San Juan Basin CarbonSAFE Phase III: Ensuring Safe Subsurface Storage of CO_2 in Saline Reservoirs

DE-FE0031890

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National Energy Technology Laboratory

Carbon Management and Natural Gas & Oil Research Project Review Meeting

Virtual Meetings August 2 through August 31, 2021

Presentation Outline

- Project overview
- Project Objectives
- Accomplishments
- Geology of San Juan Basin
- Technical Approach
- Synergy Opportunities
- Summary

Program Overview

- Funding Profile
- Overall Project Performance Dates

October 2020 – September 2023

	BP 1		BP 2		Total	
	DOE Funds	Cost Share	DOE Funds	Cost Share	DOE Funds	Cost Share
NMIMT	12,372,219	578,070	1,064,448	52,268	13,436,668	630,338
University of Utah	502,730	125,683	247,270	61,817	750,000	187,500
University of New Mexico	134,117	-	49,423	-	183,540	-
University of Wyoming	200,000	-	-	-	200,000	-
Wheaton College	30,322	-	15,847	-	46,170	-
Los Alamos National Laboratory	1,333,334	-	466,774	-	1,800,107	-
Sandia National Laboratories	502,539	-	233,256	-	735,794	-
Enchant Energy Corporation		675,988	-	337,994	-	1,013,982
Schlumberger		2,388,999	-	131,001	-	2,520,000
Total ($)	15,075,260	3,768,739	2,077,018	583,080	17,152,278	4,351,820
Total Cost Share %		20.00		21.92		20.24

Project Objectives/ Technical Approach

The overall objective of this proposed project is to perform a comprehensive commercial-scale site characterization of a storage complex located within San Juan County, New Mexico to accelerate the deployment of integrated carbon capture and storage (CCS) technology at the San Juan Generating Station (SJGS).

- Task 1.0 – Project Management and Planning
- Task 2.0 – National Environmental Protection Act (NEPA)
- Task 3.0 – Site Characterization
- Task 4.0 – Reservoir and Caprock Characterization
- Task 5.0 – Geologic Modeling and Simulation
- Task 6.0 – Underground Injection Control (UIC) Class VI Permit Application
- Task 7.0 – Integrated Assessment Modeling
- Task 8.0 – Stakeholder/Policymaker Outreach/Education and Engagement
- Task 9.0 – Coordination with other DOE Projects

Technical Approach/Project Scope

Task/ Subtask	Milestone Title & Description	Planned Completion Date
1.0	Project Kick-off meeting	
2.3	NEPA documentation progress	3/31/2023
3.1	Evaluation of available data such as seismic	Completed
3.3	Acquisition and processing of Seismic data	Completed
3.4.5	Stratigraphic well drilled	9/30/2021
4	Complete needed Caprock and reservoir analysis for Modeling	5/31/2022
5.2	Complete initial simulations for UIC permit application	7/31/2022
5.2.8	Complete AOR modeling	8/31/2022
5.3	Complete initial Risk assessment for UIC permit application	8/31/2022
6	Complete documentation to submit UIC class VI application	9/30/2022
6.10	Progress report on submitted UIC class VI application	3/30/2023
6.10	Progress and/or receiving approval for UIC class VI application	9/30/2023

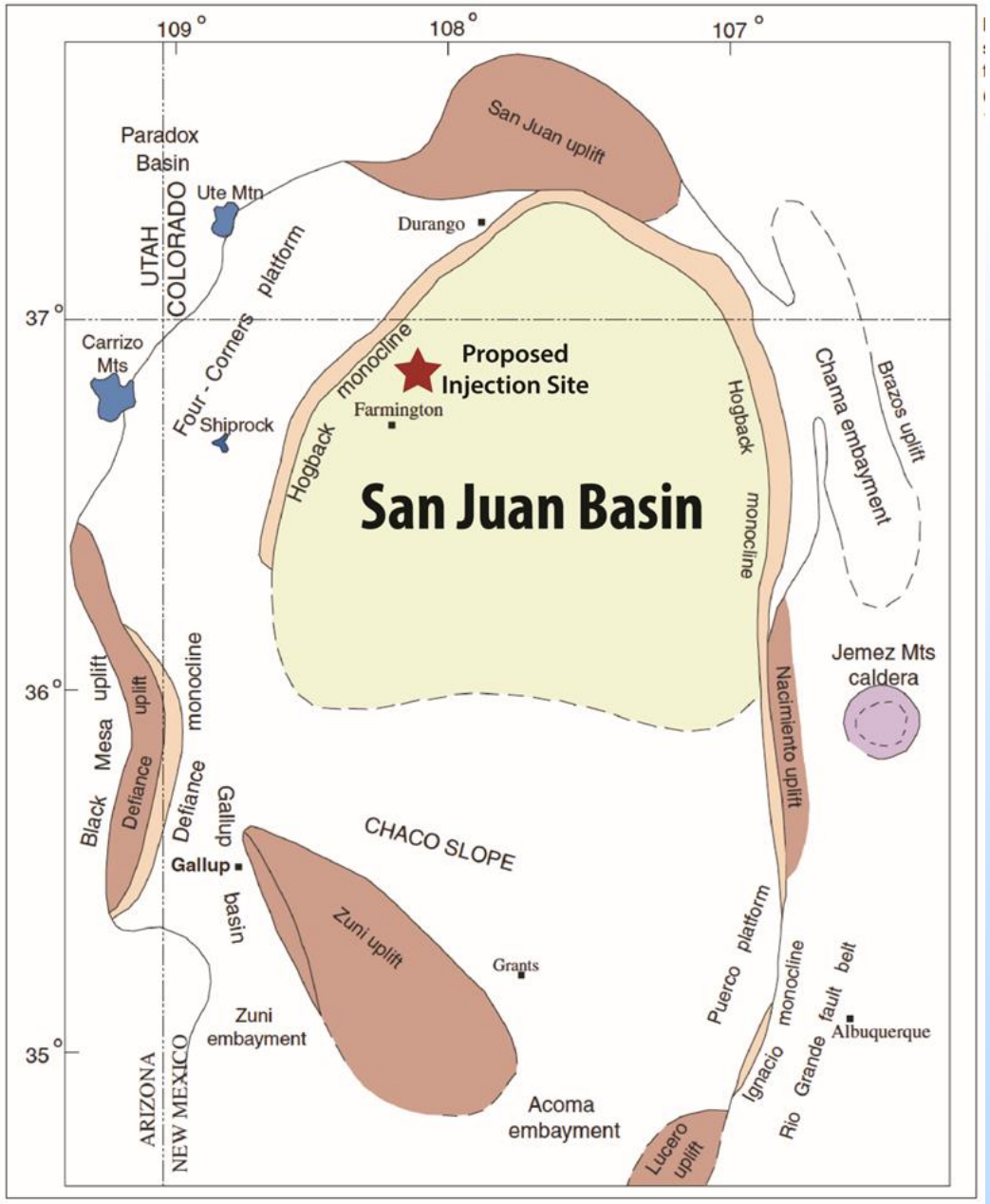
Accomplishments to Date

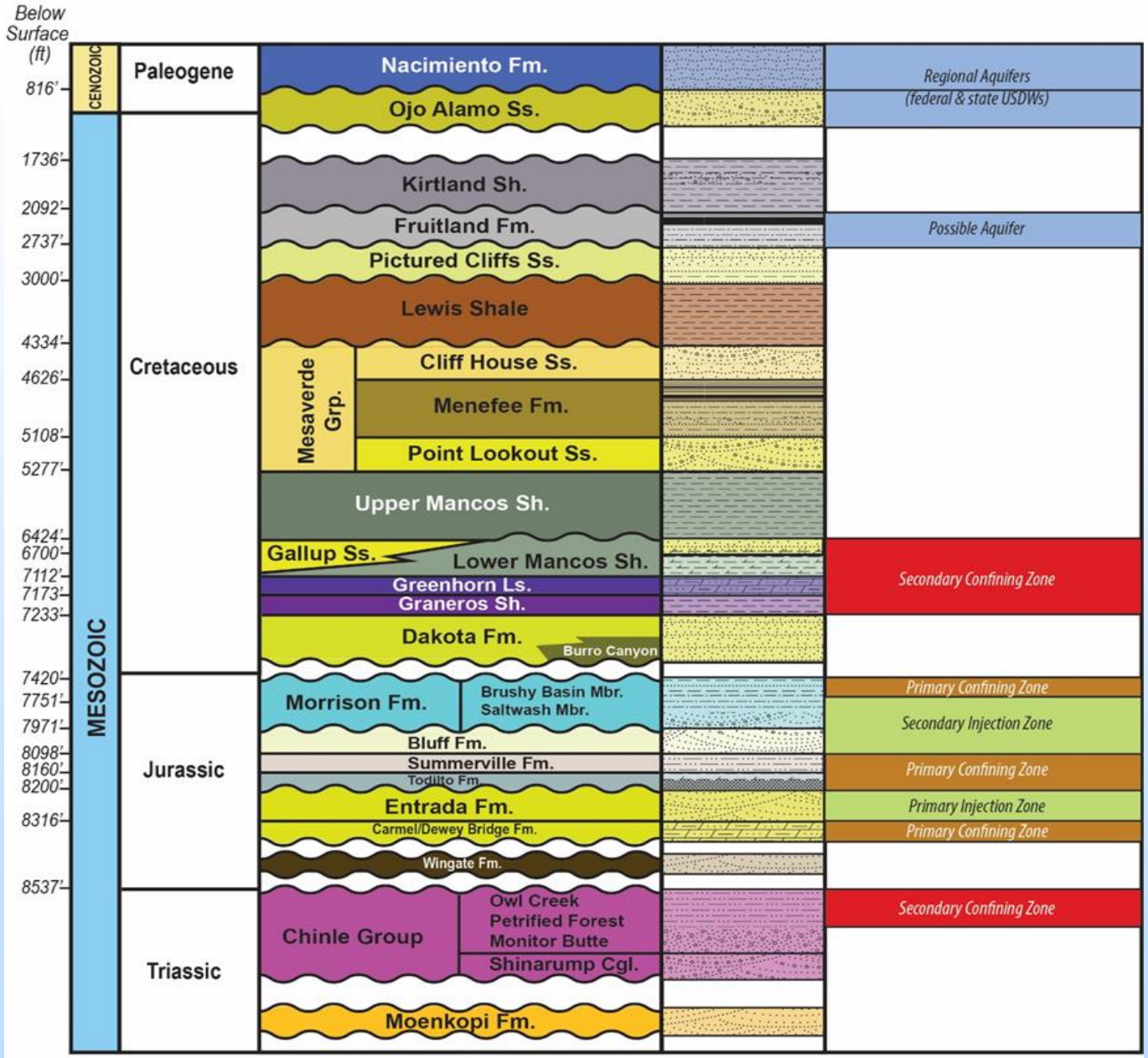
- Expanded the geologic database with data on target seals and potential CO_2 reservoirs for all available deep wells in the area
- Analyzed the Hogback Monocline and associated faults and developed structure and isopach maps
- Completed petrophysical and geomechanical analysis on key wells
- Completed first field work on reservoir and seal characterization on outcrops
- Completed relative permeability test and flow through experiments on outcrops samples
- Completed first field sampling and analysis on produced and USDW water quality
- Analyzed available core and cuttings
- Developed preliminary models and conducted simulations to evaluate CO_2 storage capacity and migration pathways within the San Juan Basin
- Completed analysis of background seismicity
- Workflow has been developed importing physics-based reservoir simulator (CMG) pressure and CO_2 saturation results into NRAP Integrated Assessment Model (NRAP-Open-IAM)

Accomplishments to Date

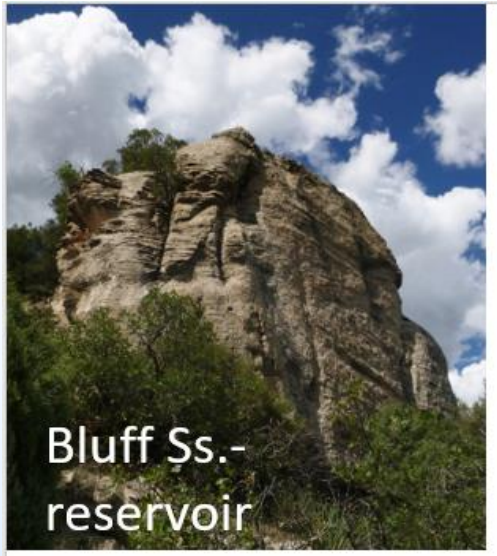
- Utilized available data and experience in the study area to select a potential location to drill stratigraphic well and continue with Class II well permit to drill application with NMOCD
- Completed strat well survey, strat well design, logging and coring program
- Developed a data management system to securely store and share data
- Draft for the Environmental Information Volume (EIV) has been completed and undergoing final reviews
- Developing UIC Class VI required documentations for submittal to the EPA GSDT modules.
- A project website social media accounts have been developed and will be maintained.
- The economic assessment work has been initiated and is underway. The initial work is focused on delineating the counties included in the study area and the time frame of the study.
- Environmental justice analysis is also being performed in a manner coordinated with the economic assessment work.

