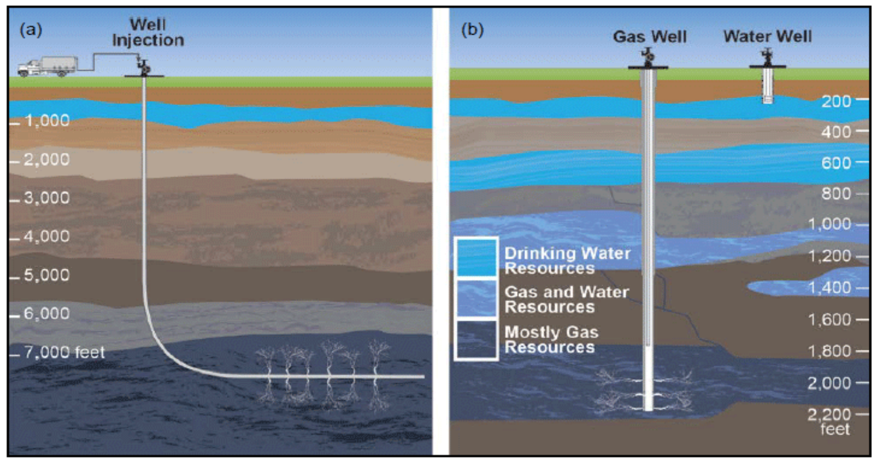
Subsurface Scenarios: What Are We Trying to Model?

Technical Workshop Series:
Follow-up Discussion on Subsurface Modeling



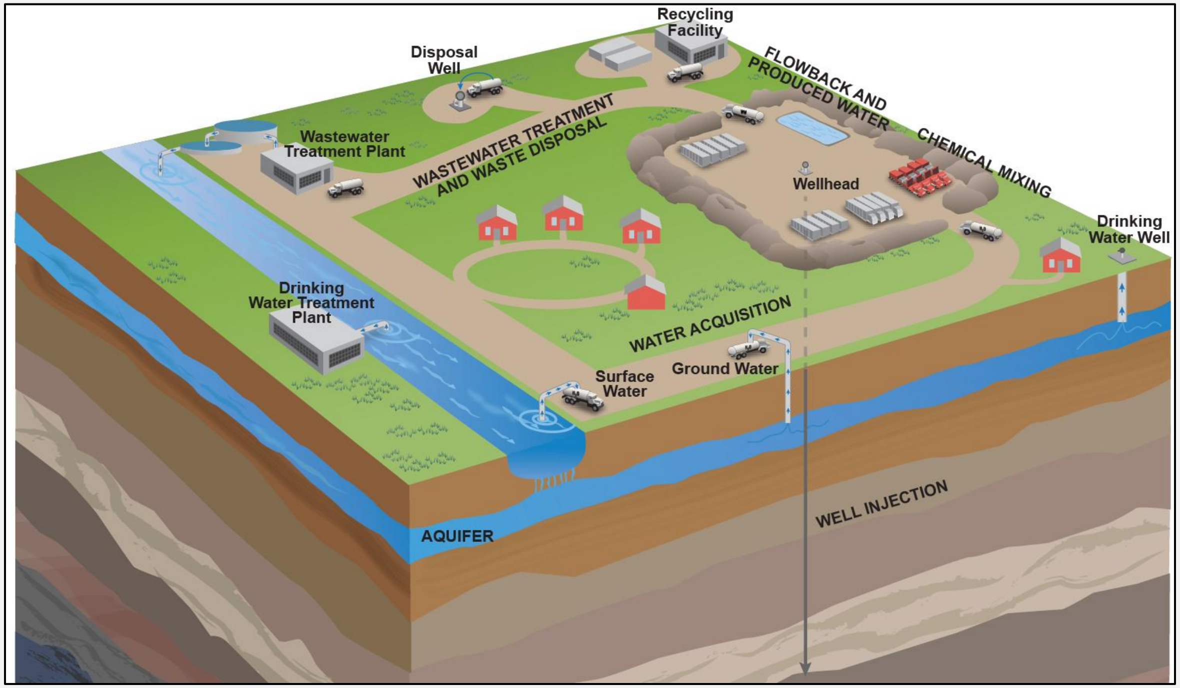
Stephen Kraemer (EPA), George Moridis (LBNL)

EPA-Arlington, VA • June 3, 2013

EPA Hydraulic Fracturing Study – research questions

Water Acquisition | Chemical Mixing | Produced Water | Waste and Wastewater

Well Injection → **What are the possible impacts of the fracturing process on drinking water resources?**



How effective are current well construction practices at containing fluids (gases, liquids) before, during, and after fracturing?

Can subsurface migration of fluids (gases, liquids) to drinking water resources occur, and what local geologic or man-made features might allow this?

