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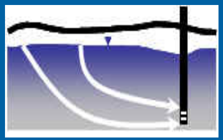
Evaluating uncertainty in areas contributing recharge to wells for water-quality network design

Jeff Starn, Hydrologist, Connecticut
National Water Quality Assessment (NAWQA)

U.S. Department of the Interior
U.S. Geological Survey



Take-home message

- "…science aims to separate the probably true from the definitely false…"[1]
- More effective monitoring networks can be developed by considering uncertainty in ground-water-flow paths

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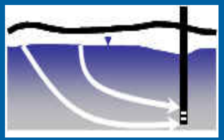
[1]Robert Lempert, EOS, v84, n30, p 285



Three sources of uncertainty that affect simulation of areas contributing recharge

- Boundary and internal flow rates, including recharge
  - Often estimated outside model
  - May vary in time, such as flows from irrigation wells
  - Not discussed in this presentation
- Heterogeneity of hydraulic conductivity
  - Briefly illustrated using 3 examples
- **Uncertainty caused by model calibration to sparse data**
  - Illustrated using a Monte Carlo model with parameter correlation
  - Main topic of this presentation

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Sources of uncertainty in 4 modeled areas

Source of uncertainty	Tampa Florida	York Nebraska	Modesto California	Woodbury Connecticut
Small-scale heterogeneity	conduit—sinkholes/ fractures	conduit—irrigation wells	hydrofacies—vertical	none simulated
Large-scale heterogeneity	layers	layers	hydrofacies—horizontal	zones

Geology	karst/ fractured rock	alluvial	alluvial	glacial/ fractured rock

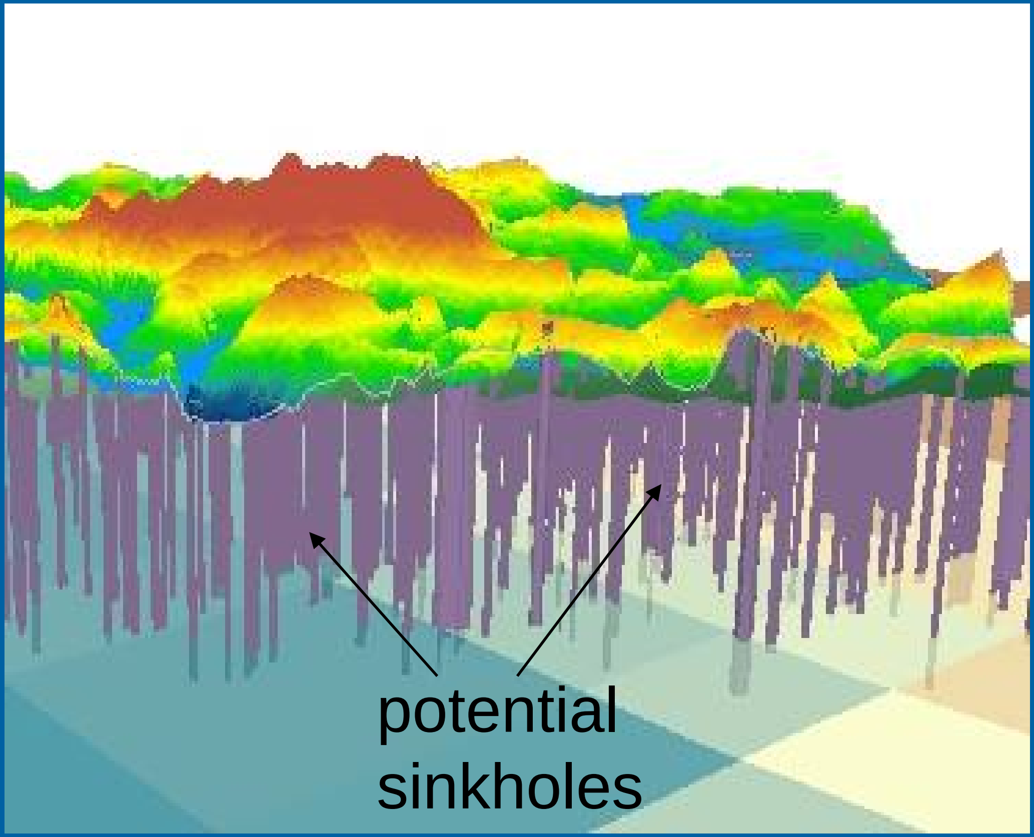
Heterogeneity in the Florida study area

Small-scale hydraulic conductivity variation

- Sinkholes that penetrate vertically
- Dissolution along fractures in a specific horizontal layer

