Modeling Aquifer Storage and Recovery

California Water & Environmental Modeling Forum

Tailoring Complexity to the Needs of Operators and Regulators

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INTERA

April 17, 2023

Outline

- Intro to Aquifer Storage and Recovery (ASR)
- Typical ASR Modeling Applications/Objectives
- ASR Modeling Techniques
- Case Studies (if time)

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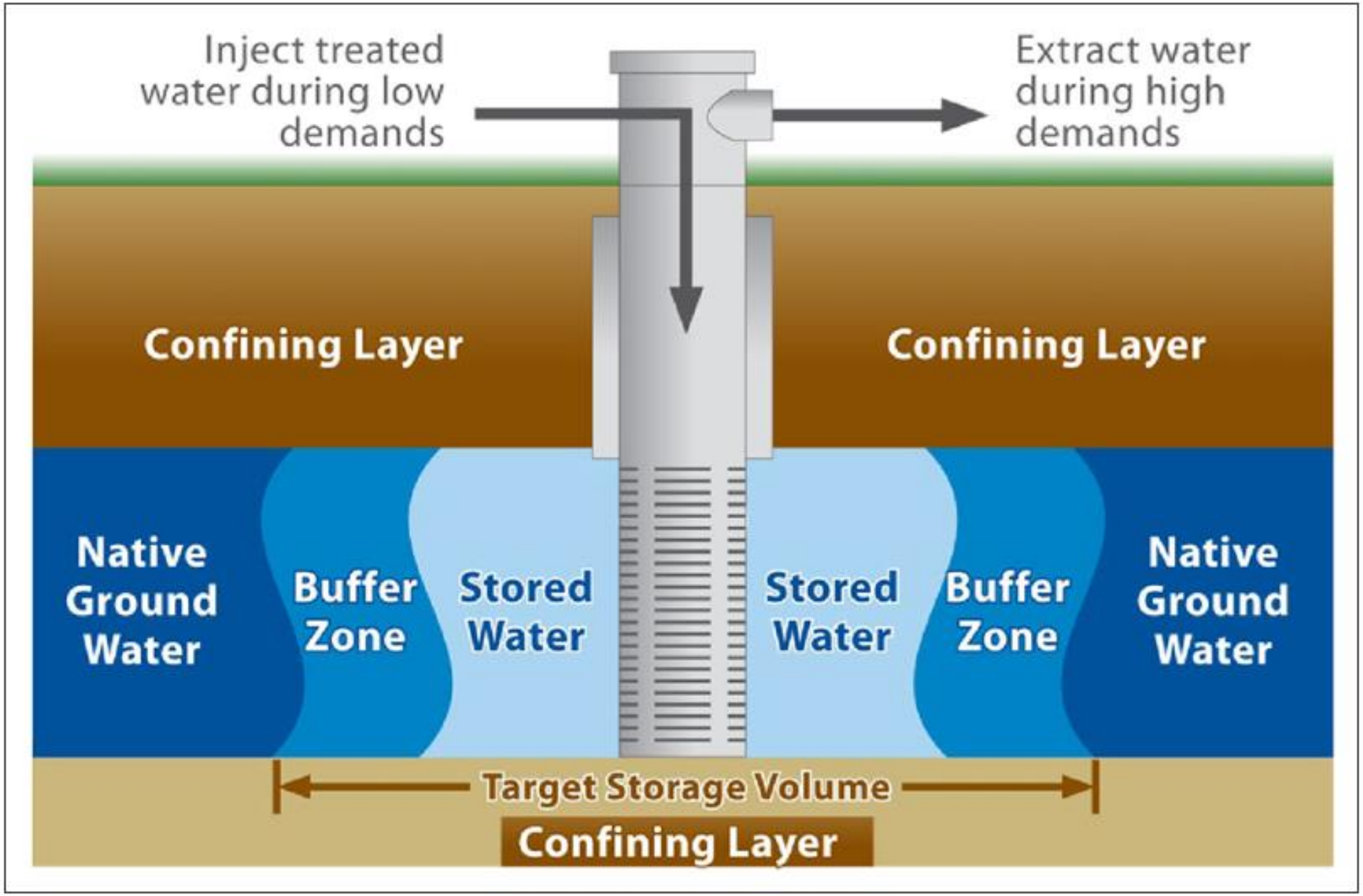
Aquifer Storage Recovery (ASR)

Storing water underground during wet periods for recovery when needed, usually during dry periods



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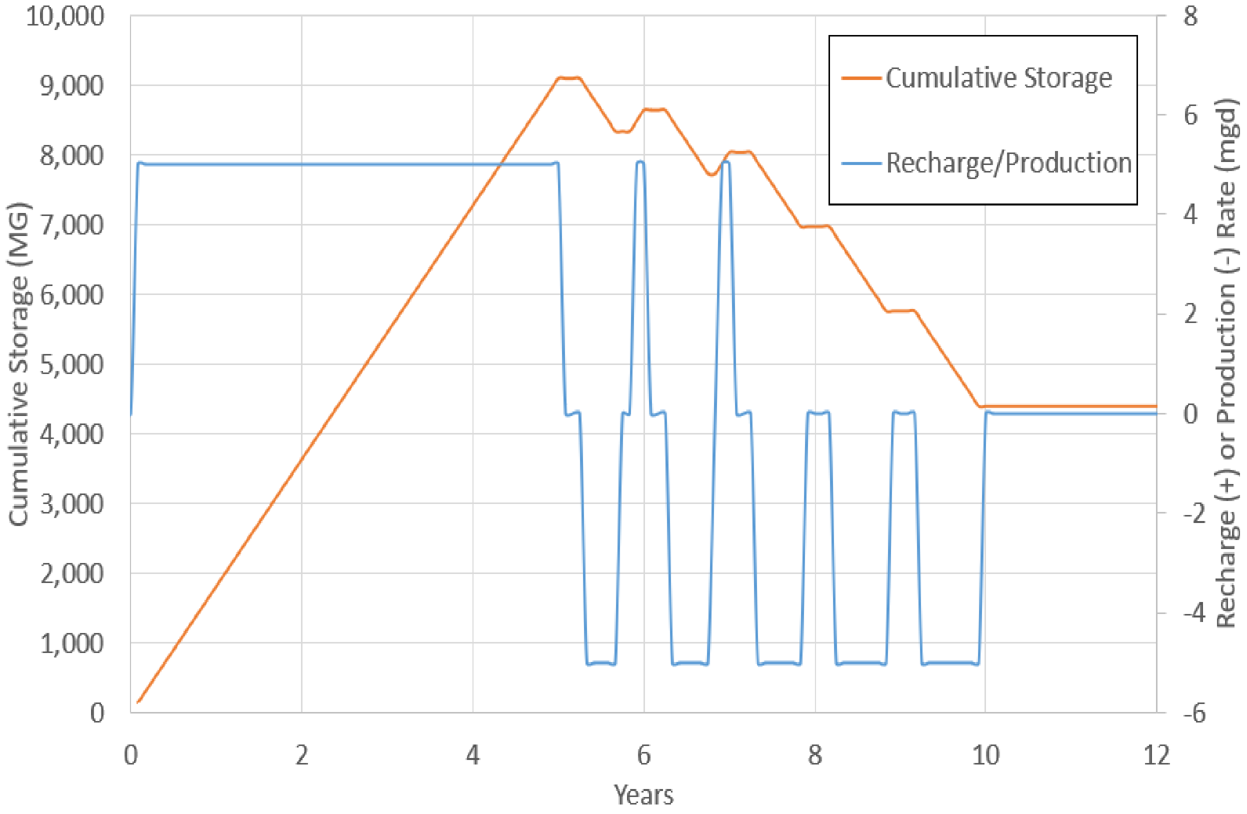
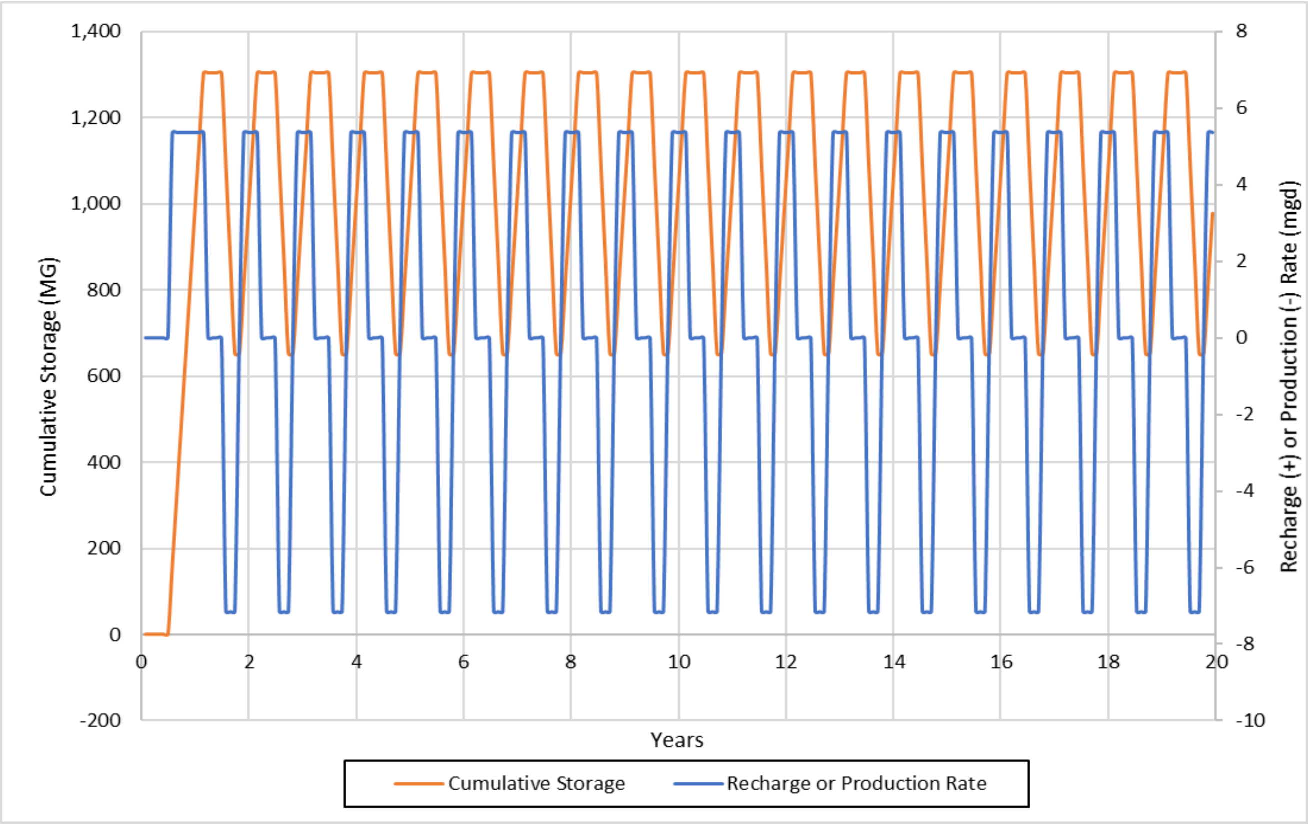
ASR: Typical Applications

Drought storage



Summer Peaking



ASR Modeling: Why?

- Wellfield design/operation
  - Hydraulics (uplift/drawdown, wellhead pressures)
  - Interwell interference
  - Stored water migration
  - Recovered water quality
- Regulation/ permitting
  - ASR boundary
  - Hydraulic control
  - Recoverability

STATE WATER RESOURCES CONTROL BOARD
WATER QUALITY ORDER 2012-0010

GENERAL WASTE DISCHARGE REQUIREMENTS FOR AQUIFER STORAGE AND RECOVERY PROJECTS THAT INJECT DRINKING WATER INTO GROUNDWATER

ATTACHMENT C
NOTICE OF INTENT TECHNICAL REPORT REQUIREMENTS
GENERAL WASTE DISCHARGE REQUIREMENTS FOR ASR PROJECTS THAT INJECT DRINKING WATER INTO GROUNDWATER

At a minimum, the technical report shall address the following:

1. The Applicant's statement of intent to comply with the terms and conditions of this Order.
2. A copy of the CDPH domestic water supply permit for the injected source water.
3. A project description that includes:
   a. A map that identifies all of the wells that will be used for injection/extraction and/or monitoring.
   b. The target aquifer zones into which water will be injected. Provide available information on the aquifer thickness, the presence of low or high permeability zones, and groundwater elevations.
   c. The area of hydrologic influence of the proposed project. This information shall be supported by analysis of existing data or a numerical model.

Texas Commission on Environmental Quality
Application for Class V Underground Injection Control (UIC) Wells for an Aquifer Storage and Recovery (ASR) Project

Section VIII. Demonstration of Recoverability

:he commission to make a determination as to whether injection of water into a
ıation will result in a loss of injected water or native groundwater, as required
§27.154(b), please provide an analysis of the volume of injected water that will be
'his analysis should consider the geologic, hydrogeologic, and hydrochemistry of the
e, the quality of the injected water, and the operational conditions proposed for the
commission anticipates that this analysis will require groundwater modeling.