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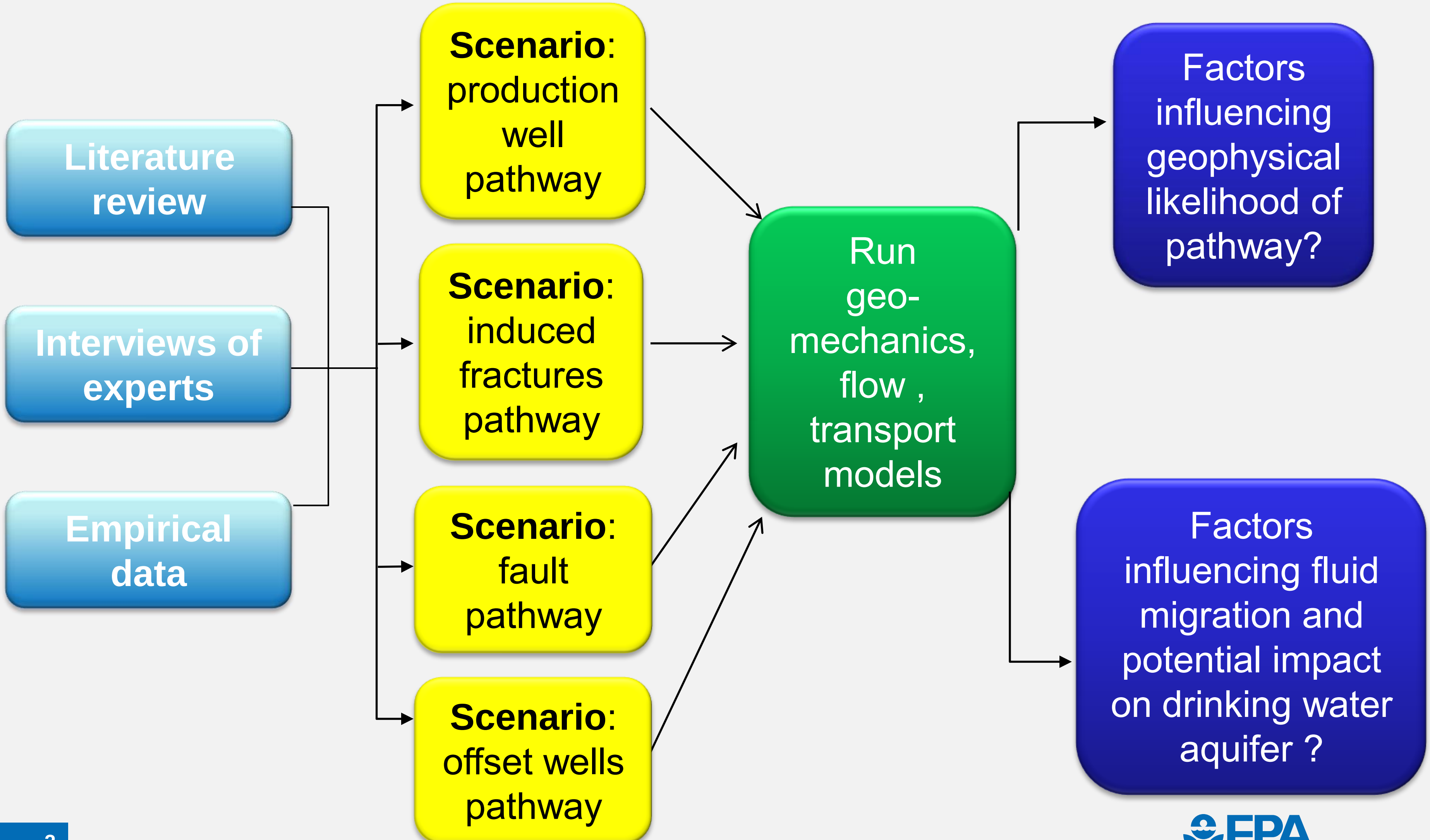
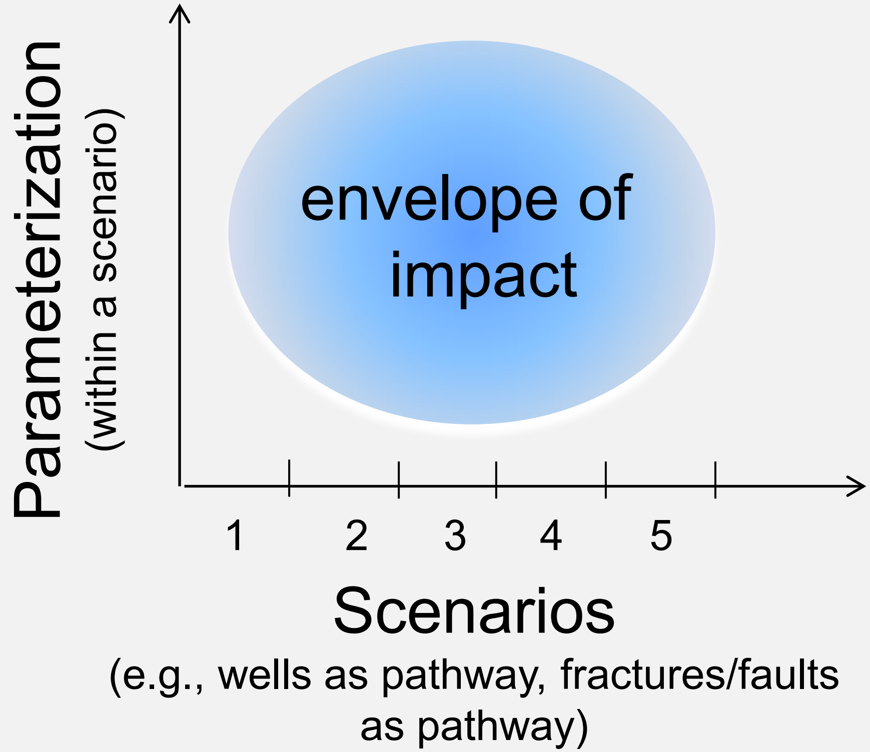
Critical Path for Subsurface Migration Modeling



Impact assessment
(not a comprehensive risk assessment!)

For each hypothetical potential failure scenario, we are looking for combinations of parameters that result in drinking water aquifer impact or no-impact, in order to assess an estimated “envelope” of impact



