SPE STATE OF THE UNION

Presented to
Mexico Section SPE

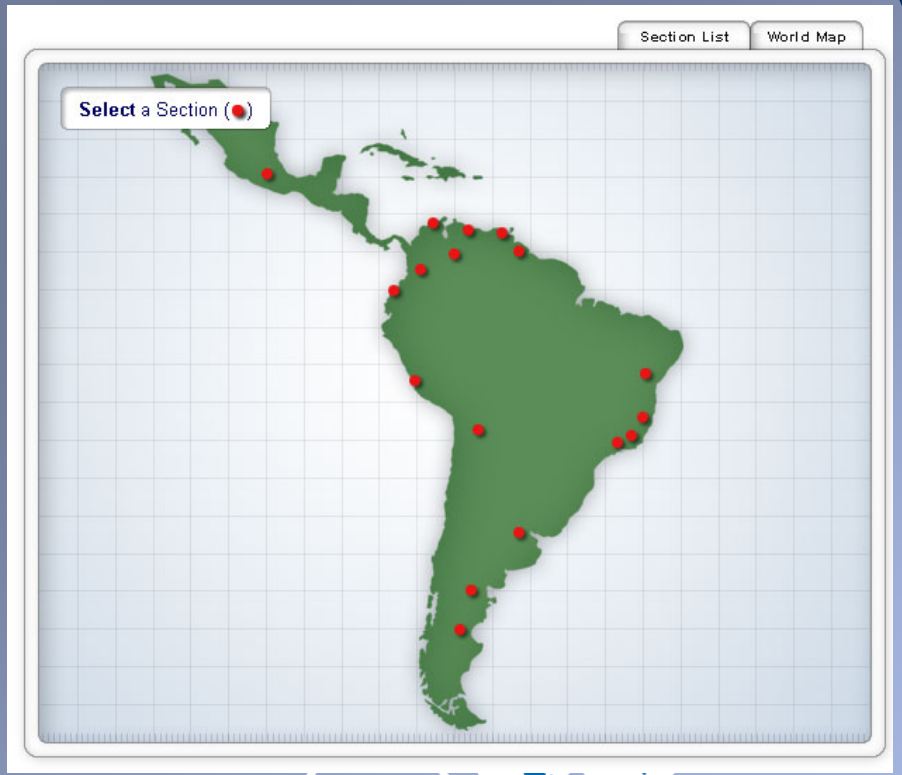
June, 2008

By
Dr. William M. Cobb
President
William M. Cobb & Associates, Inc.
and
Worldwide SPE President 2008