STATE OF COLORADO
GROUND WATER COMMISSION

ULES AND REGULATIONS FOR THE MANAGEMENT AND CONTROL OF DESIGNATED GROUND WATER

2 CCR 410-1

3 Aquifer storage and recovery plans (ASR Plan).
charge water into, store water in, and recover water fr
ıter that is so recharged, stored, and recovered is refe
ater.

5. If a ground water model is submitted or required, then plan approvals shall include appropriate terms and conditions for updating and/or recalibration of any groundwater model(s) and a schedule for specified adjustments to the plan in accordance with the potential results of any such updated/recalibrated modeling.

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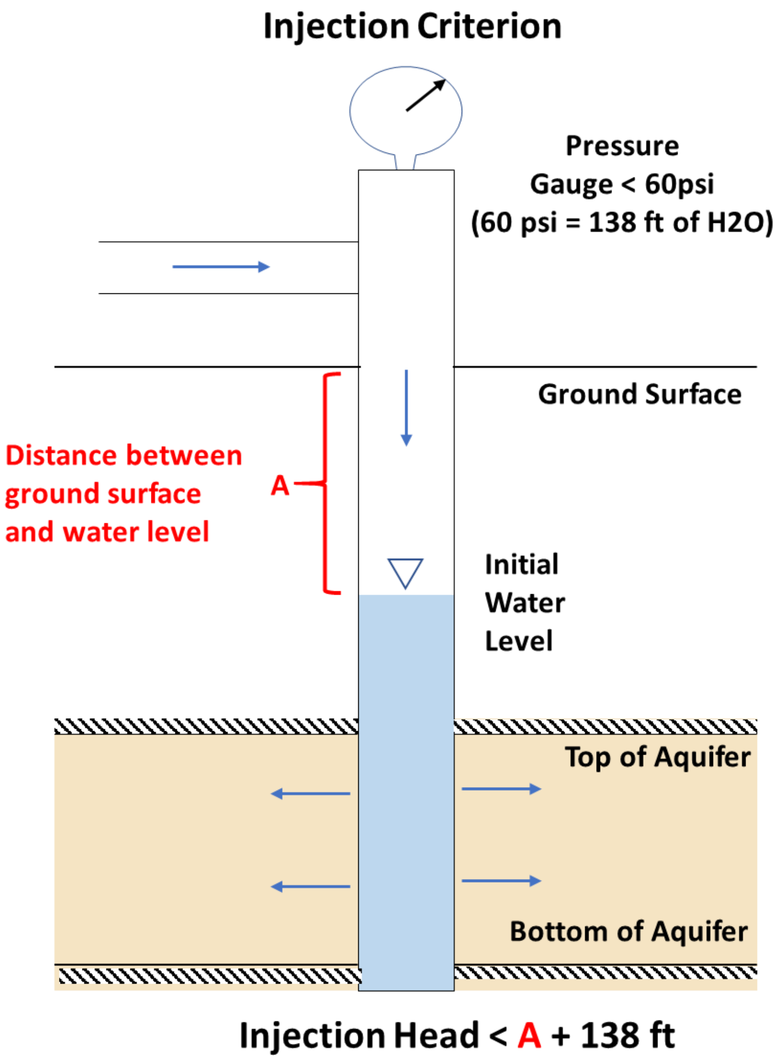
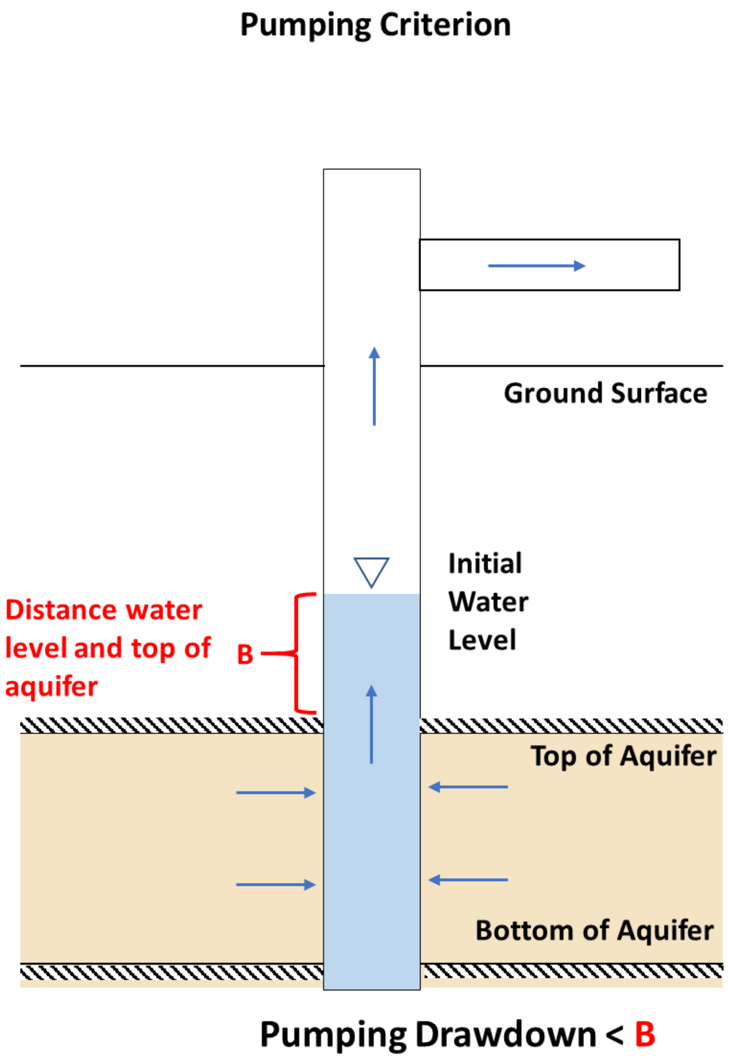
Well Hydraulics





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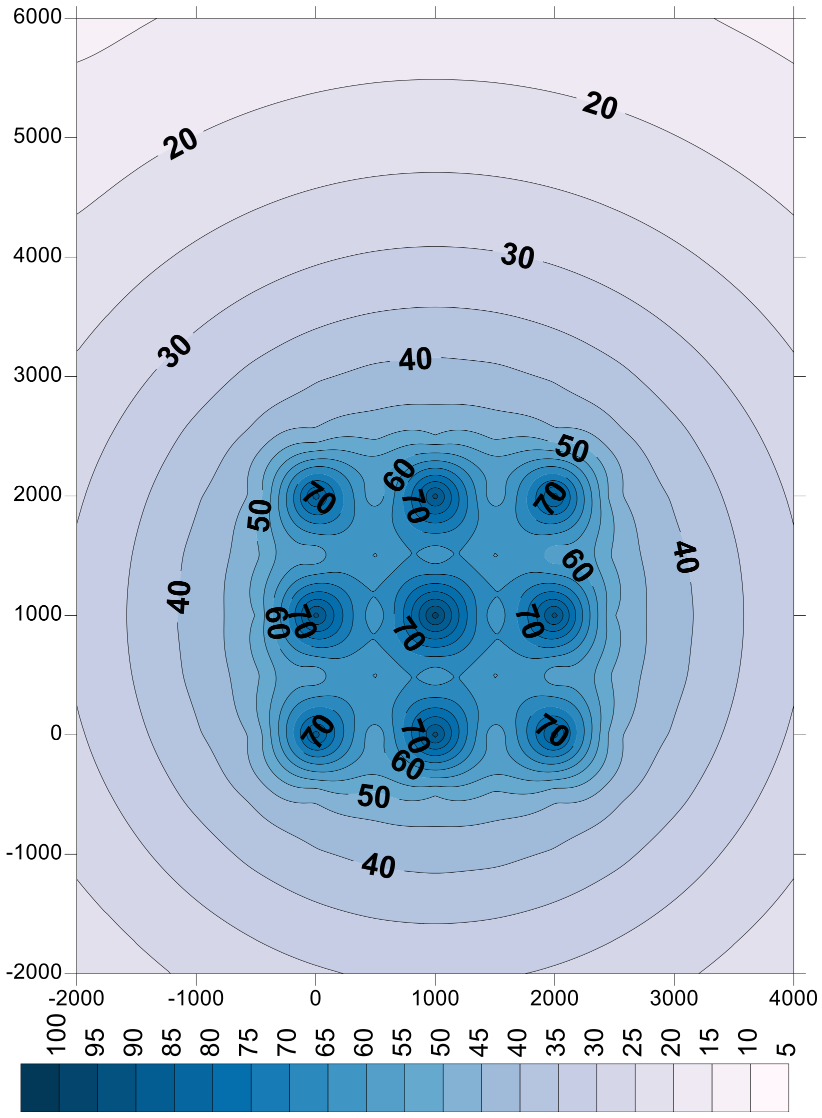
Wellfield Hydraulics

- The uplift and drawdown from one well affects wells around it
- This is called “interference” and must be considered in overall wellfield operation



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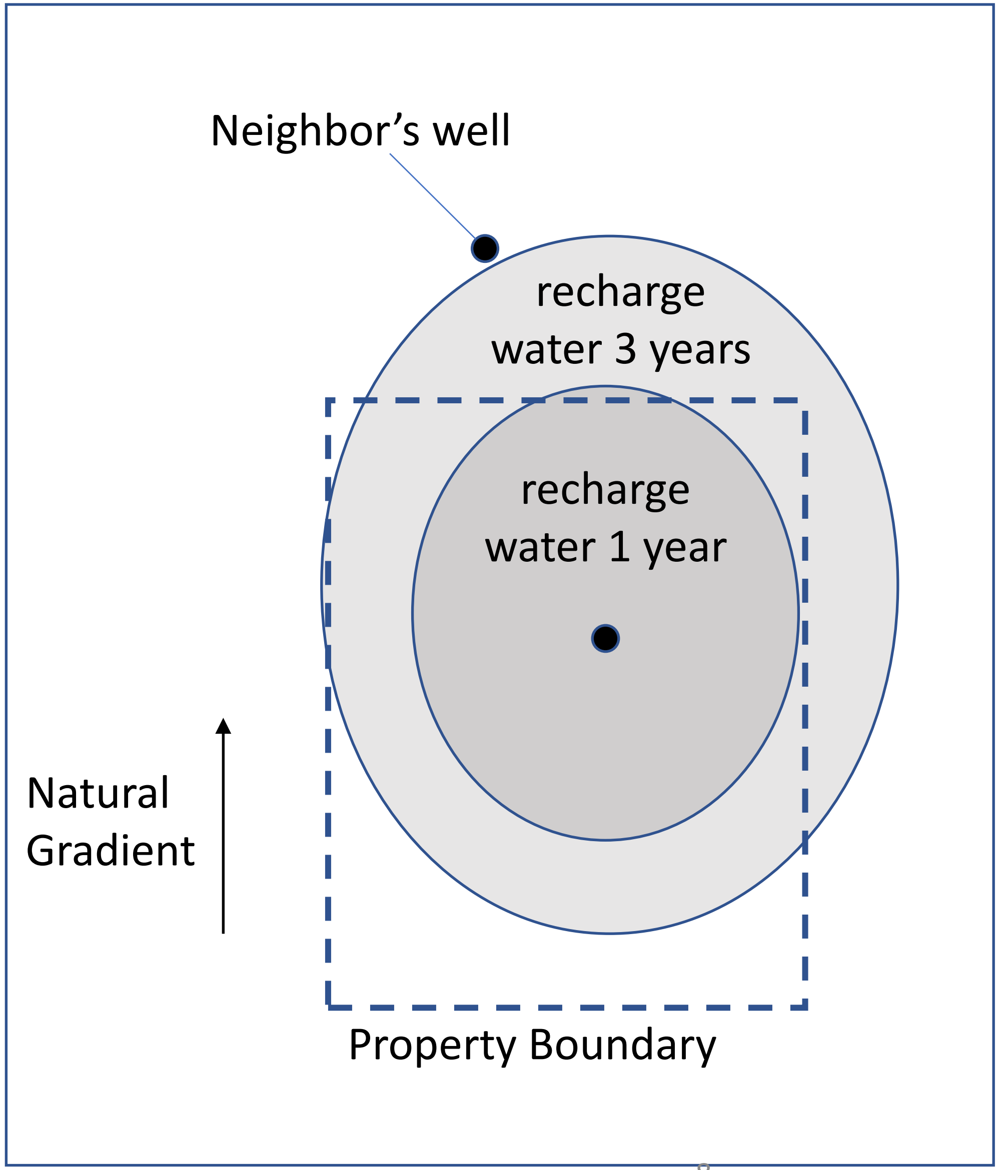
Hydraulic Control

