

SPE's 29th Annual John "Jocko" Evans Symposium

Evaluating the Potential of Enhanced Oil Recovery (EOR) to Increase Oil Production in Montana

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What's The Problem?

Declining Oil Production

- Low oil production rates
- Can production be improved ?
 - EOR potential

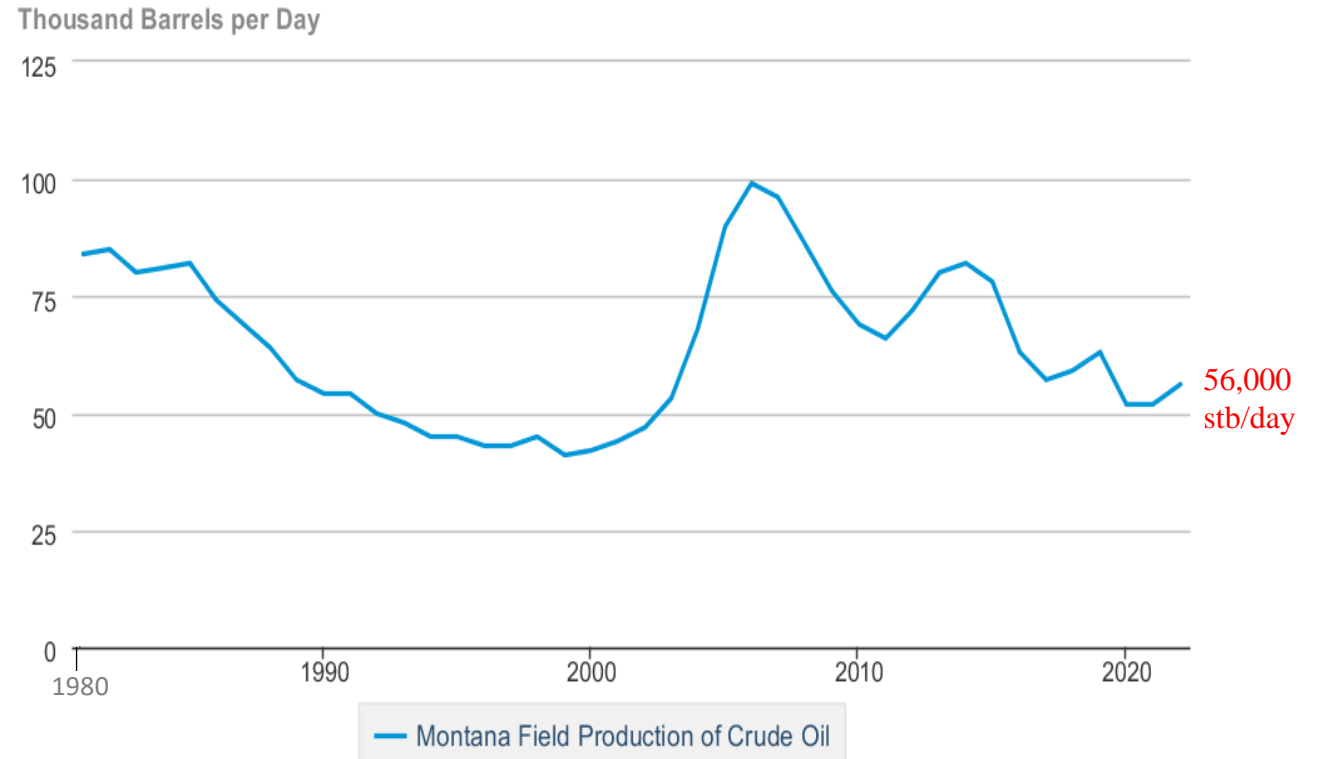
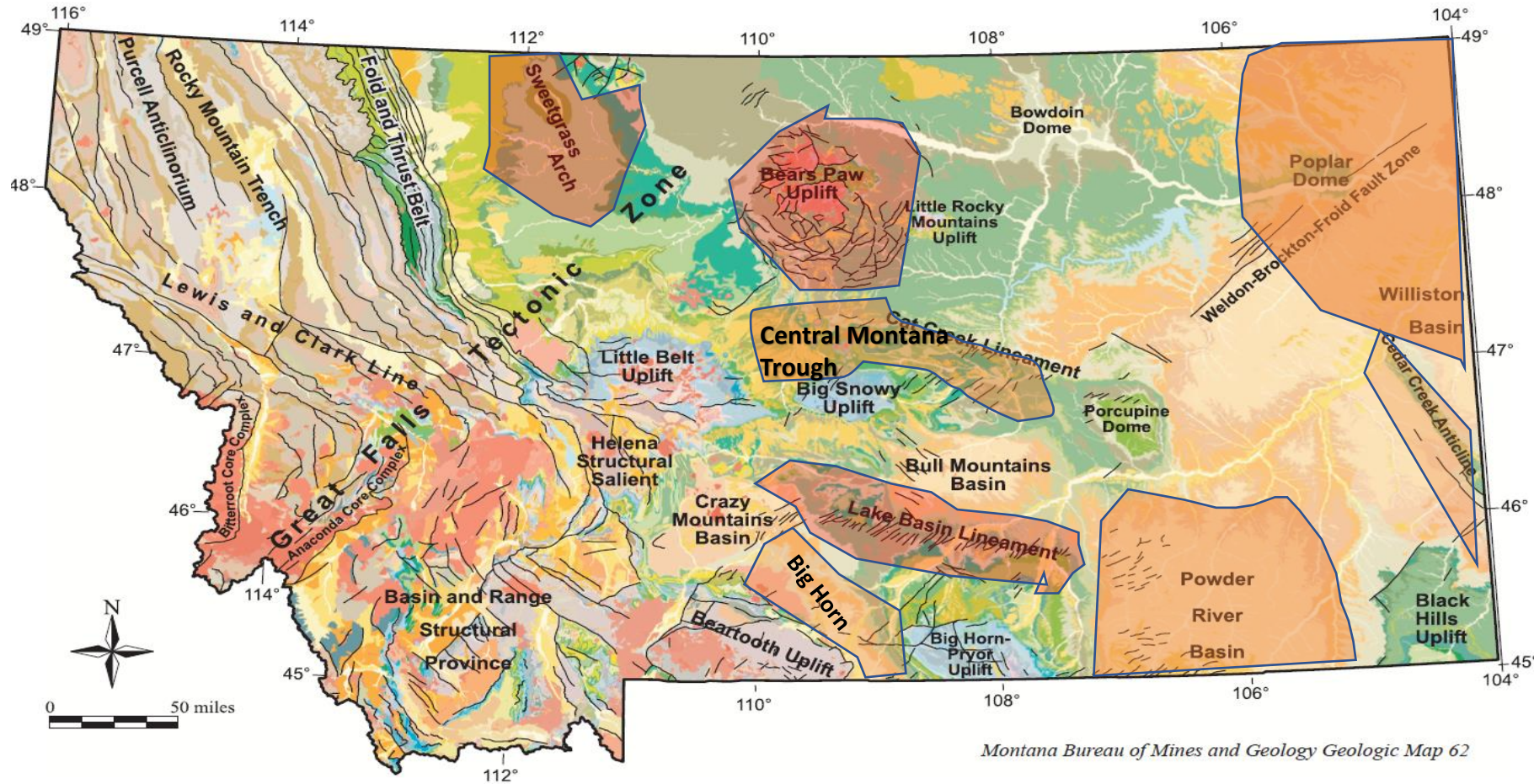


