Methane leakage from hydrocarbon wellbores into overlying groundwater: Numerical investigation of the multiphase flow processes governing migration

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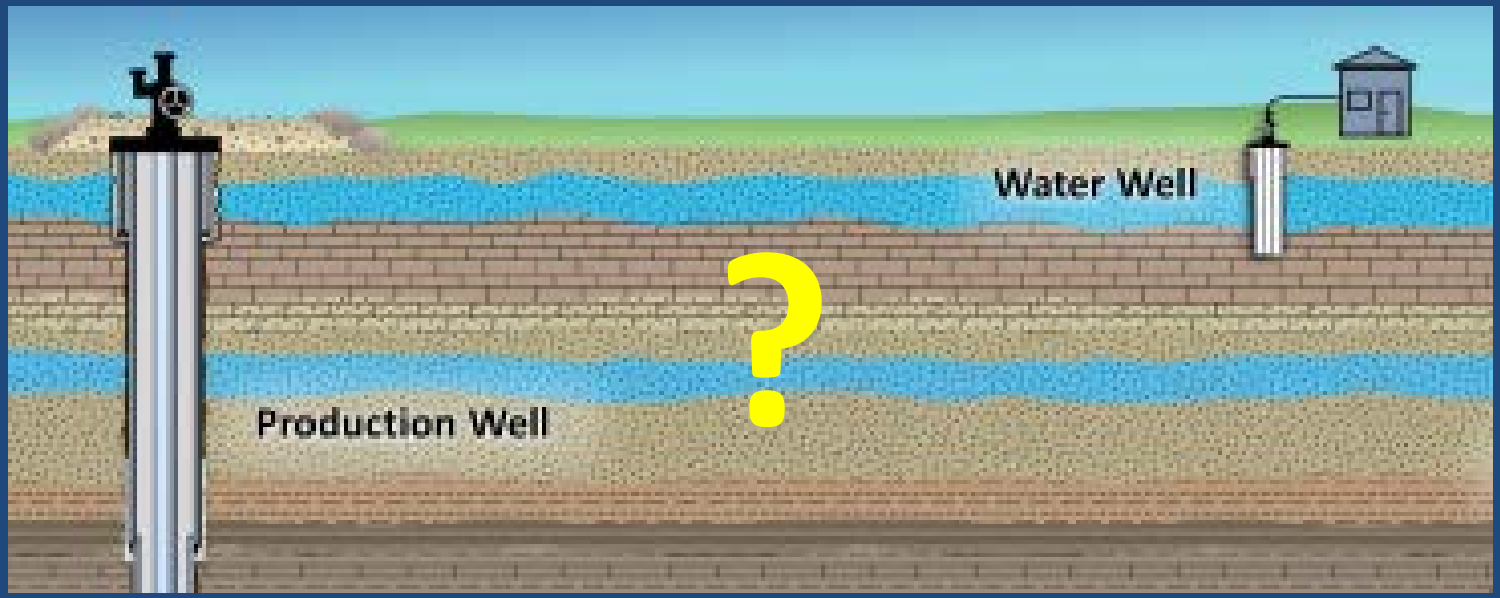
Motivation

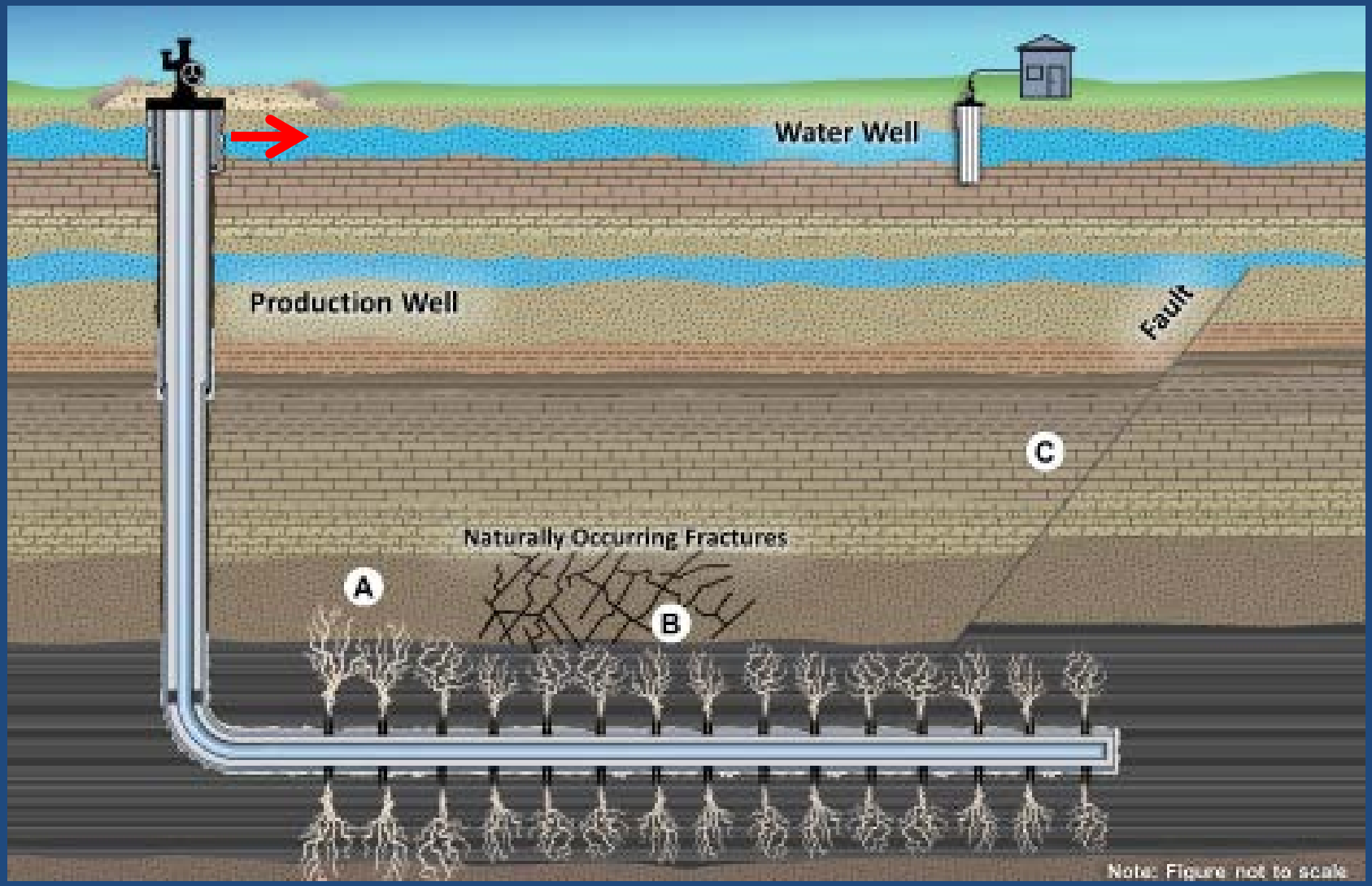
Investigate groundwater quality impacts from wellbore methane leakage. Quantify relative importance of:

- Multiphase flow processes;
- Hydrogeology between leakage and groundwater; and
- The methane source zone.



US EPA 2015

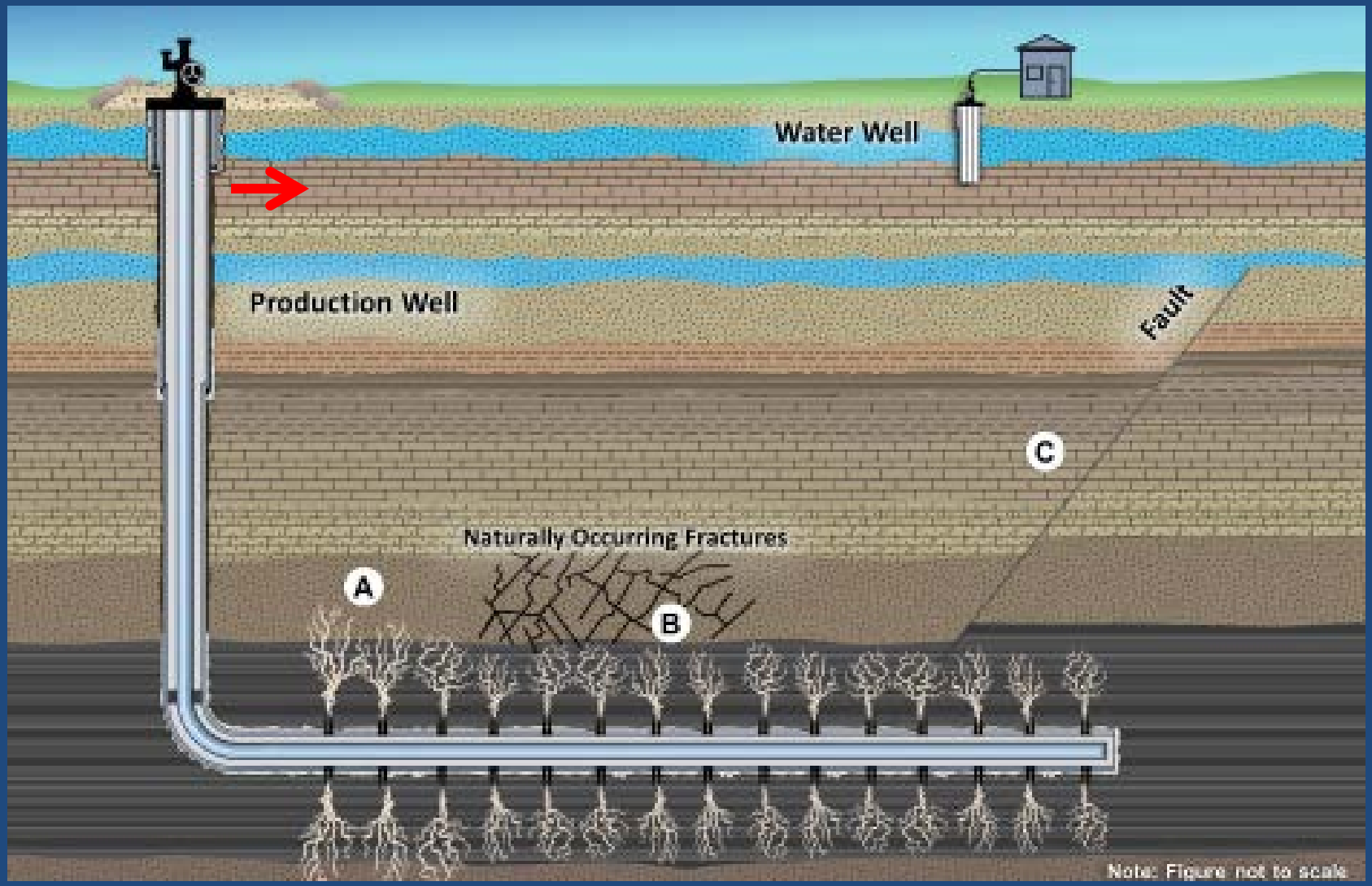
Leakage where?



