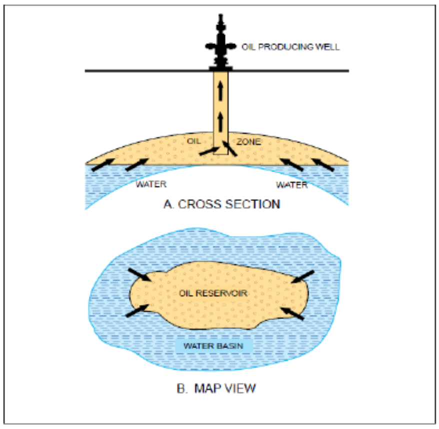
WATER INFLUX

- **Aquifers** are water bearing rocks surround nearly all hydrocarbons reservoirs.
- These aquifers may be larger than the oil/gas reservoirs to appear infinite in size, and they may be so small in size as to be negligible in their effect on reservoir performance.



- Many gas/oil reservoirs are produced by a mechanism termed ***water drive.***
- This drive comes in a form of *water influx,* usually called ***water encroachment,*** which is due to:

✓ Expansion of the water in the aquifer.

✓ Compressibility of the aquifer rock

Water Influx Characteristics

- The hydrocarbon and aquifer are part of the same reservoir system responding to the various pressure changes resulting from the production of fluids.
- The most significant characteristics of a water drive system are:
  1. Pressure decline is very gradual.
  2. Excess water production occurs in structurally low wells.
  3. The gas-oil ratio normally remains steady during the life of the reservoir.
  4. A good recovery of oil can be anticipated

- Water influx models focuses on those reservoir-aquifer systems in which the size of the aquifer is large enough and the permeability of the rock is high enough that water influx occurs as the reservoir is depleted.

Classification of Aquifers

Reservoir-aquifer systems are classified on the basis of:

- Degree of pressure maintenance.
- Flow regimes.
- Outer boundary conditions.
- Flow geometries.

Degree of Pressure Maintenance

- Based on the degree of the reservoir pressure maintenance, the water drive is often described as:

✓ Active water drive.

✓Partial water drive.

