Waterflooding

A Tried and True Technique for Secondary Oil Recovery

Houston Bar Association

Oil, Gas and Mineral Law Section

March 26, 2013

F. J. "Deacon" Marek, P.E
President
William M. Cobb & Associates, Inc.
Dallas, Texas

Brian R. Sullivan, P.E
Attorney/Petroleum Engineer
McElroy, Sullivan, Miller, Weber & Olmstead, LLP
Austin, Texas

General Topics

- What is a “waterflood”?
- How does it work?
- What types of properties make better candidates?
- Unitization
  - Why is it sometimes needed?
  - How does the process work?
  - Example equity formula

What is a Waterflood?

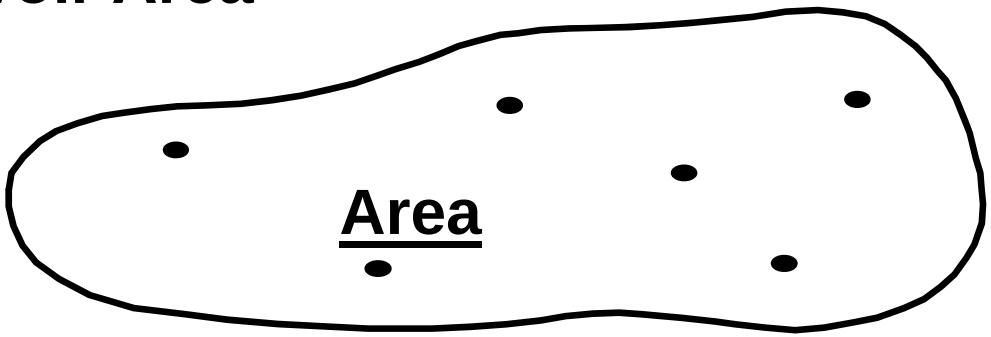
- It is the injection of water into a wellbore to push, or “drive” oil to another well where it can be produced
- Recognized enhanced oil recovery technique since early 1900’s
- Some oil reservoirs have natural water influx, which increases oil production
  - Called “water drive” reservoirs
  - They are natural “waterfloods”

How Does a Waterflood Work?

- Oil reservoirs and “Original Oil in Place”
- Oil recovery under “primary” production
- Target oil for waterflood recovery

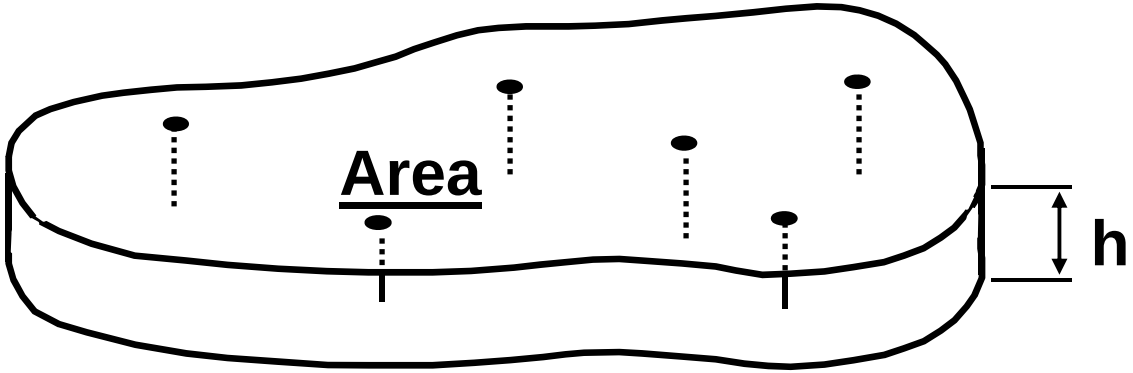
Bulk Volume Calculations

Reservoir Area



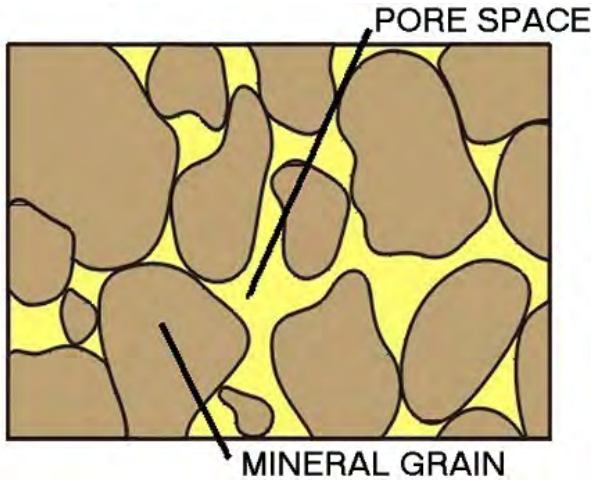
Reservoir Bulk Volume (BV) :

BV = Area x Thickness



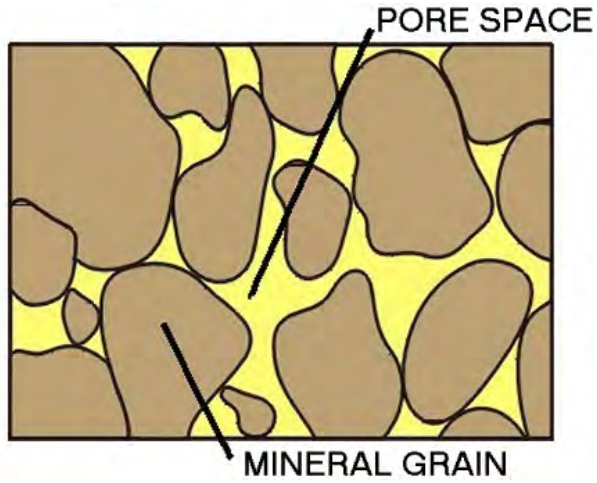
Calculating Original Oil in Place (OOIP)

- Bulk Volume
  - Area
  - Thickness
- **Porosity**
  - **Pore space within the rock**
  - **Generally 5% to 30% of the bulk volume**



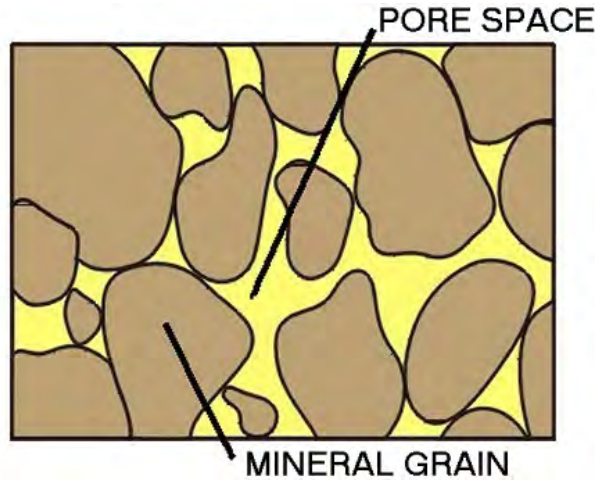
Calculating Original Oil in Place (OOIP)

- Bulk Volume
  - Area
  - Thickness
- Porosity
- **Fluid saturations**
  - **Water (usually 10% to 50% of pore space)**
  - **Oil**



Calculating Original Oil in Place (OOIP)

- Bulk Volume
  - Area
  - Thickness
- Porosity
- Fluid saturations
  - Water
  - Oil
- **Shrinkage (oil formation volume factor)**



Formation Volume Factor (Bo)

- Oil “shrinks” as it is produced from the reservoir to the surface due to…
  - gas evolving from the oil
  - Lower temperature at the surface
- The sales unit for oil is a “stock tank barrel”, or STB, which is equal to 42 US gallons
- Units of Bo are RB/STB (reservoir barrels per stock tank barrel)
- Bo in typical waterflood projects ranges from about 1.1 to 1.5 RB/STB

Calculating Original Oil in Place (OOIP)

$$OOIP = 7{,}758 * A * h * \phi * (1 - S_w) / B_o$$

Where:

OOIP = original oil in place, STB

7,758 = factor converting acre-feet to barrels

A = reservoir area, acres

h = average reservoir thickness, feet

ϕ = average reservoir porosity, fraction bulk volume

S_w = average water saturation, fraction pore volume

B_o = oil formation volume factor, RB/STB

Example Calculation

Problem - Calculate OOIP oil for a new oil well with the following conditions:

Reservoir area = 40.0 acres

average reservoir thickness = 25 feet

average reservoir porosity = 22%

average water saturation = 30%

oil formation volume factor = 1.32 RB/STB

Example Calculation

$OOIP = 7{,}758*A*h*\phi*(1-S_w)/B_o$

OOIP = 7,758*40*25*0.22*(1-.30)/1.32

OOIP = 905,100 STB

So once we've calculated OOIP……

So once we've calculated OOIP……

How much of that oil is recoverable?