US EPA 2015

Induced fractures:
a) grow into overlying formations; b) intersect natural fractures; c)intersect a transmissive fault

Leakage where?

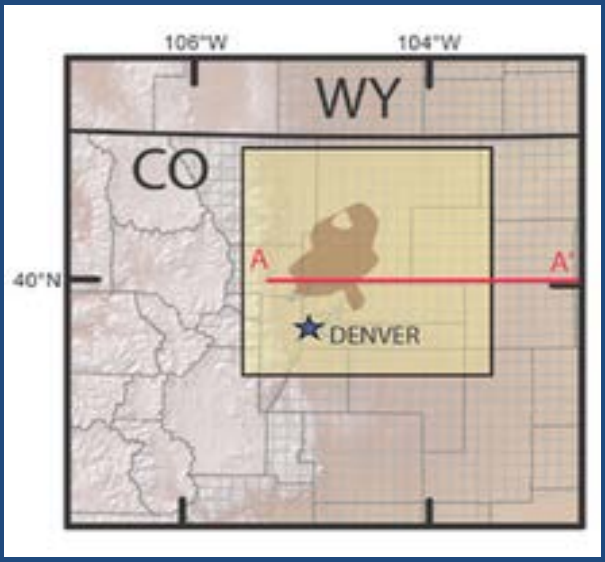


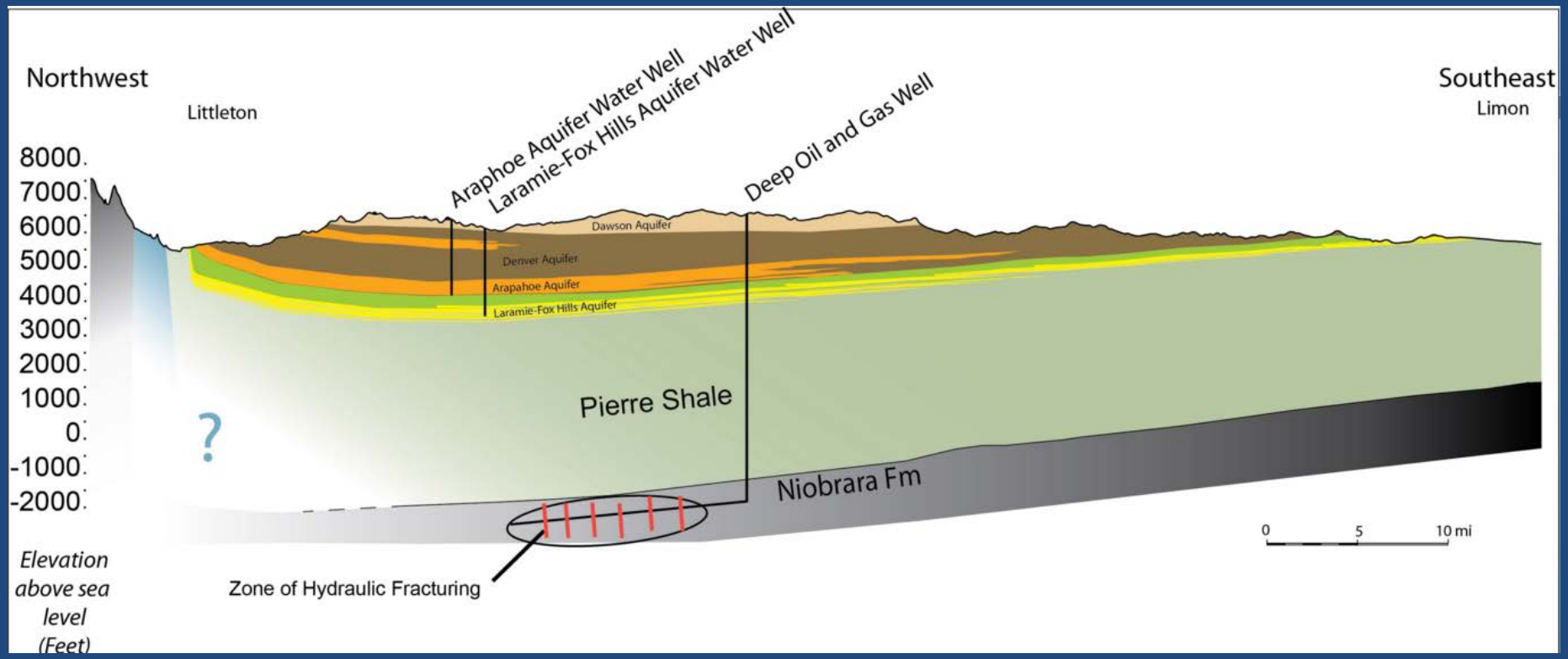
US EPA 2015

Induced fractures:
a) grow into overlying formations; b) intersect natural fractures; c)intersect a transmissive fault

Leakage where?

Wattenberg field:
low permeability Pierre Shale separates groundwater and the hydrocarbon production zone.





Pierre Shale, up close and personal

US GS Core Research Center:
Denver Federal Center

Research questions

1. Does wellbore methane leakage into unfractured media reach groundwater in human timescales (**<100 years**)?

2. Is the volume and timing of methane reaching groundwater as strongly impacted by **multiphase** flow? How about compared to permeability?

A numerical what now?

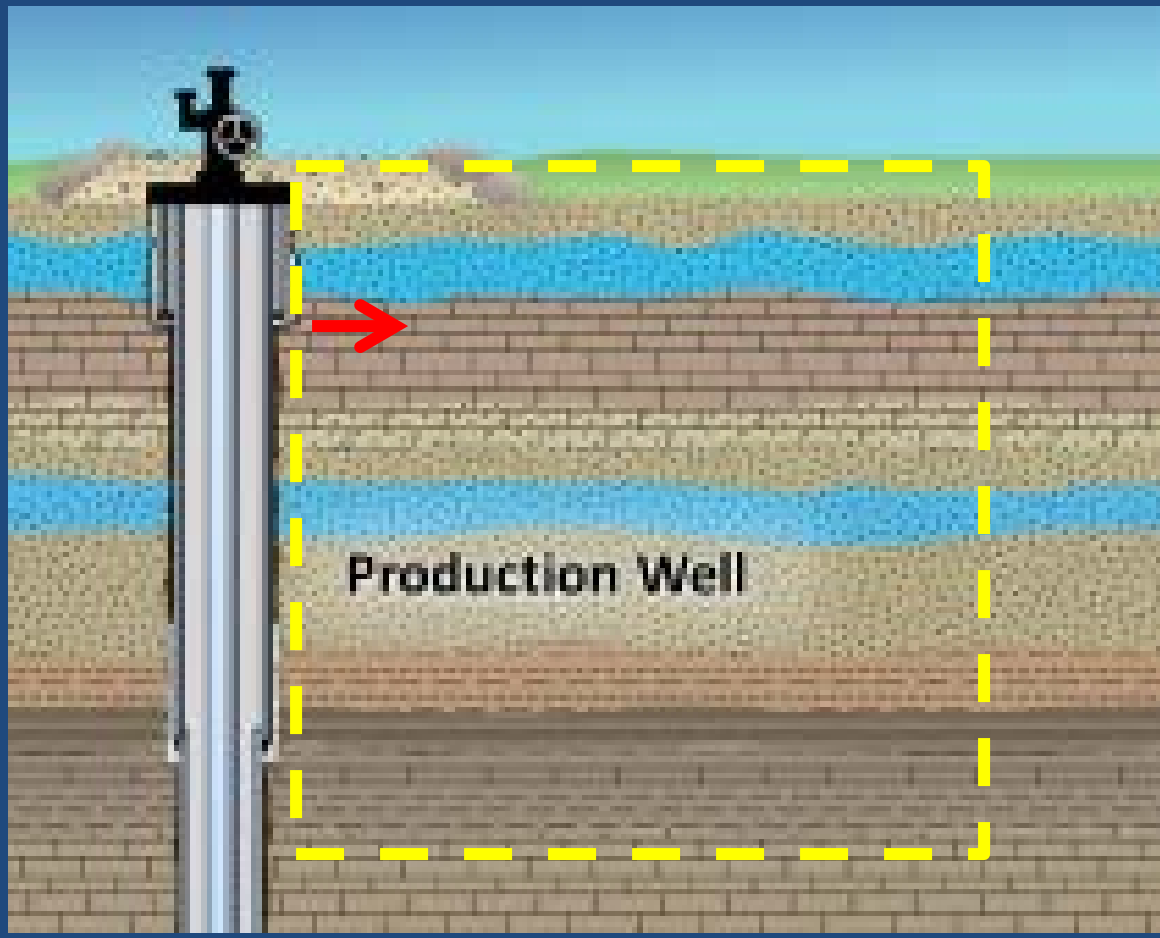
- All models are wrong, but some are useful.
  - George Box (statistician)

- The purpose of models is not to fit the data but to sharpen the questions.
  - Samuel Karlin (mathematician, game theory researcher)

- Clearly defined research goals are essential to effective model use.
  - Amy Rice (hey, that's me!)

