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WHAT STARTS HERE CHANGES THE WORLD

A Modeling Approach to Assess the Feasibility of Water Injection, Storage, and Recovery

ASR Recoverability Guidance Project

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Austin, TX

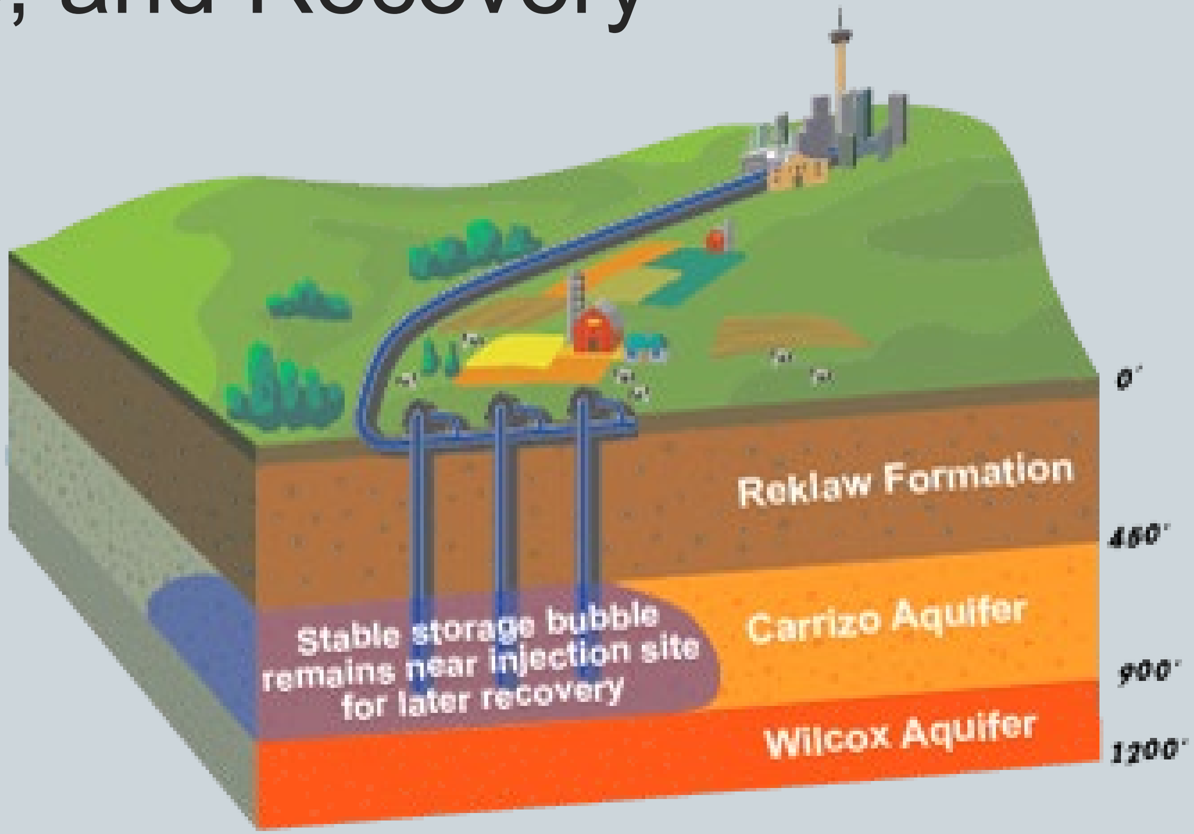
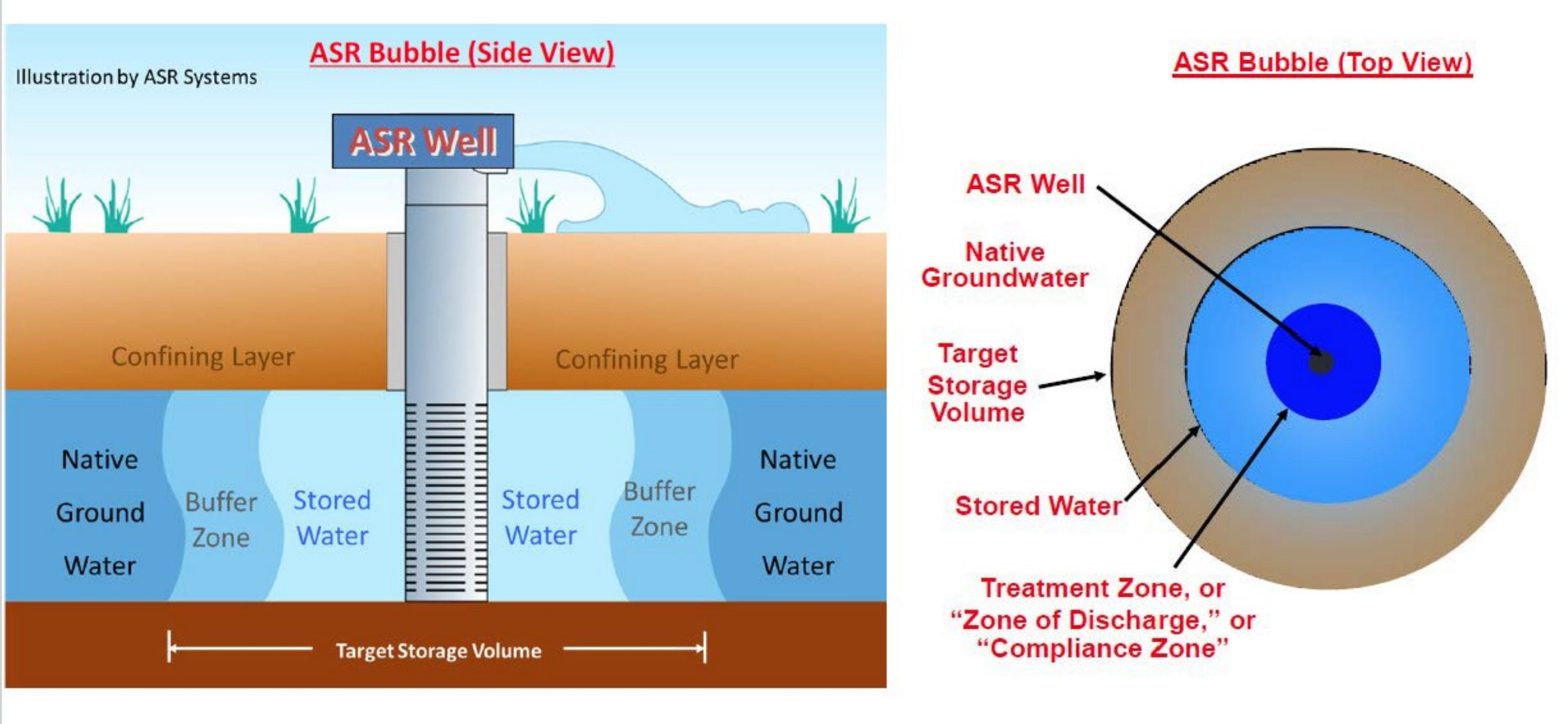


Image source: http://www.saws.org/Your_Water/WaterResources/Projects/asr.cfm

Aquifer Storage and Recovery (ASR)