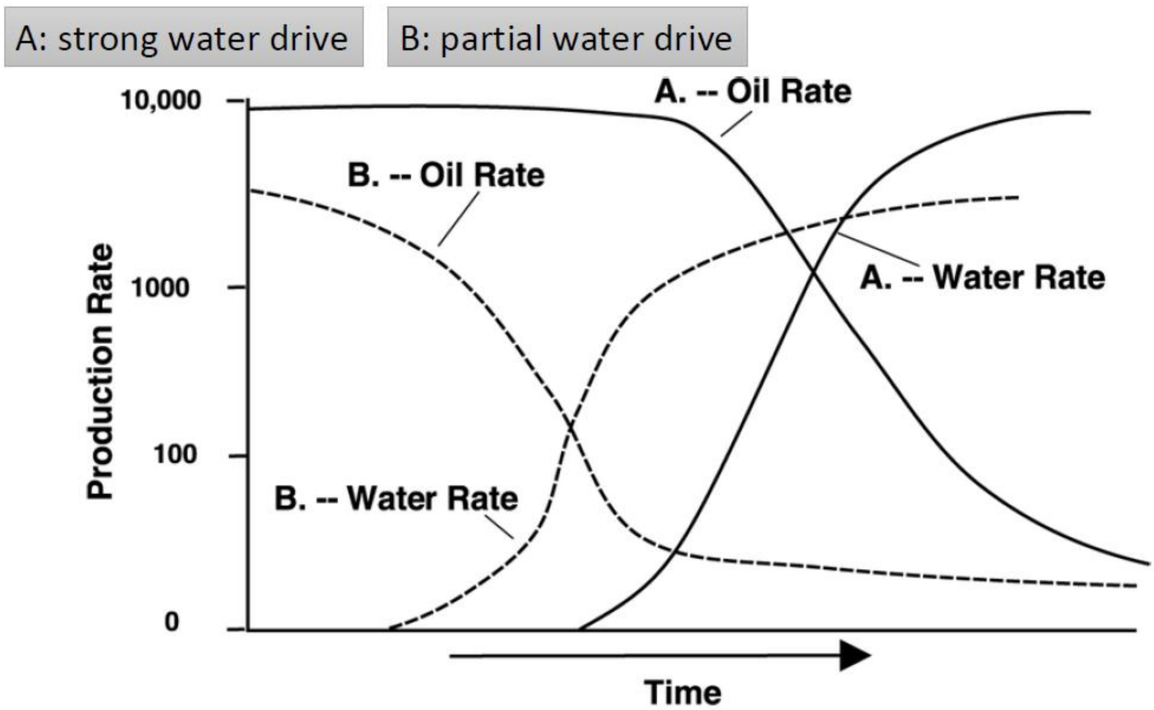
✓Limited water drive

Active(strong) Water Drive

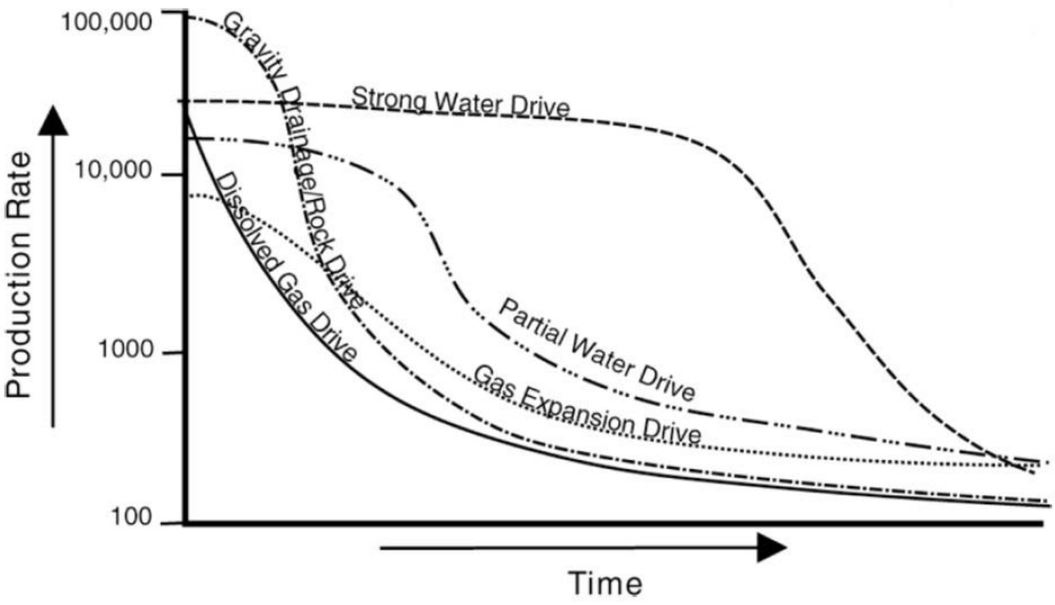
- A strong water drive provides very good pressure support from the aquifer (100% voidage replacement) with minimal pressure drop at the wellbore.
- The aquifer water expands slightly, displacing the oil or gas from the reservoir toward the borehole as pressure drops around the borehole.
- This mechanism exists only where the aquifer is of equal or better quality than the reservoir and has a much larger volume than the reservoir (about 10 times).
- A strong water drive is more effective in oil reservoirs than in gas reservoirs. ??
- On a semi-log plot of production decline, the curve tends to be flat.

Partial Water Drive

- A partial water drive results where an aquifer is smaller and/or has lower quality than the reservoir, i.e. there is limited expansion of water into the reservoir as oil or gas is withdrawn.
- In partial water drive, the hydrocarbon production rate drops more rapidly than in a reservoir with a strong water drive and recovery is reduced.
- Partial water drive production decline curve trends more concave upward on a semi-log plot than a decline curve for a strong water drive.



Decline Curves For Drive Types



- The ***active* water drive** is the water encroachment mechanism, in which the rate of water influx equals the reservoir *total* production rate.
- Active water-drive reservoirs are typically characterized by a gradual and slow reservoir pressure decline.

$$\begin{bmatrix}\text{water influx}\\ \text{rate}\end{bmatrix} = \begin{bmatrix}\text{oil flow}\\ \text{rate}\end{bmatrix} + \begin{bmatrix}\text{free gas}\\ \text{flow rate}\end{bmatrix} + \begin{bmatrix}\text{water production}\\ \text{rate}\end{bmatrix}$$

or

(1)

$$e_w = Q_o B_o + Q_g B_g + Q_w B_w$$

where e_w = water influx rate, bbl/day
Q_o = oil flow rate, STB/day
B_o = oil formation volume factor, bbl/STB
Q_g = **free** gas flow rate, scf/day
B_g = gas formation volume factor, bbl/scf
Q_w = water flow rate, STB/day
B_w = water formation volume factor, bbl/STB