Large-scale hydraulic conductivity variation

- Geologic layers (not shown)
- Vertical only



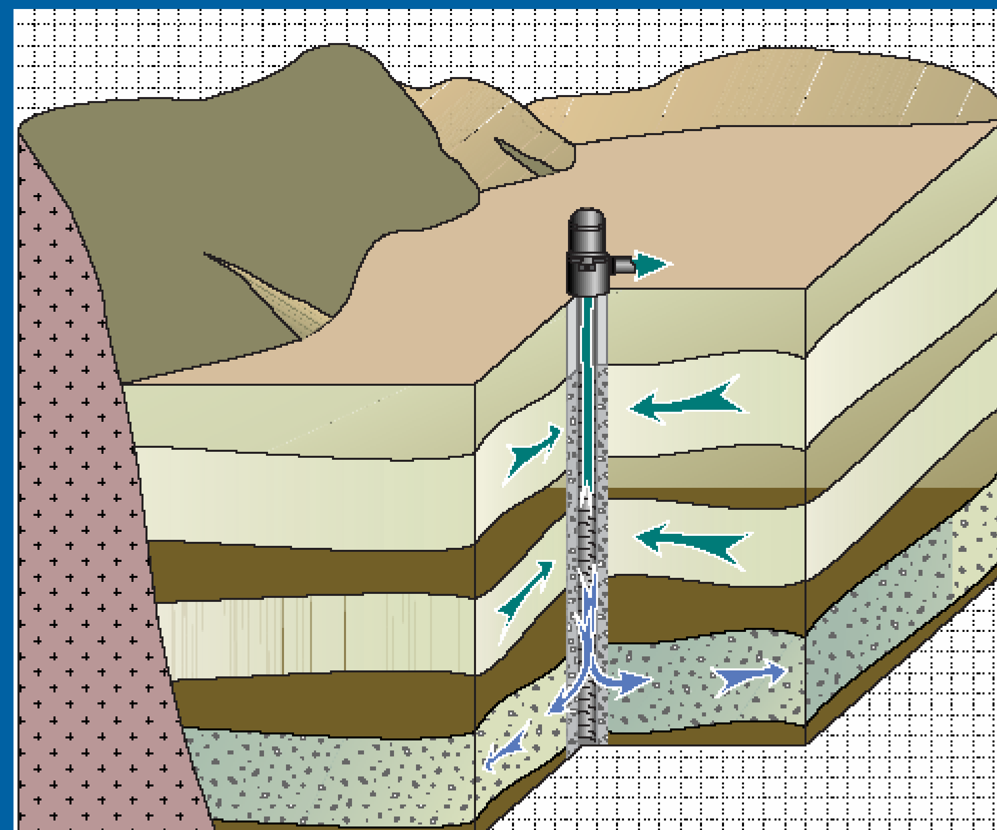
Heterogeneity in the Nebraska study area

Small-scale hydraulic conductivity variation

- Locations of wells
- Screened depths of wells
- Active or abandoned wells

Large-scale hydraulic conductivity variation

- Geologic layers
- Vertical only



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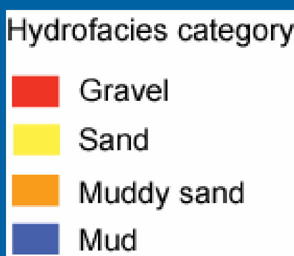
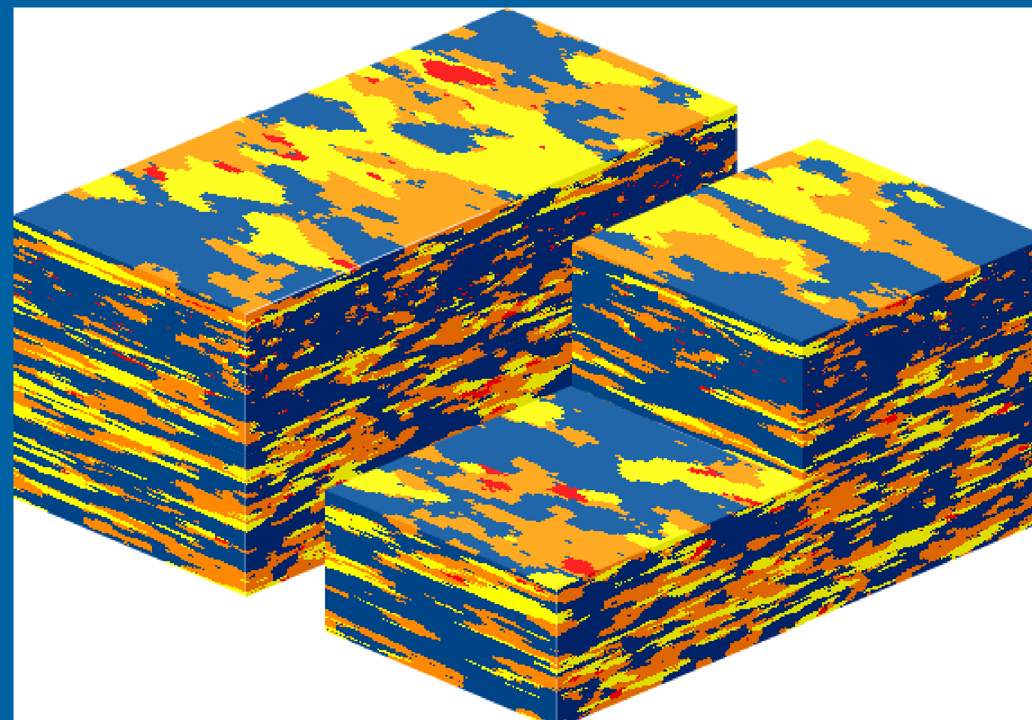
Heterogeneity in the California study area