The Amount of Recoverable Oil Depends on the Natural (Primary) Reservoir Drive Mechanism

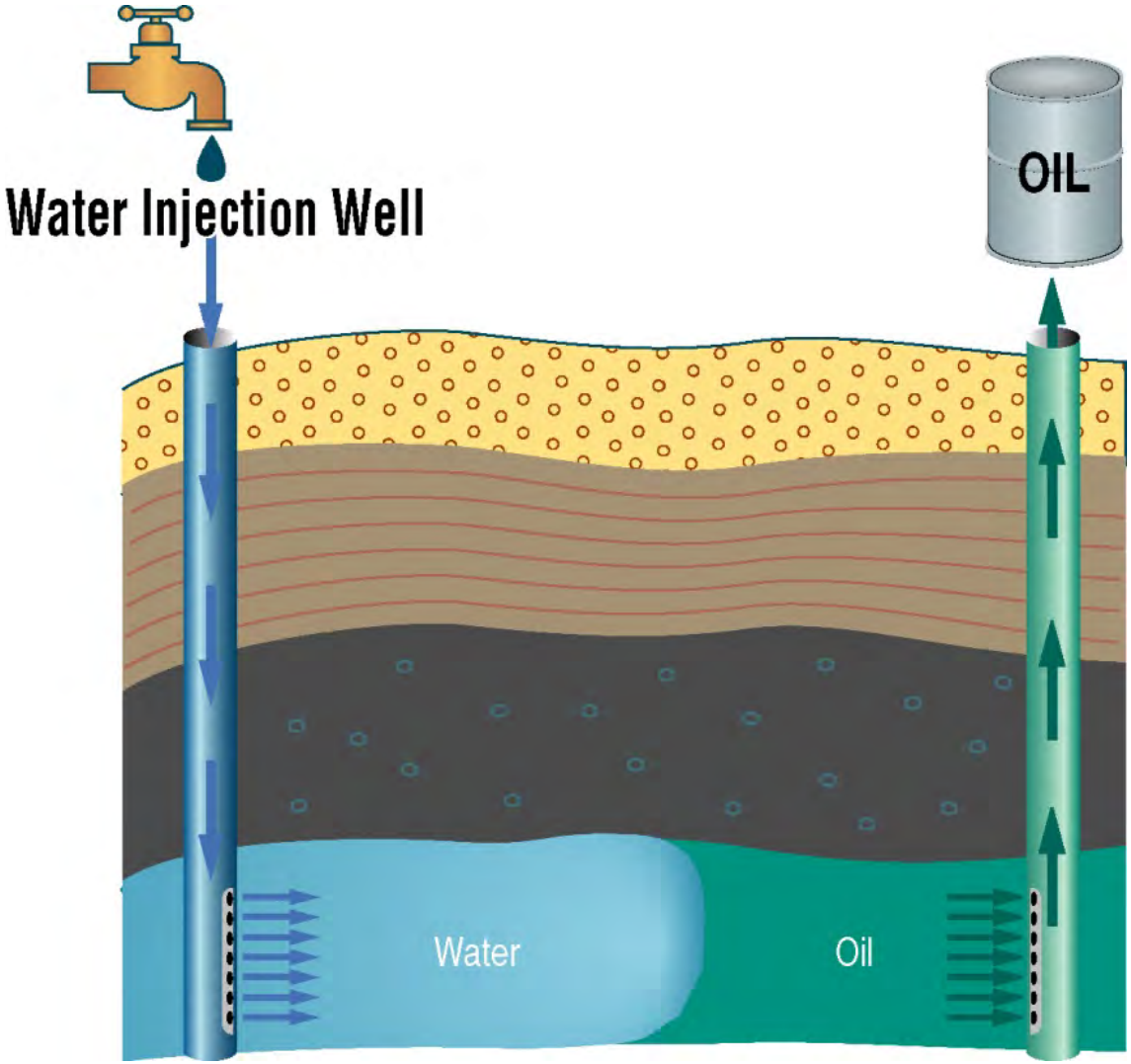
- Solution Gas Drive
  - Recovers 5% to 15% OOIP
  - Leaving behind 85% to 95% of the OOIP
- Solution Gas Drive + Gas Cap Expansion
  - Recovers 15% to 25% OOIP
  - Leaving behind 75% to 85% of the OOIP
- Natural Water Drive
  - Recovers 25% to 50% OOIP
  - Leaving behind 50% to 75% of the OOIP

Why would you need to waterflood?

- MANY (majority?) oil reservoirs are solution gas drive
- Waterflooding can recover much of the oil left behind under “Primary” production, especially a solution gas drive system
- Since waterflooding usually follows “primary” production, it is often called a “secondary” recovery technique

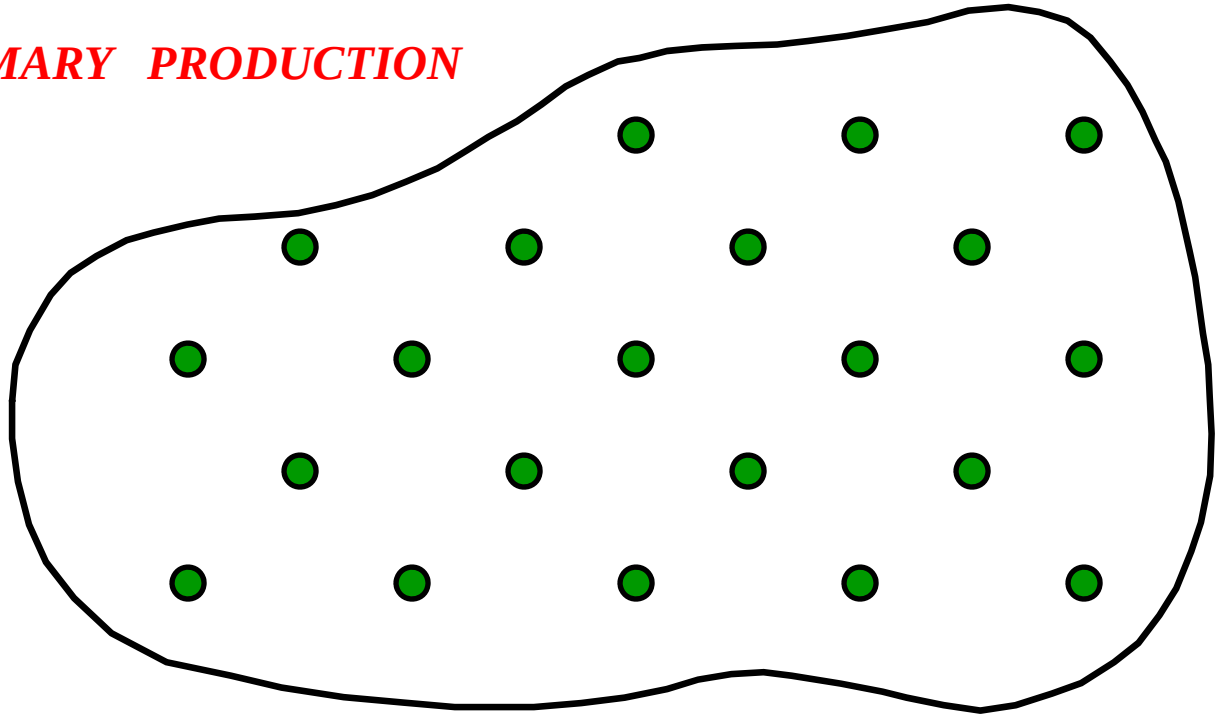
How does a waterflood work?

