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Decision Support for Aquifer Impact Remedial Response to CO_2 and Brine Leakage

(A Web-App Tool Overview)

November 13-17, 2023

Presenter: Eusebius J Kutsienyo
Earth Scientist

2023 Global Summit
on Environmental Remediation
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Team Members: Pejman Rasouli, Eusebius J Kutsienyo, Ashton Kirol, Kyle Wilson, Nicolas J Huerta, Delphine Appriou

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Outline

- National Risk Assessment Partnership (NRAP)
- Objectives of the environmental remediation response tool
- Approaches and remediation response strategies
- User interactive features of tool

NRAP National Risk Assessment Partnership

About the National Risk Assessment Partnership

- **Goal:** develop computational tools and workflows to quantitatively assess risks and potential liabilities associated with geologic carbon storage and address critical stakeholder questions in support of commercial CCUS deployment.
- Research collaboration between five U.S. DOE national laboratories supporting geologic carbon storage deployment goals (2010 – present)

Approach:

- Build the engine to identify and quantify risks associated with CO_2 injection, and design risk-based monitoring
- Mature workflows to support stakeholder decision making on risk management and liability

Outcome:

- Reduce uncertainty in risk and liability
- Decrease cost for operators
- Expedite risk evaluation

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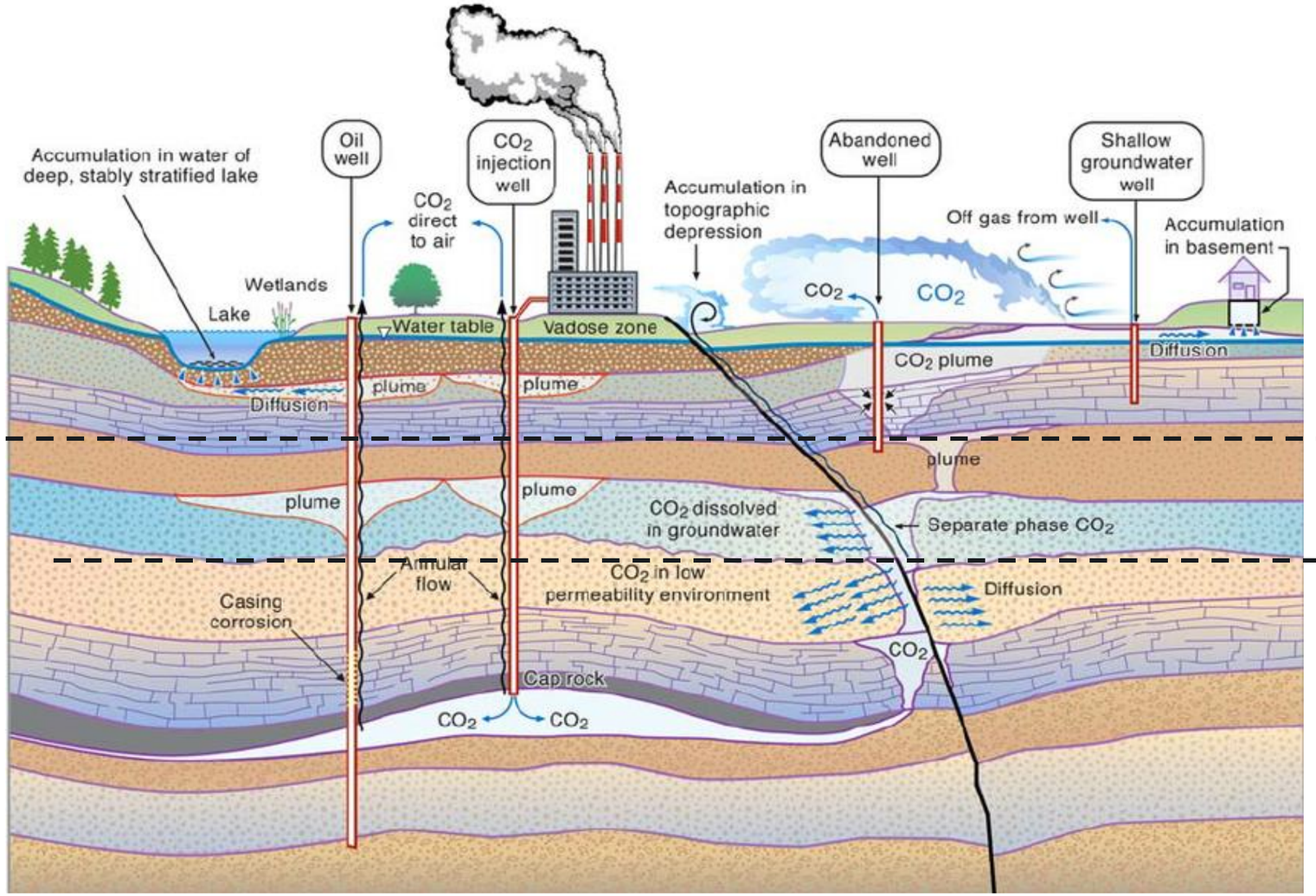
CO_2 Storage and Leakage Risk

Potential Pathways

- Wellbores
- Natural fractures and faults
- Caprock integrity
- Reservoirs boundaries

Potential Risks

- Aquifer impact
- Greenhouse gas emission
- Human health
- Economic risks
- Induced seismicity
- Infrastructure risks
- Ecological risks
- Reputational and public perception



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Objectives

What are we developing?

- Decision support system for Environmental Remedial Responses (ERR) design and costs estimate for CO_2 and brine leakage risks in Geologic Carbon Storage (GCS) sites.

- Focus on CO_2 and brine leakage impacts on Underground Sources of Drinking Water (USDW) per EPA definition.

- Evaluates CO_2 or brine plume distribution over time in the impacted aquifer.

- Estimates potential leaked mass treatable, remediation time, and remediation costs.

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Approach

How are we doing it?

- Using analytical solutions to model fate and transport and extraction well capture zone.
- Utilizing interactive user interface and web-hosting capability to define the ERRs and compare their costs.
- Run Technoeconomic analysis (TEA) on the results to model the project cost.