- Operational - “can somebody steal my water?”
- Regulatory - must demonstrate “no trespass” of recharge water



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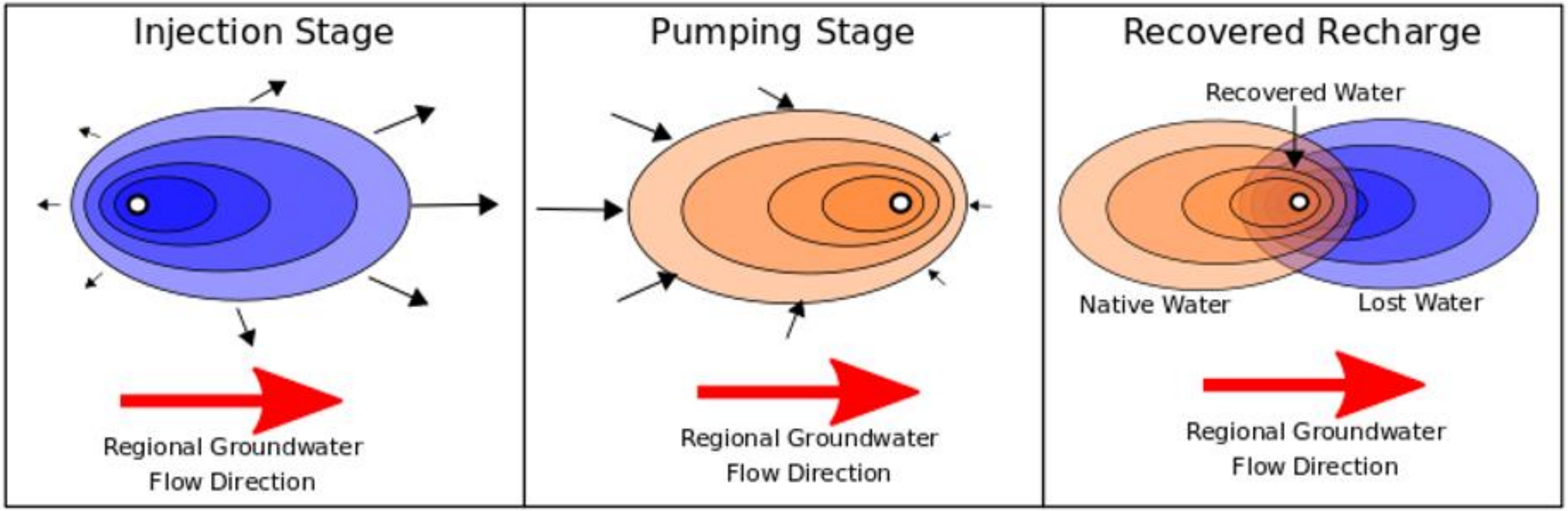
Recoverability

- Operational – "what is the quality of the recovered water"
- Regulatory – permitted amount may be dependent on demonstration of recoverability



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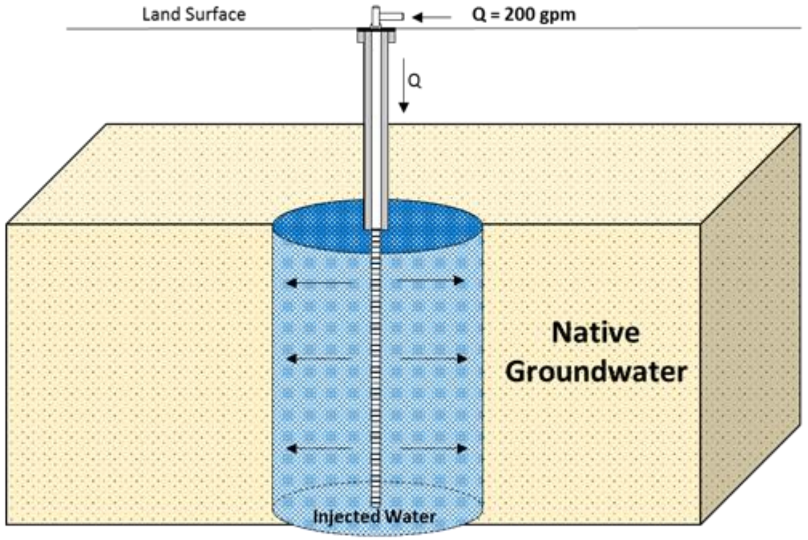
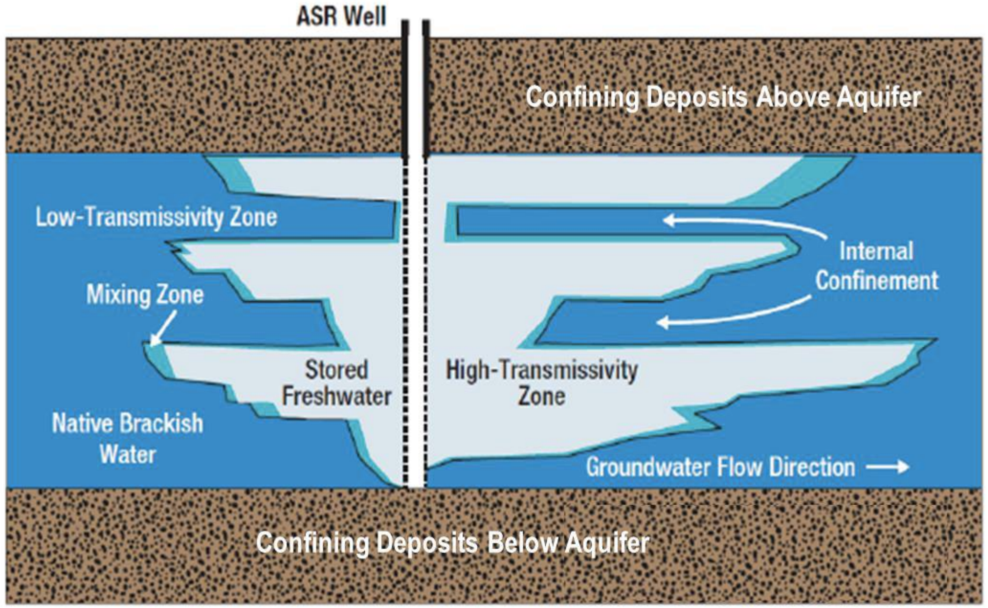
Modeling Approaches

- Analytic or Analytic Element
  - Hydraulics: Single well with superposition
  - Simple recoverability estimates
- Numerical Flow Model
  - MODFLOW or similar gridded approach
  - Requires more data to support
- Numerical Transport
  - Particle tracking, e.g. MODPATH
  - “Full” flow and transport, e.g MT3DMS

Homogenous Aquifer Conditions





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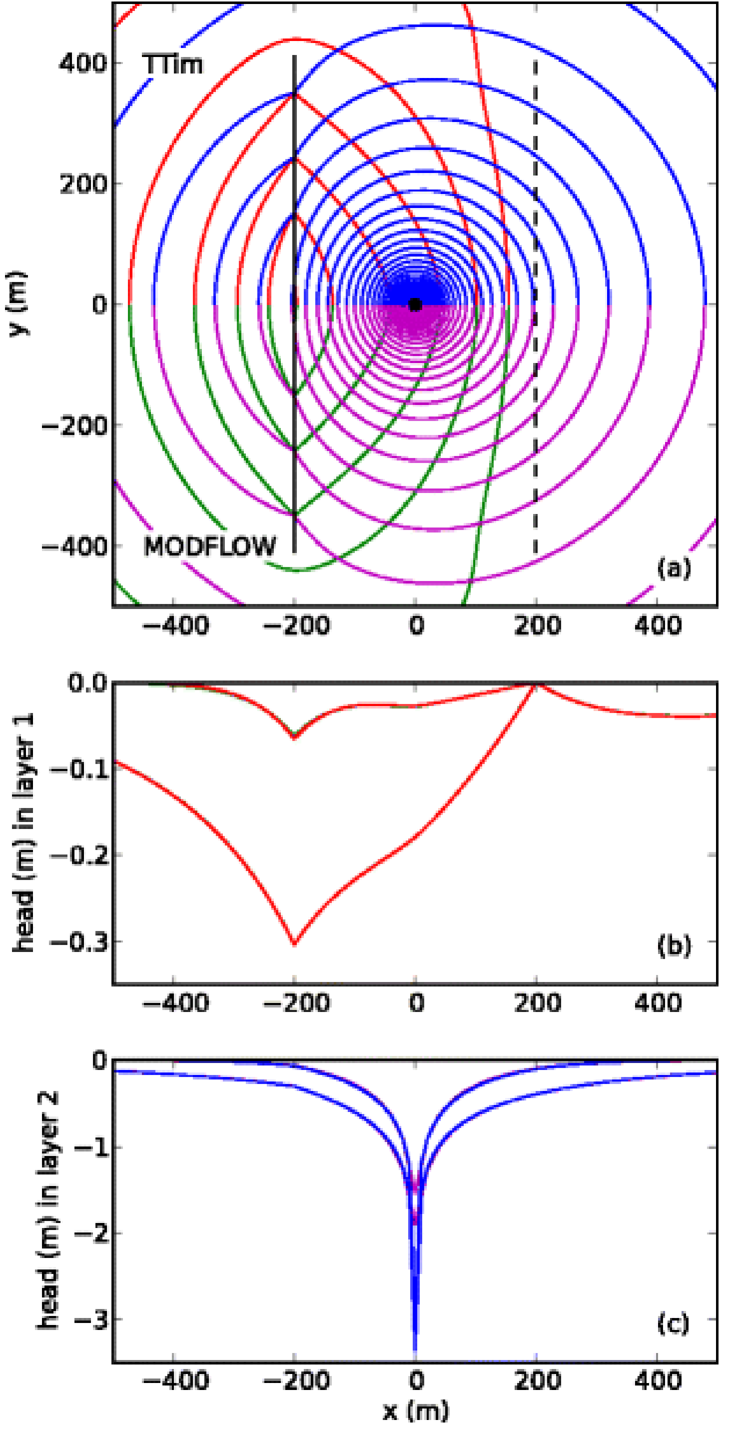
Analytic Modeling: Hydraulics

- Uplift/drawdown
- Advantage: Simple and Fast
- Theis solution
  - Single layer, confined, isotropic
  - Superposition for multiple well locations
- TTIM or other AE codes
  - Multiple layers, confined, isotropic by layer
  - Linear boundaries (stream/fault)



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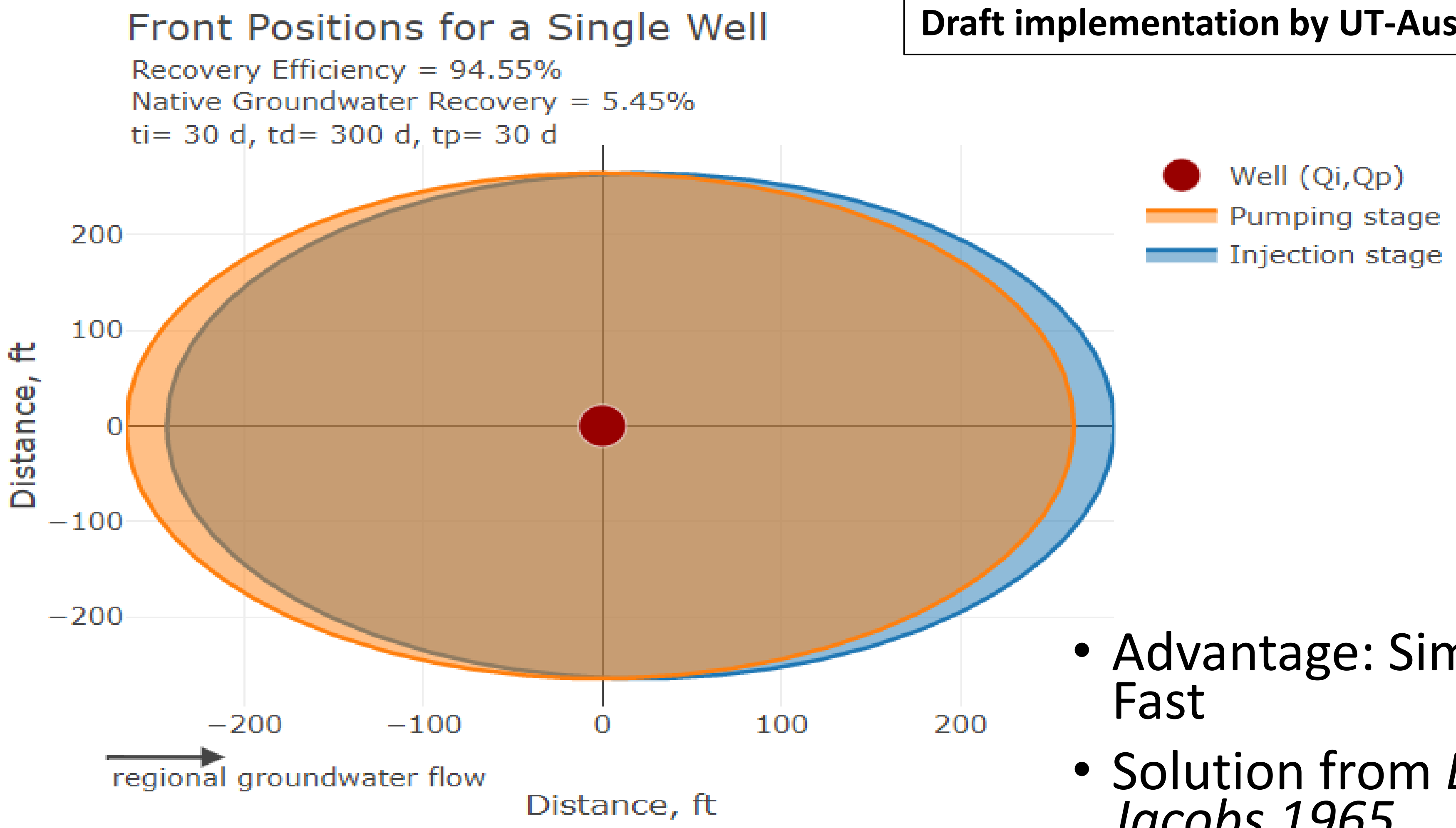
Analytic Modeling: Recoverability