- Certain oil wells are converted to water injection wells
- Other oil wells remain as producers
- The injected water displaces, or “pushes” oil to the producing wells


Water Injection Well
OIL
Water
Oil

Waterflood Example

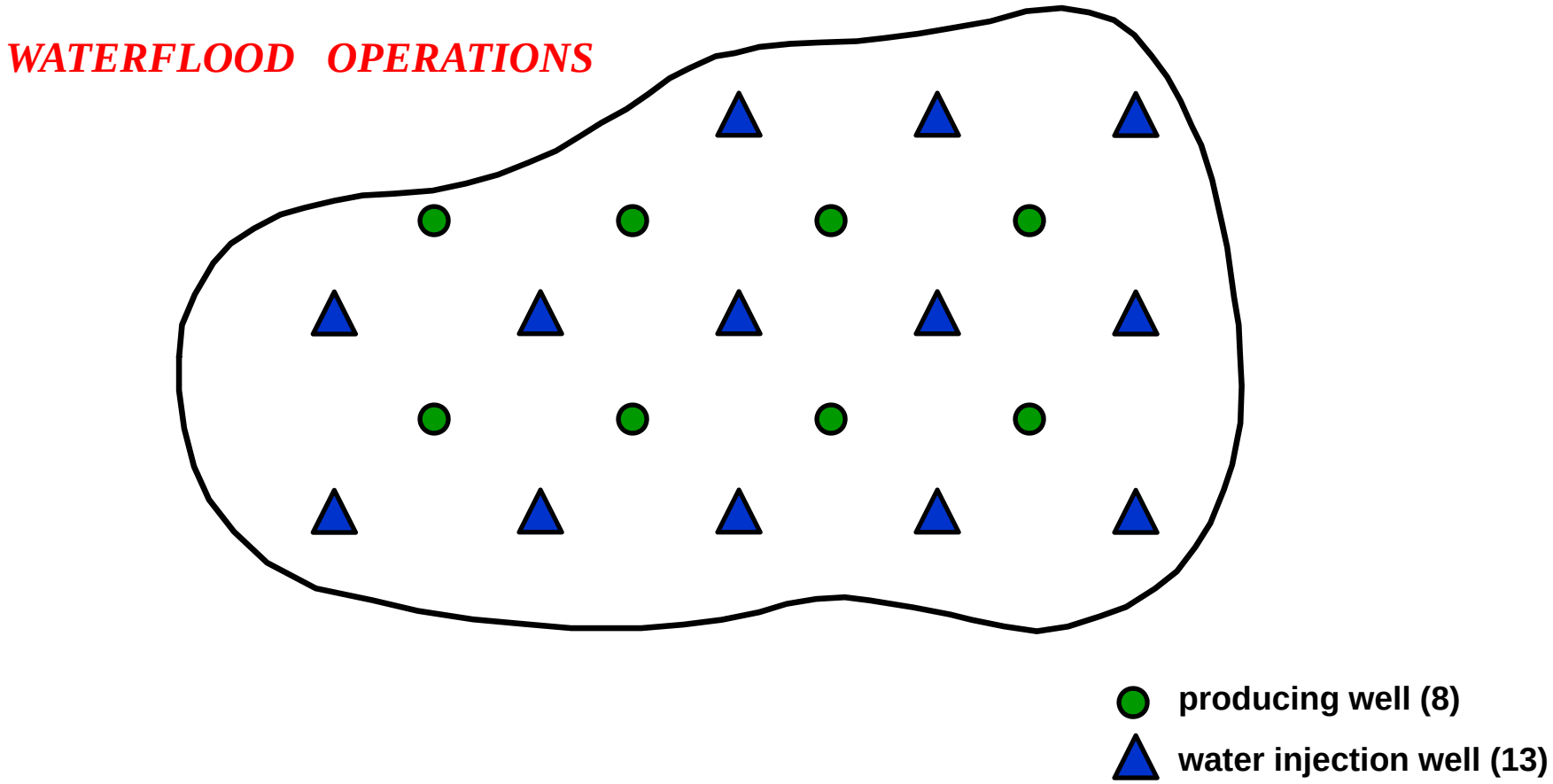
PRIMARY PRODUCTION



producing well (21)

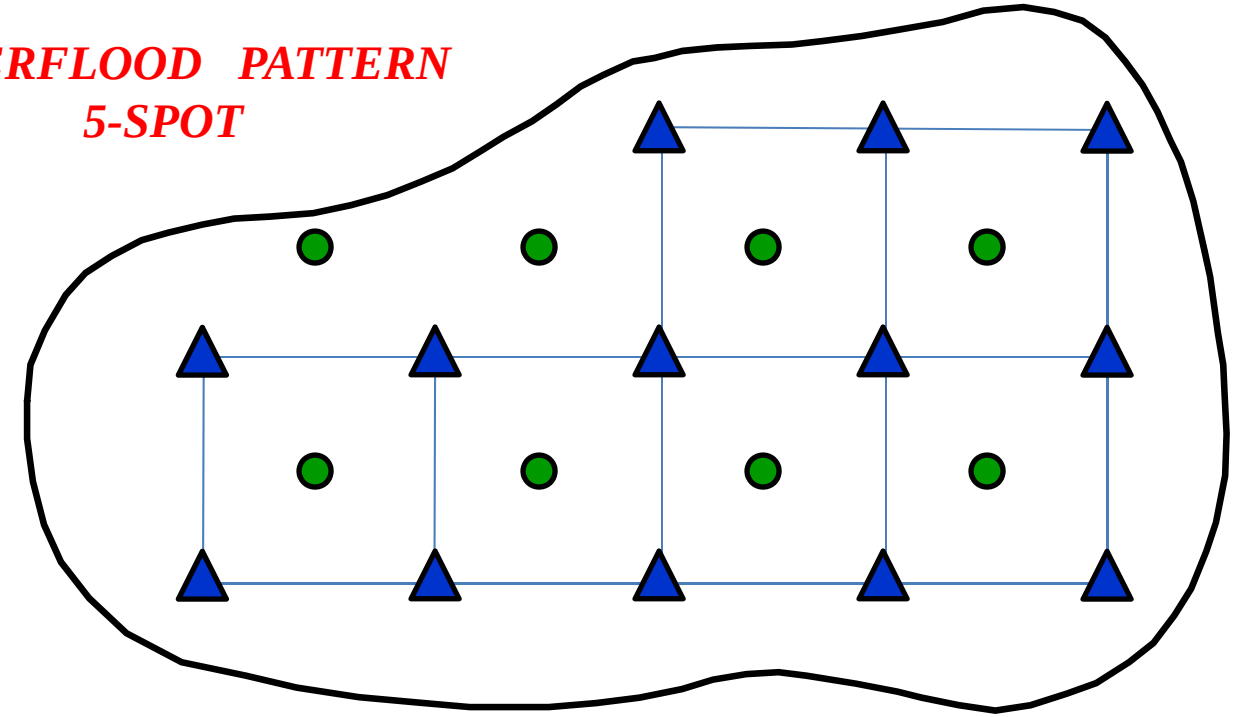
water injection well (0)

Waterflood Example



Waterflood Example

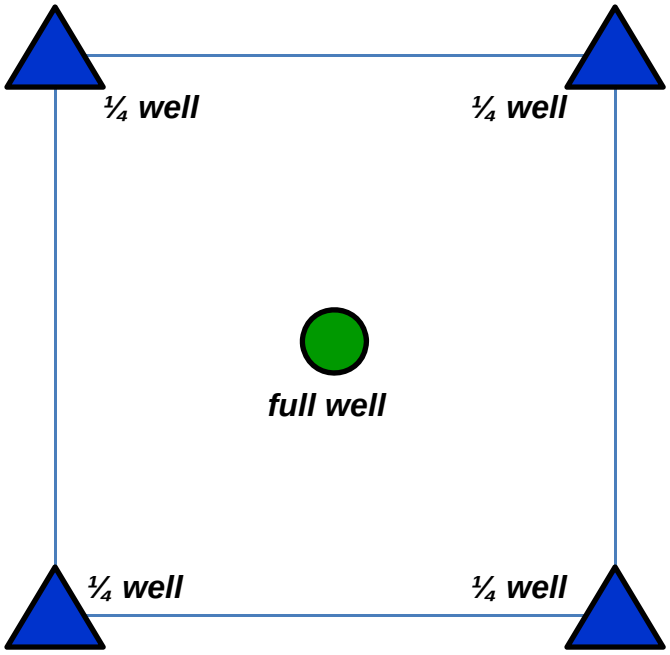
WATERFLOOD PATTERN
5-SPOT



producing well (8)

water injection well (13)

