IEA GHG Weyburn CO_2 Monitoring and Storage Project

CO_2 Storage Capacity & Distribution Predictions and The Application of Economic Limits

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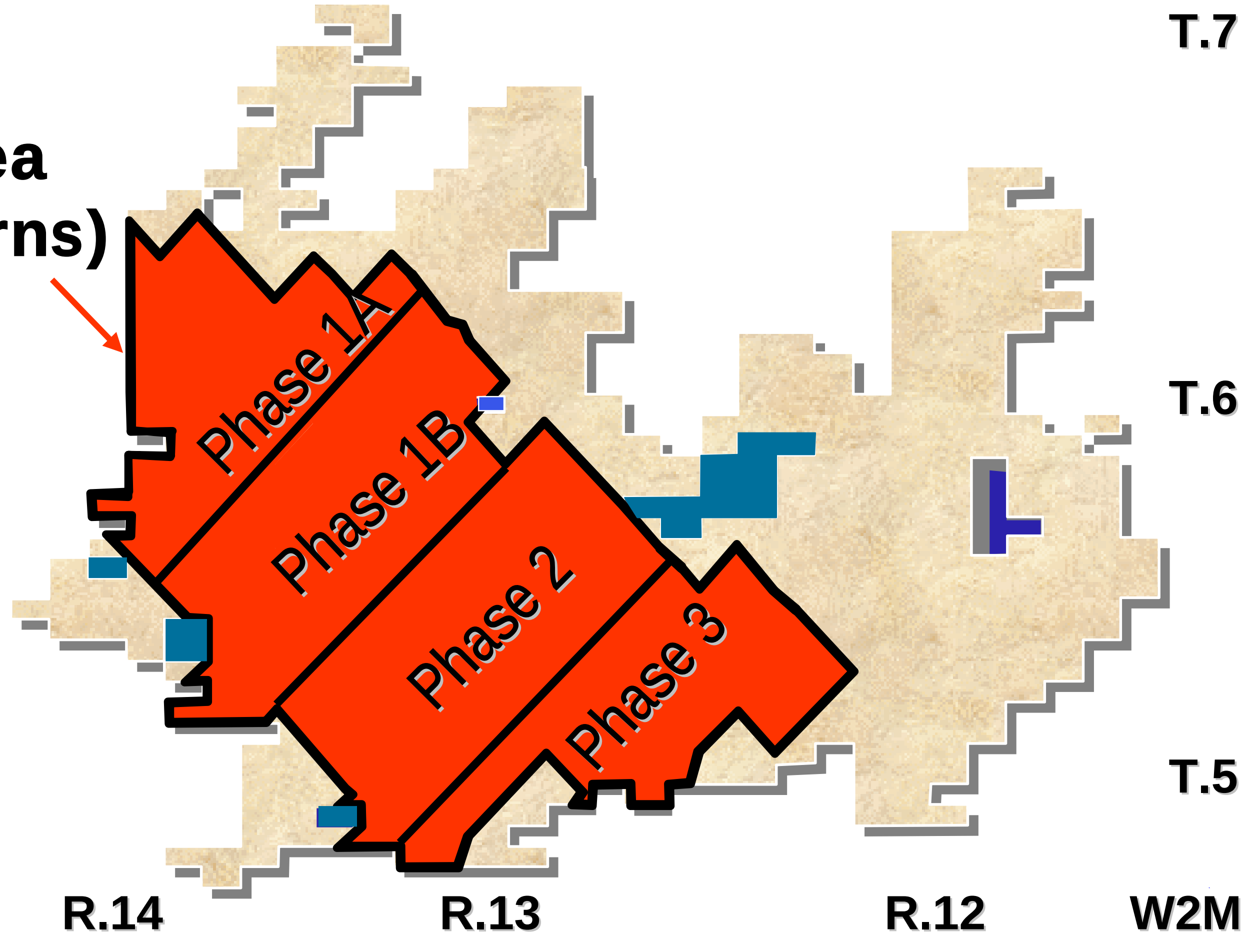
Natural Resources Canada   Ressources naturelles Canada

Weyburn Unit

Field Size:	**70 sq. miles**
OOIP:	**1.4 billion bbls**
Primary:	**1955 – 1964**
Water Flood:	**1964 - 2000**

Rollout of CO_2 flood

EOR Area
(75 Patterns)



Start CO_2 Injection: Fall 2000

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Integration Process & Information Flow

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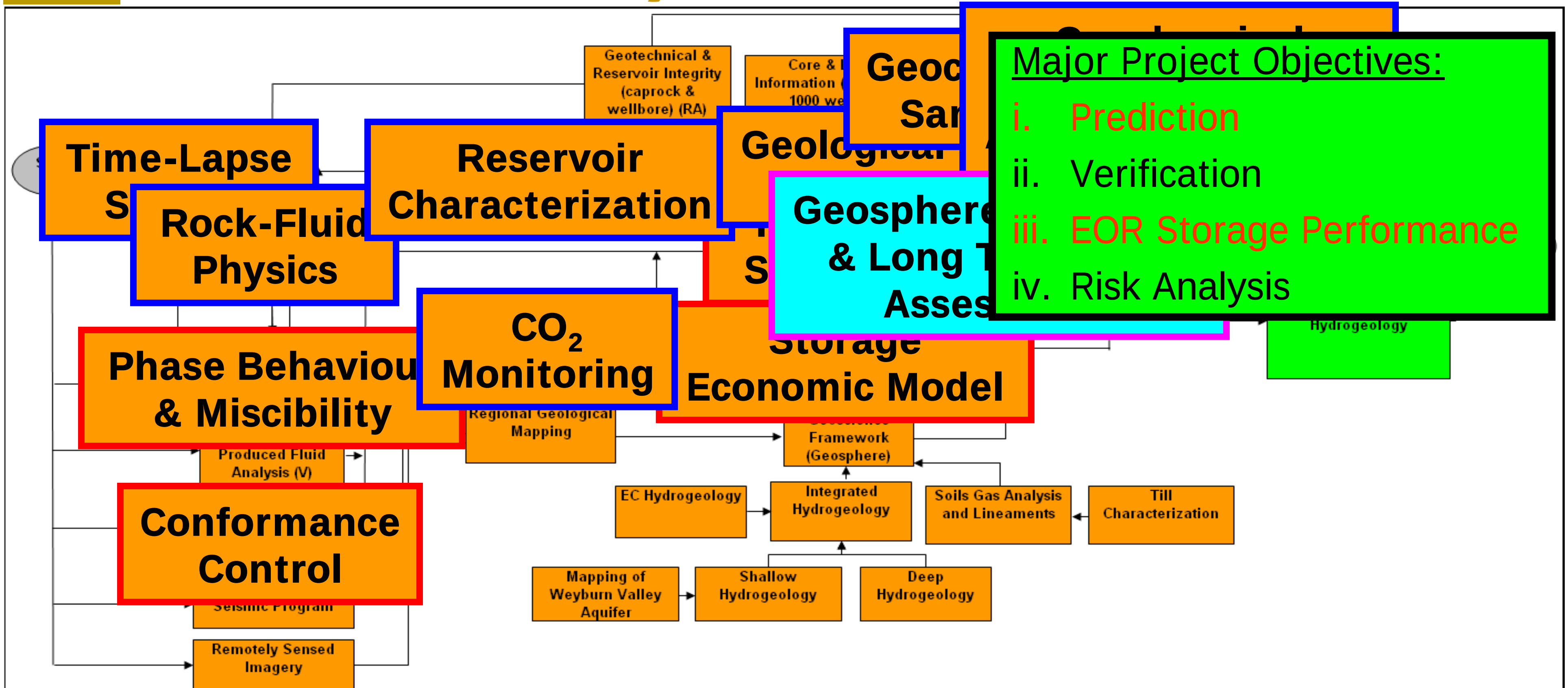