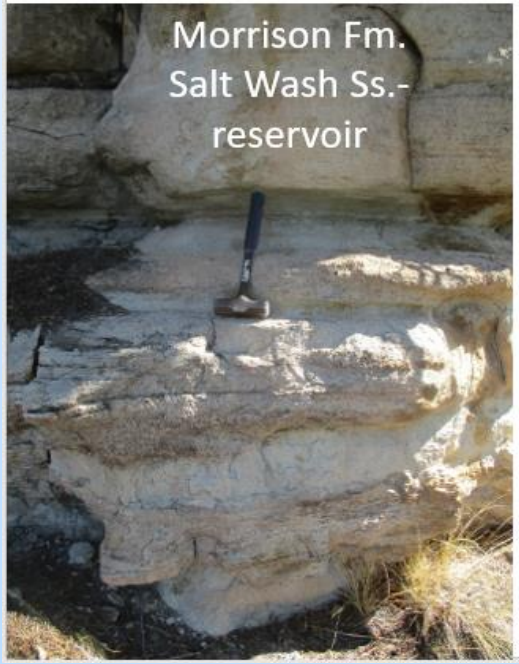
San Juan Basin Geology

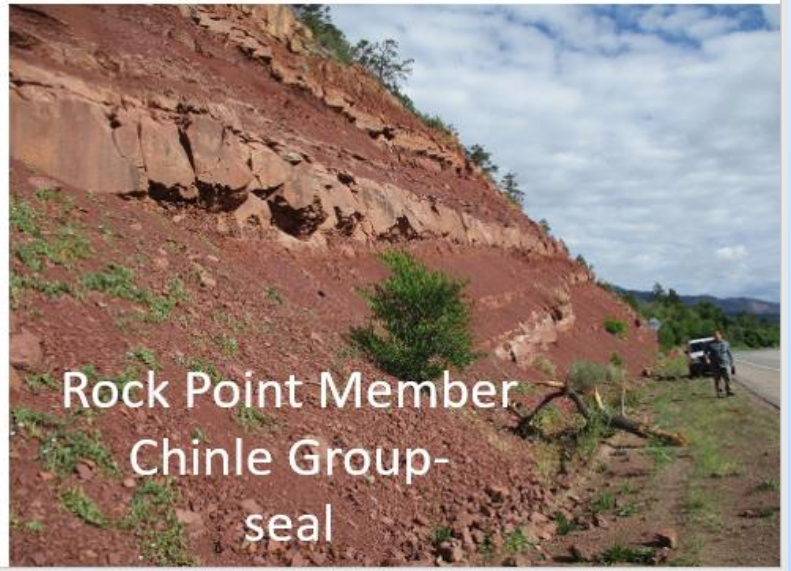




Field Trip to Outcrops

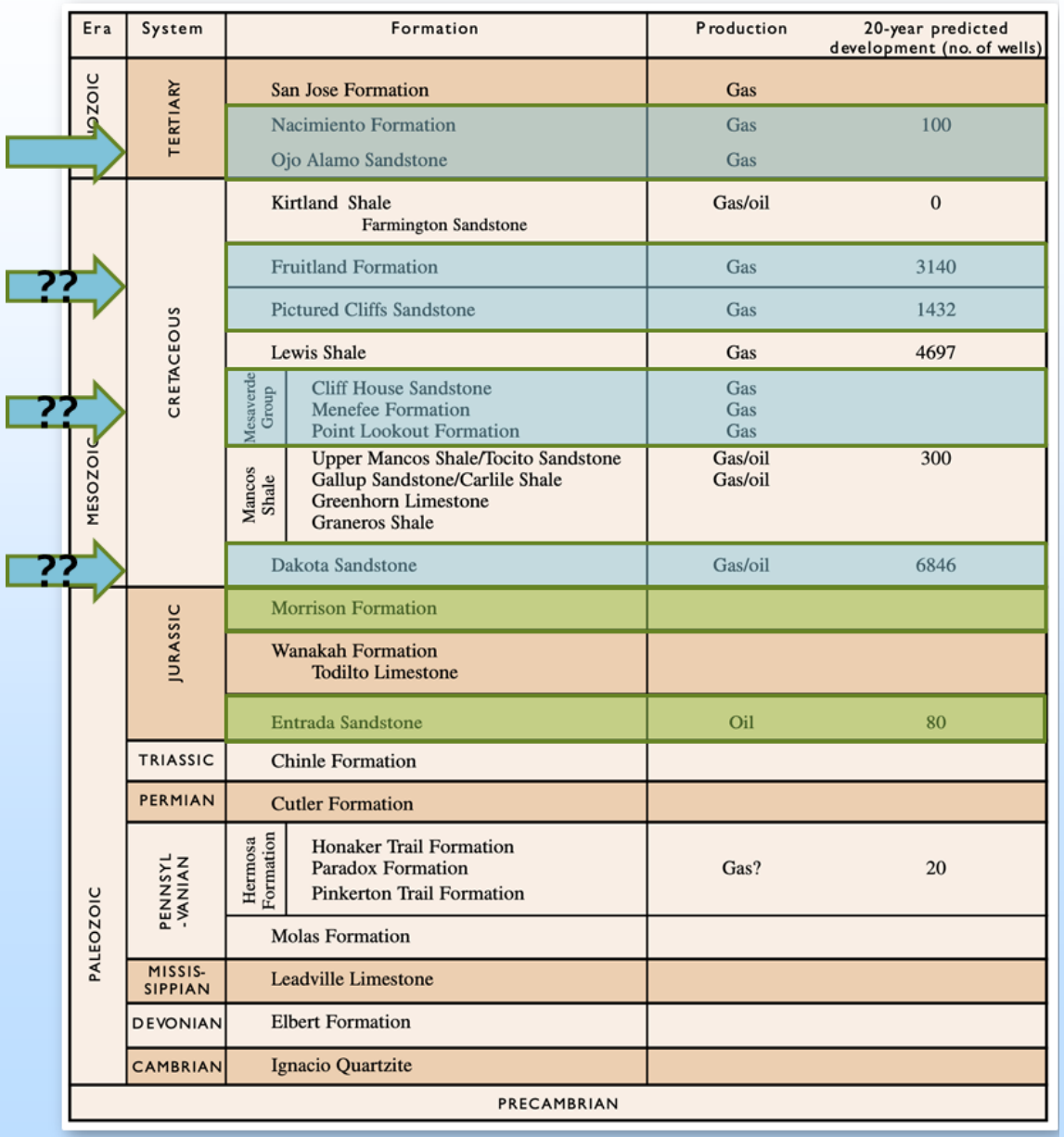






USDWs in the San Juan Basin

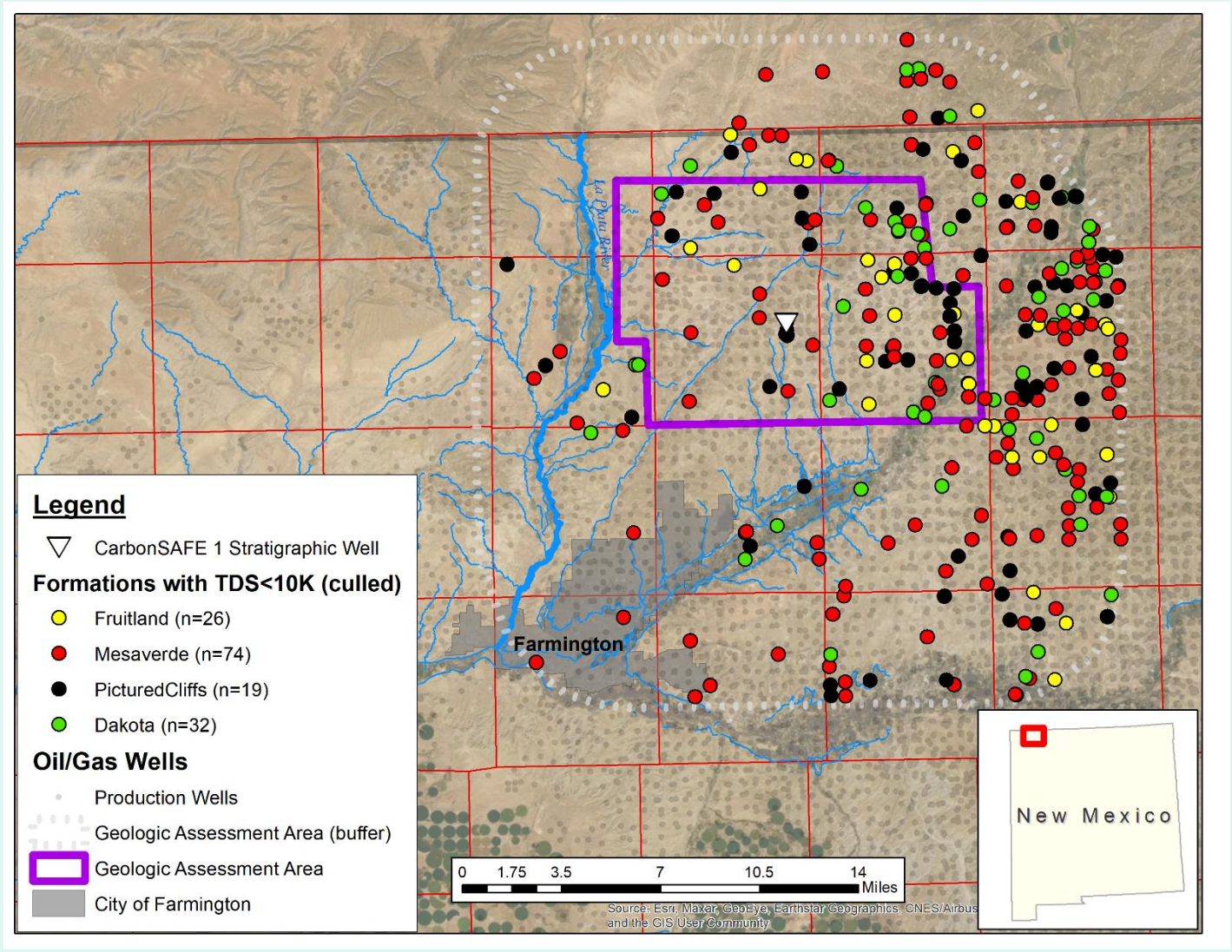
- Evaluation and monitoring of USDWs required by EPA Class VI permit
- USDWs identified by Project team
  - alluvial aquifer
  - Nacimiento Formation
  - Ojo Alamo Sandstone
- Literature/historical/modern data show some low TDS (<10,000 mg/L) producing formations/pools
  - Fruitland Coal
  - Mesaverde
  - Pictured Cliffs
  - Dakota



Era	System	Formation	Production	20-year predicted development (no. of wells)
CENOZOIC	TERTIARY	San Jose Formation	Gas	
		Nacimiento Formation	Gas	100
		Ojo Alamo Sandstone	Gas	
MESOZOIC	CRETACEOUS	Kirtland Shale Farmington Sandstone	Gas/oil	0
		Fruitland Formation	Gas	3140
		Pictured Cliffs Sandstone	Gas	1432
		Lewis Shale	Gas	4697
		Mesaverde Group: Cliff House Sandstone	Gas	
		Mesaverde Group: Menefee Formation	Gas	
		Mesaverde Group: Point Lookout Formation	Gas	
		Mancos Shale: Upper Mancos Shale/Tocito Sandstone	Gas/oil	300
		Mancos Shale: Gallup Sandstone/Carlile Shale	Gas/oil	
		Mancos Shale: Greenhorn Limestone		
		Mancos Shale: Graneros Shale		
		Dakota Sandstone	Gas/oil	6846
	JURASSIC	Morrison Formation		
		Wanakah Formation Todilto Limestone		
		Entrada Sandstone	Oil	80
PALEOZOIC	TRIASSIC	Chinle Formation		
	PERMIAN	Cutler Formation		
	PENNSYLVANIAN	Hermosa Formation: Honaker Trail Formation	Gas?	20
		Hermosa Formation: Paradox Formation		
		Hermosa Formation: Pinkerton Trail Formation		
		Molas Formation		
	MISSISSIPPIAN	Leadville Limestone		
	DEVONIAN	Elbert Formation		
	CAMBRIAN	Ignacio Quartzite		
PRECAMBRIAN				

Produced Water in the San Juan Basin

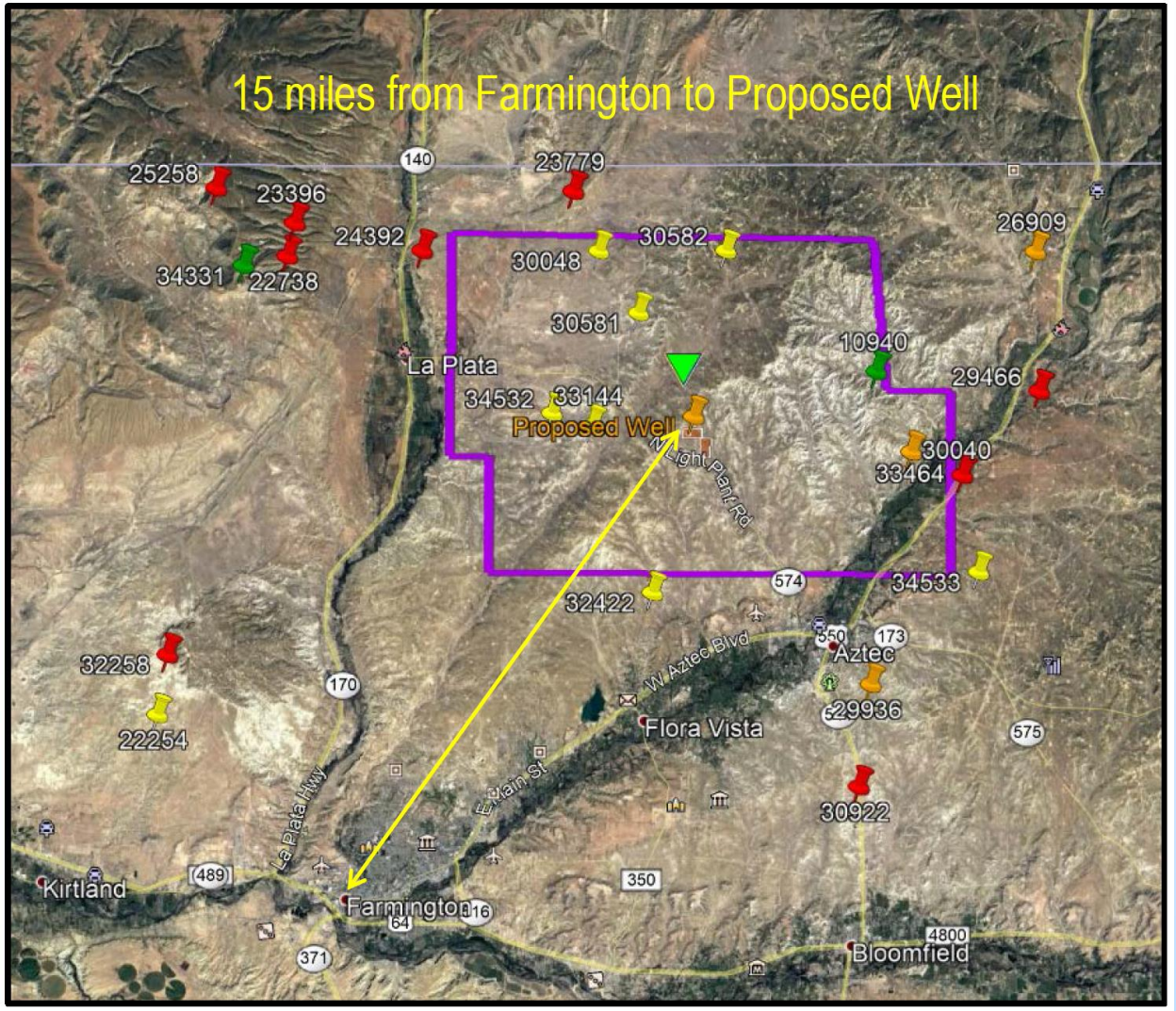
- USGS and NM Produced Water Database
  - Within 500 square mile area in CarbonSAFE Area of Interest, there are 151 wells with formation waters below 10,000 mg/L TDS (after QA/QC culling)
  - The low TDS values are 13% to 32% of the total water chemistry data available, depending on formation
  - We have developed strategies with guidance from EPA to estimate our deepest USDW for AoR delineation



