Chapter 1

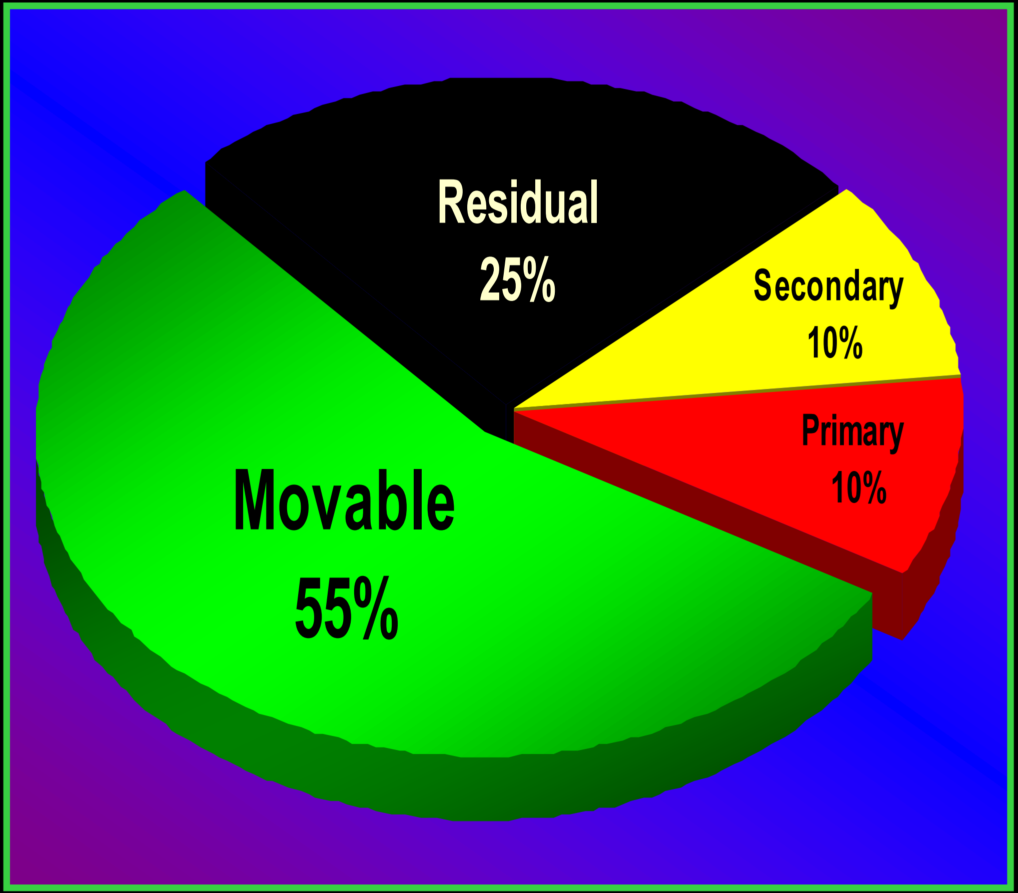
RESERVOIR

Chapter 1

Will a horizontal well make sense (cents) in my candidate reservoir?

Are there economic reserves to provide a satisfactory rate of return?

