Hydraulic Fracturing Theory & Practice

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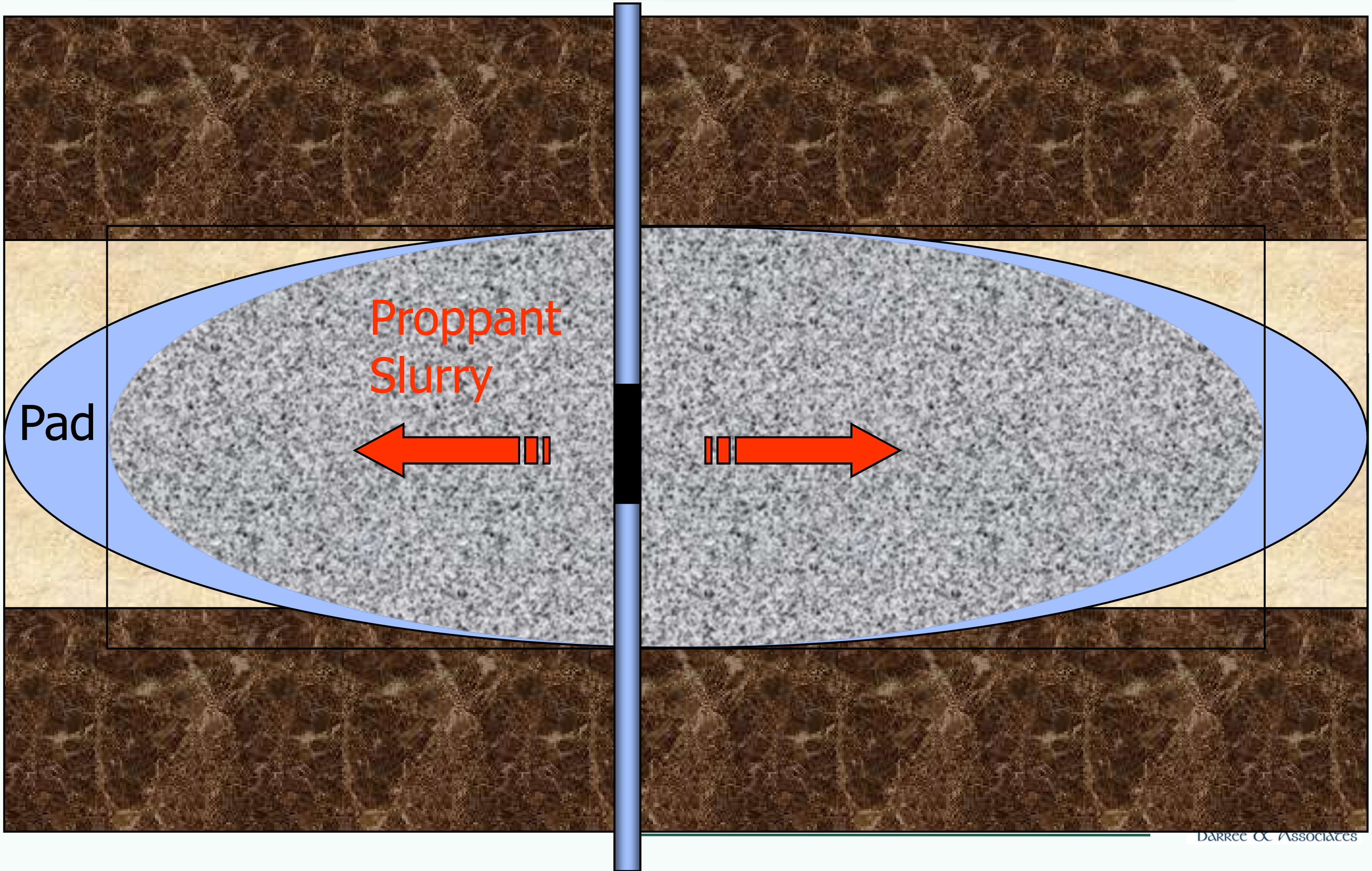
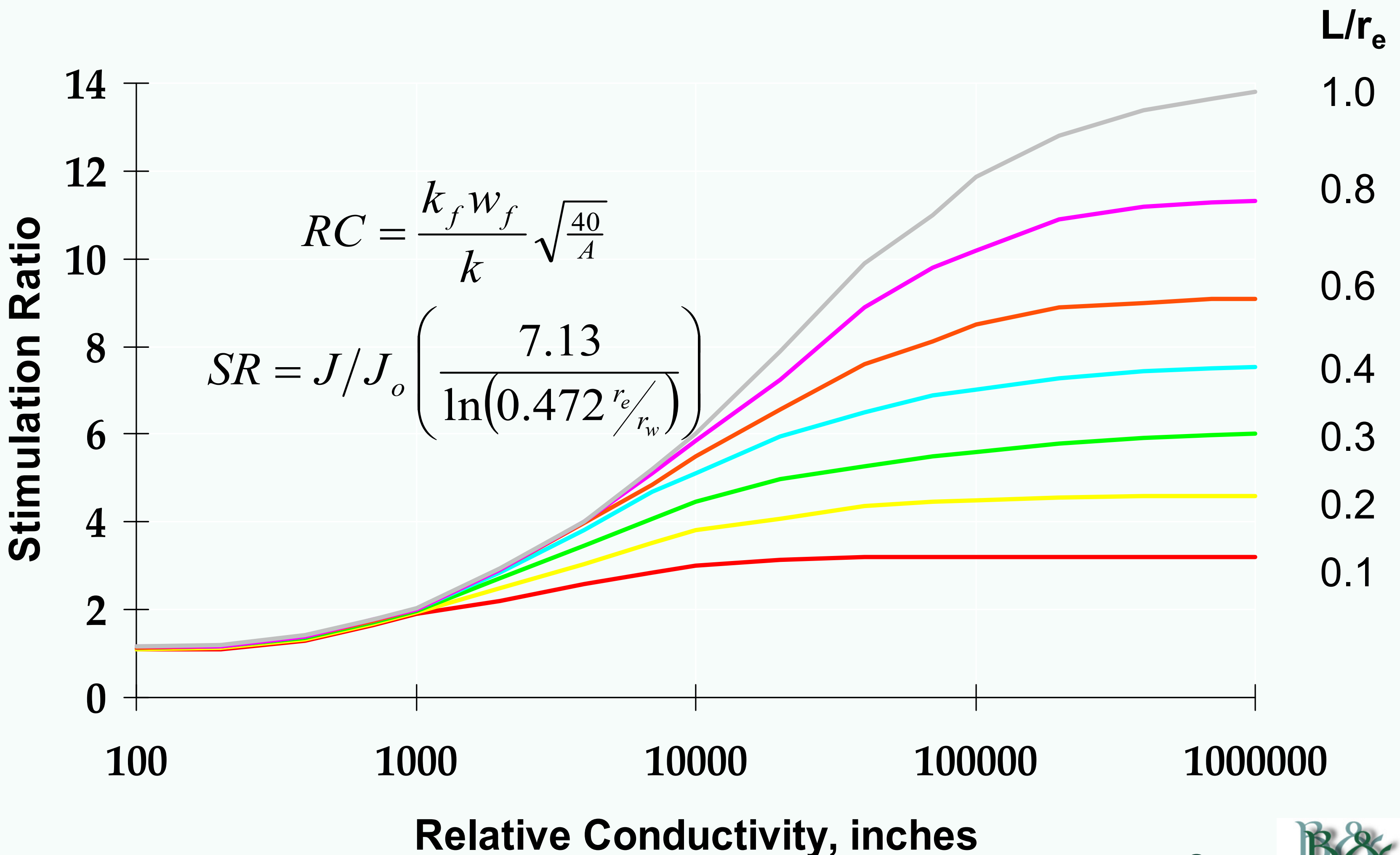
What is Hydraulic Fracturing?