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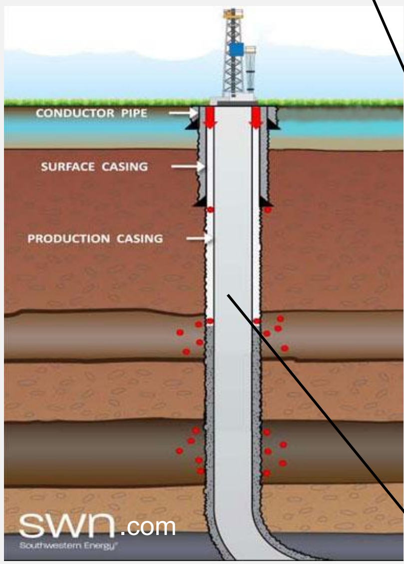
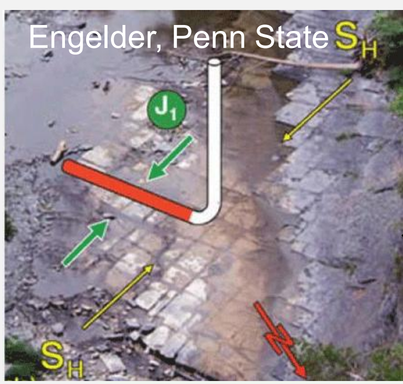
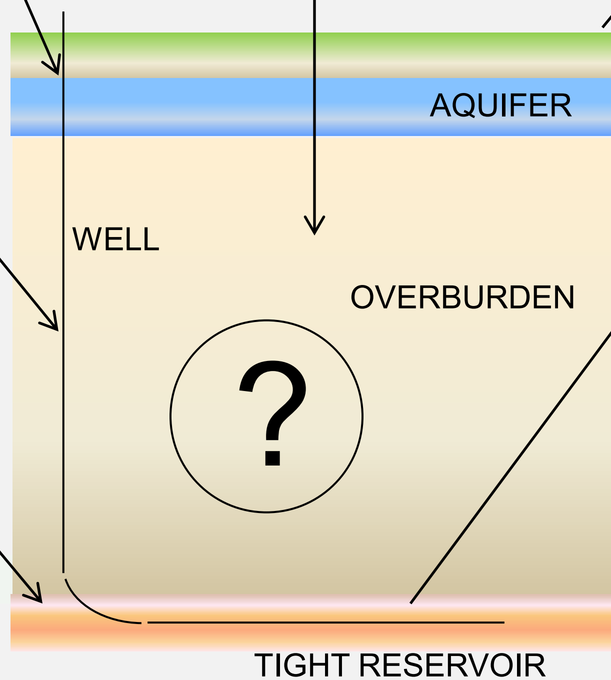
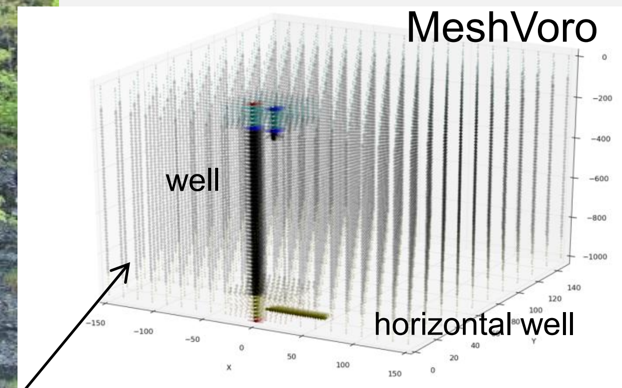
Reality --- Conceptual --- Computational



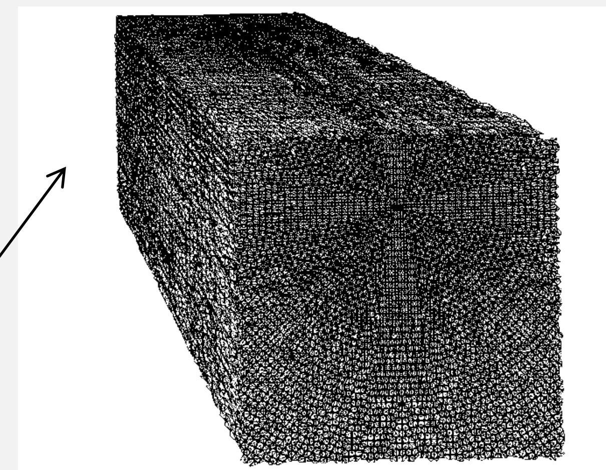


http://en.wikipedia.org/wiki/File:Marcellus_I80_MP307.jpg





Freeman et al, LBNL



Tetrahedralization of region surrounding the horizontal well

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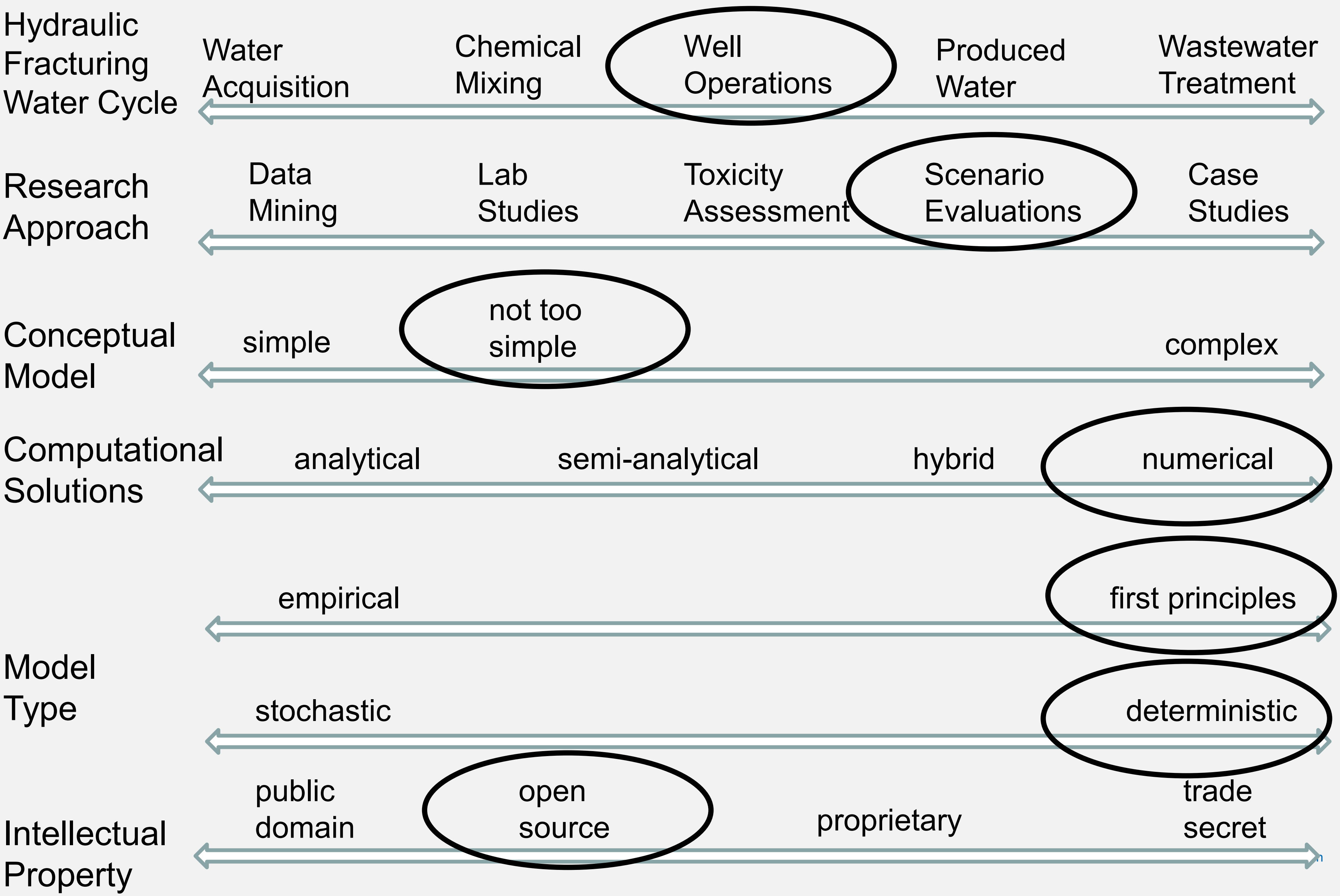
Computational Model Selection