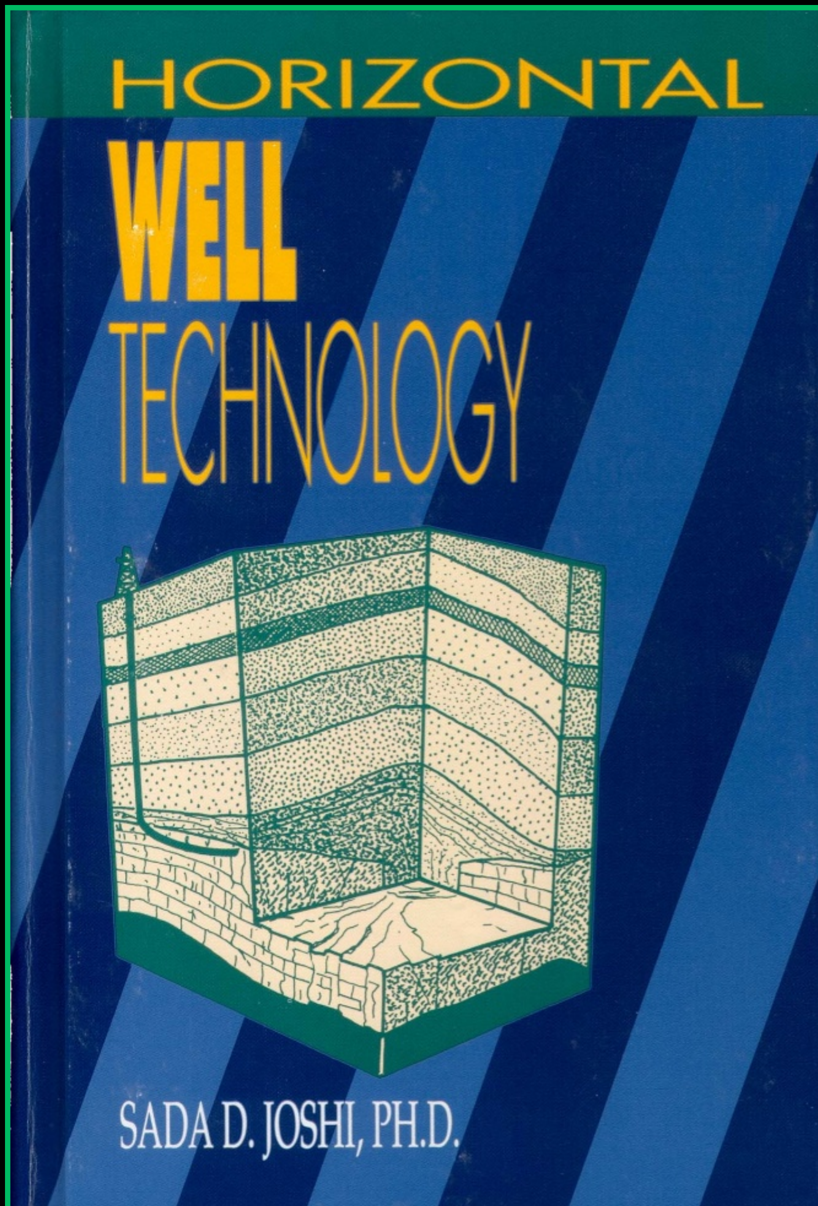
Recoverable Oil



Reservoir Considerations

The first portion of the chapter is an abridged version of material from Dr. Sada Joshi's book and other published papers of his and is used with his permission.