Draft implementation by UT-Austin for TCEQ



- Advantage: Simple and Fast
- Solution from *Bear and Jacobs 1965*

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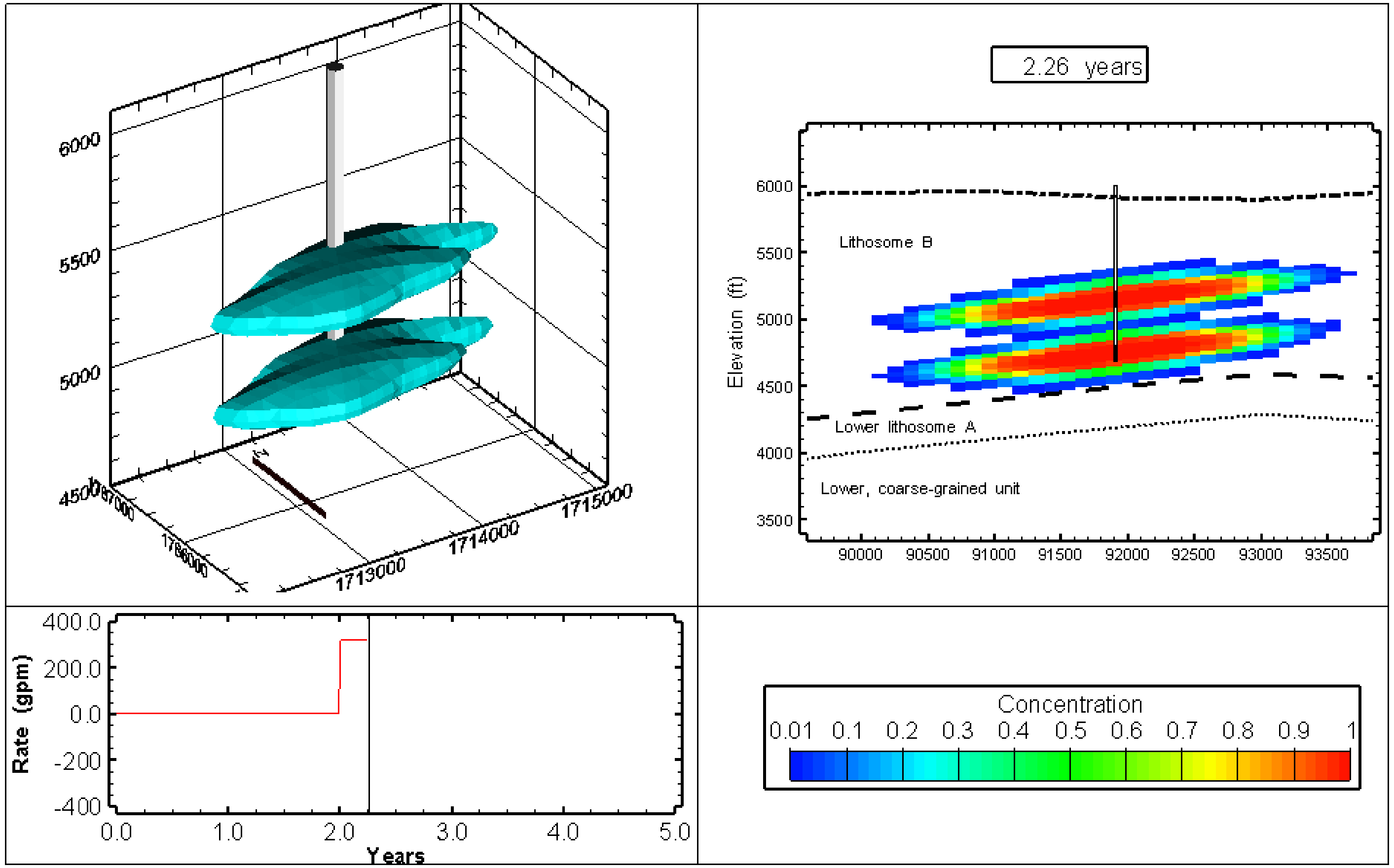
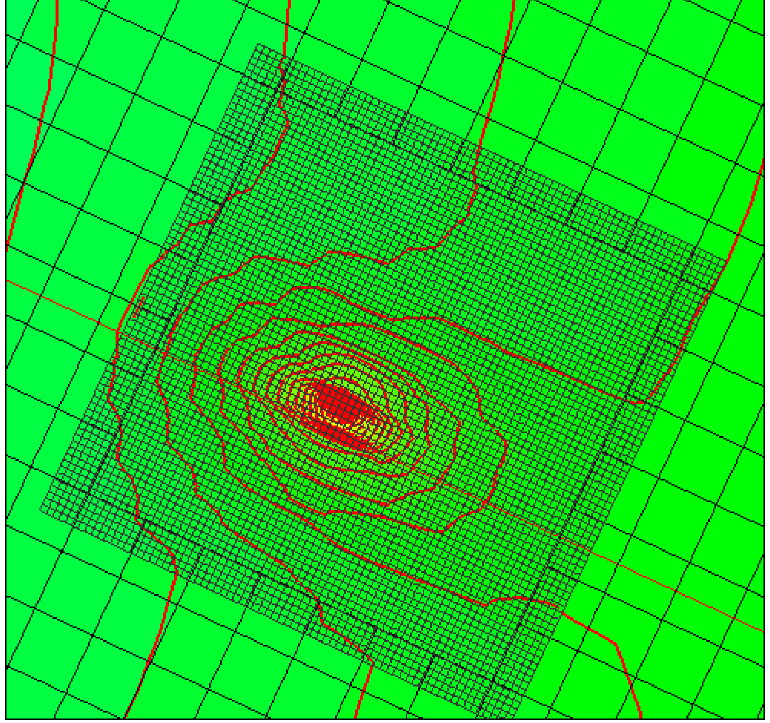
Numerical Flow Modeling

- Represent horizontal and vertical heterogeneity in structure and properties





- Represent irregular boundaries
- Data intensive
- Grid refinement

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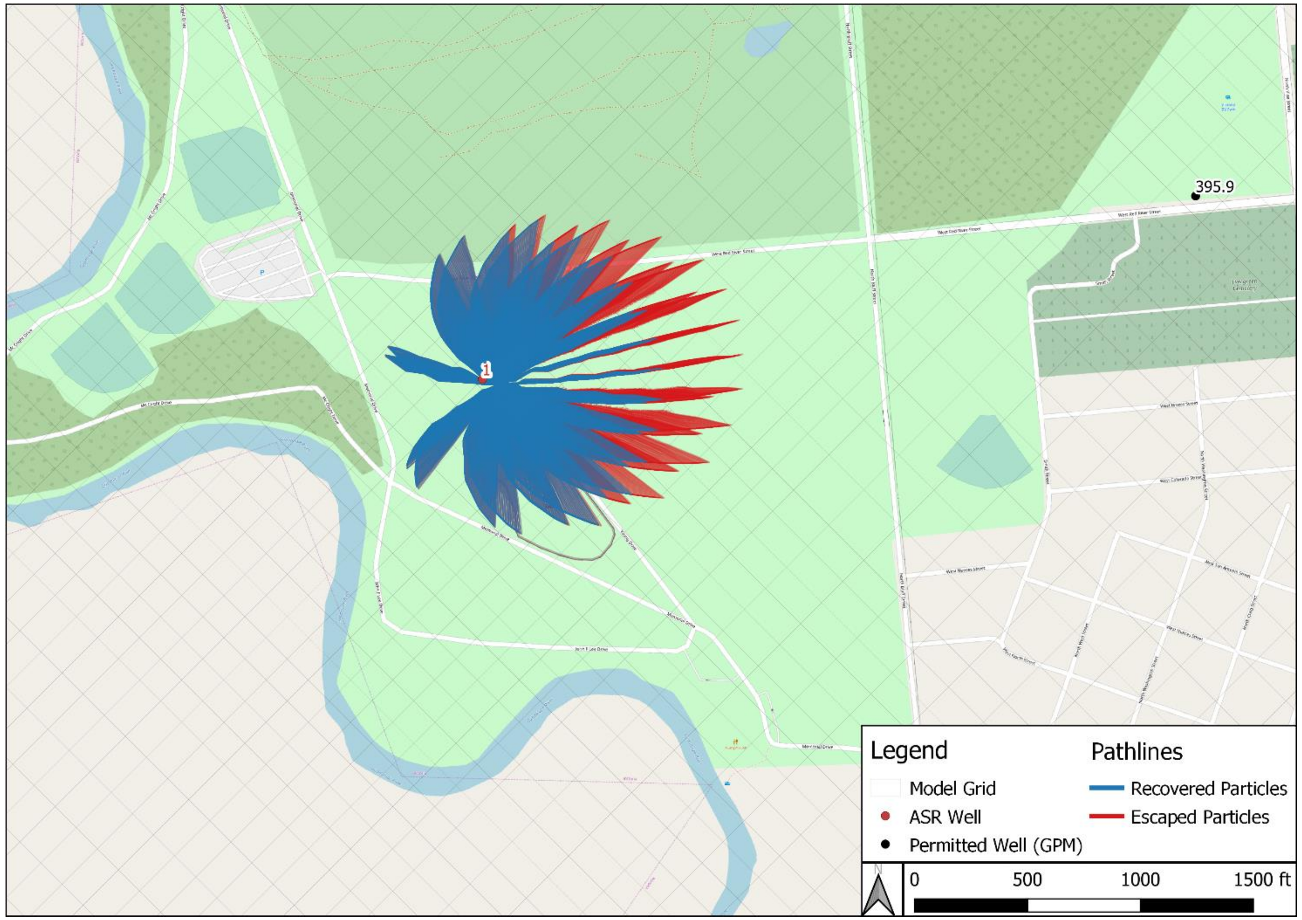
Transport: Particle Tracking

- Represents advective flow only
- Advantage: Simple and Fast
- Good for simple recoverability modeling

- Cannot easily represent dispersivity/mixing that occurs on the leading edge of the recharge water