Our Approach to Earth Modeling

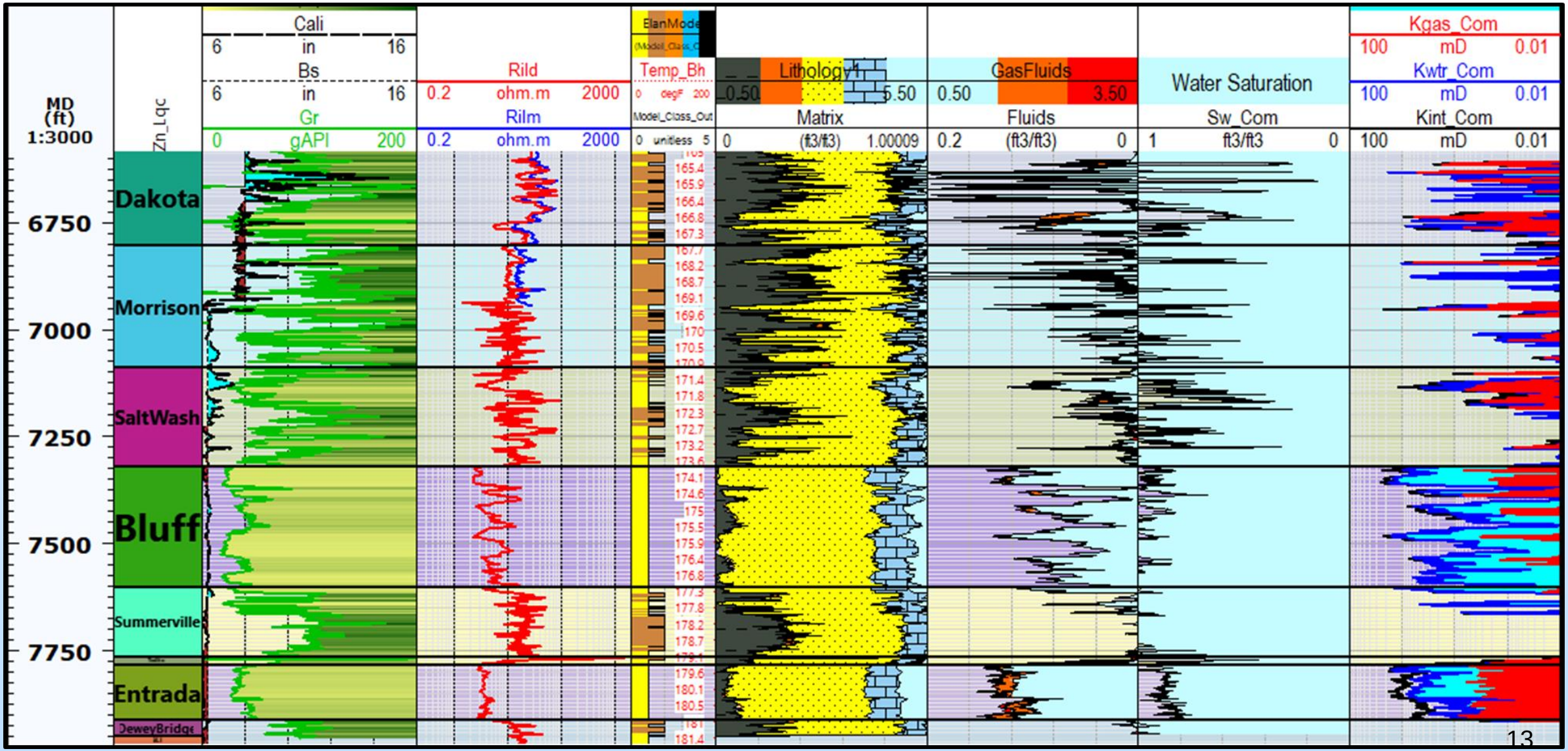
	Seismic, Wellbore images	Triple-combo, Sonic, Core	Wellbore images, Sonic, Core	Petrophysics, Sonic, Core
Intrinsic properties	**Framework** Structure Faults Horizons	**Petrophysics** Lithology, Vcl Porosity, Sw Matrix Perm Elastic Moduli	**Mechanical** Strat Column Facies Support Fracture Attributes	**Rock Strength** Compressive & Tensile Strength Friction Angle
Extrinsic properties	**Vertical Stress** Overburden	**Pore Pressure** Pore Pressure	**Stress Direction** Maximum Horizontal Stress Direction	**Stress Magnitude** Minimum & Maximum Horizontal Stress
	Density log, Petrophysics	**Formation testing, Petrophysics, Mud logs**	**Wellbore images, Sonic, 4-Arm calipers**	**In-situ stress tests, Sonic**