SPE International
50th 1957–2007
Celebrating Around the World

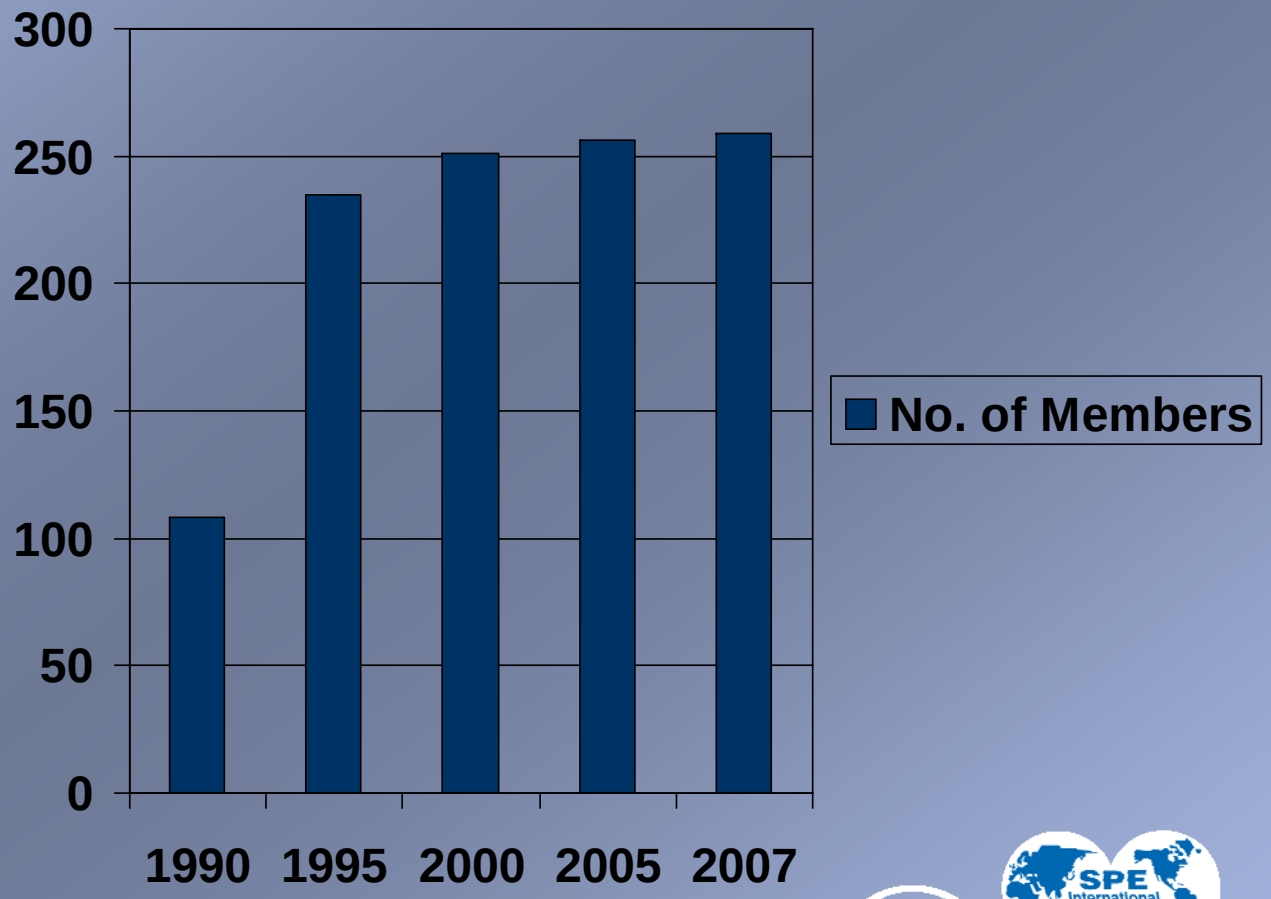
SPE in Latin America

- Total members in region – 2,011
- Mexico Section membership: 259



SPE Mexico Section

Established 1990



SPE International
50th 1957–2007
Celebrating Around the World

Recent Conferences in Mexico

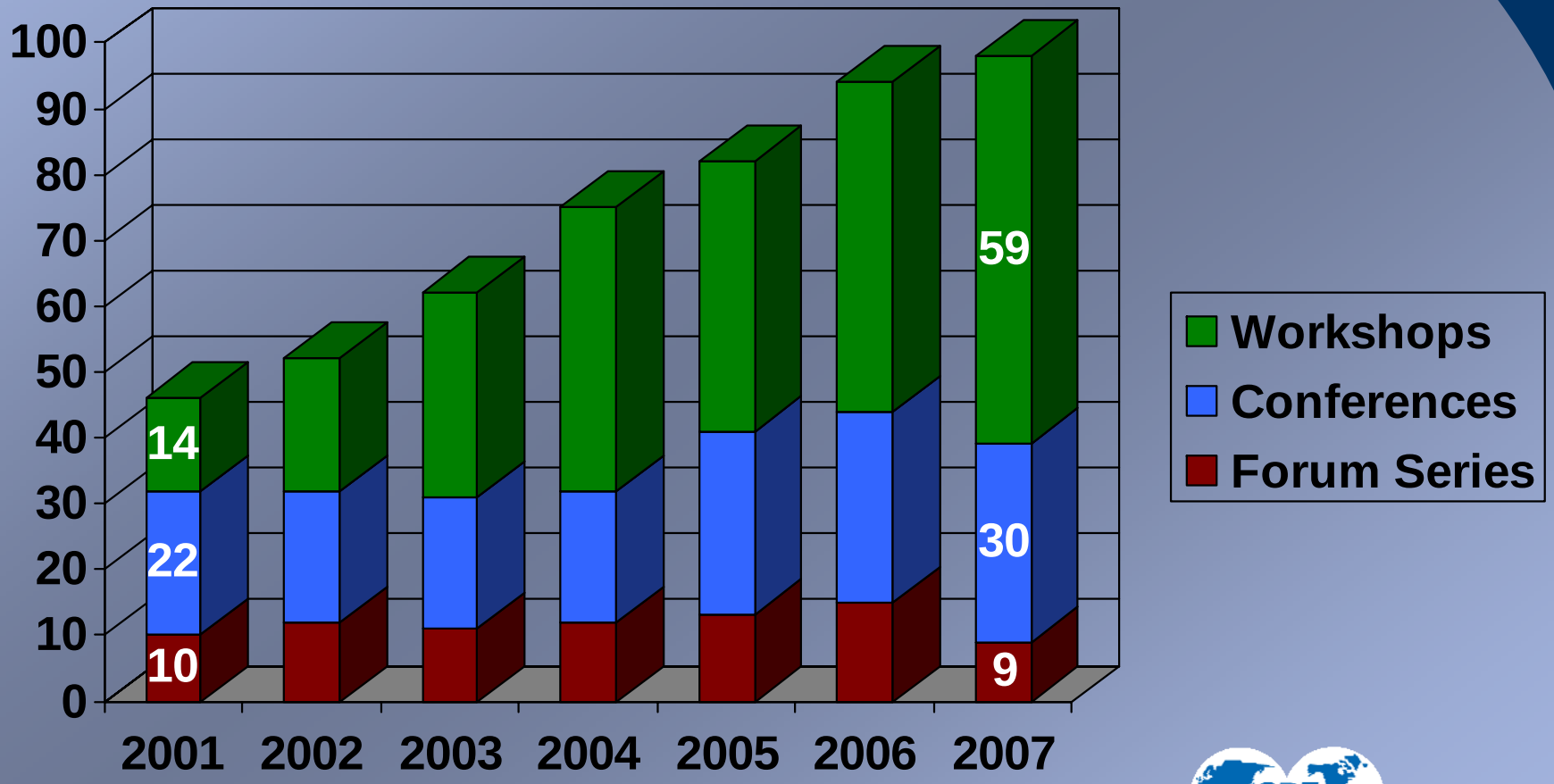
- 27-29 February 2008
  Horizontal and Multilateral Wells Workshop Merida
- 10-11 March 2008
  SPE/AMGE Geosciences for Reservoir Characterization and Performance Simulation Workshop Villahermosa
- 27-30 June 2007
  International Oil Conference and Exhibition in Mexico
  Veracruz, Mexico

SPE University Chapters: Mexico

- Instituto Politecnico Nacional

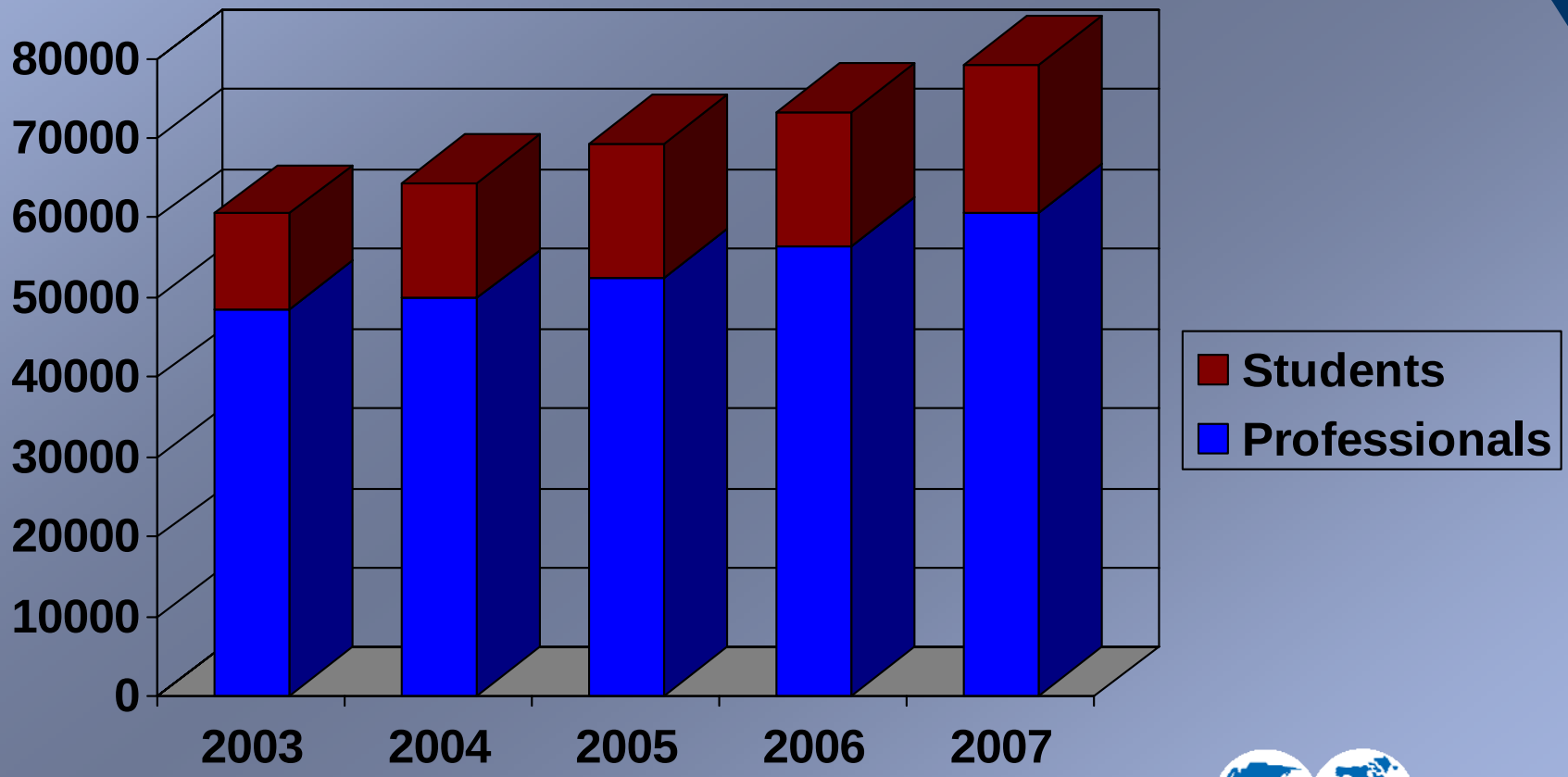
  Mexico City – 160 student members
- Universidad Nacional of Mexico Mexico City- 345 student members

Meetings



SPE International
50th 1957–2007
Celebrating Around the World

Membership



SPE International
50th 1957–2007
Celebrating Around the World

Then and Now

	1957	2008
Membership	12,500	79,300+
Sections	31	170
No. of Countries	3	117
Meetings held	4	100+
Attendance	3,500	200,000

The Future is

- A constant vision in a changing world
- Constant search for new ways to meet member needs in all parts of the world
  - Dues structure review
  - LookUpstream and OnePetro
  - Online journals
  - Certification pilot program

The Future

- Have developed an SPE industry advisory council representing NOC's, IOC's, Independents to provide suggestions and guidance to SPE BOD
- Have developed a committee on CCS
- Continue to work and support and gain worldwide acceptance of the new SPE, et al, reserve definitions
- Constantly monitor and update SPE LRP

Practical Reservoir Management Considerations for Mature Waterfloods

Why Inject Water?