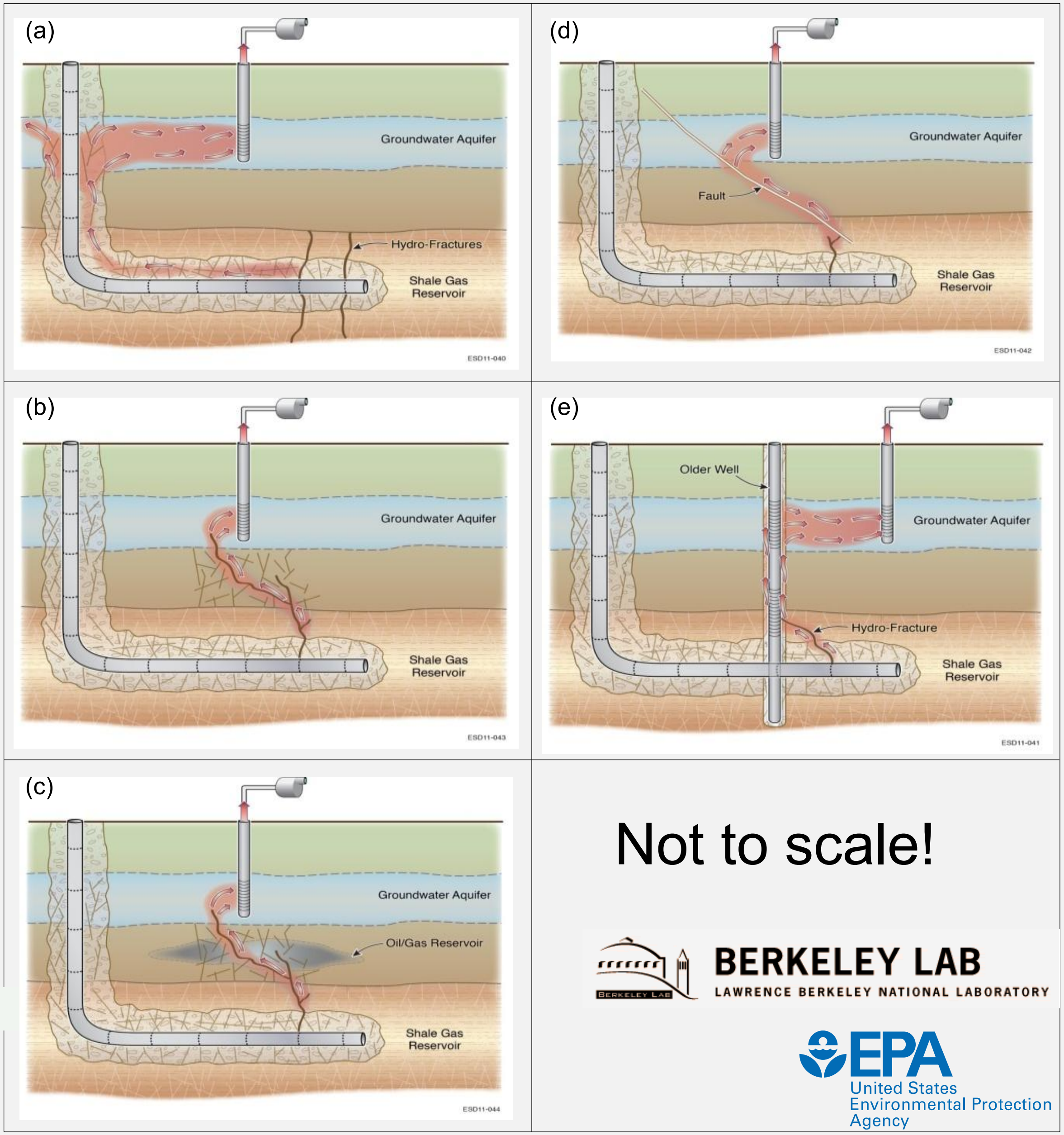


Computational Model Selection

Property	Attributes
multidimensional	2D, 3D
multiphase	liquid, gas
temporality (time)	transient
multicomponent	water, brine, introduced chemicals
non-isothermal	heat
fractured-media	equivalent continuum, dual porosity, multiple interacting continua, dual permeability
coupling	fully coupled (mass and energy), fully implicit

Conceptual Models --- Scenarios

- Geophysical likelihood of pathways?
- Potential for fluid migration?