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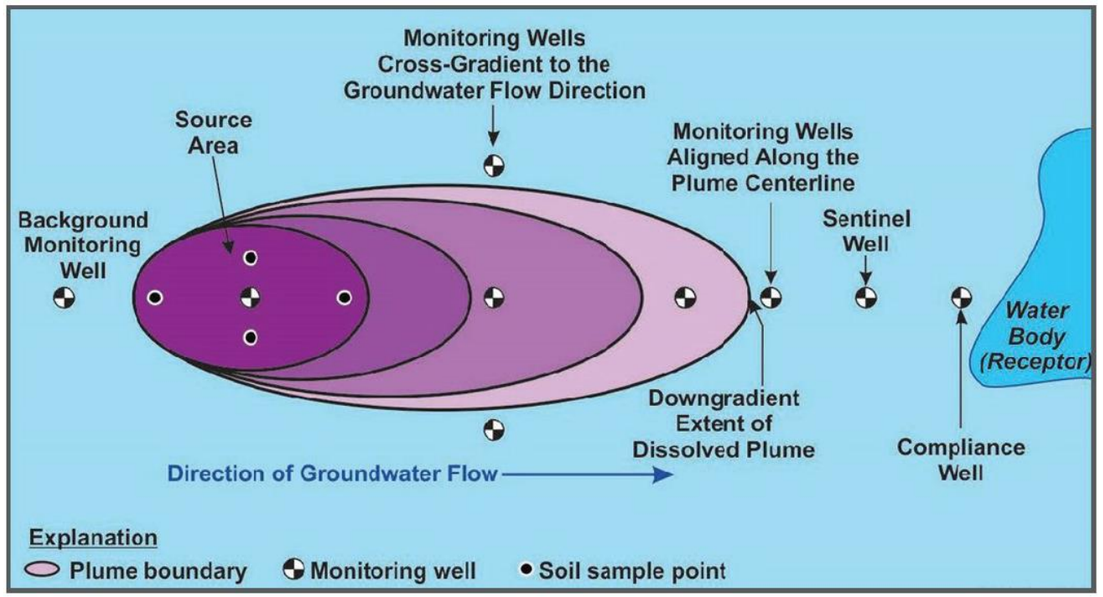
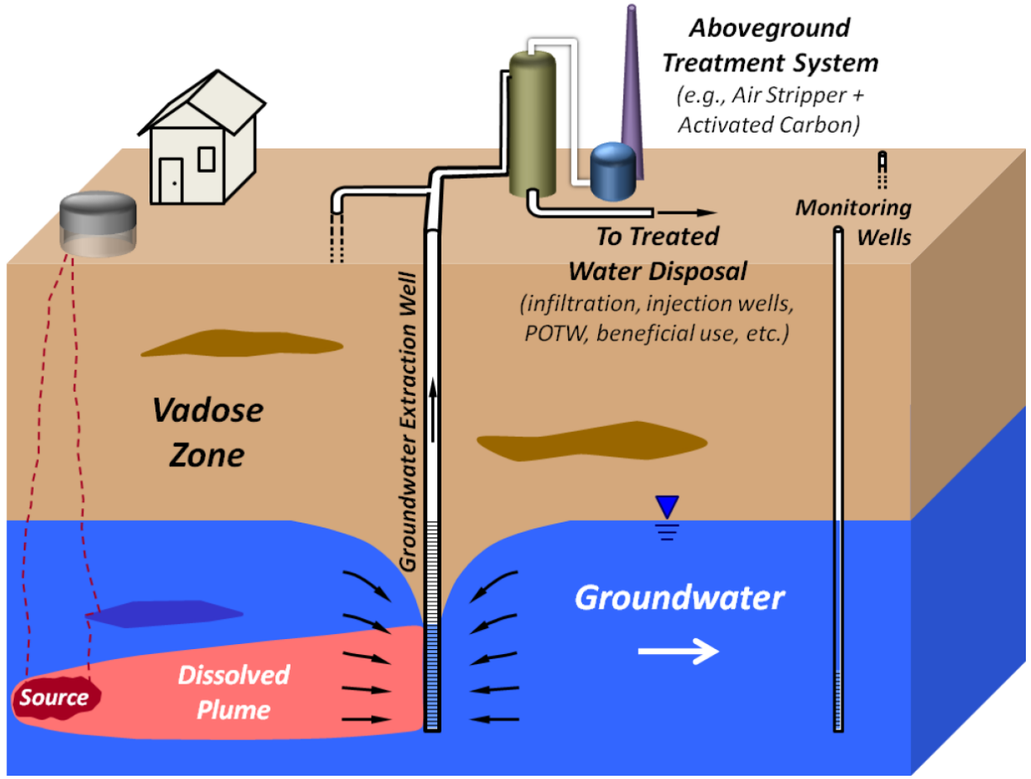
ERR Strategies & Designs

Supports two major environmental remediation response strategies:

1. Monitored Natural Attenuation (MNA)
2. Pump and Treat (P&T)



MNA schematic (Source: Federal Remediation Technologies Roundtable)



P&T profile (Source: PNNL-24696RPT-DVZ-AFRI-029)

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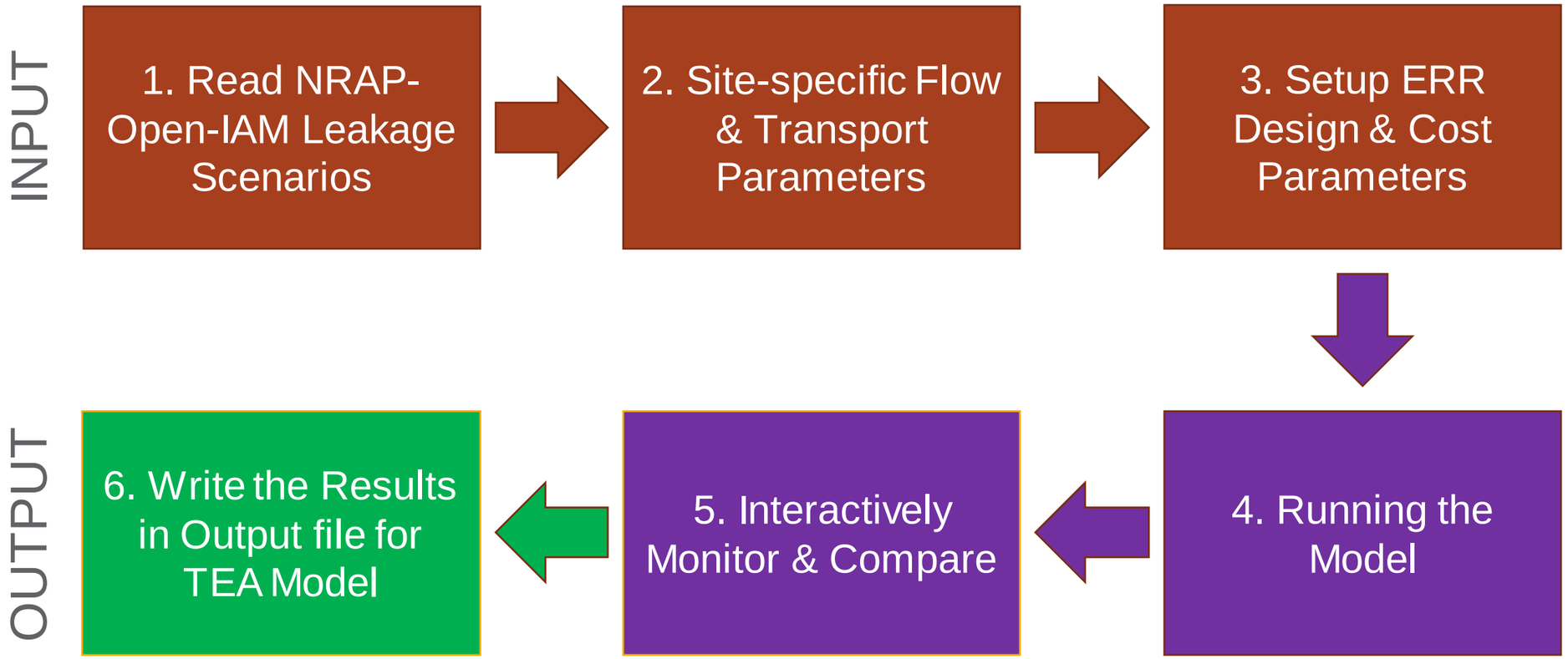
User Interaction Workflow



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Graphical User Interface

Decision Support for Aquifer Impact Remedial Response of CO_2 and Brine Leakage

Select Response Method:

Pump and Treat

Input Parameters for Pump & Treat

Release Model:
- (•) Impulse Release
- ( ) Continuous Release

Max. Concentration Level (MCL) [kg/m³]	0.1
Pumping Rate [m³/day]	250
Aquifer Thickness [m]	25
Porosity	0.2
Specific Storage [1/m]	0.0025
Hydraulic Conductivity [m/day]	0.5
Hydraulic Gradient	0.006
Mass [kg]	1000
Longitudinal Dispersivity [m]	0.1
Transverse Dispersivity [m]	0.03
Decay Coefficient [1/day]	0

Plot MCL

0 250 500 750 1,000

Upload File

Well Configuration

Well Name	X [m]	Y [m]	
Pumping Well	500	0	☐
Monitoring Well 1	260	-60	☐
Monitoring Well 2	320	60	☐
Monitoring Well 3	94	50	☑
Monitoring Well 4	94	50	☐
Monitoring Well 5	605	17	☐
Number of Additional Monitoring Wells:		5	☐
Well Sampling Option:	Set Universally		
Sampling Frequency:		Quarterly	
Number of Anolytes:		10	