JTI



Dr. S.D. Joshi

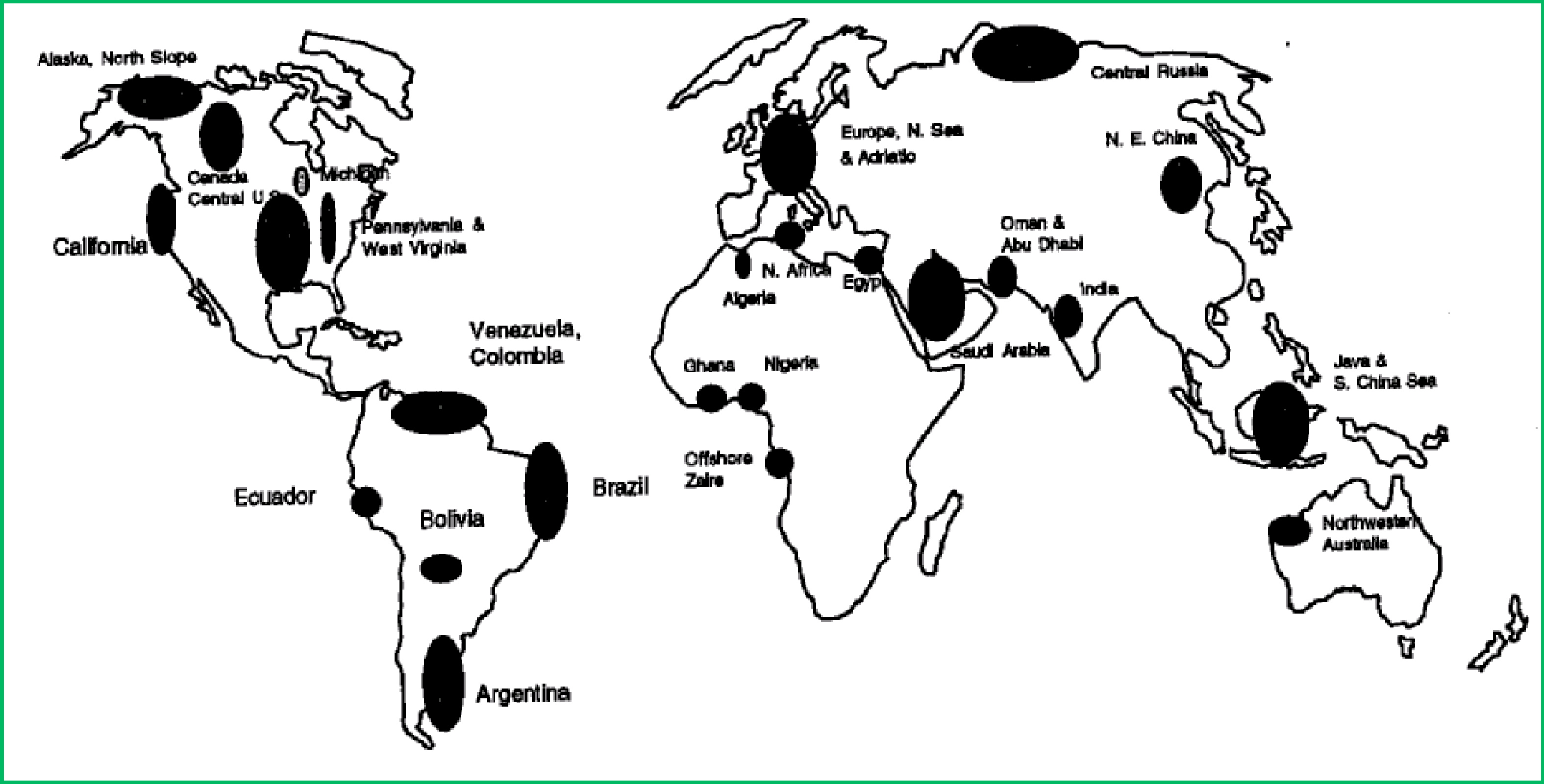
Objectives

Selecting reservoirs for horizontal well application

Important parameters that affect screening and commercial success

Worldwide Horizontal Drilling Activity

JTI



Horizontal Wells

As of 2001:

Over 17,000 wells in the United States

Over 12,000 wells in Canada

About 5,000 wells in the rest of the world!

Horizontal Wells Applications

- Natural fractures
- Thin zones (7 to 10 ft thick)
- Coning applications, Infill Drilling
- Tight gas formations (k ~ 0.01 md)
- Conventional gas reservoirs
- Waterfloods (Texas, Utah, Canada, Middle East)
- CO_2 floods (West Texas)
- Heavy oil (Canada, California, Venezuela)
- Shale reservoirs
- Coal bed methane

Issues

- Well Rate
- Well Reserves
- Well Cost
- Probability of Success

Approximate Horizontal Well Costs

Onshore:

- New horizontal well from the surface
  = 2 to 2.5 times vertical well costs

- Re-entry horizontal well
  = 0.6 to 1.2 times vertical well costs

Horizontal Well Rates

Stabilized rates of horizontal wells are 2 to 4 fold more than stabilized rates of vertical wells.

Horizontal Well Reserves

Horizontal well reserves are observed to be the same as to as high as 6 times vertical well reserves.

In certain cases, where vertical wells are uneconomical, per well reserves of a horizontal can be significantly higher than a vertical well reserves.

Productivity Improvement Factor

Comparing the performance of 12,080 horizontal wells and 137,950 off-set vertical wells drilled as of December 2001:

1) Medium productivity improvement factor is in the range of 3 to 5.
2) After five years of production, the cumulative oil production from horizontal wells is about 2 times larger (range 1.5 to 3) than the cumulative oil production from vertical wells.
3) About one in three horizontal wells have been economic failures. Thus, economic success rate of horizontal wells is 66%.