A. Maintain Reservoir Pressure – Pressure Maintenance
B. Increase Reservoir Pressure – Waterflooding
C. Supplement Natural Water Influx

But . . .

A, B & C are Displacement Processes and the Goal is to Displace Oil to a Production Well

Important Reminders When Monitoring Waterflood Activities

- Pressure Depletion Stops
- Volumetric Sweep
- Net Pay Cutoffs
- Decline Curve Analysis
- WOR Analysis
- Keep Fluid Levels Pumped Off
- Waterflood Quarterback
- Keep the Ax Sharp

What are the Key Factors that Drive the Outcome of a Water Injection Project?

$$N_p \approx N^*E_A^*E_V^*E_D$$

N_p = Cumulative Waterflood Recovery, BBL.

N = Oil in Place at Start of Injection, BBL.

E_A = Areal Sweep Efficiency, Fraction

E_V = Vertical Sweep Efficiency, Fraction

E_D = Displacement Efficiency, Fraction

Waterflood Recovery Factor

$$\frac{N_p}{N} = RF$$

$$RF = \underbrace{E_A * E_V}_{E_{VOL}} * E_D$$

E_A = f (Mobility Ratio, Pattern, Directional Permeability, Pressure Distribution, Cumulative Injection & Operations)

E_V = f (Rock Property variation between different flow units)

E_{VOL} = Volumetric Sweep of the Reservoir by Injected Water

E_D = f (Primary Depletion, K_{rw} & K_{ro}, μ_o & μ_w)

Compute Volumetric Sweep Based on Oil Production Data

Oil in place at start of waterflooding = Produced oil since the start of injection
+ Oil currently in reservoir

Where:

Oil in place at start of waterflood = $\frac{V_p S_o}{B_o}$, STBO

Produced oil since the start of injection = N_p, STBO

Oil currently in reservoir = Oil in water bank + oil in oil bank

Oil in water bank = $\frac{V_p E_{vw}(1.0 - \bar{S}_w)}{B_o}$, STBO

Oil in oil bank = $\frac{V_p(1.0 - E_{vw})(1.0 - S_{wc})}{B_o}$, STBO

Volumetric Sweep Based on Oil Production Data

$$E_{vw} = \frac{\frac{N_p B_o}{V_p} + 1.0 - S_o - S_{wc}}{\bar{S}_w - S_{wc}}$$

SPE-38902

Example

Waterflood Statistics		
Conditions at Start of Waterflood		
Connate Water Saturation	=	22 percent
Gas Saturation	=	8 percent
Oil Saturation	=	70 percent
Residual Oil Saturation	=	31 percent
Oil Viscosity	=	0.3 centipoise
Oil Formation Volume Factor	=	1.57 RB/STB

Example (con't.)

Total Unit		
Pore Volume	=	350,000 MB
Cumulative Oil Production Since Start of Injection	=	40,000 MSTB
Current Volumetric Sweep Efficiency	=	**0.552**
Remaining Oil Production under Current Operations	=	5,000 MB
Estimated Waterflood Ultimate Recovery	=	45,000 MSTB
Ultimate Volumetric Sweep Efficiency under Current Operations	=	**0.600**

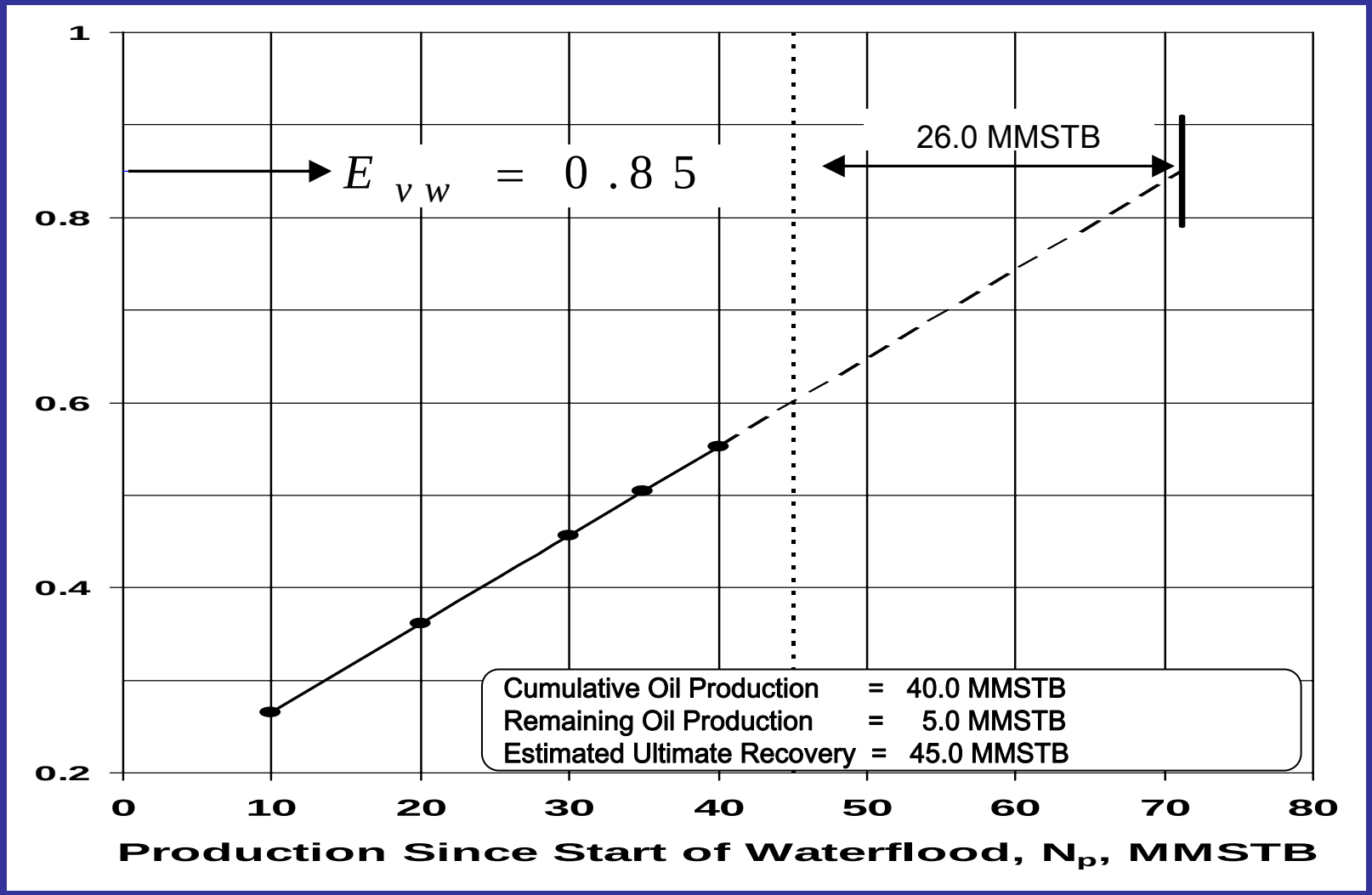
What's the Secret for Maximizing E_A and E_V (and E_{VOL})?