Small-scale hydraulic conductivity variation





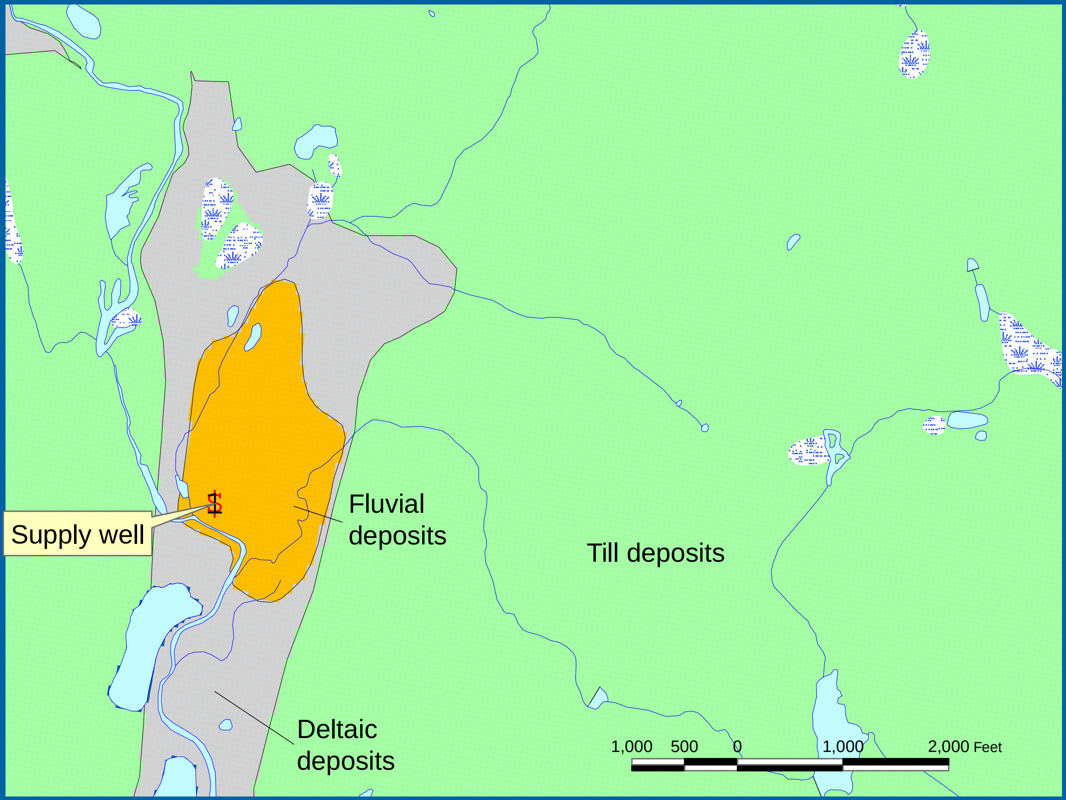
Large-scale hydraulic conductivity variation

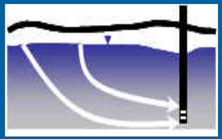
- Hydrofacies category
- Additional clay layer (not shown)