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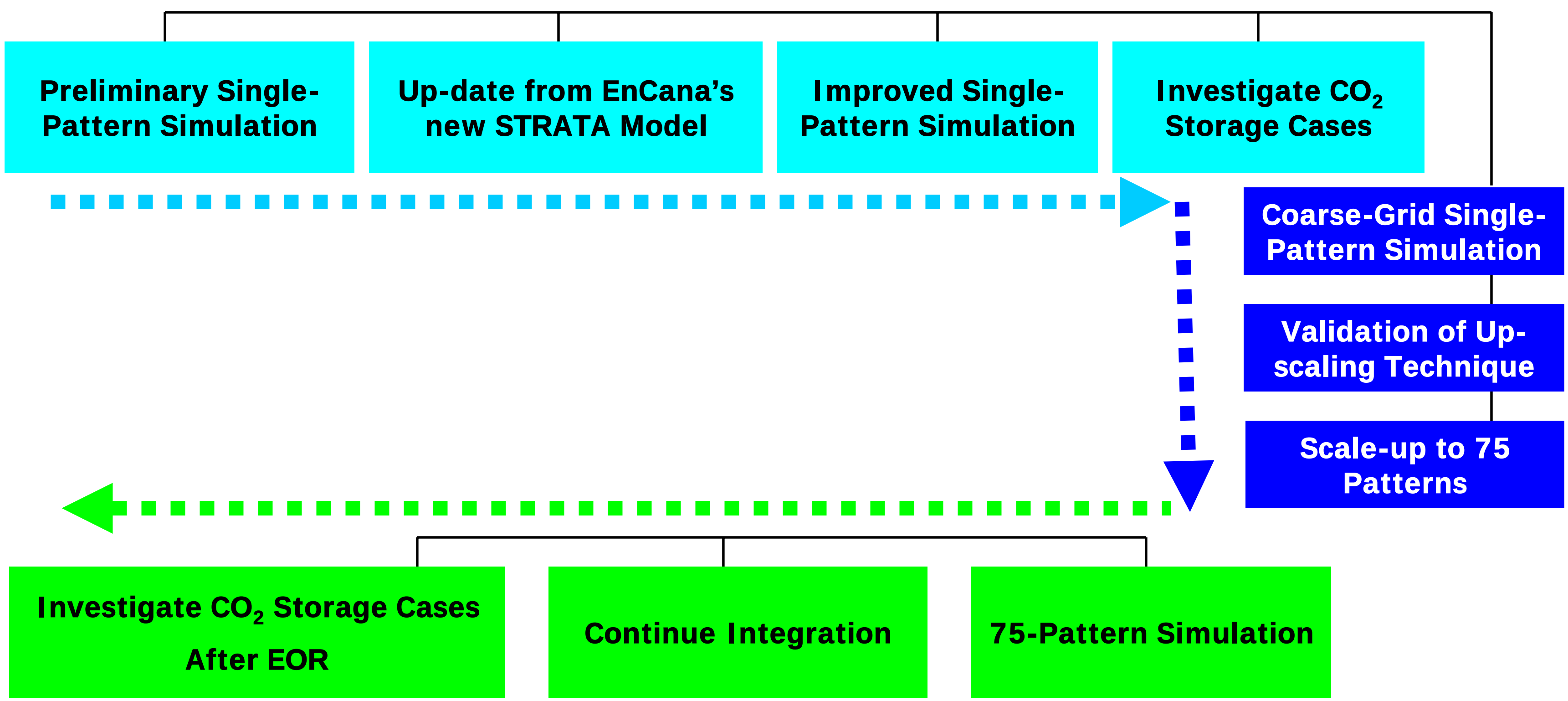
Reservoir Simulation Methodology