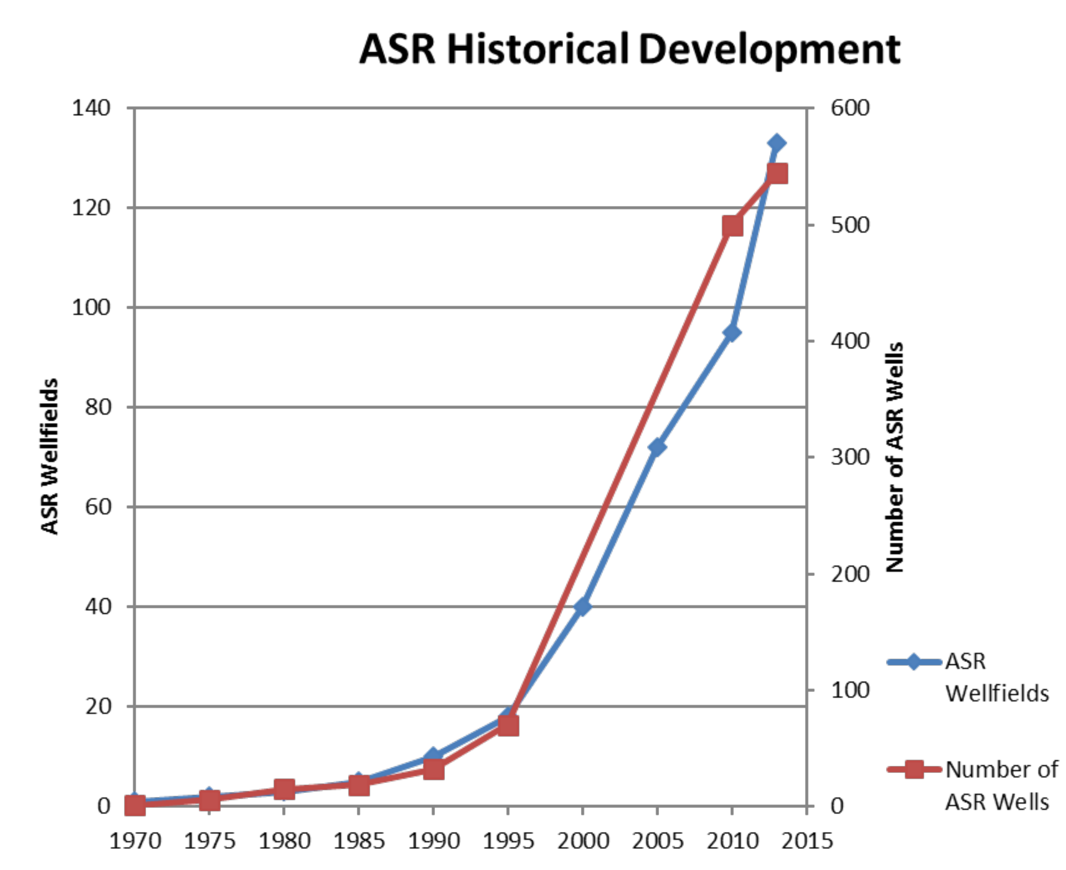
ASR: The injection of water into a geologic formation, group of formations, or part of a formation that is capable of underground storage of water ***for later retrieval and beneficial use.***

– TCEQ: 30TAC 331.2(8)



ASR Advantages

- Little to no evaporative losses
- Minimized environmental disturbance and land consumption
- Low capital cost of implementation on a gallon-per-day capacity
- Versatile technology: Seasonal storage, long-term storage, emergency storage, diurnal storage
  - *Bouwer, 2001, Khan et al., 2008, Maliva et al., 2006, Maliva and Missimer, 2010, National Research Council, 2008, Belser and Pyne et al., 2014, Smith et al., 2017*



Belser and Pyne et al., 2014

TCEQ ASR Authorization Application

Required Elements:

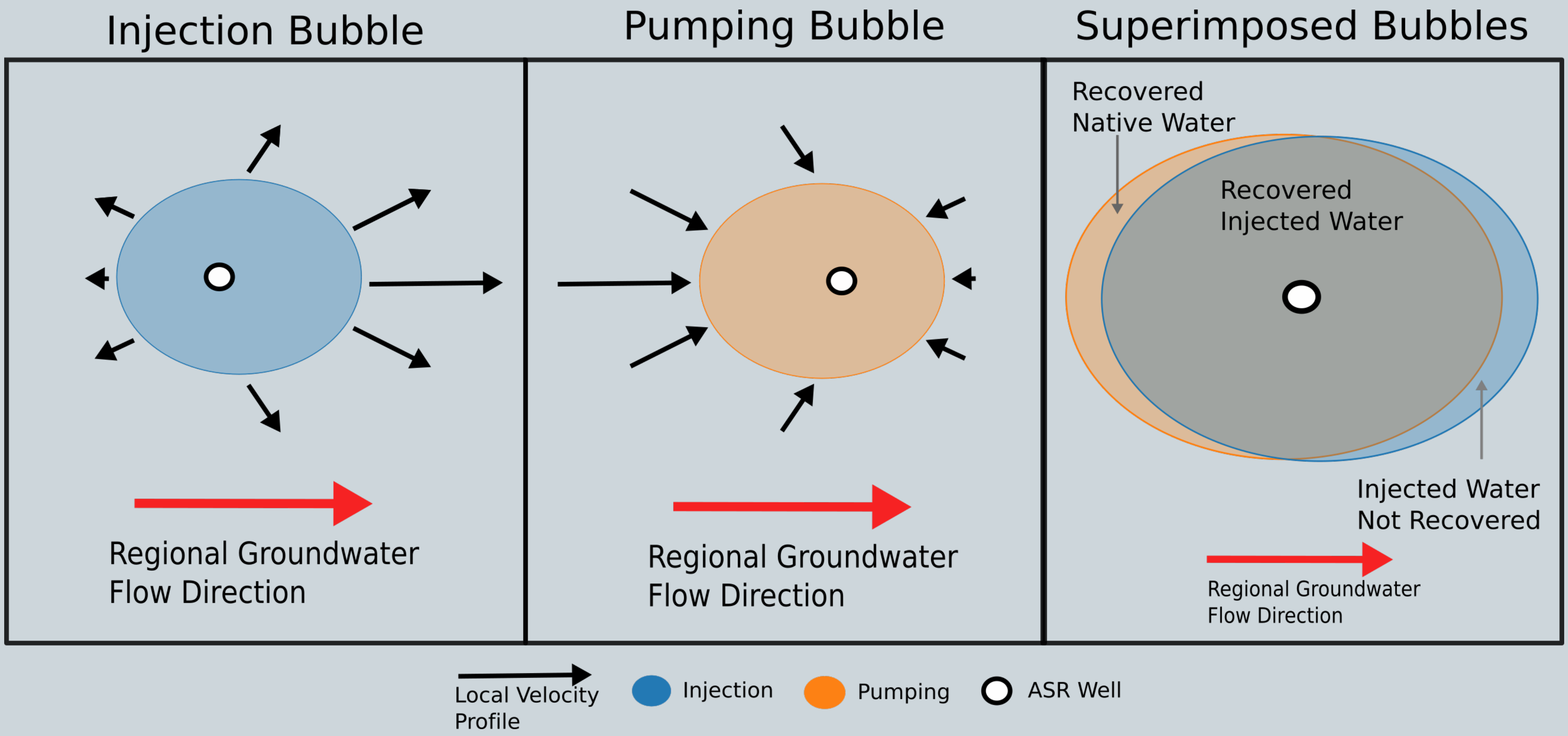
- General Facility/Operator Information
- ASR Project Area
- Area of Review & Artificial Penetrations
- Well Construction & Closure
- Injection Well Operation
- Project Geology, Hydrogeology, and Geochemistry
- Demonstration of Recoverability

Project Objectives and Tasks

Objective: Develop a **site specific** analytical tool for assessing the recoverability of injected waters in ASR operations

- **Task 1:** Identification of Data Needed (physical/operational parameters)
- **Task 2:** Identification of Modeling Approaches to Assess ASR
- **Task 3:** User Friendly Implementation of Modeling Approach

Schematic for Recovery



Recovery Efficiency (RE):

$$RE = \frac{V_r}{V_i} * 100\%$$

$$V_i = injected\ volume$$

$$V_p = pumped\ volume$$

$$V_r = recovered\ volume$$

Example:

$Vi = 100\ acre - feet$

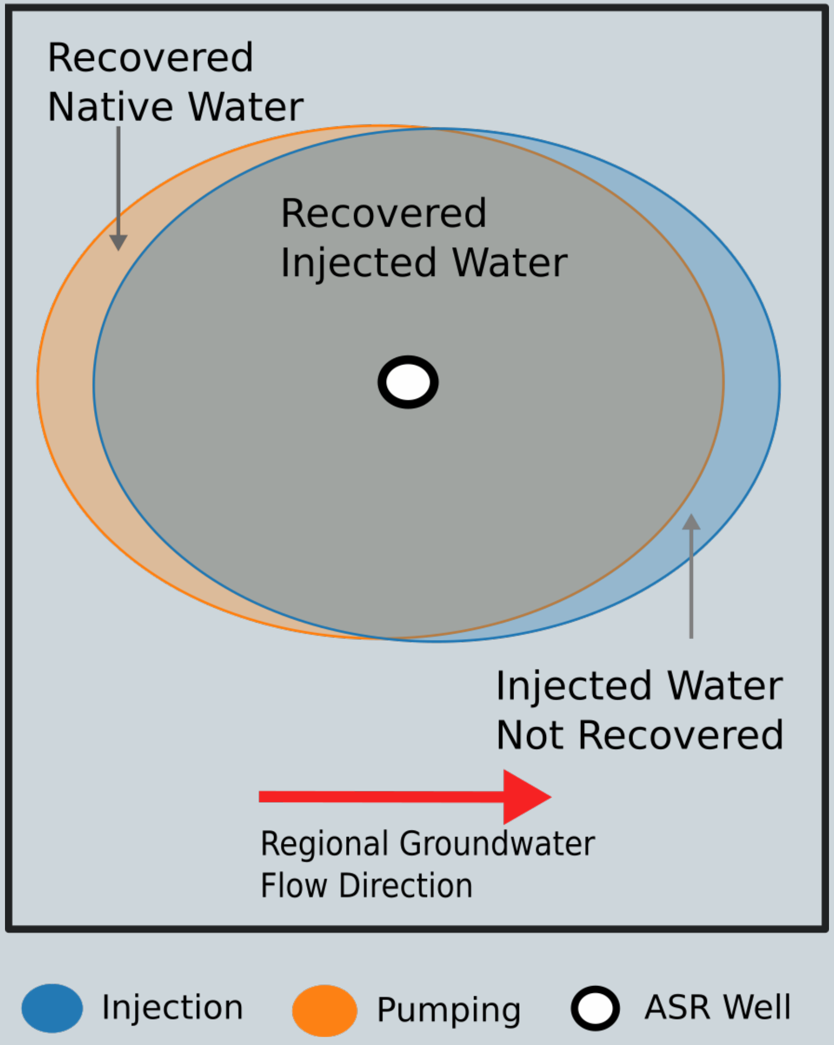
$Vr = 80\ acre - feet$

$Vp = 95\ acre - feet$

$$Recovery\ Efficiency = RE = \frac{V_r}{V_i} * 100\% = \frac{80}{100} * 100 = 80\%$$

Lost Injected Fraction = 100% - RE = 20%

Superimposed Bubbles



Native Fraction (NF):

$$NF = \frac{Vp - Vr}{Vp} * 100\%$$

$$V_i = injected\ volume$$

$$V_p = pumped\ volume$$

$$V_r = recovered\ volume$$

$Example$:

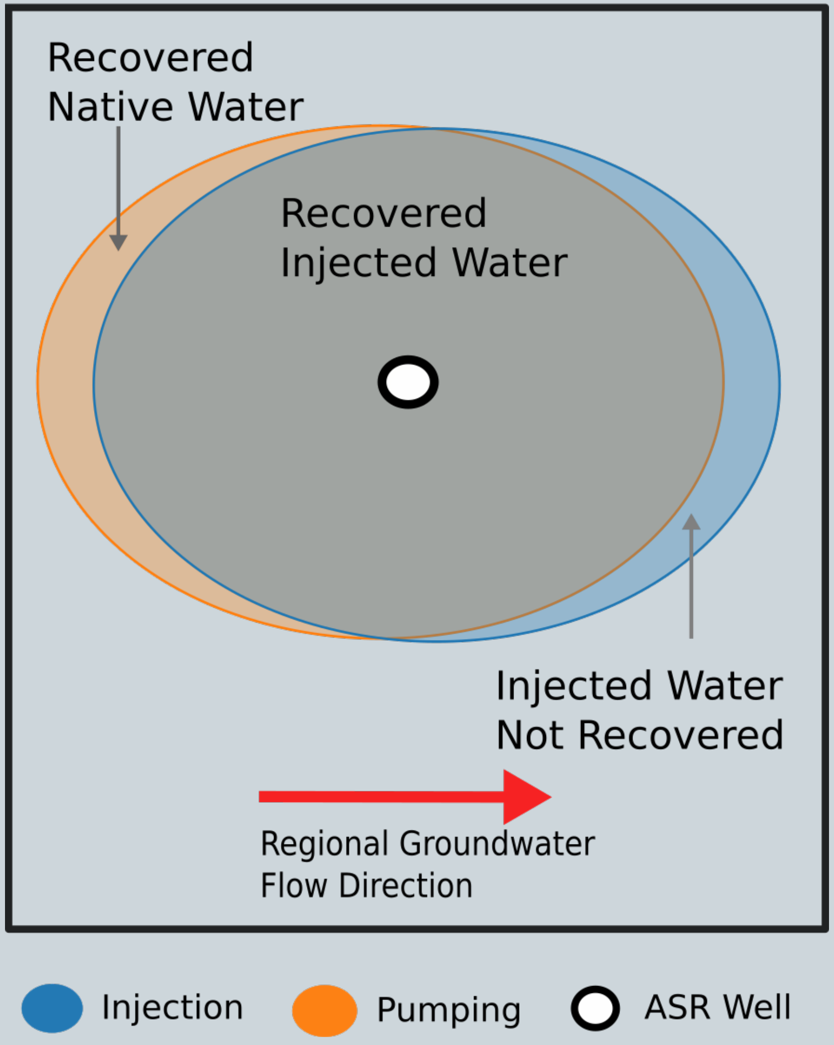
$Vi = 100\ acre - feet$

$Vr = 80\ acre - feet$

$Vp = 95\ acre - feet$

$$Percent\ Native\ Fraction = \frac{Vp - Vr}{Vp} * 100 = \frac{(95 - 80)}{95} * 100 = 15.8\%$$

Superimposed Bubbles



General Approach: Groundwater Models

Groundwater Models: Computational mathematical approximations describing groundwater flow and transport

- Analytical Model
  - Equations have exact solution
  - Solution limited by assumptions made
  - Opportunity for misuse is low
- Numerical Model
  - Equations approximate exact solution
  - Adaptable for complex groundwater flow systems
  - Computationally taxing
  - Opportunity for misuse is high

Our Approach: 2-D Analytical Model for Simulating ASR Recoverability

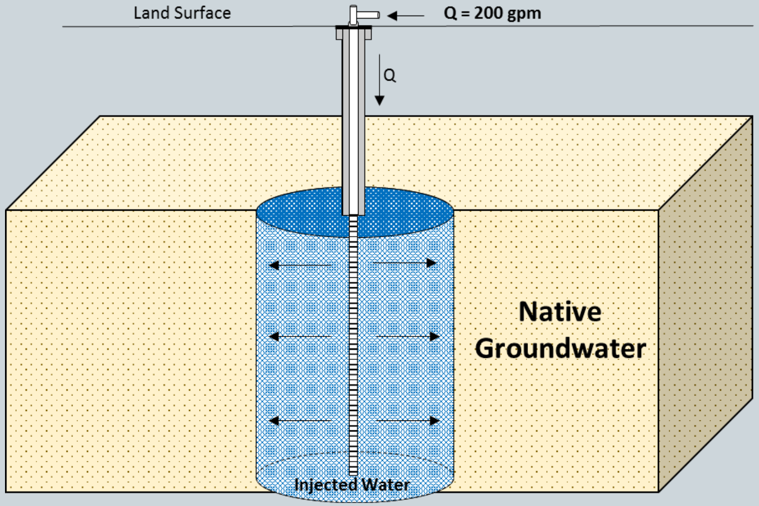
- Obtained by superposition of the **complex potentials of uniform flow** (derived from hydraulic head and streamlines) *Bear and Jacob (1965)*