Figure 1: Montana Oil production 1980-2023
(EIA,2023)

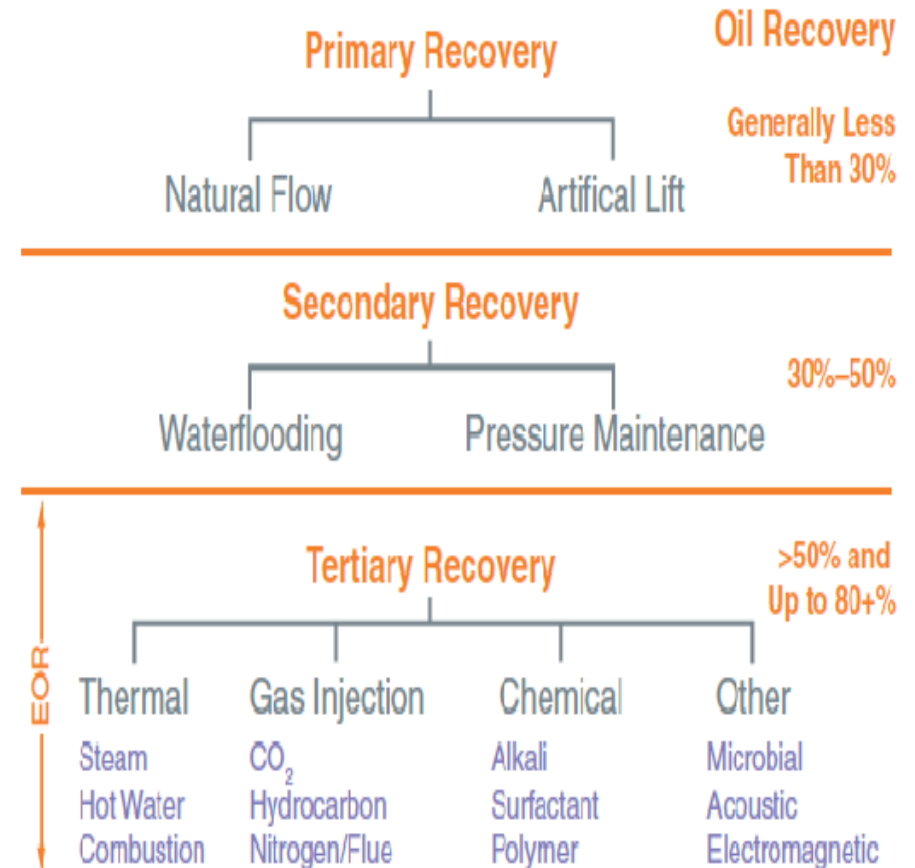
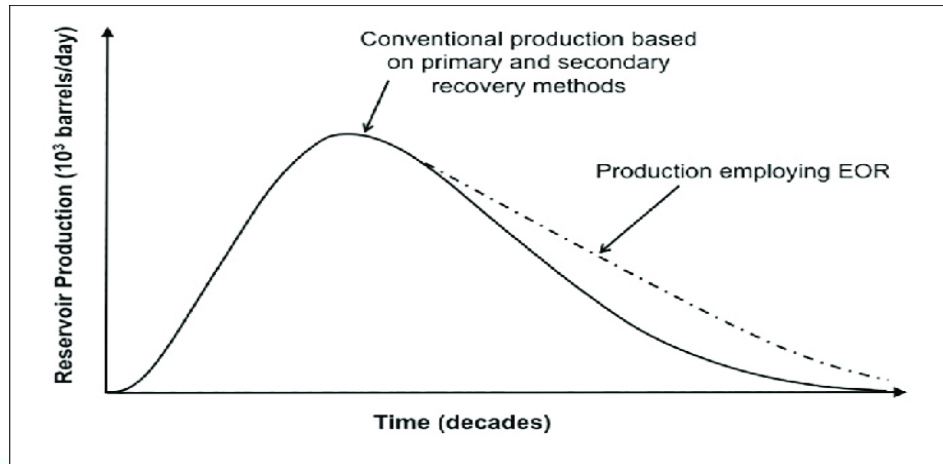
Where Are We Doing This?



About 350
oilfields known
across Montana

What We Are Doing To Increase Production?

- Estimate oil remaining in Montana's known oilfields
- Investigate potential of enhanced oil recovery opportunity



How Are We Going To Do It ?

Phase 1

- Determine oil in place and remaining oil in Montana
 - Quality control/assessment of production and reservoir data
 - Select fields for further investigation for EOR potential

Based on:

- i. Recovery factor at present
- ii. Development Phase
- iii. EOR screening criteria (formation depths, pressure, fluid types-ideal conditions for EOR)

How Are We Going To Do It ?

Phase 2

- Study selected field(s) in detail (Geology and Reservoir Characteristics)
- Perform reservoir simulation to determine the effectiveness of EOR
- Make recommendations for future development

Challenges To The Project

- Limited source of data
 - Montana Geological Society (MGS) production data pre 1986.
 - Montana Board of Oil and Gas (MBOG) post 1986
- Incomplete data
 - Saturation, porosity, area etc.
- Inconsistent production data
 - Fields producing from multiple formations
 - Pre and post 1986 data inconsistent

Challenges To The Project

MGS data

M O N T A N A G E O L O G I C A L S O C I E T Y 281

By Matthew R. Silverman
Texas Gas Exploration
Denver, Colorado
December 1, 1985

GENERAL FIELD DATA

Regional Setting:
Central Montana Uplift

Surface Formations and Elevation:
Bearpaw Shale 3000'

Discovery Well and Date:
True Oil #42-10 71 Ranch Co. Completed 9-5-76.

Exploration Methods:
Subsurface geology, land play, limited seismic, stratigraphy later.

Oldest Horizon Penetrated:
Mississippian Otter Formation

Horizons with Shows:
Lower Tyler sandstone body

Nature of Trap:
Stratigraphic, isolated sandstone body

Area of Trap:
520 acres

No. of Producing Wells: 13
Abandoned Wells: 0
Shut In/Temp Abdn Wells: 0
Disposal/Injection Wells: 0
Dry Holes: 10

Major Operators:
True Oil, Petroleum, Inc., Coastal Oil & Gas, Milestone Petroleum

Drilling and Casing Practices:
Drill 175' of 12 1/4" surface hole, set 8 1/2" casing. Drill out with 7 1/2" bit. Mud up around Third Cat Creek Sand. Run 5 1/2" production casing.

Logging Suite:
Dual Induction, Sonic

Testing Practices:
DST's currently uncommon due to underpressured conditions. Originally run on sample shows.

Market:
Trucked to Melstone and shipped by Conoco pipeline; thence to Billings.

RESERVOIR DATA

Producing Formation:
Lower Tyler 'B' Sandstone

Lithology, Continuity, Thickness:
Continuous, shoestring, 10' to 40' thick (gross).