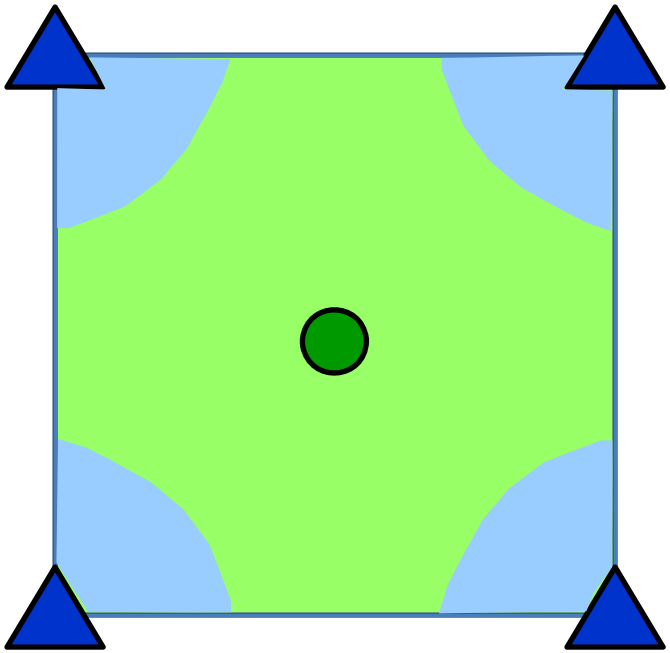
5-Spot Waterflood Pattern



A single 5-Spot pattern has:

One net producer, and one net injector, or two total wells

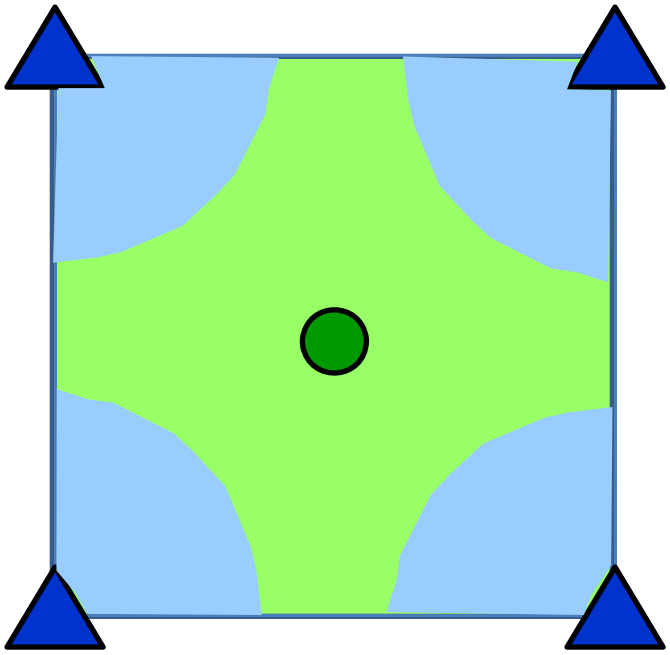
Waterflood Progression



Time 1

Early in life of waterflood.
Producer making 100% oil.

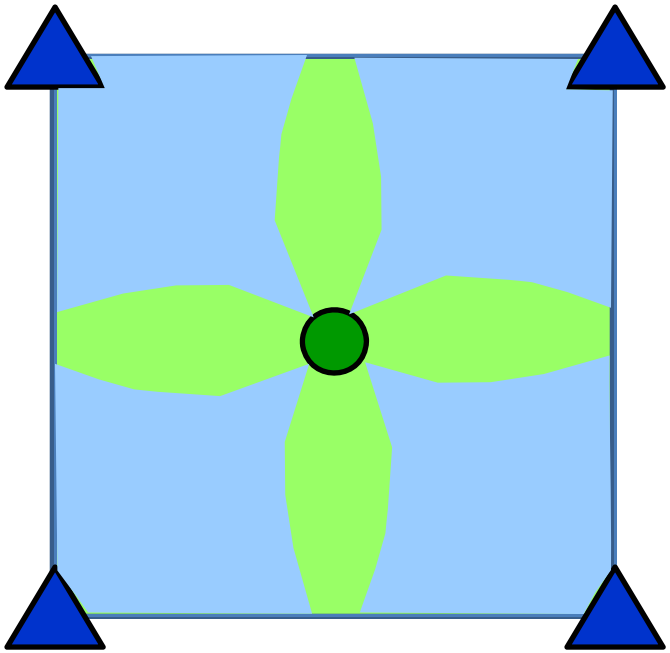
Waterflood Progression



Time 2

Still relatively early in life of waterflood. Water banks expanding, but producer still making 100% oil.

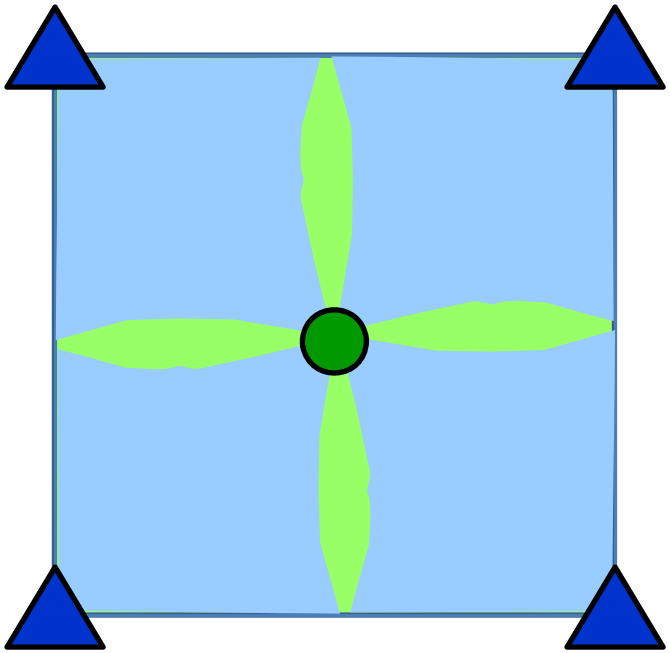
Waterflood Progression



Time 3

Mid-life of the waterflood. Water has reached the producing well. Producer now makes oil and water.

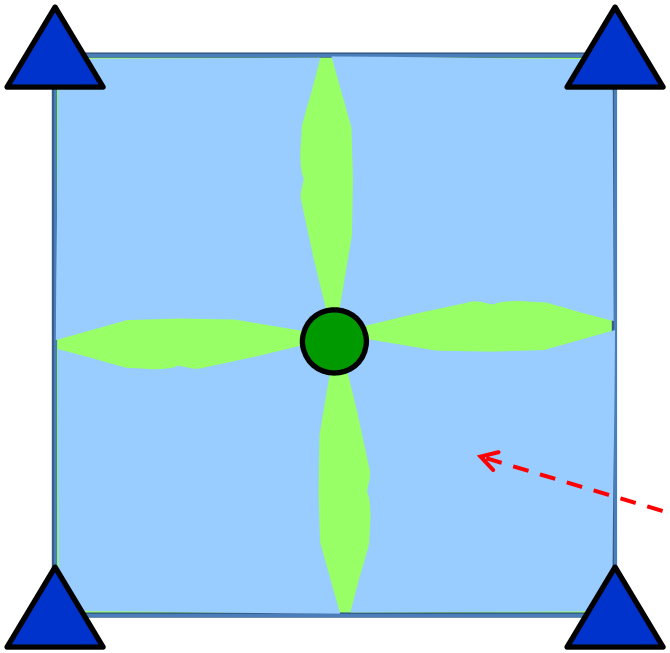
Waterflood Progression



Time 4

Late in the life of the waterflood. Producer now making large volume of water compared to the oil volume.

