.7%**	18.3%	9.1%	11.9%	**40.7%**	18.4%
R-06	3.0%	0.1%	3.9%	3.0%	0.1%	0.0%	0.0%	8.5%	6.4%	5.4%	5.7%	7.2%	4.2%	6.4%	1.5%	0.8%	10.4%	2.4%	3.5%	2.3%	0.1%
R-07	1.4%	0.0%	2.9%	1.3%	0.0%	0.0%	0.0%	14.5%	5.6%	0.8%	15.8%	0.8%	15.9%	0.4%	0.0%	0.0%	16.7%	1.8%	3.5%	0.1%	0.0%
R-08	4.0%	0.2%	4.2%	3.4%	0.1%	0.0%	0.0%	7.1%	7.2%	8.1%	2.0%	12.0%	1.1%	11.8%	3.8%	0.6%	3.7%	0.5%	0.9%	2.9%	0.1%
R-09	15.8%	4.2%	16.0%	14.7%	7.9%	0.2%	0.1%	17.7%	18.0%	21.1%	9.6%	22.4%	12.2%	20.3%	27.2%	**33.0%**	19.8%	8.4%	13.0%	**31.8%**	**34.8%**
R-10a	8.0%	3.8%	7.8%	6.6%	5.6%	0.5%	0.3%	7.8%	8.5%	10.7%	3.0%	10.7%	2.3%	5.8%	8.8%	12.7%	4.1%	1.5%	2.1%	10.5%	15.7%
R-11	12.2%	1.3%	12.5%	11.6%	1.5%	0.1%	0.1%	12.8%	14.1%	16.9%	7.3%	24.7%	2.1%	11.9%	4.3%	1.0%	3.2%	0.4%	0.7%	2.2%	0.1%
R-12	**30.0%**	21.7%	**30.2%**	28.5%	28.8%	2.8%	0.2%	**31.4%**	**32.3%**	**36.9%**	18.7%	**37.6%**	13.6%	28.7%	**34.4%**	**36.2%**	21.7%	9.5%	13.8%	**34.8%**	24.3%
R-13	12.5%	7.0%	12.5%	11.6%	11.3%	0.4%	0.1%	11.7%	12.9%	15.9%	5.4%	13.1%	0.9%	3.2%	2.1%	1.4%	1.0%	0.1%	0.2%	1.0%	0.0%
R-14	10.7%	0.0%	13.0%	9.5%	0.0%	0.0%	0.0%	24.8%	13.2%	4.6%	10.2%	0.6%	3.2%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%
R-15	26.7%	2.2%	28.2%	26.2%	1.4%	0.1%	0.1%	28.7%	**30.5%**	**35.5%**	15.4%	19.1%	6.0%	2.8%	0.1%	0.1%	1.0%	0.1%	0.2%	0.3%	0.0%
R-16	9.7%	4.9%	10.0%	9.7%	9.5%	0.9%	0.7%	10.6%	10.8%	12.9%	8.5%	12.7%	6.5%	12.7%	13.3%	13.2%	10.0%	3.4%	6.0%	13.2%	15.5%
R-17	27.8%	0.1%	25.2%	29.5%	0.0%	0.0%	0.0%	4.8%	1.8%	0.5%	1.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-18	11.3%	0.0%	**30.0%**	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-19	2.3%	18.4%	0.8%	0.4%	1.4%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-20	2.7%	25.5%	1.5%	1.0%	26.2%	18.6%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-21	0.5%	10.2%	0.2%	0.1%	8.2%	18.5%	8.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-22	2.6%	17.0%	1.6%	1.1%	13.2%	17.9%	25.9%	0.5%	0.2%	0.6%	0.0%	0.4%	0.0%	0.1%	0.0%	0.2%	0.0%	0.0%	0.0%	0.1%	0.2%
R-23	7.5%	**31.5%**	5.3%	4.0%	**31.4%**	25.8%	27.0%	1.6%	2.1%	2.7%	0.2%	1.8%	0.0%	0.5%	0.6%	1.1%	0.4%	0.1%	0.0%	1.0%	0.8%
R-24	0.4%	0.0%	0.5%	0.4%	0.0%	0.0%	0.0%	1.2%	0.8%	0.7%	0.9%	1.3%	1.5%	3.0%	1.8%	0.8%	3.6%	0.9%	1.5%	16.8%	0.1%
R-25	3.3%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-26	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-27	0.3%	28.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-28	23.7%	4.2%	24.2%	22.8%	2.8%	0.2%	0.1%	24.8%	26.0%	**31.8%**	15.0%	**31.7%**	3.9%	12.8%	1.2%	0.3%	3.3%	0.2%	0.6%	1.3%	0.0%
R-31	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-32	0.4%	13.6%	0.1%	0.0%	6.3%	14.0%	10.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R-33	27.1%	0.2%	29.0%	26.0%	0.2%	0.1%	0.0%	**31.4%**	**32.1%**	**30.9%**	17.2%	10.7%	4.7%	0.7%	0.1%	0.0%	0.3%	0.1%	0.1%	0.0%	0.0%
R-34	3.2%	10.6%	3.1%	1.6%	21.0%	0.6%	0.0%	1.4%	1.3%	2.4%	0.2%	1.3%	0.0%	0.1%	0.1%	0.2%	0.0%	0.0%	0.0%	0.5%	0.0%
R-35	3.0%	0.7%	3.2%	2.7%	0.9%	0.0%	0.0%	3.5%	3.7%	4.8%	1.8%	7.2%	1.0%	4.5%	5.8%	1.1%	1.5%	0.6%	0.7%	1.5%	0.1%
TW-1	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.2%	0.2%	0.2%	0.1%	0.2%	0.2%	0.3%	0.4%	0.6%	0.3%	0.1%	0.2%	0.7%	18.7%
TW-2	2.3%	0.0%	4.3%	2.0%	0.0%	0.0%	0.0%	10.8%	6.7%	4.0%	12.7%	5.4%	16.3%	4.3%	0.3%	0.1%	23.1%	12.0%	19.3%	1.2%	0.0%
TW-3	3.9%	0.1%	4.5%	4.2%	0.1%	0.0%	0.0%	9.4%	7.9%	6.6%	6.1%	11.1%	3.8%	13.3%	1.9%	0.5%	6.4%	1.9%	3.1%	2.2%	0.0%
TW-4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
TW-8	22.6%	0.1%	25.9%	20.9%	0.0%	0.0%	0.0%	**33.0%**	**33.9%**	22.5%	20.1%	6.9%	7.4%	0.2%	0.0%	0.0%	0.2%	0.1%	0.1%	0.1%	0.0%

