Water Flood Workshop
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Long Beach, California

Water Flooding and Waterflood Design

by

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Water Flooding

- Water Flood Process
- Reasons for Water flooding
- History of Water flooding
- Water Flood Patterns
- Water Flood Recovery Efficiency
- Oil Displacement by Water flooding
- Variables Affecting Recovery Efficiencies

Water Flood Process

Water flooding consists of injecting water into a set of wells while producing from the surrounding wells. It maintains reservoir pressure and displaces oil from the injectors to the producers

Reasons for Water Flooding

- Primary Production Method Leaves Behind 1/3 to 1/2 or More of the Original Oil In Place
- After Primary Production, Waterflooding Enhances Substantially Production and Reserves
- It Is the Most Widely Used Recovery Method After Primary
- Generally Available Water
- Efficient Agent for Displacing Light/Medium Gravity Oil
- Low Capital Investment, Operating Costs, and favorable Economics
- Easy to Inject and spreads easily

History of Water flooding

- Accidental Water Injection in Pithole City Area in 1865
- In Earliest Days started at a Single well and then to Circle Drive, Line Drive, Peripheral Floods
- First 5-Spot Flood Initiated in 1924 in Bradford Field
- Grew to Oklahoma in 1931and then to Texas in 1936
- Widespread application started in early 1950

Water Flood Patterns

- Five Spot Regular – 4 Injectors and 1Producer
- Five Spot Inverted – 1 Injector and 4 Producers
- Seven Spot Regular – 6 Injectors and 1Producer
- Seven Spot Inverted – 1 Injector and 6 Producers
- Nine Spot Regular – 8 Injectors and 1Producer
- Nine Spot Inverted – 1 Injector and 8 Producer

Waterflooding Recovery Efficiency

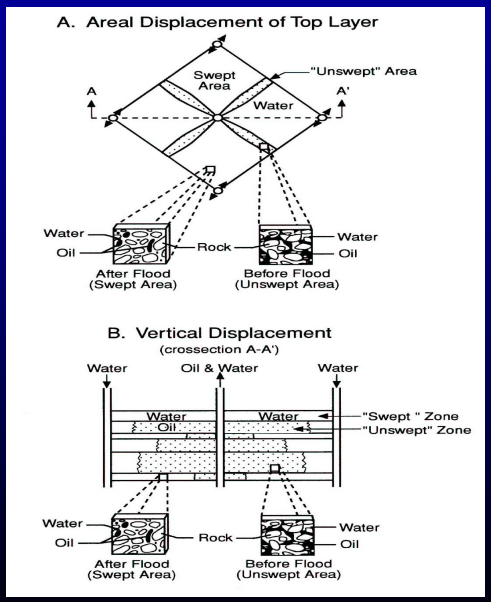
Overall Recovery Efficiency

$$ER = ED \times EV$$

Where:

ER	=	Overall recovery efficiency, %
ED	=	Displacement efficiency within the volume swept by water, %
EV	=	Reservoir Volume swept by water, %
	=	EA x EI
EA	=	Areal sweep efficiency, %
EI	=	Vertical or invasion sweep efficiency, %

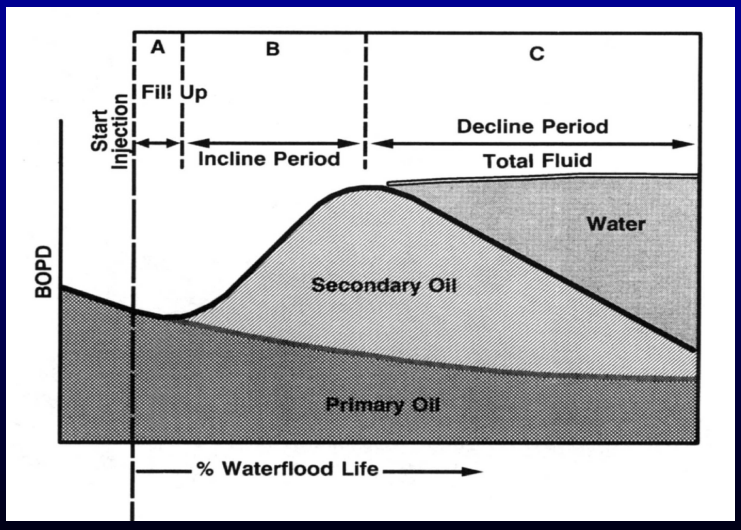
Oil Displacement by Waterflooding



Variables Affecting Efficiencies

- Displacement Efficiency by Rock and Fluid Properties, and Throughput (Pore Volume Injected)
- Areal and Pattern Sweep Efficiencies by Flooding Pattern Types, Mobility Ratio, Reservoir Heterogeneity, and Throughput

