



# **Modeling ASR Hydraulics and Plume Geometry**

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**Aquifer Storage and Recovery IV**

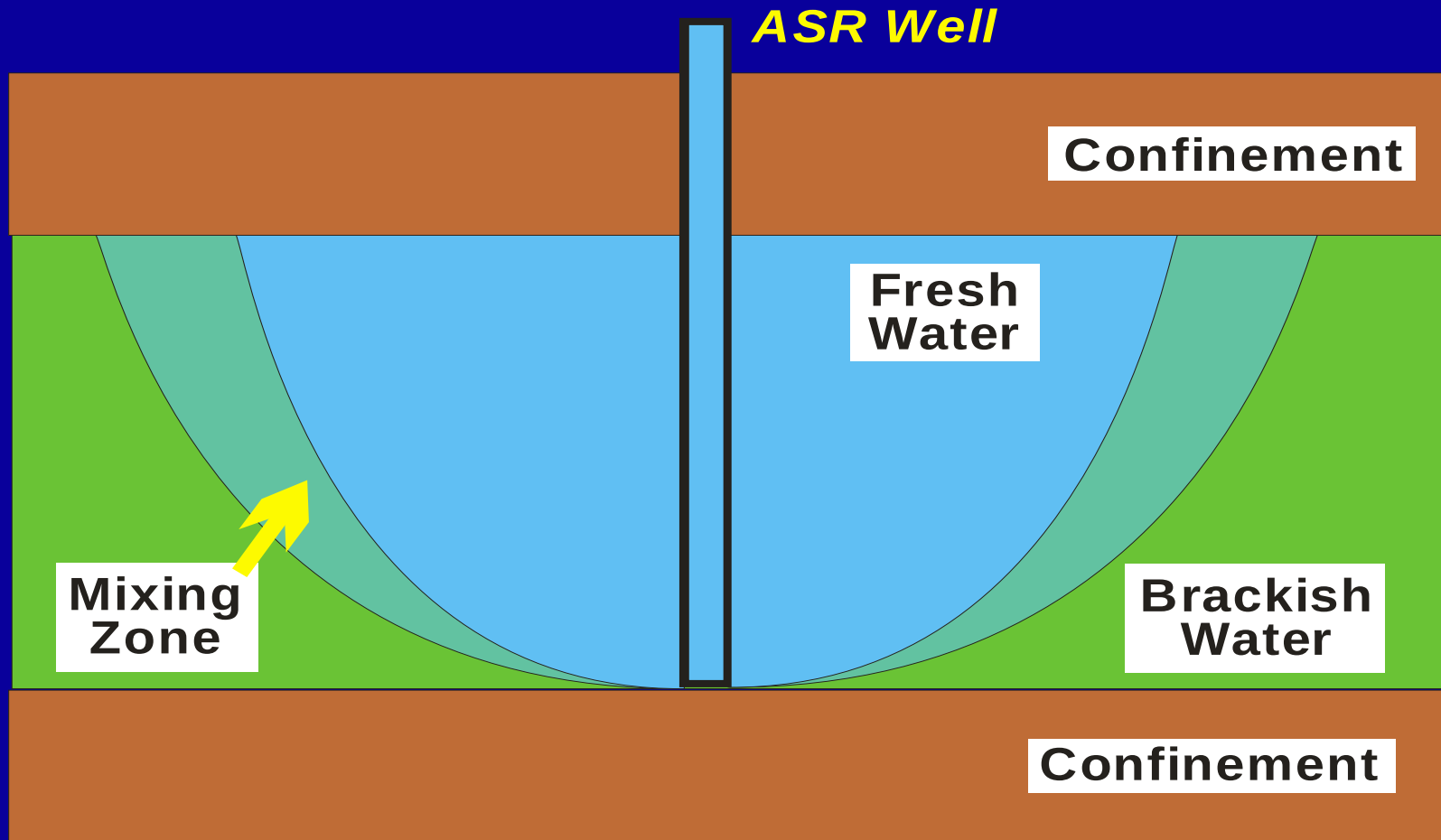
**American Groundwater Trust**

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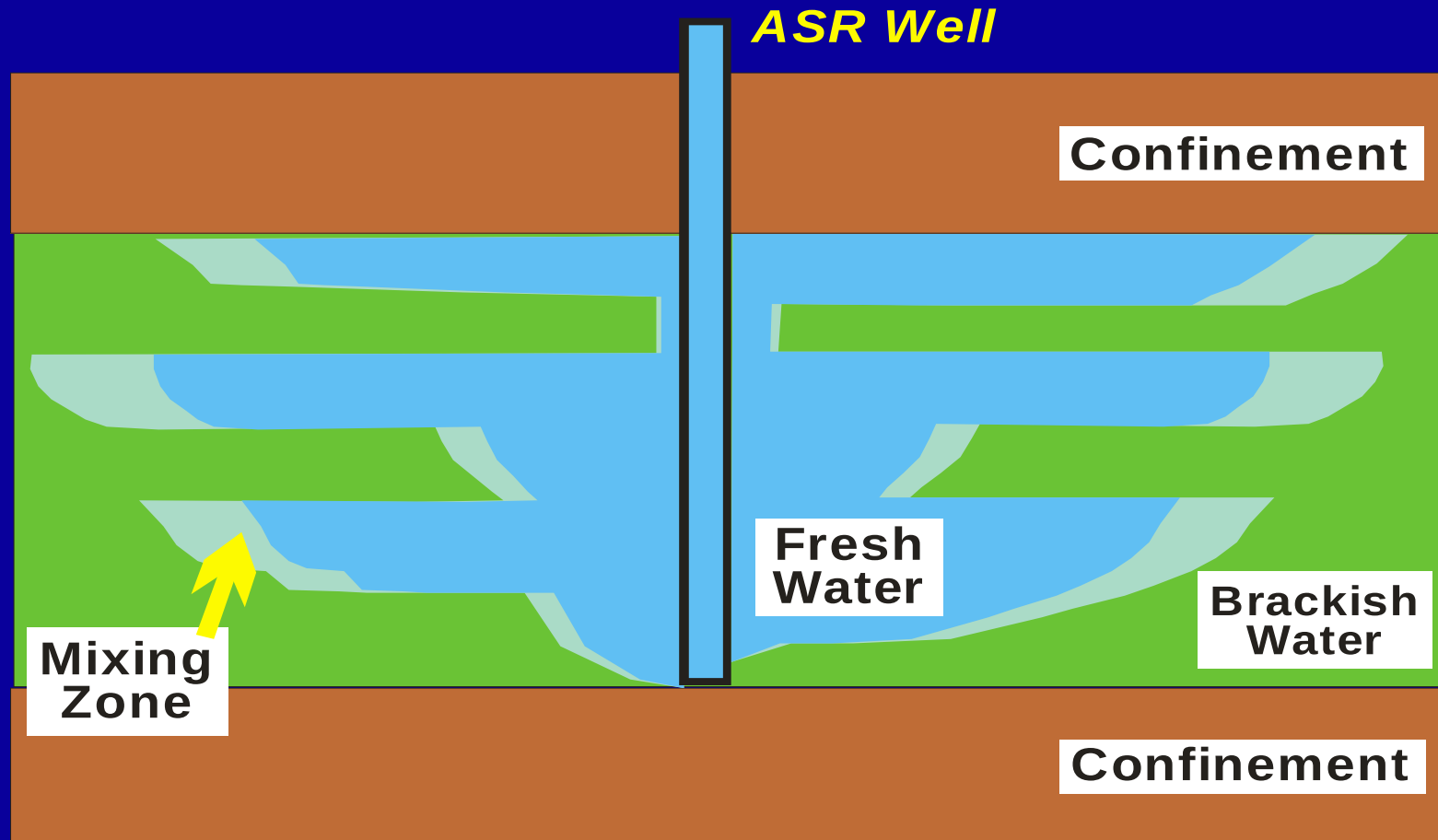
# Purpose

**To discuss the scientific issues involved in modeling and evaluating ASR systems in carbonate aquifers.**

# ASR Concepts: “The bubble”



# ASR Concepts: the real world



# **Aquifer Heterogeneity**

**“Geology is ubiquitously heterogeneous, exhibiting both discrete and continuous spatial variations on a multiplicity of scales. It is therefore natural to expect that hydrogeologic and other geophysical variables would due likewise.”**