Heterogeneity in the Connecticut study area

Large-scale hydraulic conductivity variation by zone

- Fluvial
- Deltaic
- Till
- Streambed
- Basalt—underlying glacial units





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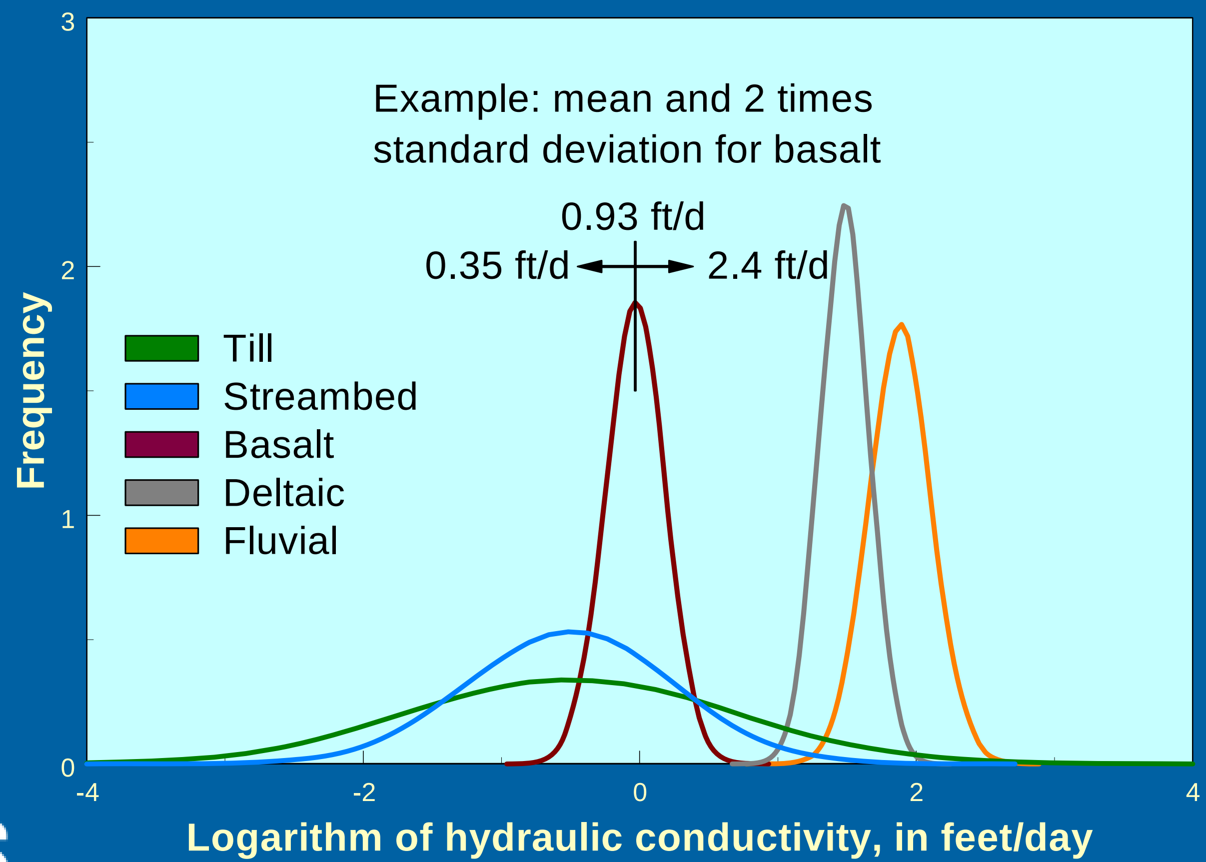
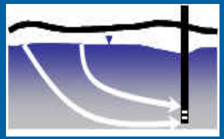
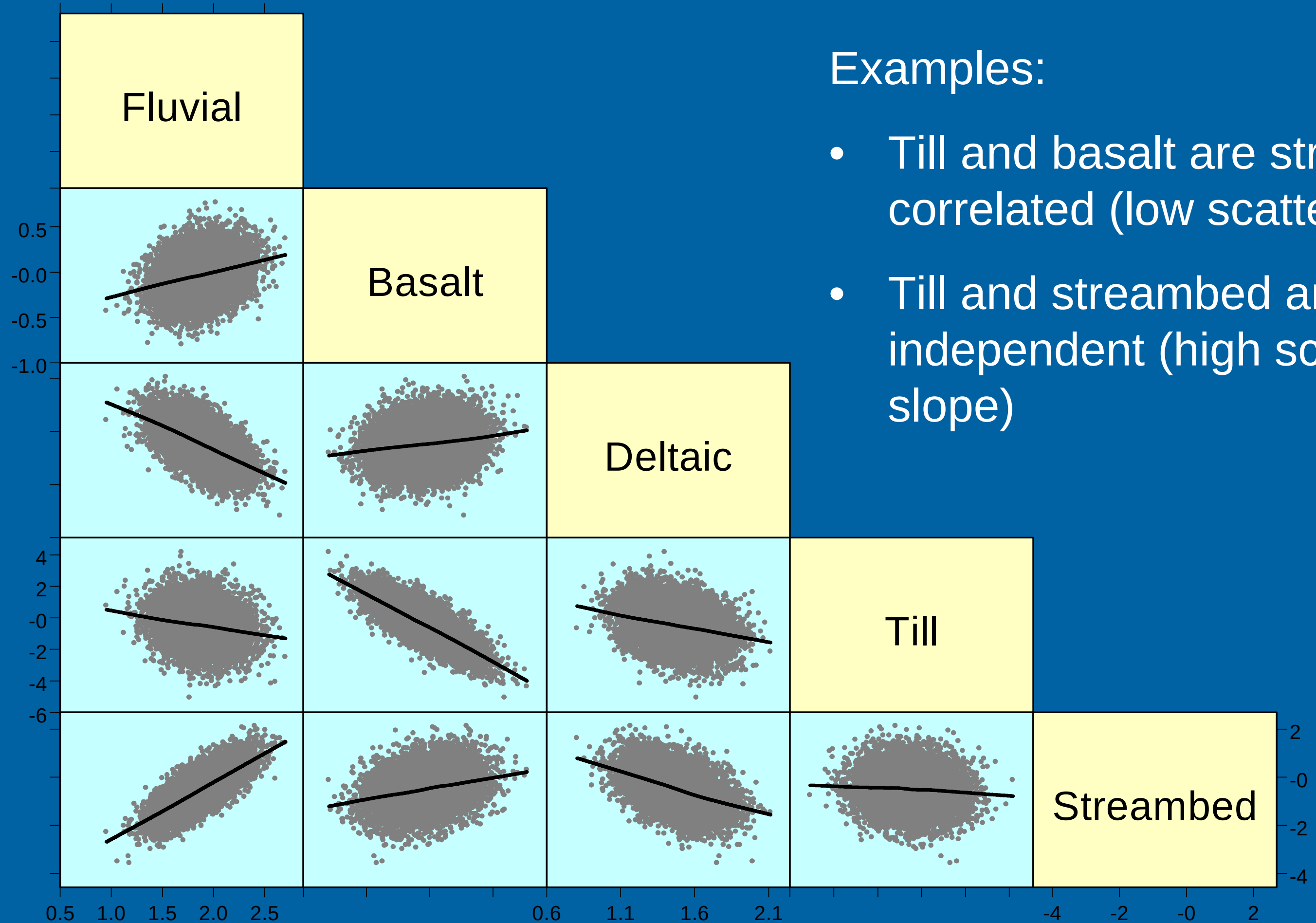
Model is used to estimate mean and standard deviation of hydraulic conductivity





Hydraulic conductivity estimates are correlated to various degrees



Examples:

- Till and basalt are strongly correlated (low scatter/high slope)
- Till and streambed are weakly independent (high scatter/low slope)

Uncertainty in hydraulic conductivity zones was assessed using a probabilistic model