IT'S THE **INJECTION WELL**!

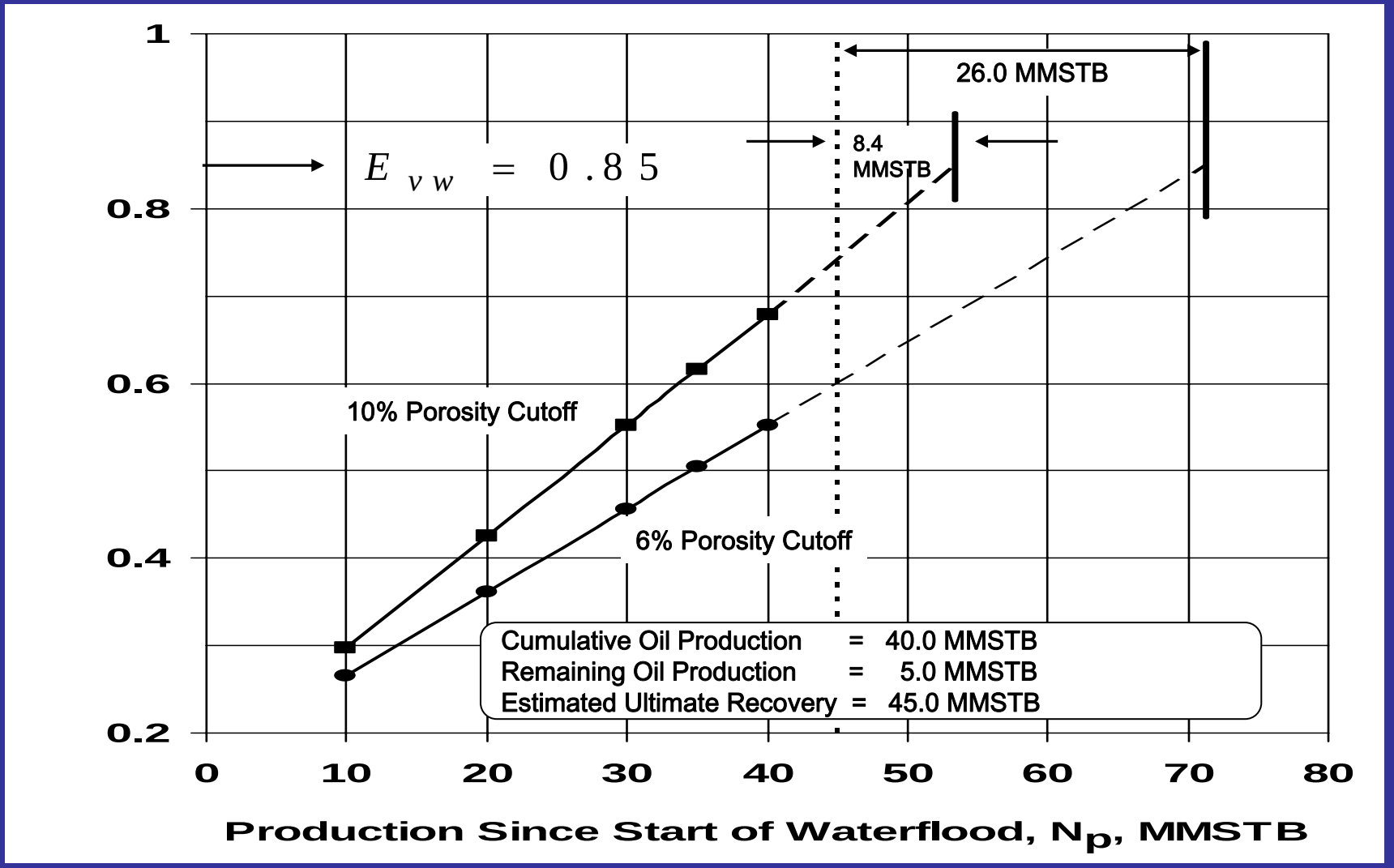
- Properly Locate the Injection Well
- Develop an Appropriate Pattern!
- Inject Water where You Find the Oil!
- Keep Fluid Levels Pumped Off
- Measure and Manage Injection Profiles
- Balance Injection and Withdrawals

Remember the Quarterback!

Volumetric Sweep Efficiency for Waterflood Project (Pore Volume Based on 6.0% Porosity Cutoff)



Volumetric Sweep Efficiency for Waterflood Project (Pore Volume Based on 6.0% and 10.0% Porosity Cutoff)



SHIFTING GEARS

Net Pay

- Static OOIP
- Dynamic OOIP
  - Drive Mechanism
  - Controlled by Cutoffs
    - Permeability Distribution between Flow Units (Dykstra-Parson Coefficient)
    - Oil/Water Relative Permeability
    - Mobility Ratio (Oil and Water Viscosity)
    - Fluid Saturations at Start of Injection (So, Sg, Swc)
    - Water Cut Economic Limit

Permeability Cutoff Using the Watercut Method at a 95 Percent Watercut Economic Limit

80 Acre Pattern

$k_{50} = 20\text{md}$

Dykstra-Parsons, V	Sg = 0%	Sg = 10%
0.6	0.24	1.10
0.7	0.71	3.30
0.8	1.20	5.60

SPE-48952

CHANGING HORSES

Decline Curve Analysis

Assume

- ✓Gas Fillup has been Achieved (Reservoir contains oil and water
- ✓Reservoir Pressure is Approximately Constant (B_o is constant)
- ✓Steady State Flow Prevails (Approximately)

Conclusion

- ✓Effective Water Injection = Liquid Production (at Reservoir Conditions)