Key Parameters

- Fracture intensity and direction
  - Primary recovery – well should be perpendicular to natural fractures
  - Secondary recovery – well should be parallel to natural fractures
- Net pay – contiguous zone
- Well spacing
- Vertical & horizontal permeability

Key Parameters

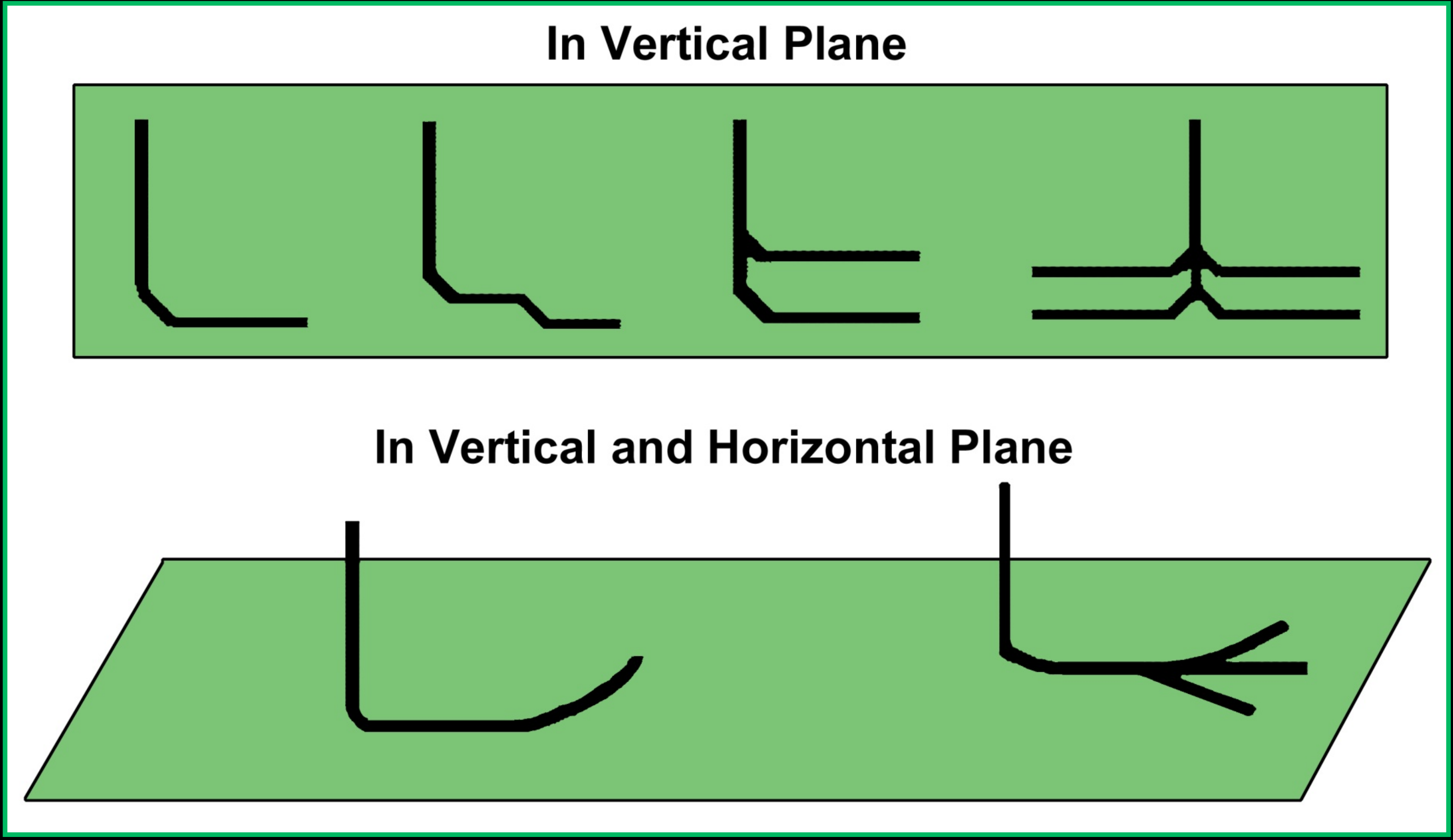
JTI

- Areal anisotropy (directional permeability)
- Formation damage and required cleanup
- Multi-well program (learning curve)
- Geological control
- Reservoir bottom hole pressure

Key Parameters

- Drilling Costs
- Completion Costs
- Wellbore size and length
- Cooperation in various disciplines
- Confidence in reservoir simulation (modeling)