Avg. Depth (& MSL):

BREED CREEK FIELD

T.12&13 N., R.33 E.
Rosebud County, Montana

6.4%, maximum 26.6%, average 17.2%; Permeability: minimum 0.30 md, maximum 185 md, average 12.86 md.

Oil, Gas Column: (Water Contact MSL):
About 115', little gas or water produced, OWC approx. -1883.

Avg. Net Pay Thickness:
25'

Area this Reservoir:
440 acres (Stensvad Sandstone produces in 2 other wells)

Order/Docket No. and Spacing Details:
40 acre; statewide spacing regulations

BO/MCF Per Acre-Foot:
215-230 BO/Acre-Foot

Drive Mechanism:
Dissolved-gas drive

Character of Oil/Gas:
32 degrees API, Viscosity: 2.5 cp, sweet

Gas-Oil Ratio:
Unknown, low

Water Rw, Salinity:
Approx. 0.15 @ BHT

Avg. Saturation:
Logs calculate Sw = 25-35%, average So in core = 18.8%, 4.4% minimum, 32.7% maximum.

Initial and Present Pressure:
1945 lbs. initial, 200-400 lbs. present

Temperature:
120 degrees F = BHT average

Initial Potential (High, Low, Avg.):
270 BOPD, 6 BOPD, 74 BOPD

Decline Rate:
Unknown

Present Daily Avg. Production:
29 BOPD per well

Amount of Water Produced:
10,974 BW

Completion/Perforation/Treatment:
Frac, small acid job.

Cumulative Production:
592,137 BO

Est. Ultimate Primary Recovery:
1,000,000 BO

Est. Ultimate Secondary Recovery:

ANNUAL PRODUCTION HISTORY CHART

NO. OF WELLS @ YR. END				PRODUCTION OIL IN BARRELS GAS IN MCF	
YEAR	TYPE	PROD.	SHUT-IN	ANNUAL	CUMULATIVE
1976	OIL	2		19,084	19,084
	GAS				
1977	OIL	5		149,132	168,216
	GAS				
1978	OIL	2		79,362	247,578
	GAS				
1979	OIL	4		100,589	348,178
	GAS				
1980	OIL	4		110,529	458,707
	GAS				
1981	OIL	4		83,469	542,176
	GAS				
1982	OIL	4		57,269	599,445
	GAS				
1983	OIL	10		92,692	692,137
	GAS	40	40		

Challenges To The Project

MBOG data

1				
FIELD BBLs OIL POST 1986 MCF GAS DT DISC LAST YEAR				
Divide	5024617	1695041	7/31/1979	2024
1				

Annual Production By Field

1							
FIELD	YEAR	FMTN CODE	PROD ZONE	BBLs OIL	MCF GAS	REPORTED WELLS	REPORTED WELL DAYS
Divide	1986	MAD	Madison	33060	11633	4	1445
Divide	1986	RAT	Ratcliffe	89514	20171	4	1430
Divide	1987	MAD	Madison	30457	11472	4	1434
Divide	1987	RAT	Ratcliffe	79297	32288	5	1577
Divide	1987	RR	Red River	42797	18300	1	196
Divide	1988	MAD	Madison	27136	11560	4	1445
Divide	1988	RAT	Ratcliffe	73535	28557	6	1654
Divide	1988	RR	Red River	153675	62625	3	906
Divide	1989	MAD	Madison	23390	11456	4	1432
Divide	1989	RAT	Ratcliffe	68177	20061	5	1658
Divide	1989	RR	Red River	90123	49712	3	1035
Divide	1990	MAD	Madison	20999	11424	4	1428
Divide	1990	RAT	Ratcliffe	63660	16181	5	1421
Divide	1990	RR	Red River	69312	38416	3	1076
Divide	1991	MAD	Madison	13894	8488	3	1051
Divide	1991	MC	Mission Canyon	4652	2840	1	355