Decline Curve Analysis

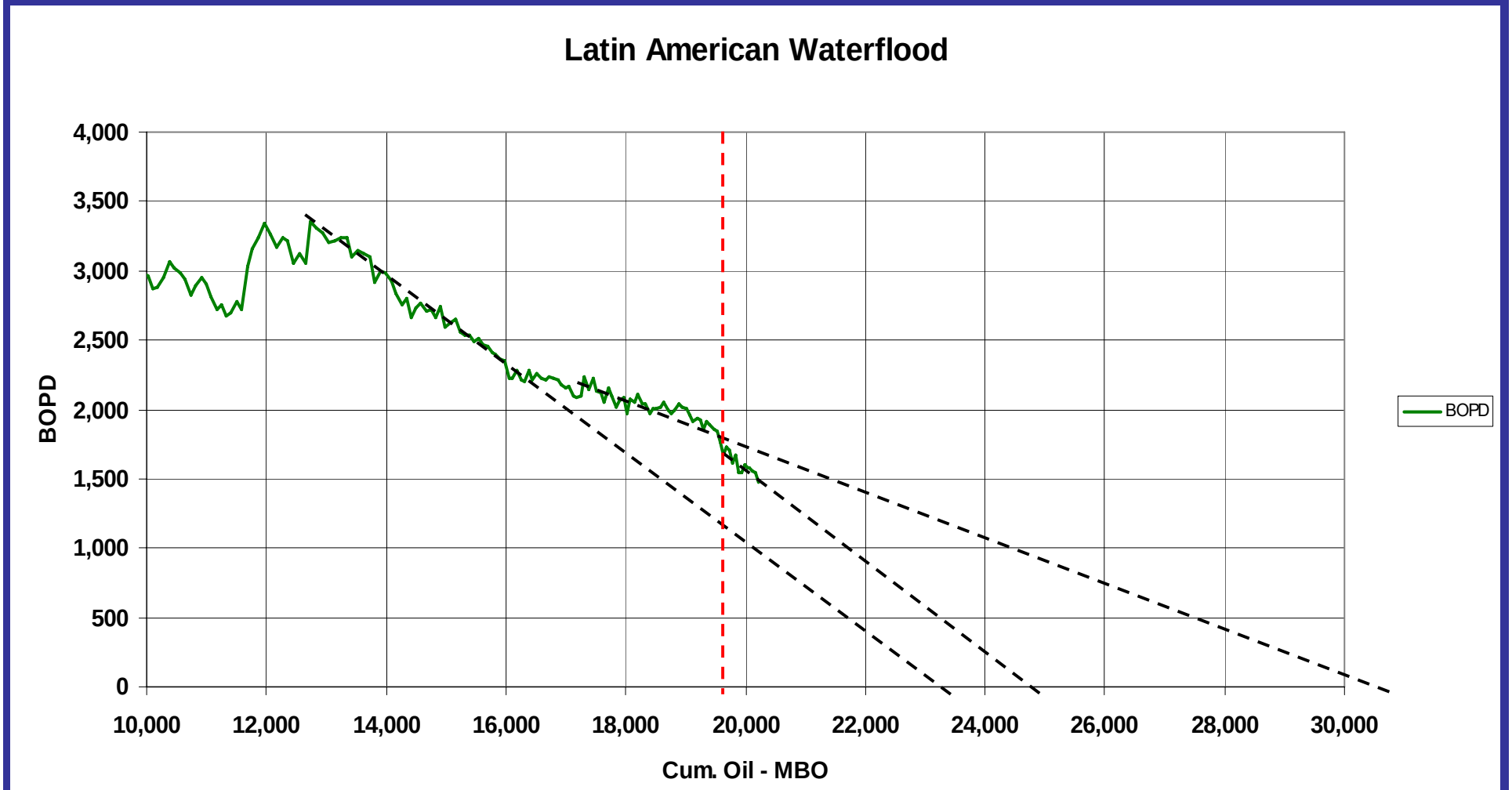
Fact:

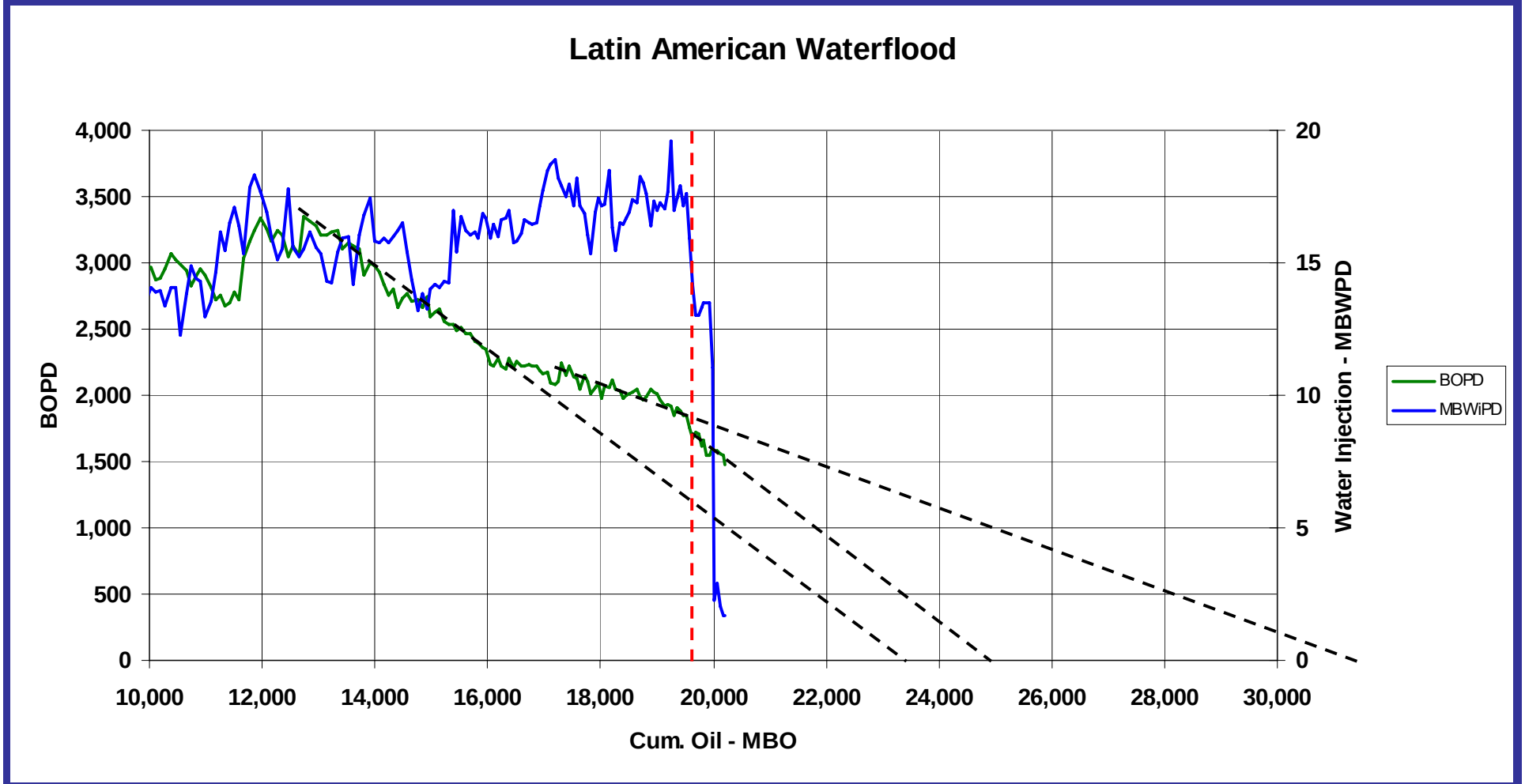
$$q_o = \frac{i_w * E_{inj} * f_o}{B_o} = \frac{i_w * E_{inj} * (1 - f_w)}{B_o}$$