Brie and Bratton, 1994

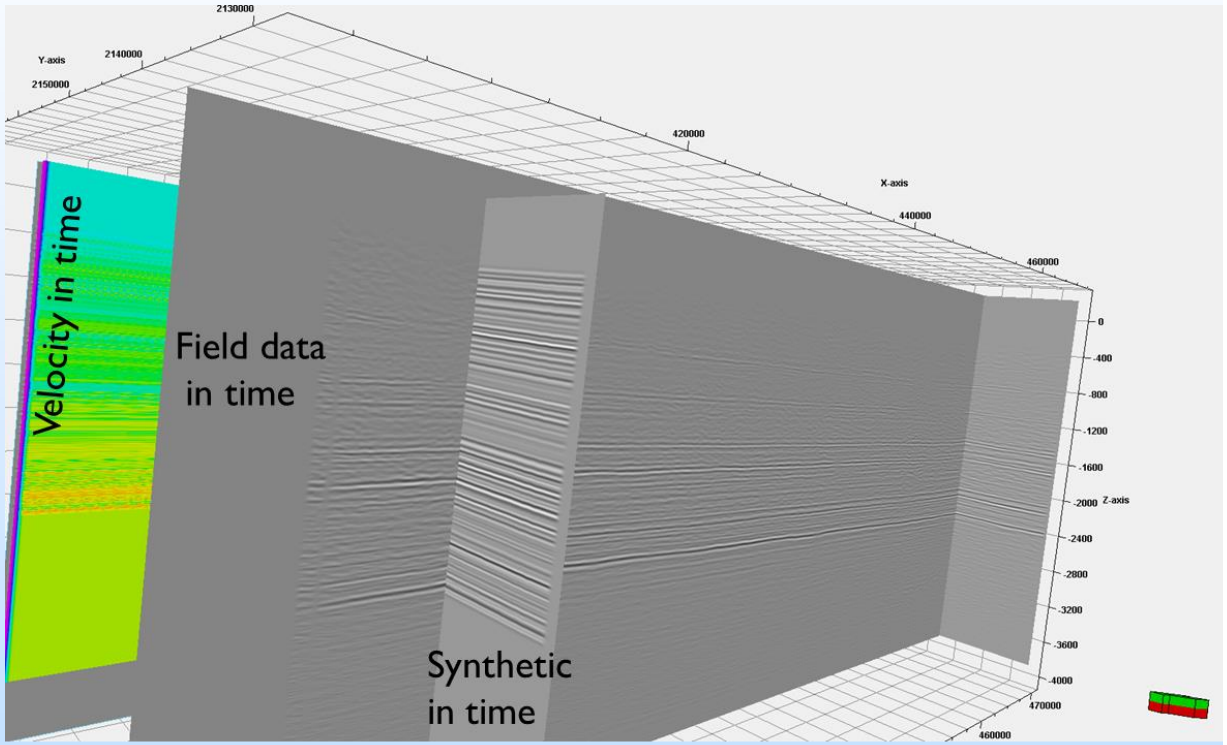


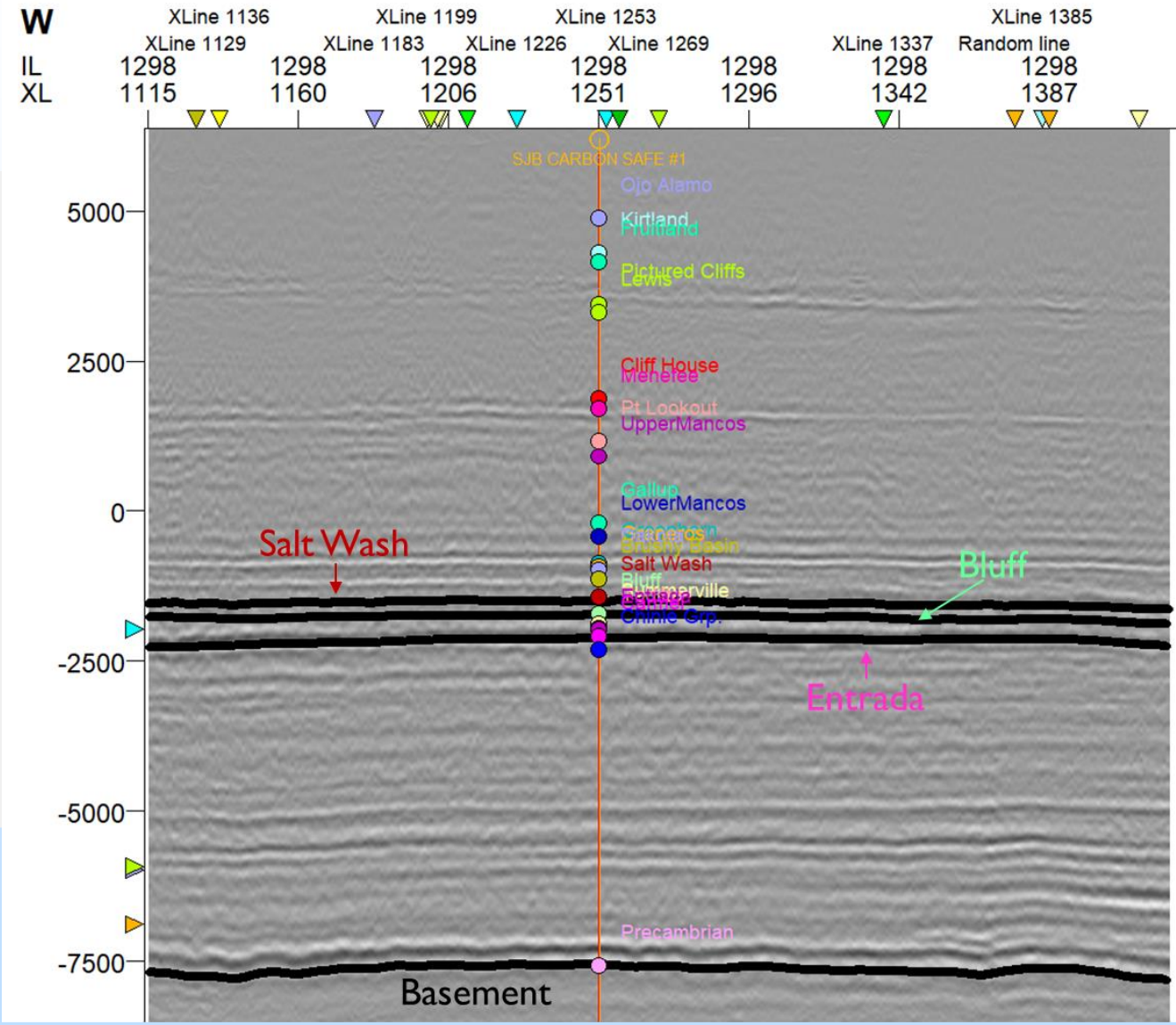
Wells used for Petrophysical analysis

Petrophysics

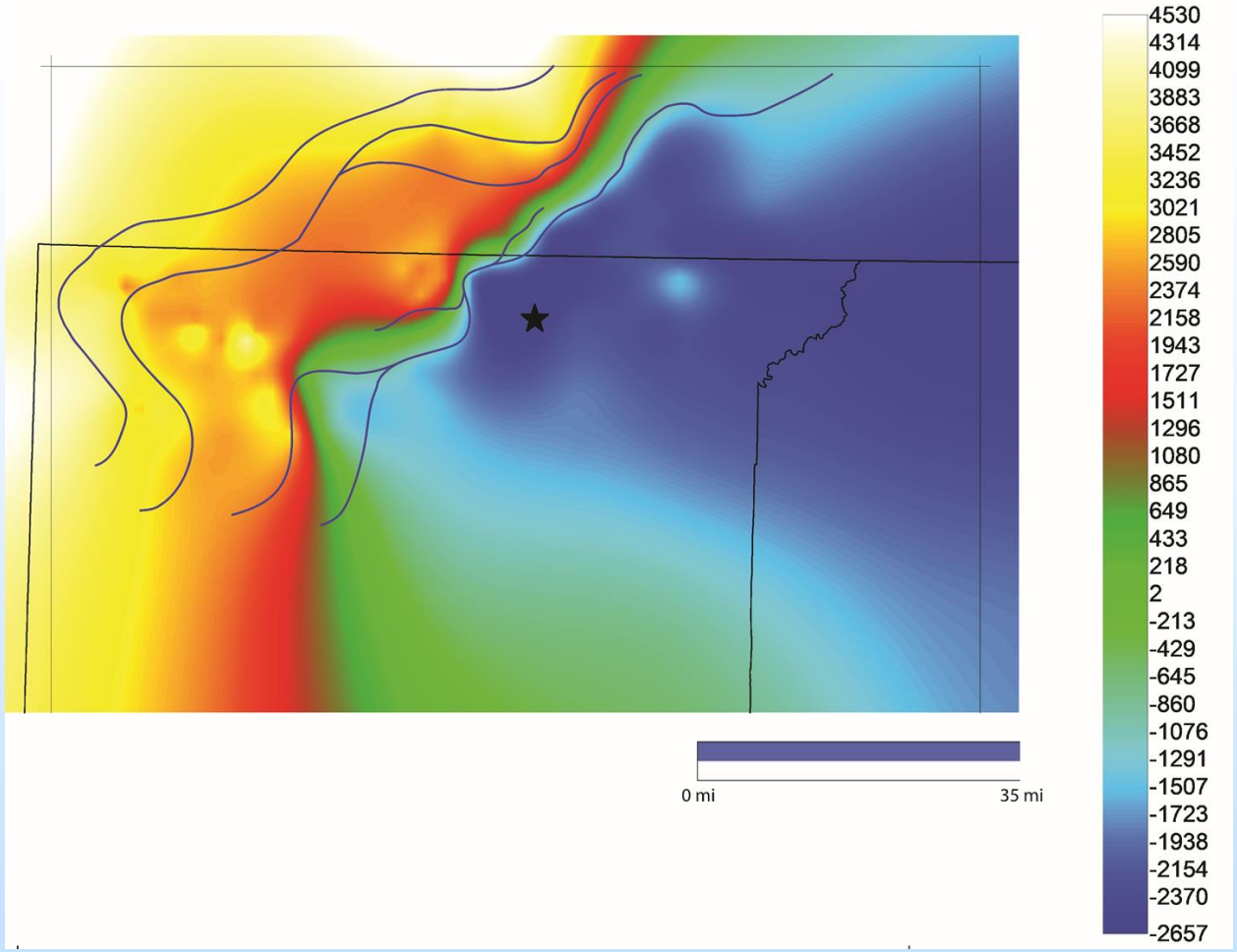


Seismic Interpretations

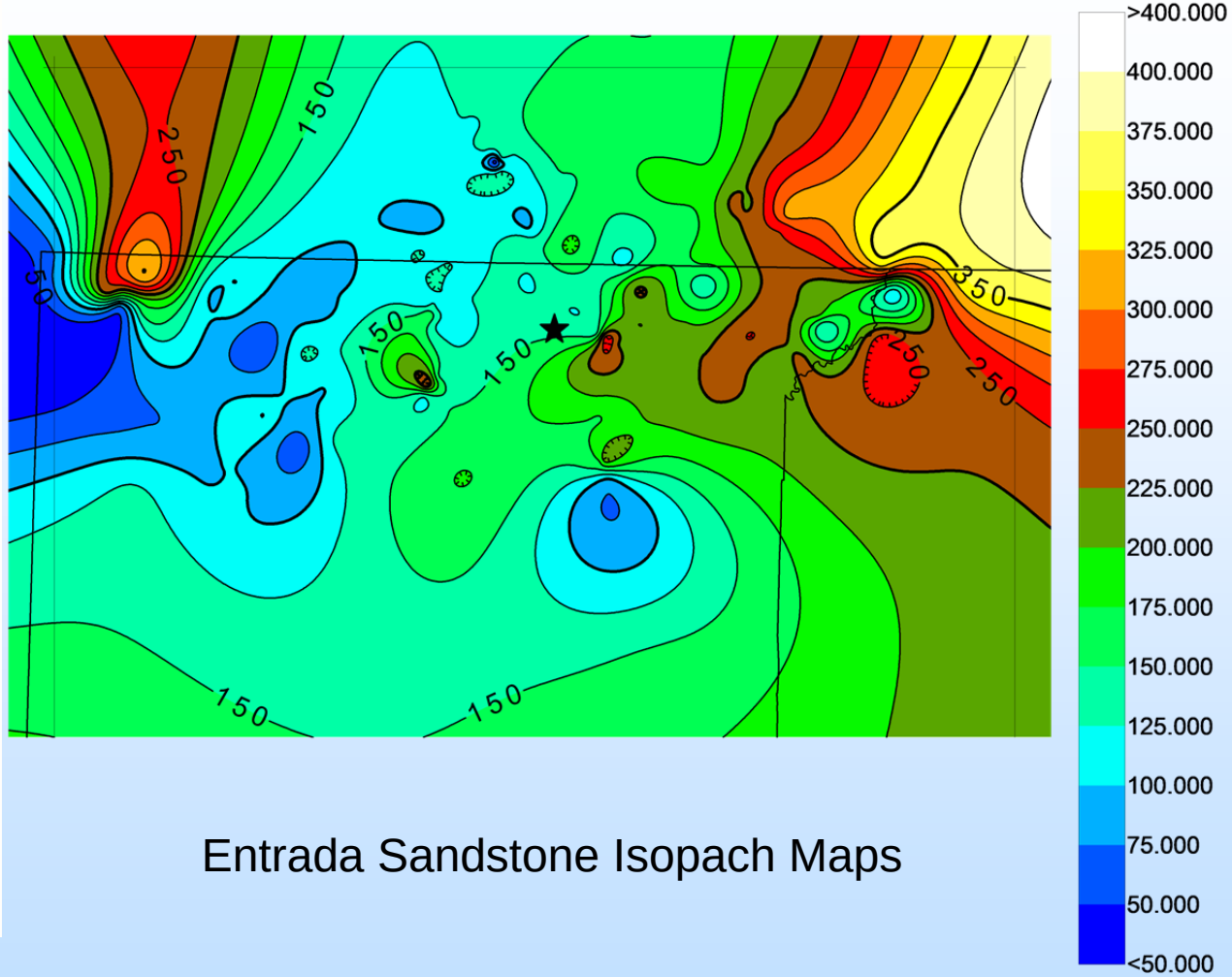




Entrada Ss. Structure Map and Isopach Map

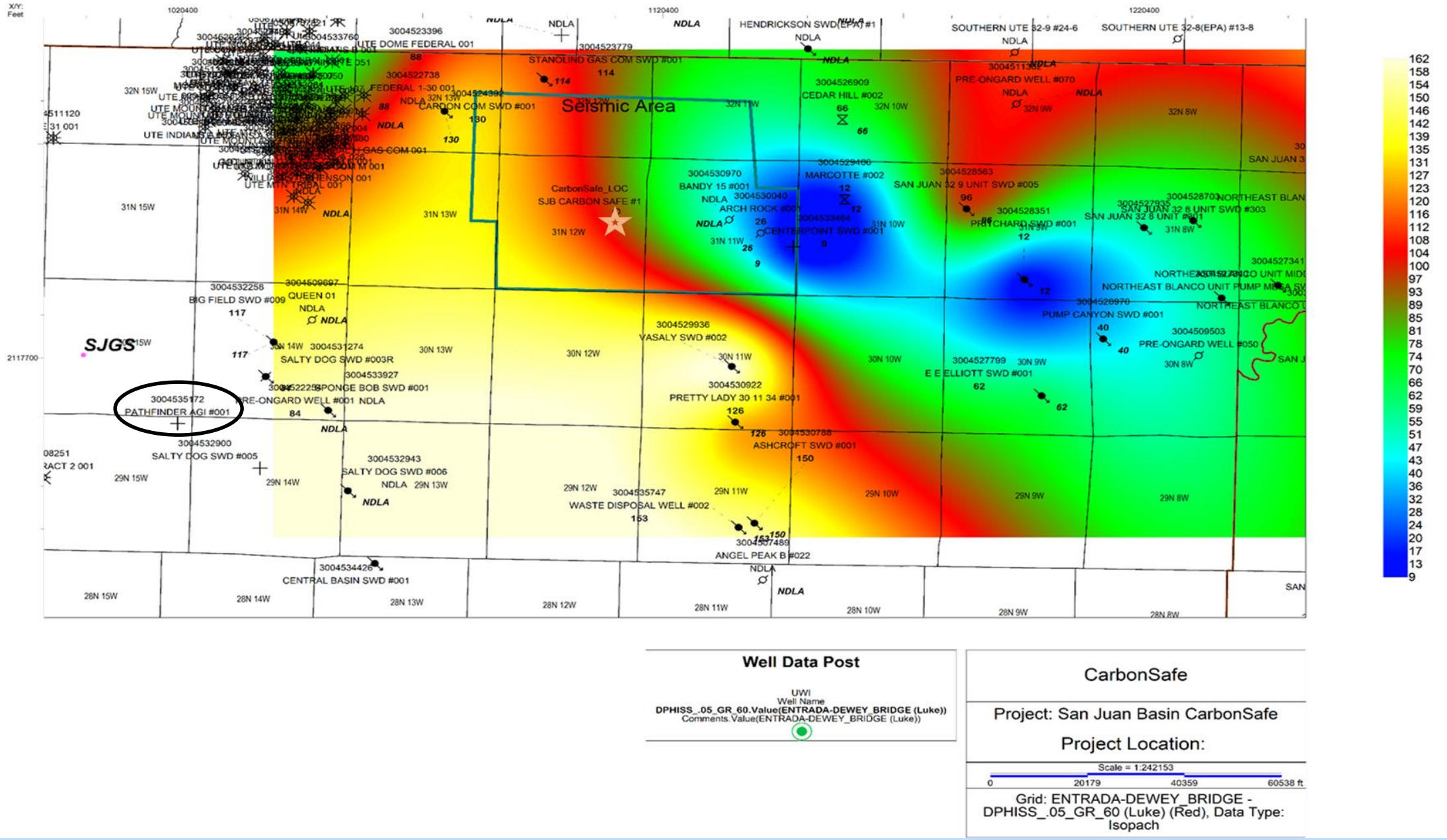


Entrada Ss. structure map with an overlay of the possible complex network of faults that make up the Hogback Monocline

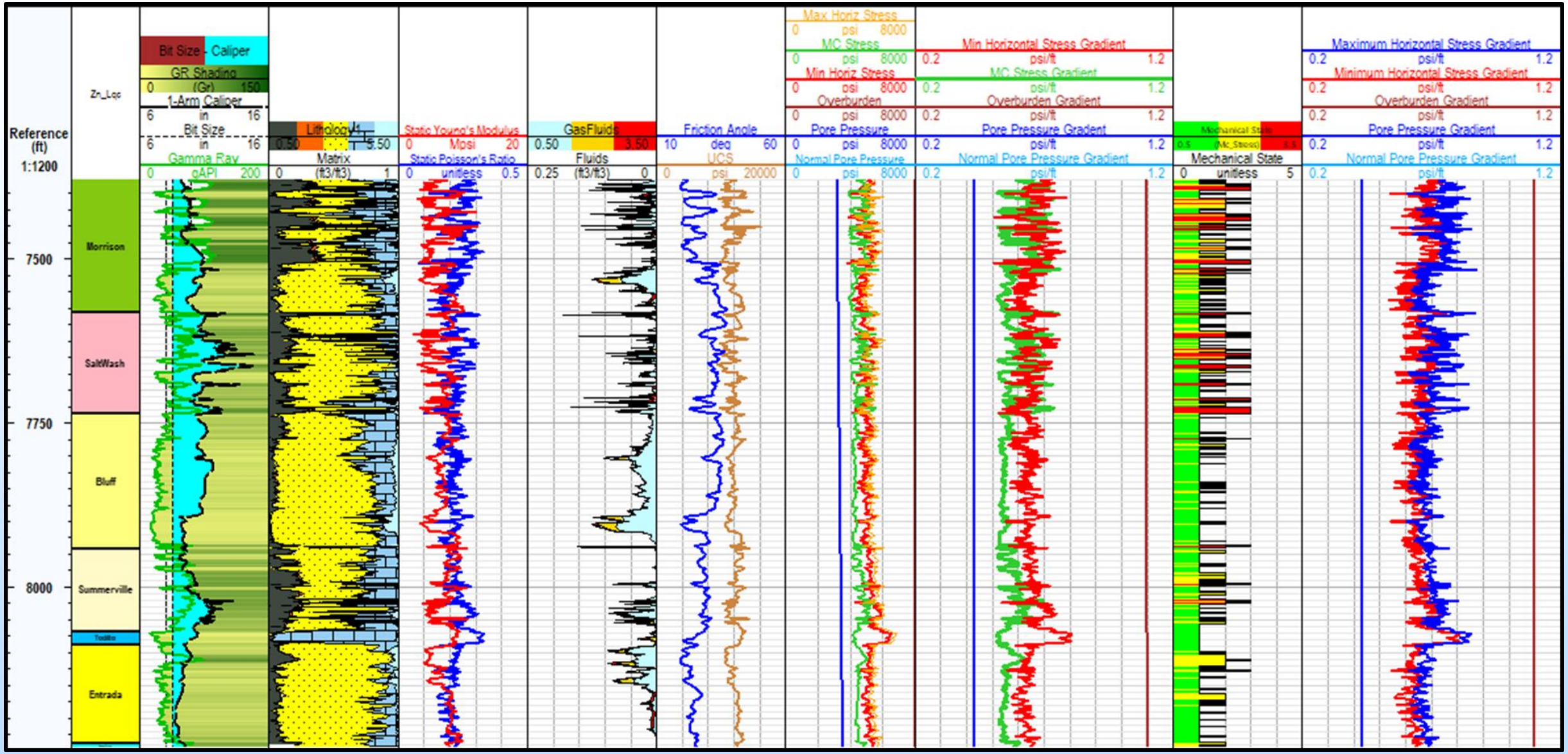


Entrada Sandstone Isopach Maps

Entrada - Net SS (ft) >5% Porosity/Site Selection



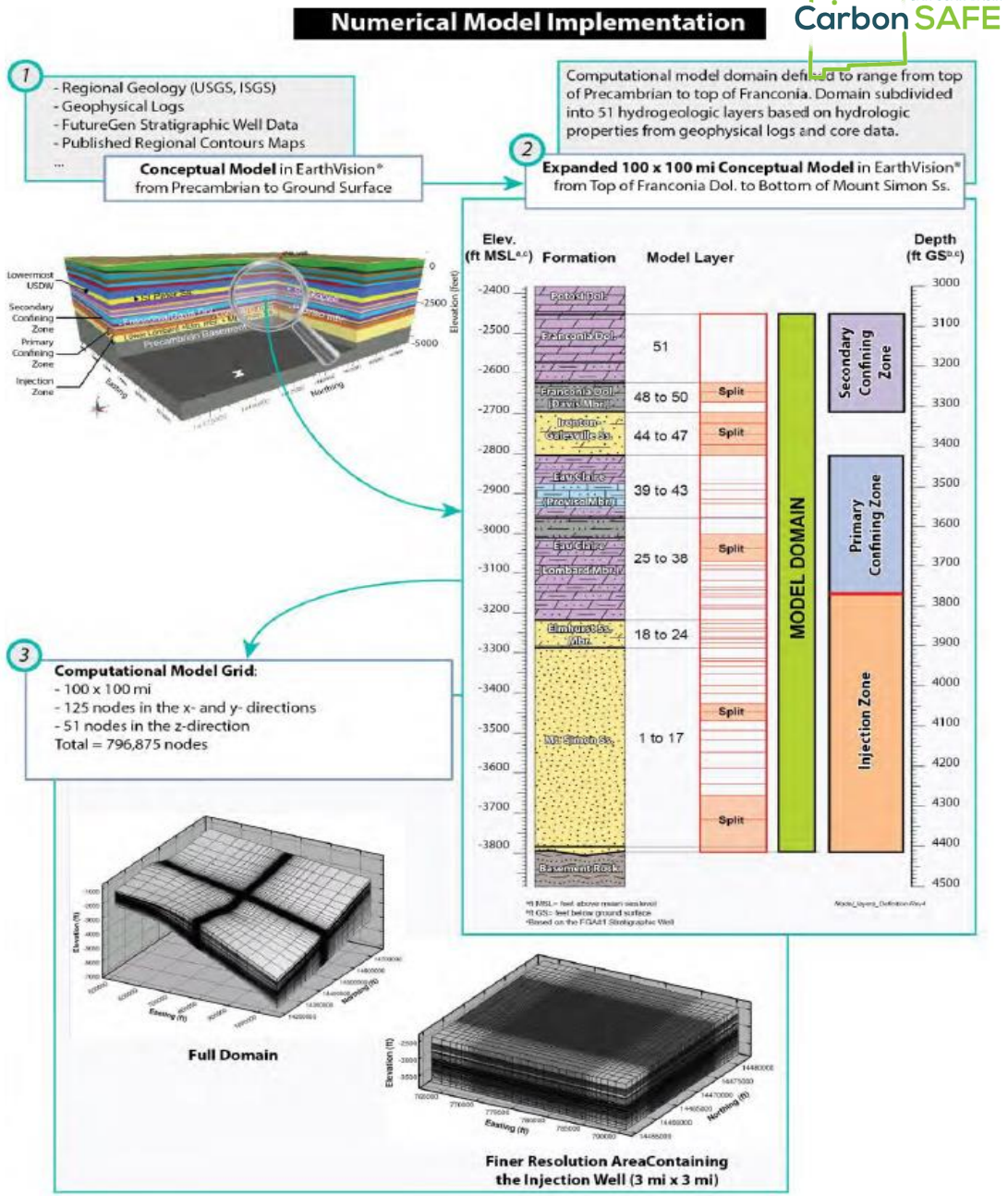
Geomechanics- 1D MEM



Performing AoR modeling and delineation

- 146.82(a)(2)"A map showing the injection well for which a permit is sought and the applicable area of review consistent with § 146.84."