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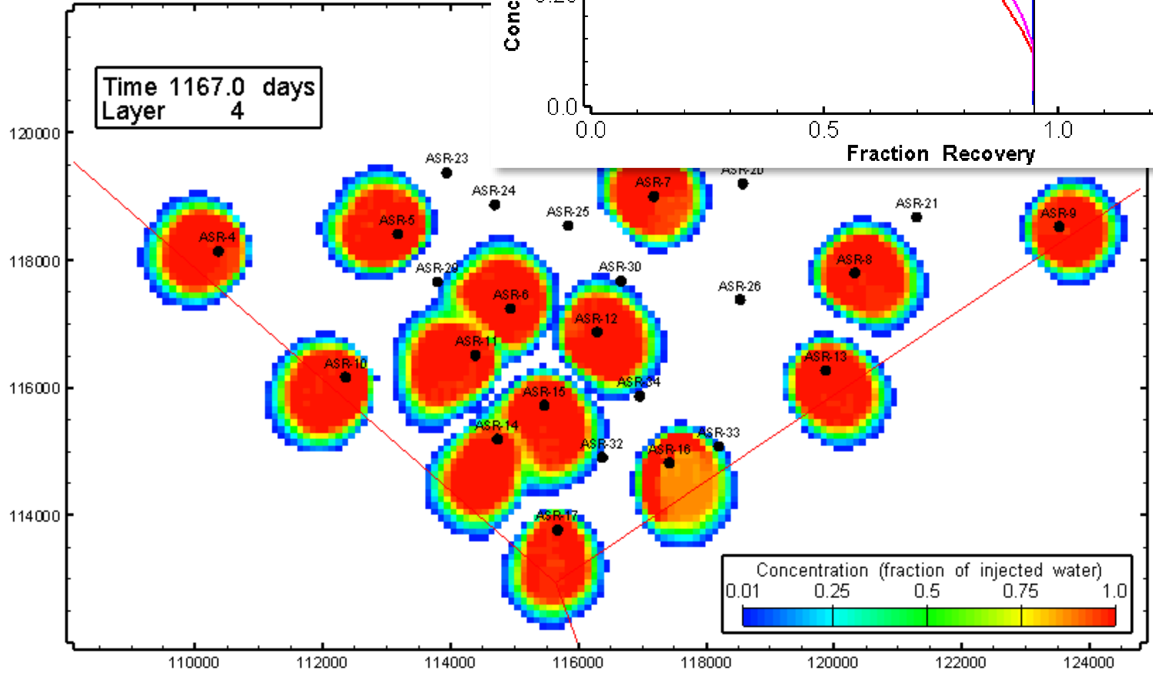
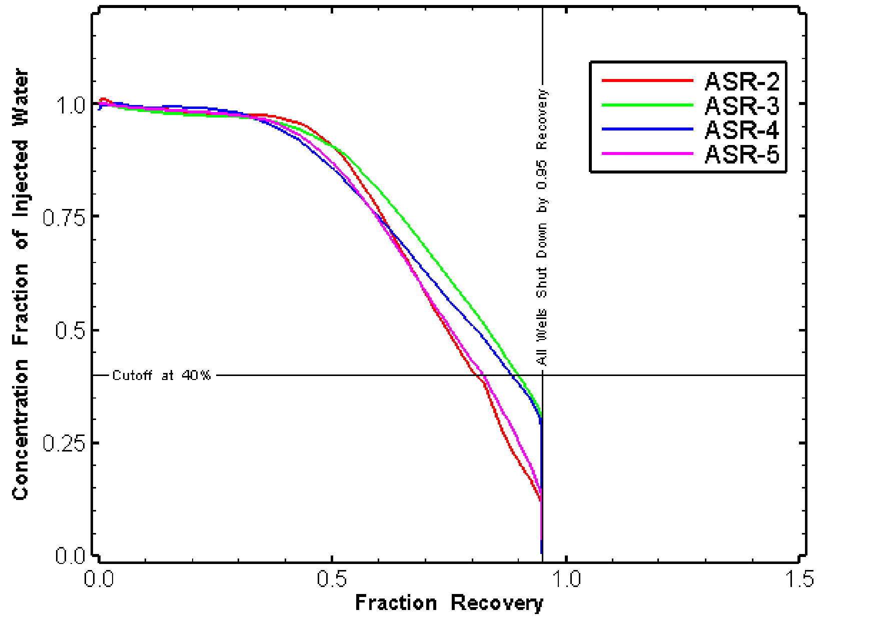
Transport: Full F&T with Dispersivity

- Allows consideration of dispersion/mixing on the leading edge of the bubble
- Requires estimates of dispersion coefficient based on breakthrough of recharge water at monitor wells





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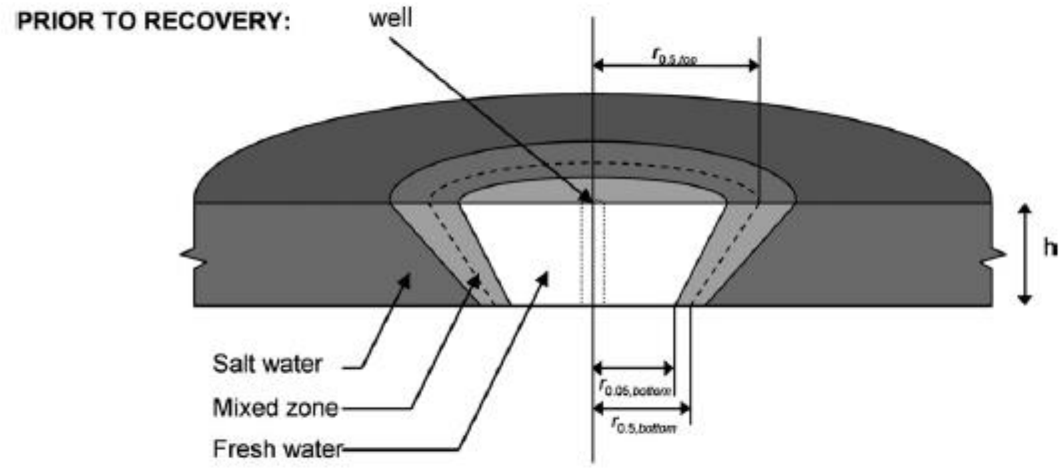
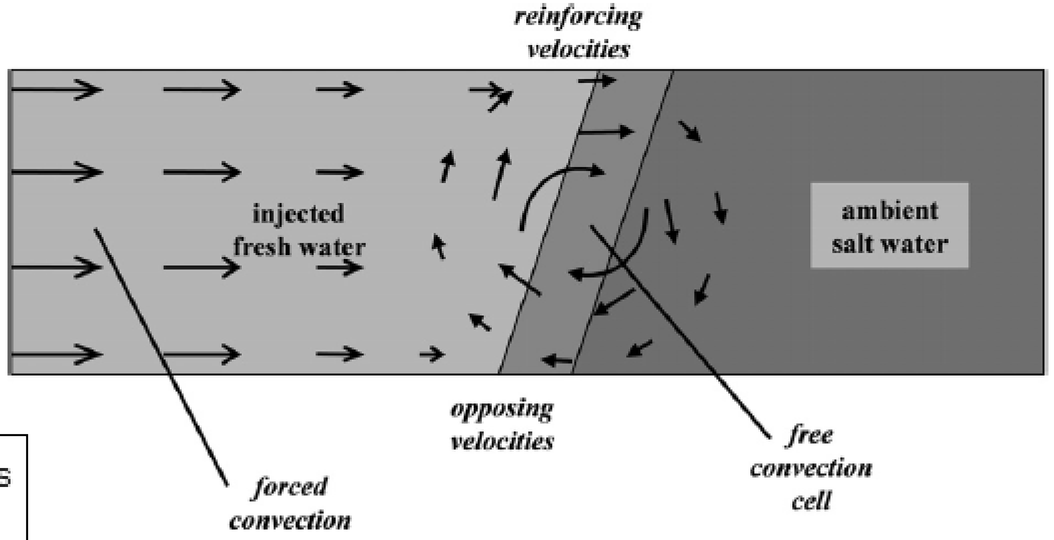
Transport: Variable Density



Modest density differentials (<5,000 mg/L) should not have a large impact on mixing

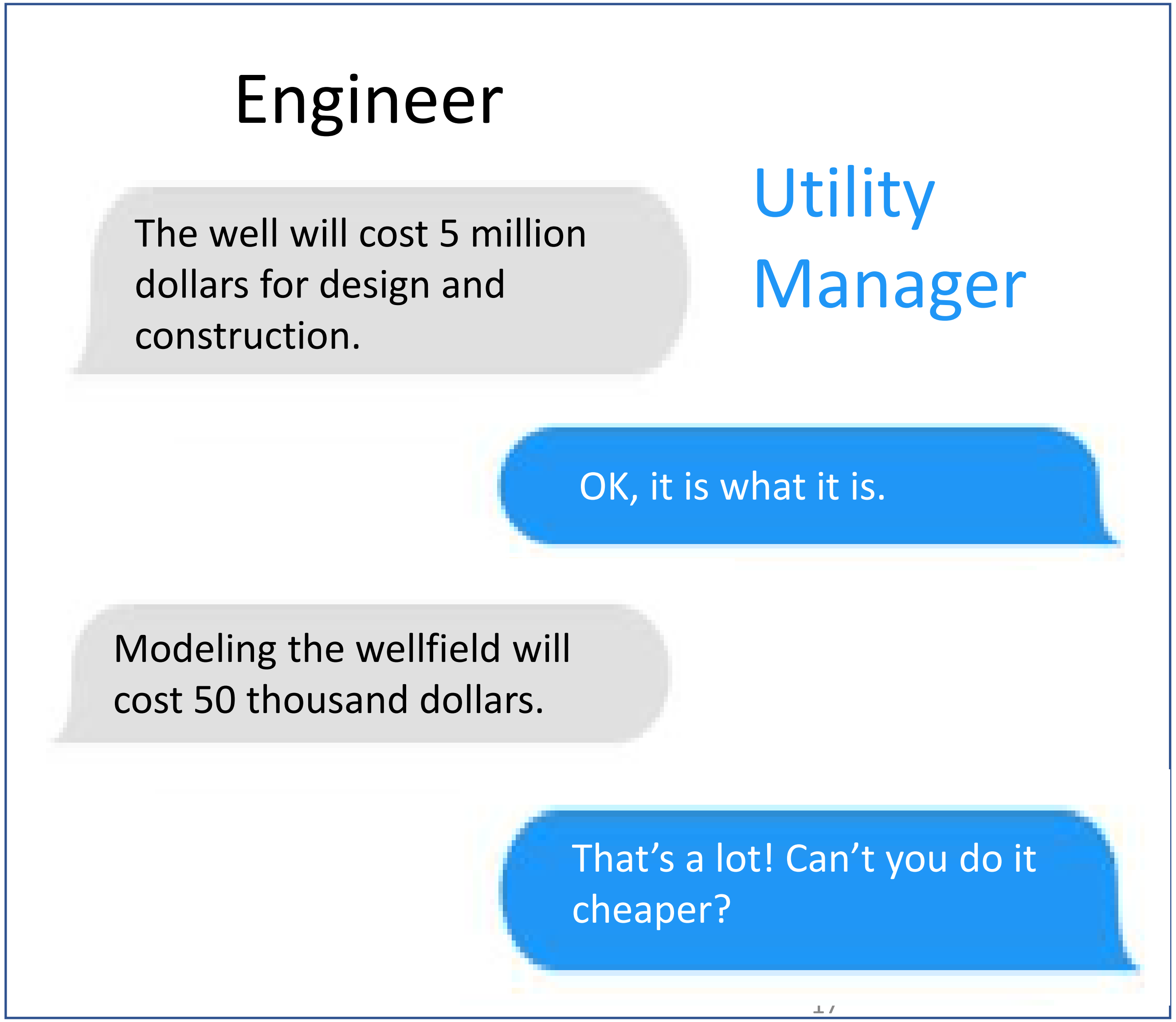
Increasing density difference increases mixing for longer storage durations



Ward, James D., Craig T. Simmons, and Peter J. Dillon. "A theoretical analysis of mixed convection in aquifer storage and recovery: How important are density effects?." *Journal of Hydrology* 343.3 (2007): 169-186.

