Reserve booking guidelines for CO2 Floods

A practical approach from a reserve auditor

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11th Annual CO_2 Flooding Conference
Midland, Texas
December 7-8, 2005
www.spe-pb.org

DISCLAIMER:

- The information presented herein represents informed opinions about U.S. SEC reserves reporting regulations but does not purport to be identical to advice or rulings that may be obtained from the SEC.

- The SEC interprets each case individually & may alter interpretations based on facts particular to each case.

Agenda

1. SEC Proved Reserve Definitions
2. SPE/WPC Probable Definitions
3. SEC vs. SPE/WPC Reserve Definitions
4. Use of Analogies
5. Other Considerations

SEC Reserve Definitions

- SEC regulations applicable to oil and gas:
  - Regulation S-X, 210.4-10
    - Defines oil and gas producing activities
    - Defines proved oil and gas reserves
  - Guidelines to Regulation S-X, 210.4-10
    - Accounting Series Release No. 257 – Topic 12
    - March 2001 – Interpretations and Guidance
- Other regulations
  - Federal Accounting Standard Board (FASB)
    - FASB #69 reserves <u>reporting</u> guidelines

SEC Reserve Definitions

- **Proved reserves only**

- Approved in 1978

- Applications Modified in part by
  - Staff Accounting Bulletins
  - Web site releases
  - Letters to operators
  - SEC-SPEE Forums

SEC Reserve Definitions

SEC 1978 –Current Definition *(Rule 4.10 Regulation S-X)*

Proved oil and gas reserves are:

- **the estimated quantities of crude oil, natural gas, and natural gas liquids, which**
- **geological and engineering data demonstrate with reasonable certainty**
- **to be recoverable in future years**
- **from known reservoirs**
- **under existing economic and operating conditions;**
- **i.e., prices and costs as of the date the estimate is made.**

SEC Reserve Definitions

SEC 1978 –Current Definition -continued

- **Reservoirs which can be produced economically through application of improved recovery techniques (such as fluid injection) are included in the “proved” classification when:**
  - **successful testing by a pilot project, or**
  - **the operation of an installed program in the reservoir provides support for engineering analysis on which the project or program was based.**

SEC Reserve Definitions

SEC 1978 –Current Definition -continued

- **Proved Developed Reserves:**
  - Those reserves that can be **expected to be recovered** through **existing wells** with **existing equipment** and operating methods.
  - Additional oil and gas expected to be obtained through the application of fluid injection or other improved recovery techniques for supplementing the natural forces and mechanisms of primary recovery should be included as "Proved Developed Reserves" only after **testing by a pilot project** or after the operation of an installed program has **confirmed** through **production response** that increased recovery will be achieved.
  - Expansion of an improved recovery operation is still **undeveloped**
- **Proved Undeveloped Reserves (PUD's):**
  - Under no circumstances should estimates for proved undeveloped reserves be attributable to any acreage for which an application of fluid injection or other improved recovery technique is contemplated, unless such techniques have been proved effective by actual tests in the area and in the same reservoir.

SEC Reserve Definitions

- Improved recovery
  - Reserves cannot be classified as proved undeveloped reserves based on improved recovery techniques **until**
  - **such time that they have been proved effective in that reservoir or an analogous reservoir in `the same geologic formation in the immediate area.**
  - **An analogous reservoir is one having at least the same values or better for porosity, permeability, permeability distribution, thickness, continuity, fluid properties, and hydrocarbon saturations.**

SEC Reserve Definitions

The SEC guidelines state "the intent of the definition of proved reserves is interpreted as estimates that are more likely to result in a positive revision than a negative revision" (a deliberate low estimate, which is a probabilistic bias).

Best use of all available engineering, geological, and geophysical data, good engineering judgment, and use of analogous reservoirs should be used to estimate the recovery efficiencies and other engineering parameters involved in the estimation of reserves for investment purposes to establish a compelling case that influences the SEC acceptance for booking of proved reserves.

The ultimate test of reasonable certainty is reservoir performance.

SEE Reserve Definitions

- **Does this mean we will always have to "low-ball" our proved SEC estimates?**

- No, It means we need to do the **best possible technical analysis**, **document our estimates**, and conform to the SEC regulations while presenting a compelling case to defend our estimates.

- The documentation must be kept for audit purposes

SEC – “reasonable certainty”

Reasonable Certainty Requirements for SEC Defense

1. Generated by supporting geological and engineering data.

2. Validation of assumptions are necessary.

3. Where supporting data is scarce and validation difficult, a conservative approach must be used until this data is available.

4. Concept - with validation, reserves should increase rather than decrease.

5. Analogy – Criteria for analogies should be equal to or better than referenced reservoirs used as analogies.

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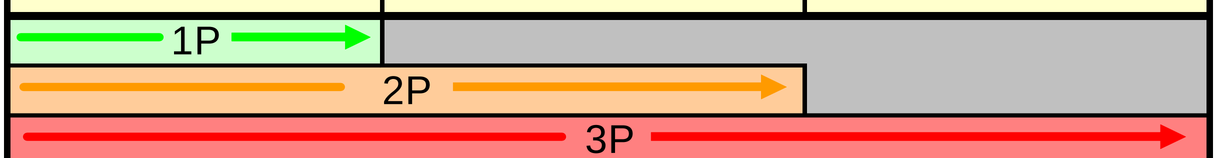
SPE/WPC Reserve Definitions

- **SEC**
  - Securities & Exchange Commission (SEC)
- **SPE/WPC**
  - Society of Petroleum Engineers (SPE)
  - World Petroleum Congress (WPC)

Proved Reserves	Probable Reserves	Possible Reserves
SEC SPE/WPC	- SPE/WPC	- SPE/WPC



SPE/WPC Reserve Definitions

Probable Reserves

- **Probable reserves are reserve estimates in known reservoirs which cannot yet be considered reasonably proved on the basis of current geologic and engineering information.**

This is an industry definition. Not recognized by SEC

Comment

These volumes are expected to become proved as additional information becomes available, and it is important to be able to define the event which will allow the reserves to become proved.

SPE/WPC Reserve Definitions - Probable

- Typical Examples

  - Down-spacing with questionable drainage patterns
  - Market, contract limitations
  - Enhanced recovery without successful testing
  - Certain step-out development wells
  - Work-over treatments without analogies
  - Alternative performance interpretation

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Purpose of Analogies

- Apply knowledge gained from analogous and mature reservoirs or recovery processes to estimate the performance in target reservoir

- Mostly relied on early during the field life when no definitive performance and/or geologic data is available

- Also important when new recovery mechanism or enhancements are introduced to a field (e.g. waterflood, CO2 flood)

Proof of Analogy

- Establish proof that target or new reservoir is analogous to other more mature reservoir

- Rock and fluid properties of the target reservoir need to be equal to or more favorable than the analogous reservoir properties in order to qualify for proven reserves

- Target and Analogy Reservoir must be within reasonable proximity

Establish the Analogy

- Procedure
  - Establish the existence of an analogous and mature reservoir or recovery process
  - Compare multiple parameters
  - Study performance and operations of analogous reservoir(s) or recovery processes
  - Apply study findings to estimate the recovery from the new reservoir

Establish the Analogy

- Geologic analogy requirements:
  - Structural configuration
  - Lithology
  - Deposition Model
  - Age and Depth of Rock
  - Reservoir Continuity
  - Average net thickness and net-to-gross
  - Configuration and Size Ratios of Gas, Oil, Water Columns

Establish the Analogy

– Petrophysical analogy requirements:

- Water saturation (Sw)
- Permeability (k)
- Porosity
- Rock Wettability

Establish the Analogy

- Reservoir Parameter Analogy Requirements:
  - – BHP & BHT or gradients
  - – Fluid properties (PVT)
  - – Expected Drive Mechanism
  - – Fluid Distribution in Reservoir
    - Wedge zones
    - Thickness of gas, oil, water zones
  - – Reservoir maturity
    - Infill Drilling or Spacing Maturity

Establish the Analogy

- Operational analogy requirements:
  - Well spacing
  - Natural or Artificial Lift Methods
  - Completion & Stimulation Methods & Designs
  - Well Design (vertical or horizontal)
  - Pattern spacing, configuration, and orientation
  - Injector to producer ratio
  - Annual injection volumes
  - Fluid handling capacity
  - Displacement pressures for EOR methods
  - Injection fluid and treatment (solids and corrosion control)