**Neuman and Federico, 2003**

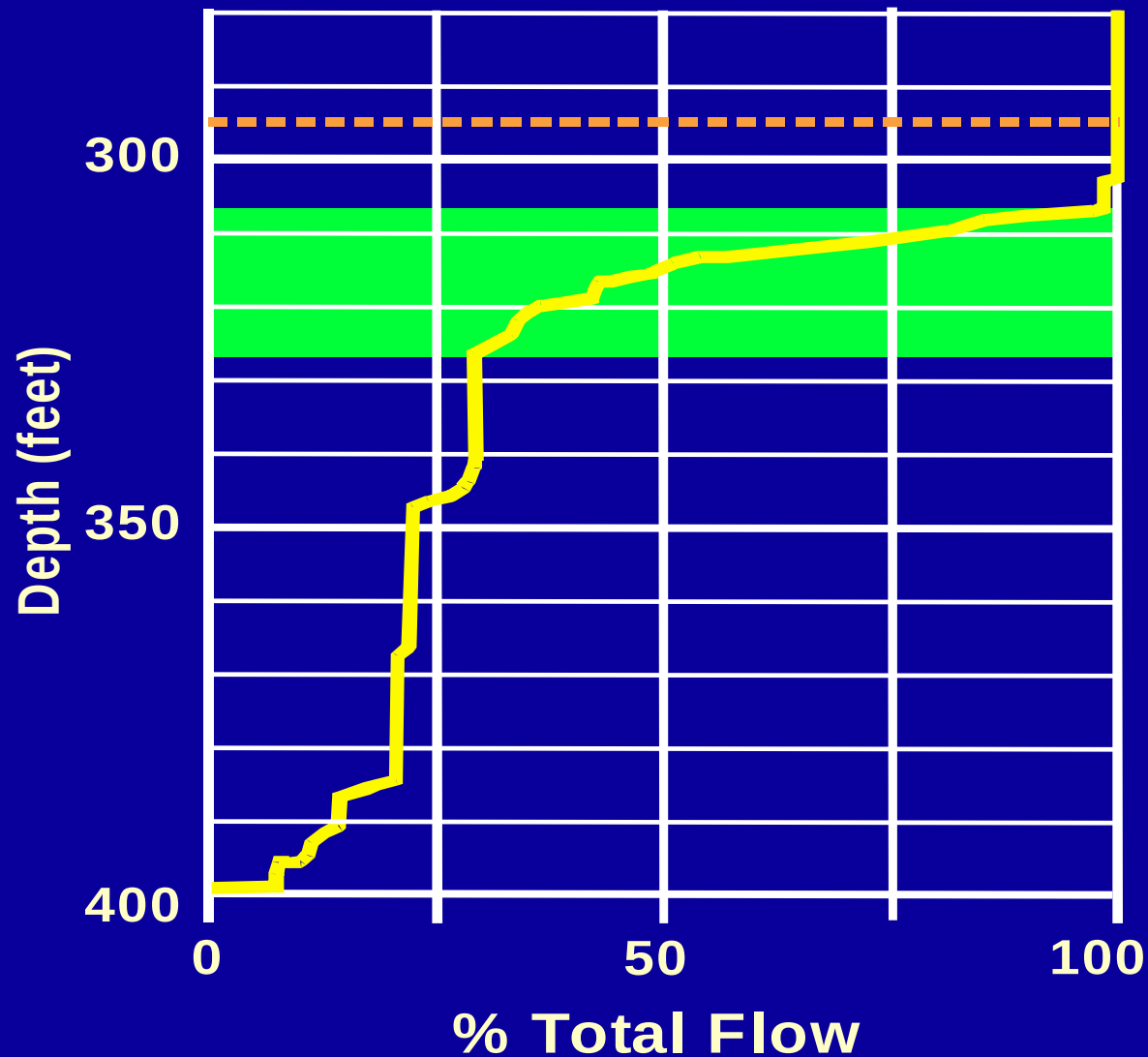
# How heterogeneous are carbonate aquifers?