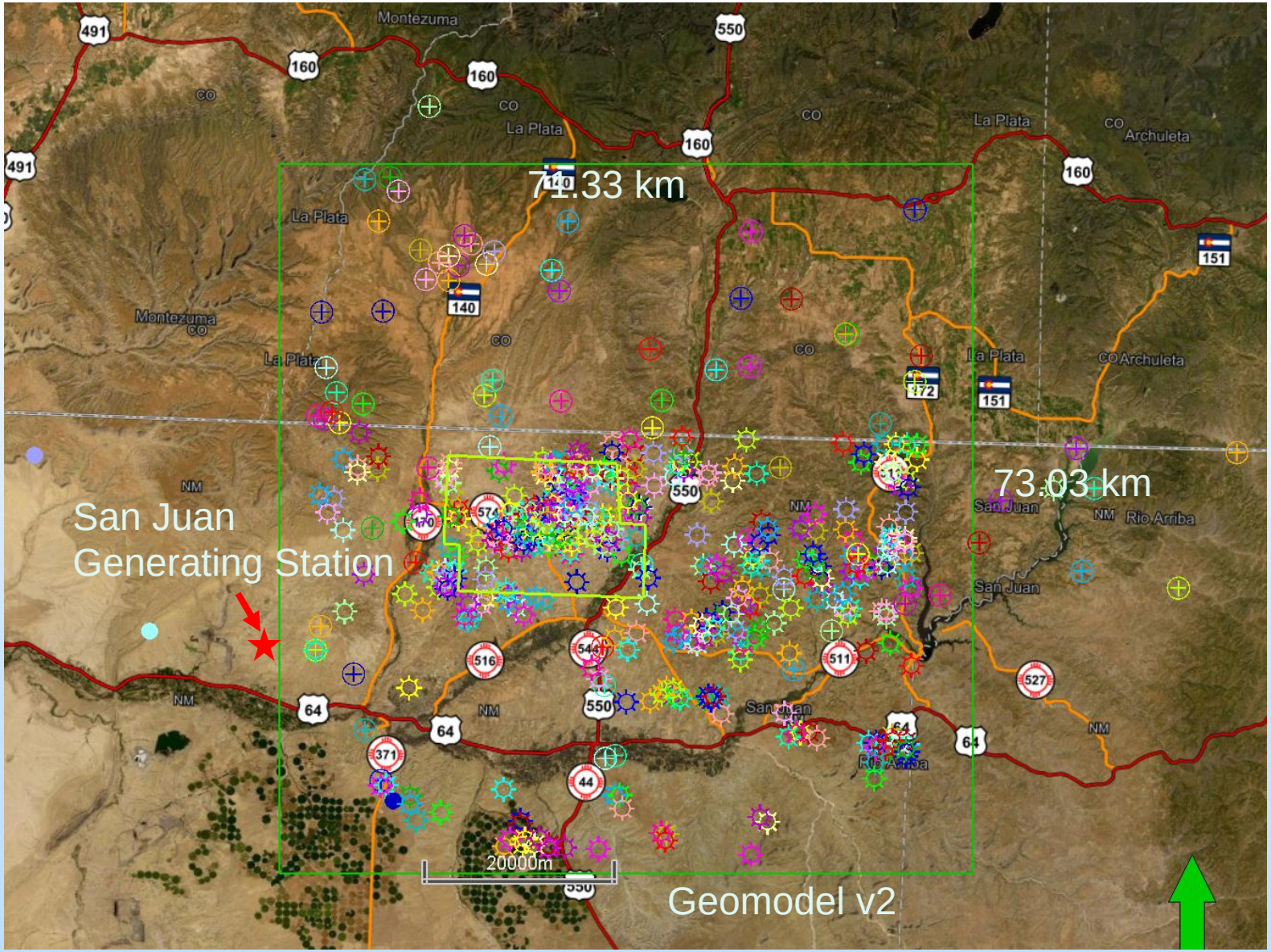
1. Model Development
   - Area encompasses proposed injection site
   - Determination of physical processes
   - Model design
     - Computational Code Determination
     - Model Spatial Extent, Discretization, and Boundary Conditions
     - Model Timeframe
     - Parameterization, etc …
2. Multiphase Numerical modeling
   - CO_2 saturation and pressure plume size thru time
3. Identify Area of Review
   - Area around injection zone where pressures are high enough to force fluid through open conduits into the overlying USDWs
   - Identify potential leaky well-bores
   - Identify potential open/high permeable faults
4. NRAP Tools to characterize endangerment of USDW due to well leakage



Implementation of the Numerical Model: From the Geological Conceptual Model to the Numerical Model

Geological Model- 2nd Generation

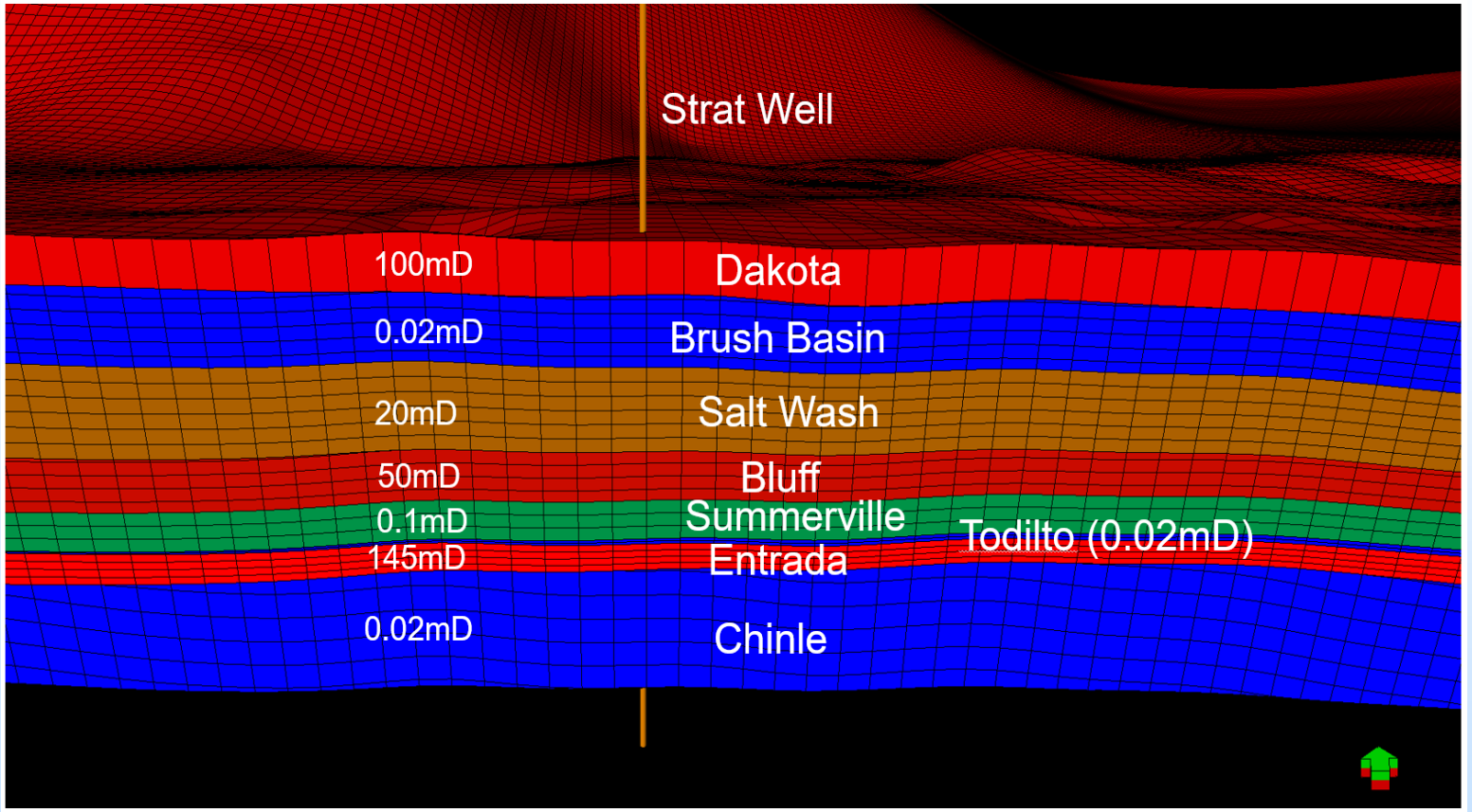
- Strat well location is 21 miles east of San Juan Generating Station
- Domain is 71km x 73km
- Seismic area is 20km x 13km
- 485 wells with formation tops
- 10 wells with logs



Model Properties

- Homogenous petrophysical property distribution

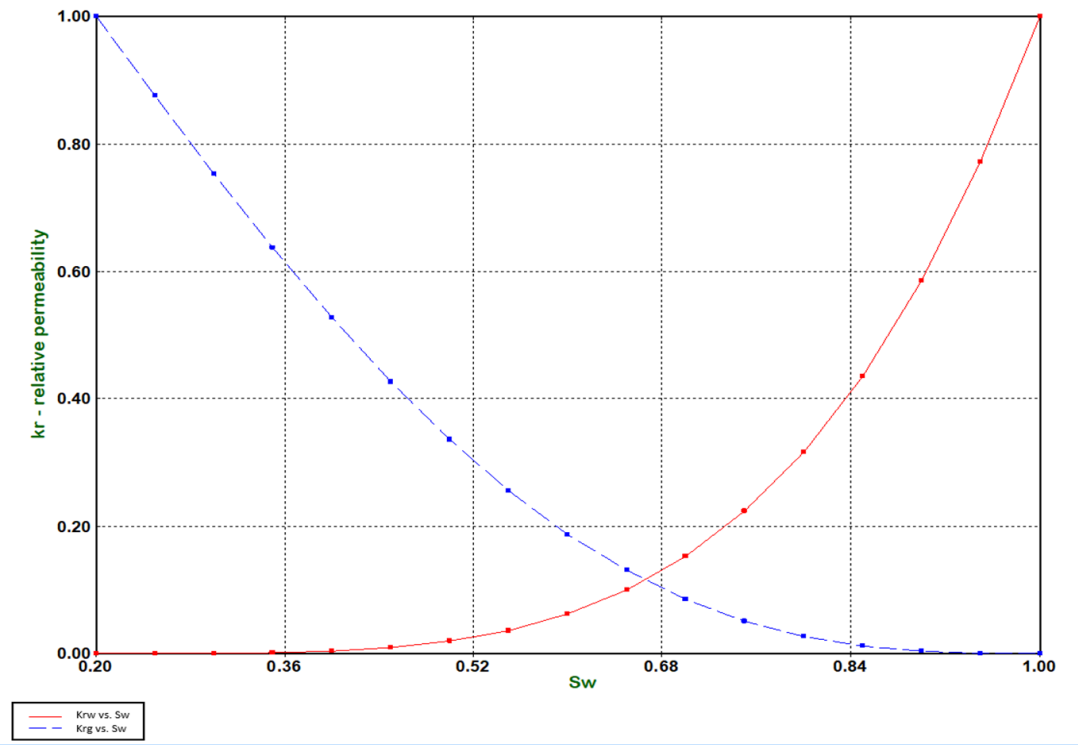
Porosity and Permeability		
	Porosity	Permeability (mD)
Dakota	14%	100
Brushy Basin	6%	0.02
Salt Wash	6%	20
Bluff	16%	50
Sumerville	4%	0.1
Todilto	2%	0.02
Entrada	15%	145
Carmel	3%	0.02



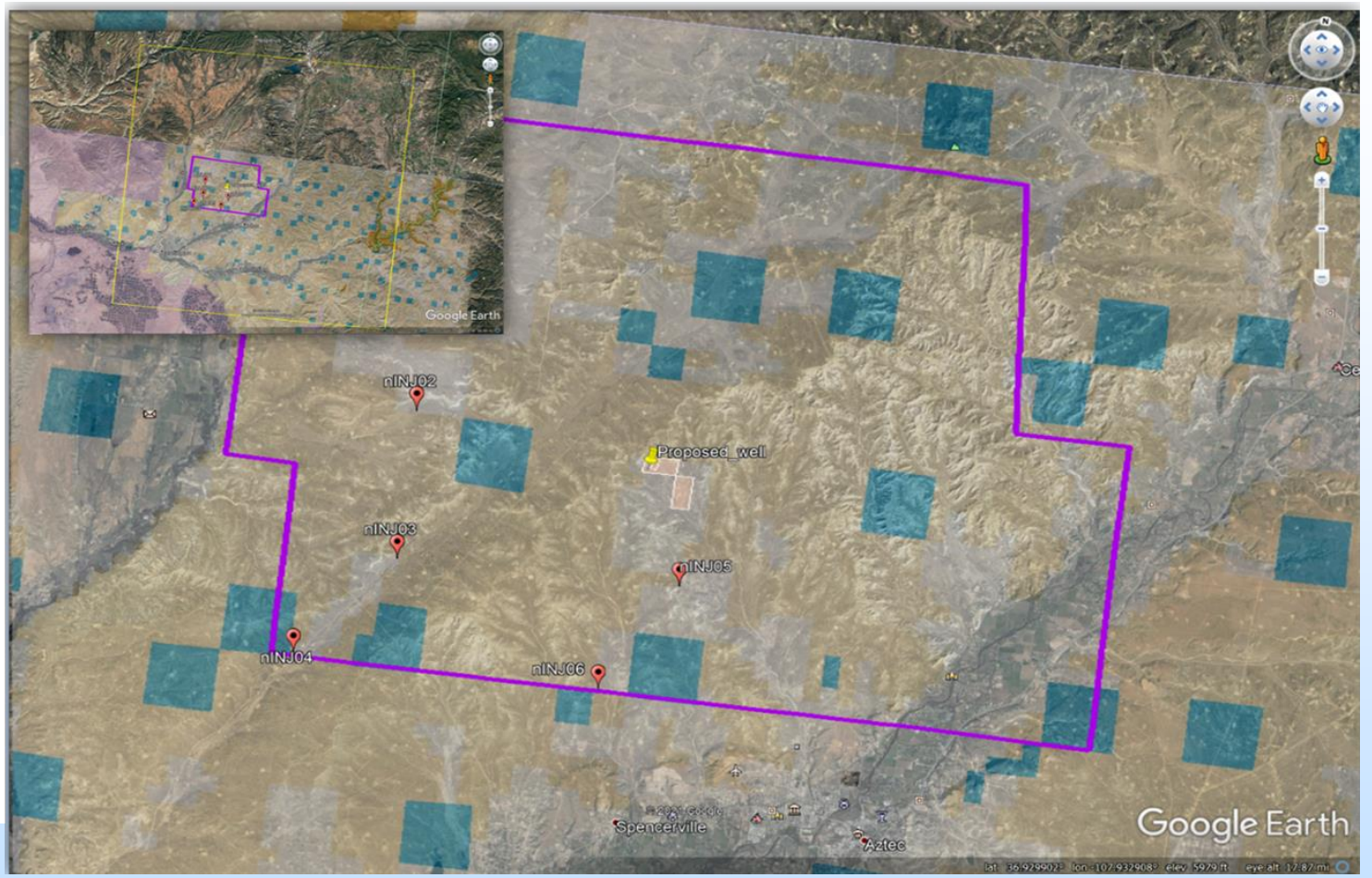
- Grid number: 355*364*112 = 1,472,640
- Grid size: 200m * 200m
- Reservoir Pressure Gradient: 0.427 psi/ft
- Reservoir Temperature Gradient: 60.0 + 0.0163 * Tvd (ft) in degF

	Depth, m	Depth, ft	T, C	T, F	P, kPa
Reference 1 - MSL	0	0	68.9	156.3	17402.37
Reference 2 – Mid Reservoir	579	1900	86.9	187.3	22993.12