- Determines recoverability for single ASR well under steady flow conditions

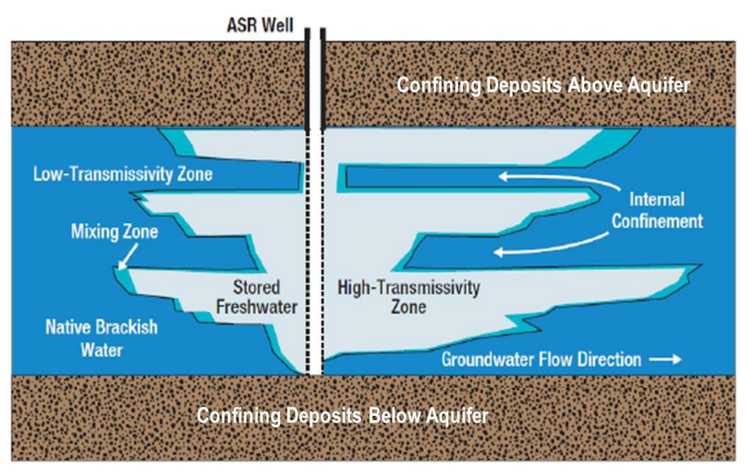
- *Assumptions:*
  - *Confined aquifer with infinite plane*
  - *Homogenous aquifer hydraulic properties*
  - *Constant pumping and injection rates*
  - *Storativity neglected*
  - *Mixing and dispersion neglected*

See documentation for more details

Ideal configuration



Complex configuration



(modified from Maliva et al., 2006).

User Friendly Model Implementation

ASR App

- **Simple** way for applicants to initiate **assessment** of water injection, storage, and recovery
- **Interactive features** for conceptual understating
- Built with **Dash**: A Python framework for building web-based applications
- **Python**: Open-sourced programming language

ASR App

Aquifer Storage and Recovery (ASR) Applet

The **ASR app** provides a simple way to assess the feasibility of water injection, storage and recovery.

Operational Parameters:

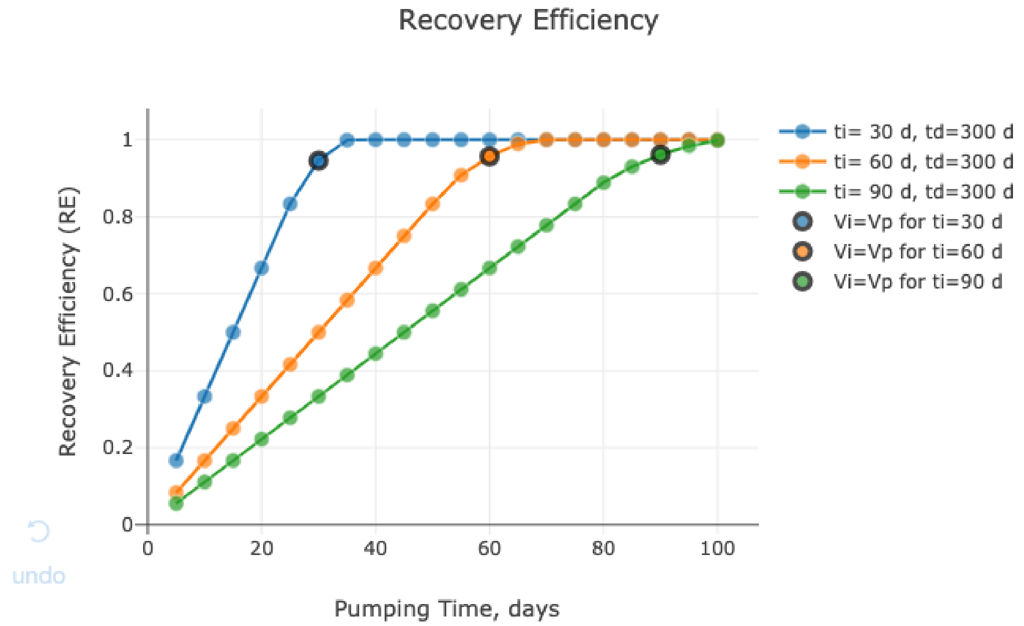
Injection Rate, ft^3/day	Puming Rate, ft^3/day	Time of Injection, day	Delay time, day	Time of Pumping, days
220000	220000	30,60,90	300,300,300	5,10,15,20,25,30,35,40,4

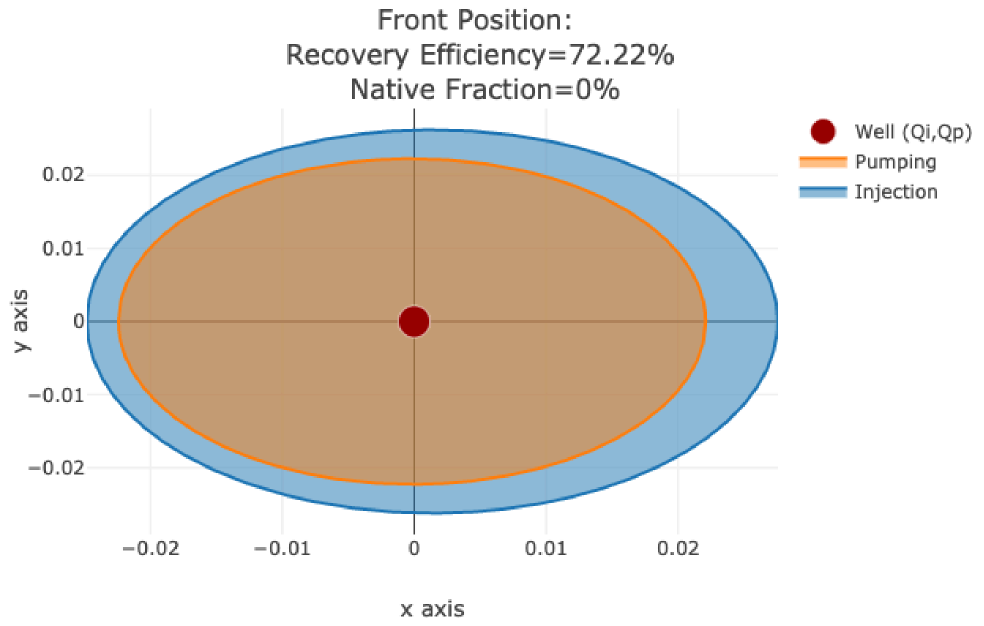
Physical Parameters:

Hydraulic Conductivity (Kd), ft/day	Hydraulic Gradient (dh/dx), ft/ft	Porosity (n), -	Thickness of Aquifer, ft	
20	0.001	0.3	100	SUBMIT

parameter options:

input option × ▾





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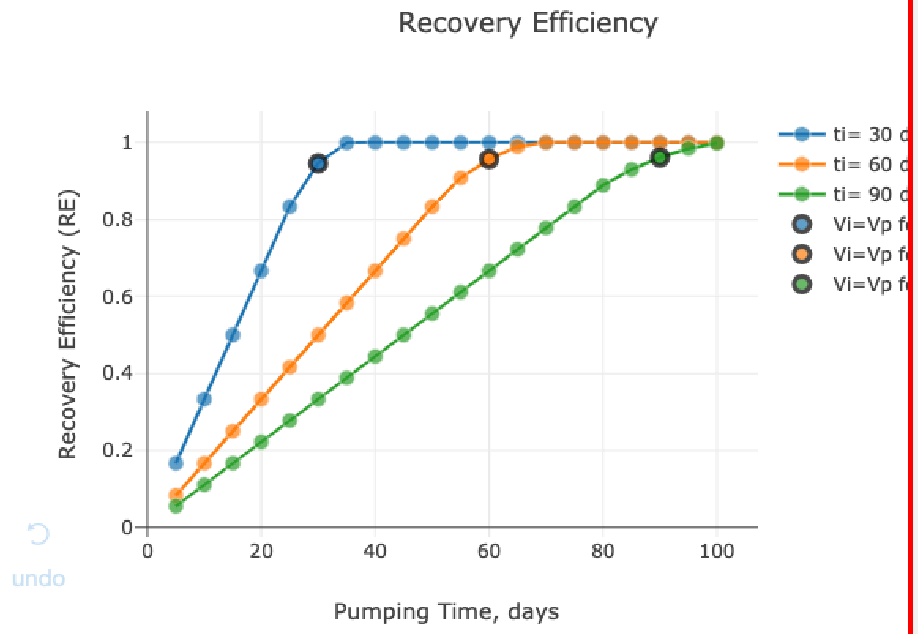

