

A framework for linking quantitatively assessed risks and costs for geologic carbon storage (GCS) to consider the impact of contingency plans at a GCS site

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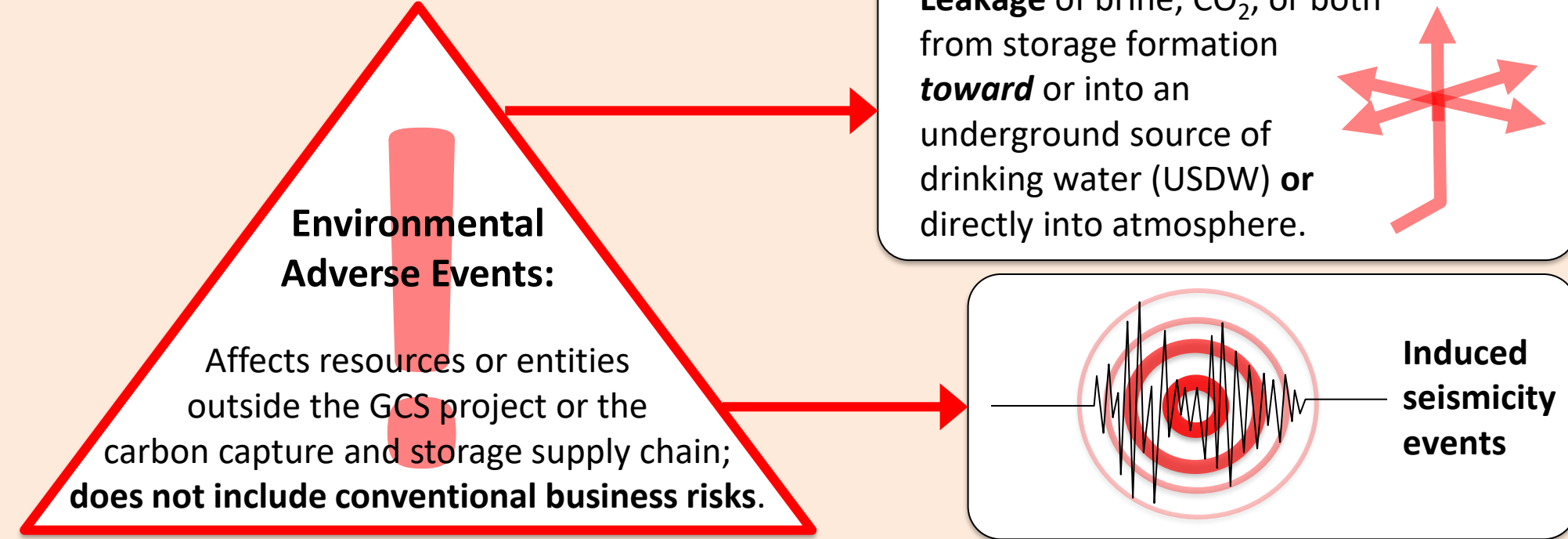
NRAP Phase III Develop tools to quantify long-term liability associated with responding to potential adverse events, such as leakage, for a GCS project.

Task 5 Case Study Motivation: Create prototype interactions between NRAP tools and the Office of Fossil Energy and Carbon Management (FECM)/NETL CO₂ Saline Storage Cost Model (CO₂_S_COM) to provide a concrete example of quantifying the costs associated with responding to a potential environmental adverse event.

Task 5 Terminology

Term	Definition
Liability	The financial consequence of an adverse event relative to a baseline (expected/hopeful) scenario where no adverse event occurs.
Adverse Event	An incident that is not part of the typical or ordinary activities of a Geologic Carbon Storage (GCS) project that adversely affects the operations of the project.

Task 5 Focus: Environmental Adverse Events



Remedial Response and Remedial Action

Term	Definition
Remedial Response	A single remedial action , or series of remedial actions, that completely address an adverse event, from start to finish.
Remedial Action	A unique action designed to address an aspect of an adverse event.