Additional Modeling Parameters



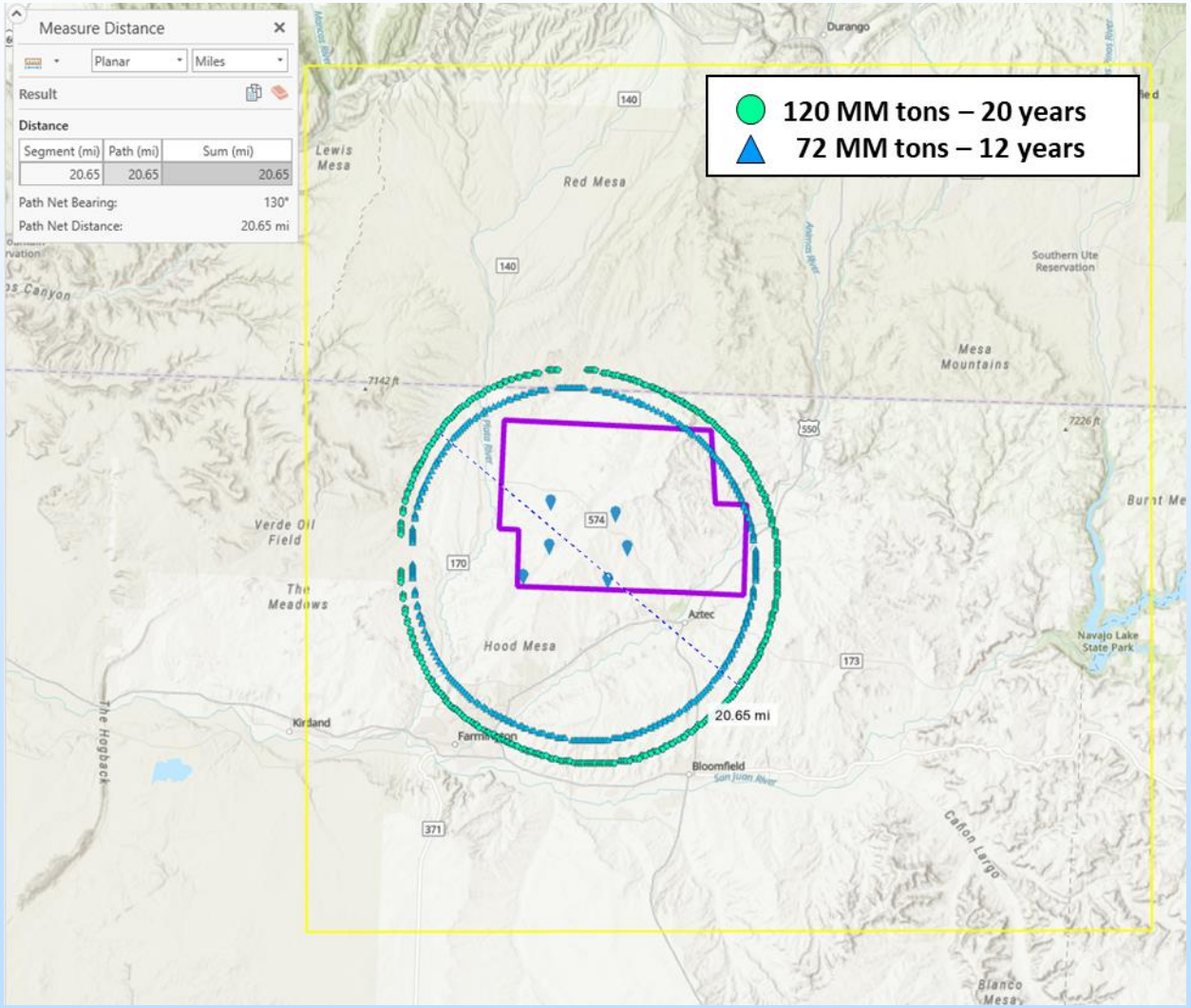
Relative Permeability data -Typical sandstone-water-CO_2 system



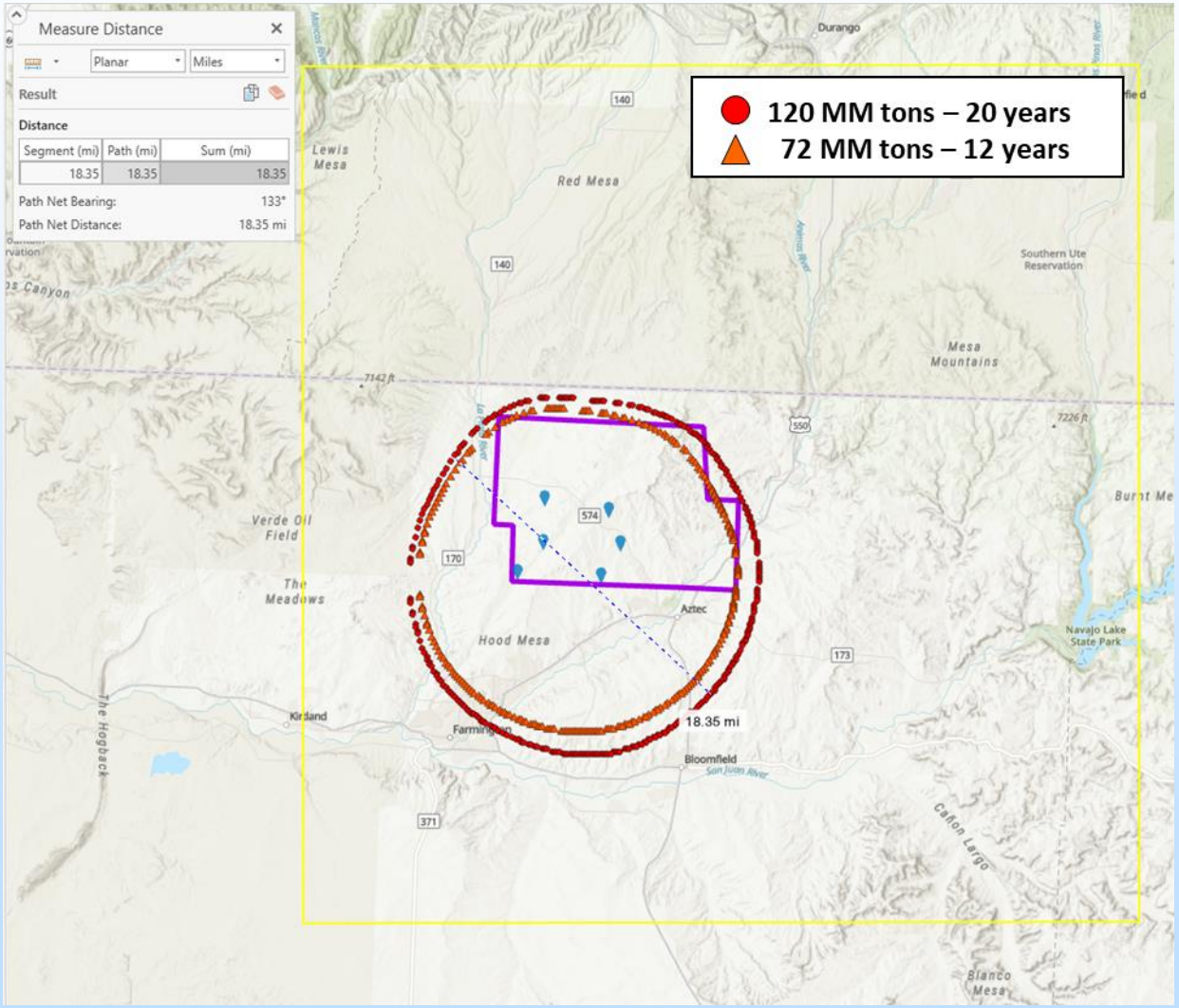
- **Target injection amount:** Complete 72 MM metric tons CO_2 injection over 12 years, or 120 MM tons for over 20 years.
- **Single Well injection rate:** 1.387E6 m3/day = 1 mm tons/year
- **BHP restrictions**: fracture gradient 0.6 psi/ft

AoR of CO_2 Injection

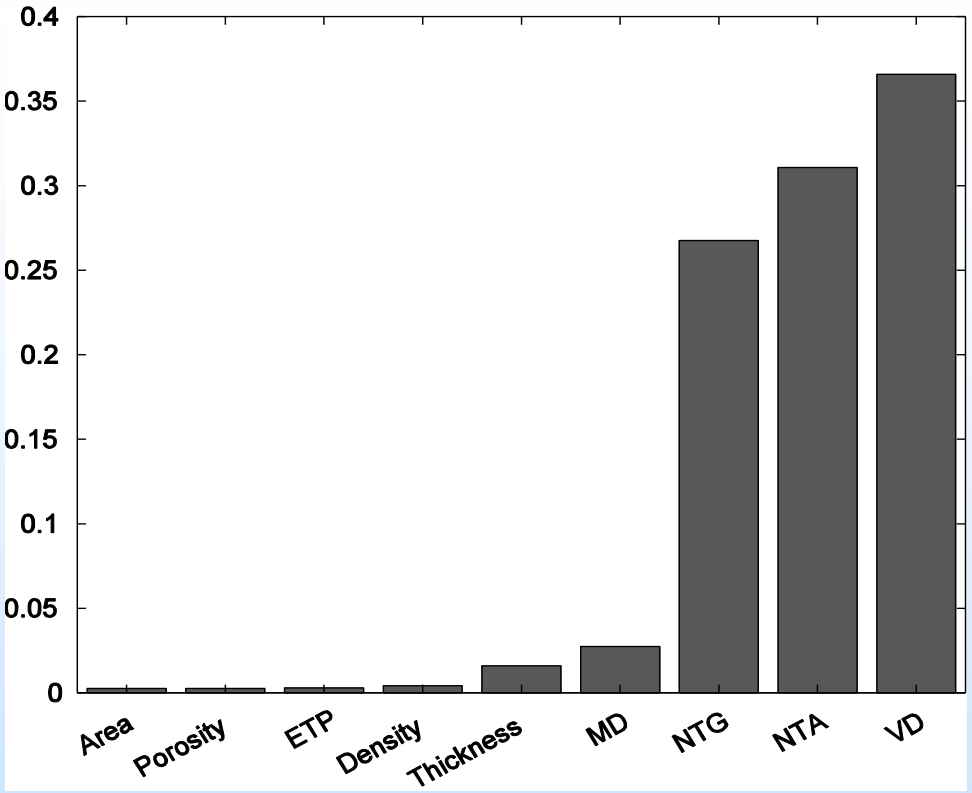
All 3 zones – Fruitland_USDW



Entrada – Fruitland_USDW



CO_2 Storage Estimation



A relative impact plot shows the percentage of variance in the parametric method storage estimate due to different inputs. Using CO2-Screen's defaults, factors with high relative impact were:

Net-To-Gross ratio
Net-To-Area ratio
Volumetric Displacement efficiency

	P10	P50	P90
Preliminary Estimation	196 Mt	701 Mt	2556 Mt
Parametric Method with CO2-Screen Efficiency Factors	185 Mt	642 Mt	2222 Mt
CO2-Screen	215 Mt	892 Mt	2718 Mt

- Preliminary estimations used assumptions about physical parameters and efficiency factors in the parametric method in a 3-cell model corresponding to the 3 storage formations over an area of 842 square kilometers.
- The parametric method was also used with the same physical parameters as in Preliminary estimates but CO2-Screen's efficiency factors.
- CO2-Screen results use the same inputs as the parametric method with CO2-Screen efficiency factors but makes different distributional assumptions (lognormal vs. logistic normal).

Risk Assessment Efforts

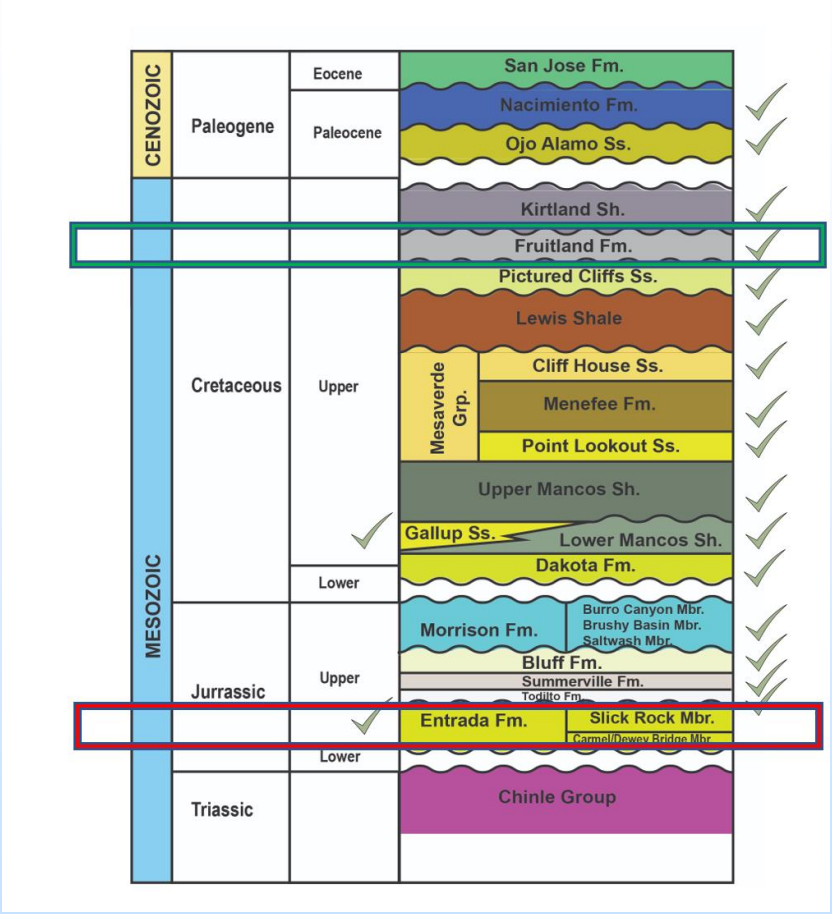
- Identify site-specific features, events, and processes (FEPs), compile a risk registry, and develop risk management and mitigation plans
- Leakage risks:
  - Inform identification of required (phased) corrective actions to ensure non-endangerment of USDW based on predicted saturation/pressure plumes and risks to USDW
  - Determine the likelihood for CO_2 and in-situ brine to migrate out of target injection zones through different pathways (wells/faults/fractures/seals) and migrate into overlying USDW affecting GW quality
  - Inform effective monitoring approaches (injection and post-injection/PISC periods) to minimize/manage leakage & induced seismicity risks by utilizing RA results
- Induced seismicity risks:
  - Compile information on past/background seismicity
  - Assess induced seismicity risks, including identify faults, state-of-stress and fault slip potential

Risk Registry

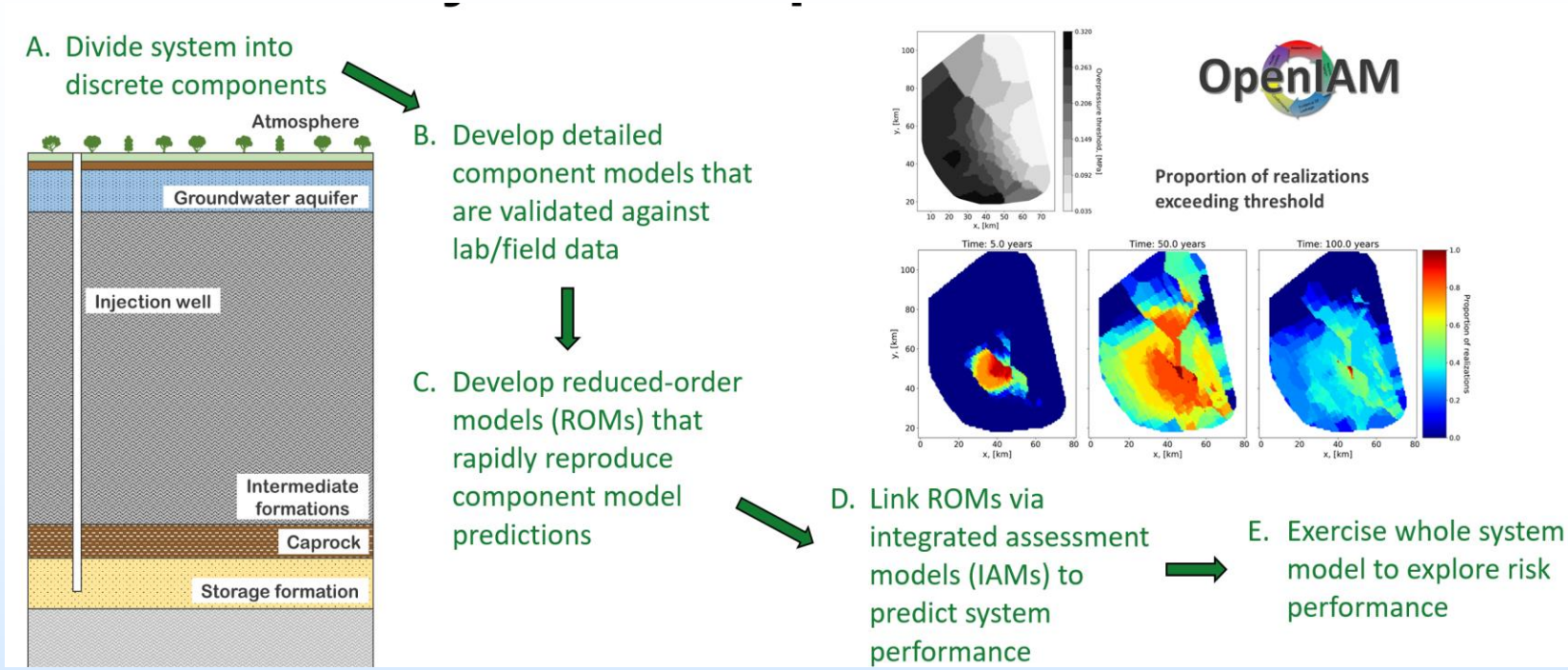
- Compiled initial risk registry
  - Contains 404 FEPs (feature, event, & process)
  - Identified data gaps
  - Integrating all site-specific data to update the risk registry
- Next Step:
  - Update risk registry
  - Develop risk mitigation plan
  - Conduct quantitative failure modes and effects analysis