SEC Hot-Button Topics - Analogies

– List of critical parameters for comprehensive review

Geoscience	Engineering	Operational
Structural configuration	Pressure and temperature	Well spacing
Lithology and stratigraphy	Fluid properties	Artificial lift methods
Principal heterogeneities	Recovery mechanism	Pattern type and spacing
Reservoir continuity	Fluid mobilities	Injector to producer ratio
Average net thickness	Fluid distribution	Annual injection volumes
Water saturation	Reservoir maturity	Fluid handling capacity
Permeability	Well productivity	Stimulation design
Porosity	EOR specifications	Areal proximity
Areal proximity	Areal proximity	

Example Parameters for Analogy Comparison

PROPERTY	RESERVOIR	START DATE OF CO_2 INJECTION	OOIP (UNIT) STB	OOIP (CO_2 AREA) STB	Boi RB/ STB	Bo RB/ STB	Pressure (Initial/Final) PSI	Temp F	B_{co2} (RB/MCF)	API º Gravity	Swi	Sor
CORDONA LAKE UNIT	Devonian	Dec-85	71,500,000	71,500,000	1.413	1.310	2635 / 1400	101	0.500	41.2	0.400	0.250
DENVER UNIT	San Andres	Apr-83	2,062,000,000	2,062,000,000	1.312	1.234	1805 / 2200	105	0.430	33.0	0.150	0.400
DOLLARHIDE DEVONIAN UNIT	Devonian	Jun-85	145,800,000	145,800,000	1.656	1.350	3300 / 3200	122	0.417	39.0	0.276	0.250
EAST MALLET UNIT	San Andres	Aug-89	98,500,000	98,500,000	1.229	1.150	1710 / 1800	107	0.465	32.0	0.250	0.400
EL MAR DELAWARE UNIT	Delaware	Mar-94	71,650,000	71,650,000	1.347	1.171	2151 / 1200	97	0.650	40.5	0.446	0.3315
FORD GERALDINE UNIT	Delaware	Mar-81	98,000,000	98,000,000	1.278	1.100	1412 / 1445	83	0.410	42.0	0.470	0.350
NORTH WARD ESTES	Yates	Feb-89	NA	146,350,000	1.200	1.100	1400 / 1500	83	0.390	35.0	0.500	0.250
ODC UNIT	San Andres	Oct-84	654,598,000	583,600,000	1.312	1.119	1805 / 2100	110	0.450	32.0	0.215	0.400
SABLE SAN ANDRES UNIT	San Andres	Mar-84	25,700,000	25,700,000	1.200	1.200	1550 / 2200	107	0.433	32.0	0.290	0.400
SALT CREEK UNIT	Canyon	Oct-93	704,000,000	704,000,000	1.237	1.297	2940 / 2500	125	0.450	39.2	0.112	0.350
SEMINOLE SAN ANDRES UNIT	San Andres	Mar-83	1,150,000,000	1,002,000,000	1.390	1.290	2020 / 2700	104	0.410	33.0	0.160	0.400
SLAUGHTER ESTATE UNIT	San Andres	Jan-85	330,400,000	330,400,000	1.228	1.119	1710 / 1900	105	0.426	32.0	0.178	0.400
SUNDOWN SLAUGHTER UNIT	San Andres	Jan-94	440,000,000	272,800,000	1.229	1.145	1725 / 2000	105	0.440	31.4	0.230	0.400
WILLARD UNIT	San Andres	Jan-86	624,000,000	450,000,000	1.312	1.200	1805 / 2500	97	0.400	32.0	0.280	0.400

Location of CO2 Floods for Analogy

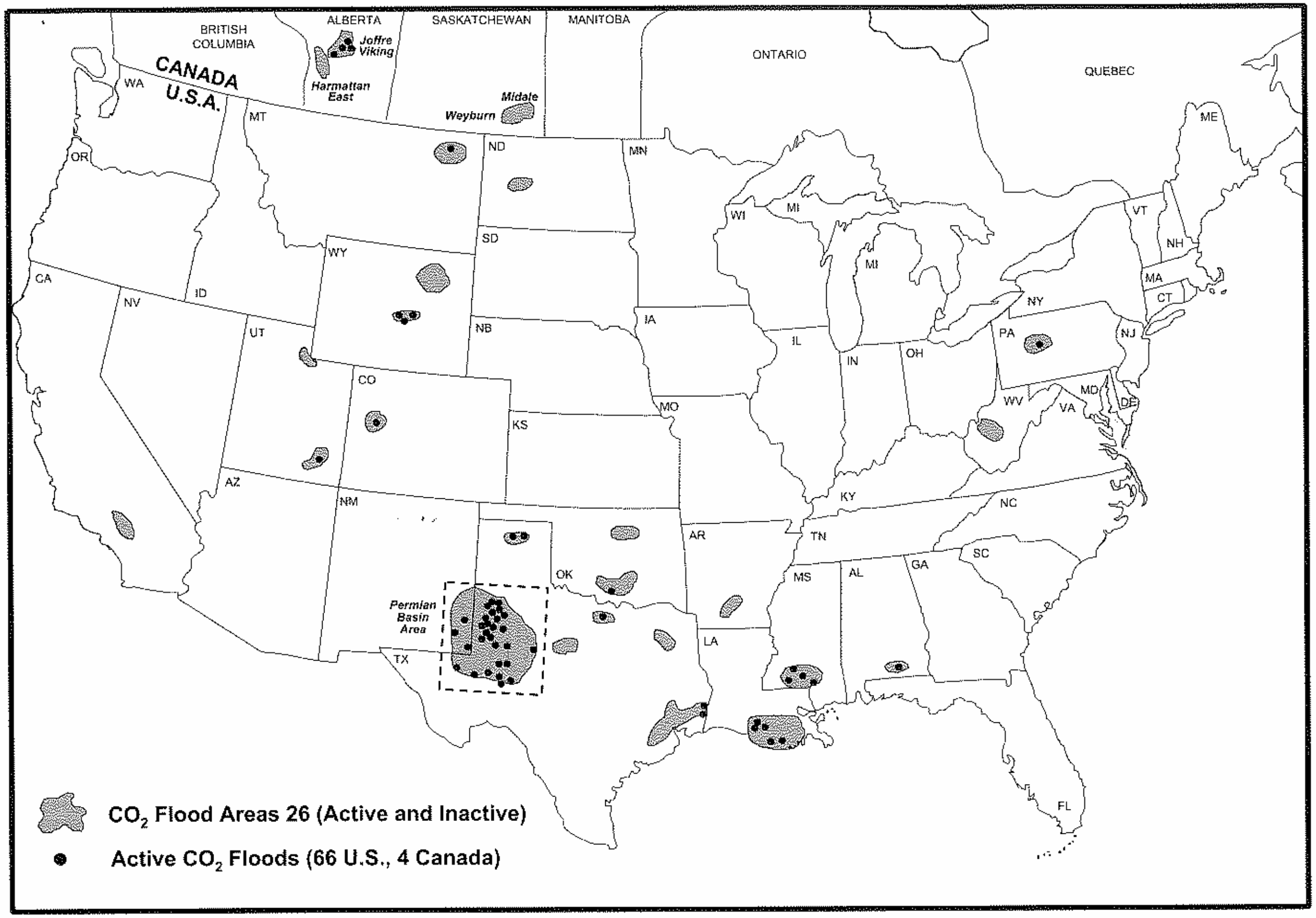
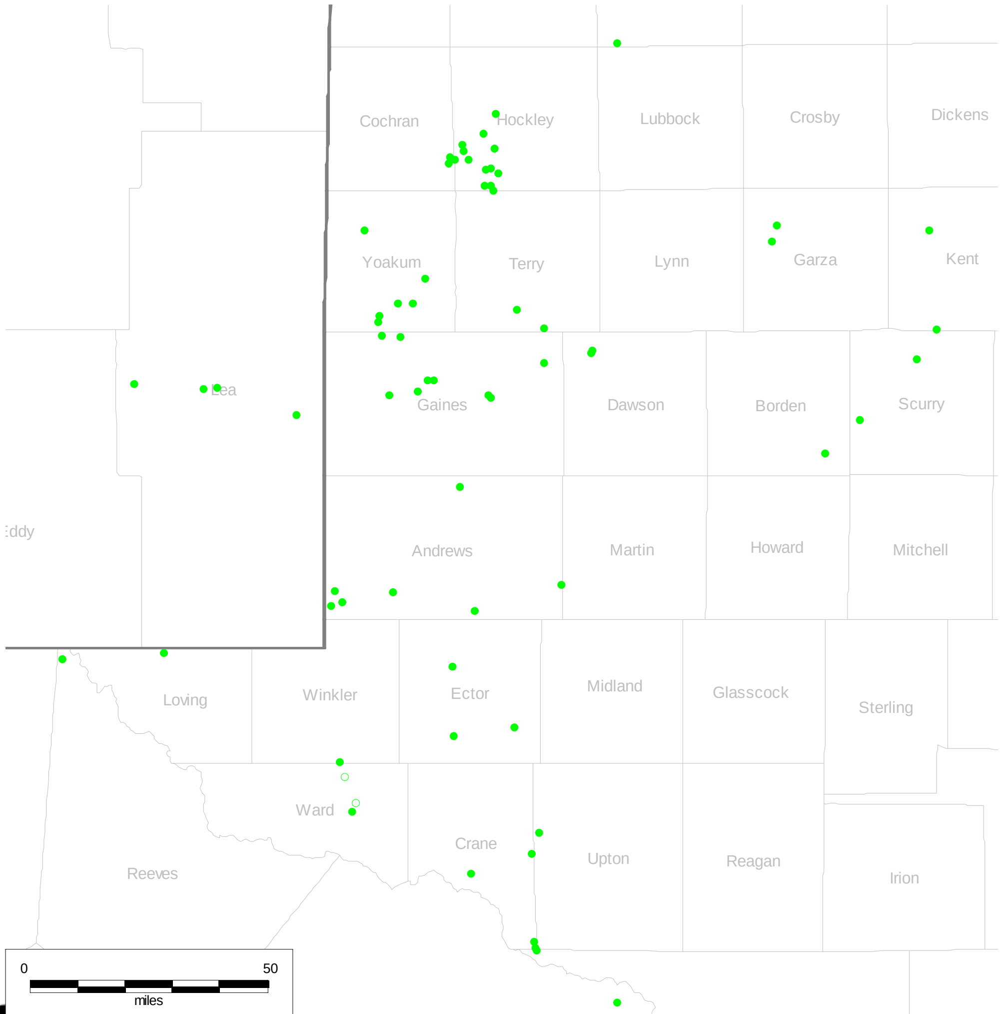
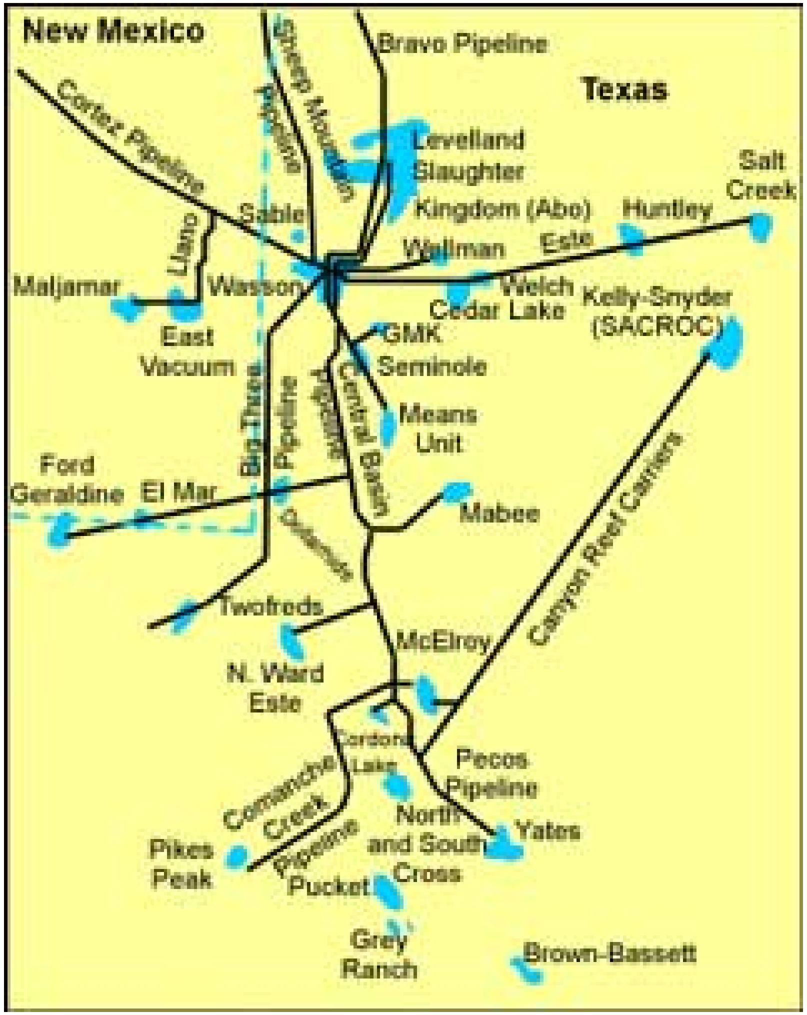