Our Model: Parameters

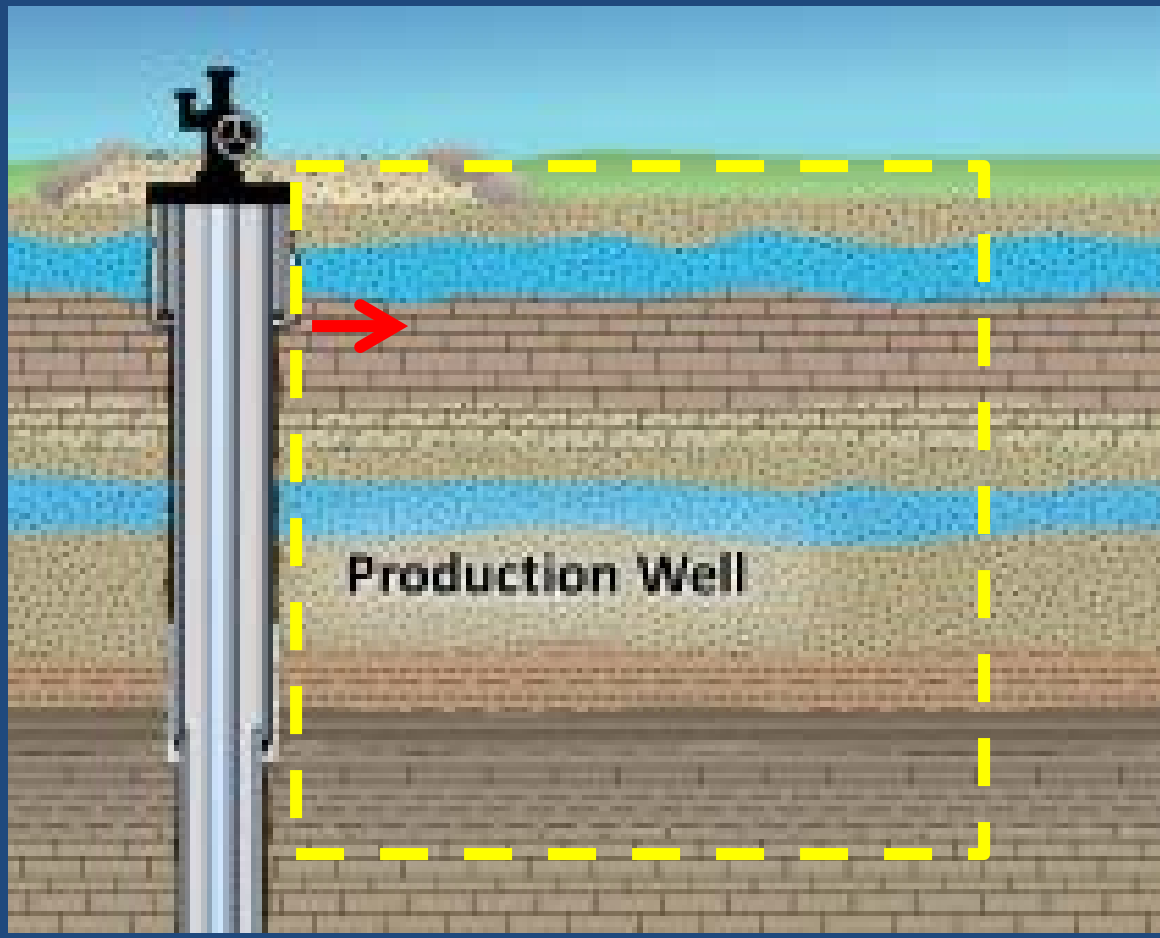
- Pierre Shale parameters (kind of)
- X,Y=946; Z=1058 m
- Constant methane injection
- Injection 20-30 m below base of aquifer



US EPA 2015

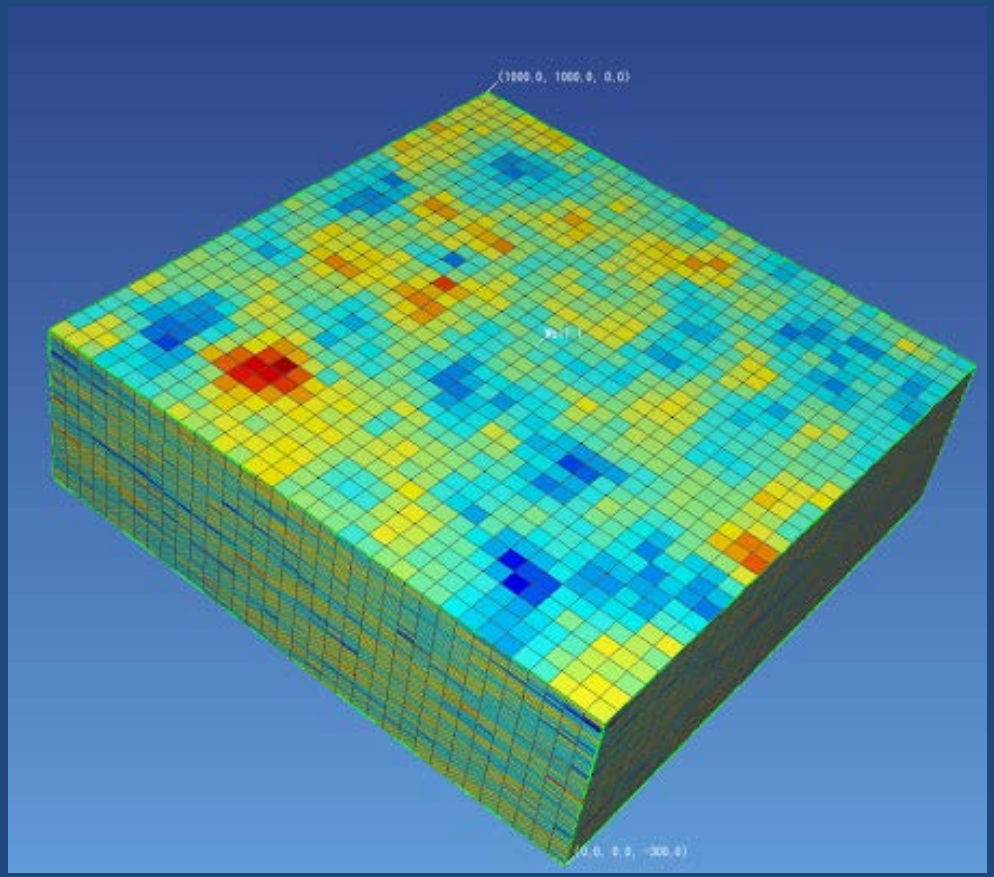
Our Model: Parameters

- TOUGH2 EOS7C
- Multiphase (liquid/vapor)
- Multicomponent
- Constant pressure top BC; no flow elsewhere



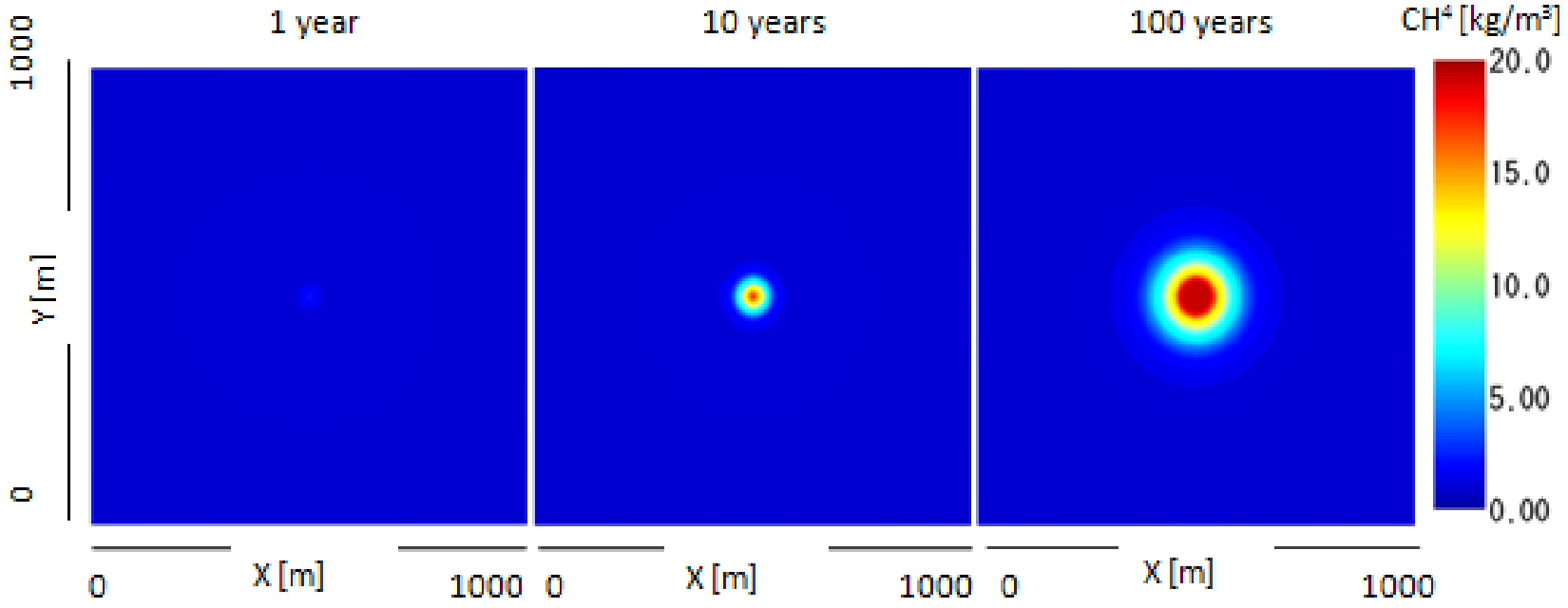
US EPA 2015

What are we testing?