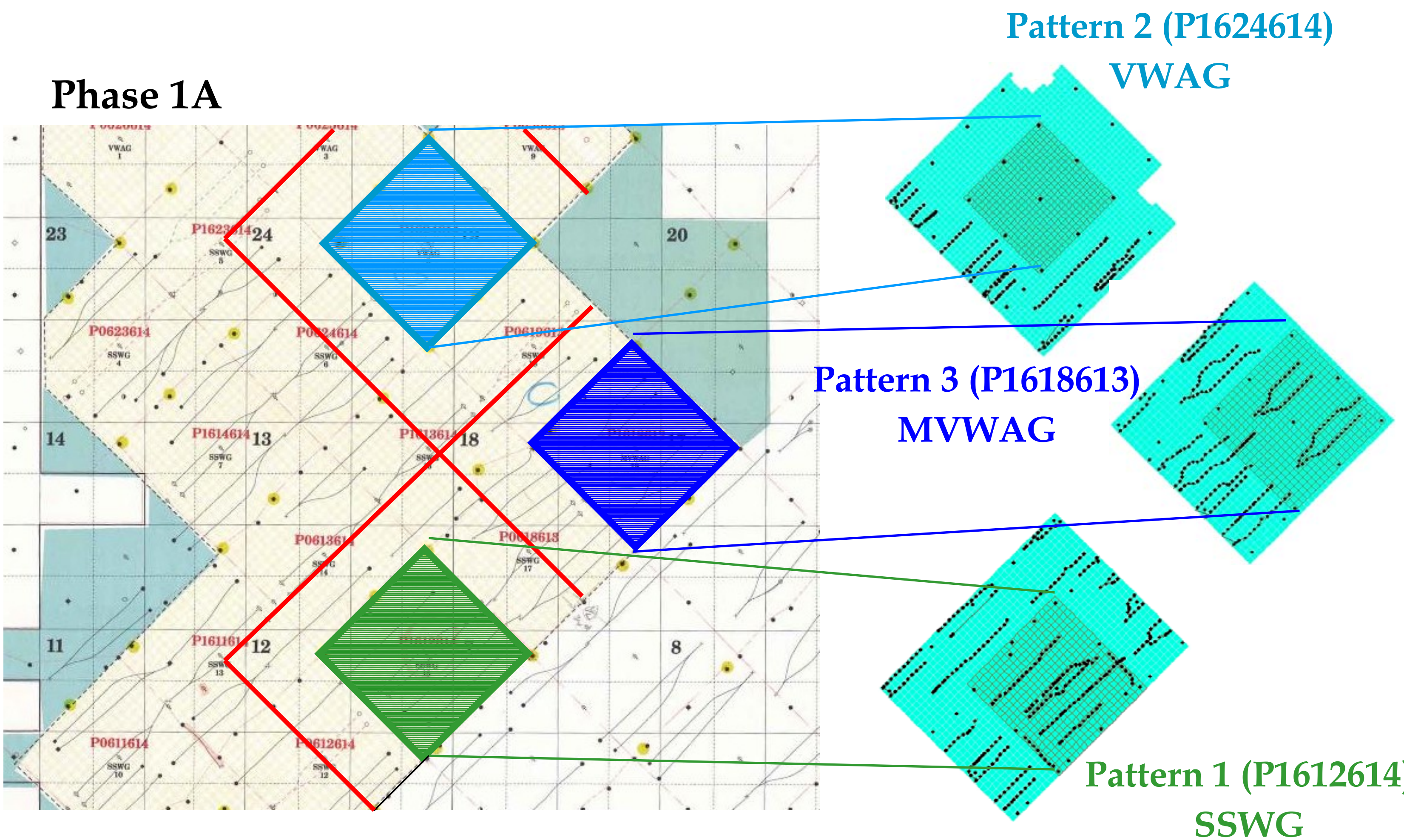
From Single Pattern to 75 Patterns



Single-Pattern Simulation

Pattern + Buffer

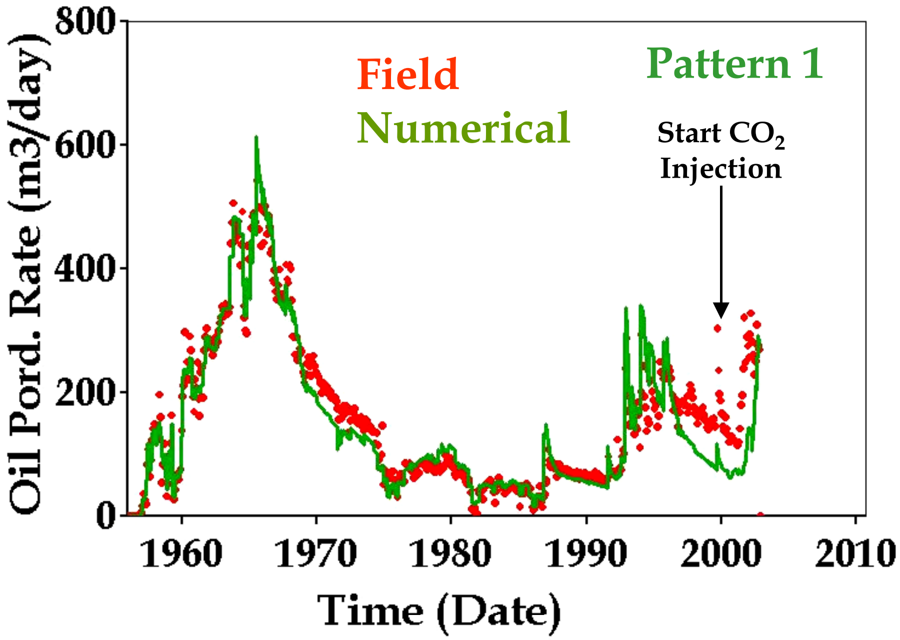
Phase 1A

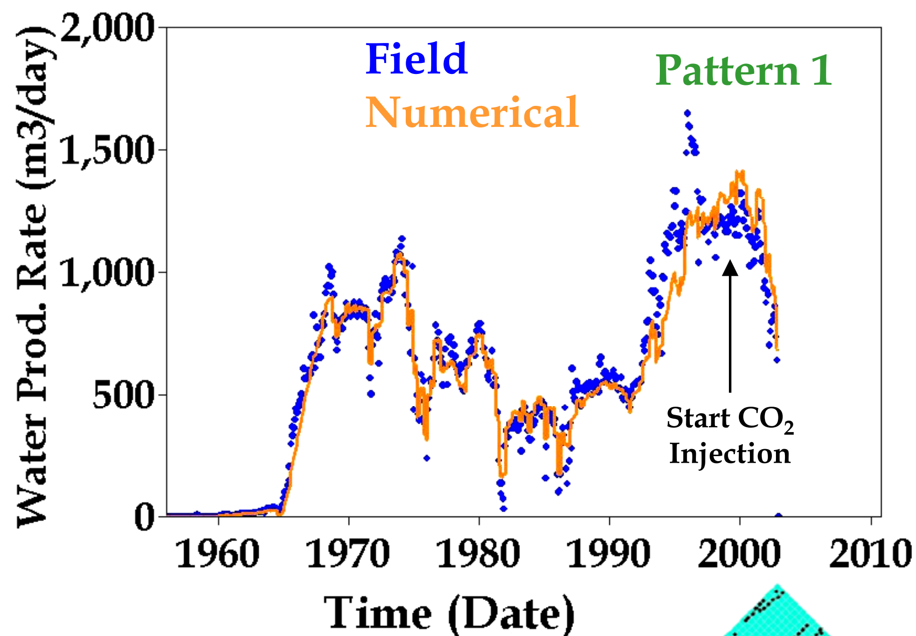


Single-Pattern Simulation

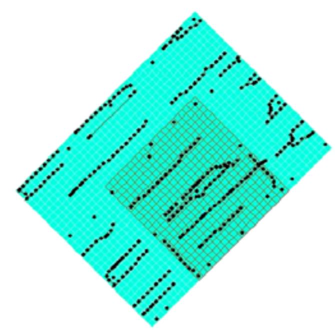
Comparison of Field Data

Total Oil/Water Production Rates (Pattern 1 + Buffer)





Pattern 1 (P1612614) - SSWG



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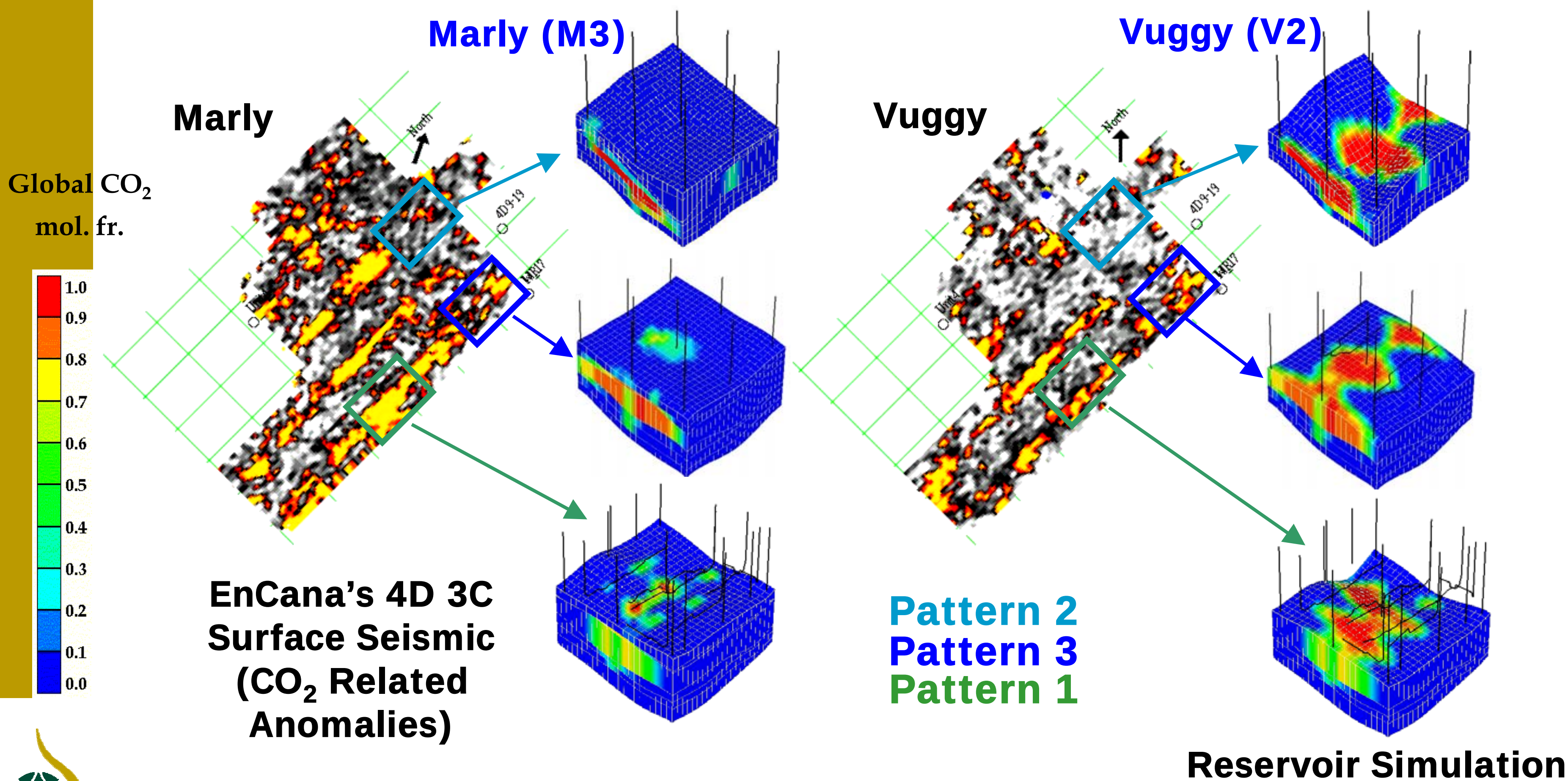
Single-Pattern Simulation