Category	# of FEPs	Category	# of FEPs	Category	# of FEPs	Category	# of FEPs	Category	# of FEPs
CO2 PROPERTIES, INTERACTIONS & TRANSPORTATION	85	FIELD SAFETY RISKS	29	CO2 MONITORING RISKS	11	EXTERNAL RISKS	9	PROCUREMENT RISKS	5
CO2 PIPELINE RISKS	75	IMPACTS	25	PROJECT MANAGEMENT RISKS	10	CO2 CAPTURE RISKS	6	ENGINEERING RISKS	4
GEOSPHERE	45	NEAR-SURFACE ENVIRONMENT	23	PERMITTING RISKS	10	LEGAL, LEGISLATION & REGULATION RISKS	6	CONSTRUCTION RISKS	4
EXTERNAL FACTORS	30	BOREHOLES	15	CO2 ON-SITE FACILITIES RISKS	10	CO2 COMPRESSION RISKS	5	CO2 DEHYDRATION RISKS	3
CO2 STORAGE	30	ASSESSMENT BASIS	12	ECONOMIC RISKS	9	COMMISSIONING AND STARTUP RISKS	5		

Assessment of Endangerment of USDW through NRAP Tool Applications



Calculation of upper formation thickness and depth ranges according to well drilling data at the project area.

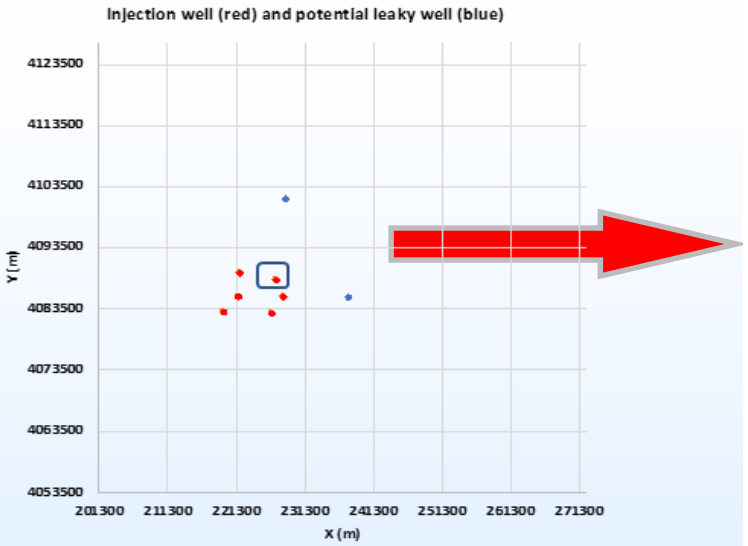


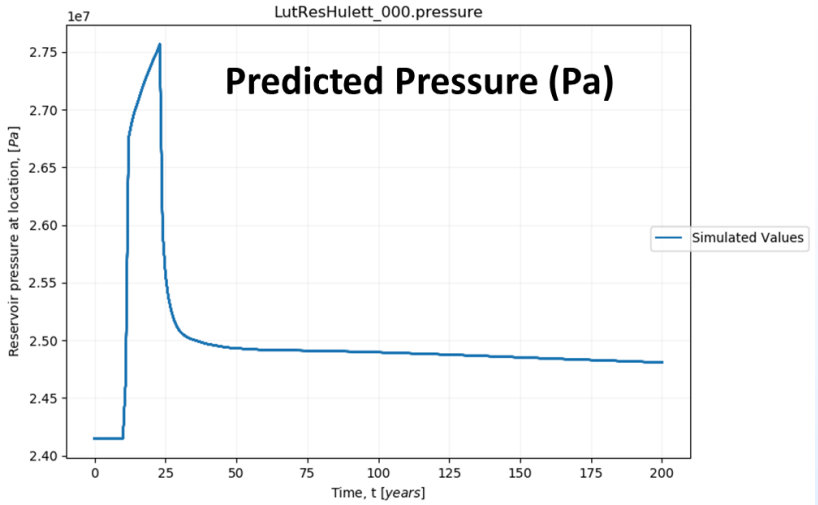
- Workflow has been developed importing physics-based reservoir simulator (CMG) pressure and CO_2 saturation results into NRAP Integrated Assessment Model (NRAP-Open-IAM)
- NRAP-Open-IAM was applied to quantify CO_2 and brine leakage
- The numerical simulations consider an ~70km x 70km area with six CO_2 injection wells penetrating the Entrada storage formation
- Preliminary study for two existing wells in the domain shows promising result with no CO_2 leakage and minimal brine leakage

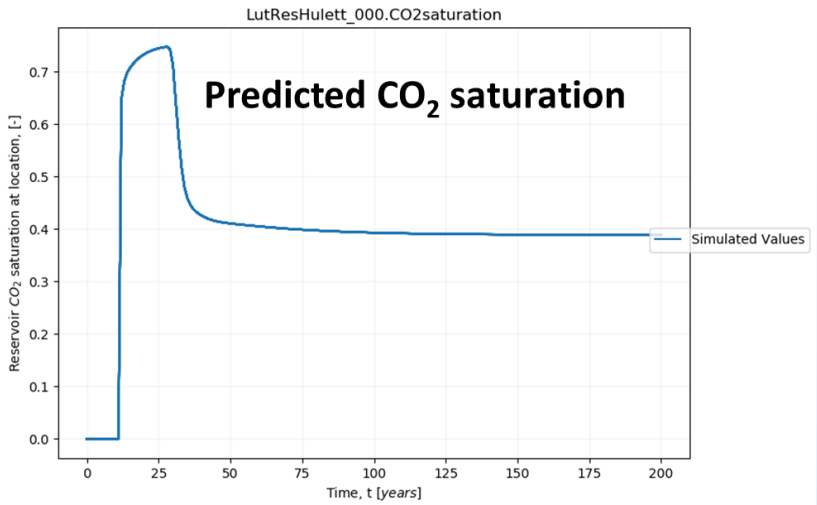
Simulation scenarios:

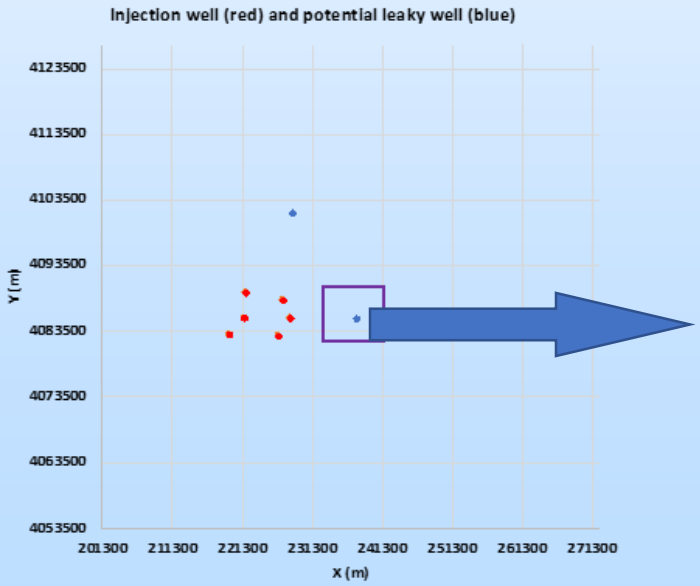
- 22 years of CO_2 injection to Entrada formation
- 200 years of post injection monitoring period

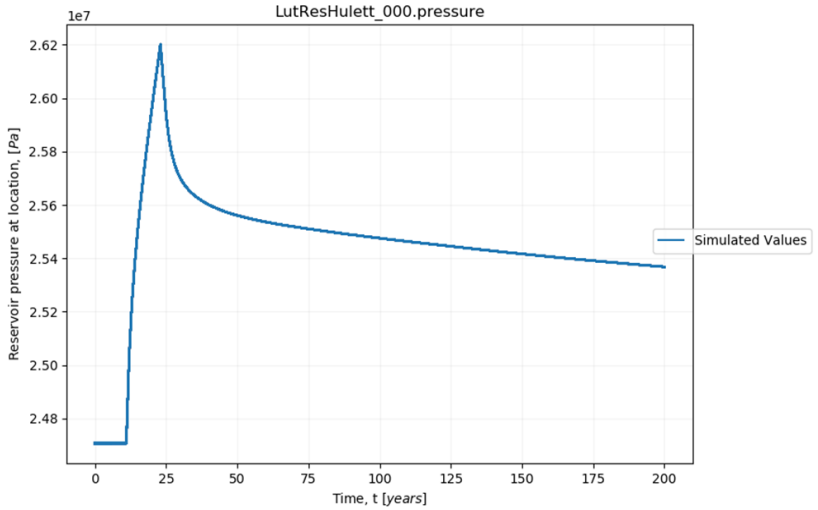
Preliminary Results and Analysis

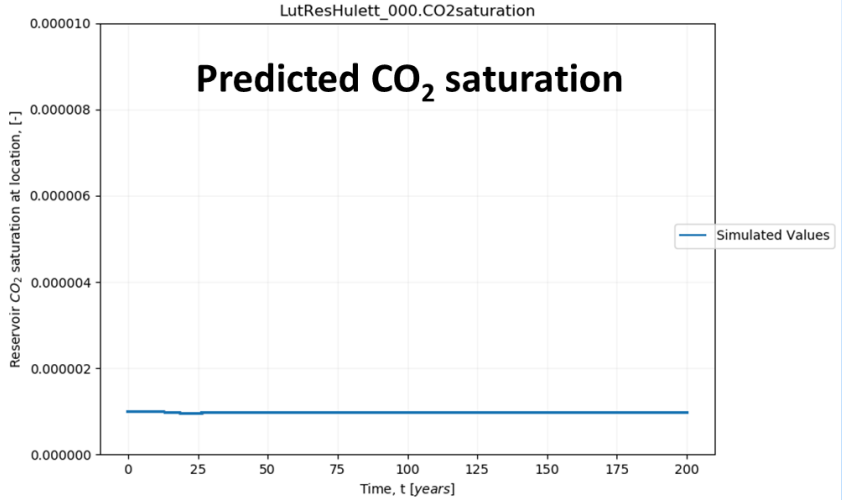






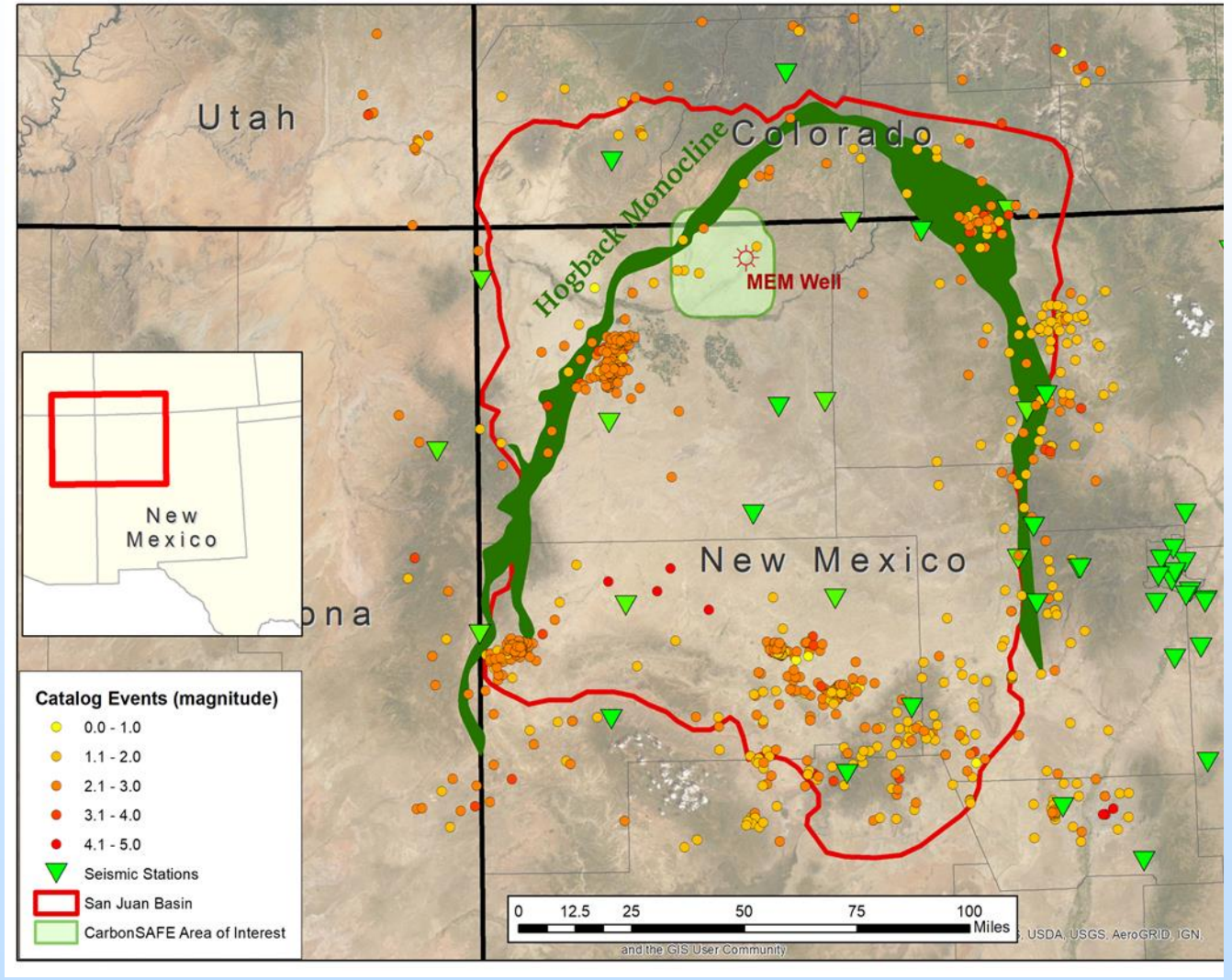






Previous Seismicity at SJB

- Compiled an earthquake catalog for San Juan Basin region
  - USGS (1966-2021)
  - ANF from USArray (mostly 2007-2009)
  - Literature
    - Historical (pre-1962)
    - Instrumental (1962-2009)
- Low seismicity region (max M=4.8, less than 1 M3+ per year)
- Most events surround the basin where more tectonic structures are present
- Few seismic events within the area of interest



Synergy opportunities

- The team is leveraging on experiences from other CarbonSAFE projects, NETL-RIC, Regional partnerships such as SWP and Regional Initiatives to ensure success of proposed efforts

- Collaboration with Enchant Energy LLC and its partners to accelerate deployment of CCS technology at the SJGS

- Collaborating with another DOE sponsored project (DE-F0032064) to install the fiber behind casing in the proposed stratigraphic well at San Juan Basin

Gaps/Challenges/Hurdles

- The currently licensed seismic coverage area does not extend to the west to fully map the Hogback structure
- Sparse well data penetrating through our reservoirs/seals
- Surface land and subsurface ownerships issues
- Salt water disposal penetrating through target zones
- Uncertainty on identifying the deepest USDW
- Slow foreign national clearance process

Summary- Next Steps

- Continue to prepare the UIC Class VI documentation for submission to EPA.
- To work with EPA to identify the acceptable deepest USDW at SJ Storage Complex
- To complete review and submit EIV to DOE
- To obtain permit from NMOCD to drill stratigraphic well in Fall 2021
- To incorporate petrophysical analysis from 22 wells into the reservoir property distribution in our geological model.
- To perform seismic inversion for reservoir properties to enhance property distribution into our geological model
- To estimate CO_2 storage capacity on 2D and 3D using CO_2 screen and parametric methods
- To incorporate adjacent SWD wells history into our simulation modeling and perform optimization on well placements and AoR estimation.