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Challenges To The Project

FIELD	Area	FLUIDS	AREAL	FM	PHIE	PERM	THICKNES	oil wt	gas/oil ratio
Devil's Pocket	CMT	oil	N/A	Heath	0.033	N/A	103.0	26.5	N/A
Divide	WB	oil & gas		1430 Ratcliffe	0.1	.85-14	25.0	33	0.44
			→	Red River					
			→	Ratcliffe, Mission Canyon					
				Mission Canyon					
Dugout Creek	WB	oil		320 Red River 'C'	0.074	2	32.0	48	972.5
Dugout Creek, South				Red River 'C'					
				Bakken					
	WB	oil		4500 Ratcliffe	0.111	.1-3.0	37.6	36	400
	WB			160 Interlake	N/A	N/A	15.0	42	222
	WB			320 Red River	0.15	42	31.0	41	630
	WB	oil		Ratcliffe			18.0	34	500
	WB			Mission Canyon			25.0	37	500
	WB			Duperow	0.12		7.0	39	1200
	WB			Red River	0.15		7.0	38	550
East Glacier	SG	oil		Cretaceous Greenhorn	0.15		100.0	45	325 to 1
	SG			500 Mississippian Sun River	0.03		90.0	64	41000 to 1
	BH	oil & gas		700 Cretaceous Frontier	0.1		60.0	43	475
	BH			Torchlight and Peay sands	0.19		40.0		
	BH			200 Greybull "A&B"	0.2		45.0		
	BH			7000 Tensleep/ Phophoria	0.15	50-550	110.0	30	135-490
	BH			5100 Madison	0.12	3-368	27.0	28	200
	BH			600 Jefferson/Bighorn	0.07	4	120.0	27	300, 80
Elk Basin, Northwest	BH	oil & gas		120 Cretaceous Frontier	0.18		35	45	1850
	BH			120 Peay/ Greybull	0.15		20	46	1350
	BH			480 Pennsylvanian Tensleep	0.13	20-25	45	36	720
	BH			160 Mississippian Madison	0.12	3-368	60	33	160
				Cloverly					
				Embar, Tensleep					
	WB	oil & gas		231907 Bakken	0.12	.01-.06	30.0	42	

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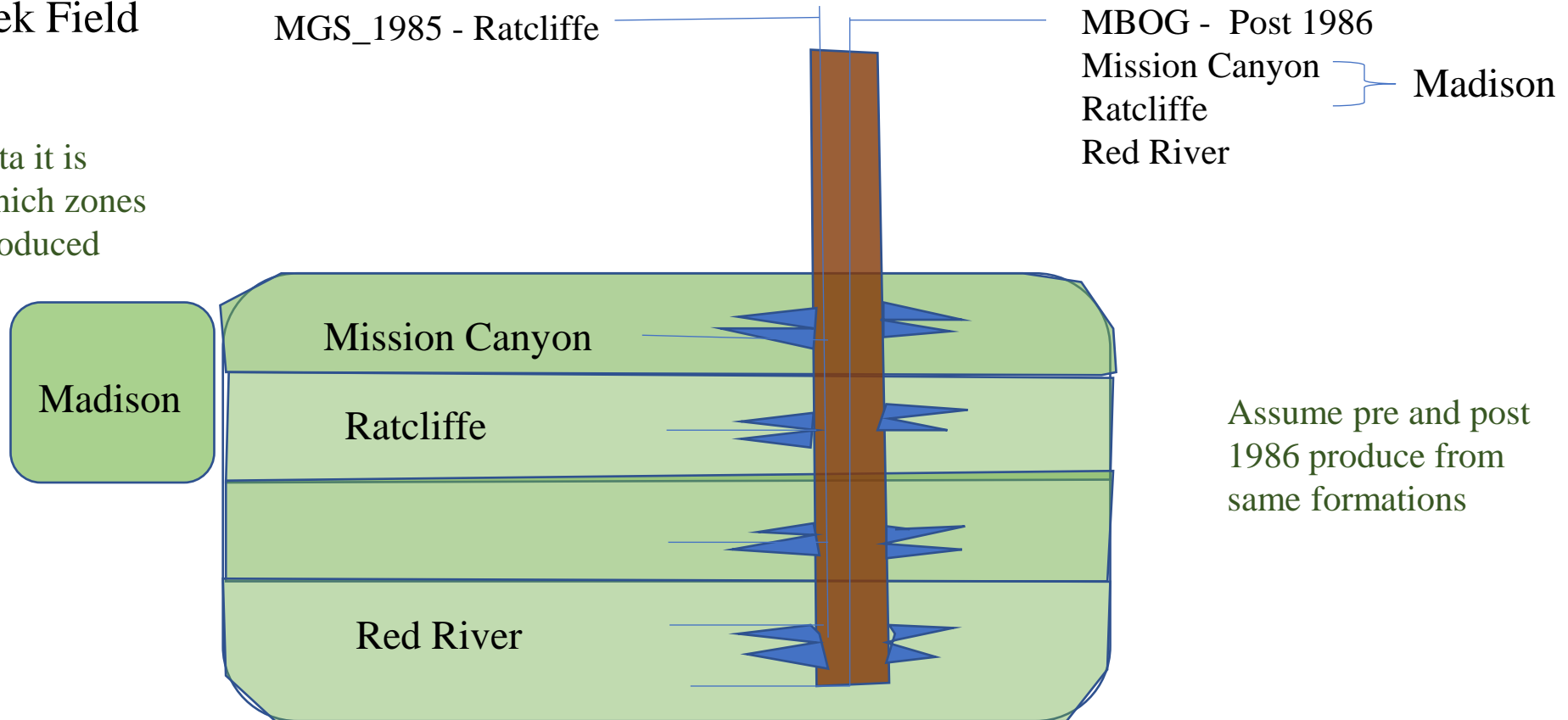
Challenges To The Project