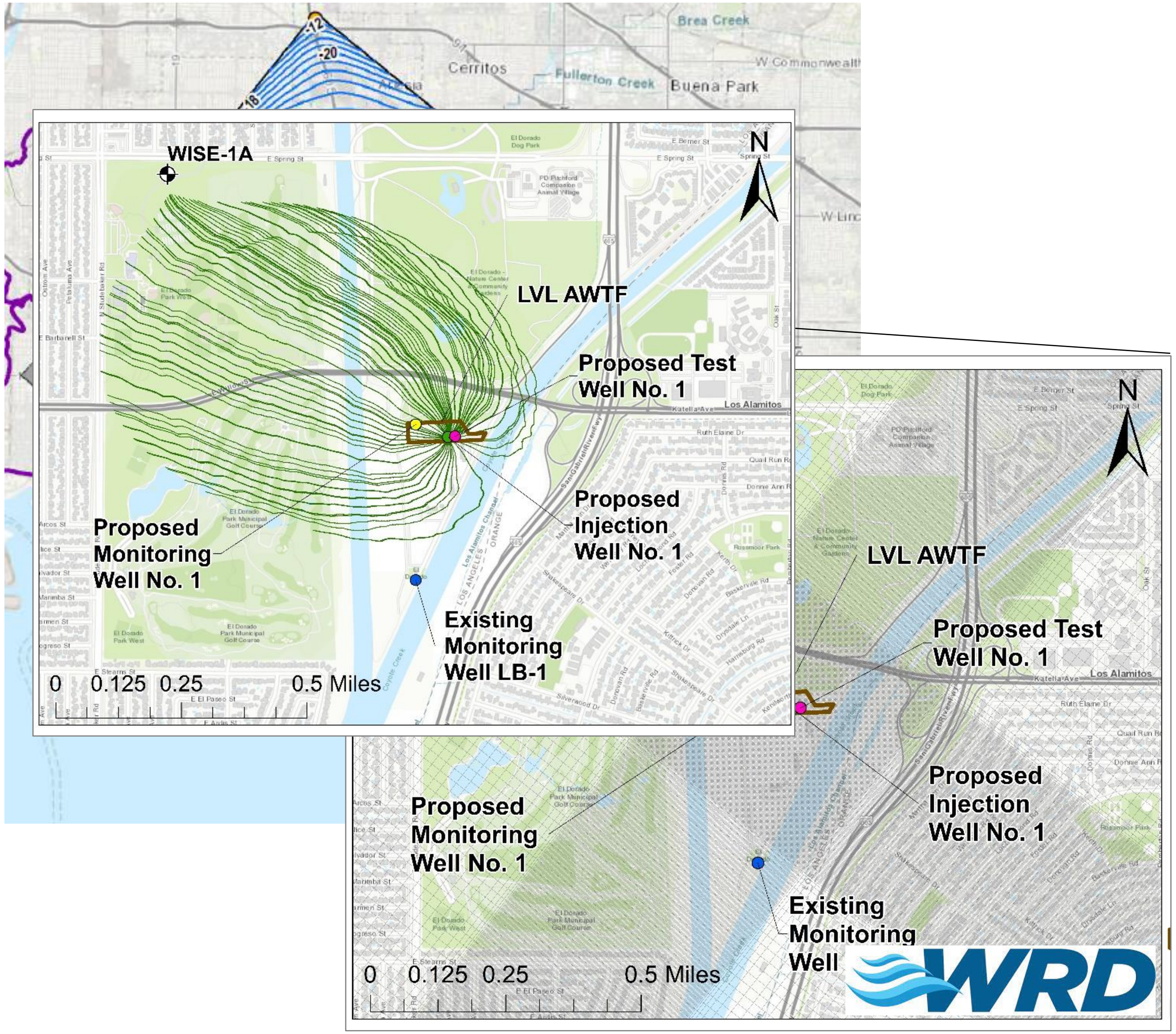
Typical Levels of Effort

- Analytic or Analytic Element
  - Limited data requirements
  - 30 – 40K
- Numerical Flow Model
  - Simple “box model” using superposition will be similar to AE
  - 50-100K if starting with existing regional model
- Numerical Transport
  - Particle Tracking: 15-25K added to flow model
  - “Full” flow and transport: 30-50K added to flow model



Case-Study– Siting and Design for LVL Facilities

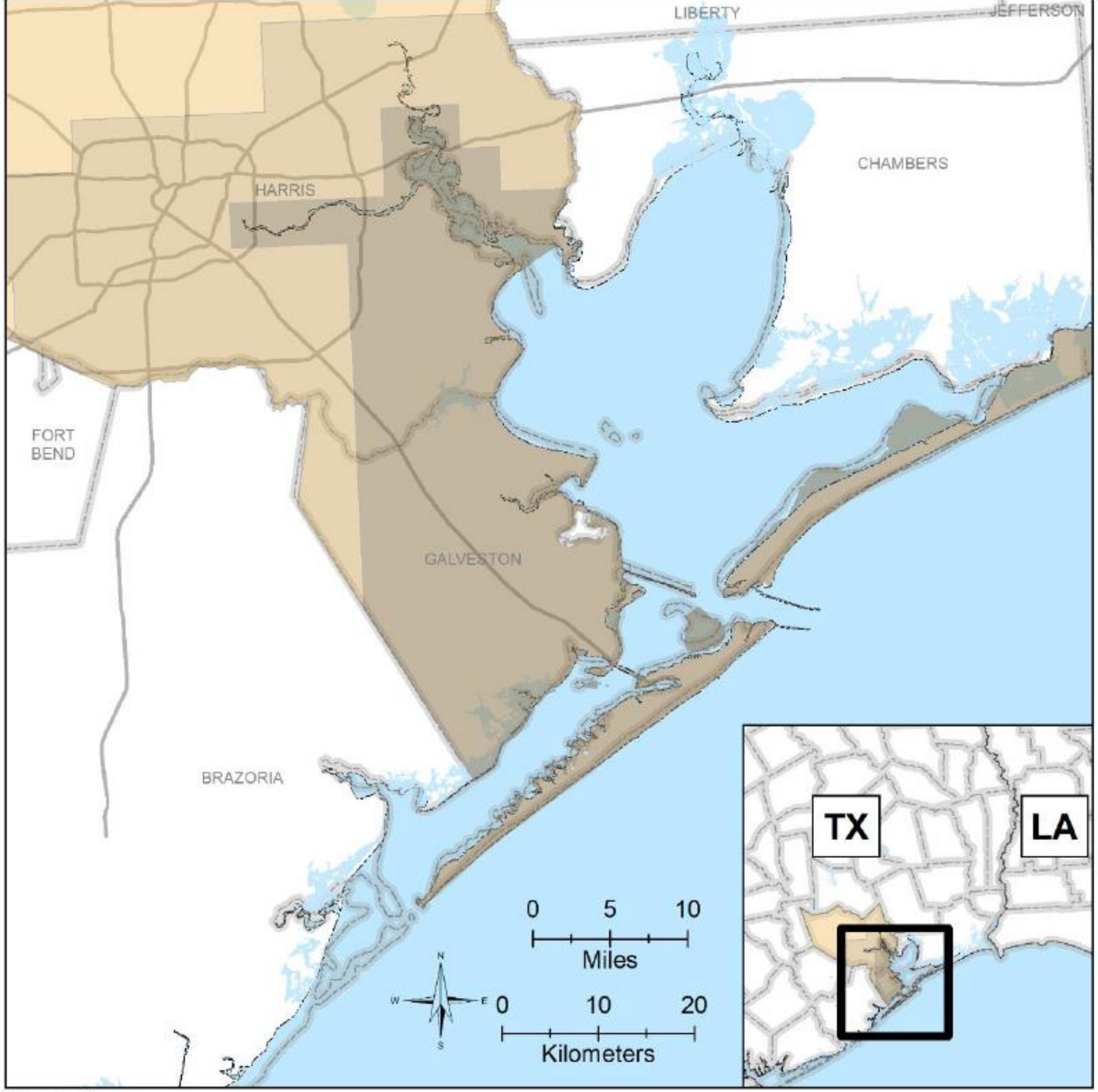
- 2 mgd inland injection well + 2 monitoring wells in the LVL WTP area
- Alamitos-Barrier Flow and Transport Model
  - Sub-Regional extent
  - 100x100 ft grid
  - Calibrated to water-levels and chloride
- Further refined model grid to 10x10 ft for final siting of injection and monitoring wells
- Particle tracking to assess residence and response-retention times
- Being used to support tracer studies
- Additional data will be incorporated from drilling/construction phase



WRD

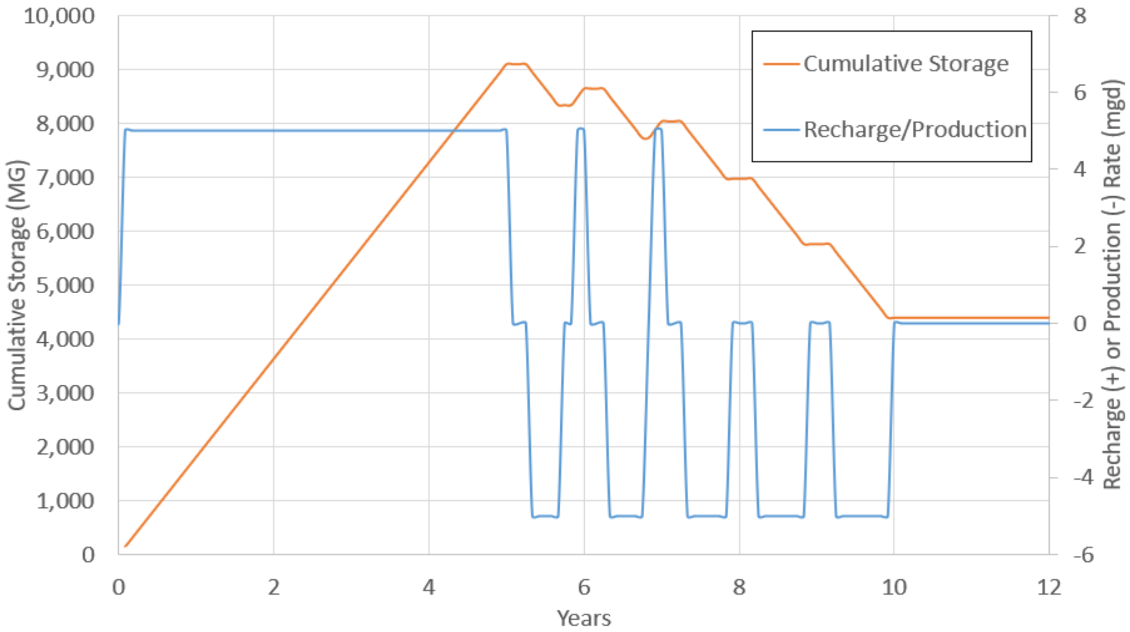
Case Study: Houston Subsidence

- Houston area subsidence District funded research into potential “net-zero” subsidence with ASR
- Simulated two scenarios
  - Summer peaking
  - Drought resiliency