Summary- Next Steps

- Continue environmental justice analysis unto completion and ensure inputs are appropriately aligned with economic assessment inputs and analysis
- To add newly gathered data into risk registry; periodically update risk registry; and develop risk mitigation plan.
- To complete leakage calculations for all existing wells in the Area of Review
- To deploy seismometers in the region of interest and monitor for both baseline and injection-related seismicity
- To calculate the pore pressure perturbation at depth due to the SWD
- To complete relative permeability and flow through fluid-rock interaction experiments on the outcrop samples

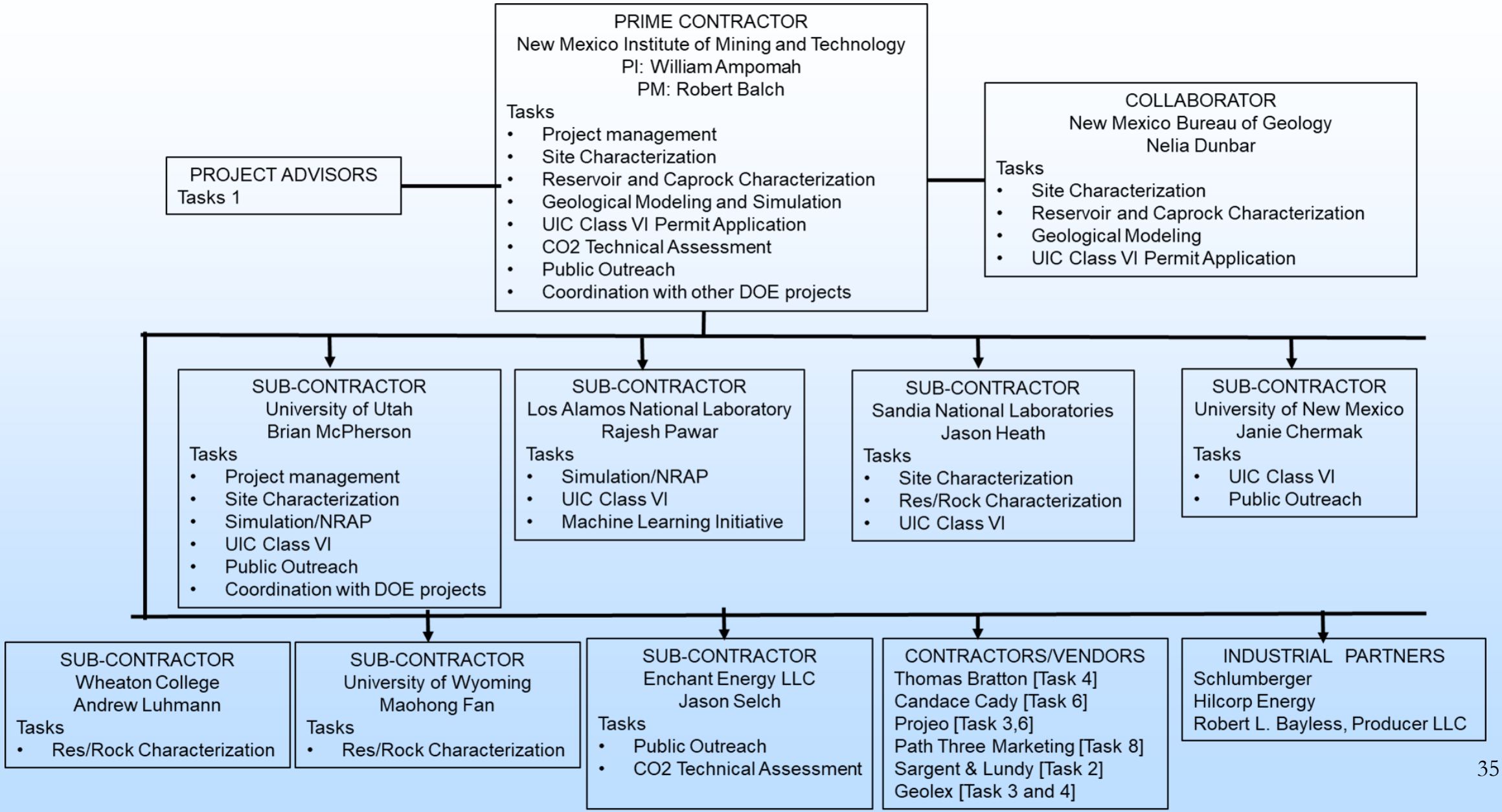
Acknowledgements

The project would like to thank DOE for the award opportunity through DE-FE0031890 and our partners.

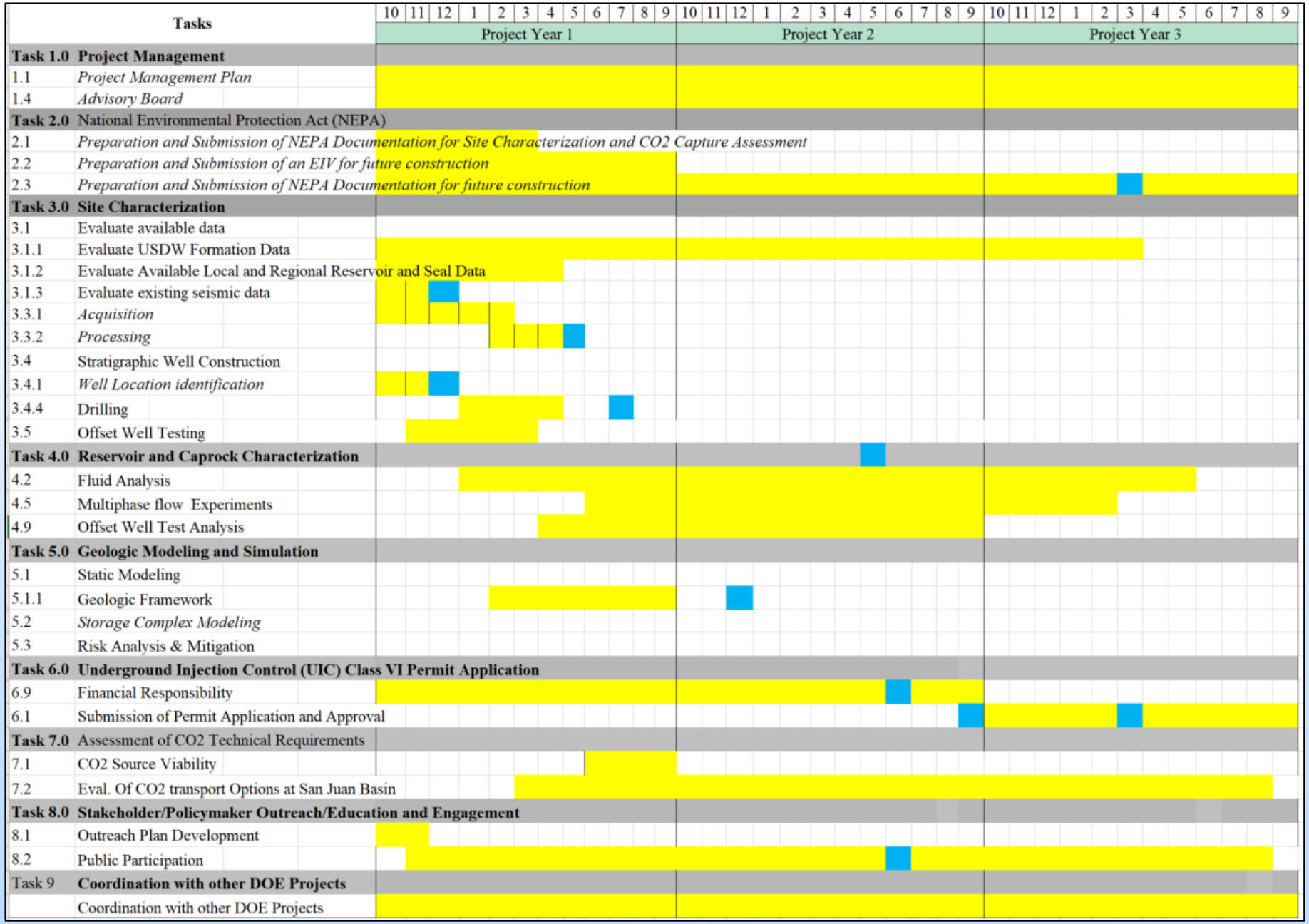
Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Organization Chart



Gantt Chart



Tasks		10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
		Project Year 1												Project Year 2												Project Year 3											
Task 1.0	**Project Management**																																				
1.1	*Project Management Plan*																																				
1.4	*Advisory Board*																																				
Task 2.0	National Environmental Protection Act (NEPA)																																				
2.1	*Preparation and Submission of NEPA Documentation for Site Characterization and CO2 Capture Assessment*																																				
2.2	*Preparation and Submission of an EIV for future construction*																																				
2.3	*Preparation and Submission of NEPA Documentation for future construction*																																				
Task 3.0	**Site Characterization**																																				
3.1	Evaluate available data																																				
3.1.1	Evaluate USDW Formation Data																																				
3.1.2	Evaluate Available Local and Regional Reservoir and Seal Data																																				
3.1.3	Evaluate existing seismic data																																				
3.3.1	*Acquisition*																																				
3.3.2	*Processing*																																				
3.4	Stratigraphic Well Construction																																				
3.4.1	*Well Location identification*																																				
3.4.4	Drilling																																				
3.5	Offset Well Testing																																				
Task 4.0	**Reservoir and Caprock Characterization**																																				
4.2	Fluid Analysis																																				
4.5	Multiphase flow Experiments																																				
4.9	Offset Well Test Analysis																																				
Task 5.0	**Geologic Modeling and Simulation**																																				
5.1	Static Modeling																																				
5.1.1	Geologic Framework																																				
5.2	*Storage Complex Modeling*																																				
5.3	Risk Analysis & Mitigation																																				
Task 6.0	**Underground Injection Control (UIC) Class VI Permit Application**																																				
6.9	Financial Responsibility																																				
6.1	Submission of Permit Application and Approval																																				
Task 7.0	Assessment of CO2 Technical Requirements																																				
7.1	CO2 Source Viability																																				
7.2	Eval. Of CO2 transport Options at San Juan Basin																																				
Task 8.0	**Stakeholder/Policymaker Outreach/Education and Engagement**																																				
8.1	Outreach Plan Development																																				
8.2	Public Participation																																				
Task 9	**Coordination with other DOE Projects**																																				
	Coordination with other DOE Projects																																				

Project Objectives

- Perform a comprehensive site characterization of a storage complex located in northwest New Mexico to accelerate the deployment of CCS technology in the San Juan Basin

- The data and analysis performed will be used to prepare, submit and obtain UIC Class VI permit from the Environmental Protection Agency (EPA).

- Public awareness of CCS technology and its benefits

- Collaborate with regional partnerships and regional initiative projects to accelerate CCS technology deployment in the region

Technical Approach/Project Scope

Task/ Subtask	Milestone Title & Description	Planned Completion Date
1.0	Project Kick-off meeting	
2.3	NEPA documentation progress	3/31/2023
3.1	Evaluation of available data such as seismic	12/30/2020
3.3	Acquisition and processing of Seismic data	5/30/2021
3.4.5	Stratigraphic well drilled	9/30/2021
4	Complete needed Caprock and reservoir analysis for Modeling	5/31/2022
5.2	Complete initial simulations for UIC permit application	7/31/2022
5.2.8	Complete AOR modeling	8/31/2022
5.3	Complete initial Risk assessment for UIC permit application	8/31/2022
6	Complete documentation to submit UIC class VI application	9/30/2022
6.10	Progress report on submitted UIC class VI application	3/30/2023
6.10	Progress and/or receiving approval for UIC class VI application	9/30/2023

(Project Success Criteria)

Objective/ Decision point	Success Criteria
NEPA assessment of selected project location(s) [Task 2]	The selected locations meet NEPA requirements. If not successful we move to a new location.
Obtain permits and drill a stratigraphic well at the selected suitable location. [Task 3]	Successful drilling, logging, and coring of well. If not successful we change location.
Purchasing of available seismic in the selected area [Task 3]	Purchase of existing seismic. If none available, we will acquire a new survey
Detailed site characterization to determine viability of selected storage complex [Task 3 and 4]	Site is found to have suitable geology for large scale CO_2 injection and storage
Modeling results from reservoir model and NRAP used to determine storage potential [Task 5]	Results show selected complex is able to securely store more than 50 million tons of CO_2 in the long term.
Complete application for UIC class VI application [Task 6]	Successful submission of UIC class VI application to EPA.
Secure approval on submitted UIC class VI application [Task 6]	Receiving approval to construct from EPA or the project cannot move forward

Project risks and mitigation strategies

Technical/Scope Risks:	Probability/Impact/Overall			Mitigation
Delays when drilling well	med	High	med	Appropriate management and well design should prevent this from happening. We will monitor drilling activities daily.
Unsuitable geology in identified area	low	High	low	Site location was chosen after a feasibility study by expert geologists with years of experience in the San Juan Basin. This study identified other potential sites in the area that could be used.
Lack of data	low	High	low	The project has identified several sources of commercial data. The New Mexico Bureau of Geology has offered access to databases and well logs for well information throughout the San Juan Basin.
ES&H Risks:				
Safety and environmental Risk	low	High	low	Experienced personnel with appropriate levels of expertise and safety will be handling field operations in the study.
External Factor Risks:				
Site access	low	High	low	We have a letter committing to site access from the operator and surface lessee (Hilcorp Energy) and additional letter from Robert L. Bayless, Producer LLC to use their site as well.
Regulatory Issues	med	High	med	New Mexico does not have a precedent for Class VI CO2 injection so issues of pore space and mineral rights may arise. However, the team has expertise from previous CarbonSAFE projects, regional partnerships and industry to overcome any potential barriers.