GOALS: Hydraulic Fracture Stimulation

- Maximize hydraulic frac length
- Achieve finite (non-zero) conductivity
- Minimize treatment cost
- Minimize conductivity damage
- Minimize damage to the formation
- Maximize number of zones producing
- Drain everything connected to the well
- Accelerate recovery & add reserves

McGuire-Sikora Folds-of-Increase Curves for Pseudo-Steady Flow

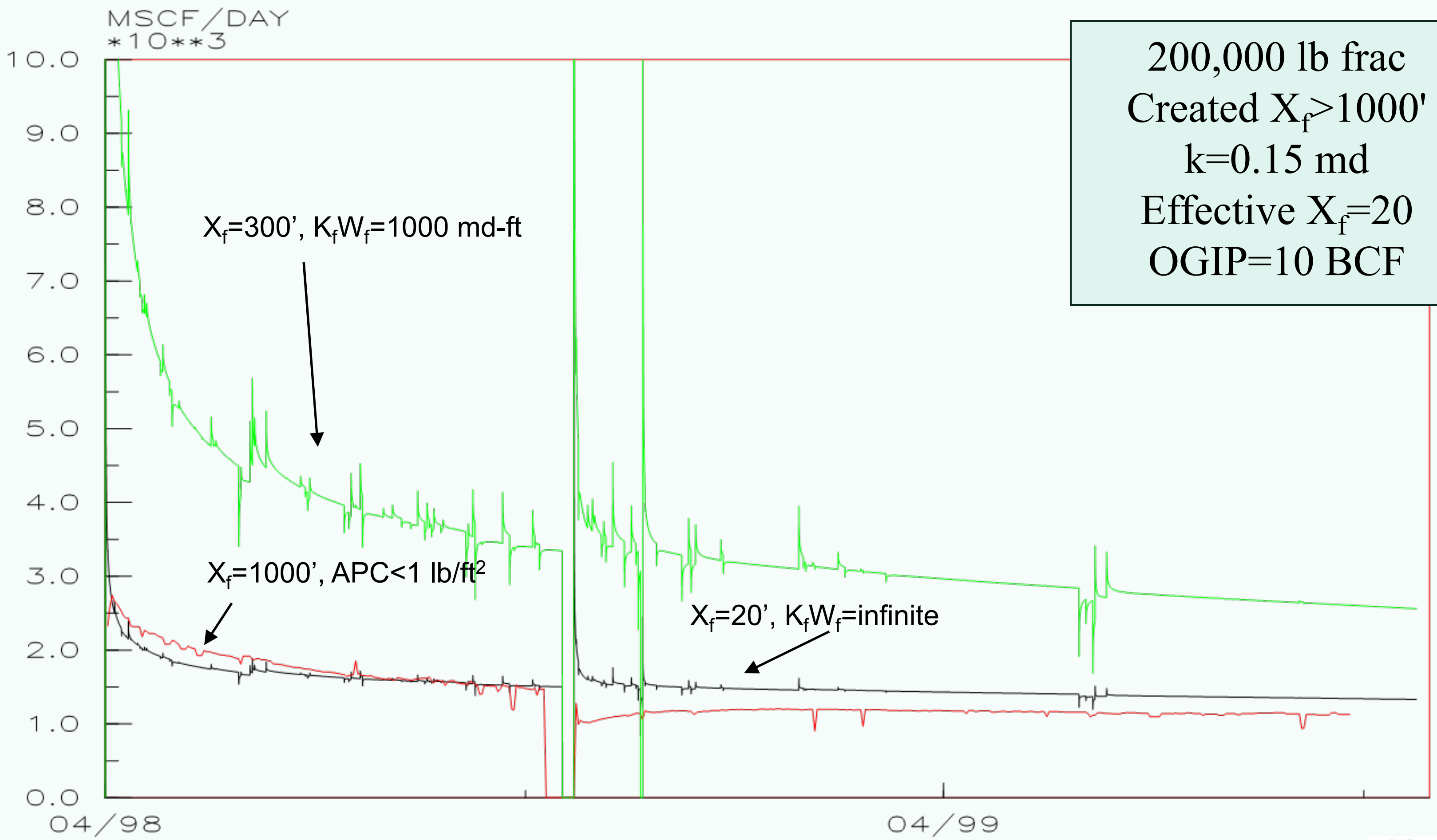


Well Performance:
Setting the Benchmark

- Pressure buildup analysis
  - lose or defer production
  - must wait for well to clean-up
  - takes ‘forever’ to reach radial flow
- Production performance analysis
  - long flow times
  - takes ‘forever’ to reach flow boundaries
  - lots of data to archive
- Decline curve (Arps) Analysis: Beware of exponents >1
  - still in transient flow
  - not volumetric reservoir performance
  - decline curves are not valid