Efficiency evaluation of a groundwater monitoring network using a risk-based decision-support process

Velimir V Vesselinov, Kay Birdsell, Paul Davis, Chris Echohawk

A series of contaminant sources have the potential to impact the quality of regional groundwater resources beneath the Los Alamos National Laboratory (LANL). Currently, 21 areas have been identified where contaminants could possibly reach the regional aquifer at the water table. Because the temporal variability of the contaminant mass fluxes through the vadose zone is not well defined, source strength uncertainty at the regional aquifer is represented by a series of unit-mass source functions. Uncertainties in the potential contaminant pathways within the aquifer and the breakthrough curves at the potential discharge locations (receptors), which include water-supply wells and springs, are investigated. Risk-based analyses of the performance of the existing groundwater monitoring network are carried out. The network should be capable of detecting the potential contaminant plumes before they reach (1) the receptors and/or (2) the LANL boundaries at unacceptably high concentrations. Individual monitoring boreholes are ranked based on their importance for plume detection. Suggestions regarding optimal sampling frequency for the monitoring boreholes are also made. The study utilizes a risk-based decision-support process. The goal is to facilitate the decision process by means of risk-based analyses of model predictions that incorporate current data and conceptual understandings. The most important question is whether the existing knowledge is adequate and sufficient for each particular contamination source / pathway in order to select a remedy(ies) now without any further characterization. The immediate evaluation of remedy options can help prioritize our efforts and reduce the time to completion and cost of the LANL environmental program. Our study addresses fundamental questions related to building numerical models, defining conceptual and parametric uncertainties, and interpreting uncertainty in model predictions.