Waterflood Progression



Time 4

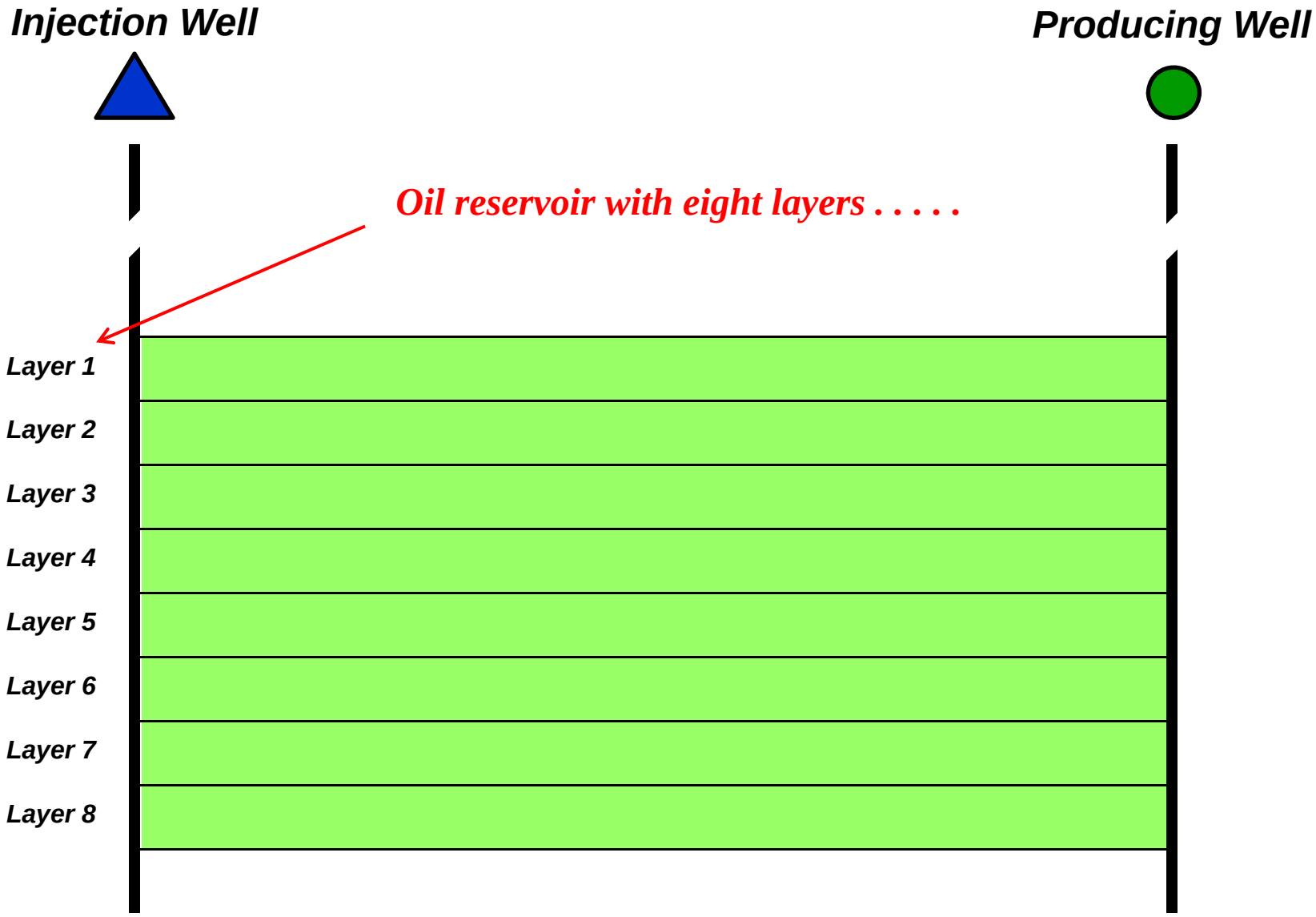
Late in the life of the waterflood. Producer now making large volume of water compared to the oil volume.

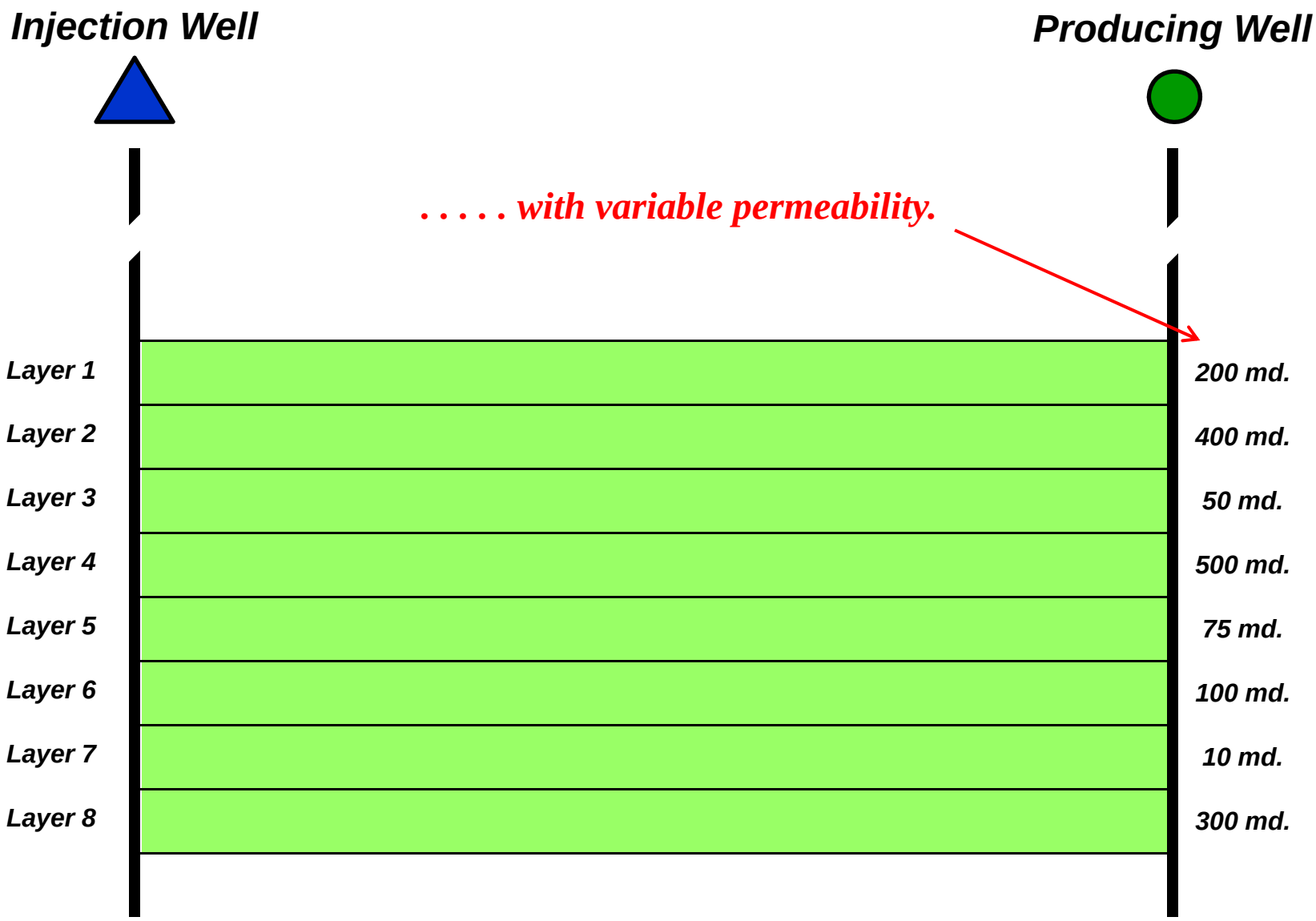
The effectiveness of the water "sweeping" the area of the pattern is called the "areal sweep efficiency", or E_a .

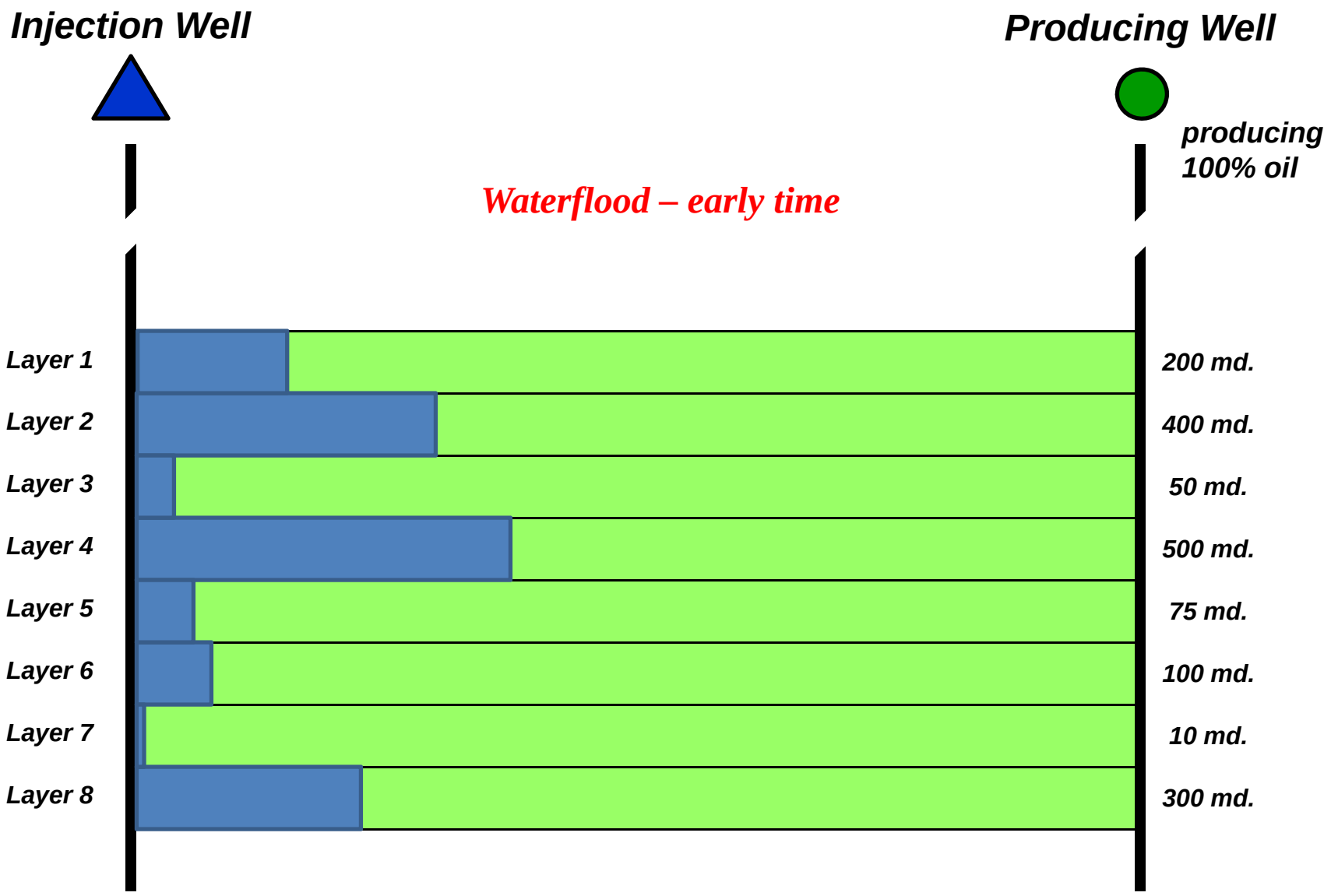
A waterflood also works in the vertical dimension…..