Fig. 1.7—Locations of all North American active and inactive CO_2 floods (1998). There are currently 66 active CO_2 floods in the U.S. and four active floods in Canada.

Location of CO2 Floods for Analogy – Permian Basin

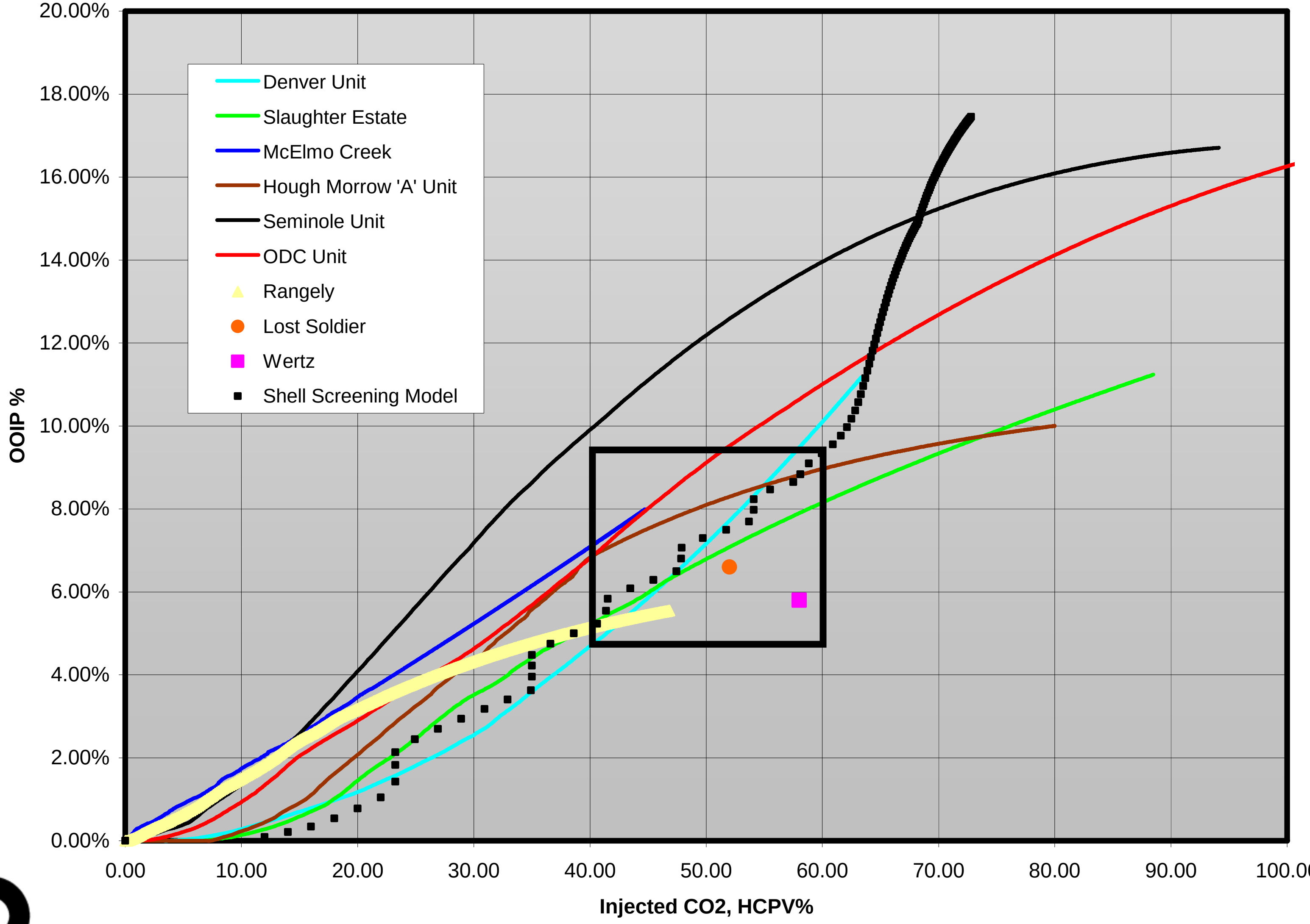




CO2 FLOOD RESERVE ESTIMATION AND PROJECTIONS USING ANALOGIES

- Determine “Dimensionless” EOR response to CO2 injection from analogous reservoirs on a Hydrocarbon Pore Volume (HCPV) basis.
  - Establish baseline waterflood forecast by month.
  - Subtract baseline WF from total oil production to determine EOR wedge.
  - Plot cumulative EOR (%OOIP) versus CO2 injection on HCPV basis (RB CO2/(OOIP*Boi))
- Scale results to the reservoir of interest on HCPV basis.