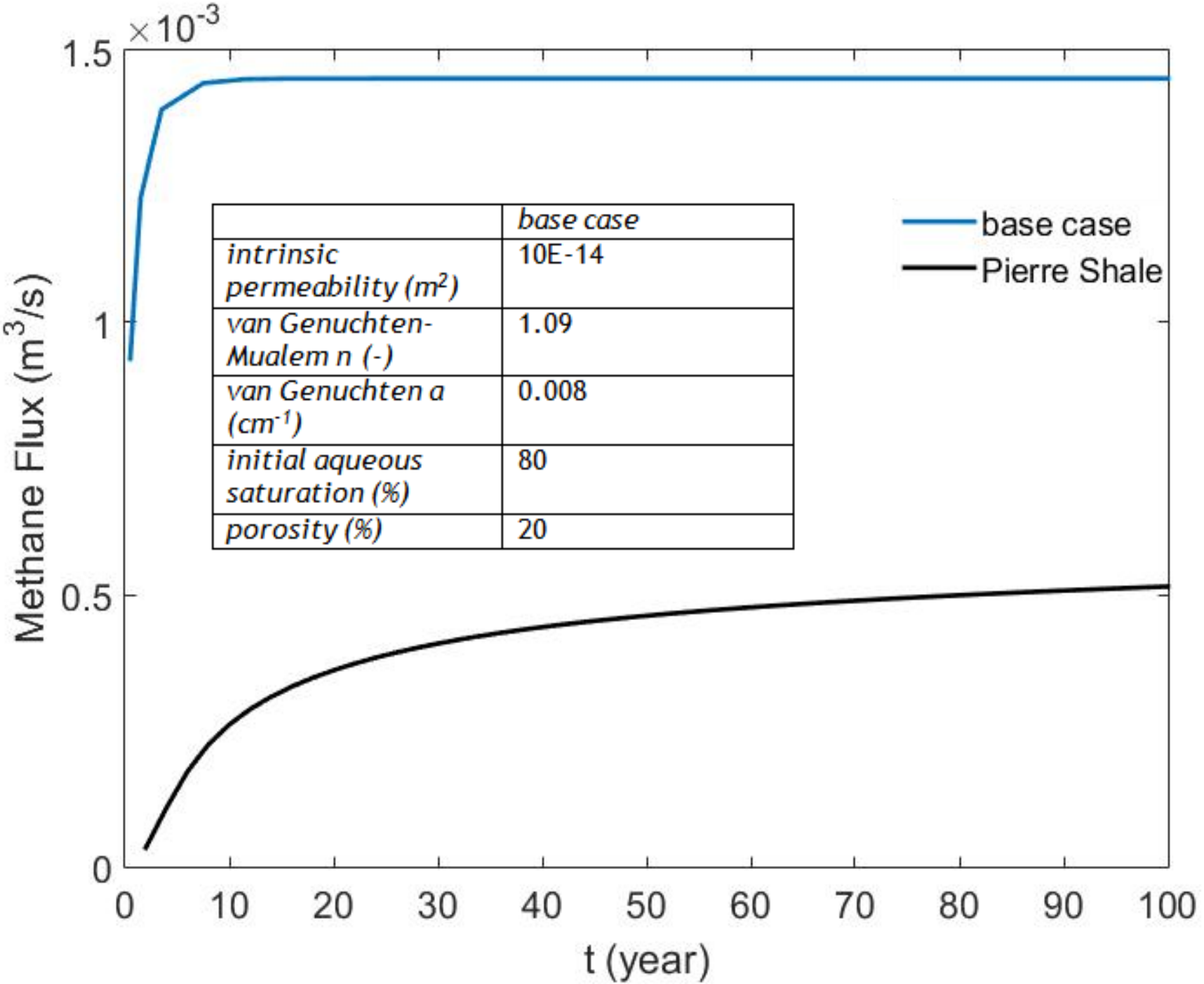


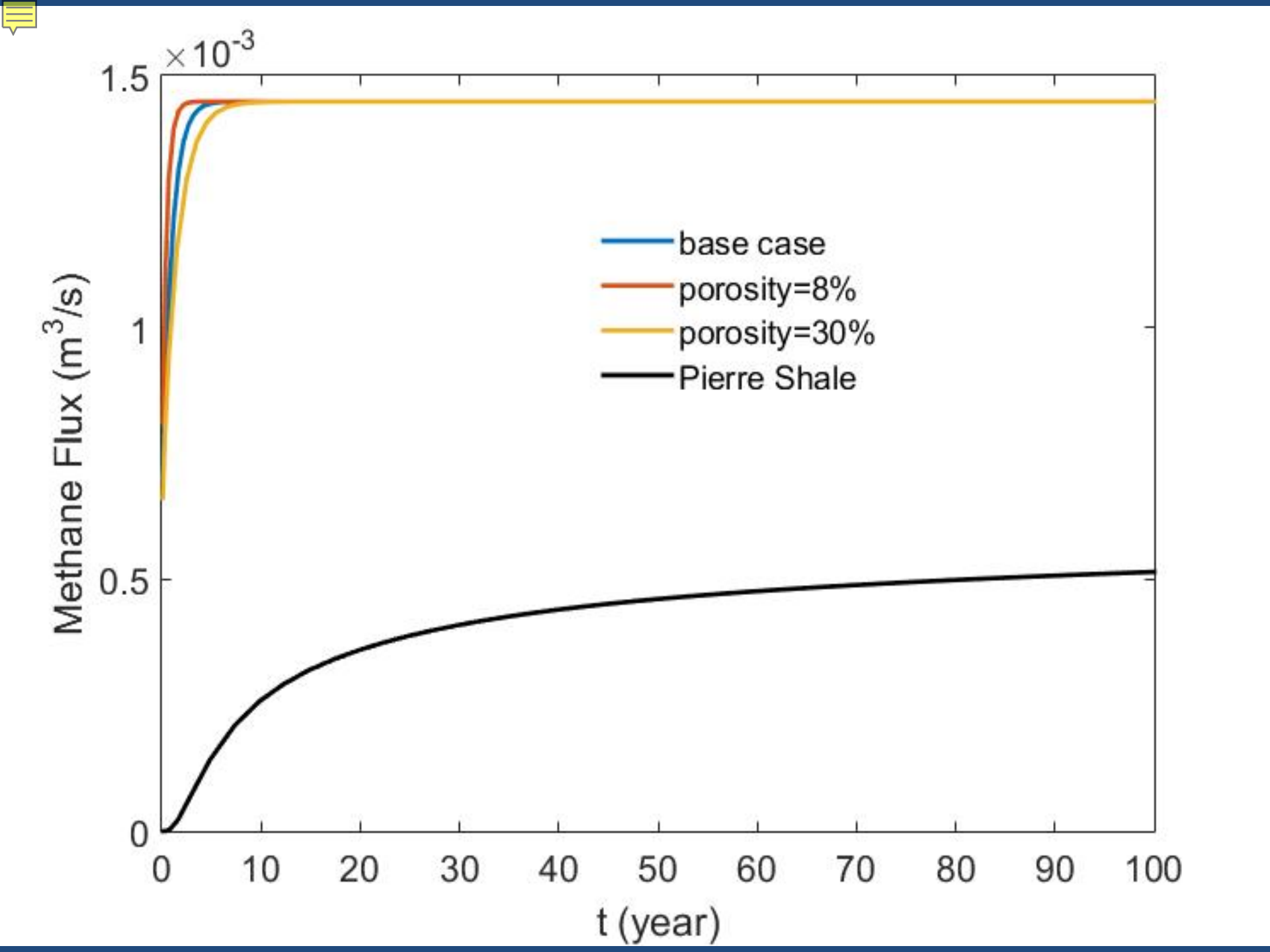
- van Genuchten α and n
  Multiphase!
- Porosity
- Aqueous saturation
- Source zone pressure
  - min=100 kPa
  - max=20340 kPa
- Intrinsic permeability
  - Mean
  - Variance
  - Correlation length (L_c)