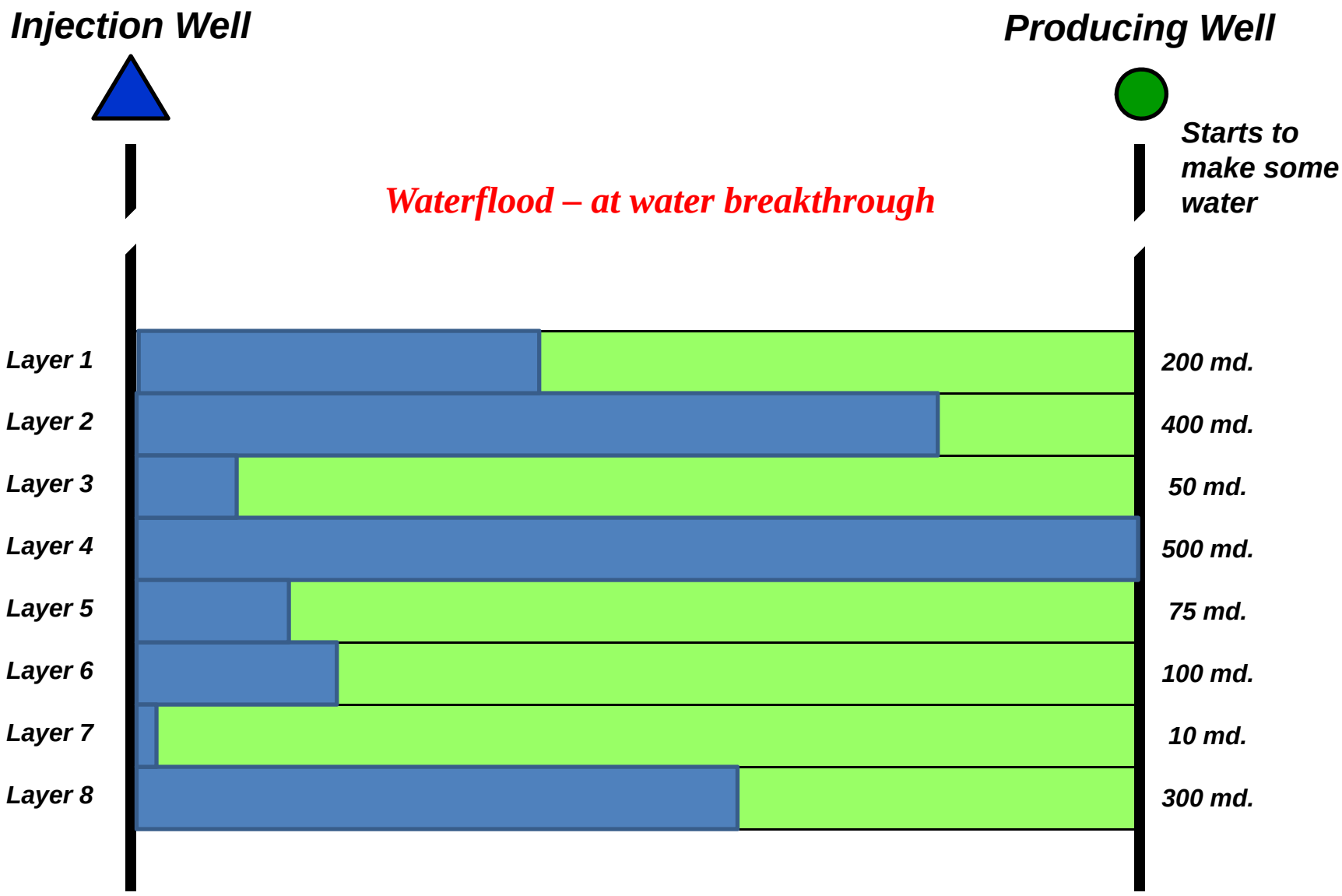
Permeability

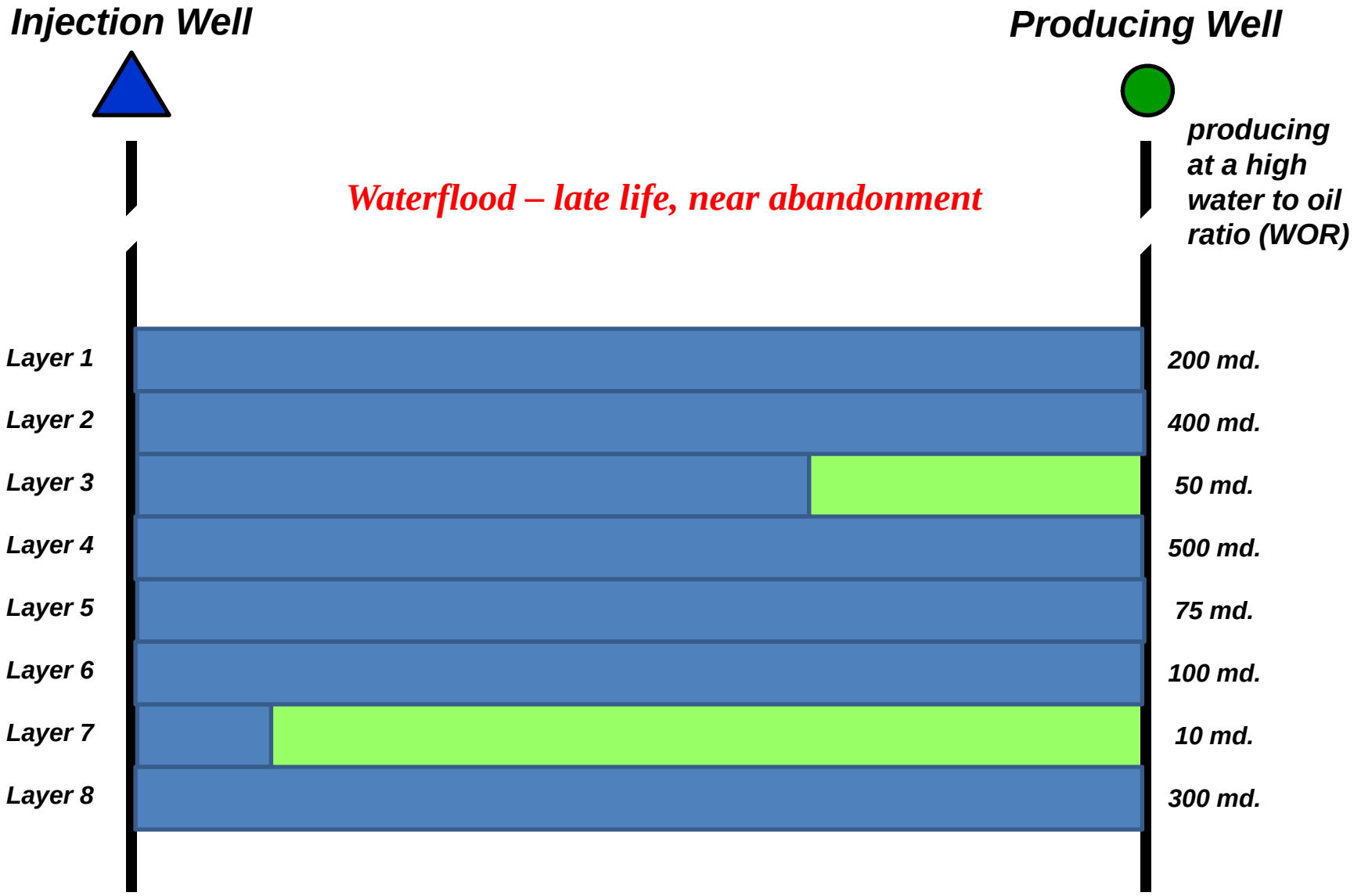
- Permeability, measured in milidarcy's (md.), is a measurement of a rock's ability to transmit fluid
- Water injection rate will be a function of permeability
- Most oil reservoirs have multiple layers with varying permeability values