- Flowmeter interpretation logs are best tool for evaluating heterogeneity
- Require dynamic and static flowmeter logs and caliper log
- Transmissivity of aquifer zones can be estimated from flowmeter interpretation logs if aquifer transmissivity is determined from an aquifer performance test

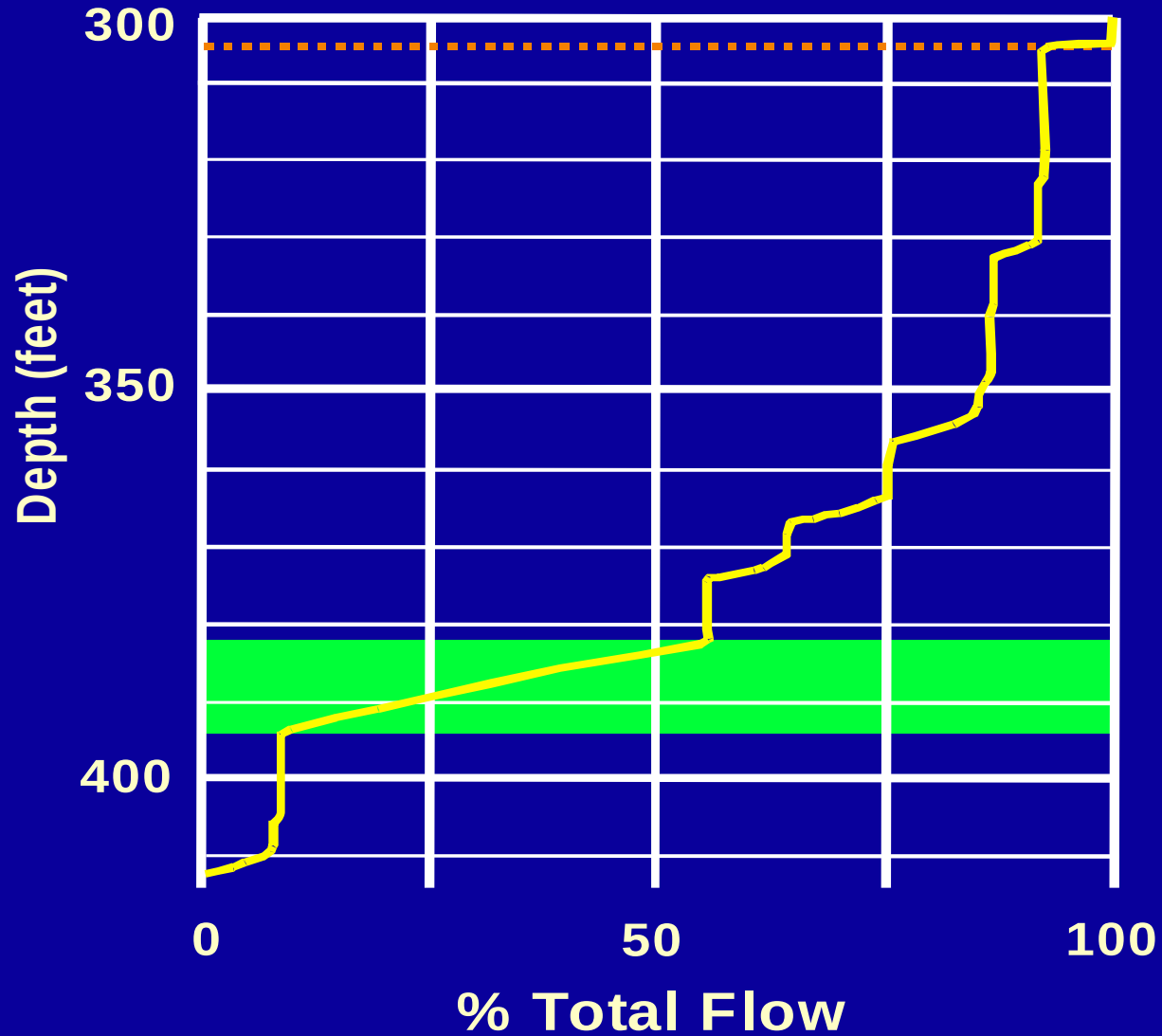
# **Factors responsible for aquifer heterogeneity.**