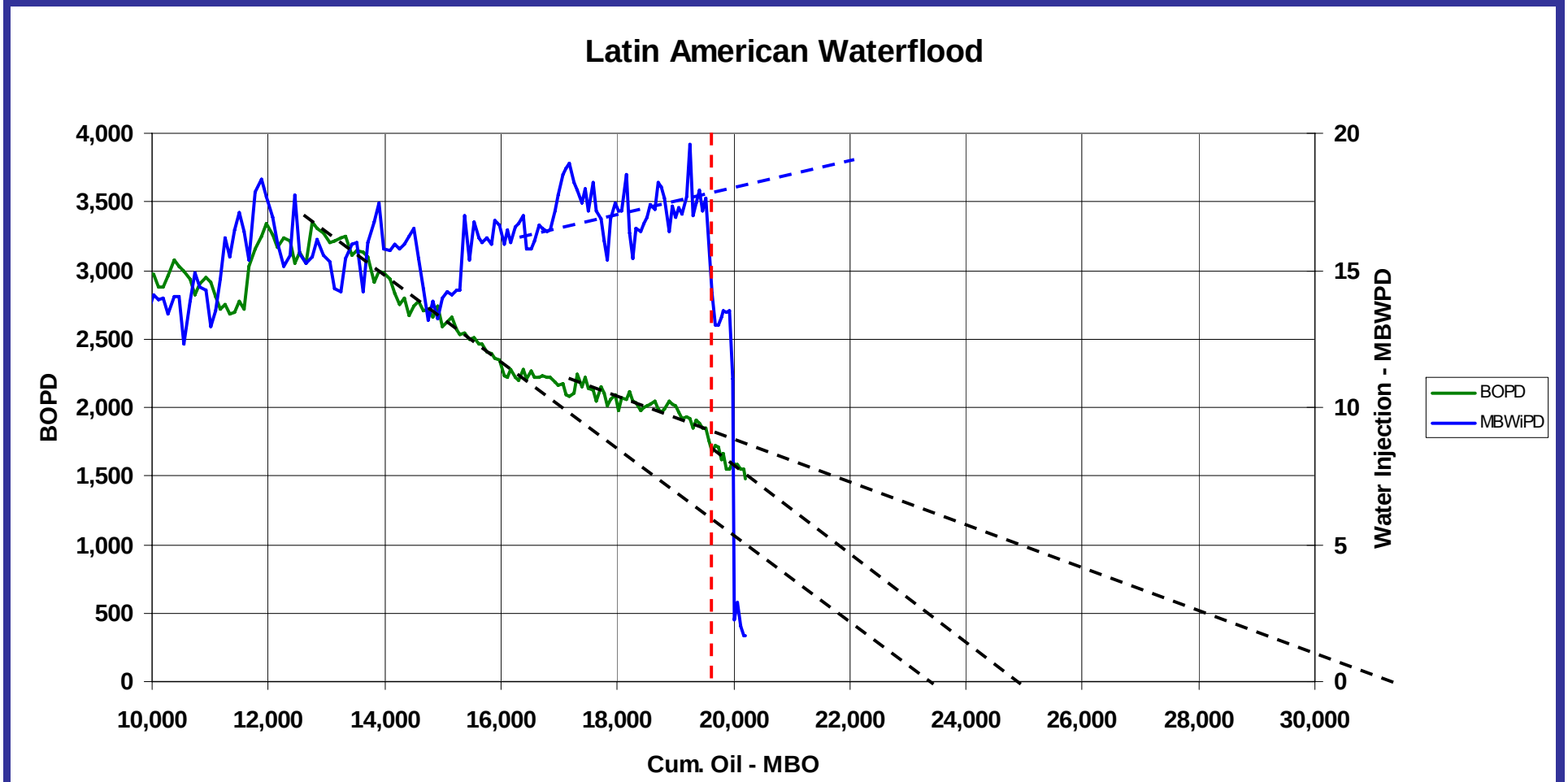
$$q_w = \frac{i_w * E_{inj} * f_w}{B_w}$$

Conculsion:

Oil and Water Production Rates are directly related to injection rates. Therefore, DCA of q_o vs t or q_o vs N_p must be evaluated only after giving consideration to historical and projected water injection rates. Also geological zonation can impact DCA projections.


Latin American Waterflood
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
BOPD
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
26,000
28,000
30,000
Cum. Oil - MBO
BOPD


Latin American Waterflood
BOPD
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Water Injection - MBWPD
20
15
10
5
0
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
26,000
28,000
30,000
Cum. Oil - MBO
BOPD
MBWiPD


Latin American Waterflood
BOPD
Water Injection - MBWPD
Cum. Oil - MBO
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
20
15
10
5
0
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
26,000
28,000
30,000
BOPD
MBWiPD

WOR is Independent of Injection Rate

$$WOR = \frac{q_w}{q_0}$$

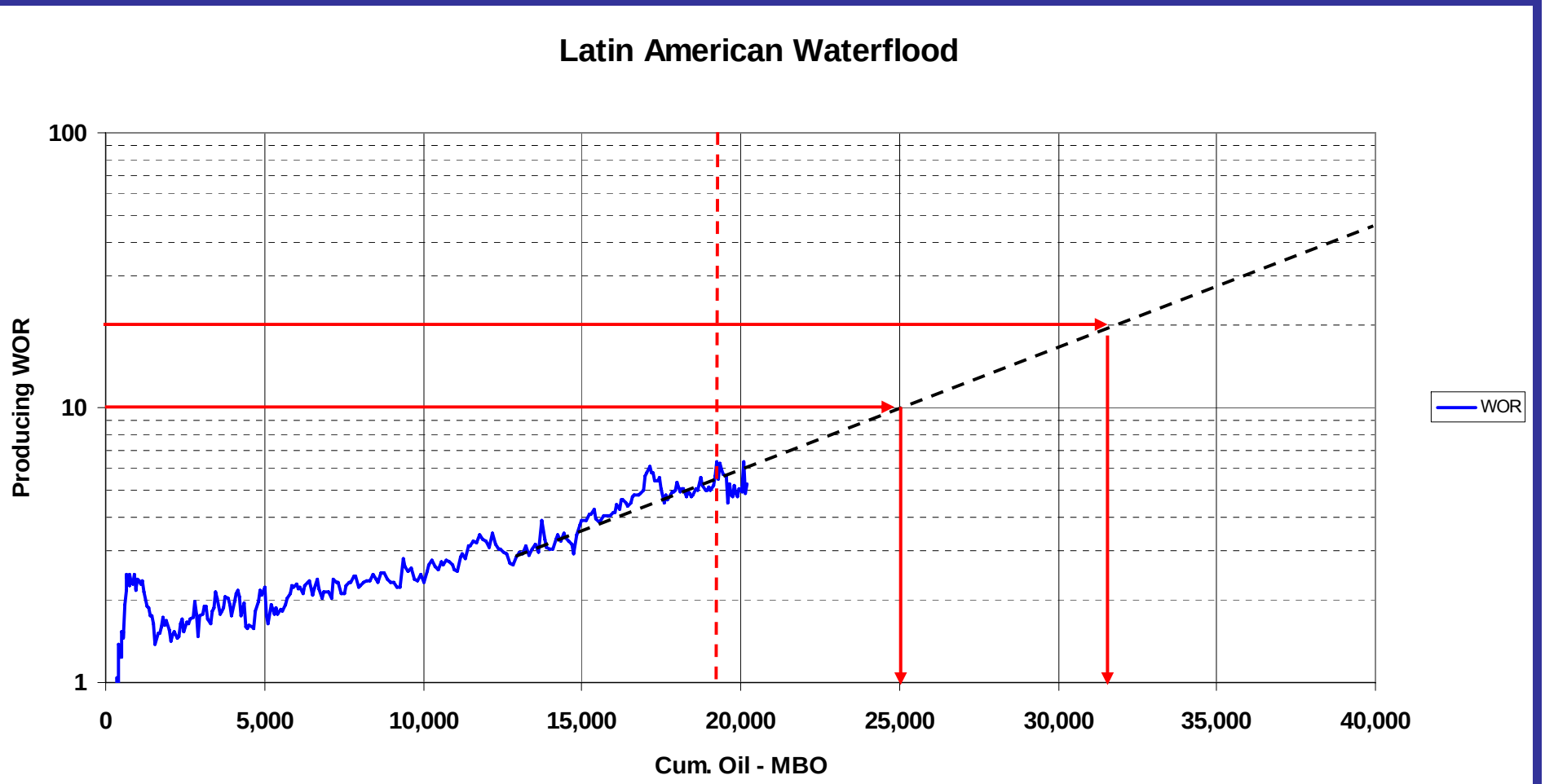
$$WOR = \frac{i_w * E_{inj} * f_w}{i_w * E_{inj} * (1 - f_w)}$$

$$WOR = \frac{f_w}{(1 - f_w)}$$

$$(WOR)_{STD.COND.} = \frac{f_w}{(1 - f_w)} * \frac{B_o}{B_w}$$

Conclusion:

- ✓ WOR is independent of injection rate
- ✓ WOR should be applied to individual wells and not field
- ✓ WOR is dependent on permeability variation (V-factor)
- ✓ WOR should be applied using values greater than 2.0 and less than about 50.0


Latin American Waterflood
100
10
1
Producing WOR
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Cum. Oil - MBO
WOR

A Friendly Reminder
Waterflood Operations

- Cartesian Plots of Oil Rate versus Cumulative Oil Production Should Be Prepared on A Well Basis
- Semi-log Plots of WOR versus Cumulative Oil Production Should Be Prepared on A Well basis
- Preparation of the Above Two Plots For The Entire Field Gives an Average Result Which May be Optimistic or Pessimistic
- Keep the fluid levels in the producing wells pumped off

Have there been Recent Developments in Waterflooding Technology??

- **NO!**

  & YES!????

  BUT . . .

- Improved application of old principles leads to better recovery

What Are the Key Elements of a Successful Waterflood?

- High Moveable Oil Saturation
- Moderate to Low Oil Viscosity
- Favorable Relative Permeability
- Low Permeability Variation
- Symmetrical Patterns
- Ability to Inject Large Volumes of Water
- Ability to Lift Large Volumes of Produced Water
- Keep Fluid Levels in Producing Wells Pumped OFF

What are the Pitfalls of Waterflooding Practices?

- Failure to clearly distinguish between ***Static*** OOIP and ***Dynamic*** OOIP (Primary vs Secondary)
- Failure to collect sufficient quantity and quality of reservoir data
- Failure to timely convert oil wells to injection wells
- Failure to keep fluid levels in producing wells pumped off – this is critical!!!!
- Failure to monitor injection water quality
- ***Failure to keep the Ax sharp***