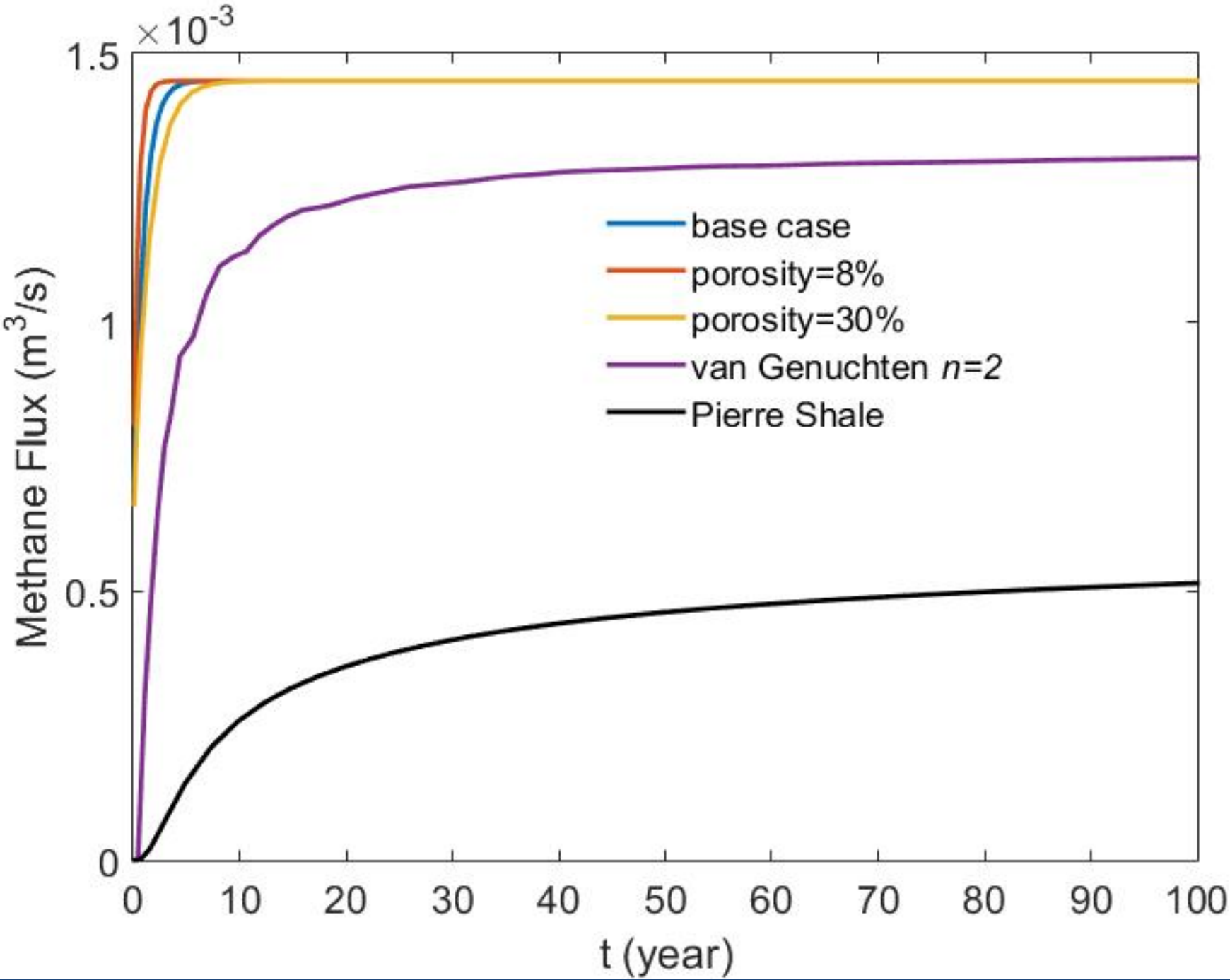
Question 1: Does leaked methane arrive at groundwater in >100 years?

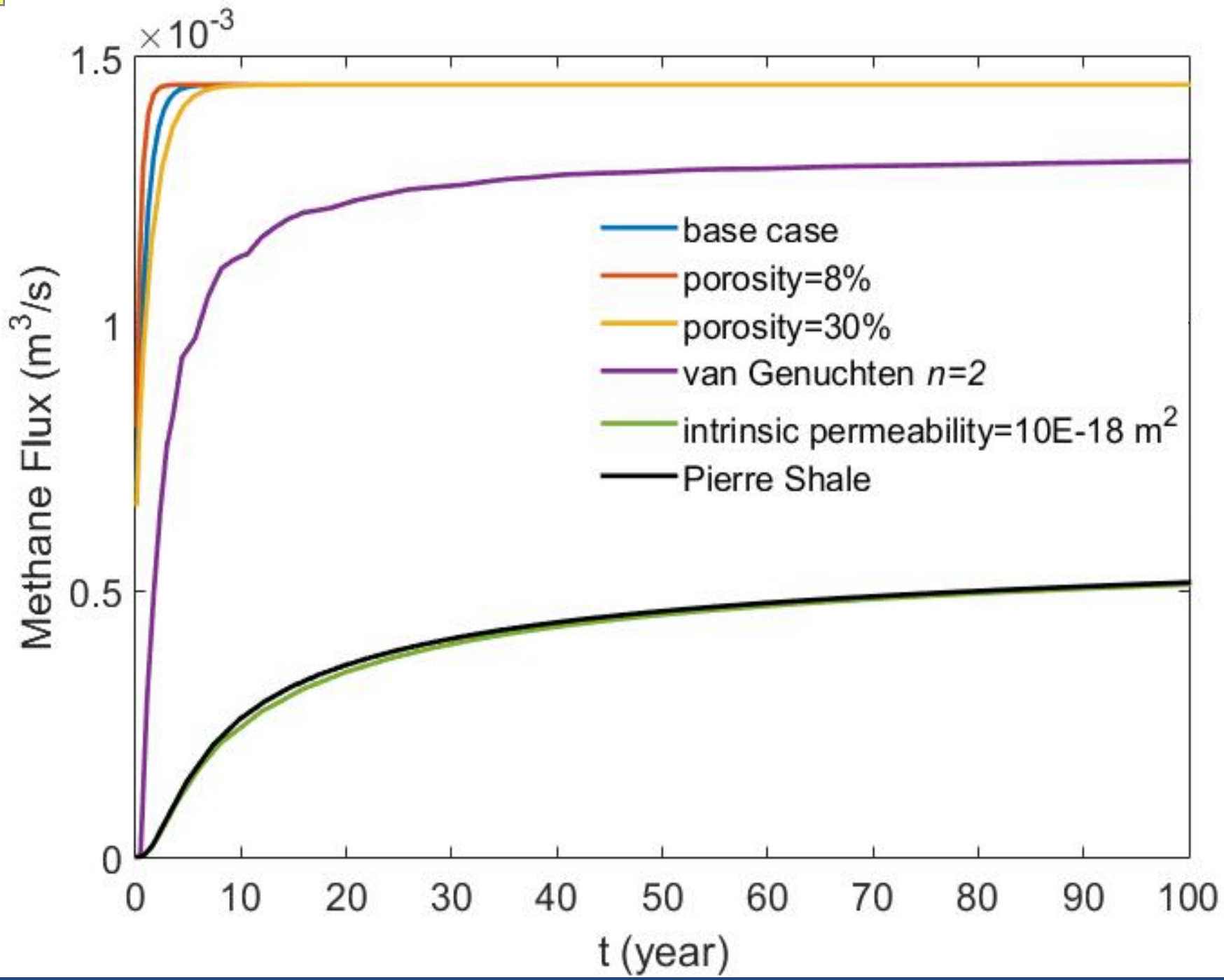


Question 2: Is multiphase analysis as important as permeability variation in terms of volume and timing of methane arriving at groundwater?


×10-3
1.5
1
0.5
0
Methane Flux (m3/s)
0
10
20
30
40
50
60
70
80
90
100
t (year)
base case
Pierre Shale
base case
intrinsic permeability (m2) 10E-14
van Genuchten-Mualem n (-) 1.09
van Genuchten a (cm-1) 0.008
initial aqueous saturation (%) 80
porosity (%) 20

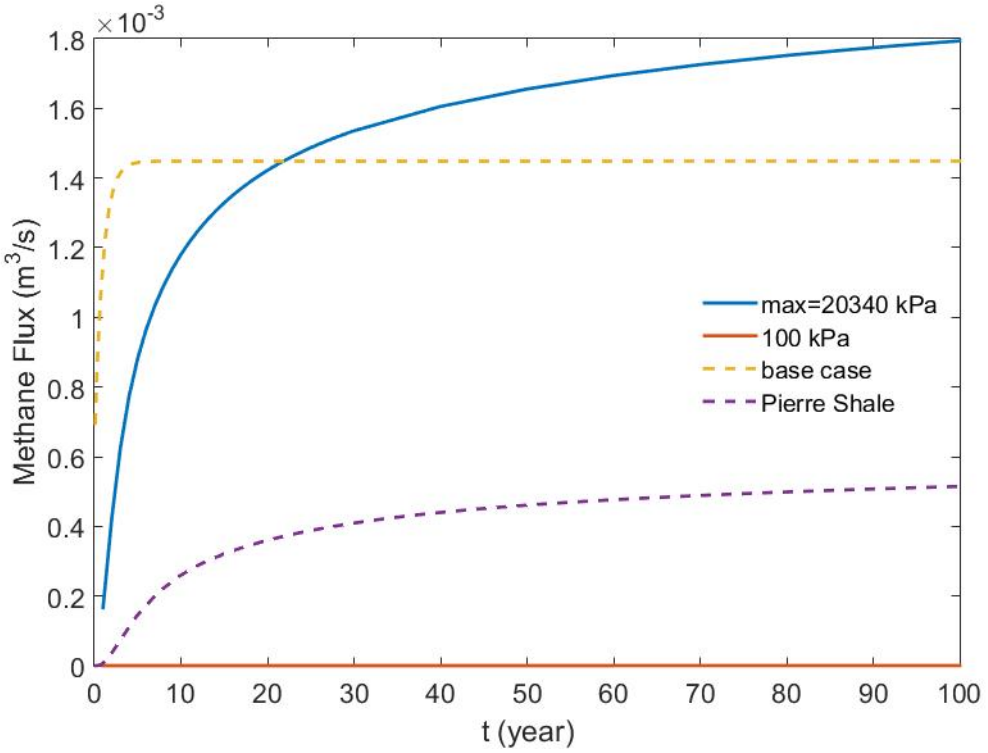

×10-3
1.5
1
0.5
0
Methane Flux (m3/s)
base case
porosity=8%
porosity=30%
Pierre Shale
0
10
20
30
40
50
60
70
80
90
100
t (year)