- **Primary (depositional) variations in hydraulic conductivity.**
- **Diagenesis, including cementation, dolomitization, and dissolution.**
- **Fracturing.**

# Collier County, Florida, Golden Gate TP-1



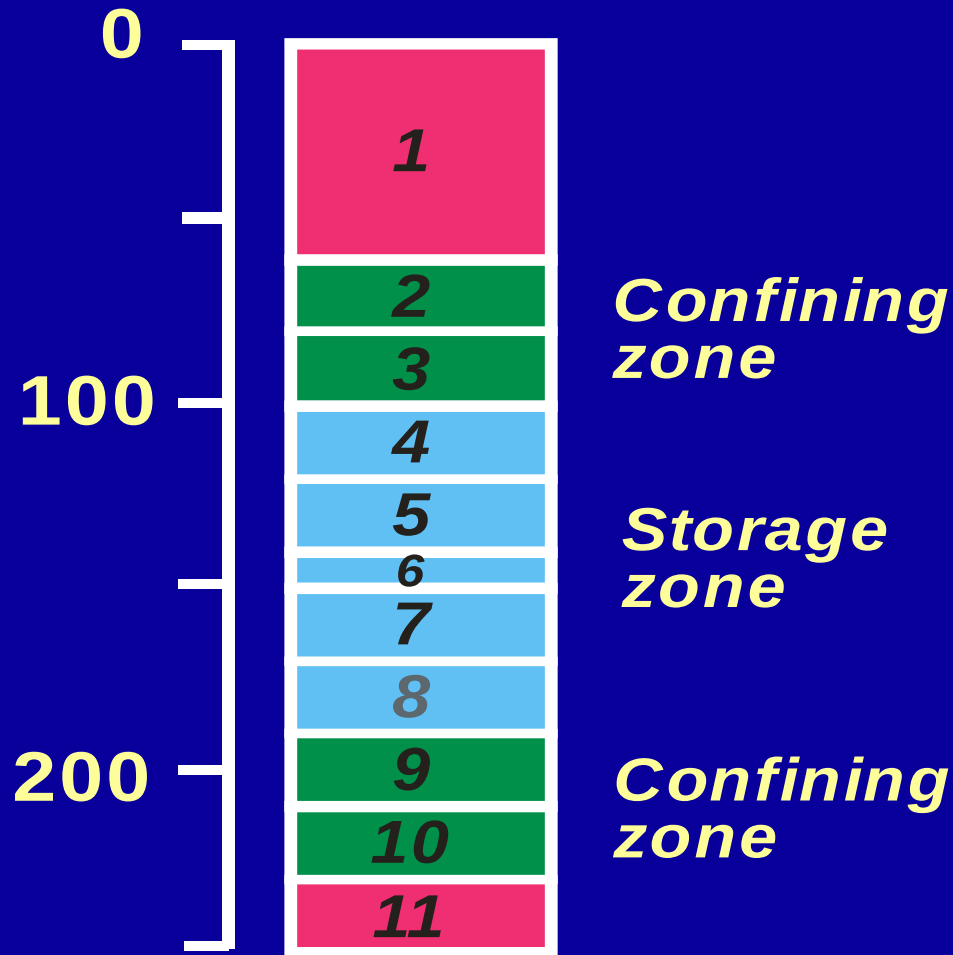
# Hillsborough County, Florida, NW ASR TP-1



# ASR modeling

- SEAWAT. Three-dimensional, variable-density, transient groundwater flow code, developed by combining MODFLOW and MT3DMS programs.
- Model based on hydraulic parameters of an existing operational ASR system (Collier County Manatee Road).
- Model scenario is based on reasonable operational mode for a utility system.

# Base model



- 121 rows and columns.
- 50 ft spacing (x,y).
- $T = 18,000 \text{ ft}^2/\text{day}$ .
- $SC = 1 \times 10^{-4}$ .
- Leakage (upper and lower)  $= 4.7 \times 10^{-5} \text{ day}^{-1}$ .
- Dispersivity = 30 ft.
- Native water = 5,000 mg/L TDS.
- Recharge water = 200 mg/L TDS.