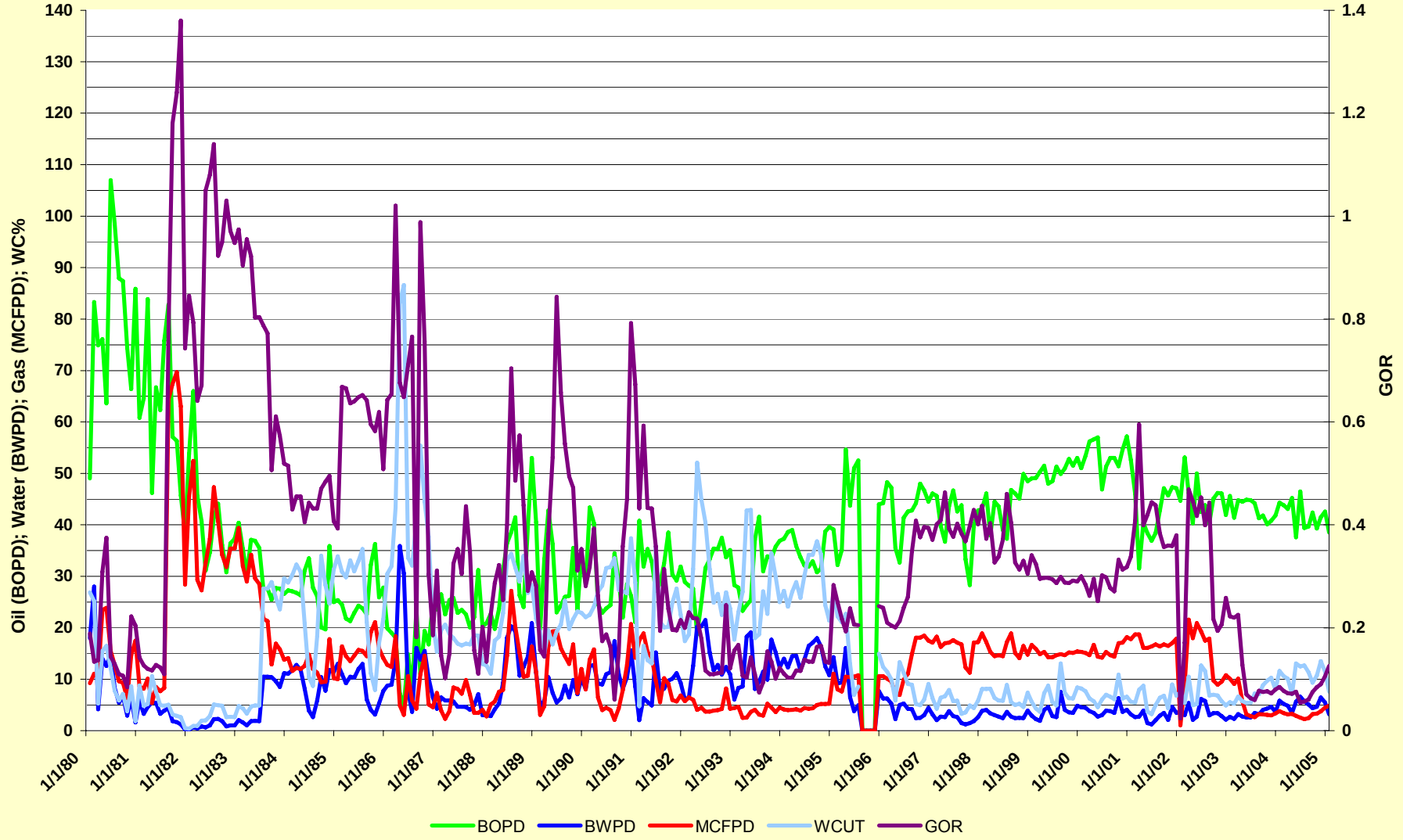
Summary of New Waterflood Paradigms

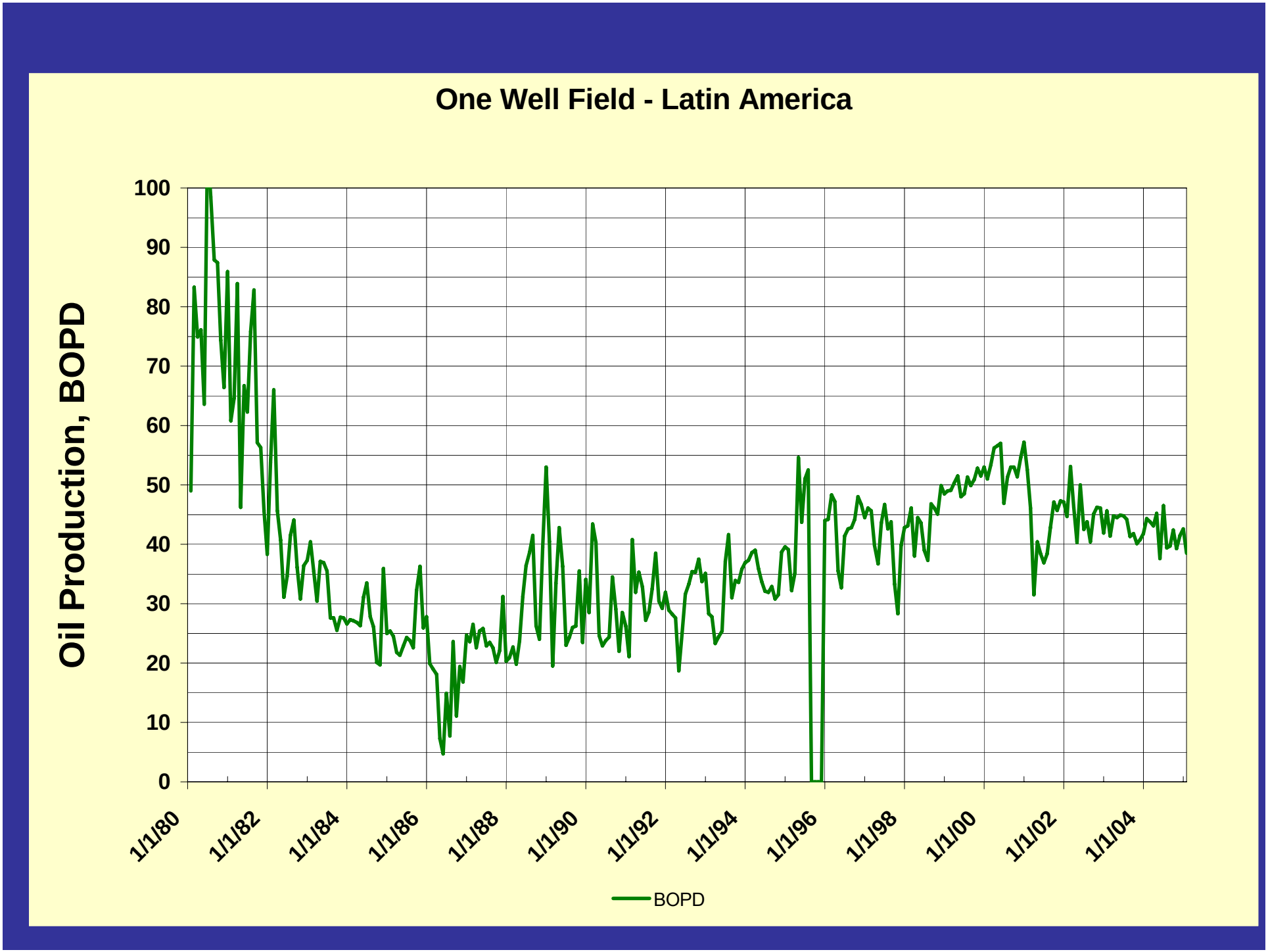
- Remember the Quarterback
  (The Injector)
- Keep the End in Mind
  (Maximize Volumetric Sweep)
- Keep the Ax Sharp
  (SPE meetings, SPE-TIGS, and SPE.org provide great opportunities to sharpen the mind!)

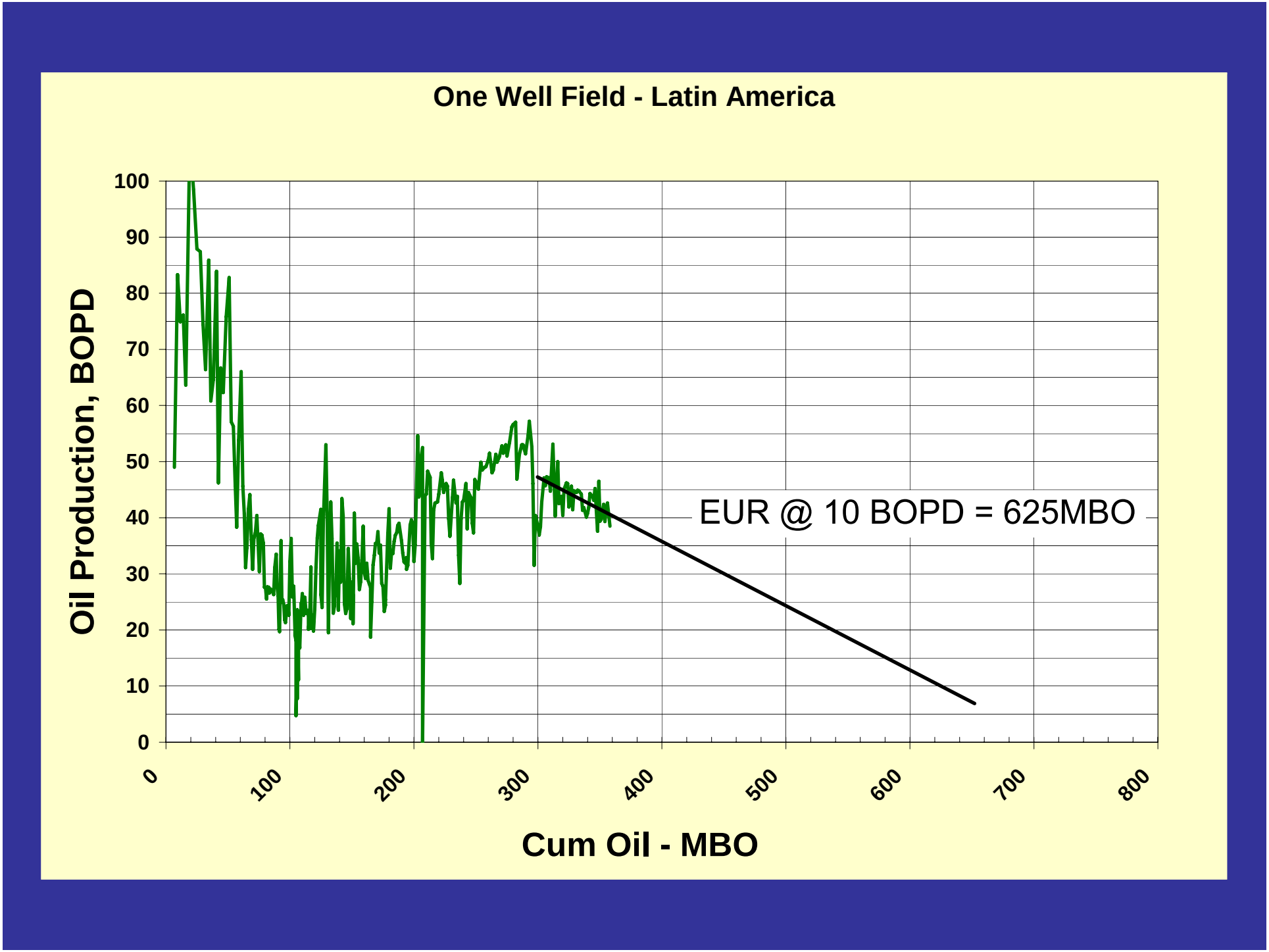
QUESTIONS

One Well Field - Latin America

Avoid the use of spaghetti graphs




One Well Field - Latin America
Oil Production, BOPD
100
90
80
70
60
50
40
30
20
10
0
1/1/80
1/1/82
1/1/84
1/1/86
1/1/88
1/1/90
1/1/92
1/1/94
1/1/96
1/1/98
1/1/00
1/1/02
1/1/04
BOPD


One Well Field - Latin America
Oil Production, BOPD
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
Cum Oil - MBO
EUR @ 10 BOPD = 625MBO

Practical Reservoir Management Considerations for Mature Waterfloods