In terms of cumulative production;

$$e_w = \frac{dW_e}{dt} = B_o \frac{dN_p}{dt} + (GOR - R_s)\frac{dN_p}{dt} B_g + \frac{dW_p}{dt} B_w \qquad (2)$$

where
W_e = cumulative water influx, bbl
t = time, days
N_p = cumulative oil production, STB
GOR = current gas-oil ratio, scf/STB
R_s = current gas solubility, scf/STB
B_g = gas formation volume factor, bbl/scf
W_p = cumulative water production, STB
dN_p/dt = daily oil flow rate Q_o, STB/day
dW_p/dt = daily water flow rate Q_w, STB/day
dW_e/dt = daily water influx rate e_w, bbl/day
$(GOR - R_s)dN_p/dt$ = daily free gas flow rate, scf/day

Outer Boundary Conditions

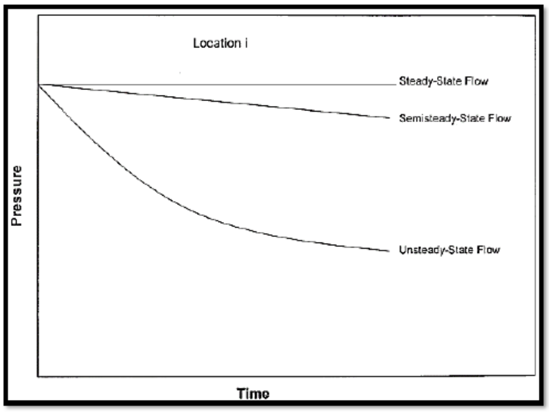
- The aquifer can be classified as infinite or finite (bounded).
- Geologically all formations are finite, but may **act as infinite** if the changes in the pressure at the OWC are not "felt" at the aquifer boundary.

A. **Infinite** system indicates that the effect of the pressure changes at the OWC boundary are not felt at the outer boundary of the aquifer. This boundary is at a constant pressure equal to initial reservoir pressure.

B. **Finite** system indicates that the aquifer boundary is affected by the influx into the oil zone and that the pressure at this boundary changes with time.

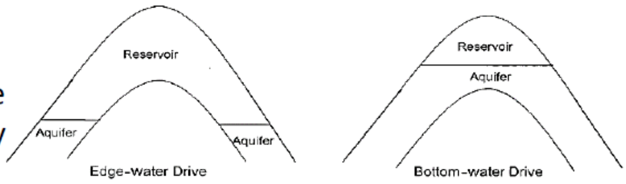
Flow Regimes

- There are basically three flow regimes that influence the rate of water influx into the reservoir. **These flow regimes are**:
- **Steady state** $\frac{dP}{dt} = 0$, The pressure does not change with time.
- **Pseudo steady state** $\frac{dP}{dt} = c$ **,** The pressure is declining linearly as a function of time, i.e., at a constant declining rate.
- **Unsteady state** $\frac{dP}{dt} \neq c$, The pressure derivative with respect to time is essentially a function of both position i and time t.



Flow Geometries

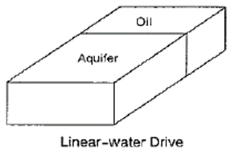
Reservoir-aquifer systems can be classified on the basis of flow geometry as:



a. Edge-water drive.

b. Bottom-water drive.

c. Linear-water drive.



- **Edge-Water Drive**, water moves into the flanks of the reservoir as a result of hydrocarbon production. The flow is radial with negligible flow in the vertical direction.
- **Bottom Water Drive** occurs in reservoir with large areal extent where the reservoir water contact completely underlies the reservoir. The flow is radial; the bottom drive has significant vertical flow.
- **Linear-Water Drive**, the influx is from one flank of the reservoir.

Water Influx Models

- Several models have been developed for estimating water influx that are based on assumptions that describe the characteristics of the aquifer.
- Due to the uncertainties in the aquifer characteristics, all of the proposed models require historical reservoir performance data to evaluate constants representing aquifer property parameters.