# Model Scenarios

- Simulate high-capacity (2 Mgd) system under potential operational conditions.
- Scenario:
  - Inject 2 Mgd for 120 days
  - 245 days of storage
  - Inject 2 Mgd for 120 days
  - 245 days of storage
  - Inject 2 Mgd for 120 days
  - 120 days of storage
  - Recovery until TDS exceeds 500 mg/L.
- Recovery efficiency calculated based on last cycle.

# Modeling results - salinity

- Native storage zone salinity in the most important variable as far as influencing recovery efficiency.
- Base model (5,000 mg/L TDS): 68%.
- TDS = 2,500 mg/L: 100%
- TDS = 1,000 mg/L: 218%
- TDS = 10,000 mg/L: 46%

# Modeling results - transmissivity

- Transmissivity has a very minor impact on recovery efficiency.
- Base model (18,000 ft<sup>2</sup>/day): 68%.
- T = 36,000 ft<sup>2</sup>/day (2X): 68%
- T = 180,000 ft<sup>2</sup>/day (10X): 67%
- T = 9,000 ft<sup>2</sup>/day (1/2 X): 68%
- T = 1,800 ft<sup>2</sup>/day (1/10X): 64%
- Transmissivity is important to the extent it impacts well yields.

# Modeling results – dispersivity

- Dispersivity is the second most important variable as far as influencing recovery efficiency.
- Base model (longitudinal = 30 feet): 68%.
- Dispersivity = 60 ft (2X): 48%
- Dispersivity = 15 ft: (1/2): 80%

# Modeling results – effective porosity

- Effective porosity has a relatively minor effect on recovery efficiency.
- Base model (porosity = 25%): 68%.
- Effective porosity = 50% (2X): 73%
- Effective porosity = 12.5% (1/2 X): (1/2): 63%

## Modeling results – leakance ( $V_{\text{cont}}$ )

- High leakances of confining strata reduce recovery efficiency.
- Base model ( $4.7 \times 10^{-5} \text{ day}^{-1}$ ): 68%.
- Leakance =  $4.7 \times 10^{-6} \text{ day}^{-1}$  (1/10 X): 69%
- Leakance = 0: 70%
- Leakance =  $4.7 \times 10^{-4} \text{ day}^{-1}$  (10X): 63%
- Leakance =  $4.7 \times 10^{-3} \text{ day}^{-1}$  (100X): 52%
- Leakance =  $4.7 \times 10^{-2} \text{ day}^{-1}$  (1,000X): 37%