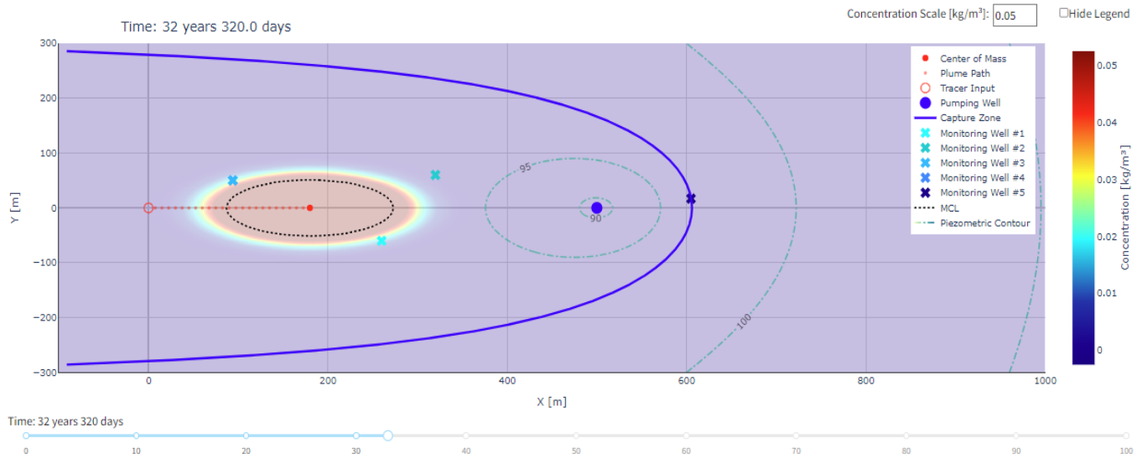
Information

Pejman Rasouli

Ashton Kirol

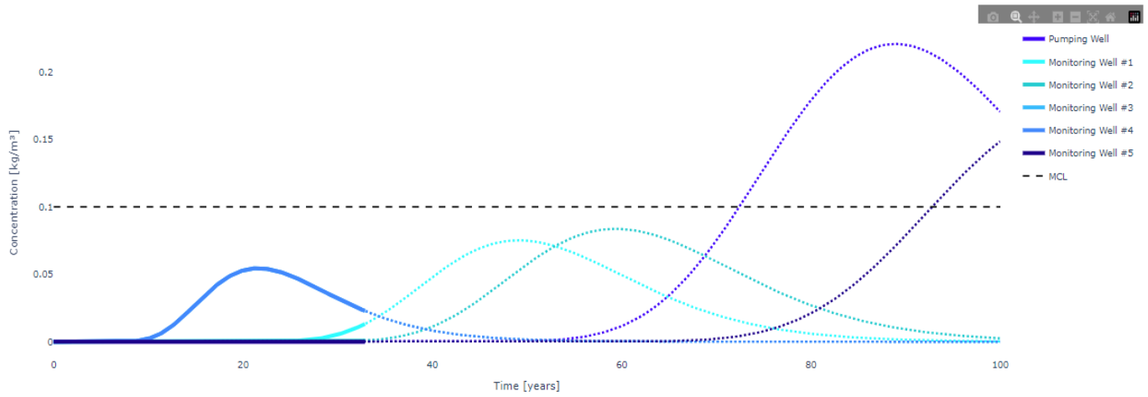
Eusebius Kutsienyo

Plume Migration and Capture Zone



Play/Stop | Final Simulation Time (years): 100 | Time Step (days): 500

Monitoring Wells



Show Full Time Series

System Performance Summary

Max. Concentration Level Area: 14,873.11 m²

Estimated Contaminant Mass: 834.10 kg

Estimated Cleanup Time: 91.78 Years

Estimated GW Removal Volume: 3,000,000 m³

Cost Analysis - Estimation

Cost Parameter		Unit Cost / Subtotal
Upfront Costs		**$1,220,000.00**
Investigation and design cost:	150000	$150,000.00
Bench and Pilot Scale Tests:	500000	$500,000.00
Regulatory Program/ Oversight and Document Preparation:	20000	$20,000.00
Construction and Startup Costs:	550000	$550,000.00
Operational Costs		**$2,900,002.00**
Process Activities:	1	$1.00
Performance Monitoring:	100	$2,400,000.00
Utilities, Raw Materials, and Waste Products:	150000	$150,000.00
Maintenance cost, routine and non-routine maintenance:	350000	$350,000.00
Demobilization and Site Restoration:	1	$1.00
Overall Total Cost:		**$4,120,002.00**

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User Interface Workflow

1 Site Parameters for Monitored Natural Attenuation Pump & Treat

Input Parameters for Monitored Natural Attenuation

Release Model:
- Impulse Release
- Continuous Release

Max. Concentration Level (MCL) [kg/m³]	0.1	Plot MCL
Aquifer Thickness [m]	25	
Porosity	0.2	
Specific Storage [1/m]	0.0025	
Hydraulic Conductivity [m/day]	0.5	
Hydraulic Gradient	0.006	
Mass [kg]	1000	
Longitudinal Dispersivity [m]	0.1	
Transverse Dispersivity [m]	0.07	
Decay Coefficient [1/day]	0	

Upload File

Input Parameters for Pump & Treat

Release Model:
- Impulse Release
- Continuous Release

Max. Concentration Level (MCL) [kg/m³]	0.1	Plot MCL
Pumping Rate [m³/day]	250	
Aquifer Thickness [m]	25	
Porosity	0.2	
Specific Storage [1/m]	0.0025	
Hydraulic Conductivity [m/day]	0.5	
Hydraulic Gradient	0.006	
Mass [kg]	1000	
Longitudinal Dispersivity [m]	0.1	
Transverse Dispersivity [m]	0.07	
Decay Coefficient [1/day]	0	

0 250 500 750 1,000

Upload File

Additional Monitoring Well

Well Configuration

Well Name	X [m]	Y [m]
Pumping Well	500	0
Number of Additional Monitoring Wells:	3	
Monitoring Well 1	70	-70
Monitoring Well 2	440	-60
Monitoring Well 3	250	30

Design Parameters for MNA

Well Configuration

Well Name	X [m]	Y [m]
Background Monitoring Well	-50	0
Source Area Well	0	0
Cross Gradient Wells	200	150
		0
		-150
Centerline Well #1	400	0
Centerline Well #2	500	0
Sentinel Well	600	0
Compliance Well	700	0
Number of Additional Monitoring Wells:	3	
Monitoring Well 1	70	-70
Monitoring Well 2	440	-60
Monitoring Well 3	250	30

ERR Method Selection

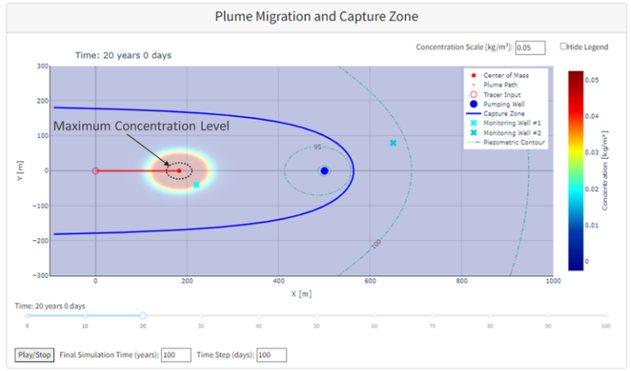
Select Response Method:

Pump and Treat
- Pump and Treat
- Monitored Natural Attenuation

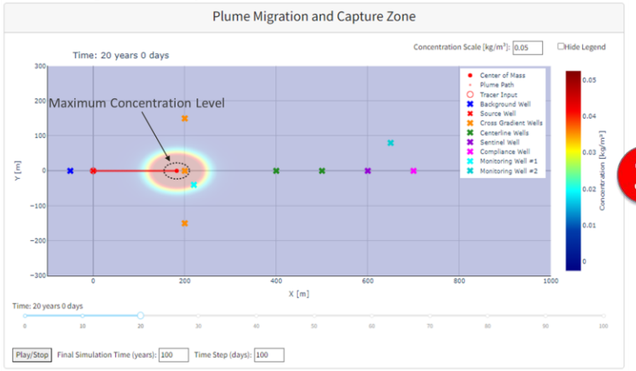
Pump & Treat

2

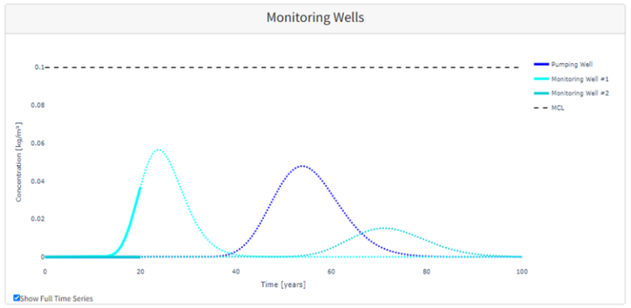
Plume Migration Output for Pump and Treat



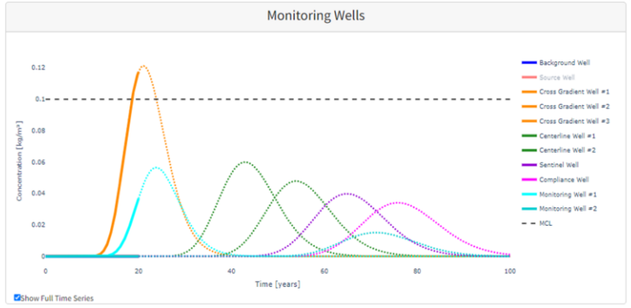
Plume Migration Output for Monitored Natural Attenuation



Concentration Breakthrough Output for Pump and Treat



Concentration Breakthrough Output Monitored Natural Attenuation



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System Performance Summary

Max. Concentration Level Area: 1,952.58 m²

Estimated Contaminant Mass: 222.60 kg

Estimated Cleanup Time: 1,000.00 Years

Estimated GW Removal Volume: 1,000.00 m³

Response Method Information

Pump and Treat .....