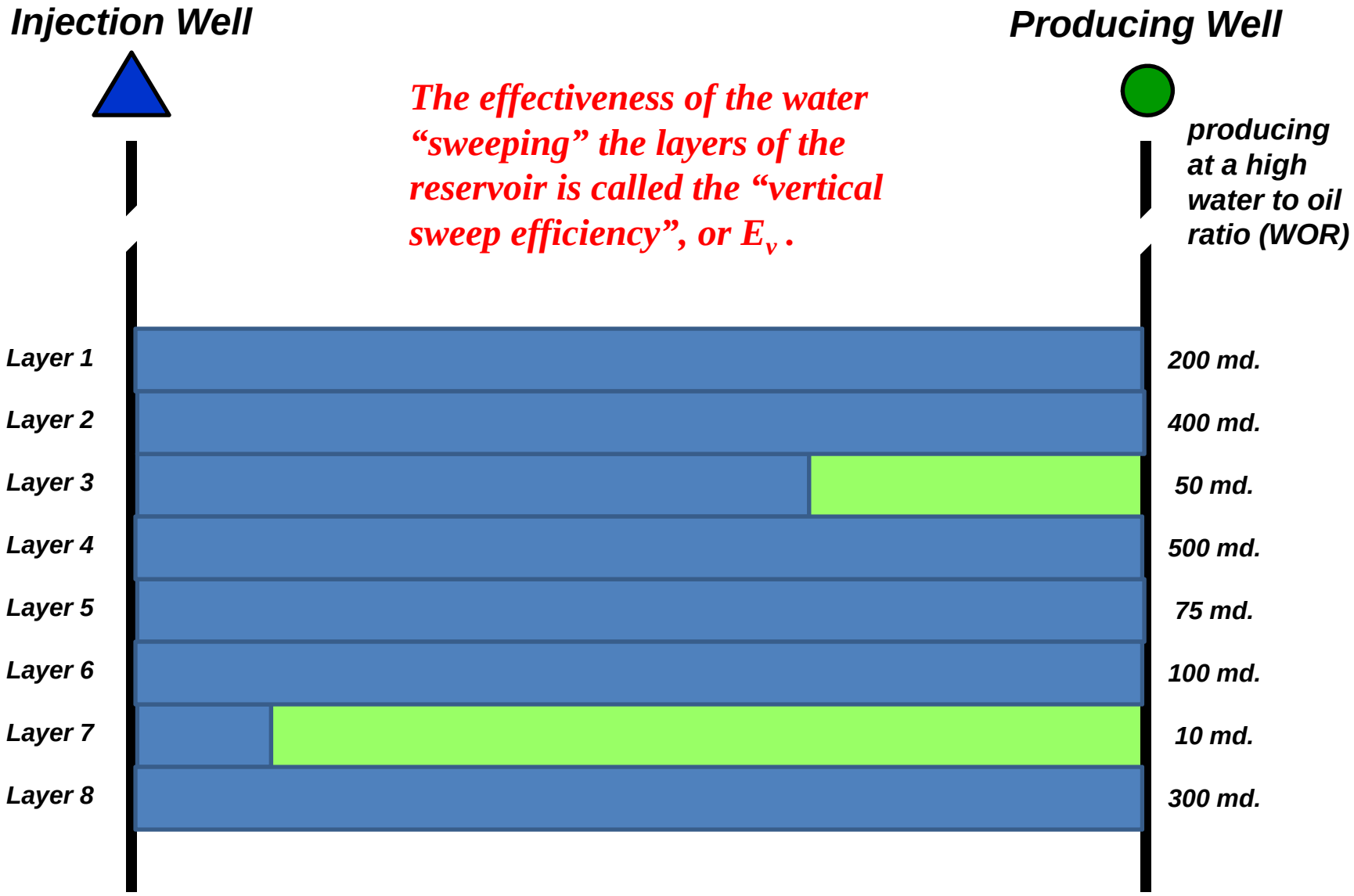

Injection Well
Producing Well
Oil reservoir with eight layers . . . . .
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8


Injection Well
Producing Well
. . . . . with variable permeability.
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
200 md.
400 md.
50 md.
500 md.
75 md.
100 md.
10 md.
300 md.


Injection Well
Producing Well
producing
100% oil
Waterflood – early time
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
200 md.
400 md.
50 md.
500 md.
75 md.
100 md.
10 md.
300 md.


Injection Well
Producing Well
Starts to make some water
Waterflood – at water breakthrough
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
200 md.
400 md.
50 md.
500 md.
75 md.
100 md.
10 md.
300 md.


Injection Well
Producing Well
producing at a high water to oil ratio (WOR)
Waterflood – late life, near abandonment
Layer 1
200 md.
Layer 2
400 md.
Layer 3
50 md.
Layer 4
500 md.
Layer 5
75 md.
Layer 6
100 md.
Layer 7
10 md.
Layer 8
300 md.


Injection Well
Producing Well
The effectiveness of the water "sweeping" the layers of the reservoir is called the "vertical sweep efficiency", or E_v .
producing at a high water to oil ratio (WOR)
Layer 1
200 md.
Layer 2
400 md.
Layer 3
50 md.
Layer 4
500 md.
Layer 5
75 md.
Layer 6
100 md.
Layer 7
10 md.
Layer 8
300 md.

Factors Affecting Waterflood Success

- Timing of flood – earlier is better
  - Higher primary depletion (lower pressure) increases gas saturation
  - High gas saturation decreases oil recovery
- Well spacing
  - Tighter well spacing is better
  - Increases E_a and E_v
  - accelerates waterflood recovery
- Pattern selection
  - Balanced patterns improve E_a and WOR performance

Waterflood Recovery Potential

- Should recover an additional 10% to 40% of the reservoir OOIP
- A term commonly used is the secondary to primary ratio (S/P)
  - Primary is the expected ultimate primary oil recovery
  - Secondary is the incremental waterflood recovery
  - S/P ratio of 1+ is generally expected