Incremental EOR Recovery vs Injected CO2



DATA NEEDED FOR ANALYSIS

- Need a good estimate of OOIP (STB) for both the analogy reservoir and the reservoir being studied.
- CO_2 Flood Area OOIP (STB)
- Initial Oil Formation Volume Factor – Boi (RB/STB)
- Current Oil Formation Volume Factor – Bo (RB/STB)
- Current Reservoir Temperature and Pressure (º F and psia)
- Carbon Dioxide Formation Volume Factor – Bco2 (RB/MCF)
- Initial and Residual Oil Saturation
- Historical production and injection rates

Sources of Data

- Operator of Analogy Reservoir
- Practical Aspects of CO2 Flooding – SPE 22
- UTPB CO2 Flooding Shortcourse
- SPE Papers
- State Regulatory Commissions or Department of Resources
- State web sites and IHS Energy for production and injection volumes

Determination of Baseline Waterflood

- Common Methods
  - Decline curve analysis
  - Water cut versus cumulative oil production
  - WOR versus cumulative oil production
  - All 3 methods can give different results

Determination of Baseline Waterflood

- Preferred Methods
  - Original Ershaghi (SPE 6977)
    - Kro/Krw = ae^{bSw} a and b are constants
    - $-\left[\ln\left(\frac{1}{f_w}-1\right)-\frac{1}{f_w}\right]$ versus cumulative oil.
  - Modified Ershaghi

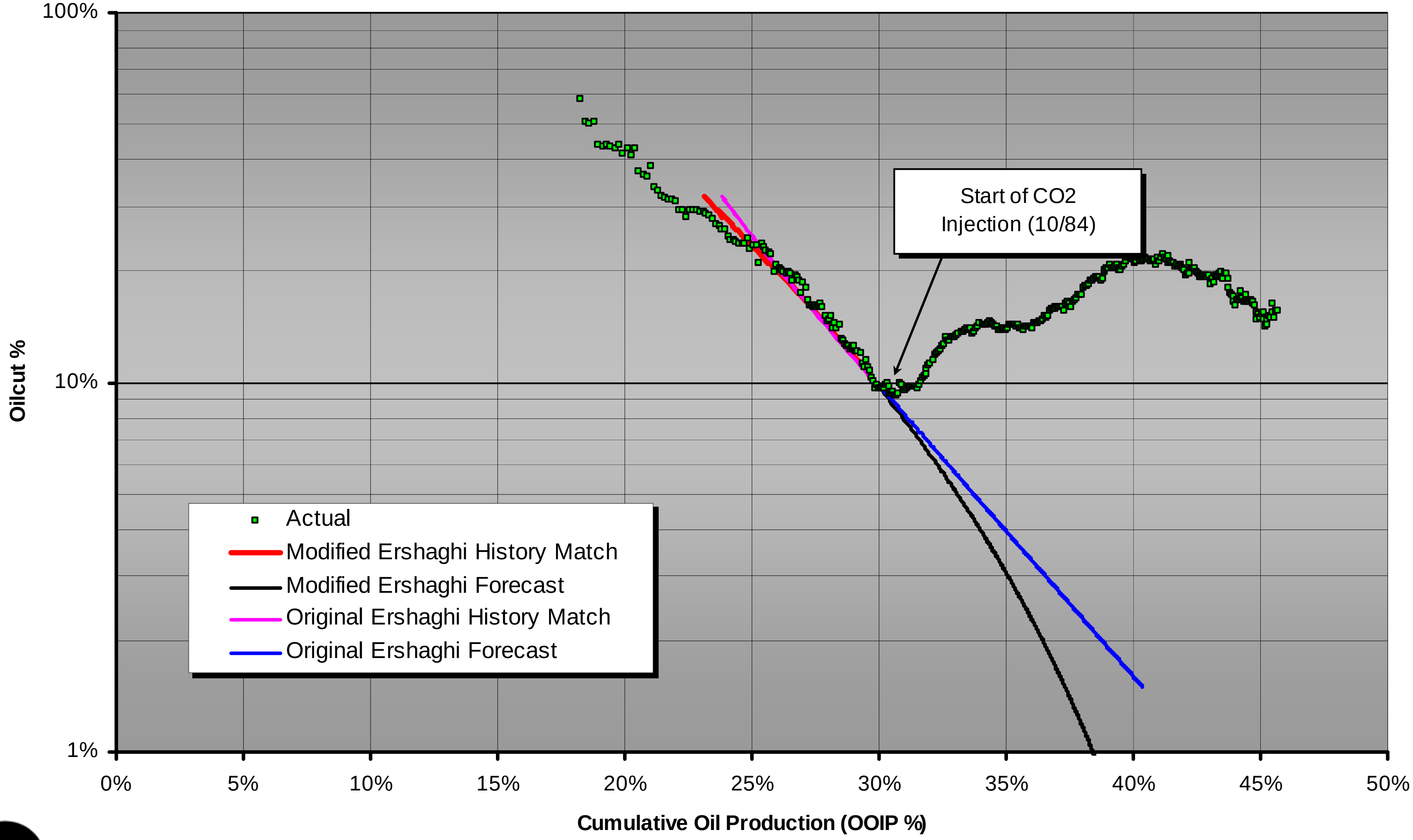
$$\frac{K_{ro}}{K_{rw}} = \frac{K_{rocw}(1-S)^m}{K_{wro}\ (S)^n} \qquad F_w = \frac{1}{1+\frac{(1-S)^m}{M(S)^n}}$$

  - Krocw = oil relative permeability at Swc
  - Kwro = water relative permeability at Sor
  - m = oil relative permeability exponent
  - n = water relative permeability exponent
  - S = $\frac{S_w - S_{wc}}{1-S_{or}-S_{wc}}$

Determination of Baseline Waterflood

- Fit parameters and constants to historical data
- Forecast total fluid production or RB voidage
- Trial and Error solution for oil production forecast
- Forecast tend to be hyperbolic