Upfront Costs

• Investigation and design cost:	250
• Bench-and Pilot Scale Tests:	350
• Regulatory Program/ Oversight and Document Preparation:	125
• Construction and Startup Costs:	458

Operational Costs

• Process Monitoring:	235
• Performance Monitoring:	145
• Utilities, Raw Materials, and Waste Products:	133
• Maintenance cost, routine and non-routine maintenance:	173
• Demobilization and Site Restoration:	890

Panels Guide

1 Input Parameters Cards
2 Output Graphic Results
3 System Performance & Cost Parameters Output

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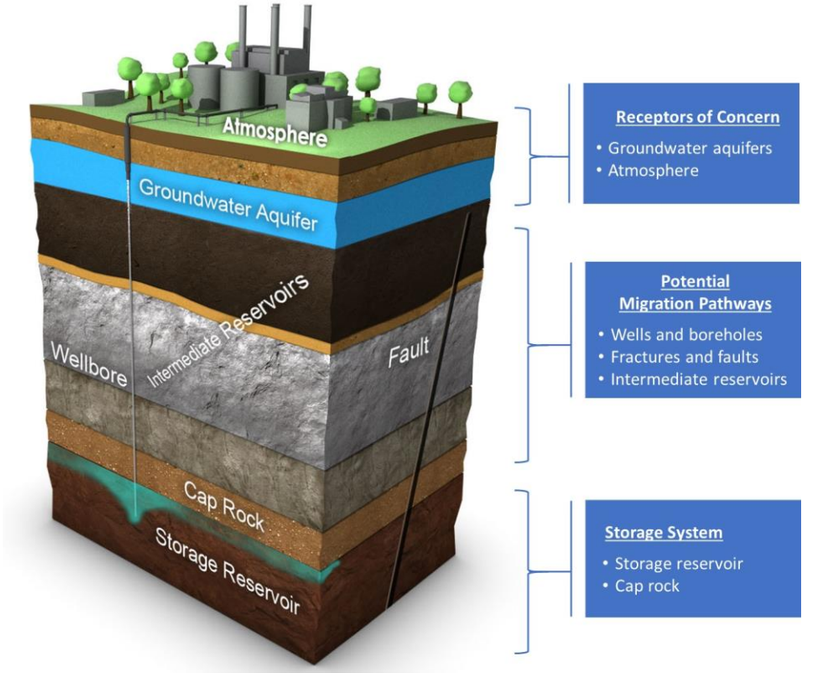
NRAP-Open-IAM Interface



NRAP-Open-IAM answers questions about potential GCS site's ability to:

- Contain injected CO_2
- Protect groundwater and other environmentally sensitive areas
- Reduce atmospheric greenhouse gas emissions

By:

- Characterizing system features (reservoir, confining zones, leakage pathways, potential receptors)
- Defining potential unintended migration pathways
- Simulating response to planned injection
- Quantifying unintended migration risks and potential impacts

Vasylkivska, V., R. Dilmore, G. Lackey, Y. Zhang, S. King, D. Bacon, B. Chen, K. Mansoor and D. Harp (2021). "NRAP-open-IAM: A flexible open-source integrated-assessment-model for geologic carbon storage risk assessment and management." Environmental Modelling & Software 143. https://gitlab.com/NRAP/OpenIAM

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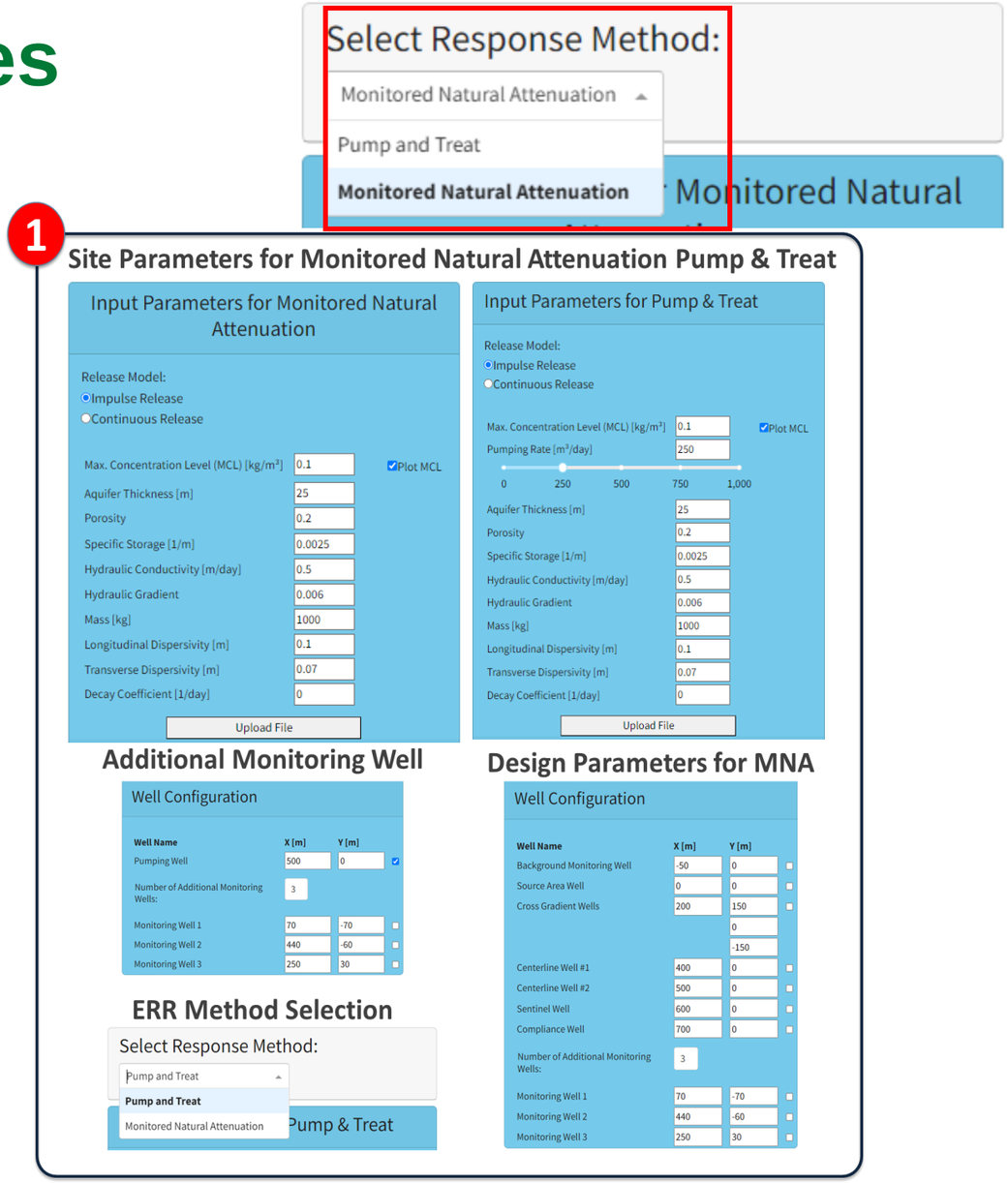
User Interaction Features