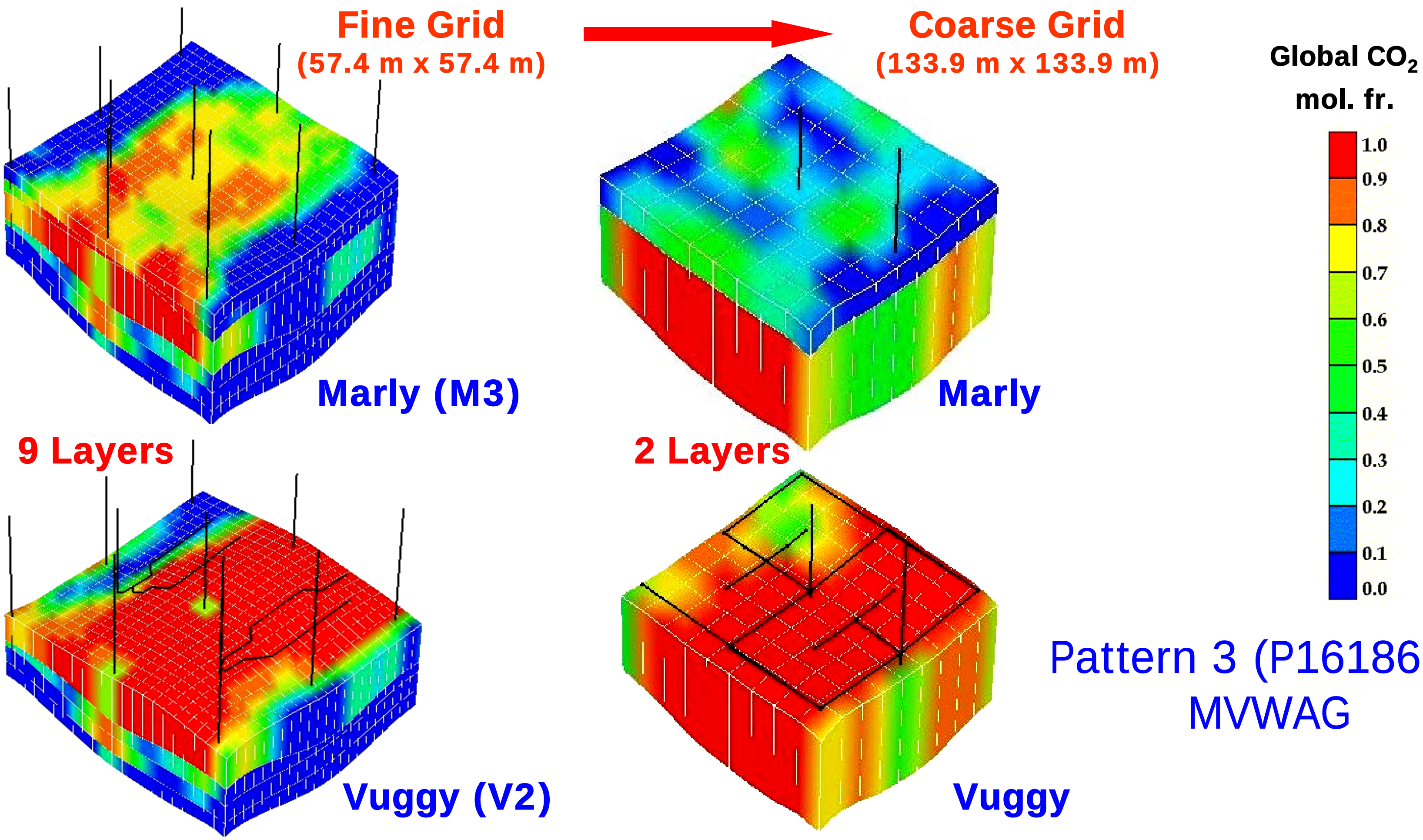
Comparison of Seismic Data



CO_2 Distribution after 2 years

Single-Pattern Simulation

Up-Scaling Technique Validation



Pattern 3 (P1618613)
MVWAG

CO_2 Distribution at 2025/01/01

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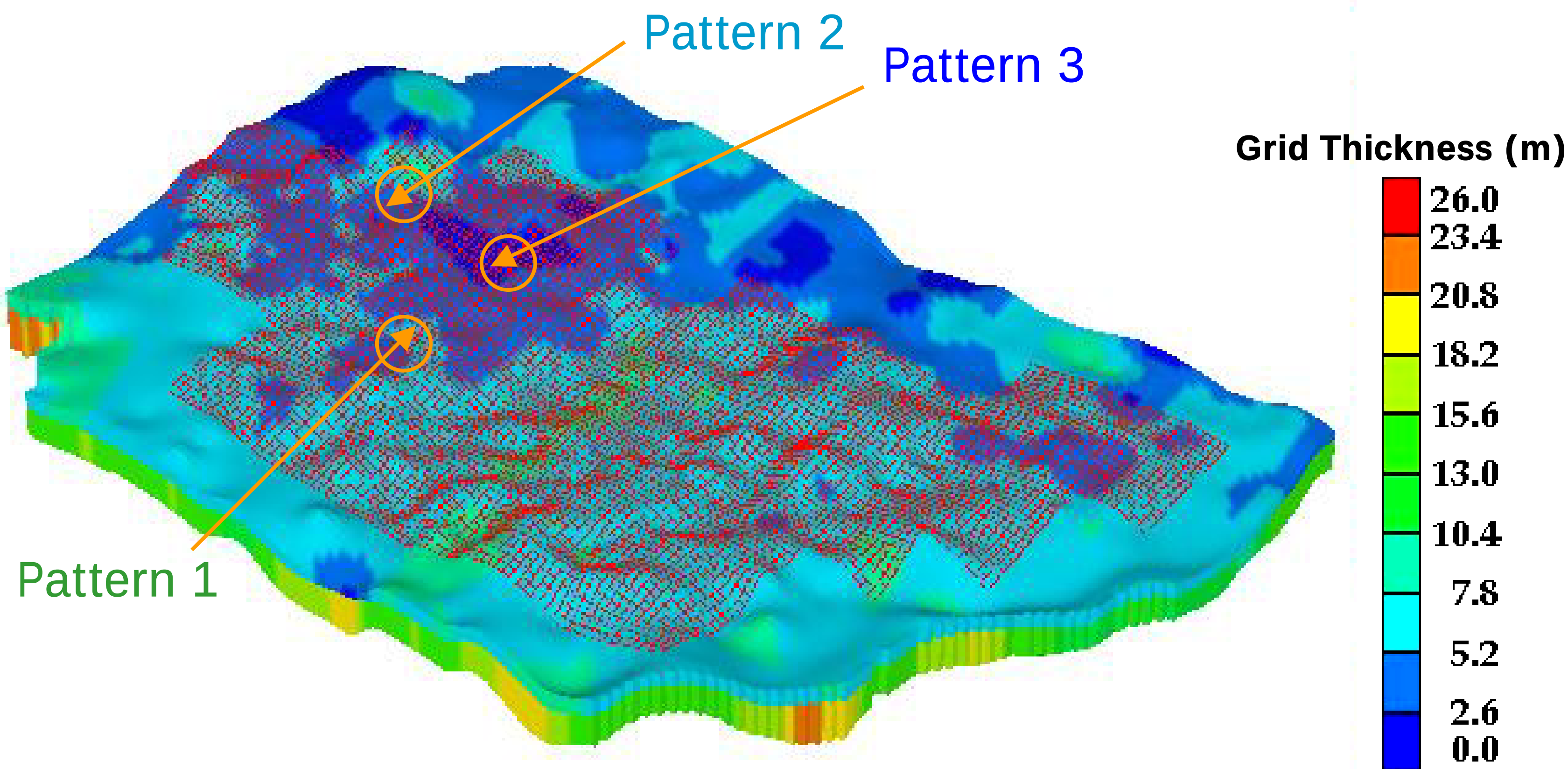
75-Pattern Simulation