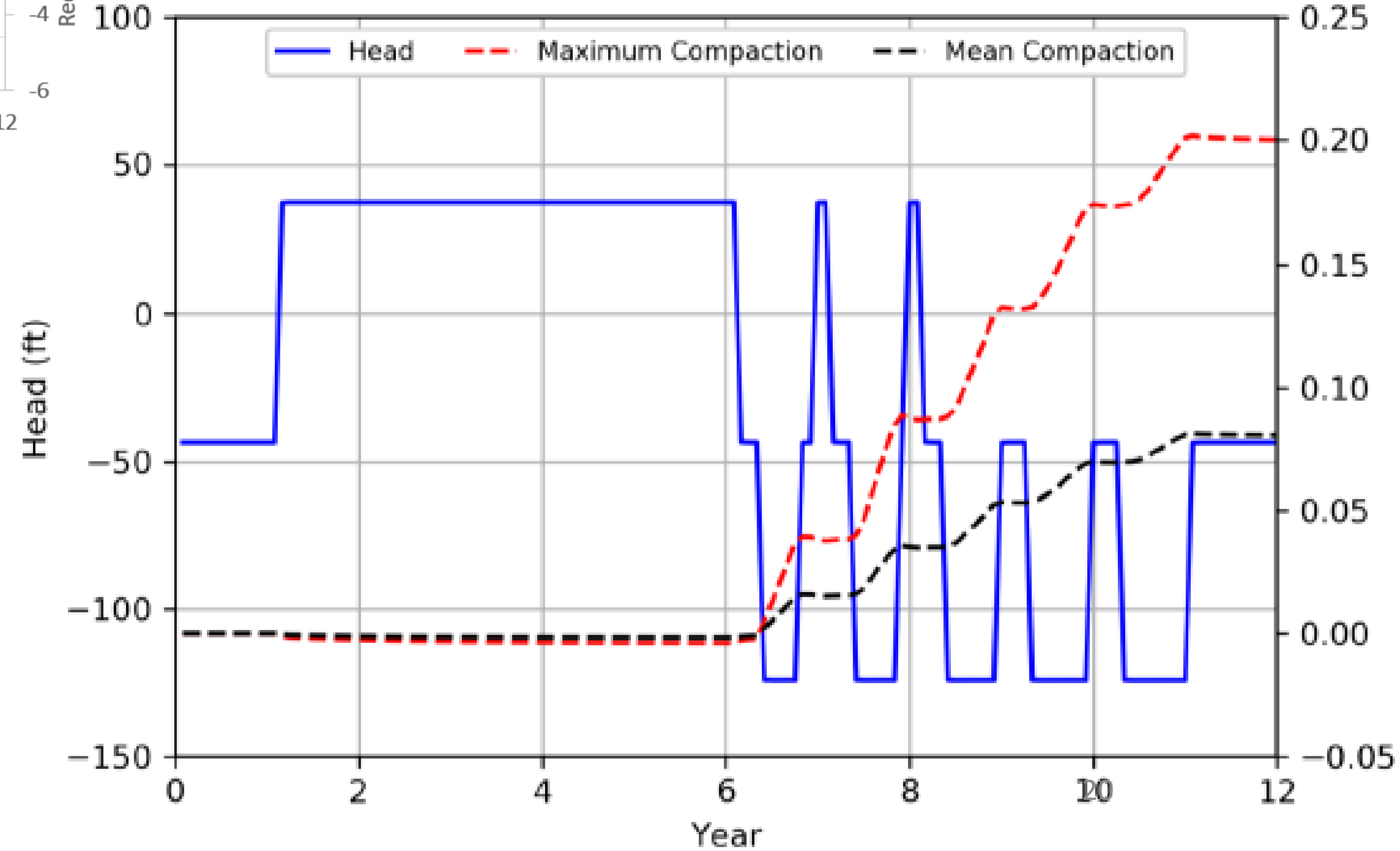


Study Area

Case Study: Houston Subsidence



Drought storage



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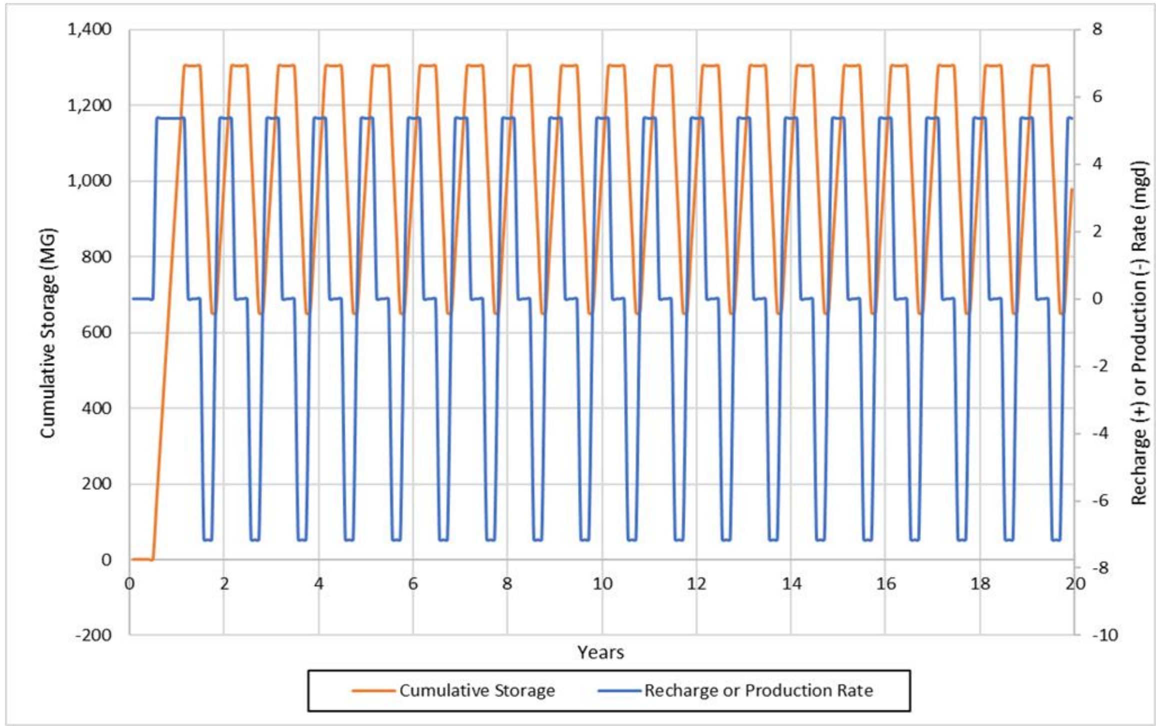
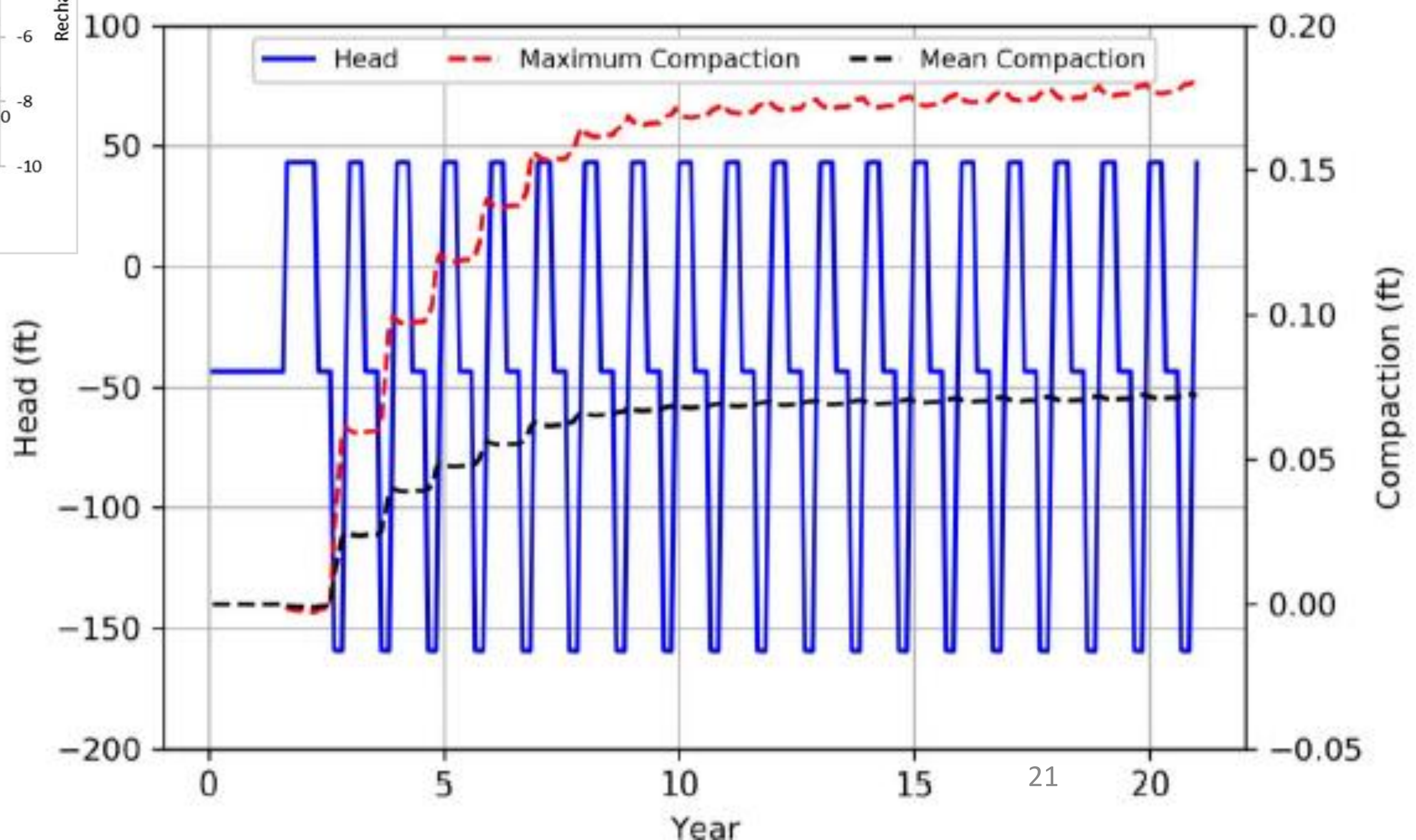
Case Study: Houston Subsidence

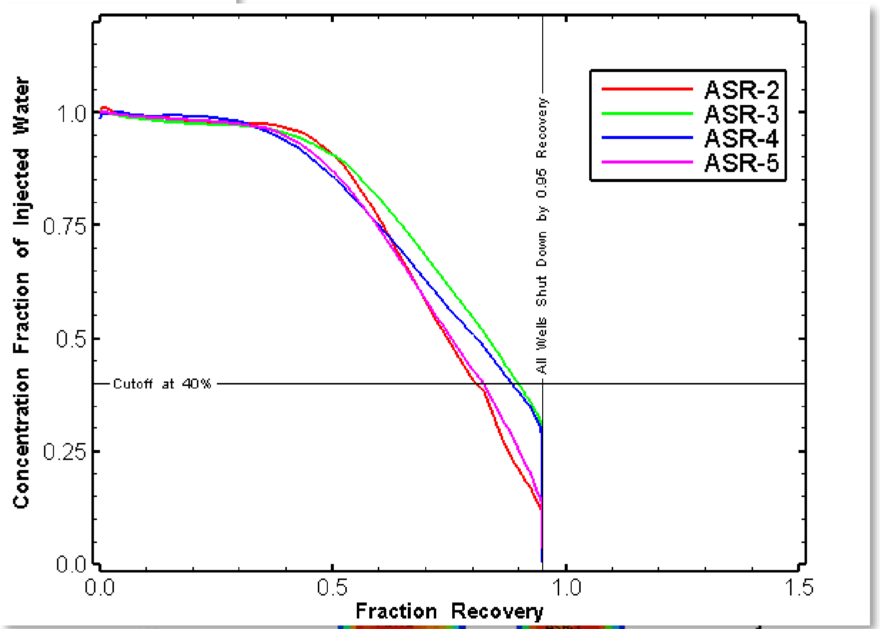


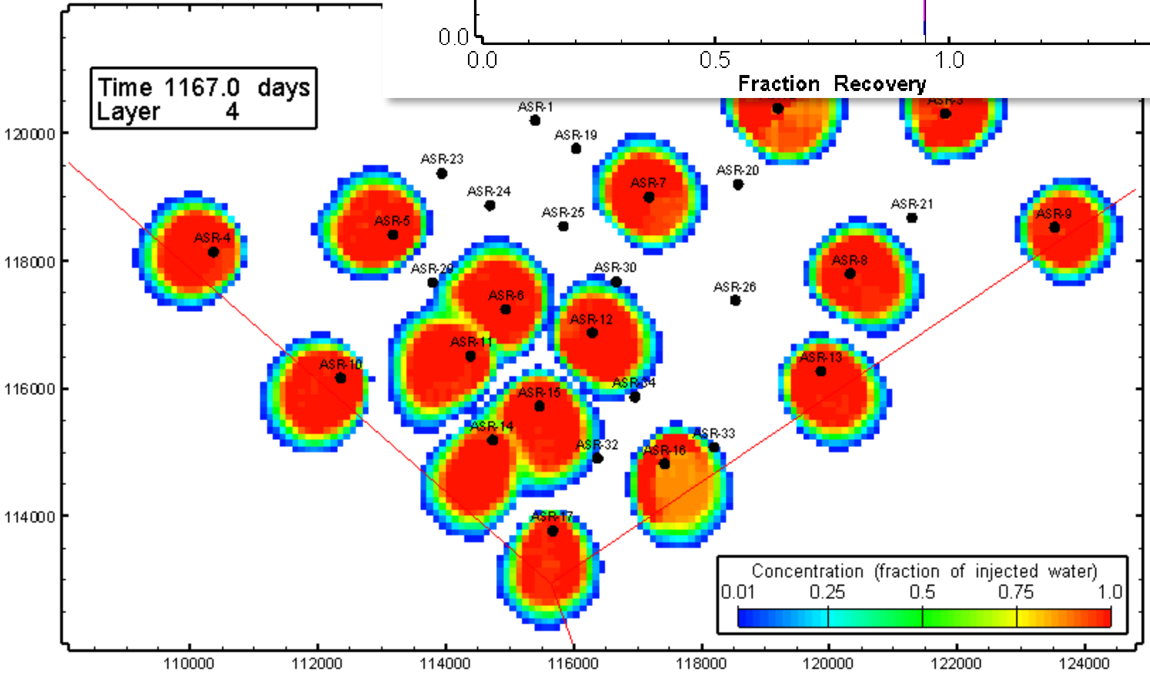
Summer Peaking



Case Study: Twin Oaks

- One of the largest ASR operations in the US
- Nearly 200,000 AF stored
- Transport modeling to determine mix of native and storage groundwater under recovery conditions
- Native groundwater requires treatment to prevent scalant leaching