- Probabilistic model did account for
  - correlation of hydraulic conductivity
  - standard deviation of hydraulic conductivity
  - large-scale heterogeneity
- But did not account for
  - small-scale heterogeneity

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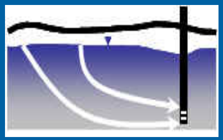

Probabilistic modeling allowed a more effective monitoring network

- A coarse model was constructed using existing data
- Predictions from the coarse model were not accurate
- A coarse probabilistic model showed that monitoring wells should be installed over a broad area
- New monitoring wells were installed
- Refined model made more accurate predictions
- Uncertainty in predictions using the refined model was less than in the coarse model

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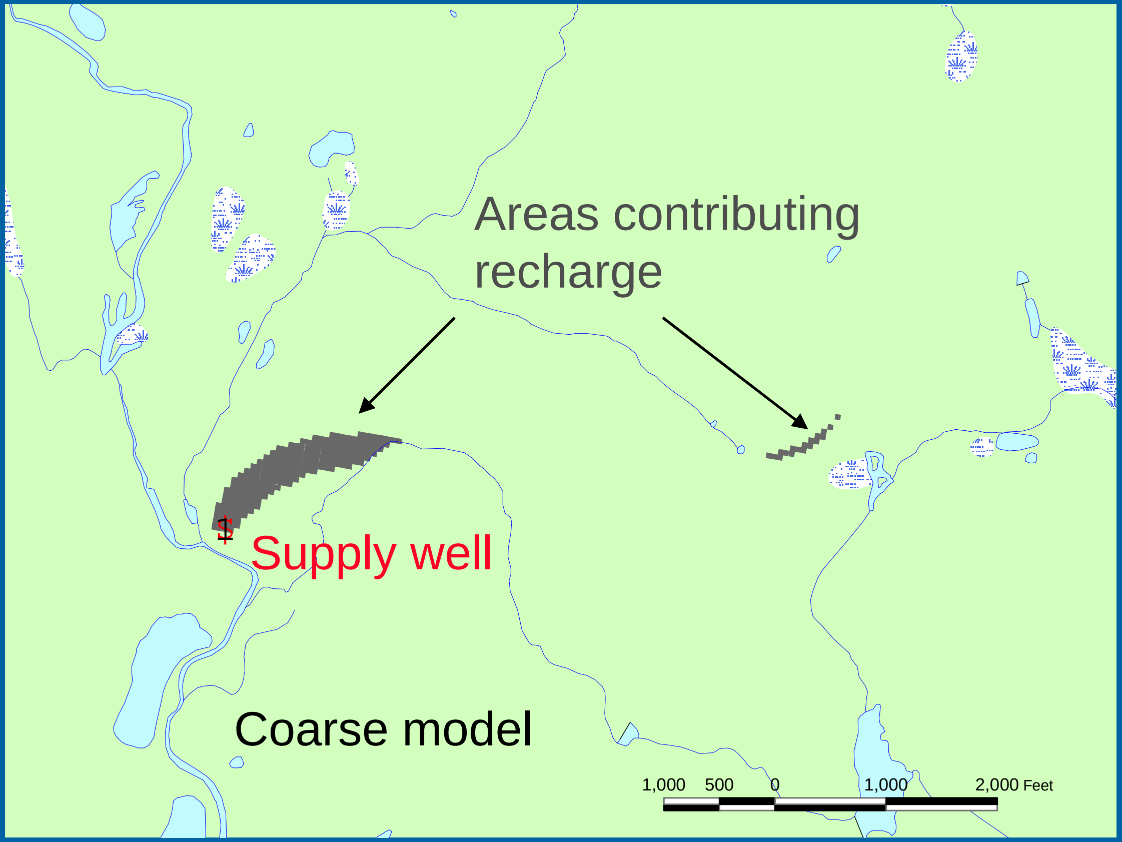
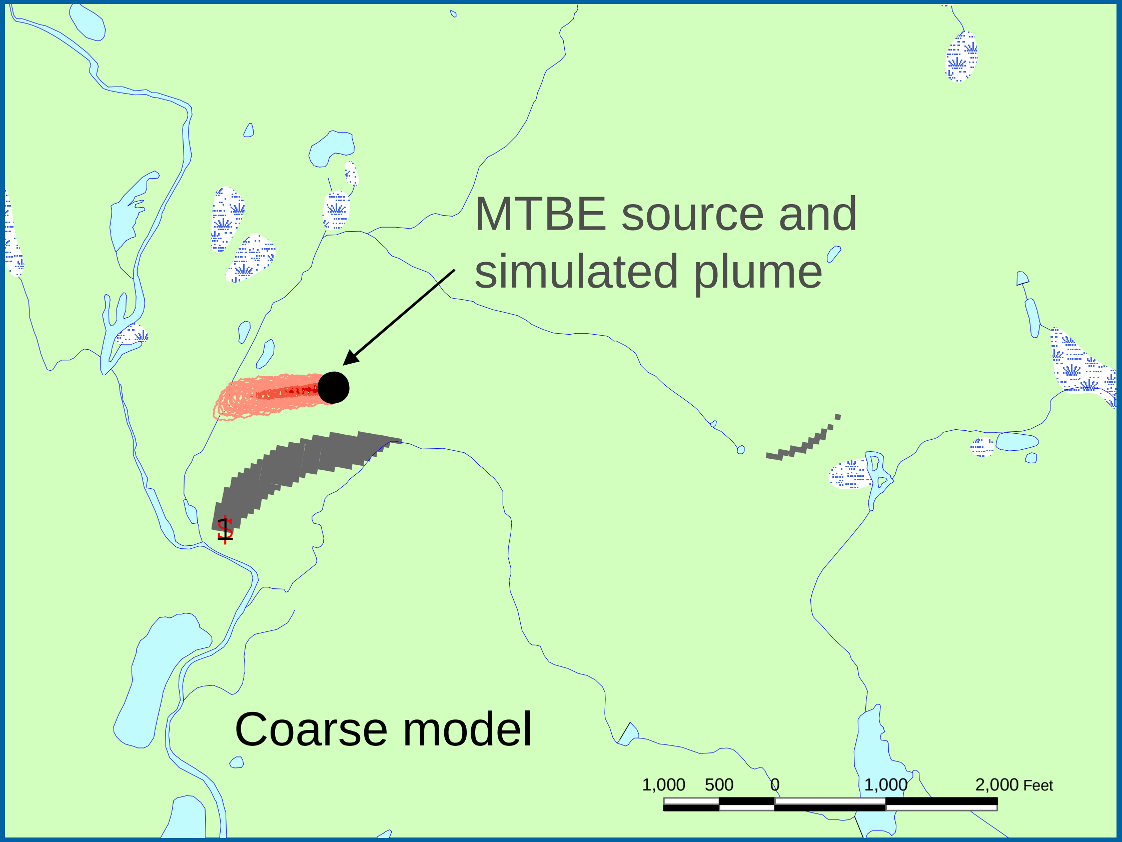
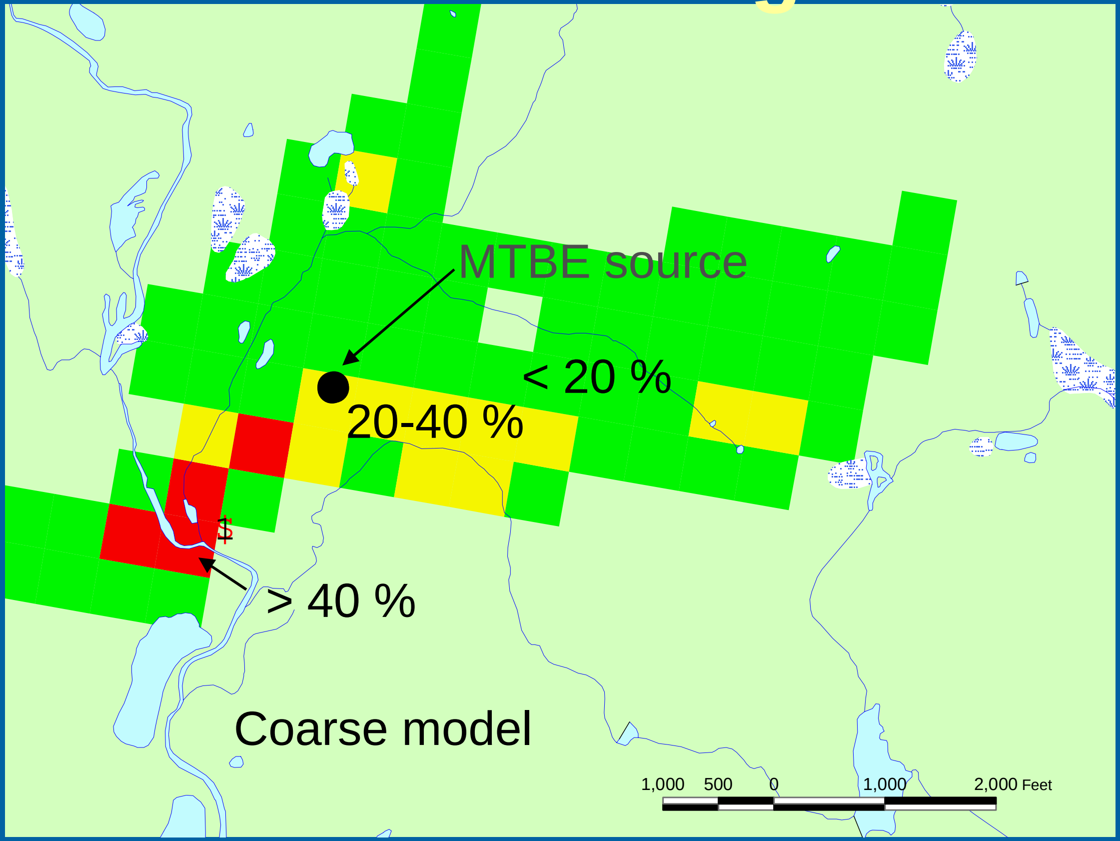
Recharge area to a public-supply well using a coarse ground-water-flow model