75 EOR Patterns + Buffer



Grid System: 135 x 90 x 2 ((9 x 9 x 2) / Pattern)

Vertical / Horizontal Scale = 30 / 1

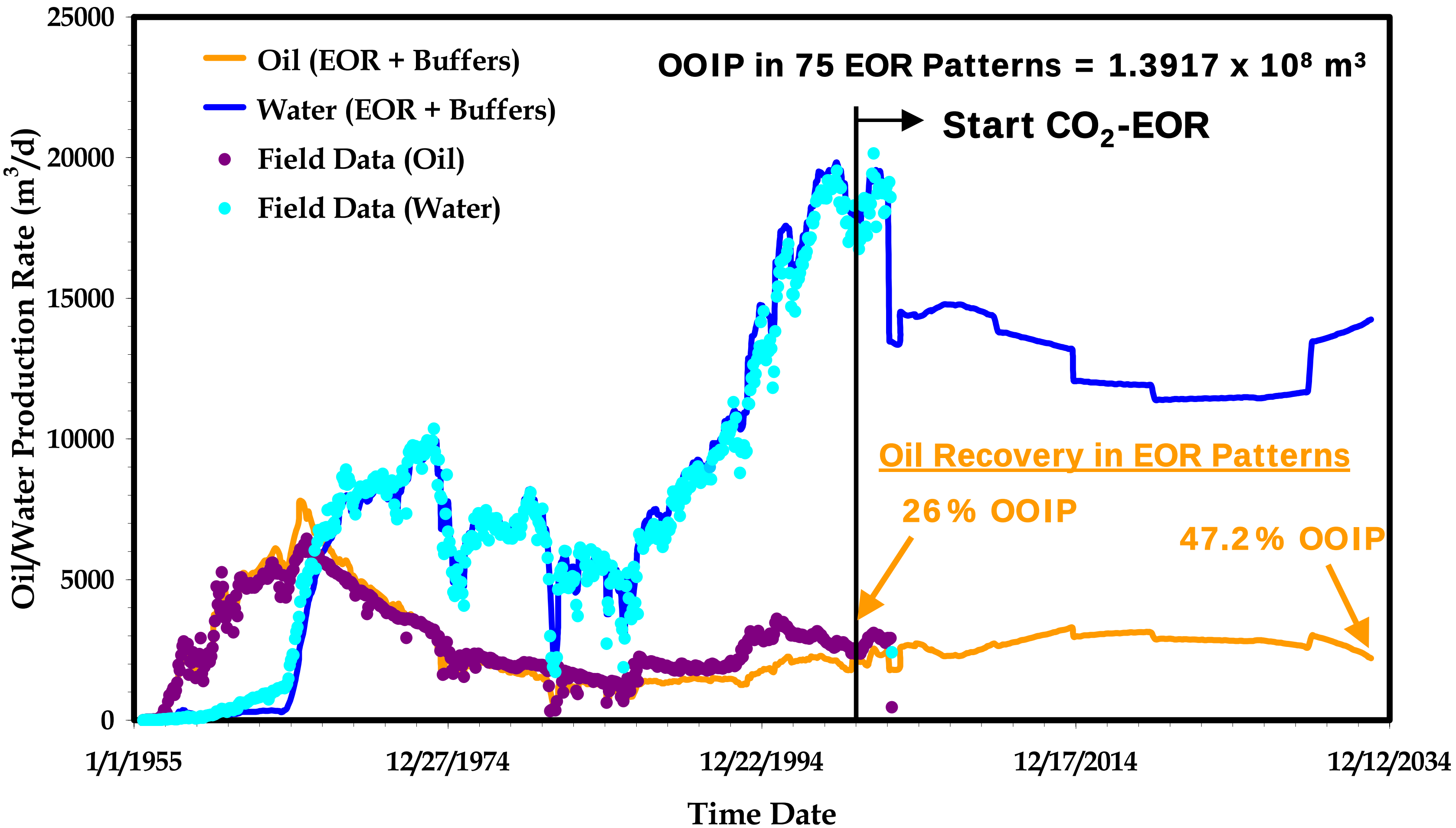
75-Pattern Simulation

Base EOR Case (2000 – 2033)

- Follow EnCana's EOR operating strategies as closely as possible
  - Injection plan: inject 50 – 60% HCPV CO_2
  - Roll out plan: 2000 - 2008
  - Maintain pressure of reservoir > 18 MPa for miscibility
  - Depletion plan: water flush of depleted patterns to liberate some of the CO_2 for recycle
  - Final CO_2 storage volume in the reservoir should equal to the total purchases of ~20 million tonnes (MT)
- Verify EnCana's prediction of oil recovery factor of 46% OOIP which will be increased from 30%, achieved with conventional water flood