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Scenario Assumptions

7 sub-domains for modeling (see diagrams):

Shale	Open wellbore
Overburden	Conventional Petroleum reserve
Aquifer	Fault
Fracture	

Each sub-domain has defined flow properties:

- Permeability
- Porosity
- Thermal Properties

And geo-mechanical properties:

- Vertical stress gradient
- Minimum principal horizontal stress
- Young's modulus
- Poisson's ratio
- Fracturing Pressure
- Fault properties

Scenario Assumptions

Properties & Conditions applying to all scenarios:

Constant bottom hole flowing pressure (at the shale reservoir)
Reference value: 3.3 MPa (=500 psi);
Range: 2 MPa to 5 MPa

Water production rate from aquifer (full penetration)
Reference value: 50 m^3;
Range: 20 to 100 m^3/hr

Initial pressure
Reference value: Hydrostatic;
Range: 1.5*hydrostatic (shale only)

Scenario Assumptions

Properties & Conditions applying to all scenarios:

Solute diffusion coefficients in water –

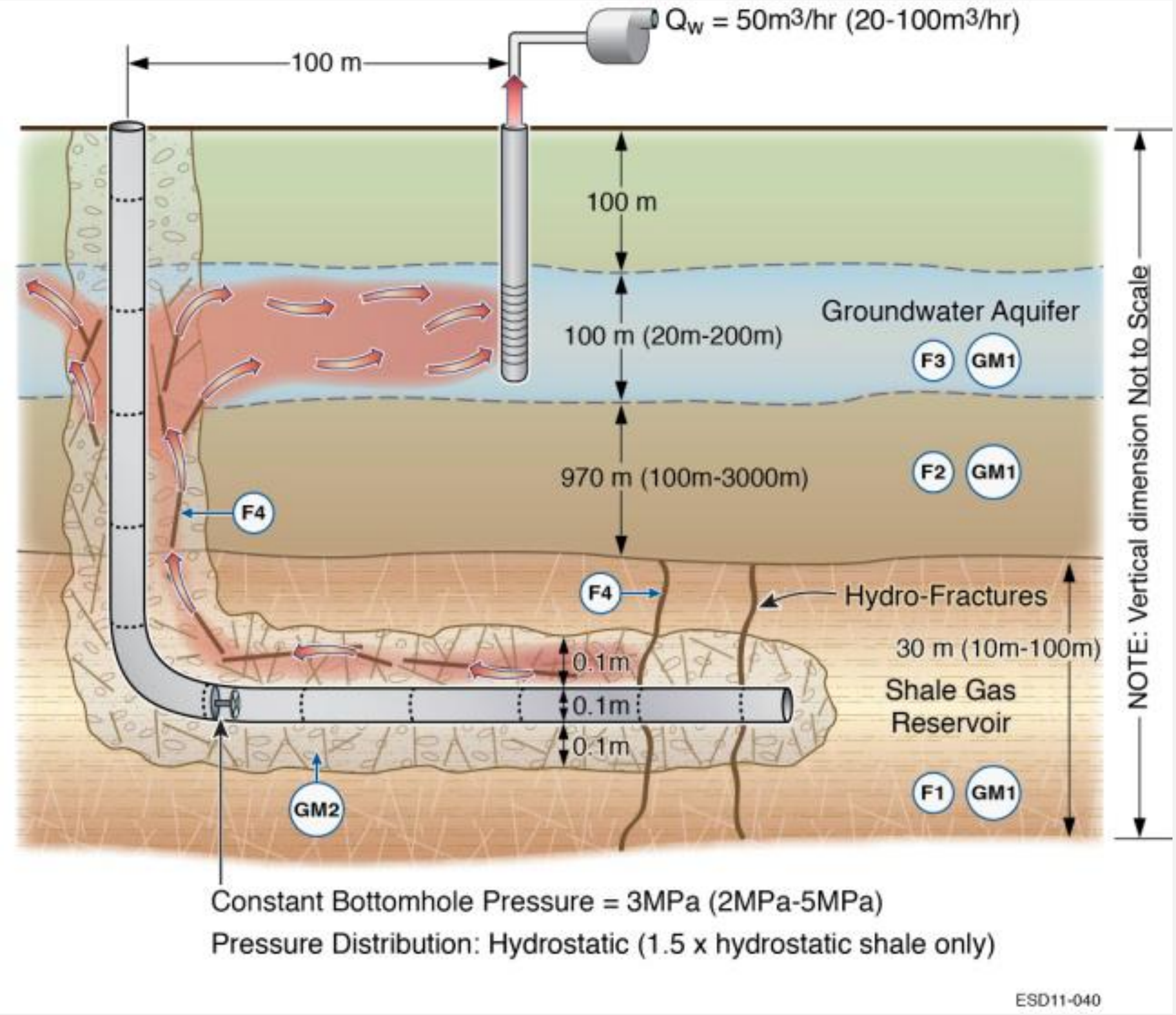
Reference cases, from CRC

Salt: 1.5E-9 m^2/s

Benzene: 1.1E-9 m^2/s

Methane: 1.5E-9 m^2/s

Scenario A: Migration Along Well Bore



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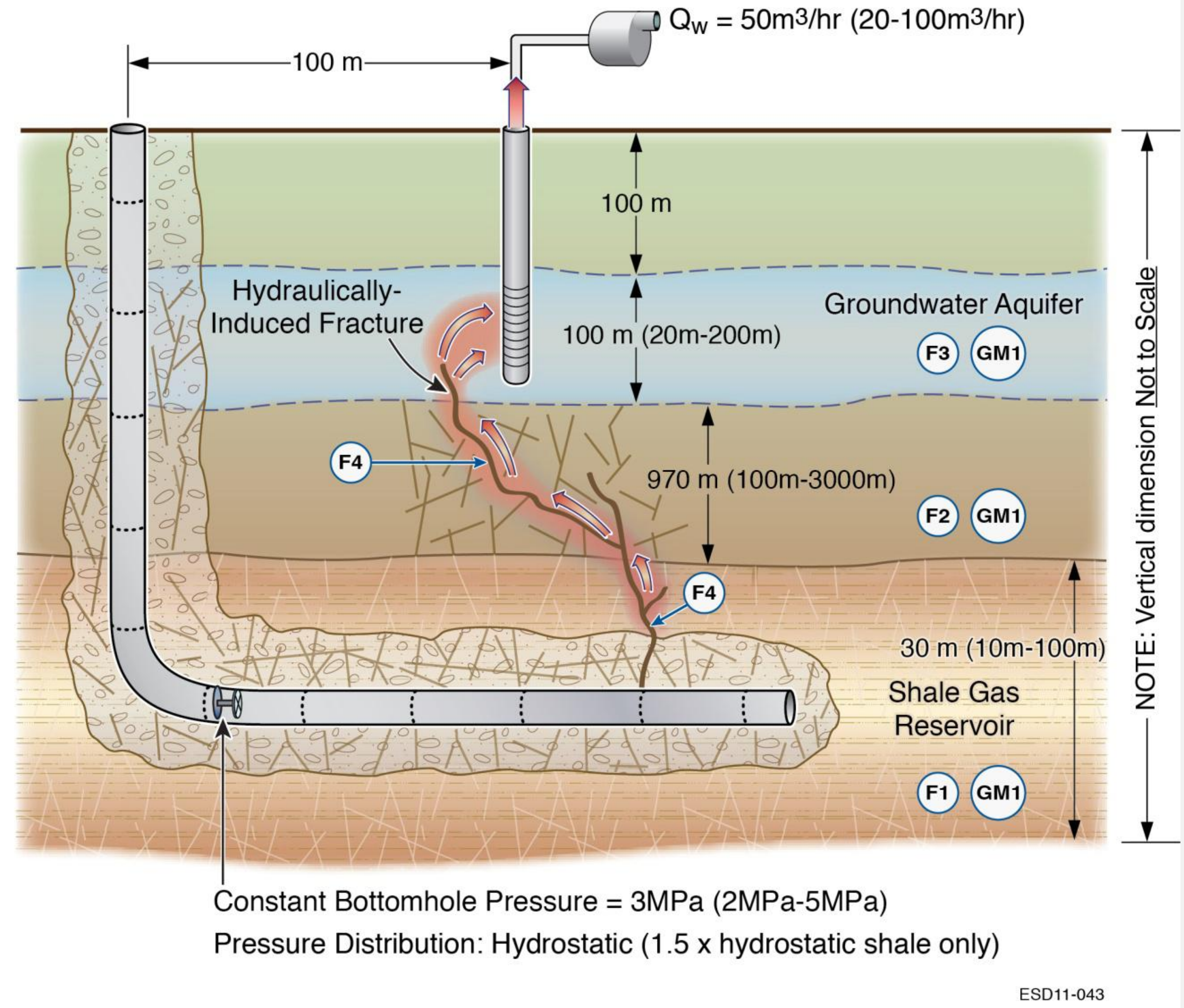
Note: see supplementary slides for properties associated with zones