Well Configurations



Potential Formation Damage Guidelines

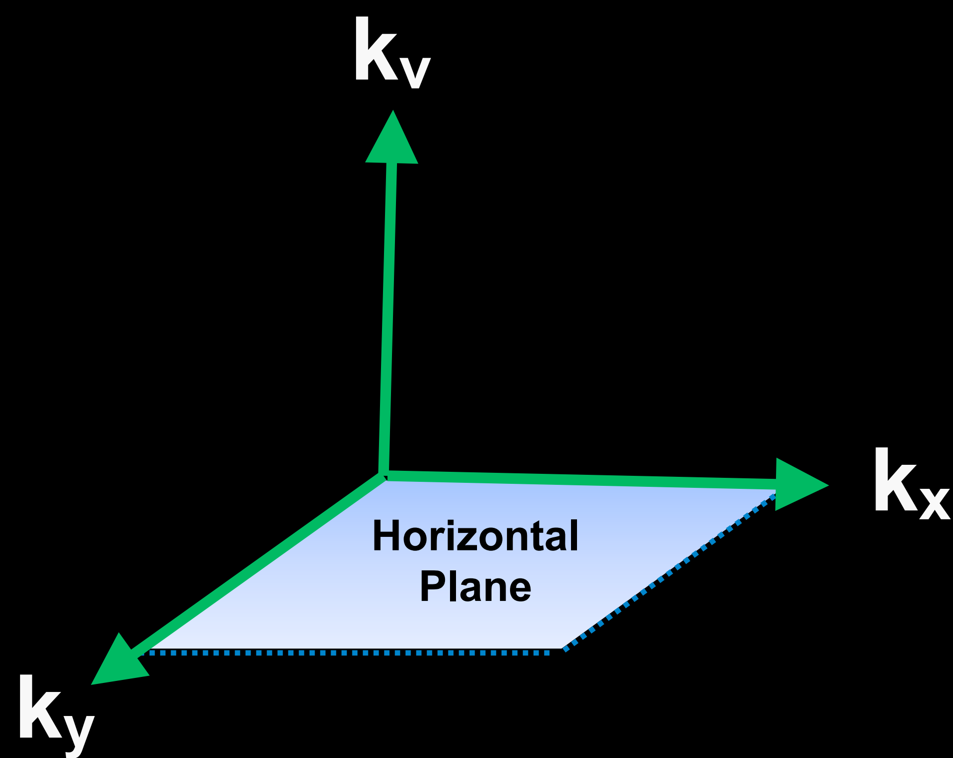
Oil Wells:

k > 1 Darcy	No damage
k ~ 500 md	Minimum damage
k < 100 md	Formation problems likely
k < 10 md	Serious formation damage probable

Gas Wells:

k > 10 md	Minimum to no damage
k < 5 md	Some damage
k < 1 md	Formation damage likely

Permeability Anisotropy



k_y / k_x indicates magnitude of anisotropy

$$k_h = \sqrt{k_x k_y} = \text{effective horizontal perm}$$

Ask yourself these questions:

Does a vertical well in your field produce satisfactory economics?

What is your horizontal well AFE cost in relation to actual vertical well costs?

Risk Management

If horizontal AFE cost is greater than 2.5 to 3 times vertical well cost you have a high risk of economic failure.

Manage your risk and drill vertical wells.

Reservoir Engineering

Key Items To Determine

- Present bottom hole pressure in target
- Present oil saturation in target
- Model & history match production
- Predict horizontal well performance

Gathering Reservoir Data

Know your target reservoir

Establish individual well files

Gather primary production history

- For individual wells
- For lease or field
- For offset wells/ leases

Gathering Reservoir Data

If Secondary Recovery is Present:

Determine injection AND production histories

- For individual wells
- For lease or field
- For offset wells/ leases

Gathering Reservoir Data

Obtain & file all logging information available

- Drillers logs
- Old E logs
- All modern open hole logs
- All cased hole logs

Find all Core Analysis

- Determine the Actual Core Location
- Use OGS Core Library Facilities

Gathering Reservoir Data

- Obtain all DST and initial production tests
- List all subsequent production tests
- Find all PVT test data
- Use values from “Standards”

Gathering Reservoir Data

Using API gravity you can obtain

- PVT correlations
- Relative permeability correlations
- ~~Viscosity correlations~~

Check viscosity at reservoir temperature conditions!

Which Wellbore to Use?

New Wells

- Planning from the get go
- Accuracy of formation tops, continuity
- Need to know casing points for long and medium radius techniques very accurately

Which Wellbore to Use?