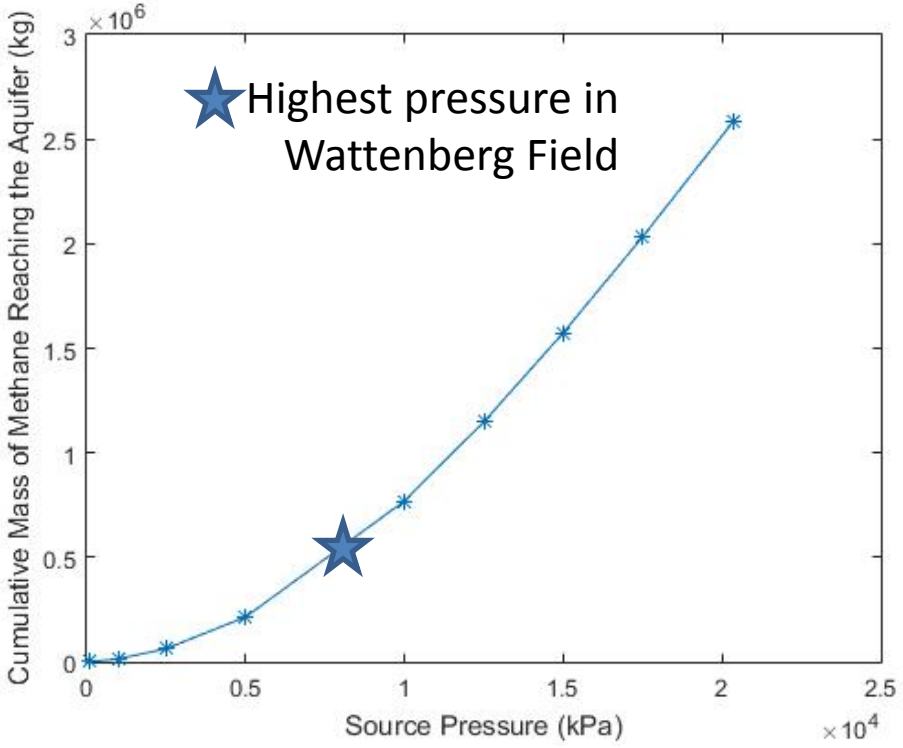

×10-3
1.5
1
0.5
0
Methane Flux (m3/s)
base case
porosity=8%
porosity=30%
van Genuchten n=2
Pierre Shale
0
10
20
30
40
50
60
70
80
90
100
t (year)


×10-3
1.5
1
0.5
0
Methane Flux (m3/s)
0
10
20
30
40
50
60
70
80
90
100
t (year)
base case
porosity=8%
porosity=30%
van Genuchten n=2
intrinsic permeability=10E-18 m2
Pierre Shale

Okay, so how important is source pressure?

Increasing source zone pressure leads to more methane at the base of the aquifer.





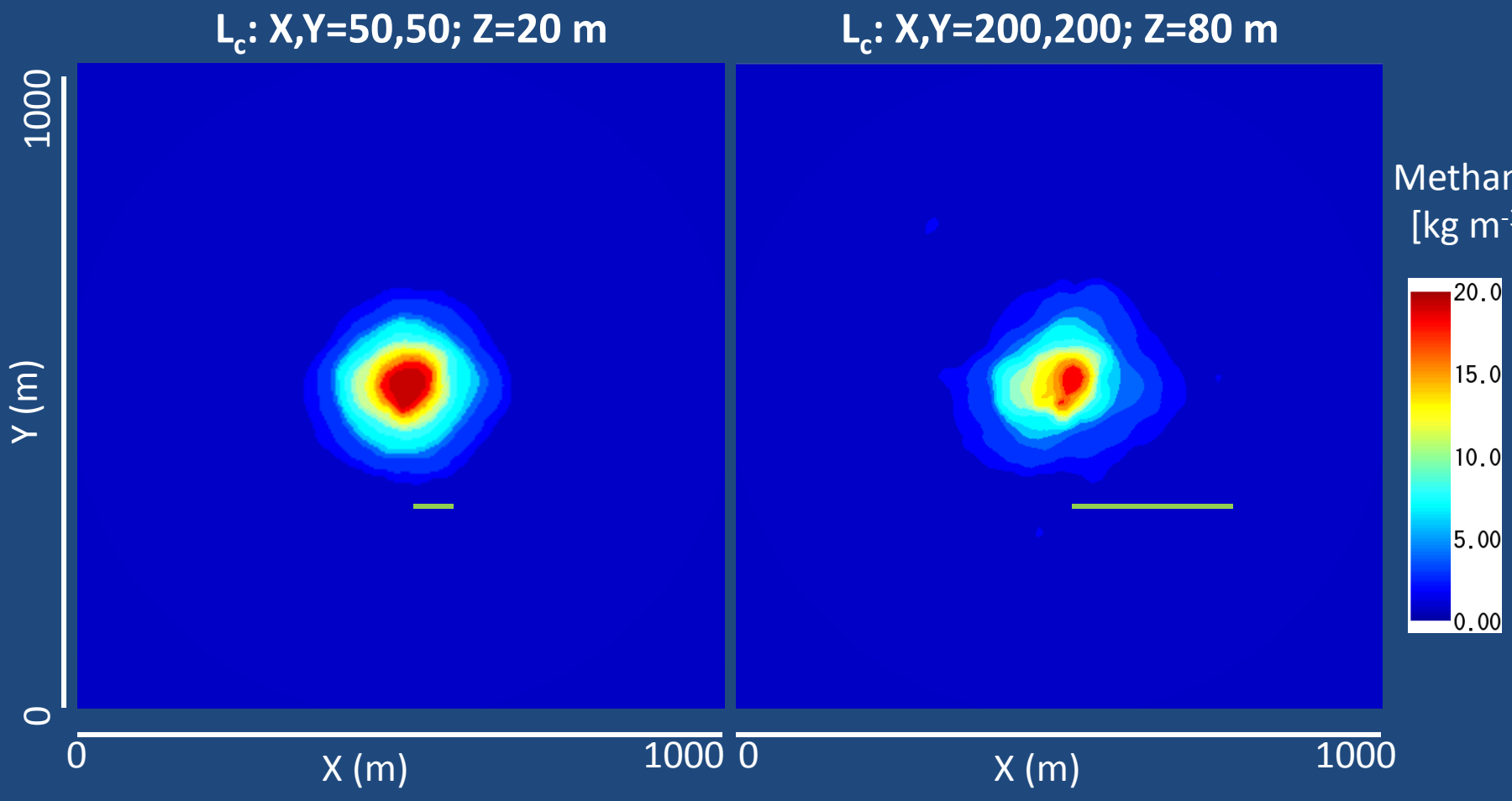
COGCC data courtesy of Greg Lackey

Conclusions

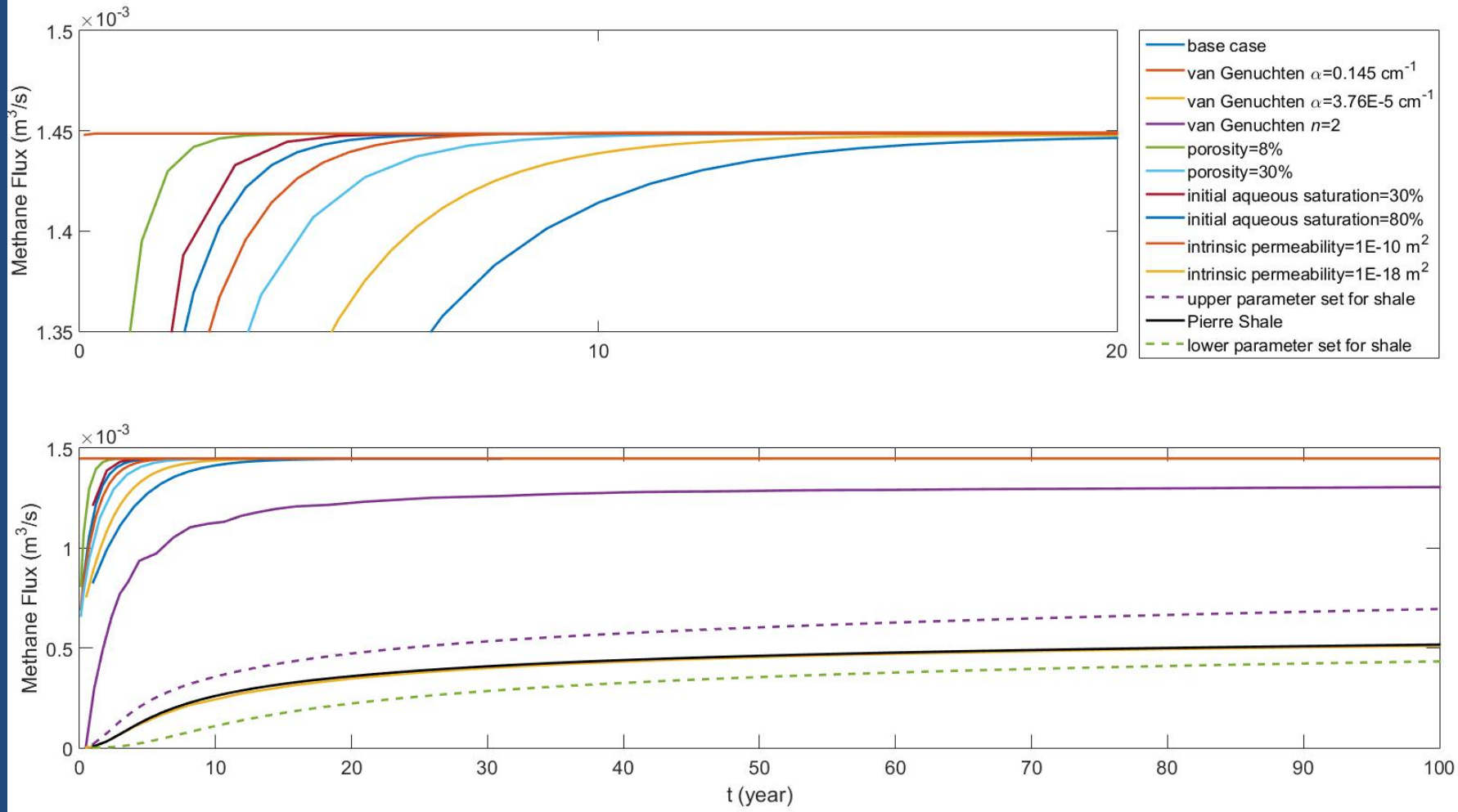
- **Methane leakage in low permeability media will reach the aquifer in less than 1 year.**