Input Parameters:

- Qi= injection rates
- Qp= pumping rates
- ti= injection time *(Multiple inputs supported)*
- tp= pumping time *(Multiple inputs supported)*
- td= delay time *(Multiple inputs supported)*
- B= thickness of aquifer
- n= porosity in aquifer
- K= hydraulic conductivity
- dh/dx = regional hydraulic gradient

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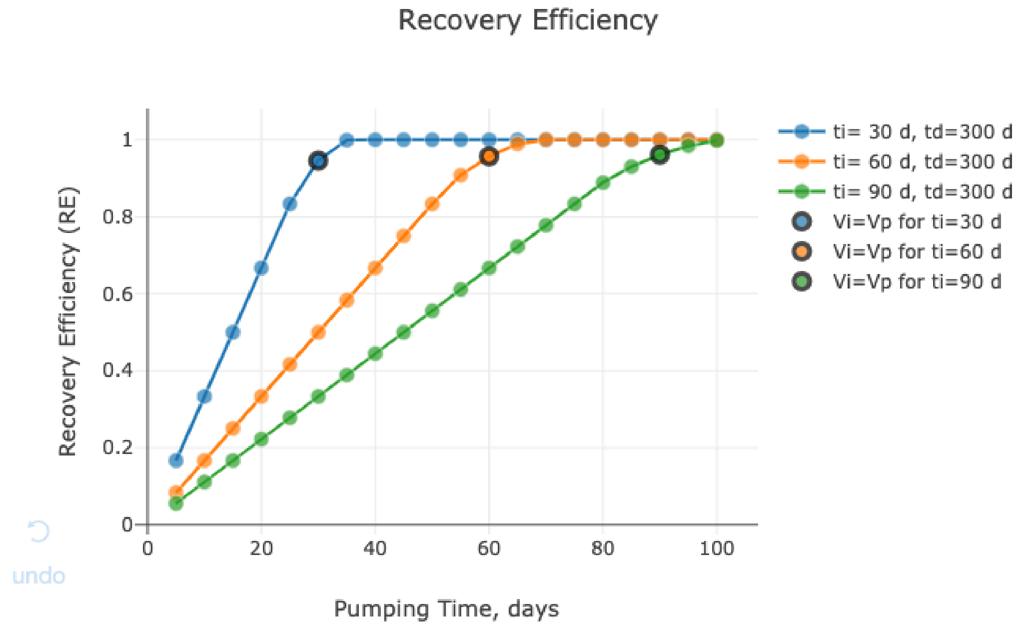
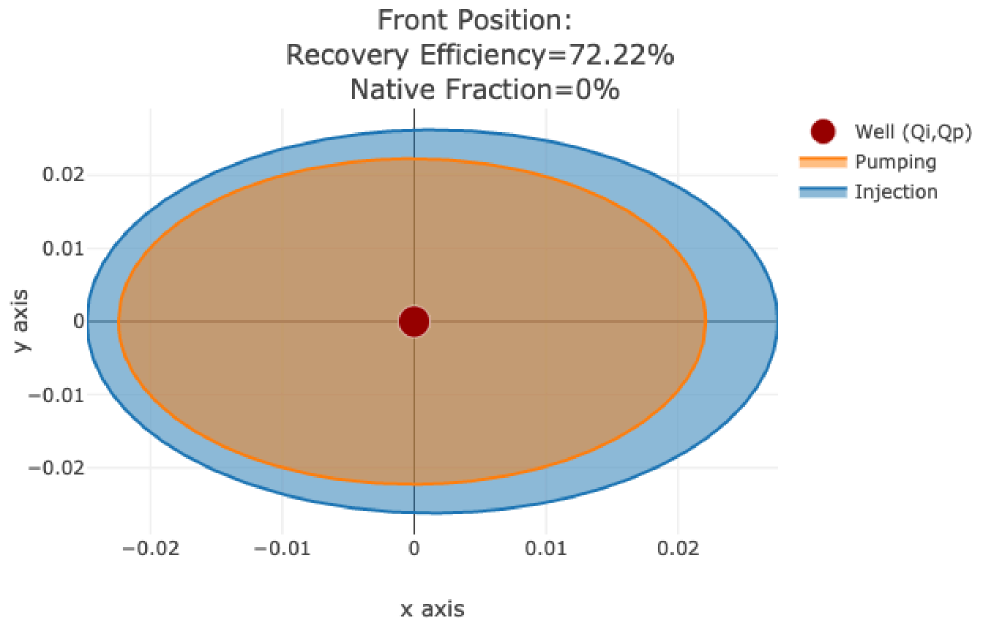




ASR App

Aquifer Storage and Recovery (ASR) Applet

The **ASR app** provides a simple way to assess the feasibility of water injection, storage and recovery.

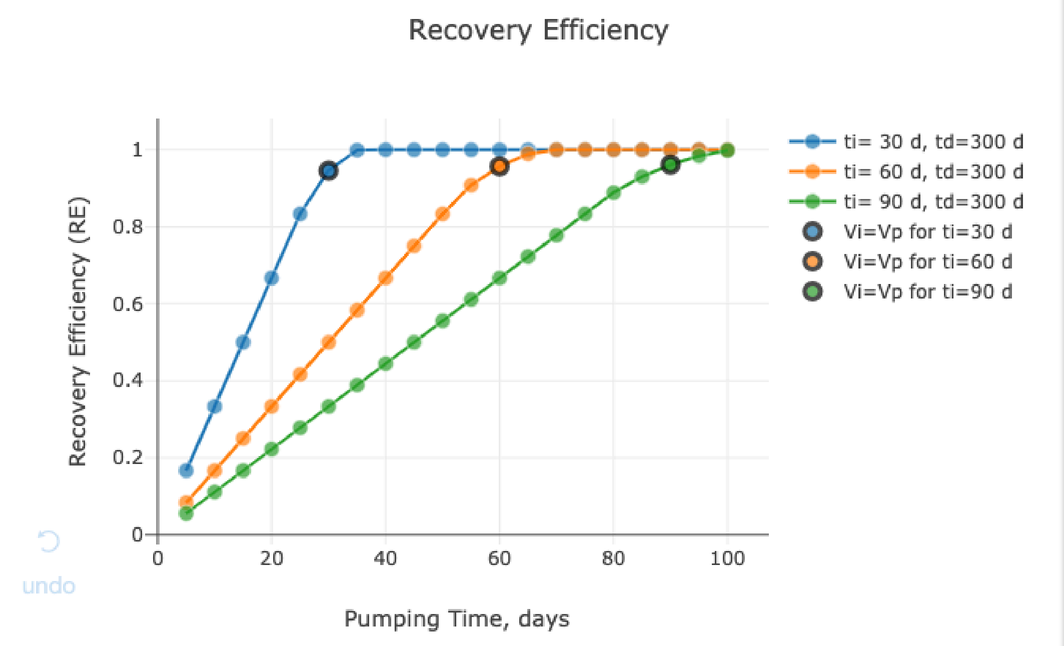
Operational Parameters:

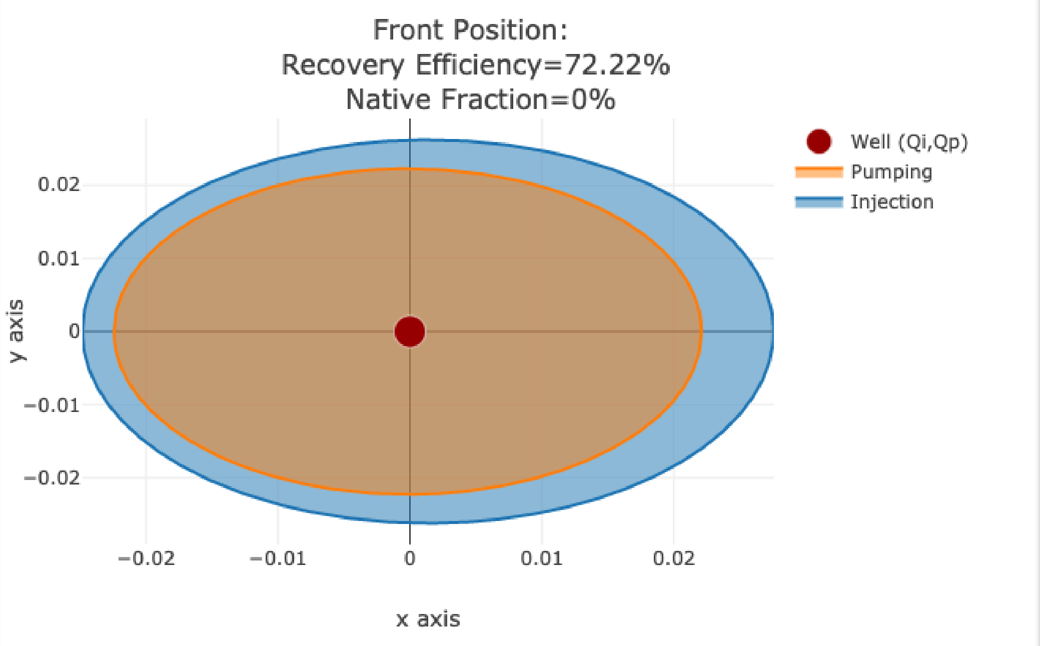
Interactive Graphical Output:

- Recovery Efficiency vs Pumping Time for multiple injection times
- Critical RE where Vi=Vp is displayed

Interactive Graphical Output:

- Allows for viewing front or bubble position for any and all RE values
- Native fraction pumped is displayed

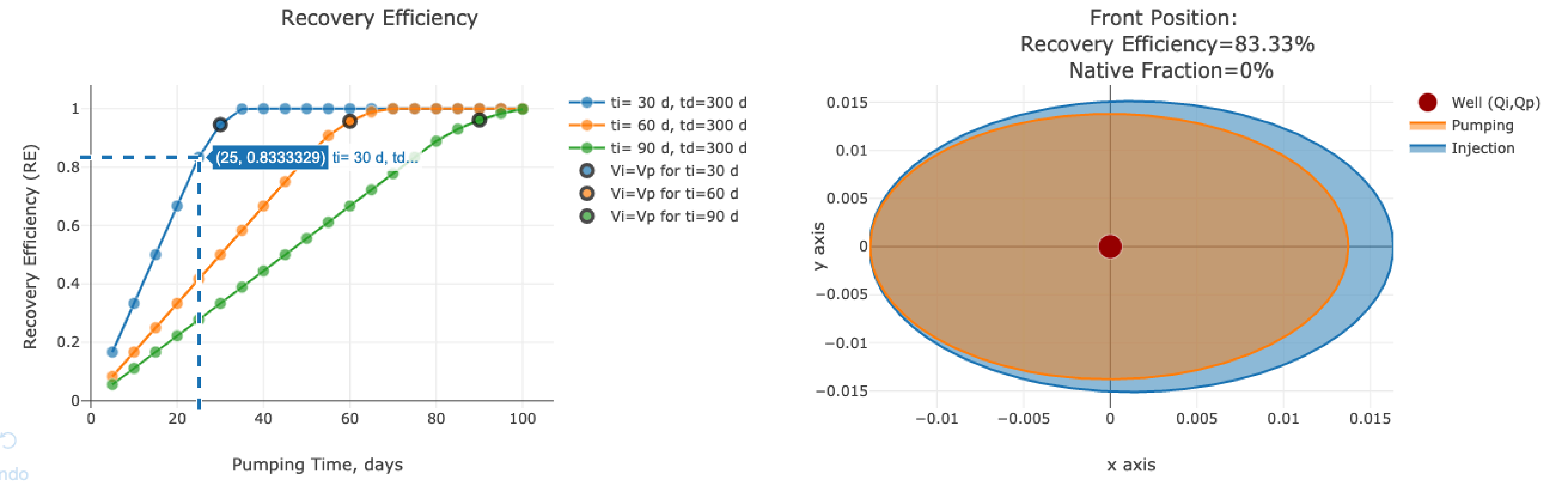




1. Example of Recoverability

Selected RE: Vp<Vi

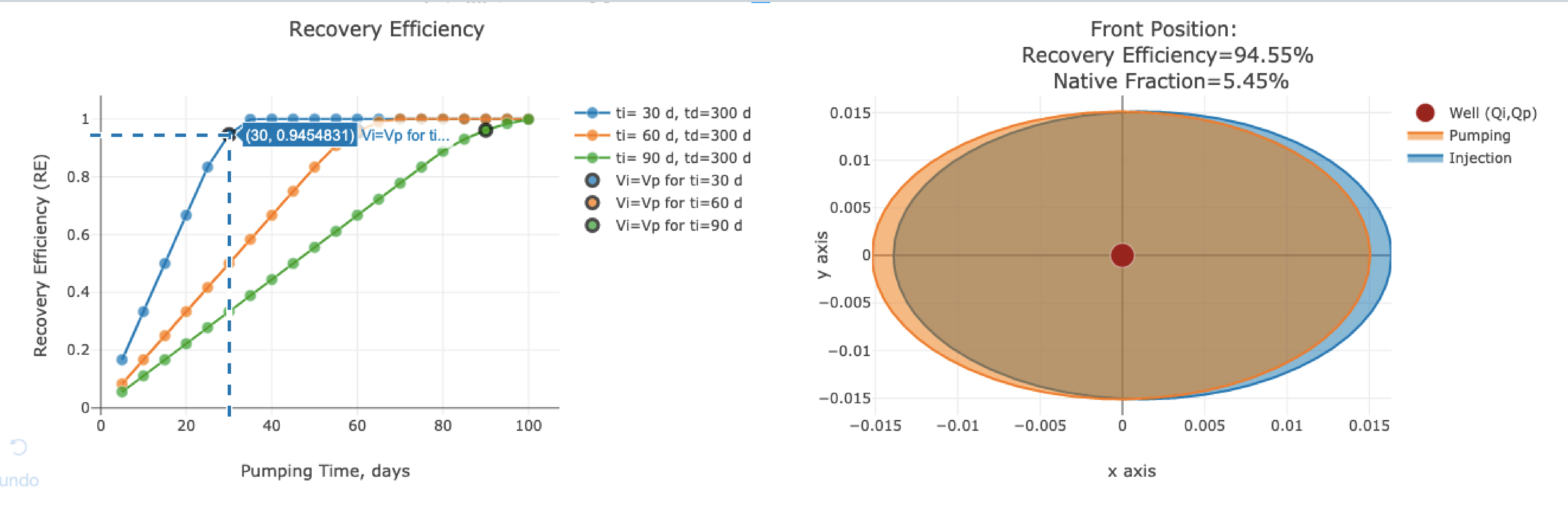
- Recovers 83.3% of injected water
- Captures 0% native water