75-Pattern Simulation

Oil/Water Prod. - Base EOR Case



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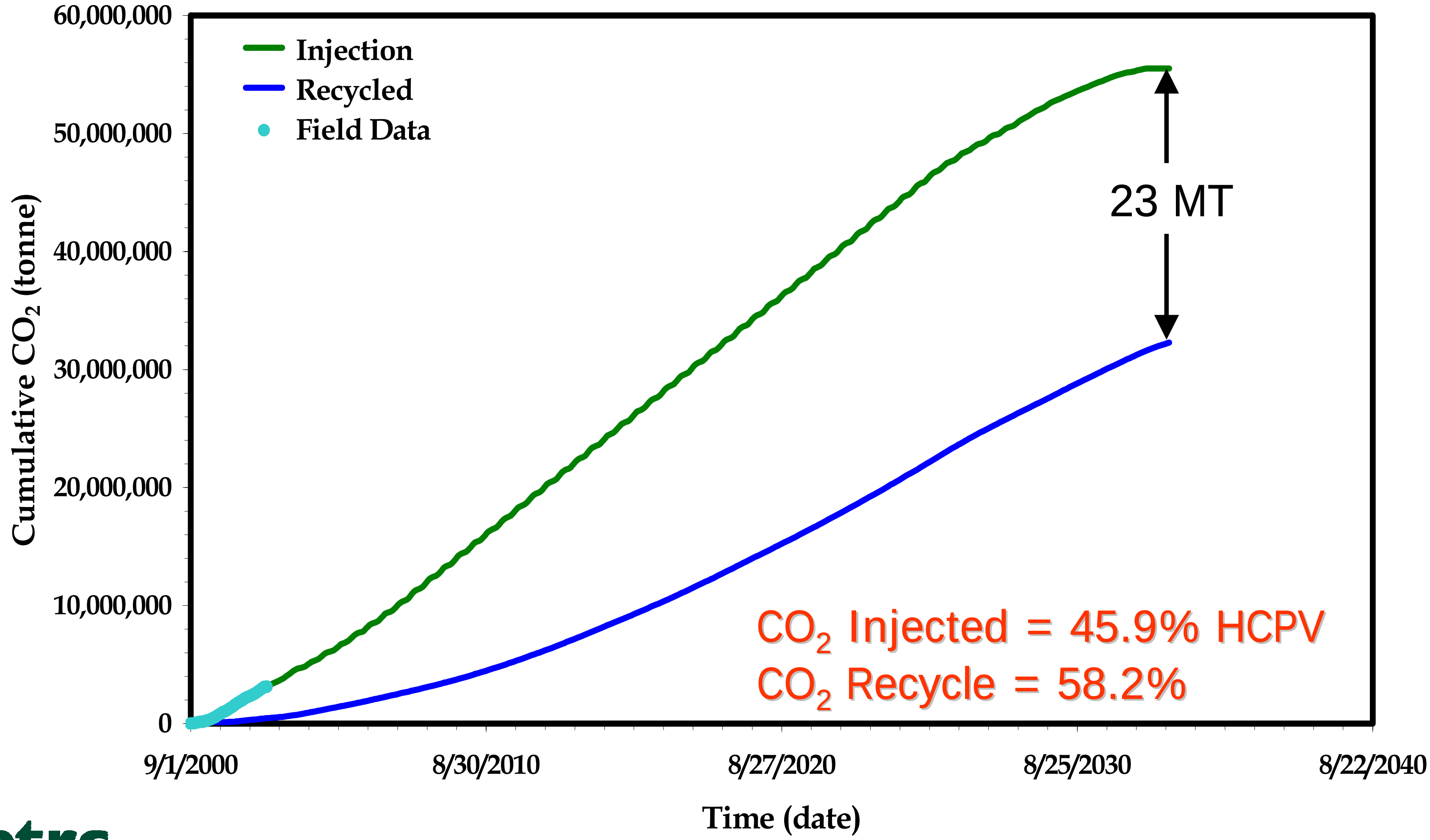
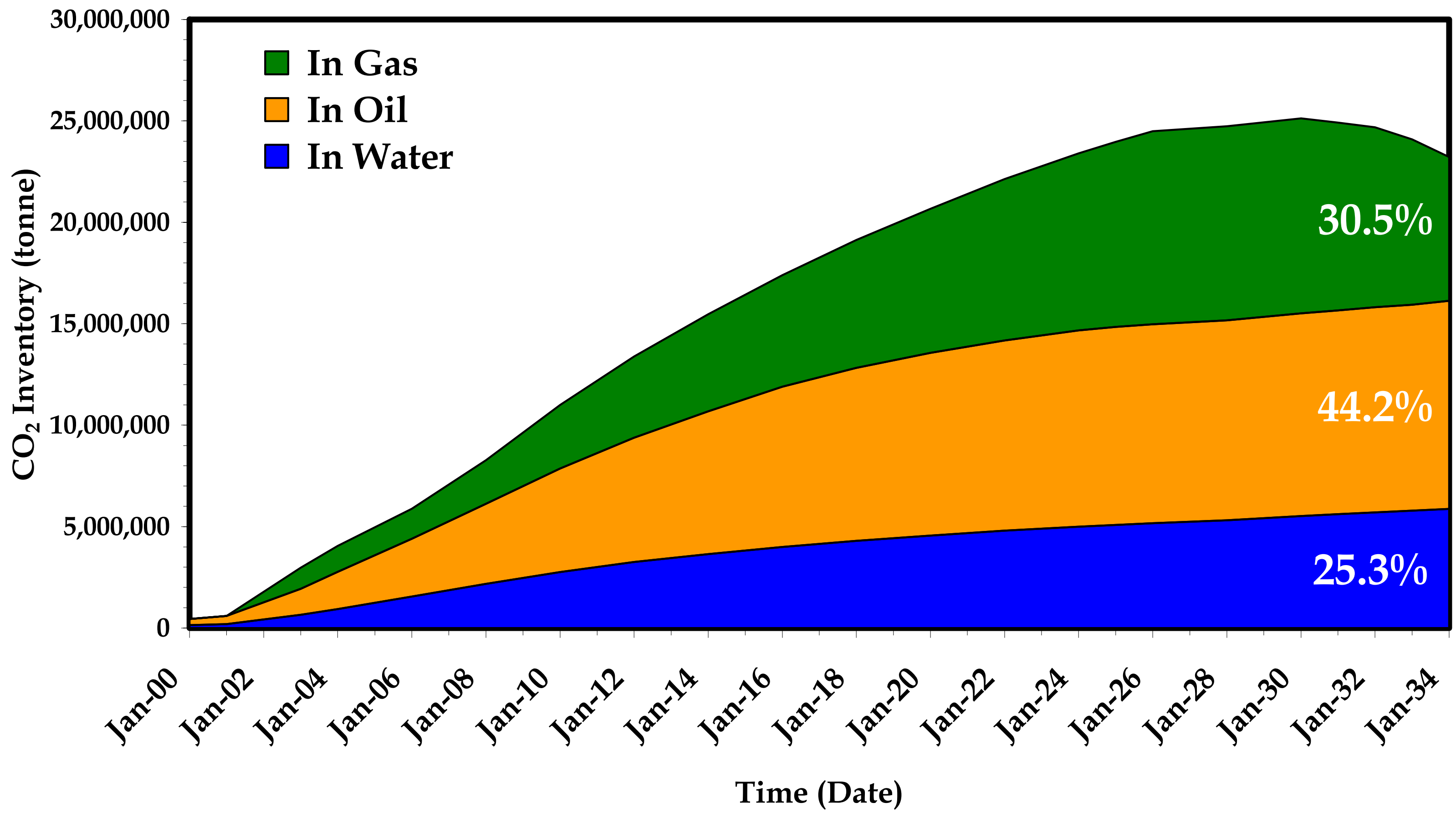
75-Pattern Simulation