Existing Wells

- Cased holes
  - Cutting windows
  - Milling sections

Open Hole

  - Going out the casing shoe

Which Wellbore to Use?

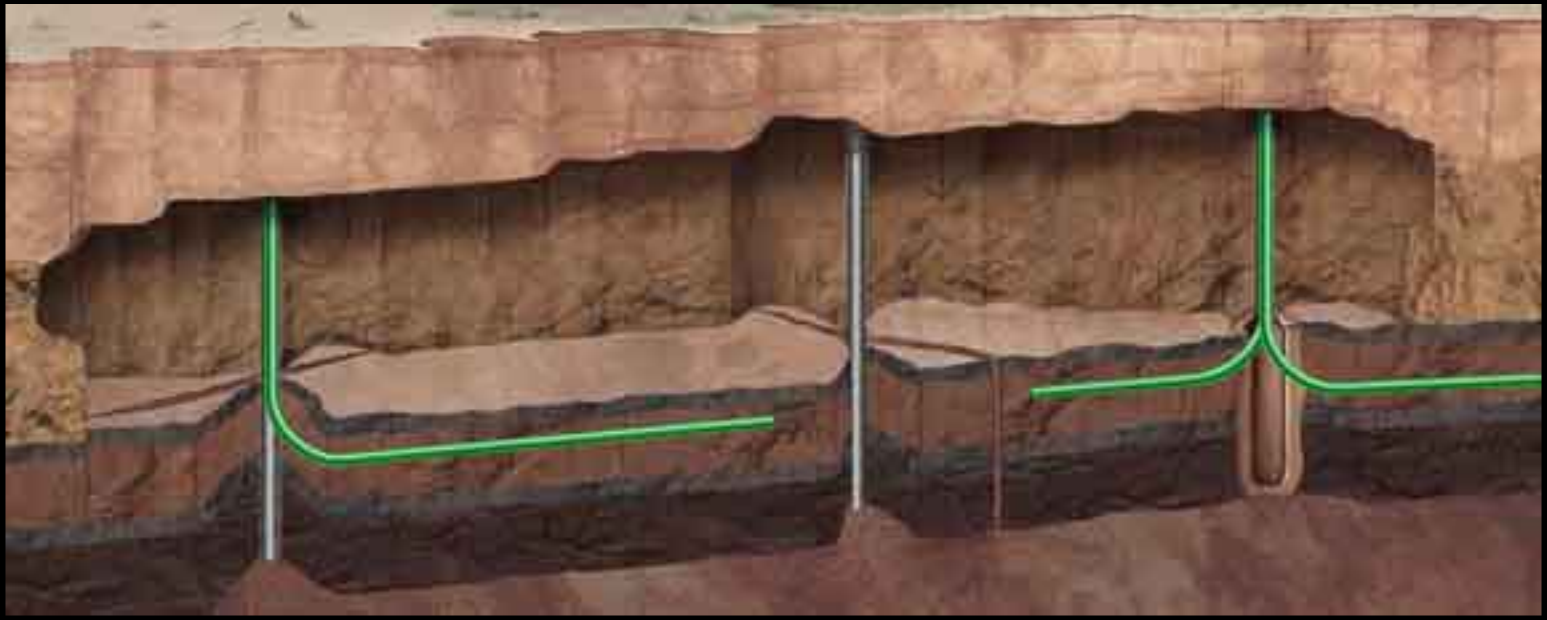
Plugged and Abandoned (P&A) Wells

- When and how was the well plugged?
- Is there a record of JUNK in the hole?
- What was reason for P&A?

Wash Downs

- Open hole cement plugs
- Any casing strings

Which Wellbore to Use?



Exiting Casing

Hydraulic Frac

Exiting Shot Hole

Reservoir Simulation

For the final screening process:

- Gather reservoir history, rock & fluid properties
- Conduct history match to validate model inputs/adjustments
- Input data into reservoir simulator

Reservoir Simulation

Based on the model results and the cost estimate for the horizontal well,

what are the economics?

The model results can encourage the project forward or it may keep you from spending your drilling dollars unwisely.

Reservoir Simulation

With confidence in the predictive quality of the model, various scenarios can be checked.

Respective payouts – or lack thereof – can be investigated.