Scenario B: Hydraulically Induced Fracture



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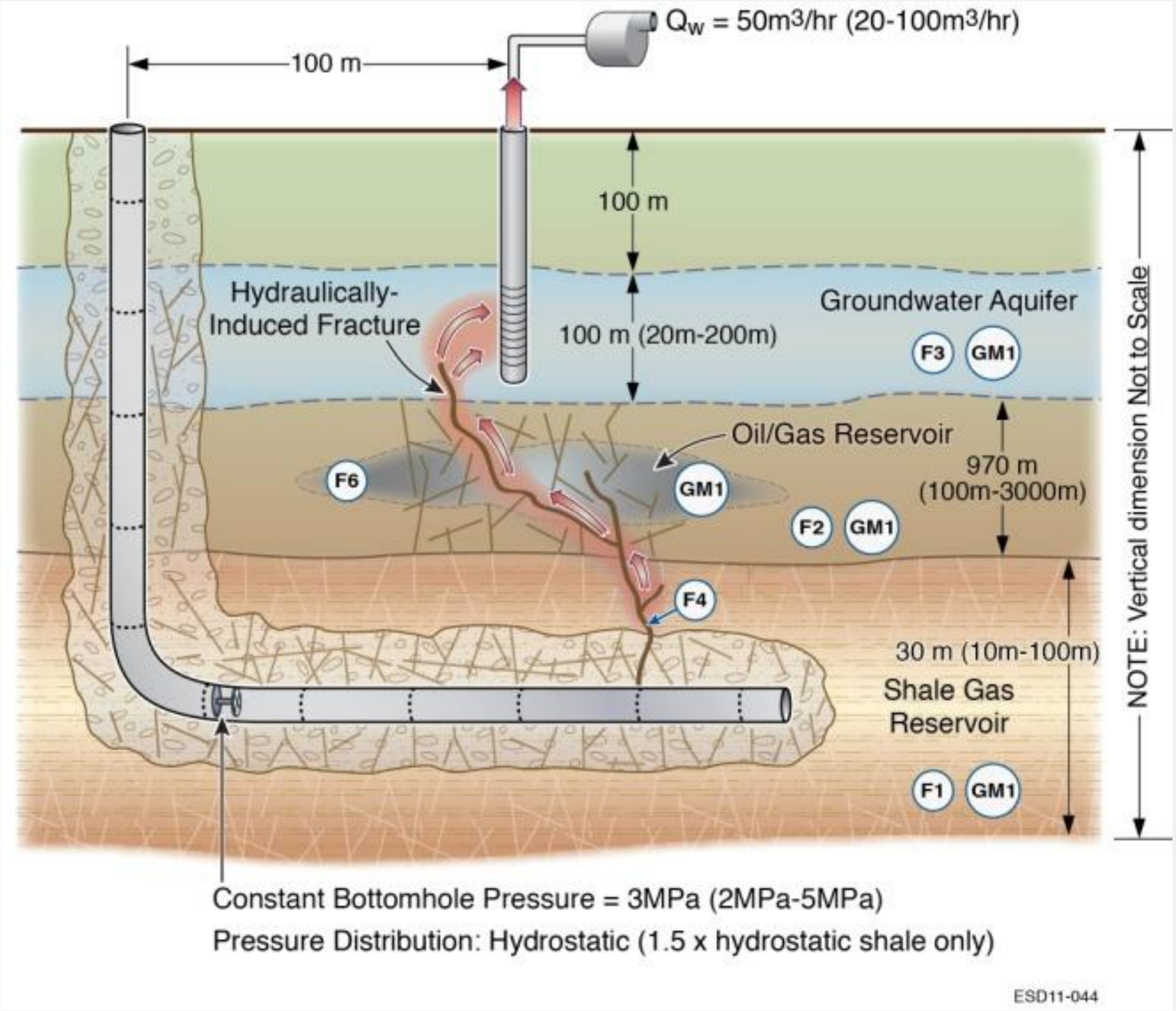
Scenario C: Hydraulically Induced Fracture Through Oil/Gas