- For fields with consistent formation or production data pre and post 1986. No assumptions are necessary :
 - OOIP, total oil production and recovery factor reliably
- For fields with inconsistent formation and production data. Assumptions must be made:

Challenges To The Project

Divide Creek Field

Pre-1986 data it is uncertain which zones are being produced



Phase 1

Goals of Phase 1:

- Address inconsistencies in the data
- Estimate the remaining oil in place in known oilfields
- Determine the current development phase of each field
- Using Taber(1997) criteria to select the most appropriate EOR methods for the fields

Estimation of Oil Originally in Place (OOIP)

Oil originally in place is calculated using volumetric analysis

$$OOIP = \frac{7758 \times A \times h \times \phi \times (1 - S_w)}{B_o} \quad (1 - S_w) = S_o$$

FIELD	Area	FLUIDS	AREAL	FM	DEPTH	PHIE	PERM	THICKNES
Sumatra	CMT	oil		200	Amsden	0.05	2	8.0
	CMT			80	Upper Tyler	0.17	280	13.0
	CMT			5700	Lower Tyler Heath	0.15	195	18.0
Sumatra NW	CMT	oil		3260	Amsden	0.23	0-350	48.0
	CMT				Tyler "A"	0.16	281	48.0
	CMT				Tyler "B"	0.12	3940	
	CMT				Tyler "C"	0.12	3940	
	CMT				Piper			10.0
	CMT				Heath			

Estimation of Oil Originally in Place (OOIP)

Challenges with Estimating OOIP:

- Missing parameters include: water saturation, porosity, temperature, pressure and API gravity

Standing's correlation:
$$B_o = 0.9759 + 0.000120 \left[R_s \left(\frac{\gamma_g}{\gamma_o} \right)^{0.5} + 1.25T \right]^{1.2}$$

Estimation of Oil Originally in Place (OOIP)

Remedy:

FIELD	FM	DEPTH	PHIE	PERM	oil wt	SAT
Fort Gilbert	Ratcliffe/ Mission Canyon	9100	0.06		34	0.29
	Duperow "C"	10900	0.24		46	0.28
	Red River "C"	12500	0.14		48	0.3

Estimation of cumulative oil production

The total oil production for each field is calculated by adding yearly production since production start to present or end (fields where production was stopped).

1				
FIELD BBLs OIL POST 1986 MCF GAS DT DISC LAST YEAR				
Divide	5025574	1695091	7/31/1979	2024
1				

Estimation oil remaining and recovery factors

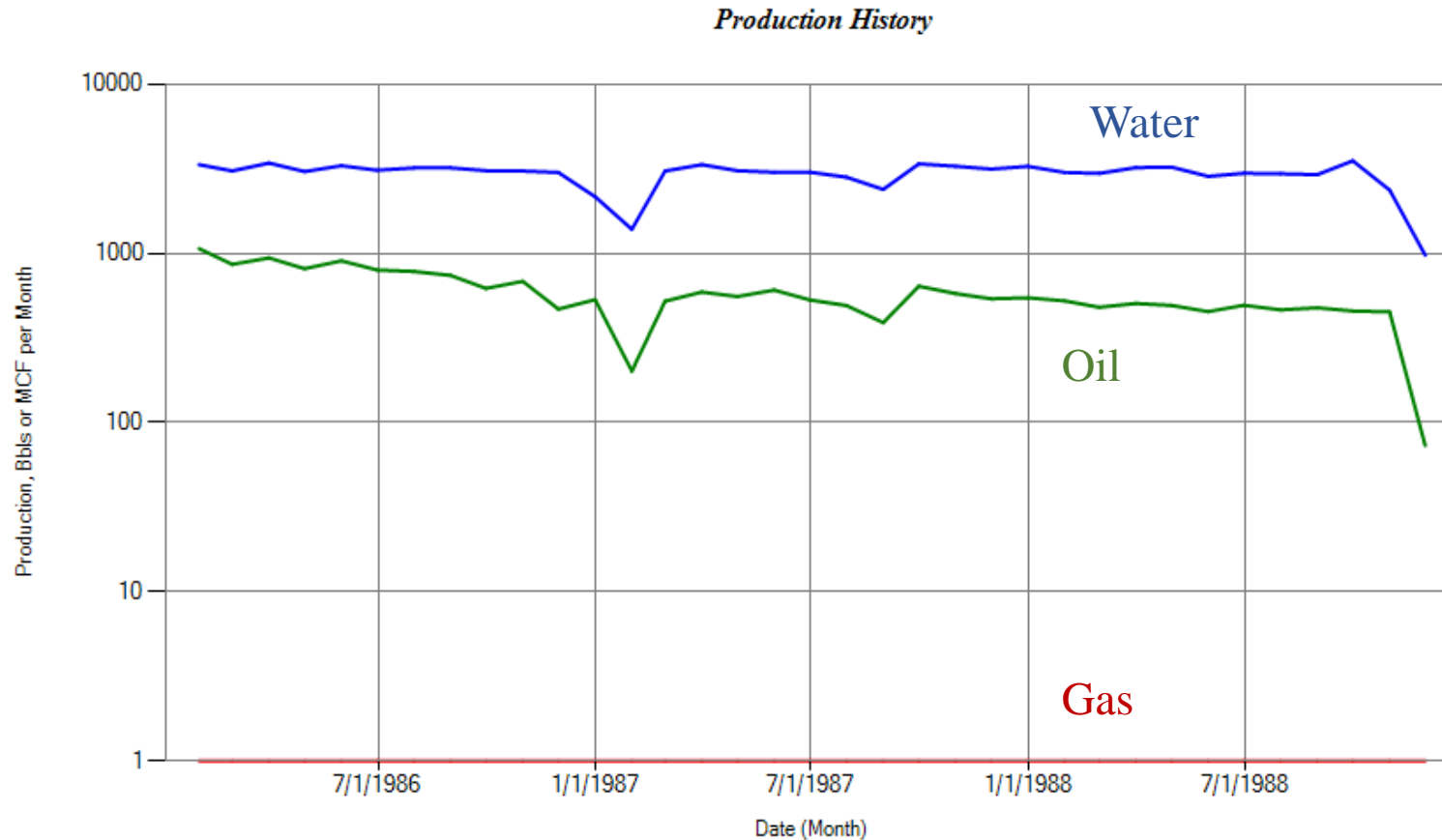
The remaining oil in place could be estimated by subtracting the cumulative oil production from the oil originally in place.