Interactive web-based functionality let the user to:

- Input site-specific parameters:
  - hydraulic conductivity
  - aquifer thickness
  - porosity
  - gradient
  - dispersity
  - decay rate
  - and more …
- Select between scenarios:
  - continuous release
  - impulse release



➢**Change parameters/scenarios on the fly and see the effect on the fly**

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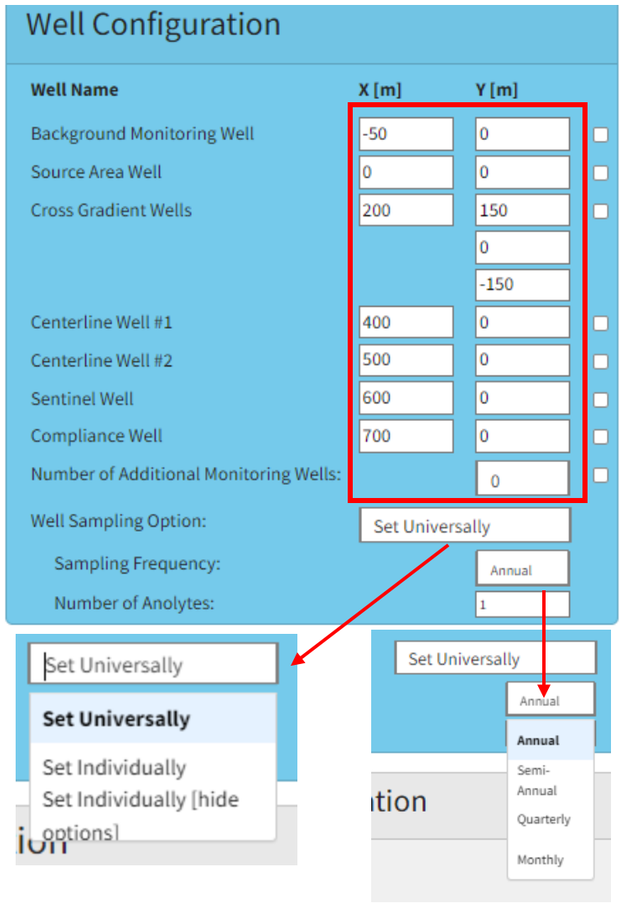
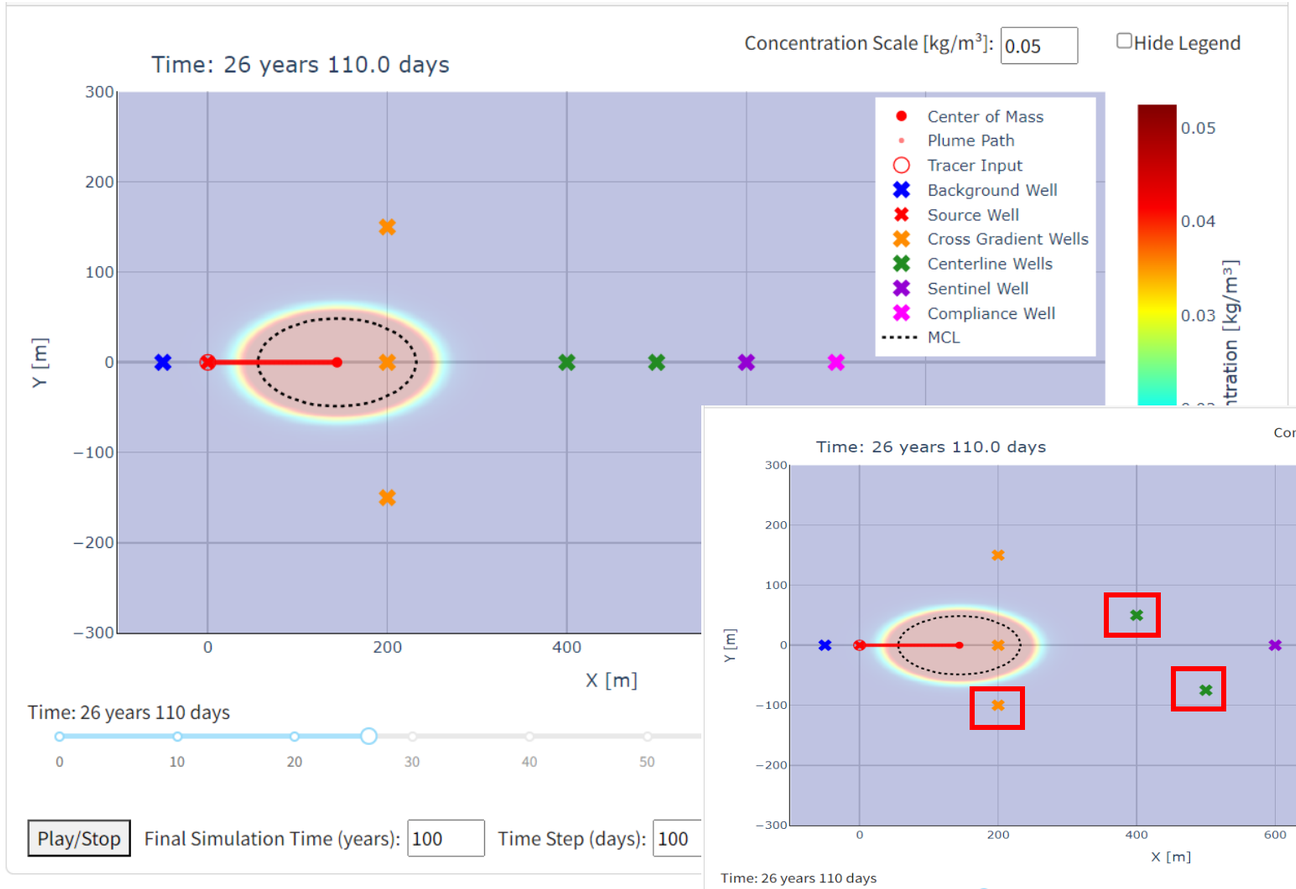
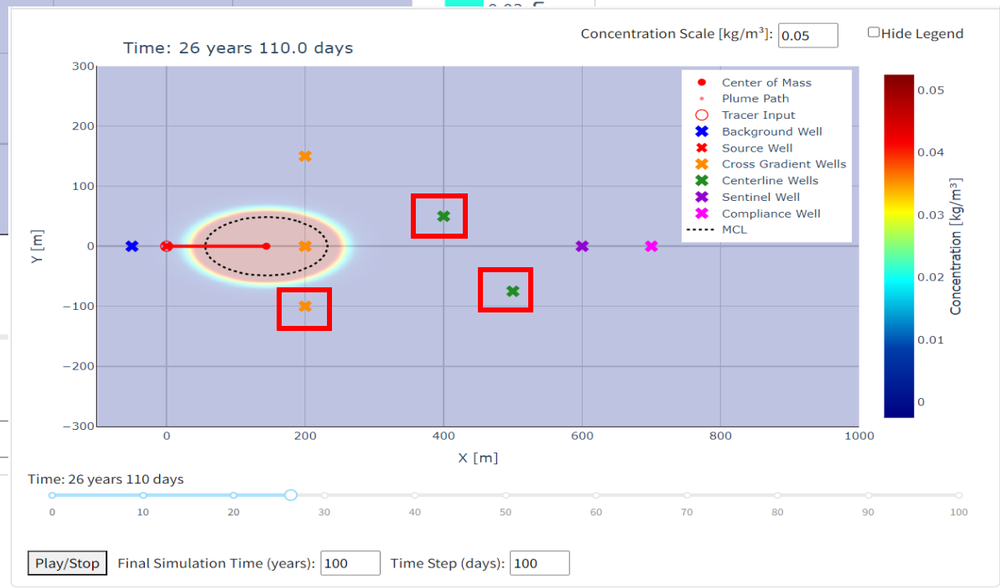
Monitored Natural Attenuation (MNA)

- ✓ Design Monitoring Network (use template for MNA or modify it)
- ✓ Design Sampling Program: annual, semi-annual, quarterly, etc.
- ✓ Define number of analytes to sample
- ✓ Monitor concentration change over time







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Pump and Treat (P&T)

- ✓ Select extraction well location
- ✓ Adjust extraction rate
- ✓ Assess capture zone
- ✓ Add monitoring wells as needed