2. Example of Recoverability

Selected RE: Vi = Vp

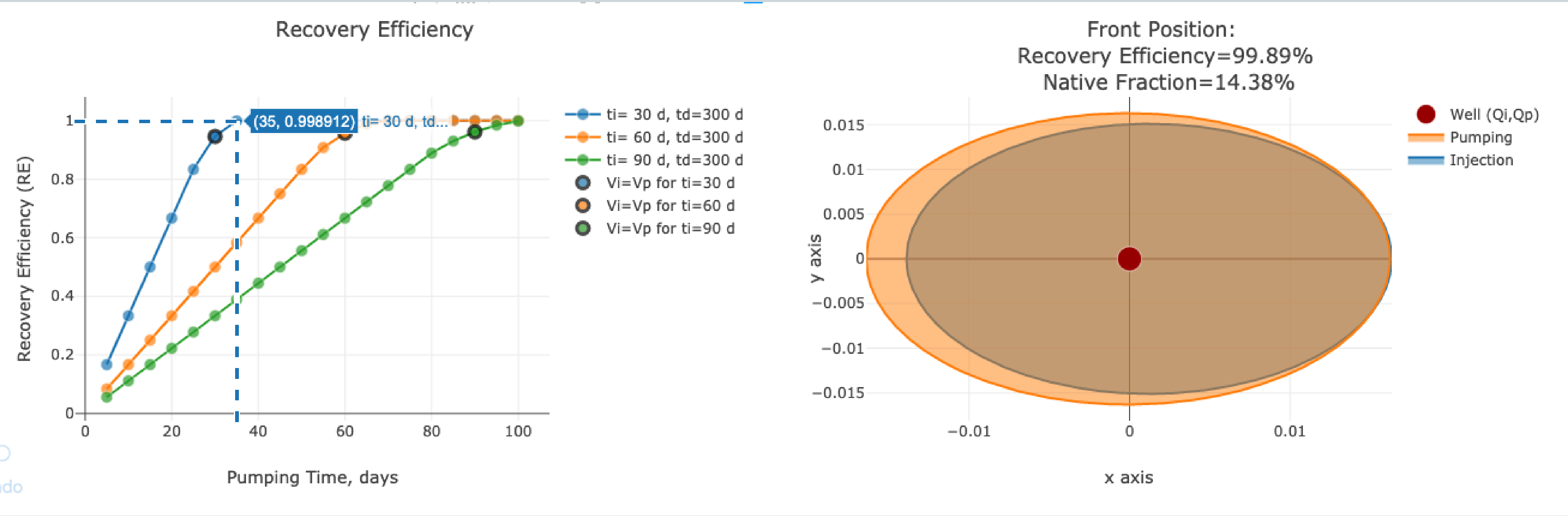
- Recovers 94.6% of injected water
- Captures 5.5% native water



3. Example of Recoverability

Selected RE: Vp > Vi

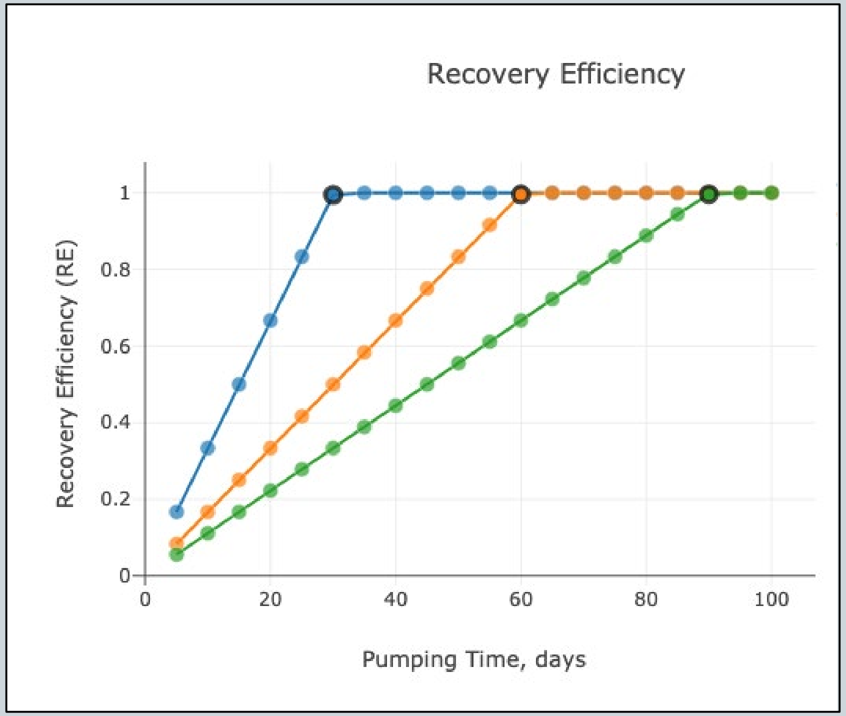
- Exceeds injected volume
- Recovers 99.9% of injected water
- Captures 14.4% native water