Reservoir Simulation

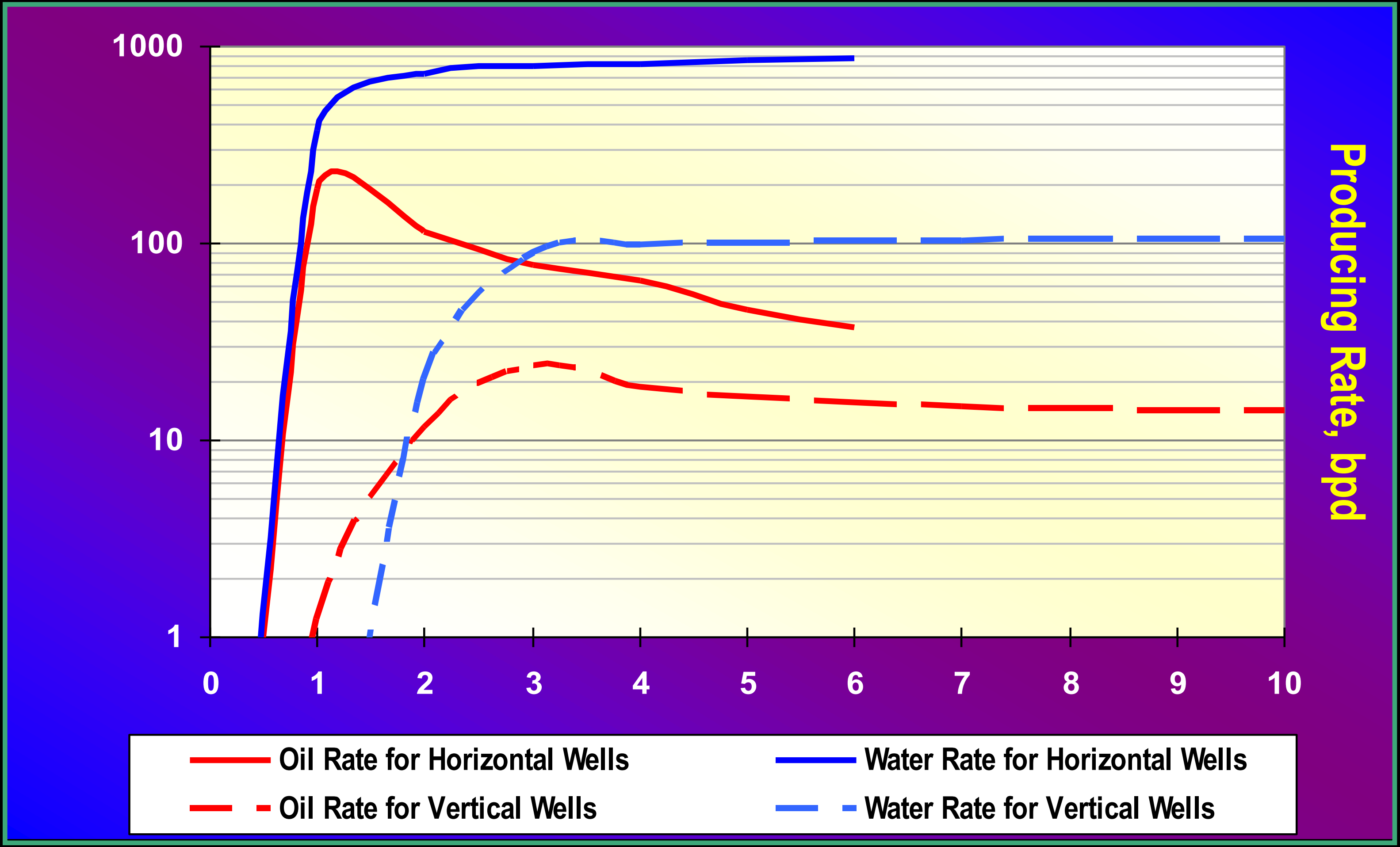
Confidence in the model's predictions is