Input Parameters for Pump & Treat

Release Model:

- (•) Impulse Release
- ( ) Continuous Release

Max. Concentration Level (MCL) [kg/m³]	0.1
Pumping Rate [m³/day]	250
Aquifer Thickness [m]	25
Porosity	0.2
Specific Storage [1/m]	0.0025
Hydraulic Conductivity [m/day]	0.5
Hydraulic Gradient	0.006
Mass [kg]	1000
Longitudinal Dispersivity [m]	0.1
Transverse Dispersivity [m]	0.07
Decay Coefficient [1/day]	0

☑ Plot MCL

0 250 500 750 1,000

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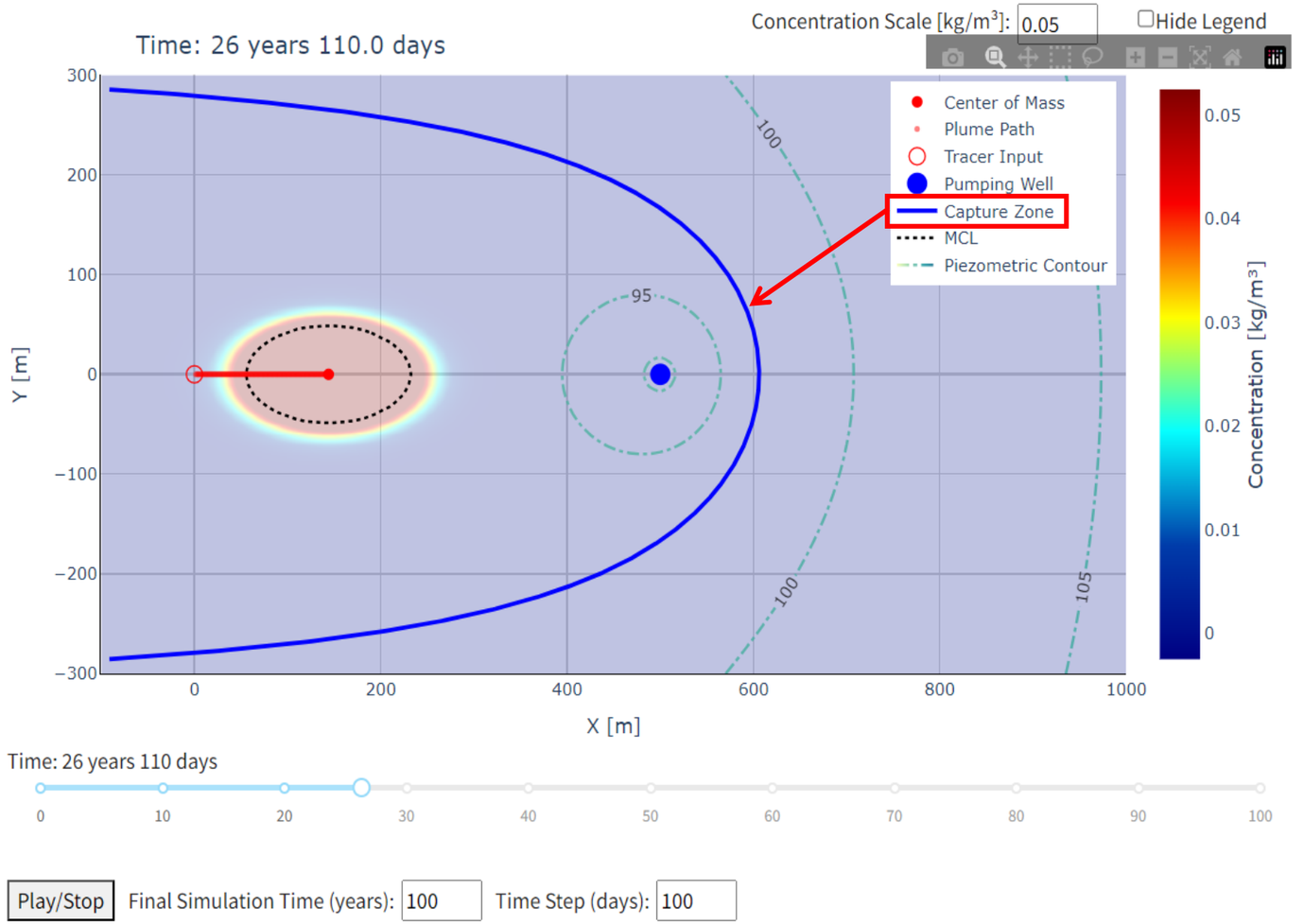
Plume Migration and Capture Zone



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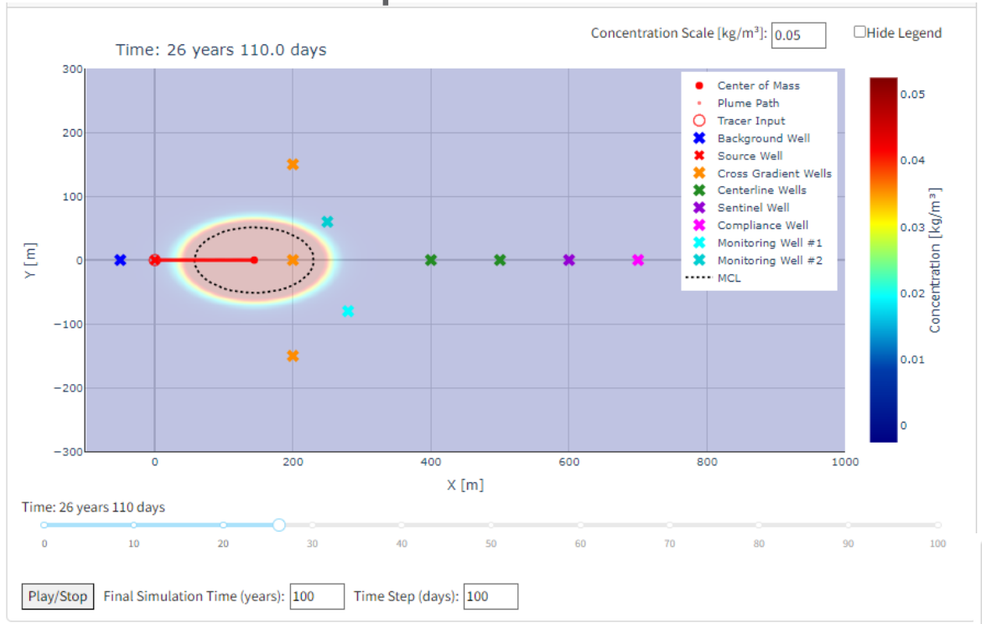
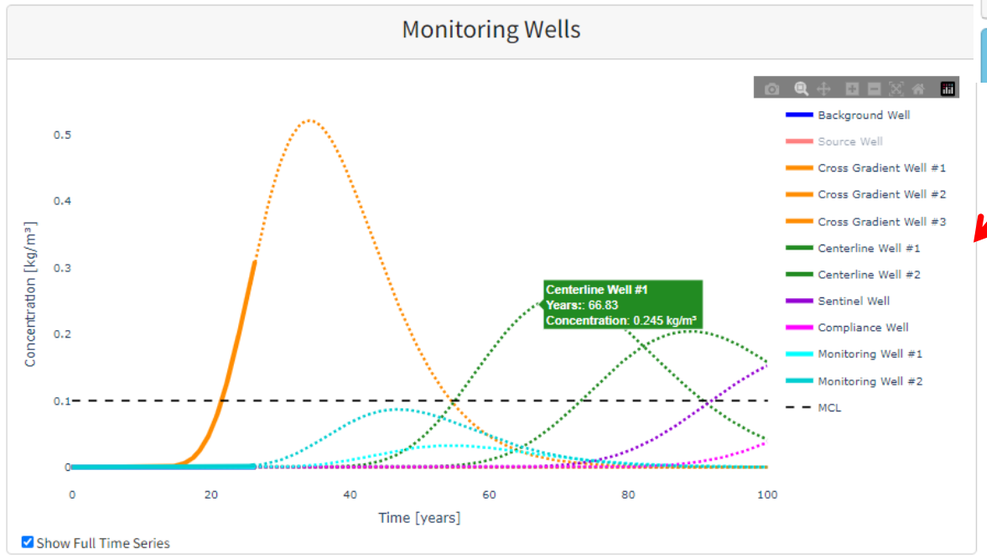
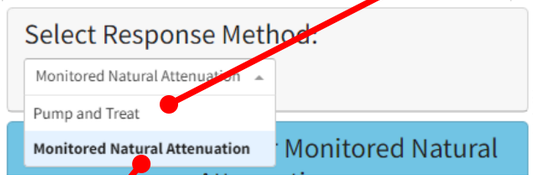
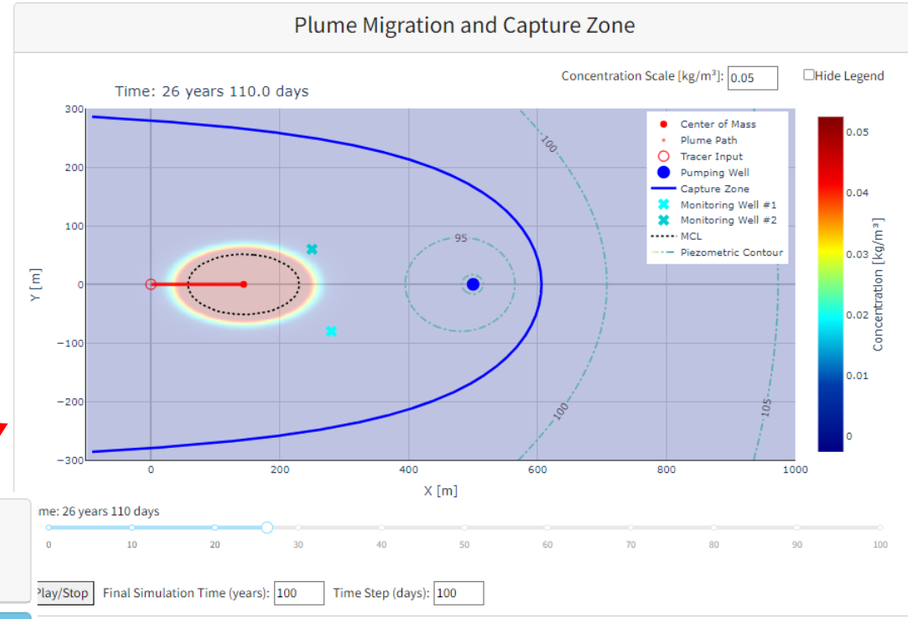
User Interaction Features