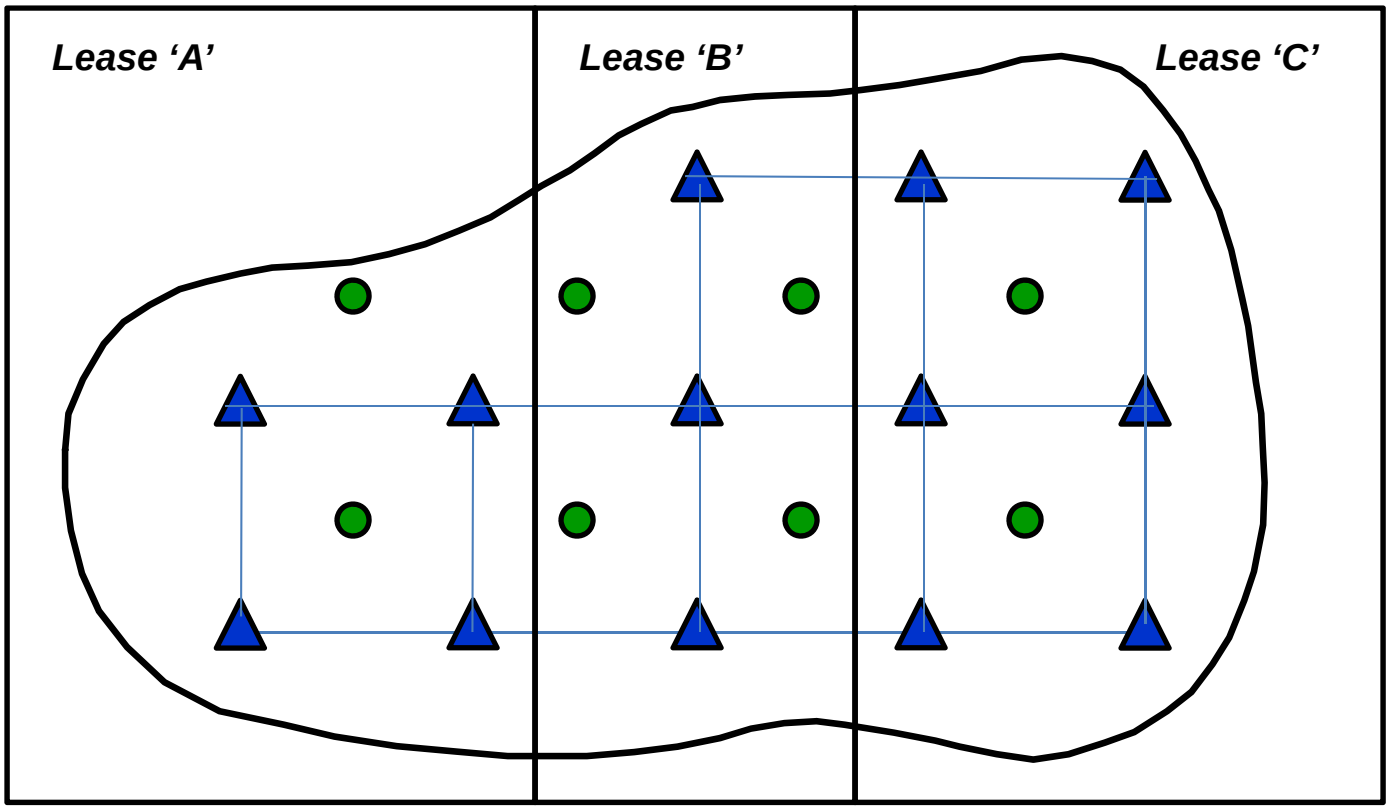
Types of Oil Reservoirs More Favorable for Waterflood

- Shallower is better
  - Cheaper drilling and operating costs
  - Typically lower primary recovery
- Low energy oil (low B_o)
  - Lower primary oil recovery
  - Lower gas saturation
- Higher permeability is better
  - Process the waterflood faster
  - May utilize wider well spacing (cheaper)

Unitization for Waterflooding

- May be needed when reservoir underlies different leases with different ownership
- A waterflood unit combines the leases into a common entity for waterflood operations
  - Allows for more efficient development and operation
  - Maximizes oil recovery
- Requires an “equity formula” to properly compensate all owners

Unitization Example



producing well (8)

water injection well (13)

Unitization in Texas

Legal Perspective

Unitization in Texas

- "A term frequently used interchangeably with Pooling, but **more properly used to denominate the joint operation of all or some portion of a producing reservoir** as distinguished from pooling, which term is used to describe the bringing together of small tracts sufficient for the granting of a well permit under applicable spacing rules.
- Williams & Meyers, "Manual of Oil and Gas Terms"

Unitization in Texas

- Unitization DOES NOT require approval of the Texas Railroad Commission.
- Private Units
- “Say No” Boundaries

Unitization in Texas

- Commission approved units must comply with Texas Natural Resources Code Chapter 101 titled “Cooperative Development”
- Statute first passed in 1949
- Not Updated

Unitization in Texas

- Unit Agreement
  - Negotiating the Equity Formula
    - "blue-eyed grandchildren"
- Unit Operating Agreement

Third Edition
January 1970

MODEL FORM

of

UNIT AGREEMENT

(With Supplement)

AMERICAN PETROLEUM INSTITUTE
Washington, D.C. 20037

Issued by
AMERICAN PETROLEUM INSTITUTE
Production Department
211 N. Ervay, Suite 1700
Dallas TX 75201

Model Form of Statutory Unit Agreement

API MODEL FORM 5U03
SECOND EDITION, JUNE 1, 1993

American Petroleum Institute
220 L Street, Northwest
Washington, DC 20005

Model Form of
Voluntary Unit Agreement

API MODEL FORM 5U01
FOURTH EDITION, JUNE 1, 1993

American Petroleum Institute
1220 L Street, Northwest
Washington, DC 20005

Model Form of
Voluntary Unit Operating Agreement

API MODEL FORM 5U02
FOURTH EDITION, JUNE 1, 1993

American Petroleum Institute
1220 L Street, Northwest
Washington, DC 20005

Unitization in Texas

- Railroad Commission Requirements
  - 65% Royalty Interest Sign-Up to the Unit Agreement
  - 85% Working Interest Sign-up to the Unit Agreement
  - "The Twenty Questions"
    - All interest owners offered to participate on the same yardstick basis

Unitization in Texas

1. Persons entering into and submitting agreement own or control production, leases, royalty or other interests in same field.
2. Agreement was voluntarily entered into (a) to establish pooled units for secondary recovery operations, or (b) to establish pooled unit for conservation and utilization of gas.
3. Agreement is necessary to accomplish purposes in No. 2.
4. Such agreement is in interest of public welfare as reasonably necessary to prevent waste and promote conservation.
5. Rights of all owners in field, whether signing or not, will be protected.

Unitization in Texas

6. Estimated additional cost will not exceed value of additional oil and gas.
7. Other available methods inadequate.

8a. Area covered contains only such part of field as reasonably defined by development.

8b. The owners of interest in the oil and gas under each tract within area reasonably defined by development have been given opportunity to enter into such agreement on same yardstick basis as owners of interests in oil and gas in other tracts in the unit.

9. Unit described in unit agreement sufficient to accomplish purposes of Unitization Act.

Unitization in Texas

10. Such agreement is subject to any valid order, rule, or regulation of the Commission relating to location, spacing, proration, conservation or other matters within the authority of the Commission.
11. Such agreement does not attempt to contain field rules for the area or field.
12. Such agreement does not provide for nor limit the amount of production of oil or gas from the unit properties.

13a. Such agreement does not bind any landowner, royalty owner, lessor, lessee, royalty interest owner or any other person who does not execute same, but binds only the persons who execute it.

13b. No person has been compelled or required to enter into such agreement.

Unitization in Texas

14. Such agreement does not provide directly or indirectly for the cooperative refining of crude petroleum.
15. Such agreement does not provide for the cooperative refining of crude petroleum, condensate, distillate or gas, or any by-produce thereof.
16. Such agreement is not a voluntary agreement for the joint development and operation of jointly-owned properties.
17. Such agreement does not restrict any of the rights which persons now have to make and enter into unitization and pooling agreements.

18a. Such agreement does or does not provide for the location and spacing of input wells and for the extension of leases covering any part of lands committed to the unit.

Unitization in Texas

18b. No such agreement shall relieve any operator from the obligation to develop reasonably the lands and leases as a whole committed thereto.

19. Agreement may provide that the dry gas after extraction of hydrocarbons may be returned to a formation underlying any lands committed to the agreement.

20. When it appears from such agreement or otherwise that ownership of any lands or properties described in such agreement is any party or parties named in Sections 2 and 3 of said Act, the requirements of said Sections of said Act should be complied with.

Unitization in Texas

- House Bill 100 – Taylor
- "Oil and Gas Majority Rights Protection Act"
- Proposed Chapter 104 of TNRC
- "Compulsory Unitization"
  - 70% Royalty Interest Sign-Up
  - 70% Working Interest Sign-up
  - Applies to
    - Repressuring
    - Waterflooding
    - Pressure Maintenance
    - Tertiary recovery operations
    - Any other similar operations

    -Commission may investigate the soundness of the equity formula (remember the "blue-eyed grandchildren")

Unit Tract Participation Factors - Example

					T O T A L >	***1.000***
			0.100	**0.400**	**0.400**	**0.100**
Tract	**Lease**	**Tract Participation**	**Surface acres**	**OOIP MSTB**	**current BOPD**	**useable wells**
1	Lease 'A'	0.28149773	200	2,100	31	6
2	Lease 'B'	0.28827399	100	1,600	52	7
3	Lease 'C'	0.43022828	220	2,500	74	8
	TOTALS	**1.00000000**	**520**	**6,200**	**157**	**21**

Lease 'A' Ownership

Owner	Net Rev. Interest	Tract Participation	Unit Ownership
Good Operating, Inc.	0.750000	0.281498	0.211123
John Geologist	0.050000	0.281498	0.014075
James Farmer	0.120000	0.281498	0.033780
Edith Farmer	0.080000	0.281498	0.022520
	1.000000		0.281498