VERY IMPORTANT

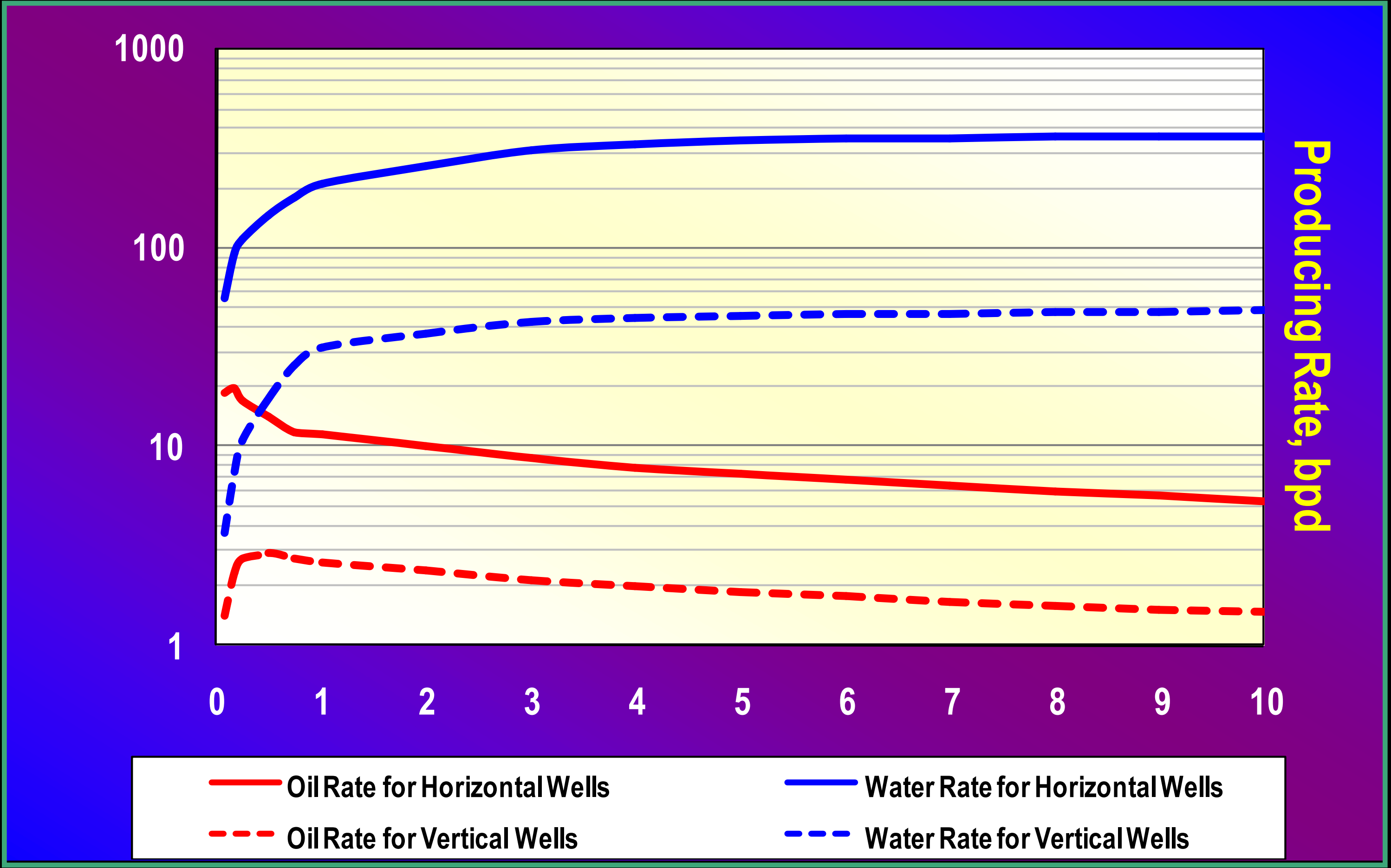
but it will come with experience.

This is the "hidden" value of the simulation:

Avoid financial failure!



1000
100
10
1
0
1
2
3
4
5
6
7
8
9
10
Producing Rate, bpd
Oil Rate for Horizontal Wells
Water Rate for Horizontal Wells
Oil Rate for Vertical Wells
Water Rate for Vertical Wells


1000
100
10
1
0
1
2
3
4
5
6
7
8
9
10
Producing Rate, bpd
Oil Rate for Horizontal Wells
Water Rate for Horizontal Wells
Oil Rate for Vertical Wells
Water Rate for Vertical Wells

Reservoir Conclusion

- Dig deep for all necessary data
- Build a computer model of the field
- Have confidence in the simulation history match
- Use future production predictions for economics