Remedial Action Types

Remedial Action Type	Remedial Action Description	Remedial Action(s) Example	Inclusion in ERR Plan Cost Estimates
Operational	"Baseline" or "normal" operation of the GCS project is altered.	Injection of CO ₂ is reduced or halted for a specified period due to leakage.	Yes (possibly)
Extrinsic	Action taken outside of "normal" operation of a GCS project; likely the major elements of the Emergency and Remedial Response (ERR) Plan.	Source of leak investigated with monitoring technologies; found to be a leaky legacy well, which is located and plugged.	Yes (definitely)
Penalty	Fine or contractual fee associated with an adverse event.	If a leak forces a GCS project to cease injection, the GCS project may have to pay a take-or-pay fee to the CO ₂ source that can no longer claim 45Q tax credits.	No

Stakeholder Perspectives on Liability

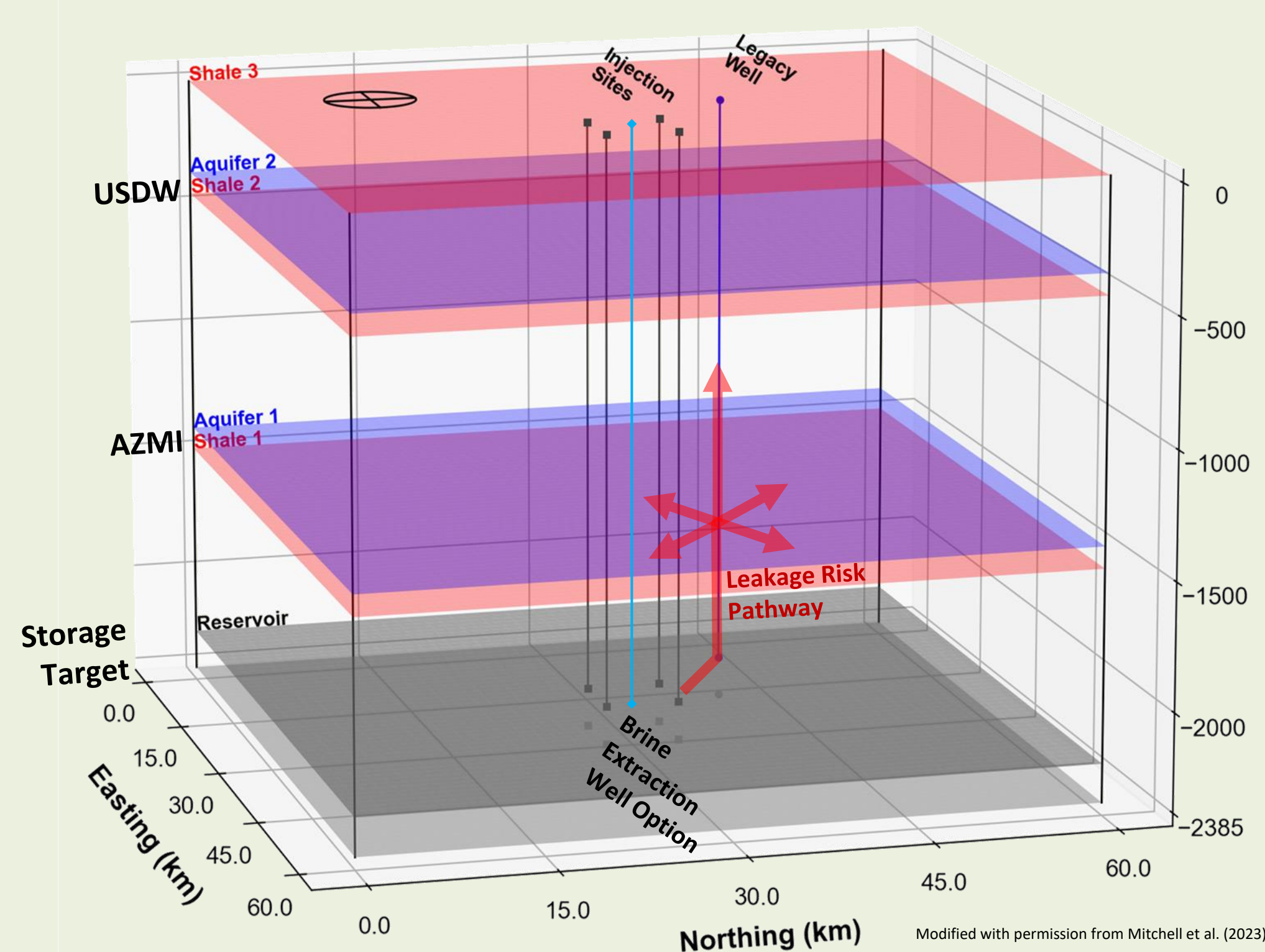
Stakeholder	Costs Included in Liability
Regulatory Authority	Capital expenditure (CAPEX) and operating expenditure (OPEX) of remedial response only; regulatory authority assumes liability if GCS owner cannot pay for ERR Plan implementation; funds provided by financial responsibility instruments purchased by the GCS owner prior to permit approval.
GCS Project Owner	Total cash flow to/from owners associated with remedial response, including CAPEX, OPEX, debt payments and proceeds, trust fund payments and withdrawals, taxes, lost revenues, penalties, and fines.