CO_2 Storage – Base EOR Case



75-Pattern Simulation

CO_2 Inventory – Base EOR Case



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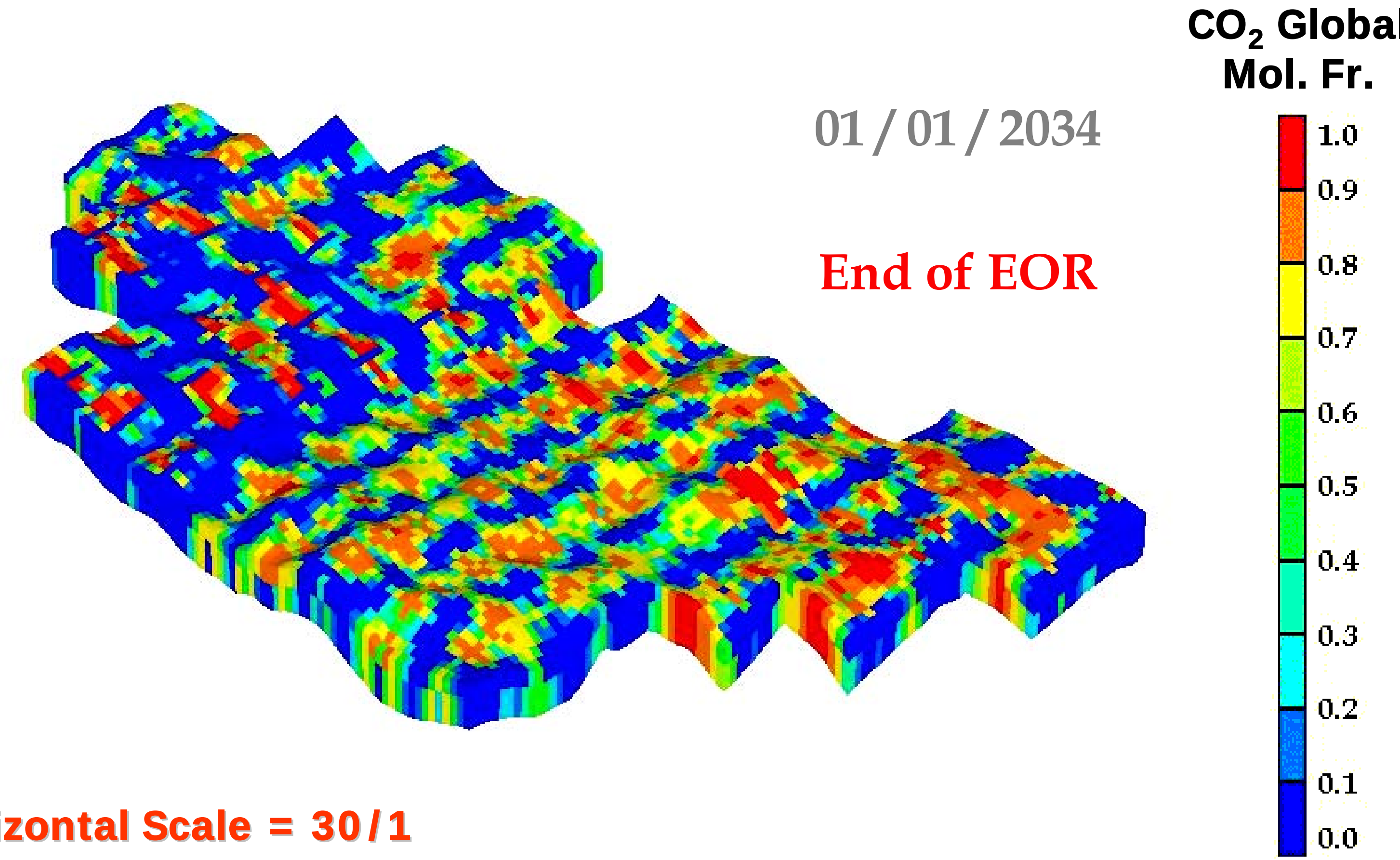
75-Pattern Simulation

CO_2 Distribution – Base EOR Case



Vertical / Horizontal Scale = 30 / 1

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75-Pattern Simulation

Alternative Cases

	Base EOR Case (2000 – 2033)		Alternative EOR Case (2000 – 2033)	
CO_2 Injected, % HCPV	45.9%		57.7%	
CO_2 recycled, % Injected	58.2%		56.9%	
CO_2 Stored, million tonnes	23.2		30.0	
Oil recovery after water flood, % OOIP	26%		26%	
Oil recovery after EOR, % OOIP	47.2%		50.3%	
Net CO_2 Utilization Ratio*, m^3/m^3	416		496	
	Alternative Storage (2033 – 2055)		Alternative Storage (2033 – 2055)	
	Case II	Case III	Case IIa	Case IIIa
CO_2 Stored, million tonnes (Additional)	28.9 (5.7)	49.2 (26.0)	37.2 (7.2)	60.7 (30.7)
Oil Recovery @2055, %OOIP (Additional)	----	54.3% (7.1%)	----	54.7% (4.4%)
Net CO_2 Utilization Ratio*, m^3/m^3	----	1,462	----	2,585

* m^3 of CO_2 stored / m^3 of oil recovery

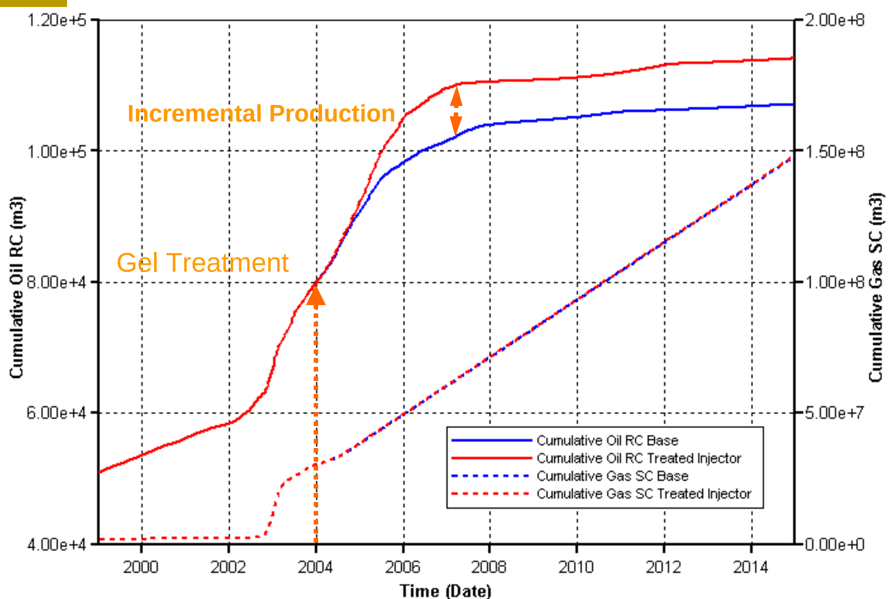
Cases II & IIa: Shut-in producer; Cases III & IIIa: GOR control at producers

Conformance Control

- Selection, optimization, testing formulations in laboratory for different technologies: foam, gel, gel-foam
- Coreflood testing in homogeneous core packs and heterogeneous cores
- Review of field applications
  - Foams, gels, gel-foams for CO_2 conformance
  - Gel applications in the Weyburn reservoir
- Design and prediction of gel treatment performance in the Weyburn reservoir
  - Candidate well selections (wells with highest GOR)
  - Cost estimation

Conformance Control

Incremental Oil Recovery



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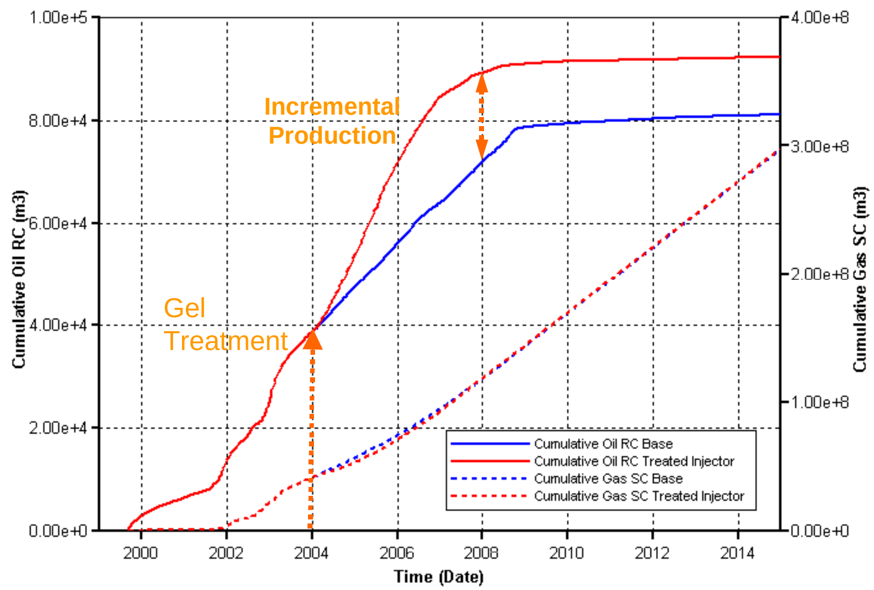
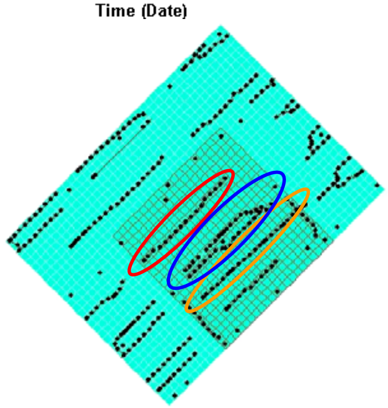