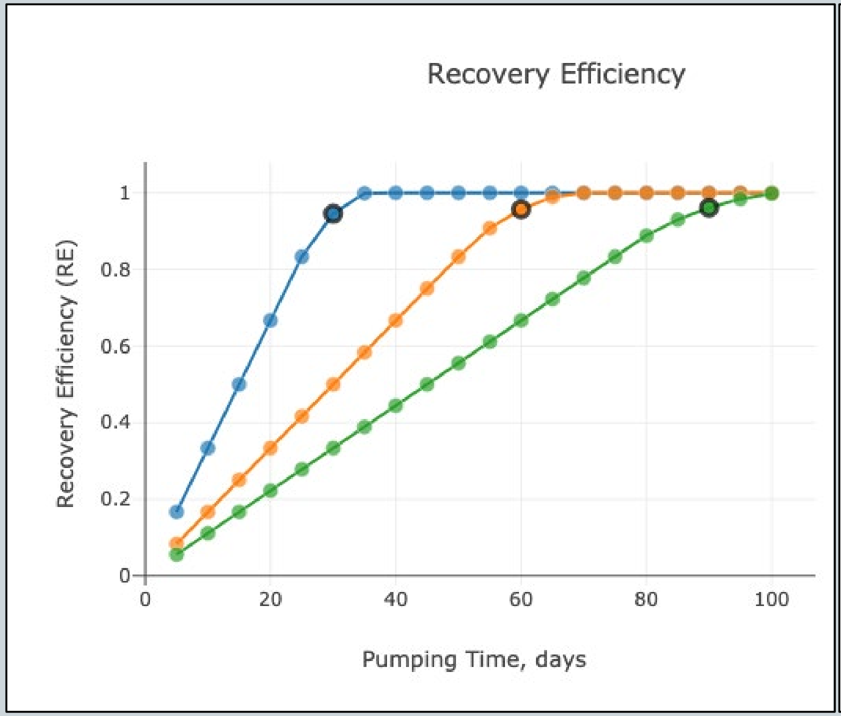
4. Example of Recoverability

Hydraulic Gradient (dh/dx) effects

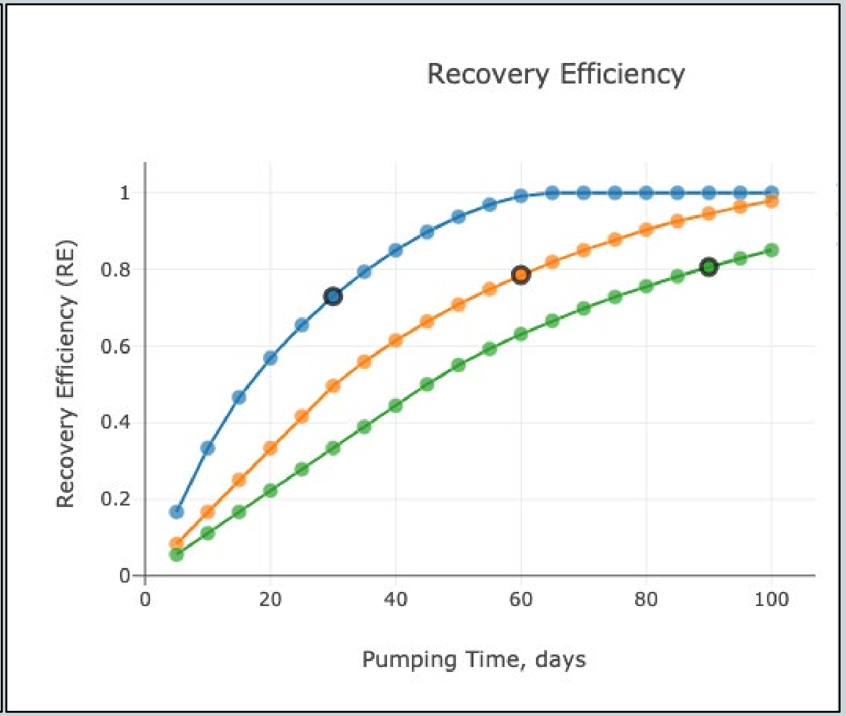
dh/dx= 0.0001 (Low)



dh/dx= 0.001 (Mid)



dh/dx= 0.005 (High)



Model Comparison: Numerical (MODFLOW) vs Analytical (ASR APP)

Parameter		Value	Units
Q_i	Injection rate	20,000	ft^3/day
Q_p	Pumping rate	220,000	ft^3/day
t_i	Injection time	330	days
t_d	Delay time	0	days
t_p	Pumping time	30	days
n	Porosity in aquifer	0.3	-
K	Hydraulic conductivity	20	ft/day
dh/dx	Regional hydraulic gradient	0.001	ft/ft
B	Thickness of aquifer	100	ft
V_i	Injection Volume	6.60E+06	ft^3
Vp	Pumping Volume	6.60E+06	ft^3

**Numerical analysis courtesy of Intera*

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Q_i	Injection rate	20,000	ft^3/day
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t_d	Delay time	0	days
t_p	Pumping time	30	days
n	Porosity in aquifer	0.3	-
K	Hydraulic conductivity	20	ft/day
dh/dx	Regional hydraulic gradient	0.001	ft/ft
B	Thickness of aquifer	100	ft
V_i	Injection Volume	6.60E+06	ft^3
Vp	Pumping Volume	6.60E+06	ft^3

Sensitivity Parameter	Numerical Model	Analytical Model
Hydraulic Gradient		
0.01	63.6%	63.6%
0.001	**96.0%**	**96.2%**
0.0001	99.5%	99.6%
Thickness		
50 feet	97.0%	97.3%
100 feet	**96.0%**	**96.2%**
200 feet	94.3%	94.6%
Hydraulic Conductivity		
6.8 ft/day	98.5%	98.8
20 ft/day	**96.0%**	**96.2%**
60 ft/day	82.4	82.9
Porosity		
30%	**96.0%**	**96.2%**
20%	95.1%	95.3%
15%	93.0%	93.3%
Injected Volume		
2.2E+06 ft^3	92.8%	93.0%
6.6E+06 ft^3	**96.0%**	**96.2%**
1.2E+07 ft^3	97.5%	97.8%
Storage Period		
No Delay	**96.0%**	**96.2%**
100 days	94.4%	94.6%
200 days	92.7%	92.9%

**Numerical analysis courtesy of Intera*

Concluding remarks…

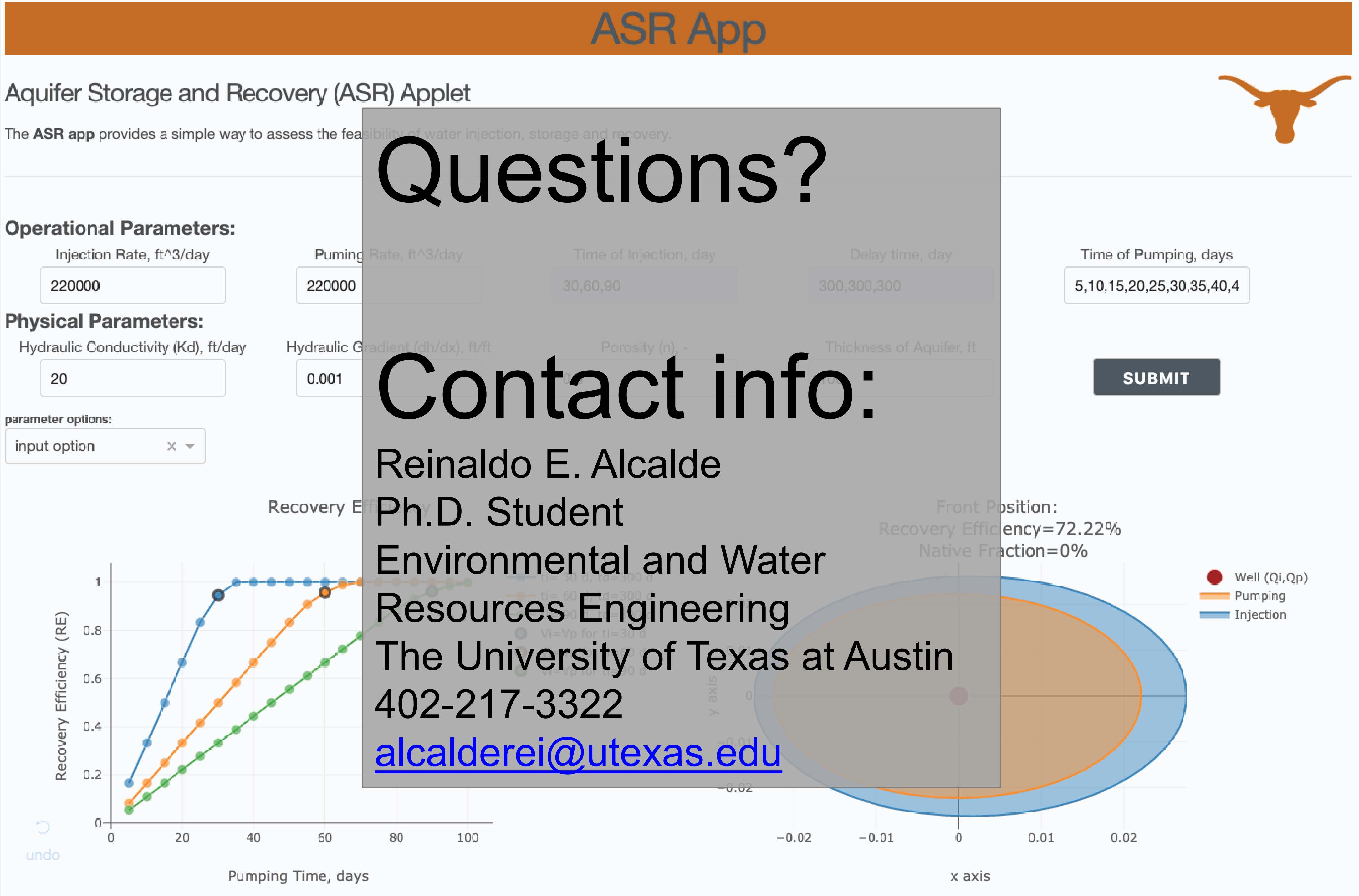
We identified and developed a user friendly application for assessing site specific recoverability of injected waters in ASR operations.

- Coded an analytical model though Python
- Developed a web-based app through Dash
- Compared our analytical solution with numerical models (MODFLOW)
- Addressed some limitations

The ASR app is an initial assessment, complex aquifer systems may require additional complex numerical modelling to justify recoverability.

Continued work…

- Deployment of ASR App to UT web-server for public use
- Case study documentation for our final deliverable



Questions?

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