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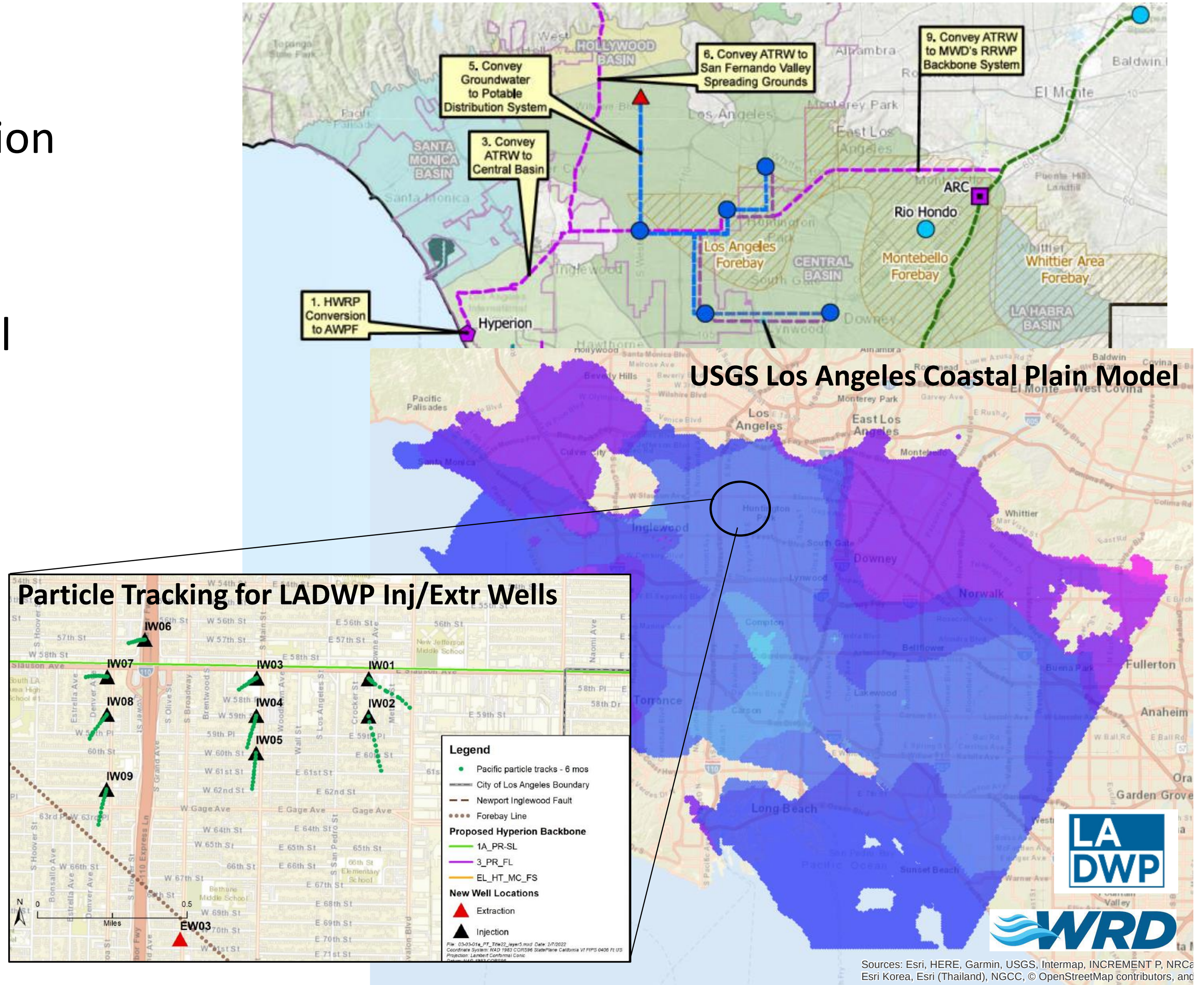
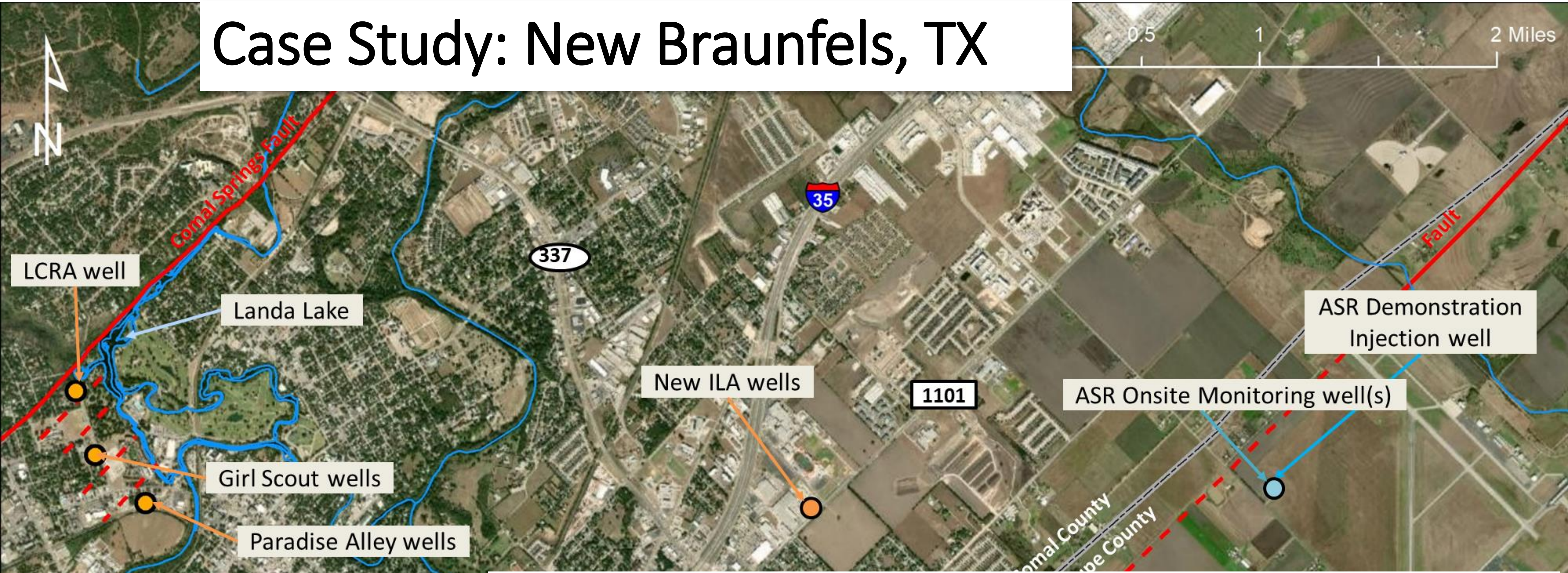
Case-Study - Operation Next Injection Well Feasibility

- 24,000 AFY capacity injection/extraction facilities
  - 20 injection wells
  - 12 extraction wells
- USGS Los Angeles Coastal Plain Model
  - Unstructured Grid
  - Flow Only
  - Regional extent
  - 1/8 mile grid
- Used for feasibility analysis and preliminary siting
- Title-22 residence times using particle tracking
  - Assumed conservative estimate
- Cannot be used for monitoring wells siting/design

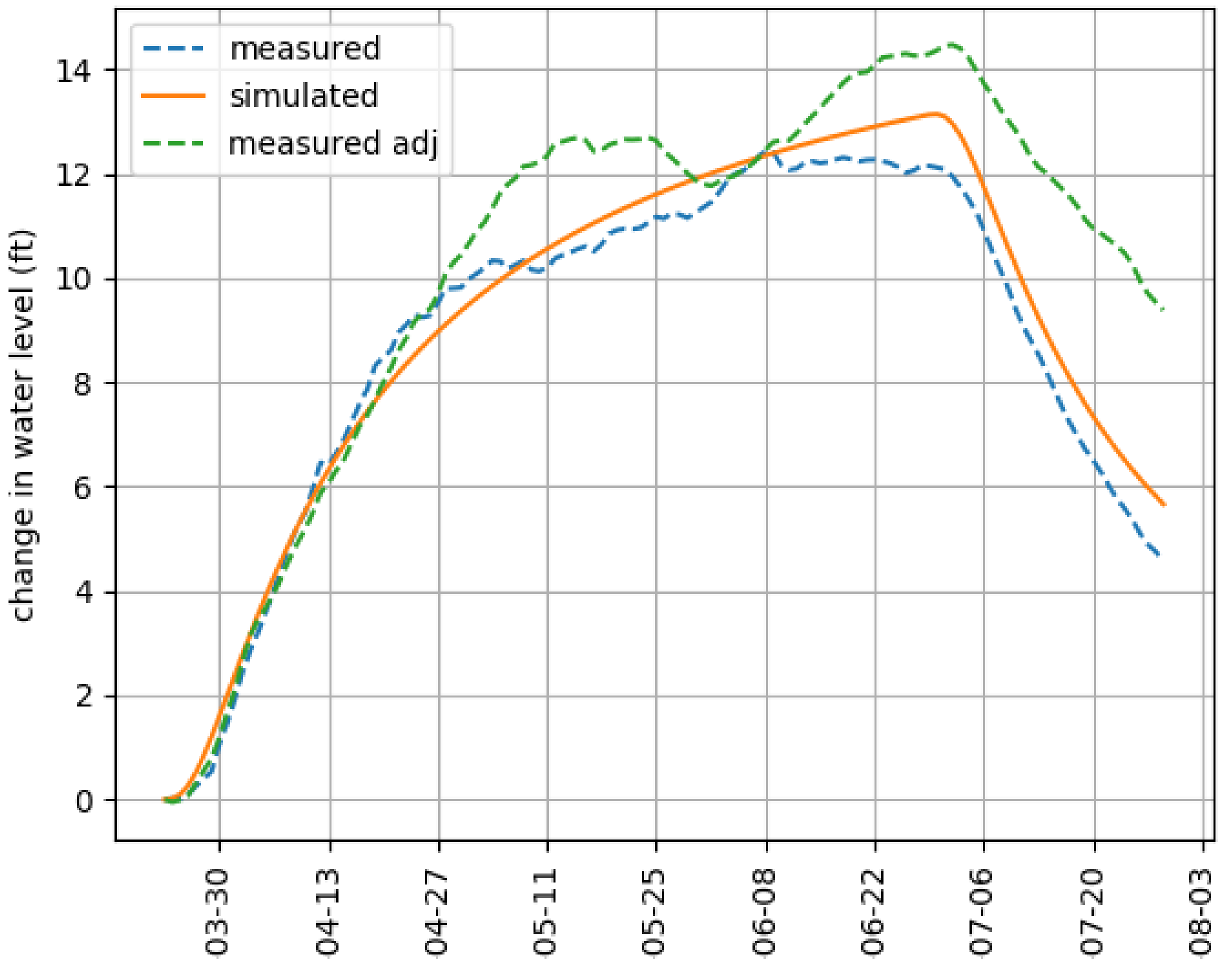


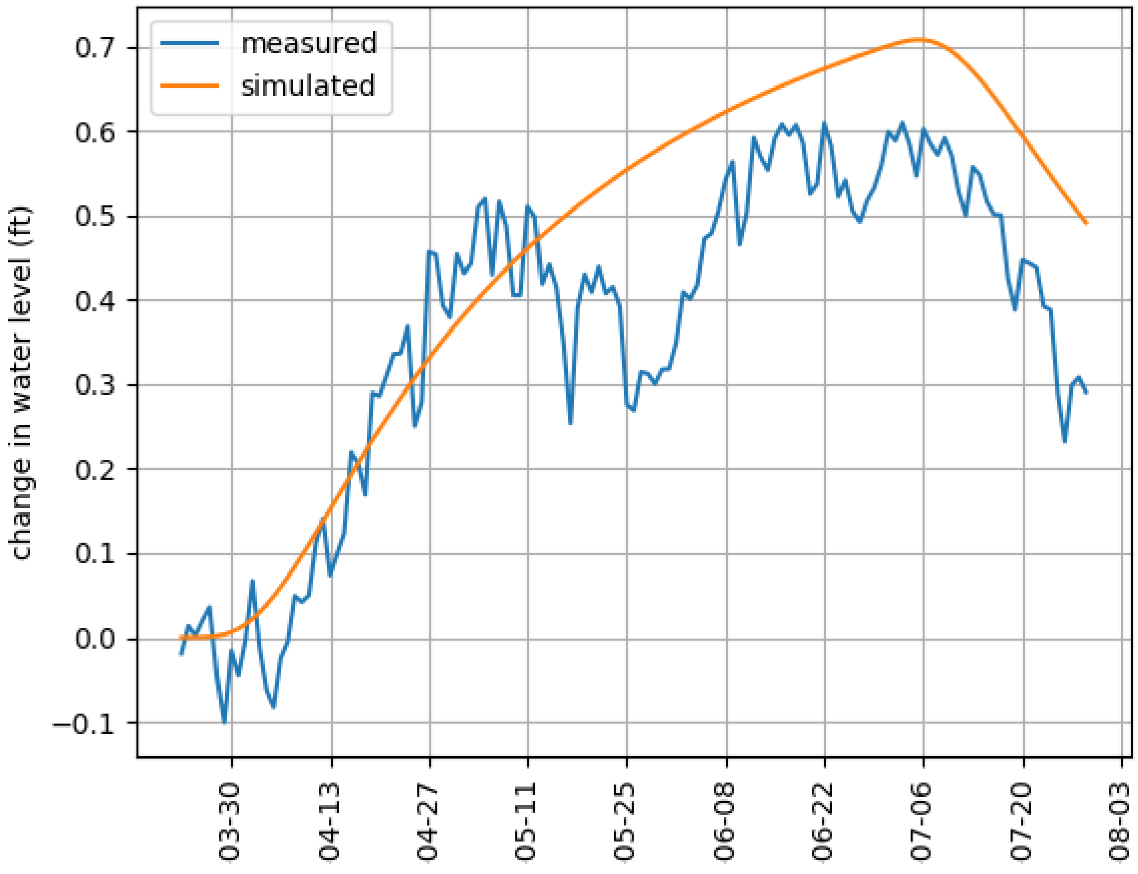
Case Study: New Braunfels, TX



- Storage in the brackish Edwards Aquifer
- Five miles downdip of Comal Springs, a highly sensitive/important water source
- Modeling to estimate potential change in water levels near springs

Case Study: New Braunfels, TX





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Summary

- ASR permitting and operations often require groundwater modeling
- ASR is particularly site-specific in terms of modeling, due to potential variation in both operations and permitting
- Variety of strategies are available for achieving objectives, best to keep things as simple as possible