Basis Study

N. Mitchell, G. Lackey, B. Schwartz, B. Stazisar, and R. Dilmore (2023). "A quantitative risk assessment approach for developing contingency plans at a geologic carbon storage site," *Greenhouse Gases: Science and Technology*, Vol. 13, Issue 3, pp. 320–339.

- Scenario:** A hypothetical GCS site discovers an unplugged legacy well at the end of the fifth year of injection operations; re-plugging and abandoning the legacy well, which provides a potential leakage pathway toward USDW, is not feasible at this site.

Basis Study GCS Project's Site Layout and Stratigraphy

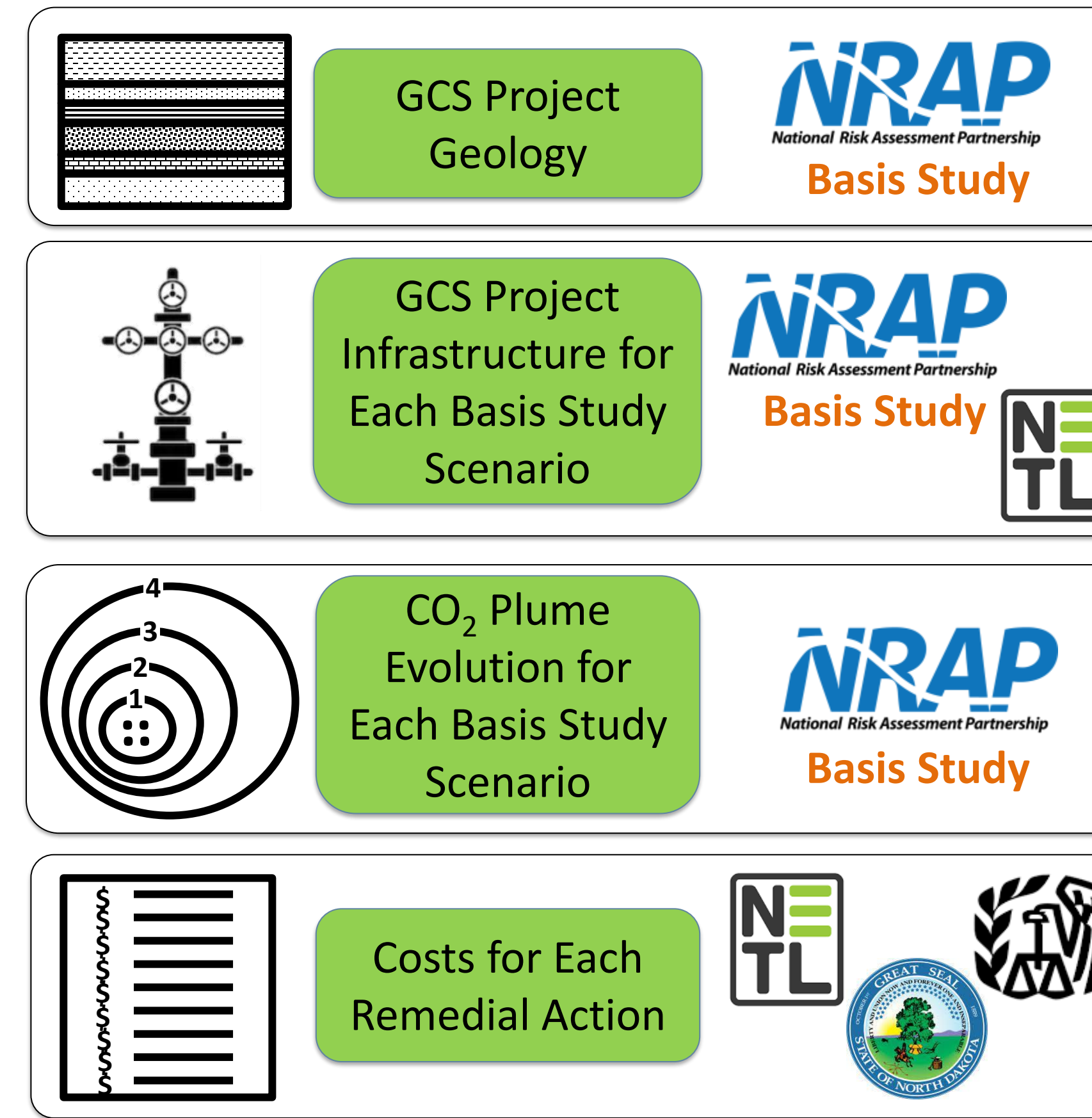


- Evaluation:** Reservoir pressure management options were evaluated using the NRAP Open-source Integrated Assessment Model (NRAP-Open-IAM) for technical risk of potential leakage.
- P50 Results:** The baseline case and early stoppage of injection after 10 operating years (ES10) posed both technical risk of potential brine leakage into the above zone monitoring interval (AZMI) aquifer.