$$\text{Oil remaining} = \text{OOIP} - \text{Cumulative oil production}$$

Recovery factor, refers to the fraction of the reservoir which has been recovered/produced with respect to the oil in place.

$$\text{Recovery factor} = \frac{\text{Cumulative Oil production}}{\text{OOIP}}$$

Current Field Development Phase



Most oilfields in Montana are currently under water flood

EOR Screening Criterion

- Based the reservoir rock properties, fluid properties and geologic setting of the oil fields, Taber (1997) screening criteria was used.
- Expected incremental recovery factor:
 - Carbon dioxide (CO₂) injection – 8-20%
 - Miscible gas injection – 5-10%
 - Polymer/Surfactant flooding – 5-8%

Source: SPE_5557, (James, 2009)

Taber EOR Screening Criteria

EOR Method	Oil Properties			Reservoir Characteristics					
	Gravity (API)	Viscosity (cp)	Composition	Oil Saturation (%PV)	Formation Type	Net Thickness (ft)	Average Perm (md)	Depth (ft)	Temp (°F)
Gas Injection Methods (Miscible)									
Nitrogen & flue gas	>35 ↗ 48 ↗	<0.4 ↘ 0.2 ↘	High percent of C ₁ to C ₇	>40 ↗ 75 ↗	Sandstone Or carbonate	Thin unless dipping	NC	>6000	NC
Hydrocarbon	>23 ↗ 41 ↗	<3 ↘ 0.5 ↘	High percent of C ₂ to C ₇	>30 ↗ 80 ↗	Sandstone Or carbonate	Thin unless dipping	NC	>4000	NC
CO ₂	>22 ↗ 36 ↗	<10 ↘ 1.5 ↘	High percent of C ₅ to C ₇	>20 ↗ 55 ↗	Sandstone Or carbonate	Wide range	NC	>2500	NC
Immiscible gases	>12	<600	NC	>35 ↗ 70 ↗	NC	NC if dipping and/or good vertical permeability	NC	>1800	NC
Enhanced Waterflooding									
Micellar Polymer, ASP/Alkaline	>20 ↗ 35 ↗	<35 ↘ 13 ↘	Light, inter-Mediate some organic acids for alkaline floods	>35 ↗ 53 ↗	Sandstone preferred	NC	>10 ↗ 450 ↗	>9000 ↘ 3,250	>200 ↘ 80
Polymer Flooding	>15	<150, >10	NC	>50 ↗ 80 ↗	Sandstone preferred	NC	>50	<11,500 ↘ 3,500	>100 ↘ 135
Thermal/Mechanic									
Combustion	>35 ↗ 48 →	<5,000 ↓ 1,200	Some Asphaltic Components	>50 ↗ 72 ↗	High-porosity Sand/sandstone	>10	>50	<11,5000 ↘ 3,500	100 ↗ 135
Steam	>8 to 13.5	<200,000 ↓ 4,700	NC	>40 ↗ 66 ↗	High-porosity Sand/sandstone	>20	>200 ↗ 2,540 ↗	<4500 ↘ 1,500	NC