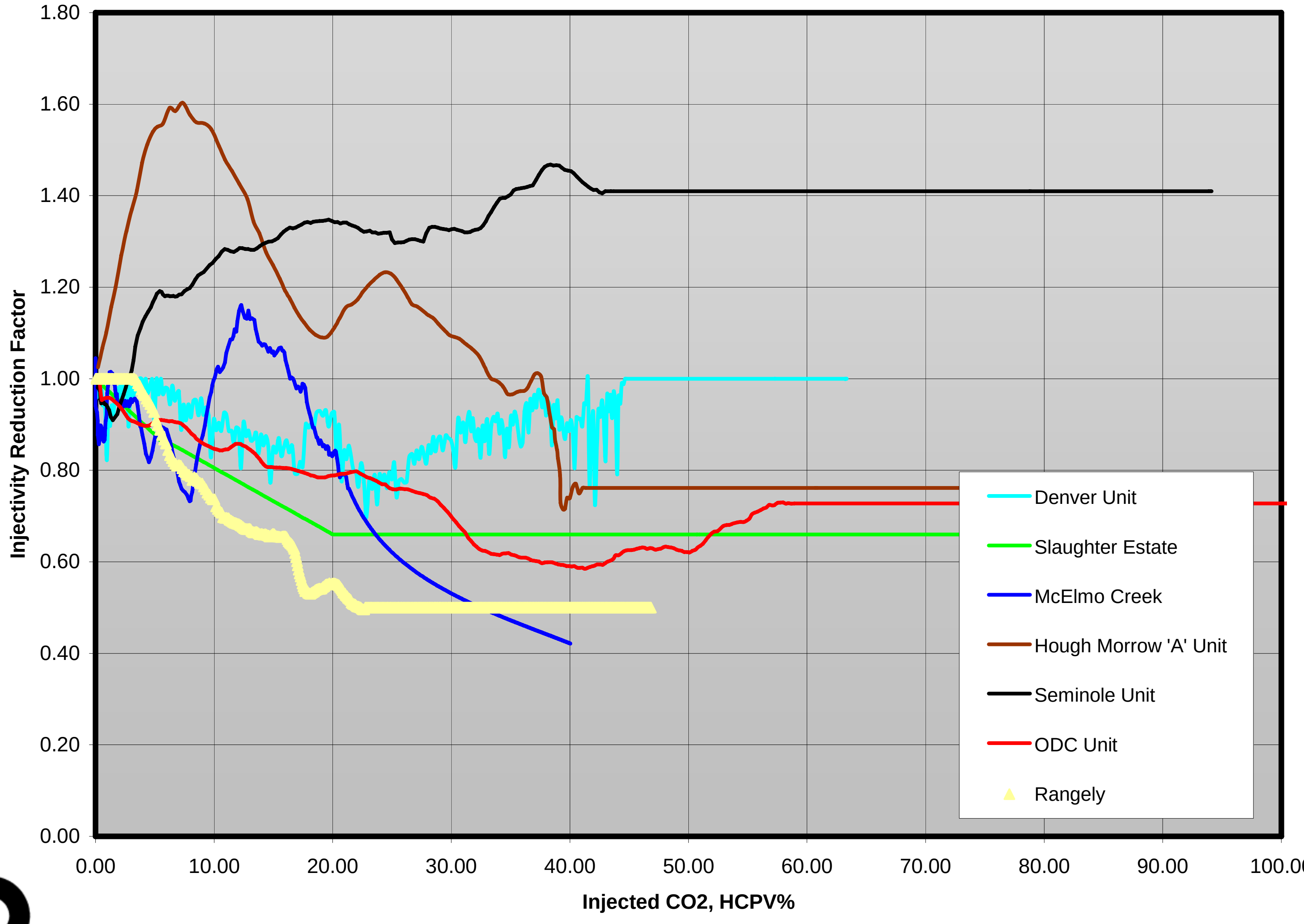
WASSON ODC UNIT



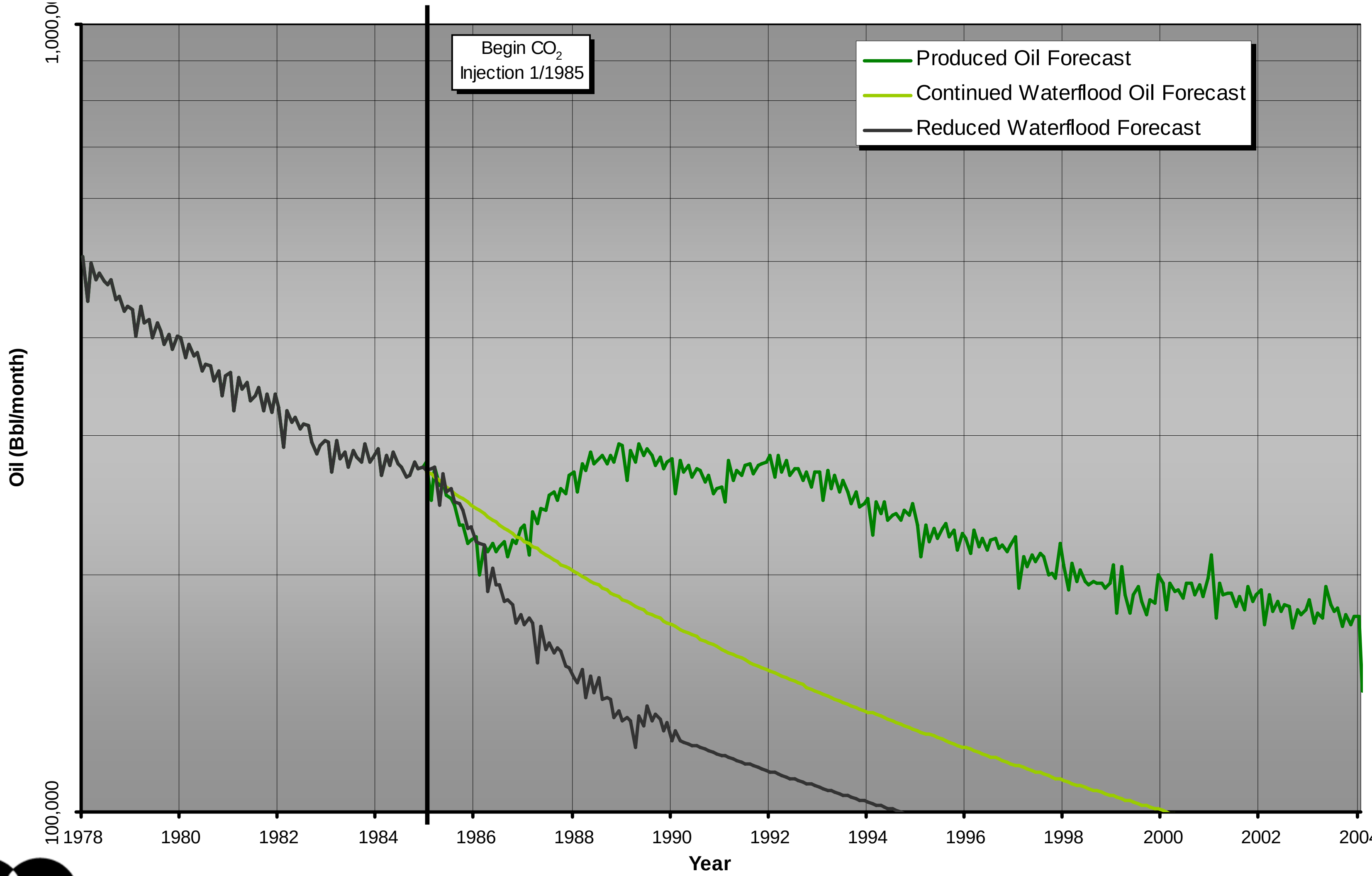
Injectivity/Voidage Reductions

- Reservoir Barrel per day rate after start of CO_2 flood compared to prior waterflood rate
- Reduction observed for most CO_2 floods studied
- Must be accounted for in CO_2 Flood Forecast and analysis

Injection/Voidage Reduction Factor vs CO2 HCPV Injection



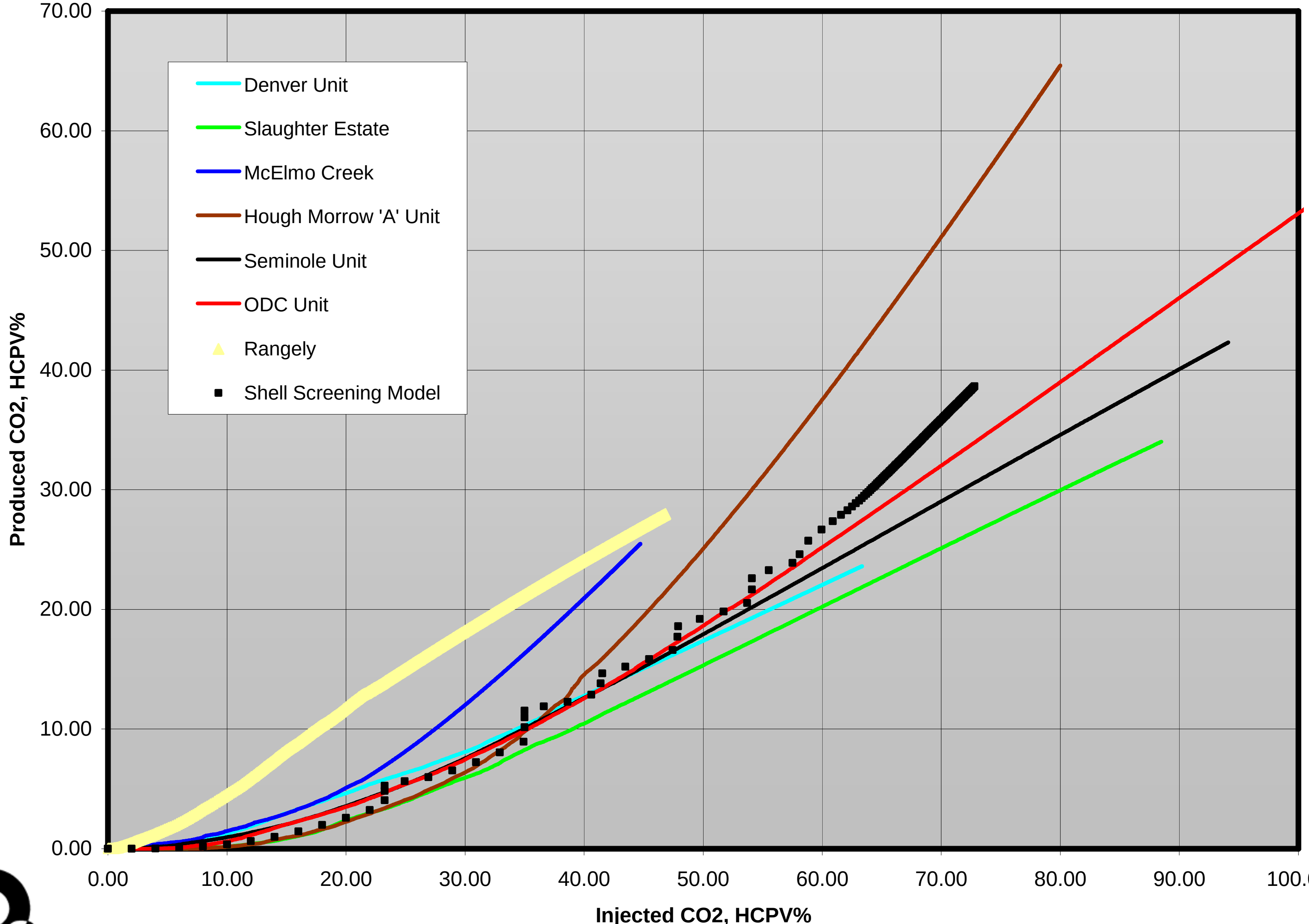
Slaughter Estate Unit
Effect of Voidage Reduction on Oil Forecast