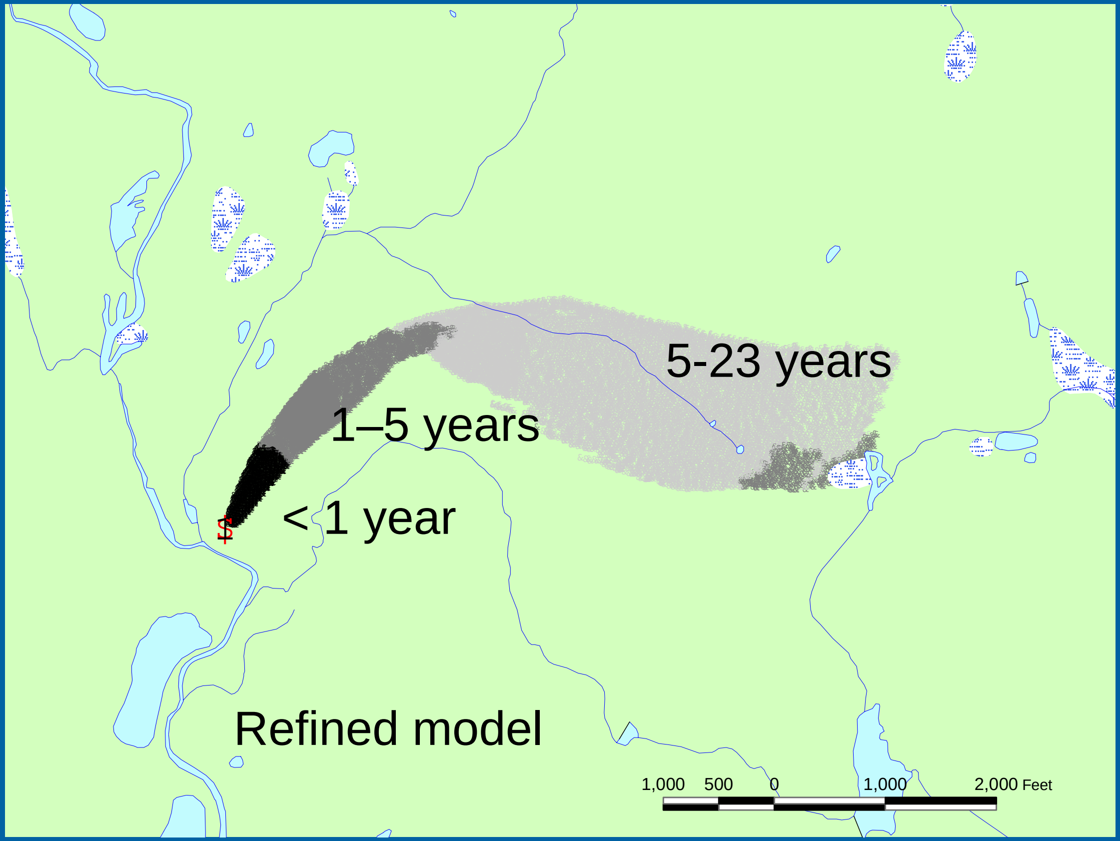
MTBE was detected in the supply well, but simulated plume does not reach well