- **Intrinsic permeability, relative permeability, and non-wetting phase (methane gas) source strength have a strong impact on quantity of methane reaching groundwater.**

Permeability and the plume!

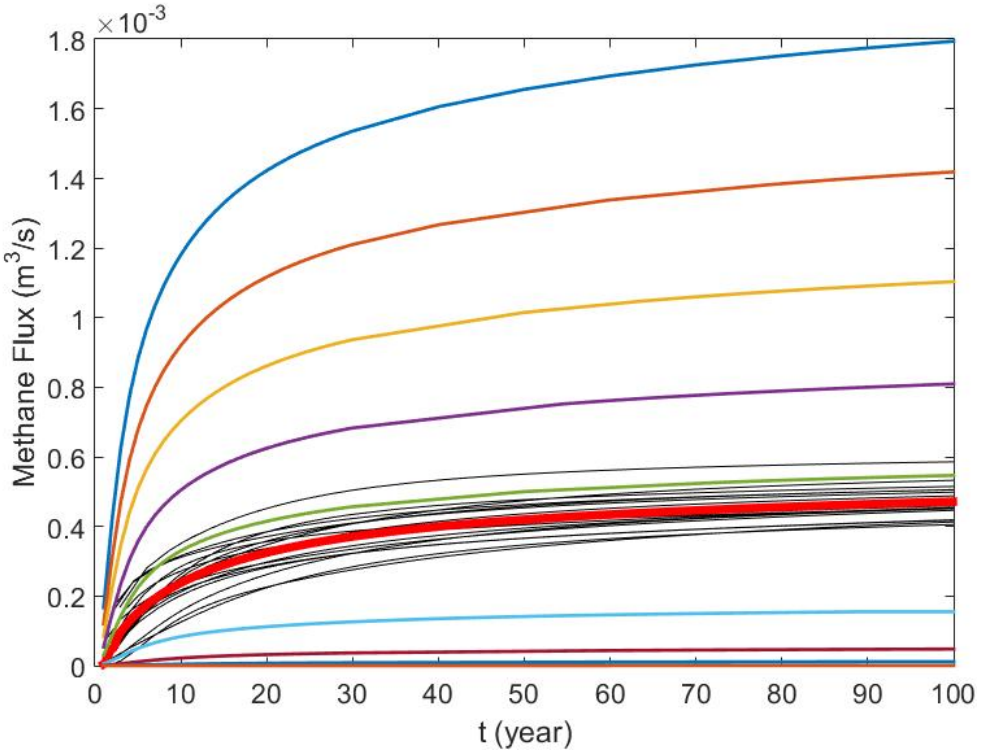


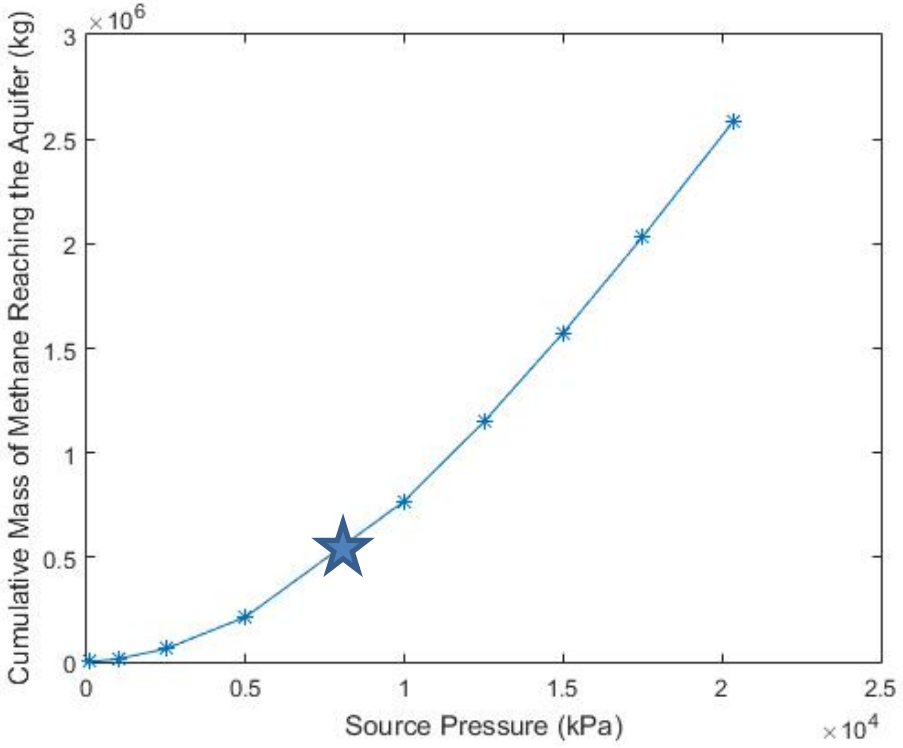
EXTRA SLIDES


×10-3
1.5
1.45
1.4
1.35
Methane Flux (m3/s)
0
10
20
base case
van Genuchten α=0.145 cm-1
van Genuchten α=3.76E-5 cm-1
van Genuchten n=2
porosity=8%
porosity=30%
initial aqueous saturation=30%
initial aqueous saturation=80%
intrinsic permeability=1E-10 m2
intrinsic permeability=1E-18 m2
upper parameter set for shale
Pierre Shale
lower parameter set for shale
×10-3
1.5
1
0.5
0
Methane Flux (m3/s)
0
10
20
30
40
50
60
70
80
90
100
t (year)