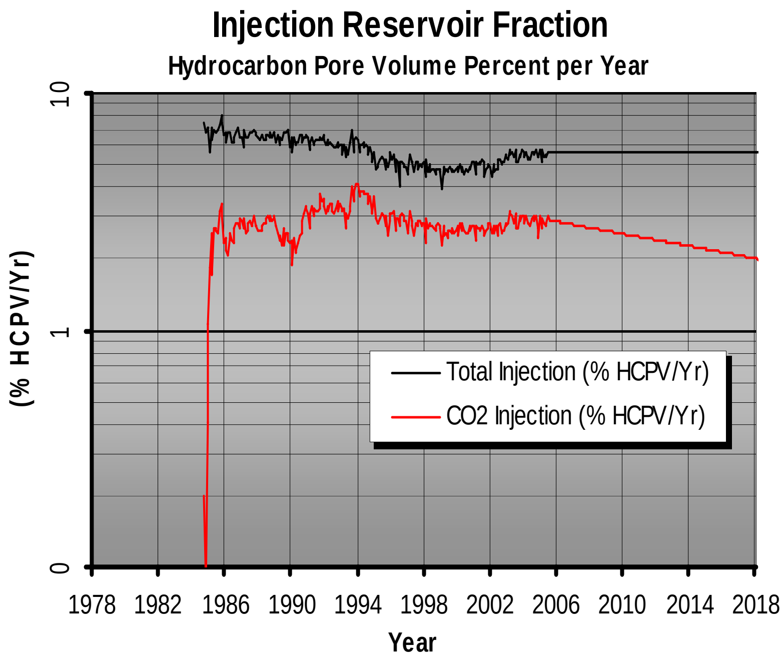
Other Streams Forecast

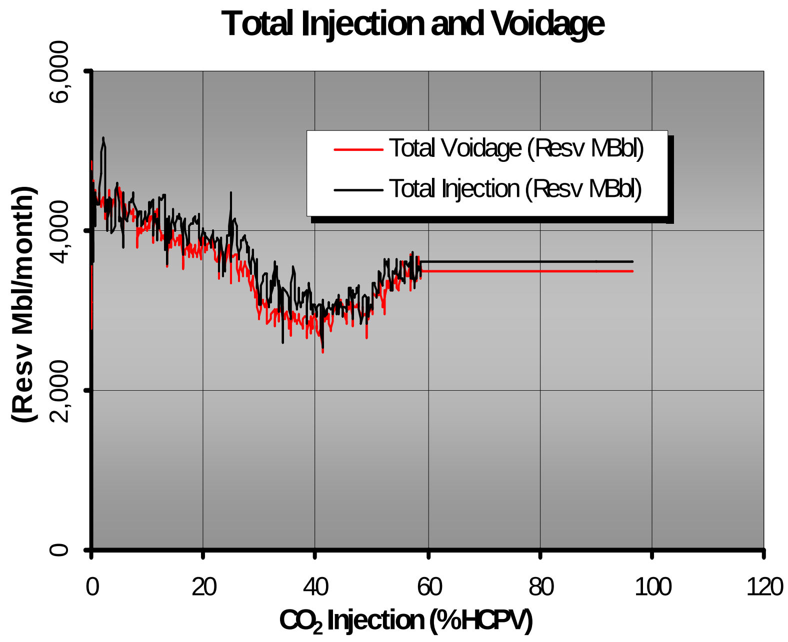
- Plot HCPV CO_2 Production vs HCPV CO_2 Injection trend to project CO_2 production
  - Best correlation observed
- Hydrocarbon Gas – Use Flat GOR
  - May increase over time
- Determine water production from Material Balance