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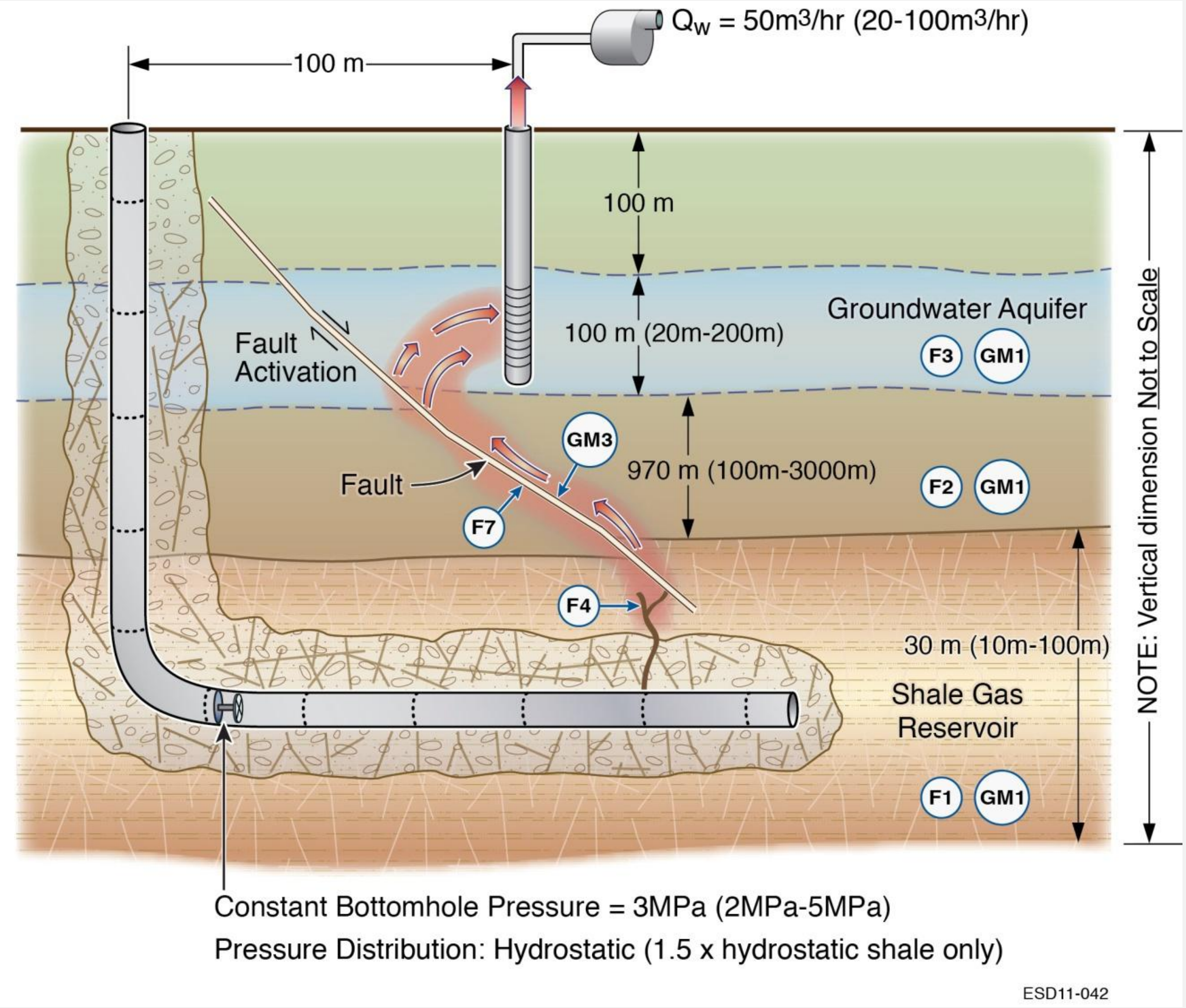
Scenario D: Natural Pathway (Fault or Fracture)



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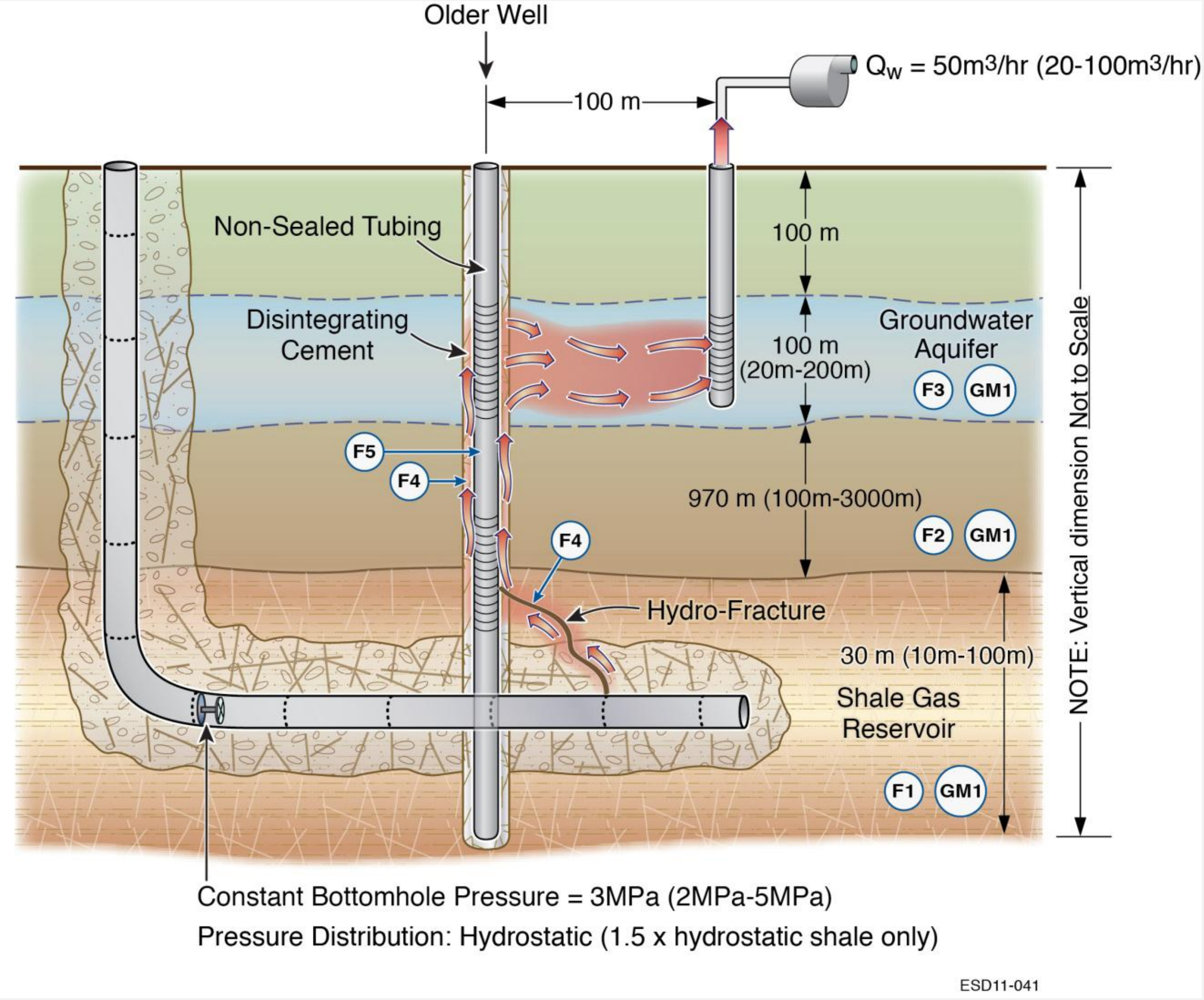
Scenario E: Artificial Pathway (Old Well)