# Modeling results – aquifer heterogeneity

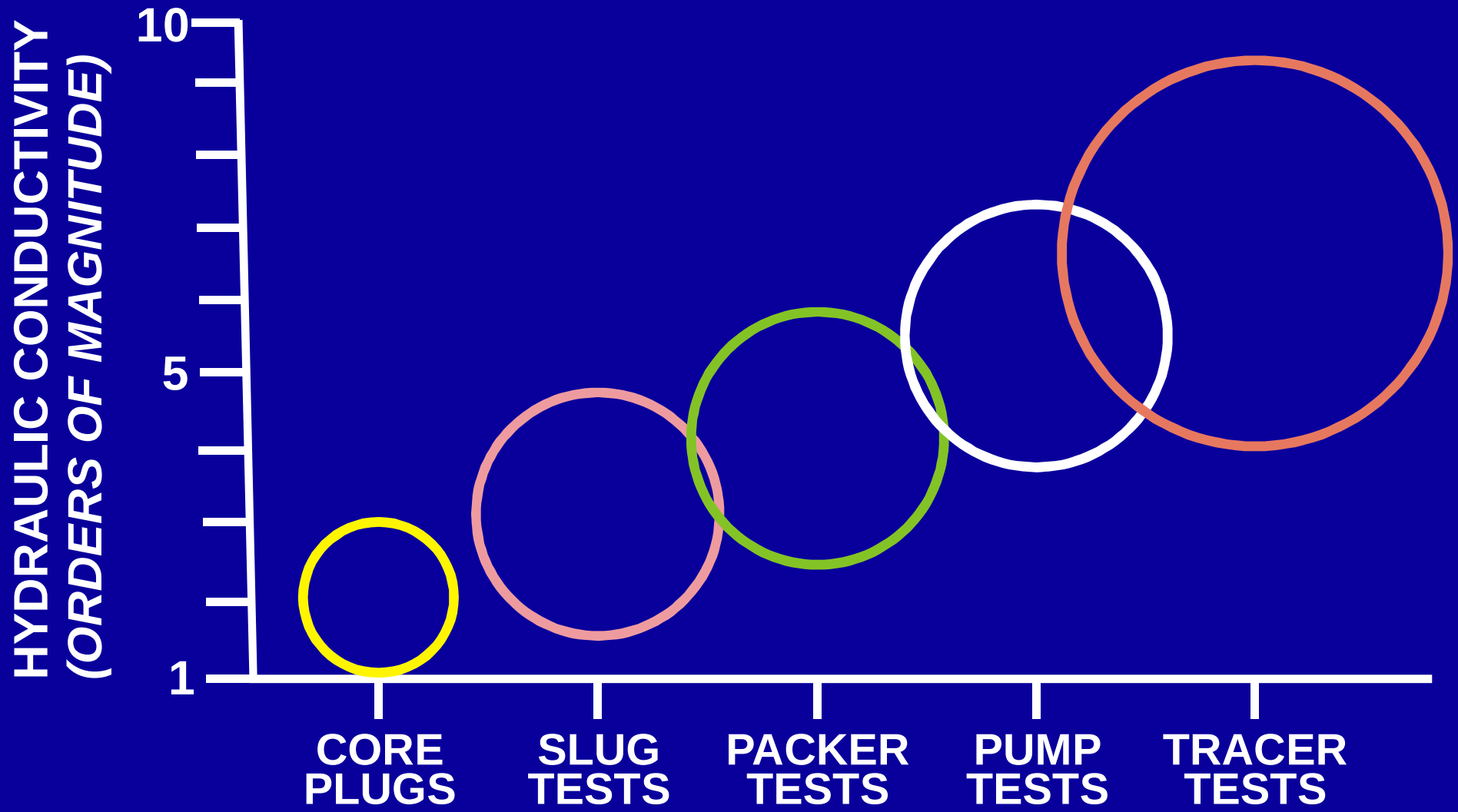
- Base model (no heterogeneity): 68%.
- 50% of flow in Layer 5: 84%
- 80% of flow in Layer 5: 80%
- 95% of flow in Layer 5: 52%
- Results suggest that some limited heterogeneity is beneficial as far as recovery efficiency, but too much heterogeneity has adverse impacts.

# Aquifer heterogeneity – effects of hydraulic gradient

- Annual flow distance under a 1 ft/mile hydraulic gradient (effective porosity = 25%).
- Homogenous aquifer (HC = 200 ft/day): 55 ft.
- Within 10 ft layer accepting 50% of flow (HC = 900 ft/day): 249 ft.
- Within 10 ft layer accepting 80% of flow (HC = 1400 ft/day): 398 ft.
- Aquifer heterogeneity is a critical variable for ASR systems in areas with a significant hydraulic gradient.

# **The Scale Factor**

- 1. The larger the scale of testing – the larger the hydraulic conductivity measured.**
- 2. The larger the scale of an ASR project – the larger the influence area.**



# The Scale Factor

- Effects plume geometry
- Effects recovery
- Extremely important in carbonate aquifers

# Conclusions

- Carbonate aquifers are inherently heterogeneous with respect to hydraulic conductivity.
- Aquifer heterogeneity can have both positive and negative impacts on the recovery efficiency of ASR systems.

# Conclusions

- Significant aquifer heterogeneity combined with a moderate to high hydraulic gradient can result in the rapid migration of stored water away from ASR systems.
- In brackish water ASR systems, native storage zone water quality is very important in determining ultimate system recovery efficiency. Dispersivity is also important.

# Conclusions

- Transmissivity, effective porosity, confining zone leakance are of subsidiary importance in determining ASR system recovery efficiency.
- Detailed hydrogeologic analyses combined with solute transport modeling has great potential value toward predicting potential ASR system performance. The data and results must be evaluated objectively to overcome project inertia.