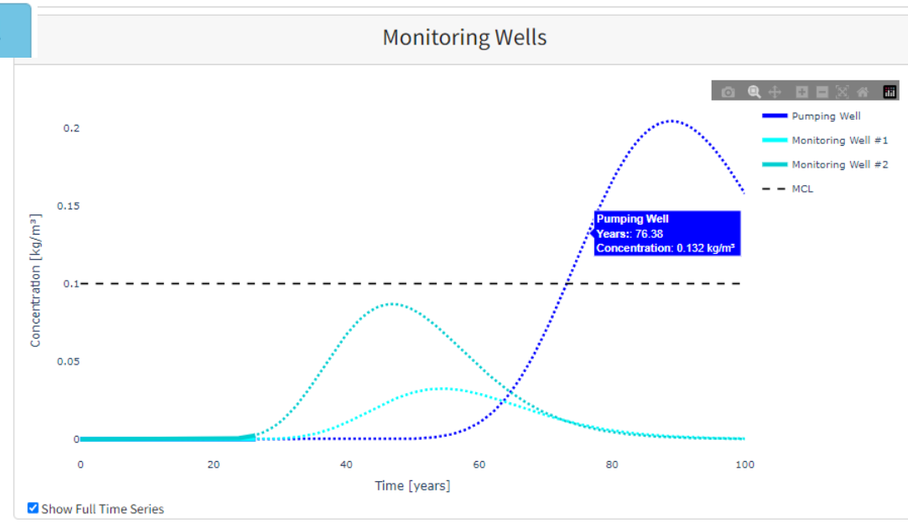
Run and compare scenarios simultaneously and switch between ERRs











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User Interaction Features

- Compare different ERR system performances and costs and see the system performance metrics:
  - Impacted area
  - Impacted water volume
  - Estimated mass to remove
  - Estimated remediation time

- Cost outputs are fed into a Technoeconomic Model to calculate Net Present Value (NPV) for the project.

3

System Performance Summary

Max. Concentration Level Area: 14,873.11 m^2

Estimated Contaminant Mass: 834.10 kg

Estimated Cleanup Time: 91.51 Years

Estimated GW Removal Volume: 3,000,000 m^3

Cost Analysis - Estimation

Cost Parameter		Unit Cost Subtotal
Upfront Costs		**$640,000.00**
Investigation and design cost:	15000	$15,000.00
Bench and Pilot Scale Tests:	50000	$50,000.00
Regulatory Program/ Oversight and Document Preparation:	20000	$20,000.00
Construction and Startup Costs:	555000	$555,000.00
Operational Costs		**$510,002.00**
Process Activities:	1	$1.00
Performance Monitoring:	100	$10,000.00
Utilities, Raw Materials, and Waste Products:	150000	$150,000.00
Maintenance cost, routine and non-routine maintenance:	350000	$350,000.00
Demobilization and Site Restoration:	1	$1.00
Overall Total Cost:		**$1,150,002.00**

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Technoeconomic Model Interface

1

Input Parameters for TEA

Project Size (tons/Year)
30000

Construction Costs ($)
1000000

Construction Time (Years)
4

Operation Costs ($/Year)
5000000

Operation Time (Years)
30

Post-Injection Costs ($/Year)
1000000

Post_Injection Time (Years)
50

Siting Cost ($/Year)
2000000

Siting Time (Years)
2

Site Selection and Screening Cost ($/Year)
1000000

Site Selection and Screening Time ($/Year)
1

Financial Parameters

Price received ($/ton)
19

Discount Rate (Equity)
0.15

Discount Rate (Debt)
0.06

Percent Funding from Equity
0.5

Federal Tax Rate
0.21

State Tax Rate
0.0884

Event Parameters

Year that Event Begins (1 = first year of operation)
0

Duration of Event (Years)
0

Initial (Fixed) Costs of Event ($)
0

Ongoing annual costs of event ($/Year)
0

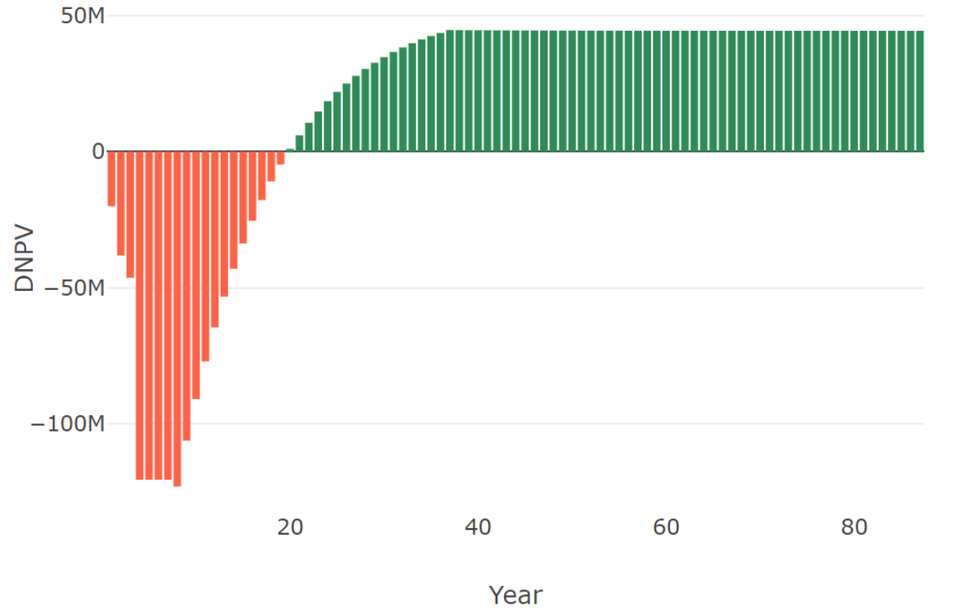
Plant Operation Parameters

Uptime (Days/Year)
365

Efficiency at Start (%)
100

Efficiency Loss (%/Year)
0

2



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Economic Metrics

levelized cost: 15.69 $/tonne

NPV: $ 44,349,715.48

Benefit-Cost-Ratio: 1.21

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Concluding Remarks & Future Developments

- This tool is designed to enhance the decision-making capabilities of stakeholders and operators by providing a rapid and accessible means to assess potential environmental and economic impacts of CO_2 and brine leakage.