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Publication Plan

Foundations	Status	Journal
1. Gas flow tightly coupled geomechanics	Accepted with minor revisions, 4/8/2013	SPE Journal
2. 3D Voronoi mesh building	In preparation	
3. RGas and RGasH2O modeling with TOUGH+	Accepted 6/18/2013 with minor revisions	Computers & Geosciences
4. RGasH2OCont modeling with TOUGH+	In preparation	
5. T+M coupled flow-thermal-geomechanical	Published online as proof, 5/22/2013	Computers & Geosciences
Physics of Pathway		
6. Modeling fault reactivation	Published online, 5/14/2013	Journal of Petroleum Science and Engineering
7. Fracture propagation in the overburden	Accepted with minor revisions, 4/18/2013	Int. Journal Rock Mechanics and Mining Sciences
8. Geomechanical failure of well cement	In preparation	
Assessment of impact		
9. Gas migration pathways	In preparation	
10. Contaminant transport pathways	In preparation	

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Supplementary Slides

F1: Flow properties of sub-domain 1 (shale)

Shale permeability
Reference value: 1.0E-18 m^2; Range: 1.0E-16 to 1.0E-21 m^2

Shale porosity
Reference value: 0.10; Range: 0.05 to 0.15

Thermal properties (invariable)
Saturated thermal conductivity: 4 W/m/K
Dry thermal conductivity: 1 W/m/K
Rock specific heat: 1000 J/kg

F2: Flow properties of sub-domain 2 (overburden)

Overburden permeability:
Reference value: 0.0 m^2

Overburden porosity
Reference value: 0.05

Thermal properties (invariable)
Saturated thermal conductivity: 4 W/m/K
Dry thermal conductivity: 1 W/m/K
Rock specific heat: 1000 J/kg

F3: Flow properties of sub-domain 3 (aquifer)

Aquifer permeability
Reference value: 1.0E-12 m^2; Range: 1.0E-11 to 5.0E-12 m^2

Aquifer porosity
Reference value: 0.30; Range: 0.15 to 0.40

Thermal properties (invariable)
Saturated thermal conductivity: 3.5 W/m/K
Dry thermal conductivity: 0.75 W/m/K
Rock specific heat: 1000 J/kg

F4: Flow properties of sub-domain 4 (fracture)

Fracture permeability: function of aperture b, i.e., $k = b^2/12\ m^2$
Reference value: b = 1.0E-3 m; Range: 1.0E-4 m to 1.0E-2 m

Fracture porosity
Reference value: 0.70; Range: 0.50 to 1.0

F5: Flow properties of sub-domain 5 (open wellbore)

Permeability
Reference value: 1.0E-8 m^2

Fracture porosity
Reference value: 1.0

F6: Flow properties of sub-domain 6 (conventional petroleum reservoir)

Permeability
Reference value: 1.0E-14 m^2

Porosity
Reference value: 0.20

Thermal properties (invariable)
Saturated thermal conductivity: 4 W/m/K
Dry thermal conductivity: 1 W/m/K
Rock specific heat: 1000 J/kg

F7: Flow properties of sub-domain 7 (fault)

Fault permeability
Reference value: 1.0E-16 m^2; Range: 1.0E-14 to 1.0E-19 m^2

Fault porosity
Reference value: 0.30; Range: 0.15 to 0.40

Thermal properties (invariable)
Saturated thermal conductivity: 3.5 W/m/K
Dry thermal conductivity: 0.75 W/m/K
Rock specific heat: 1000 J/kg

GM1: Geomechanical property set 1

Vertical stress gradient (maximum principal stress)
26487 Pa/m, corresponding to an overburden density of about 2700 kg/m^3.
Minimum principal horizontal stress
Reference value: 0.6*Vertical stress; Range: 0.5 to 0.7*Vertical stress

Young's Modulus (Marcellus shale and overburden)
Reference value: 30 GPa; Range: 10-50 GPa

Poisson's ratio
Reference value: 0.2; Range: 0.15 to 0.25

GM2: Geomechanical property set 2

Tensile strength – Reference cases
Casing-to-cement: 2 MPa
Cement: 5.0 MPa
Shale: 8.0 Mpa

Young's modulus – Reference cases
Casing-to-cement: 10 GPa
Cement: 10.0 GPa
Shale: 30 GPa (4–50 GPa)

Poisson's ratio – Reference cases
Casing-to-cement: 0.18
Cement: 0.18
Shale: 0.35

Fracturing pressure
Depends on depth, up to 150 MPa; extreme case up to 28 GPa

GM3: Geomechanical property set 3 (fault)

Fault properties - Cohesionless fault with coefficient of friction
Reference value: 0.6; Range: 0.5 to 0.7

Fault properties - residual friction (after slip) in a slip-weakening model
Reference value: 0.2

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Important references used as data sources

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