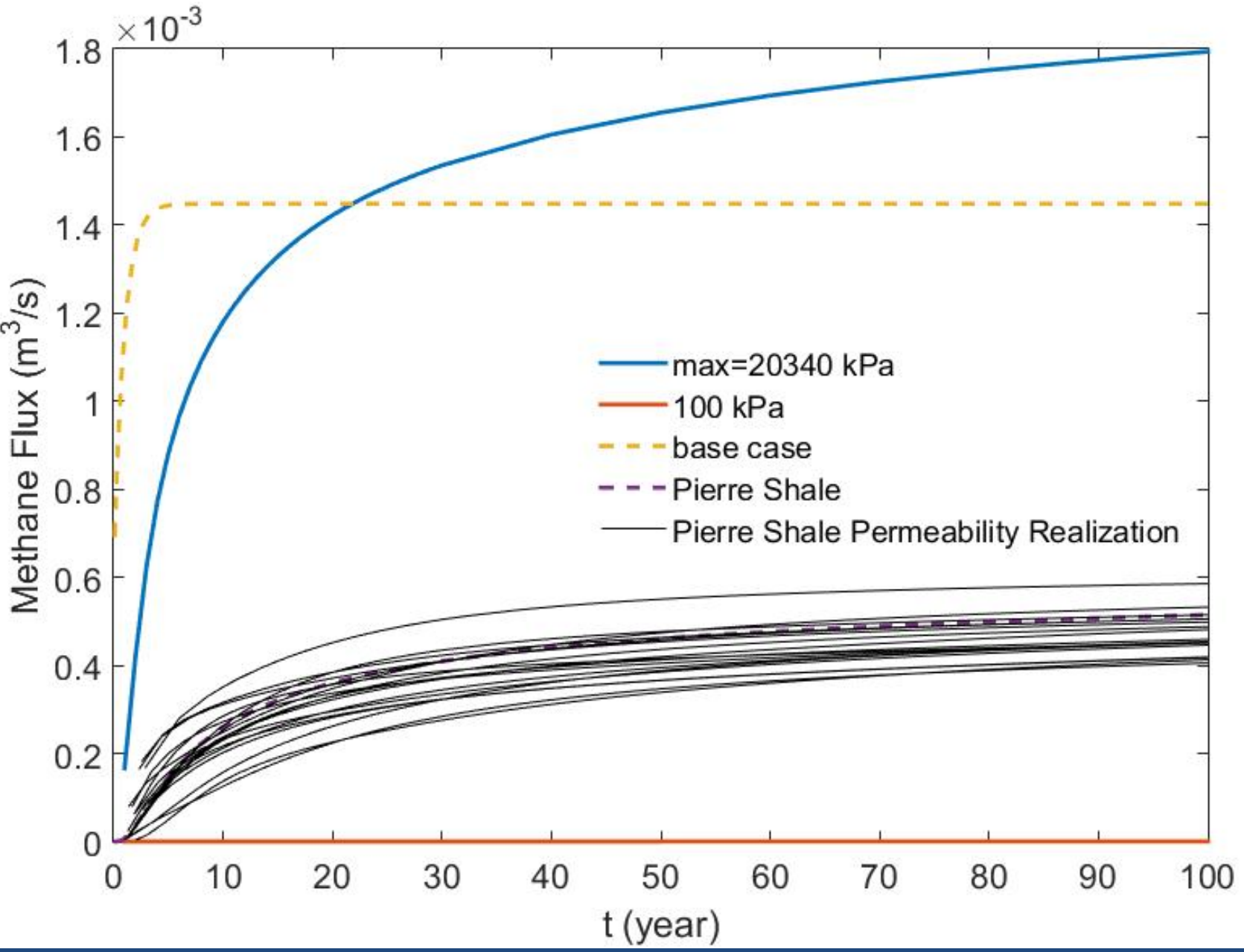
Pressure Variability

Increasing source zone pressure leads to more methane at the base of the aquifer.

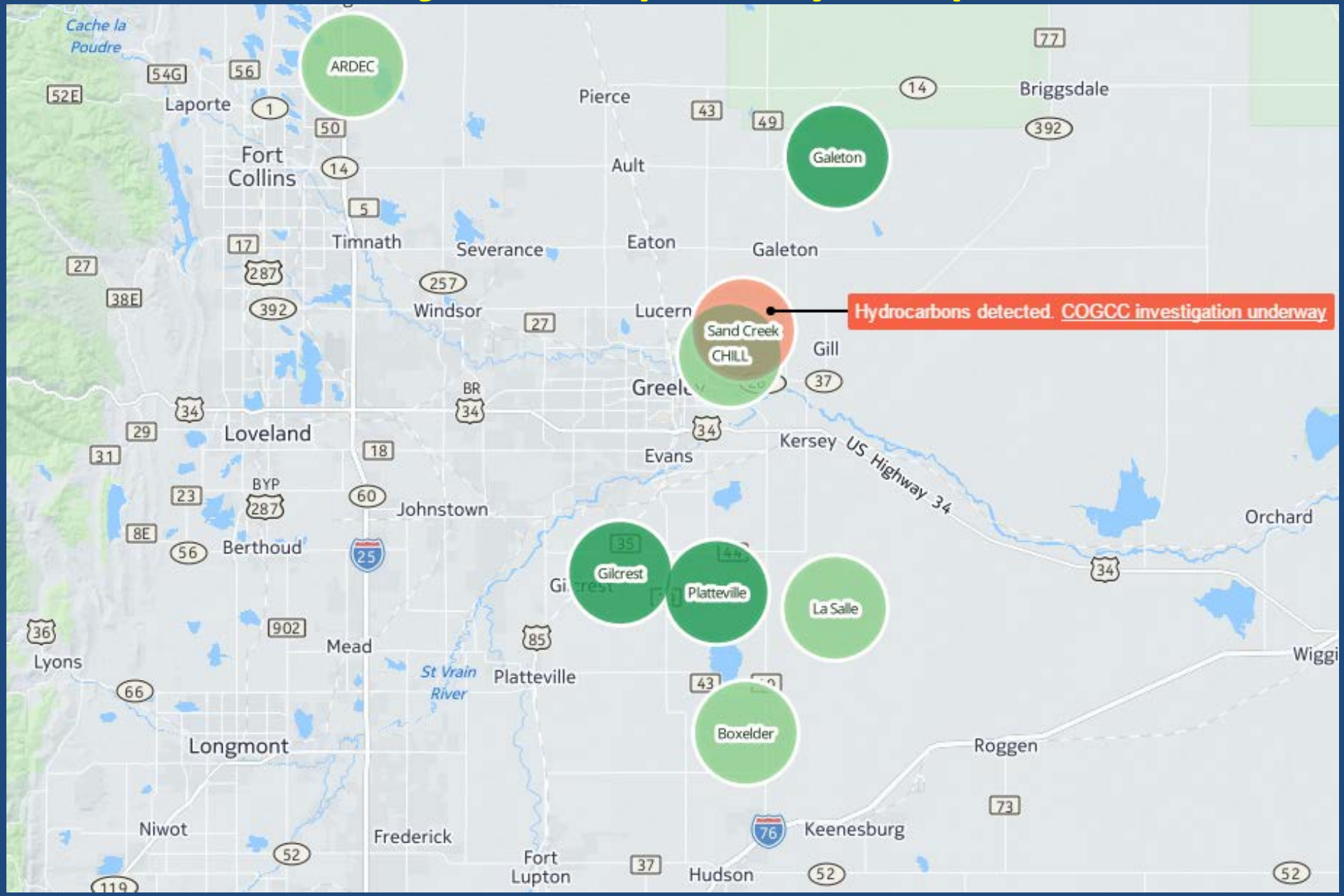




COGCC data courtesy of Greg Lackey

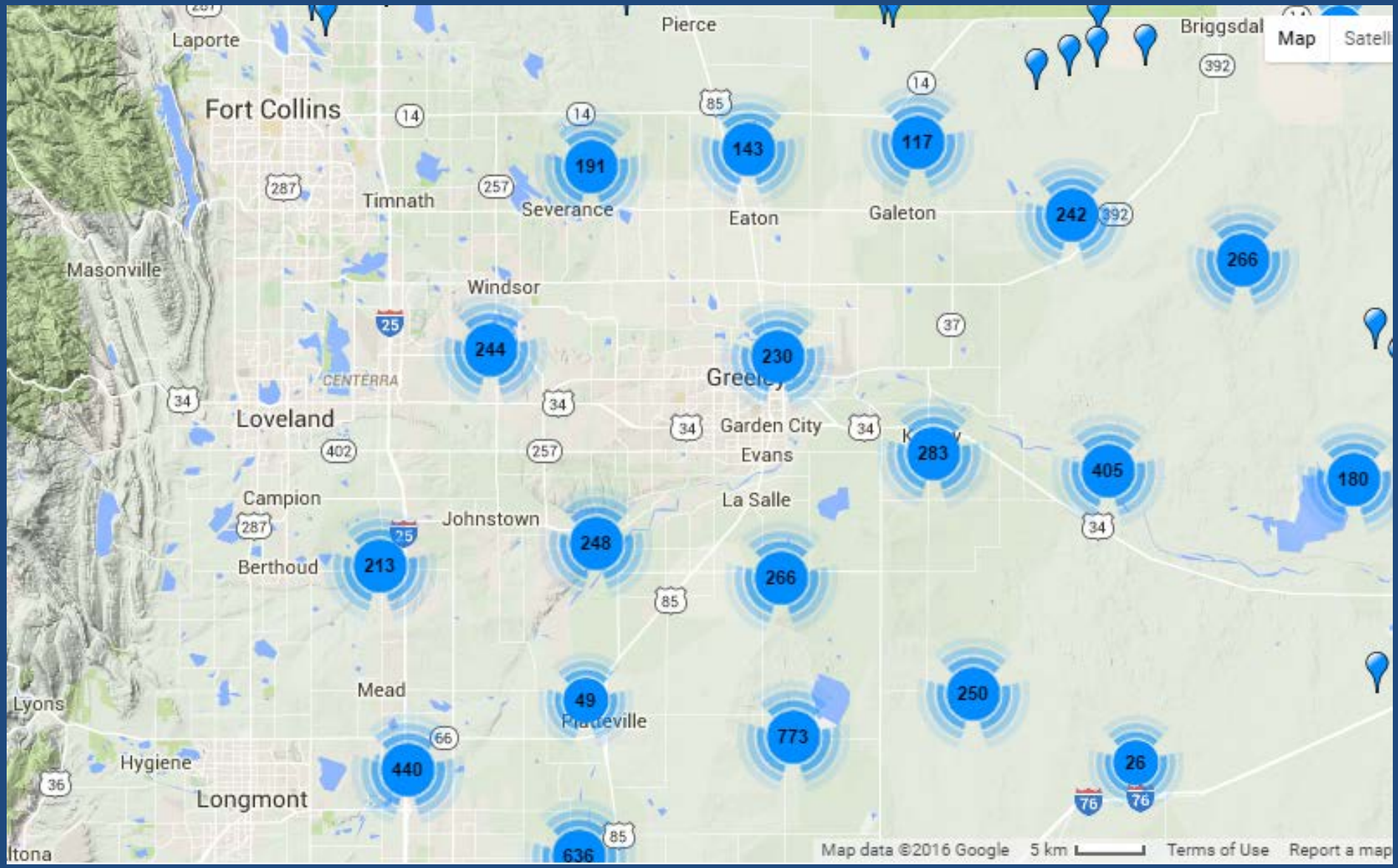

×10-3
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Methane Flux (m3/s)
0
10
20
30
40
50
60
70
80
90
100
t (year)
max=20340 kPa
100 kPa
base case
Pierre Shale
Pierre Shale Permeability Realization

Evidence of GW quality impact



Colorado Water Watch, downloaded 16-April 2016

Gas wells



Frac Focus, downloaded 26-April 2016

A numeric what now?