Typical Successful Waterflood Performance



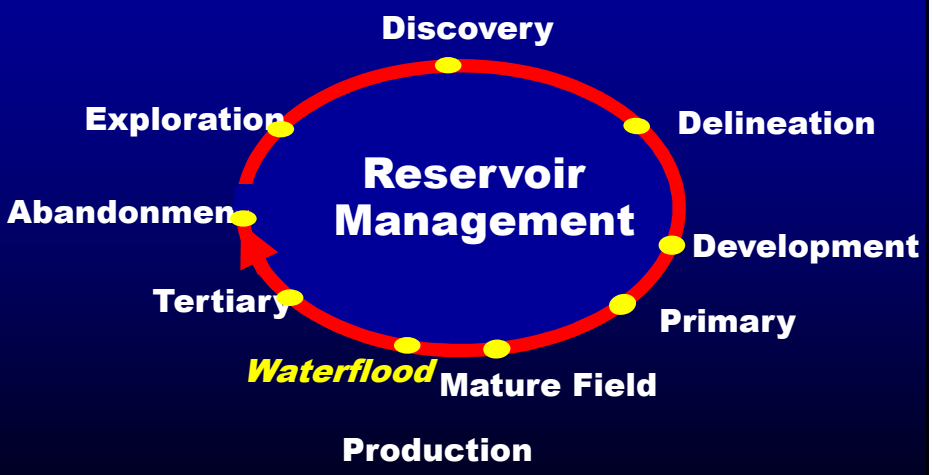
Water Flood Design

- Design Considerations
- Example Water Flood Development Plan

Design Considerations

- Reservoir Characterization – Geoscience and Engineering Data
- Potential Flooding Plans – Peripheral, Pattern, Well Spacing
- Estimate Injection, Production Rates
- Facilities Design – Fluid Volumes and Rates for Sizing Equipment, Water Source and Disposal
- Capital Expenditures and Operating Costs
- Economic Evaluation, Risk, and Uncertainties

Water Flood Development Plan



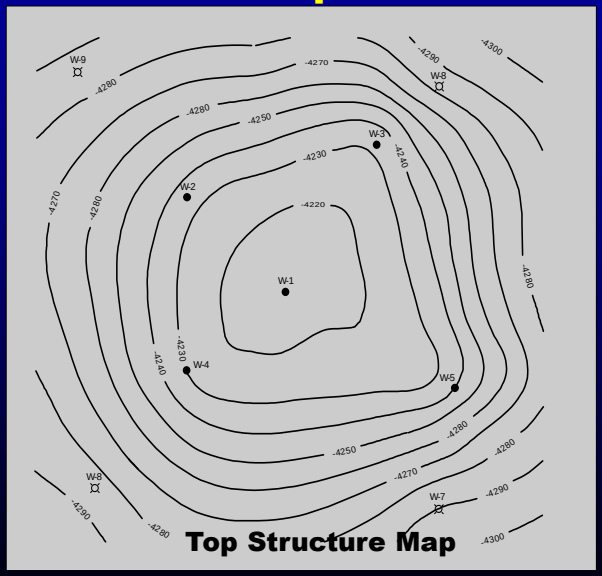
Professionals Involved

- Exploration - Geologists, Geophysicists
- Discovery - Drilling and Reservoir Engineers
  Petrophysicists
- Delineation - Sam as above
- Development - Reservoir, Drilling, Operation, and
  Facilities Engineers
- Production – Production Engineers

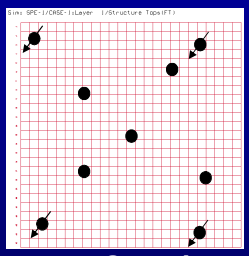
WF Project Development Approach

- **Build Integrated Geoscience and Engineering Model Using Available Data**
- **Simulate Full-Field Primary Performance**
- **Forecast Performance under Peripheral and Pattern Waterflood Drive**

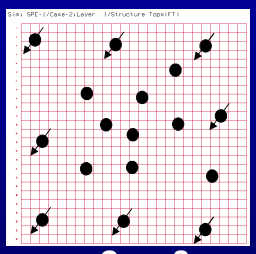
Top Structure Map
Waterflood Prospect Reservoir