Phase 1- Outcome

Total oilfields known in Montana: **350**

Total oilfields in study: **50**

Cumulative OIIP: **4.6 Billion stb of oil**

Cumulative oil production: **725 Million stb of oil**

Cumulative remaining oil: **3.8 Billion stb of oil**

10% incremental recovery: **460 Million stb of oil**

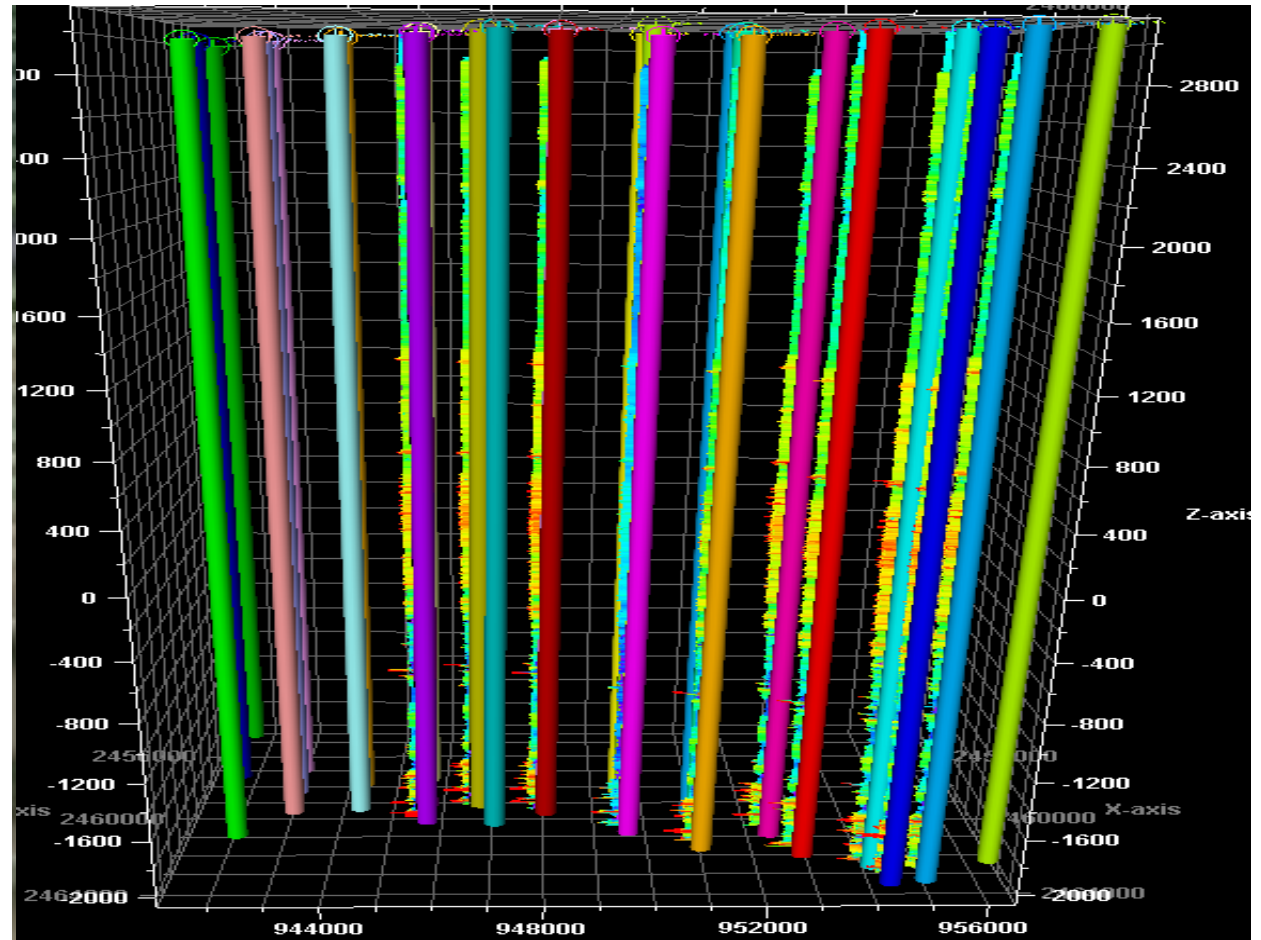


50 Oilfields

There still exist some level of uncertainty in these volumes

Phase 2

- **Breed creek** oil field has been chosen for the study
- Build a reservoir model and perform flow simulations
- Make recommendations for future development
- Expecting a 10% increment: 800,000 stb of oil



Questions?

**Thank you for your time and
attention**