Basis Study Scenarios' Remedial Response Options and Actions

Scenario Abbr.	Scenario/ Remedial Response Option Description	CO ₂ Injection Rate [Mtpa]			Cumulative CO ₂ Injected [Mt]	Extrinsic Remedial Actions		Operational Remedial Actions	Penalty Remedial Actions	
		Years 1–5	Years 6–10	Years 11–50		Short-Term (immediate; year 5)	Long-Term (years 6+)			
BC	Baseline Case		4		200	None	None	None	None	
BE	Brine Extraction After Year 5	Water Treatment	4		200	USDW endangerment actions (i.e., emergency monitoring costs to locate leak; labor to assess leak and determine appropriate ERR)	Drill brine extraction well(s); Pipeline to treatment or disposal	Treatment cost; Treated water sales Drill Class I disposal well(s) onsite; Disposal OPEX Drill Class I disposal well(s) offsite; Disposal OPEX	None	None
		Onsite Class I Disposal								
		Offsite Class I Disposal								
ES5	Early Stop of Injection Operations		0		20		None	Cease OPEX; begin Post-Injection Site Care (PISC) in Years 6+	Take-or-Pay for 4 Mtpa in Years 6–12	
ES10			4	0	40		None	Cease OPEX; Begin PISC in Years 11+	Take-or-Pay for 4 Mtpa in Years 11–12	
RI50	Injection Rate Reduced 50% of Initial Rate		2		110		None	Reduce Injection Rate	Take-or-Pay for 2 Mtpa in Years 6–12	
RI75	Injection Rate Reduced 75% of Initial Rate		1		65		None	Dependent OPEX in Years 6–50	Take-or-Pay for 3 Mtpa in Years 6–12	



Excel version of CO₂_S_COM modified to incorporate basis study's GCS project parameters and simulation results used by NRAP-Open-IAM; long-term liability calculated for each scenario.

Case Study Long-Term Liability Results

Scenario/ Remedial Response Option Abbreviation	Basis Study's Risk of Brine Leakage Into:	Financial Results Relative to BC (\$M, discounted to 2018)							BC Scenario CO ₂ Price (2018\$/tCO ₂)	Financial Results Relative to BC (\$M, discounted to 2018)			FYBE CO ₂ Price (2018\$/tCO ₂)	Extrinsic Remedial Actions' Cost (\$M, discounted to 2018)	
		Costs (negative is more \$ spent)								Sources of Cash		NPV of Project Total Cash Flow to/from Owners (Liability)			
		AZMI	USDW	OPEX	CAPEX	TOP Penalty Cost	Debt Payments	Trust Fund Payments		Taxes	Revenue				Trust Fund Withdrawal
BC	-	-	-	-	-	-	-	-	-	-	-	-	4.07	0	
BE – onsite disp.	No Risk	No Risk	-53.5	-20.2	-	3.6	-1.0	4.1	4.07	0	0.8	29.7	-36.6	7.54	-73.7
BE – offsite disp.			-107.5	-0.9	-	3.6	0	4.1		0	0.8	50.5	-49.5	8.42	-108.4
BE – water tmt.			-288.7	-0.9	-	3.6	0	4.1		0.5	0.8	158.7	-121.9	14.83	-289.6
ES5	No Risk	No Risk	21.7	10.9	-150.3	2.5	-1.1	4.1	-53.8	3.2	88.3	-74.6	15.63	-0.8	
ES10	Yes	No Risk	12.7	9.2	-32.6	2.1	-0.04	2.7	-32.1	2.5	17.4	-18.1	6.06	-0.8	
RI50	No Risk	No Risk	3.5	5.0	-75.1	-1.0	2.7	4.1	-26.9	0.8	42.9	-43.2	9.66	-0.8	
RI75	No Risk	No Risk	5.7	7.9	-112.8	1.8	0.9	4.1	-40.4	0.8	69.2	-62.7	12.54	-0.8	

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