HCPV CO2 Production vs HCPV CO2 Injection

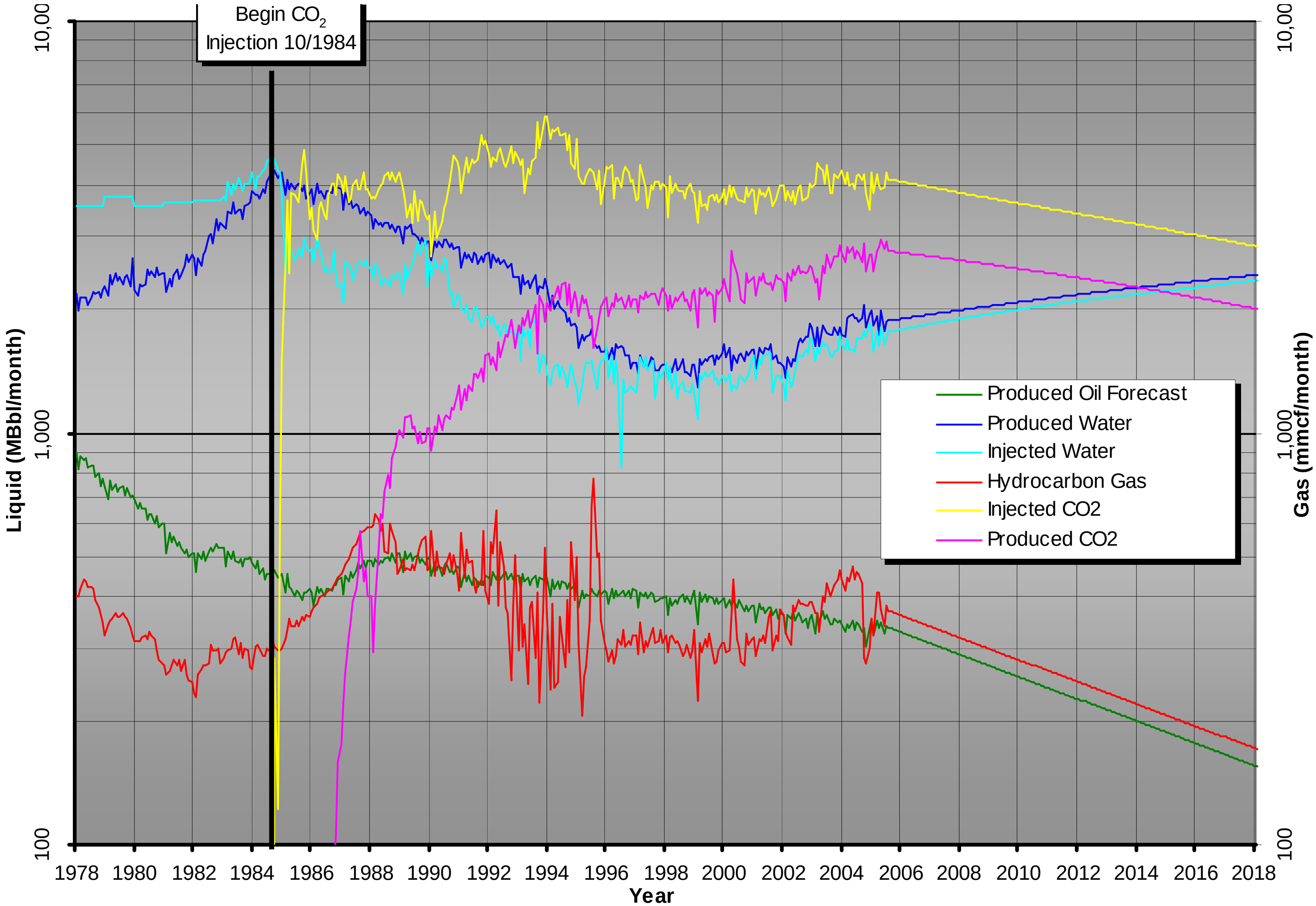


ODC Unit Injection and Voidage

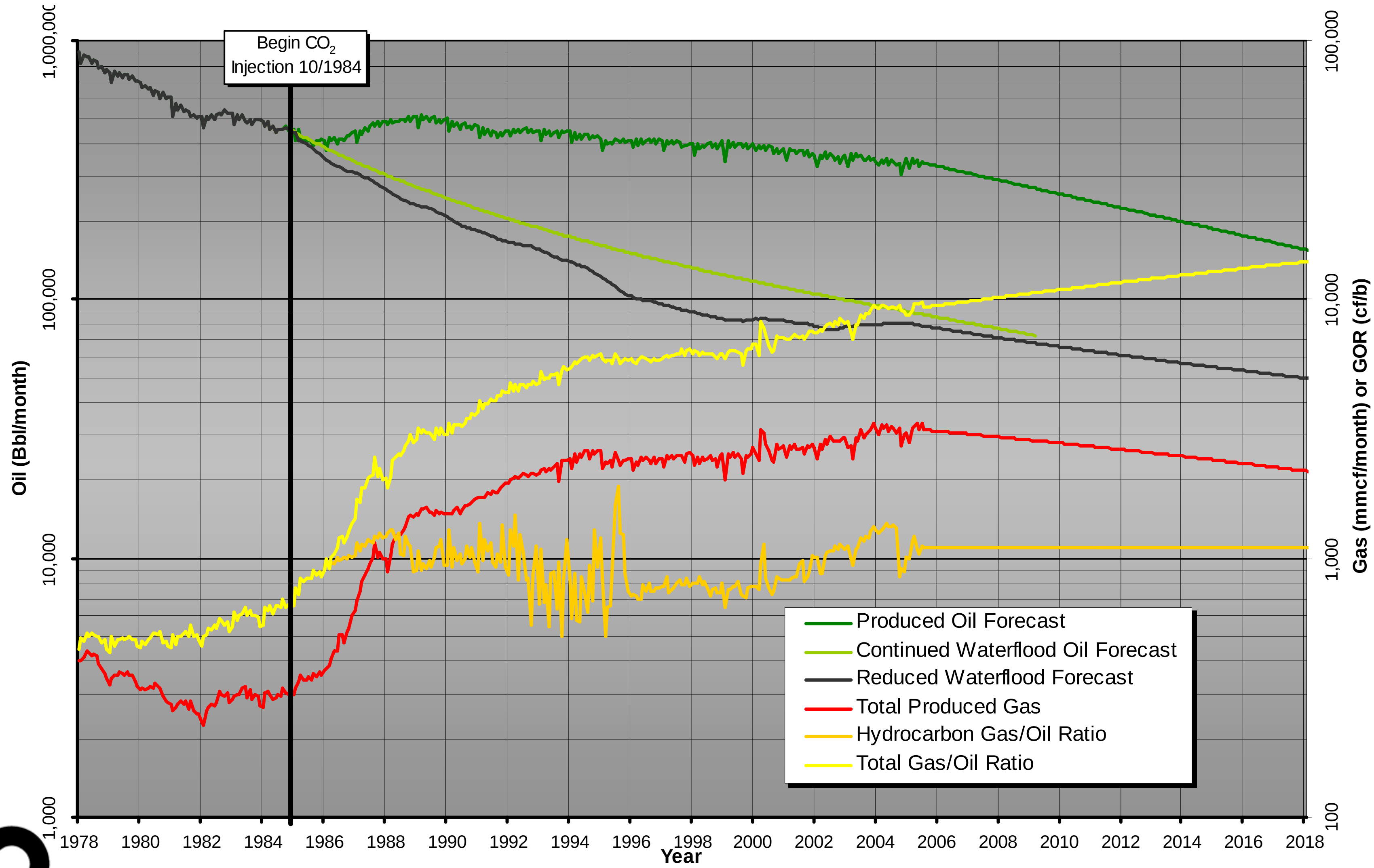




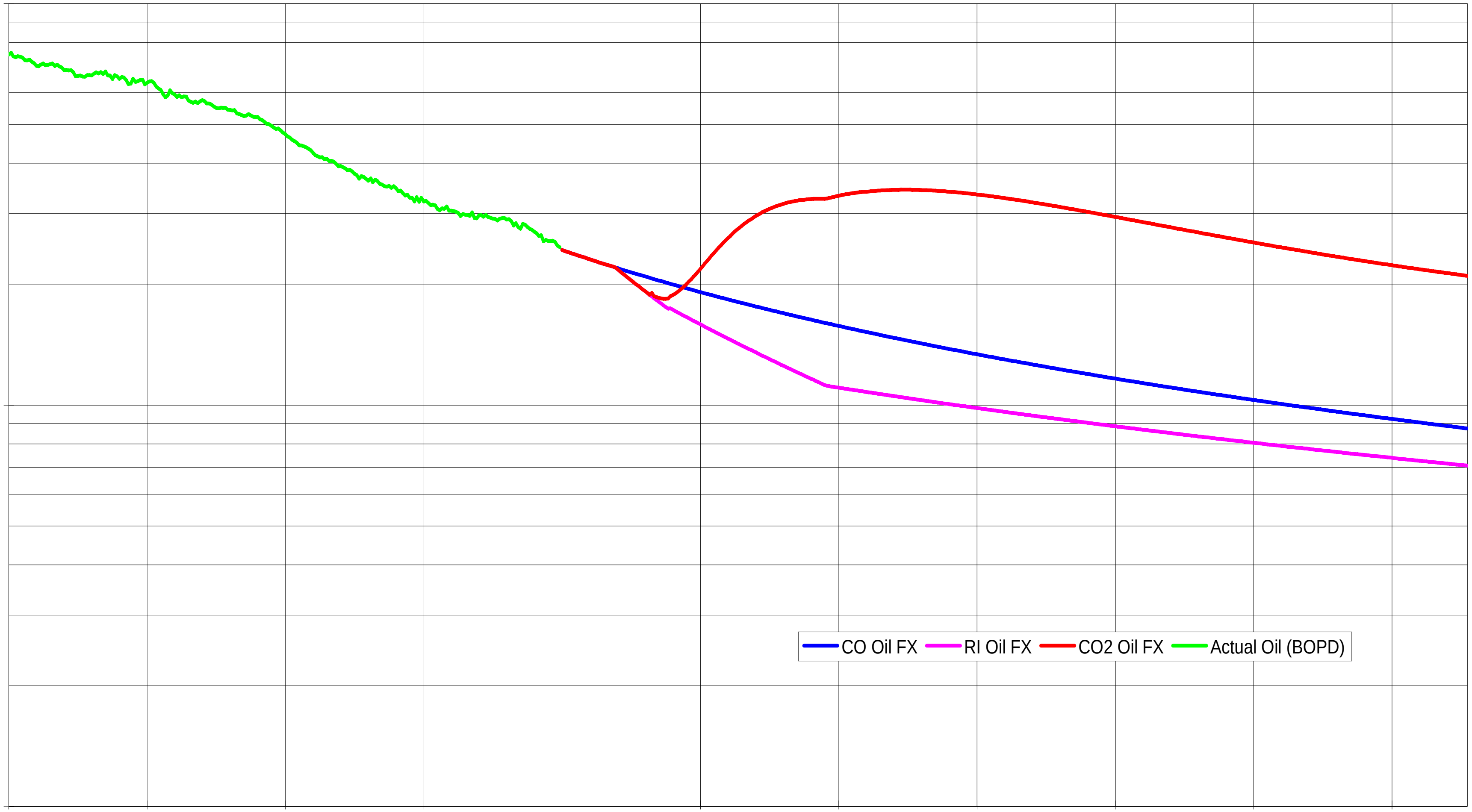
ODC Unit Production Forecast



ODC Unit Production Forecast



Sample Projection of Reservoir Under Consideration for CO2 Flooding



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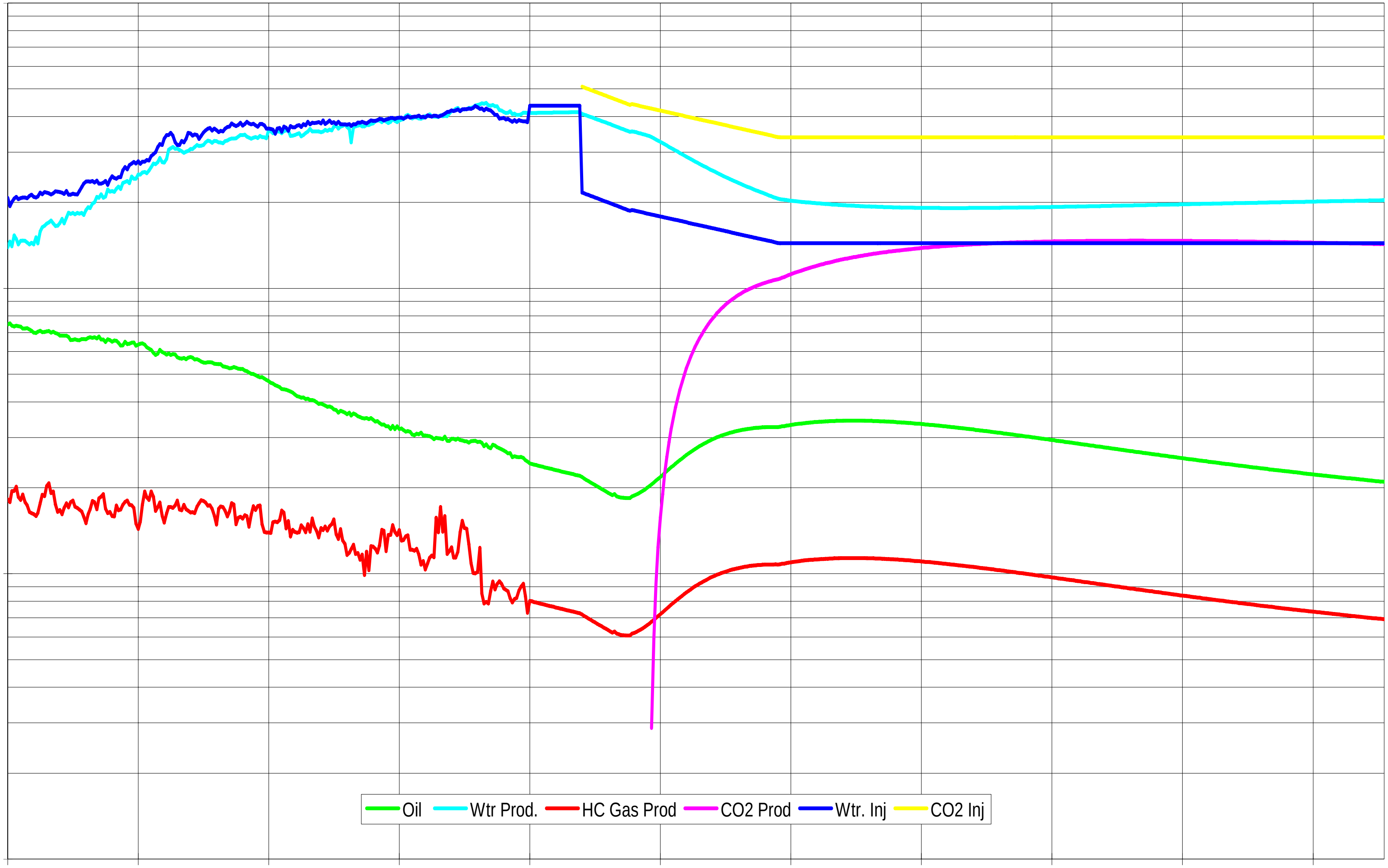

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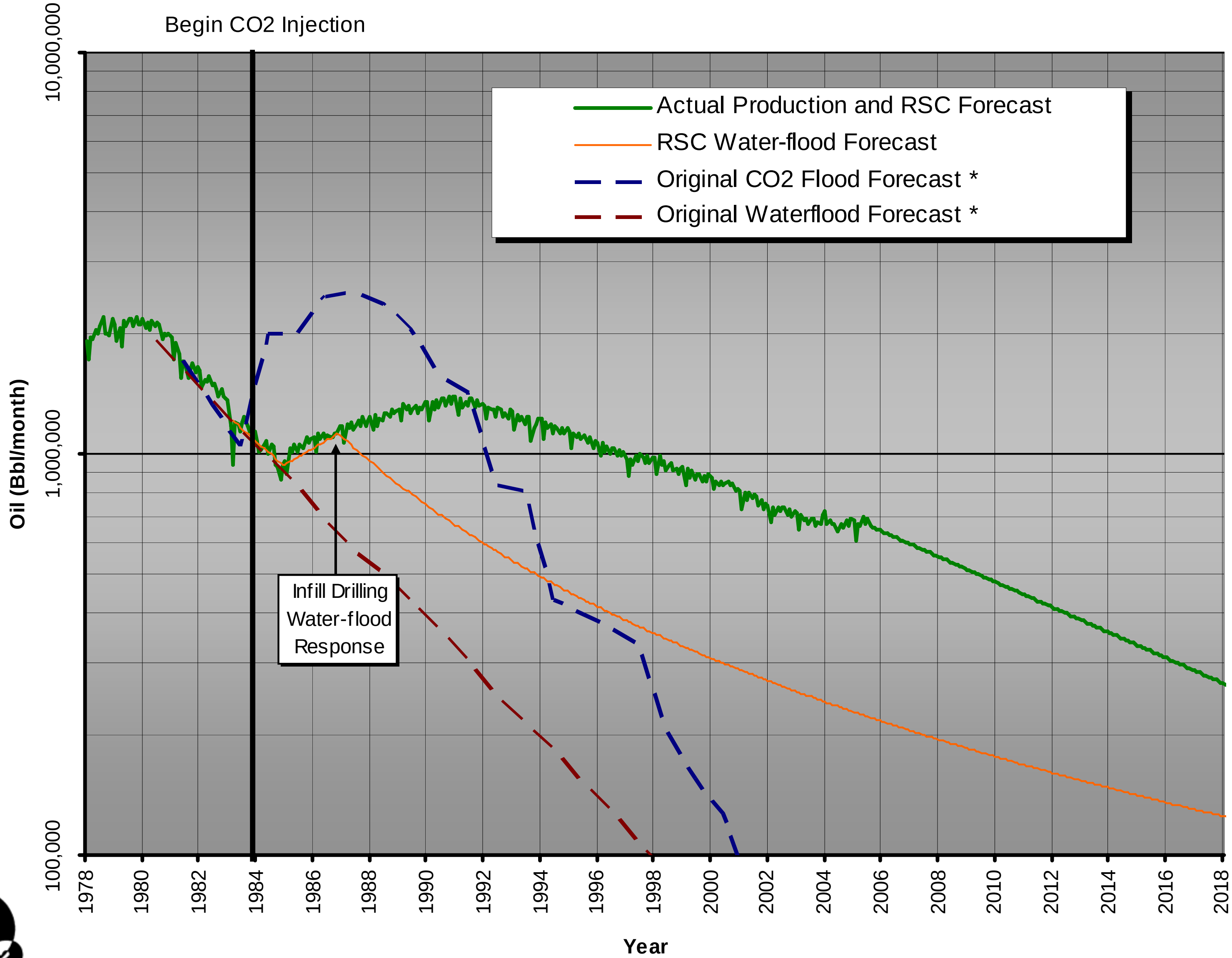
Uncertainties For CO_2 Flood EOR Reserve Determinations

- HCPV CO_2 Slug Size
- When and how much water to inject
- When to stop CO_2 Injection and what happens thereafter
- Injectivity Reductions
- May consider using simulation to define these, but keep in mind simulation tends to be optimistic.

Seminole Unit – Oil Production Forecast



Operating and Capital Cost Estimates

- Operating Cost
  - Best to be based on combination of $/B of total fluid produced, $/well fixed cost, and $/mcf of produced gas.
- Capital Cost
  - Should prepare AFE's based on forecasts, well spacing, and existing equipment.
- Guidelines shown in UTPB/Shell Manuels and Flanders (SPE 26391) for PB area.

Reserve booking guidelines for CO_2 Floods

QUESTIONS ?

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