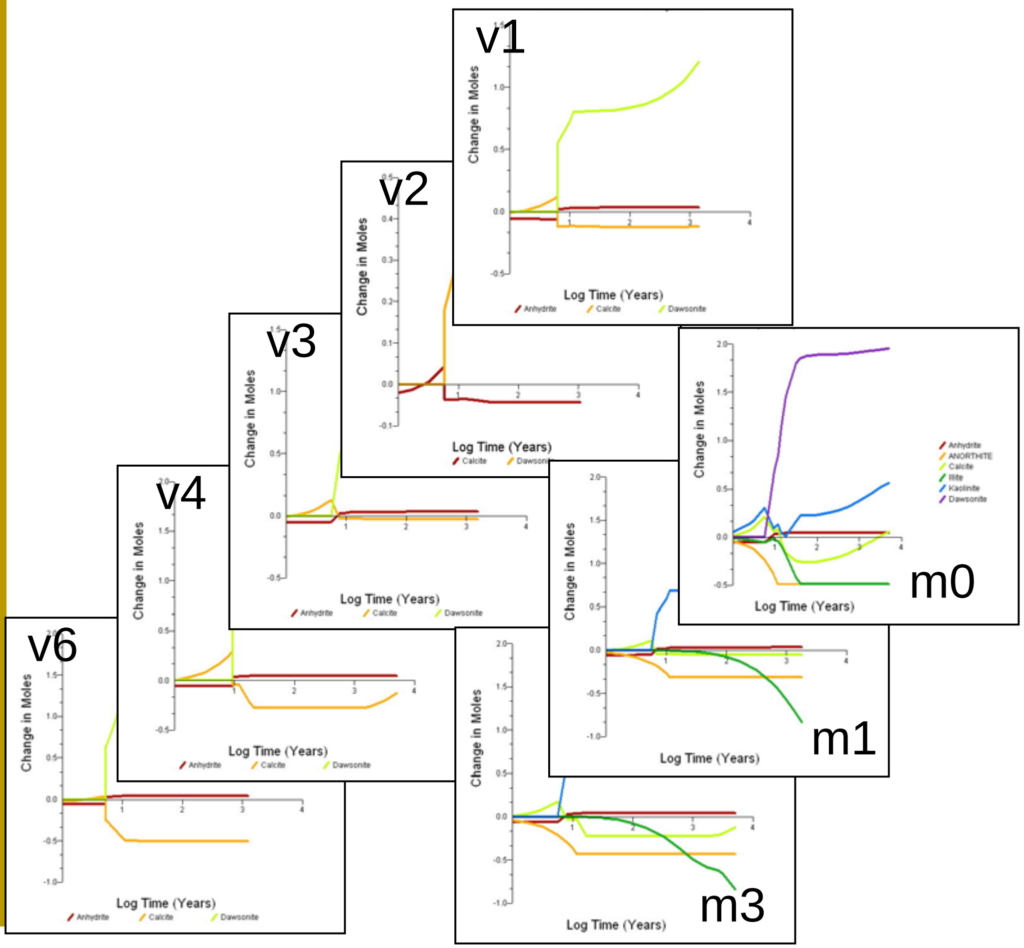
Pattern 1 (P1612614) - SSWG

Conformance Control

Additional CO_2 Storage

- Single gel treatment
  - Treated a total pore volume of 80,000 m^3
  - Gel placement limited to fractures ~1% PV
  - Treatment size 1,000 m^3 of gel
  - Cost of gel treatment C$200,000 to C$500,000
  - Incremental oil recovery 20,000 m^3 (10% increase in oil recovery without treatment)
  - An additional 28,000 tonnes of CO_2 can be stored
- Extend over the entire 75 EOR patterns
  - Assume only 20% of the patterns undergo treatments
  - An additional 1.83 MT of CO_2 can be stored

Geochemical Modelling



Shown here are the change in amount for solids due to reactions in each of the major flow units in Weyburn reservoir. There is analogous information for the changes in water chemistry.

From these, the change in carbon storage can be calculated for each flow unit.

Geochemical Modelling

Preliminary Estimation

	Trapping Capacity in Weyburn Reservoir (After 5,000 years)			
	Solubility ($MT\ CO_2$)	Ionic ($MT\ CO_2$)	Mineral ($MT\ CO_2$)	% Mineral Trapping
All Flow Units	22.65	0.2572	22.25	49%
Total	45.15			

Critical Assumptions:

- There is sufficient supercritical CO_2 for reaction in each of the flow units
- Complete/significant reaction of silicate minerals will occur over 5,000 years

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Storage Economic Model

Assumptions

(Alternative Storage Case III)

- Initial capital expenditures (capex) in year 2033 (Start of CO_2 storage) = C$67 millions
  - C$47 millions for well refurbishment costs at 2033 ($0.25 million/well of 189 wells)
  - C$20 millions for compression costs
- Sustaining capex = C$7 millions/operating year
- Estimated CO_2 cost = C$29.85/tonne
- Oil price = C$30.14/bbl (US$22.61/bbl)

Storage Economic Model

Rate of Return

(Alternative Storage Case III)

Rate of Return given Credit for CO_2 stored (C$/tonne)														
Year of Post EOR	Credit for Stored CO_2 (C$/tonne)													Additional Post EOR CO_2 Storage (MT)
	$0	$5	$6	$7	$8	$9	$10	$12	$14	$16	$18	$20	$25	
20	< 0	< 0	< 0	< 0	11%	14%	16%	21%	25%	29%	32%	36%	45%	26.2
15	< 0	3%	7%	10%	12%	15%	17%	21%	25%	29%	32%	36%	45%	20.6
14	< 0	5%	8%	10%	13%	15%	17%	21%	25%	29%	32%	36%	45%	18.8
13	< 0	6%	8%	11%	13%	15%	17%	21%	25%	28%	32%	36%	45%	17.1
12	< 0	6%	9%	11%	13%	15%	17%	21%	25%	28%	32%	36%	45%	15.3
11	< 0	7%	9%	11%	13%	15%	17%	21%	24%	28%	32%	36%	45%	14.1
10	< 0	6%	9%	11%	12%	14%	16%	20%	24%	28%	31%	35%	45%	12.9
9	< 0	6%	8%	10%	12%	14%	16%	19%	23%	27%	31%	35%	44%	11.2
8	< 0	4%	6%	8%	10%	12%	14%	18%	22%	26%	30%	33%	43%	9.5
7	< 0	2%	4%	6%	8%	10%	12%	16%	20%	24%	28%	32%	42%	7.8
6	< 0	< 0	< 0	1%	3%	5%	8%	12%	16%	20%	24%	29%	39%	7.1
5	< 0	< 0	< 0	< 0	< 0	< 0	< 0	4%	9%	13%	18%	23%	34%	6.4

Summary

This study demonstrated that:

- maximum CO_2 storage capacity that can be achieved physically and economically at a geological storage site can be estimated
- CO_2 distribution and trapping mechanisms within the storage site can be predicted
- CO_2 storage performance can be improved through the application of conformance control treatments