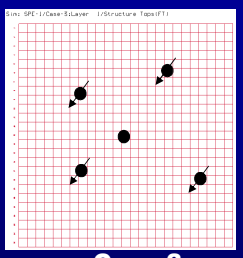
Development Cases



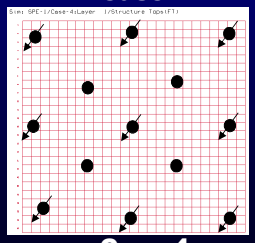
Case 1



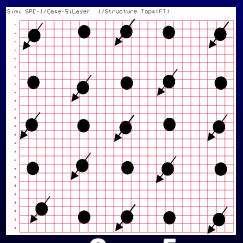
Case 2



Case 3



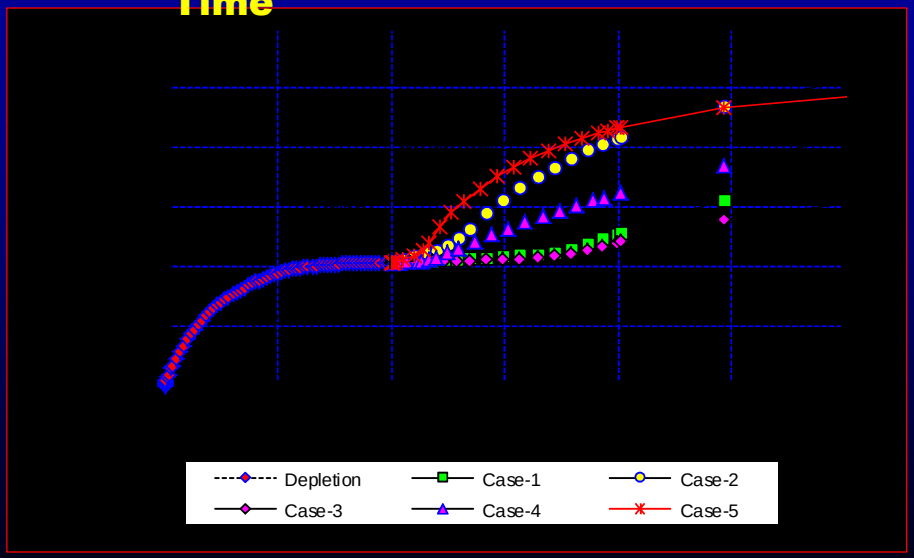
Case 4



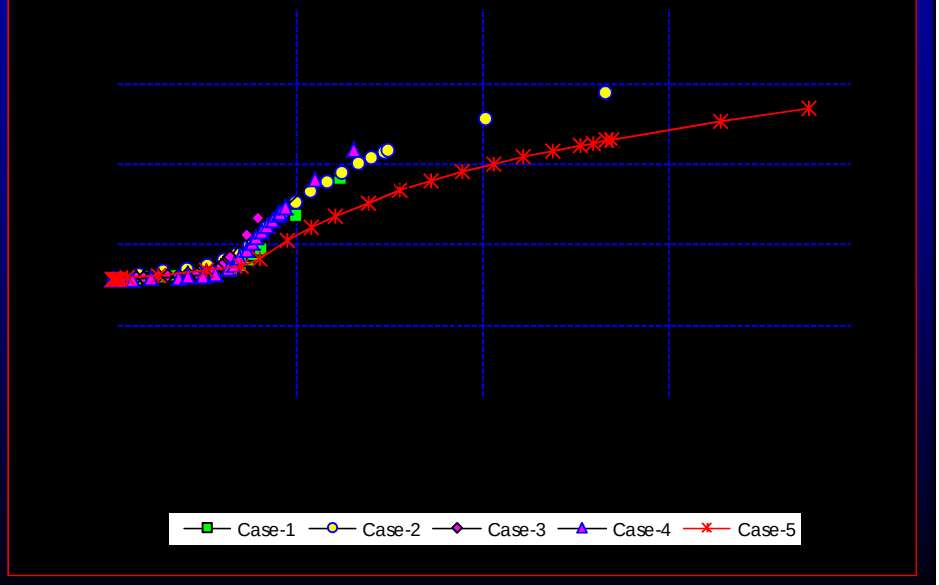
Case 5

		Producer	Injector
Case 1	Peripheral	5	4
Case 2	Peripheral	9	8
Case 3	Pattern	1	4
Case 4	Pattern	4	9
Case 5	Pattern	12	13

Cumulative Oil Recovery vs. Time



Oil Recovery vs. Water Injected



Economic Criteria

- Payout Time –Time needed to recover investment
- Discounted Cash Flow Rate of Return – Maximum discount rate needed to be charged for the investment capital to produce a break-even venture
- Profit- to- investment Ratio – Total undiscounted cash flow without capital investment divided by the total investment
- Present Worth Net Profit –Present value of the entire cash flow discounted at a specified discount rate

Economic Evaluation Results

	Case-1	Case-2	Case-3	Case-4	Case-5
Capital Investment, $MM	1.853	4.882	0.973	3.484	8.799
Reserves, MMSTBO	1.965	5.138	1.378	3.176	5.105
Project Life	15	15	15	15	15
Payout Time, Years	2.58	1.78	2.44	2.74	2.28
Discounted Cash Flow Return on Investment, %	69.64	131.15	80.12	87.83	104.84
Profit-to-Investment Ratio	16.88	16.44	23.32	13.91	8.74
Development Costs, $/STBO	0.94	0.95	0.71	1.10	1.72