Probabilistic model showed a 20-40% chance that the MTBE source was in the simulated recharge area



Refined model showed a different recharge area than the coarse model



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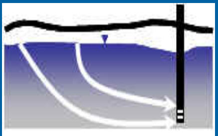
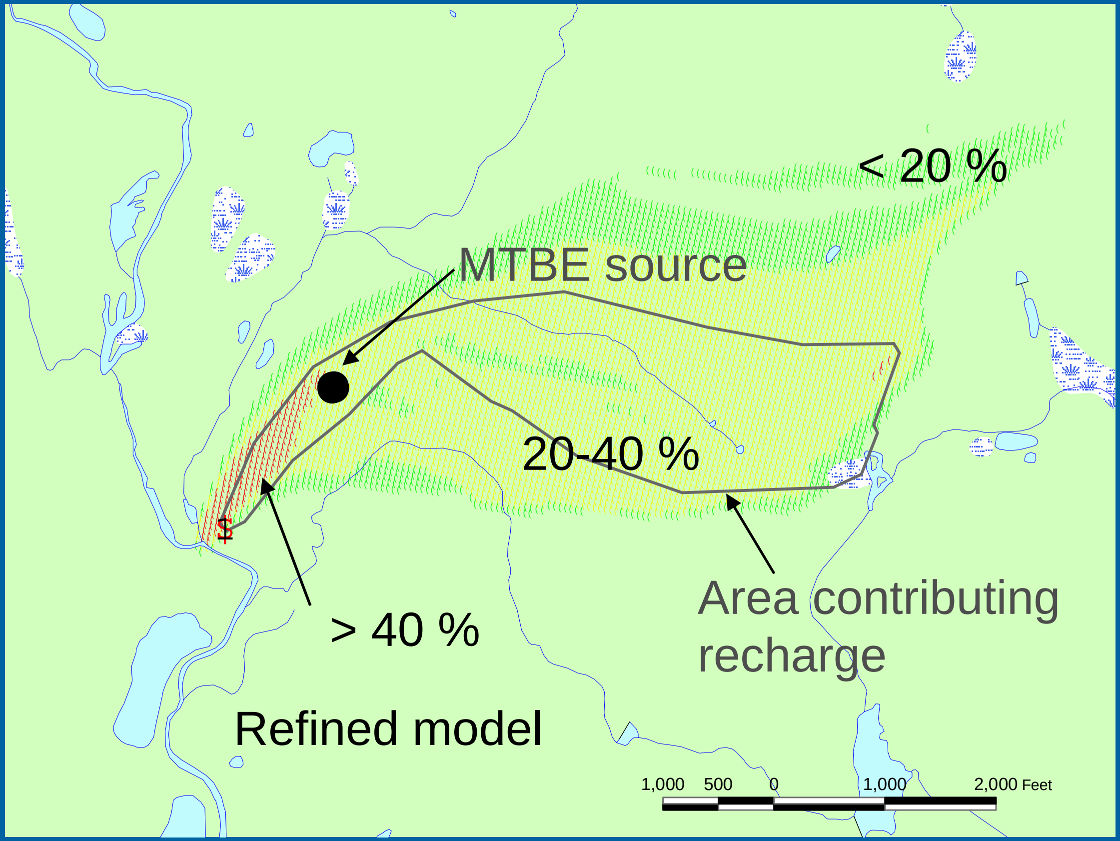
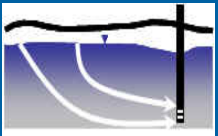
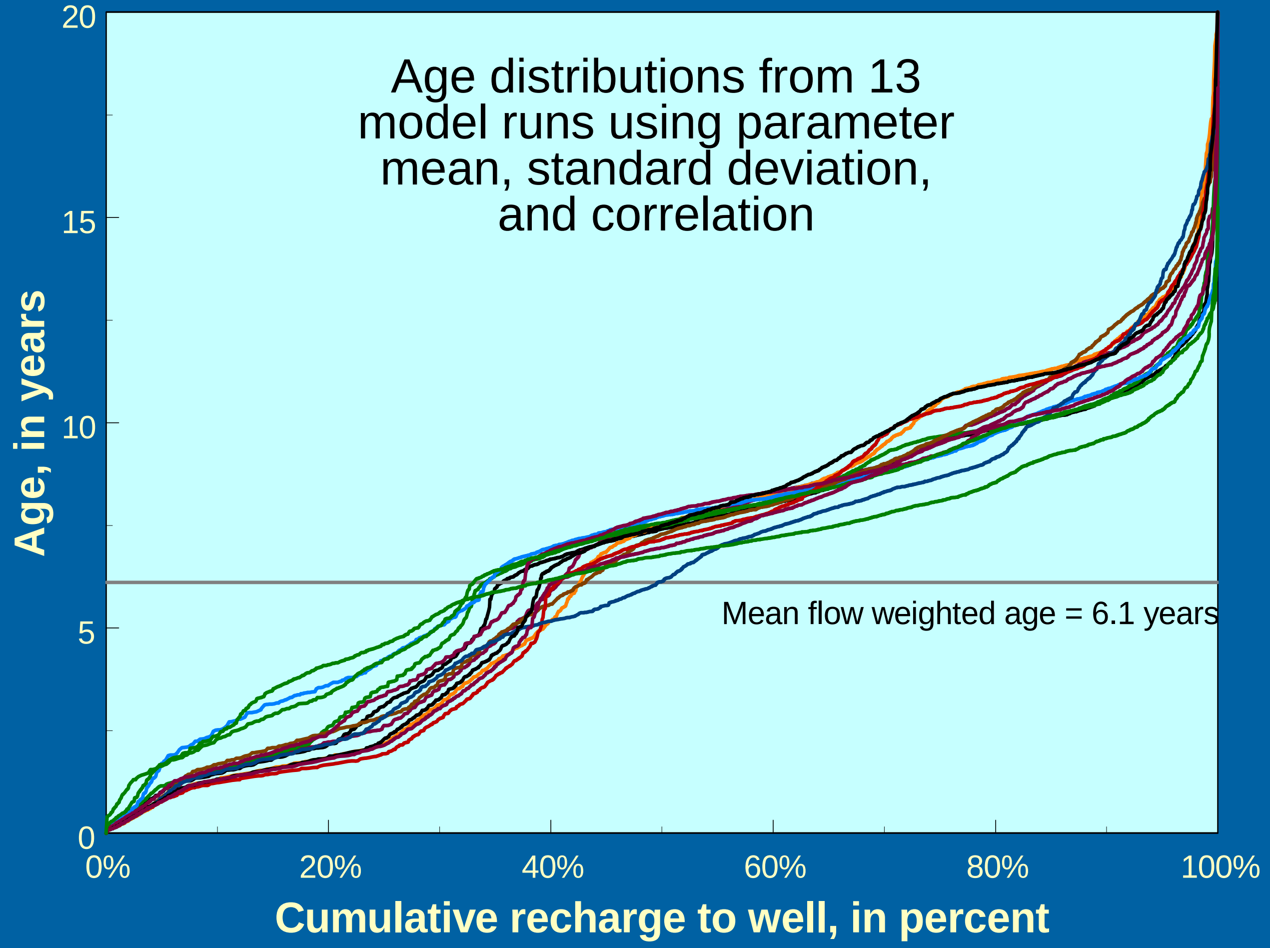


Refined model showed >40 % chance MTBE was in the simulated recharge area





Probabilistic model can be used to put error bounds on age distributions



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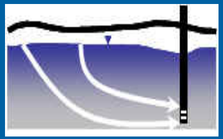
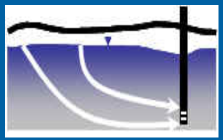


Conclusions

- More effective monitoring networks can be developed by considering uncertainty
- Level of uncertainty can be decreased by collecting more data and refining model



Conclusions

- Source-area uncertainty increases with distance and travel time from the well
- Error on vulnerability indicators such as ground-water age can be quantified

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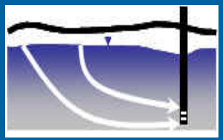

Acknowledgments

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