○ These Models are:

- **Pot Aquifer.**
- **Schilthuis Steady State.**
- **Hurst Modified Steady State.**
- **Van Everdingen and Hurst Unsteady State** a)) Edge Water b)) Bottom Water
- **Carter –Tracy Unsteady State**
- **Fetkovich** a)) Linear aquifer b)) Radial aquifer

The Pot Aquifer Model

- The *simplest model* that can be used to estimate the water influx into a gas or oil reservoir is based on the basic definition of **compressibility**.
- A drop in the reservoir pressure, due to the production of fluids, causes the aquifer water to expand and flow into the reservoir.
- The compressibility is defined mathematically as:

$$\Delta V = c \, V \, \Delta p \qquad (3)$$

- Applying the above basic compressibility definition to the aquifer gives:

Water influx = (aquifer compressibility) (initial volume of water)(pressure drop)

Or;

$$W_e = (c_w + c_f) \, W_i \, (p_i - p) \qquad (4)$$

where W_e = cumulative water influx, bbl
c_w = aquifer water compressibility, psi^{-1}
c_f = aquifer rock compressibility, psi^{-1}
W_i = initial volume of water in the aquifer, bbl
p_i = initial reservoir pressure, psi
p = current reservoir pressure (pressure at oil-water contact), psi

- Calculating the initial volume of water in the aquifer requires the knowledge of aquifer dimension and properties. If the aquifer shape is radial, then:

$$W_i = \left[\frac{\pi\left(r_a^2 - r_e^2\right) h \phi}{5.615}\right] \quad (5)$$

where r_a = radius of the aquifer, ft
r_e = radius of the reservoir, ft
h = thickness of the aquifer, ft
ϕ = porosity of the aquifer

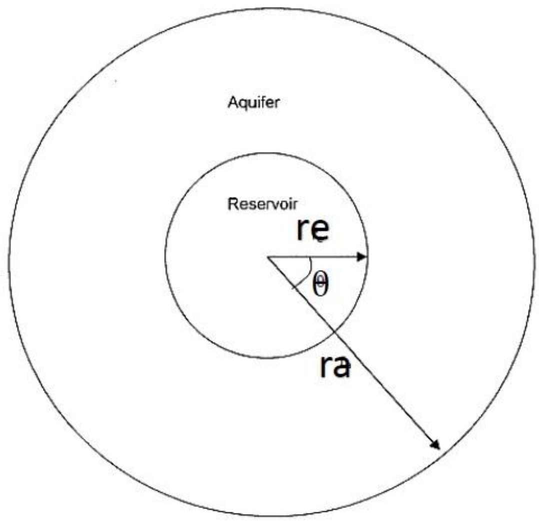
- Equation(4) suggests that water is encroaching in a radial form from all directions. Quite often, water does not encroach on all sides of the reservoir, or the reservoir is not circular in nature.
- To account for these cases, a modification to Equation(4) must be made in order to properly describe the flow mechanism.
- One of the simplest modifications is to include the **fractional encroachment angle f** in the equation(4) to give:

$$W_e = (c_w + c_f)\, W_i\, f\, (p_i - p) \quad (6)$$

where the **fractional encroachment angle f** is defined by:

$$f = \frac{(\text{encoachment angle})^\circ}{360^\circ} = \frac{\theta}{360^\circ} \quad (7)$$

- The pot aquifer model is only applicable to a small aquifer, i.e., pot aquifer, whose dimensions are of the same order of magnitude as the reservoir itself.



Example: Calculate the cumulative water influx that results from a pressure drop of 200 psi at the oil-water contact with an encroachment angle of 80°. The reservoir-aquifer system is characterized by the following properties:

	Reservoir	Aquifer
radius, ft	2600	10,000
porosity	0.18	0.12
c_f, psi^{-1}	4×10^{-6}	3×10^{-6}
c_w, psi^{-1}	5×10^{-6}	4×10^{-6}
h, ft	20	25

Solution

Step 1. Calculate the initial volume of water in the aquifer from Equation (5).

$$W_i = \left[\frac{\pi\left(r_a^2 - r_e^2\right) h \phi}{5.615}\right]$$

$$W_i = \left(\frac{\pi\left(10{,}000^2 - 2600^2\right)(25)(0.12)}{5.615}\right) = 156.5 \text{ MMbbl}$$

Step 2. Determine the cumulative water influx by applying Equation 6.

$$W_e = (c_w + c_f)\, W_i\, f\, (p_i - p)$$

$$W_e = (4+3)\, 10^{-6}\, (156.5 \times 10^6)\left(\frac{80}{360}\right)(200) = 48{,}689 \text{ bbl}$$