- It serves as a supplementary estimator, aiding in the decision-making process, rather than replacing the development of a Conceptual Site Model (CSM) or the in-depth analysis by numerical modeling.

- **Future Developments:**
  - More integration with NRAP-Open-IAM capabilities
  - Add more analytical solutions for other release scenarios and source terms
  - Coupling with numerical simulators
  - Deployment on-scale

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Atoms for Peace and Development

Thank you, Questions & Discussion

Acknowledgement:

Team Members: Pejman Rasouli, Eusebius J Kutsienyo, Ashton Kirol, Kyle Wilson, Nicolas J Huerta, Delphine Appriou.

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Supporting Slides

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Future Developments

- Future Developments:
  - More integration with Open-IAM Capabilities
  - Extend to more analytical solutions for other release scenarios and source terms
  - Coupling with numerical simulators
  - Deployment on-scale

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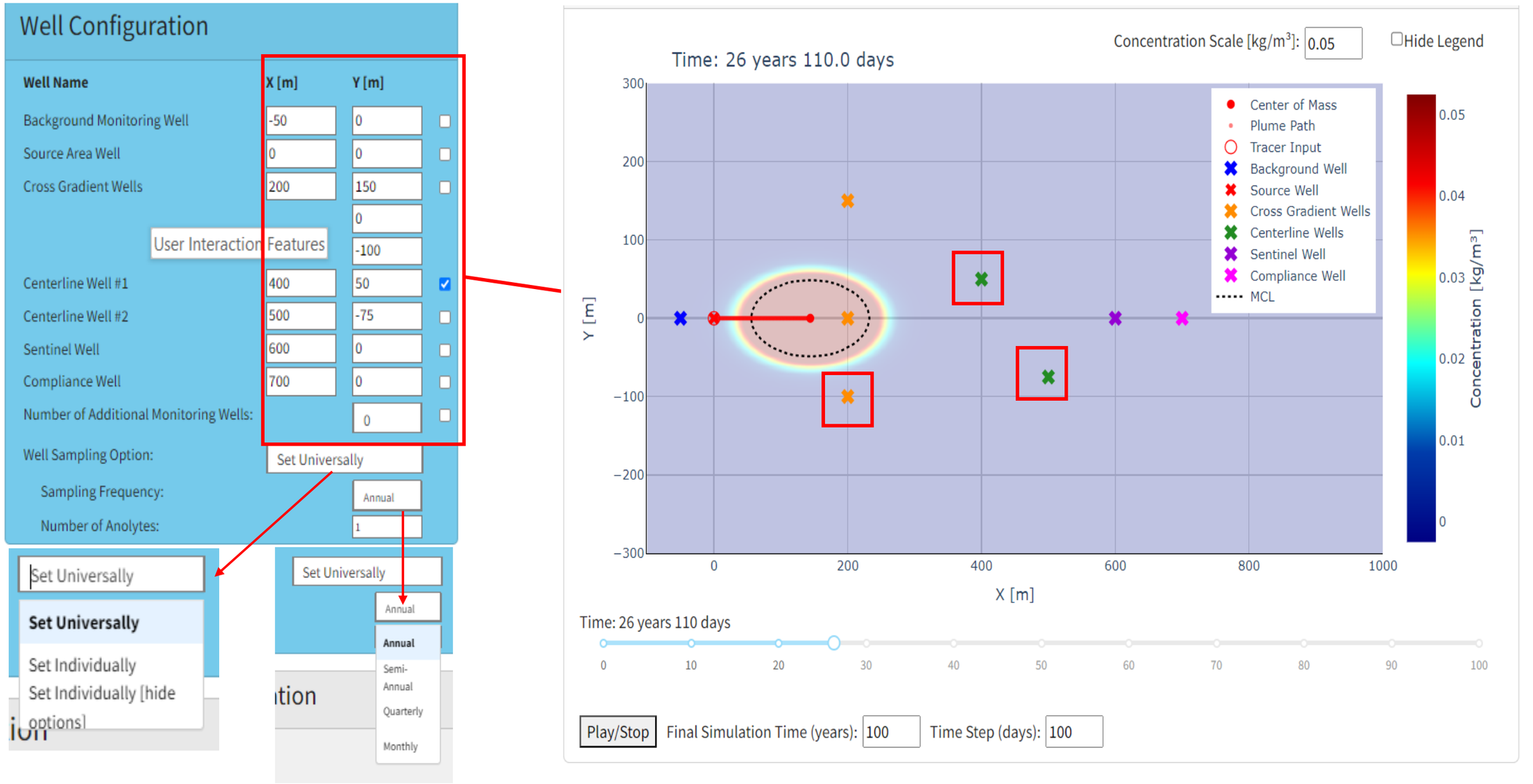
Monitored Natural Attenuation (MNA)



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Technoeconomic Model Interface

- Technoeconomic Model (TEA):
  - Combines technical and economic data.
  - Assesses viability and feasibility of CCS technology.
  - Aids in decision-making by predicting costs, benefits, and risks.

Many parameters go into a TEA such as performance metrics, operational costs, capital expenditures, and projected revenues.

Project Parameters
Project Size (tons/Year)
Construction Costs ($)
Construction Time (Years)
Operation Costs ($/Year)
Operation Time (Years)
Post-Injection Costs ($/Year)
Post Injection Time (Years)
Siting Cost ($/Year)
Siting Time (Years)
Site Selection and Screening Cost ($/Year)
Site Selection and Screening Time ($/Year)
Financial Parameters
Price received ($/ton)
Discount Rate (Equity)
Discount Rate (Debt)
Percent Funding from Equity
Federal Tax Rate
State Tax Rate
Event Parameters
Year that Event Begins (1 = first year of operation)
Duration of Event (Years)
Initial (Fixed) Costs of Event ($)
Ongoing annual costs of event ($/Year)
Plant Operation Parameters
Uptime (Days/Year)365
Efficiency at Start (%)
Efficiency Loss (%/Year)

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Introduction: Development Team & Tool

- Developed by Pacific Northwest National Laboratory **(PNNL)**, as part of National Risk Assessment Partnership **(NRAP)** program.
- **Team Members:** Eusebius J Kutsienyo, Ashton Kirol, Kyle Wilson, Nicolas J Huerta, Delphine Appriou, Pejman Rasouli.
- Web-based platform for site-specific decision support.

NRAP National Risk Assessment Partnership

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User Interaction Features

Input and estimate ERR costs:

- Upfront Costs
  - ✓ Investigation and design cost
  - ✓ Bench and pilot scale tests
  - ✓ Regulatory program/ oversight and document preparation
  - ✓ Construction and startup costs:
- Operational Costs
  - ✓ Process activities
  - ✓ Performance monitoring
  - ✓ Utilities, raw materials, and waste products
  - ✓ Routine and non-routine costs
  - ✓ Demobilization and site restoration

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User Interaction Features

- Interactive web-based functionality let the user to:

1. Connect to OPEN-IAM to read Leakage Scenarios by:
   - Using aquifer component of OPEN-IAM to run forward or stochastic leakage scenarios
   - Read OPEN-IAM output files (*.csv) and populates required field

2. Read site-specific flow and transport parameters (i.e. hydraulic conductivity, aquifer thickness porosity, gradient, dispersity, decay rate, etc.)

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User Interaction Features

Design Environmental Remedial Responses:

- Monitored Natural Attenuation (MNA):
  - ✓ Design Monitoring Network (use template for MNA or modify it)
  - ✓ Design Sampling Program: annual, semi- annual, quarterly, etc.
  - ✓ Define number of anolytes to sample
  - ✓ Monitor concentration change over time

- Pump and Treat (P&T):
  - ✓ Select extraction well location
  - ✓ Adjust extraction rate
  - ✓ Asses capture zone
  - ✓ Add monitoring wells as needed