Fractured Well Performance

Actual vs. Expected



200,000 lb frac
Created X$_f$>1000'
k=0.15 md
Effective X$_f$=20
OGIP=10 BCF

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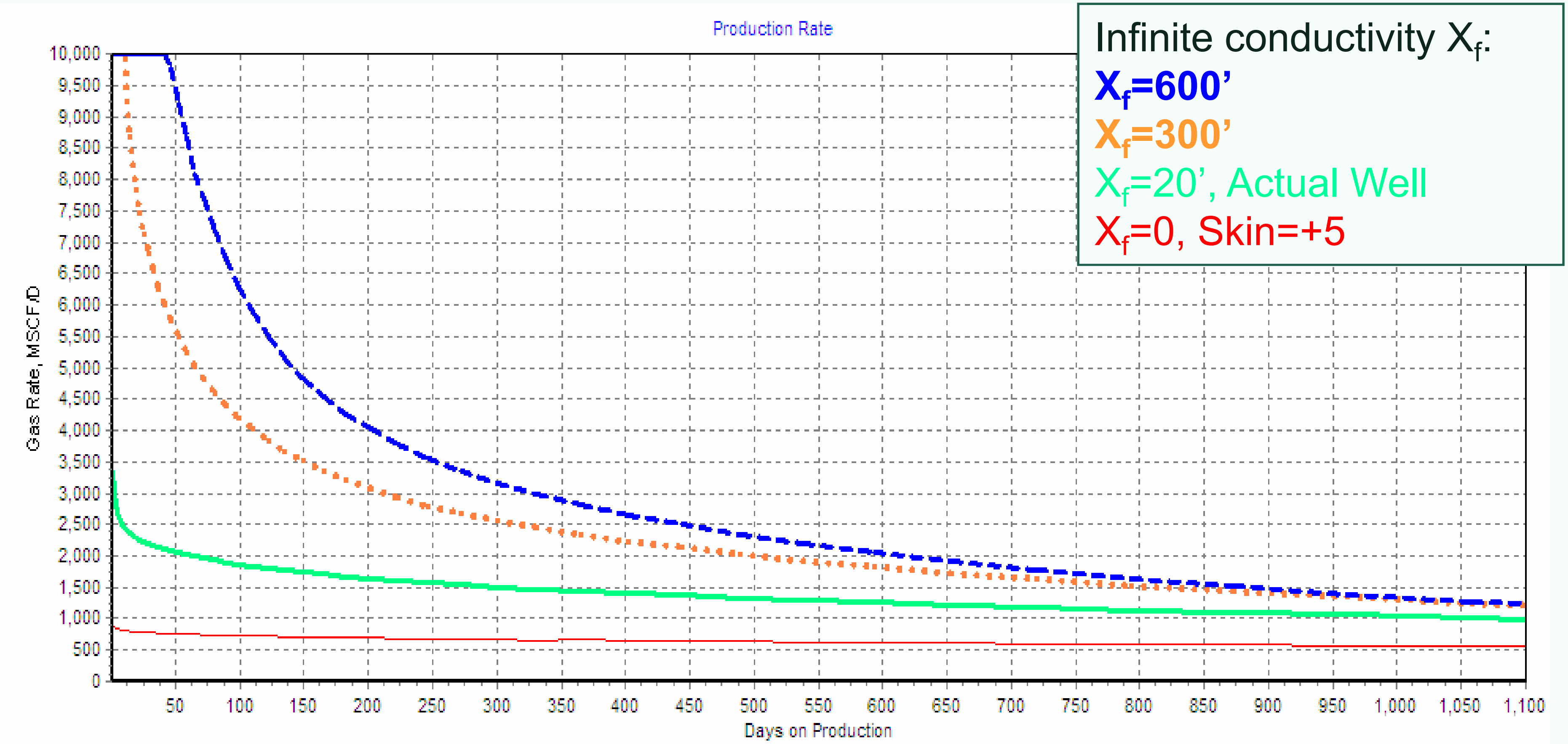
Business Case for Frac Improvement

- Assumptions:
  - Single Well, Total Depth 8500’
  - Net pay thickness = 50 feet
  - Average effective permeability = 0.15 md.
  - Drilling and Completion per Well: $1.4 mm
  - Fracture Stimulation: $80,000
  - Gas Price $6.50/mcf
  - Current Effective Fracture Half Length Xf= 20’
- Evaluate impact of an increase in effective length to 300’ or 600’ with proper design and formation characterization

Gas Rate Decline: Stimulated Wells



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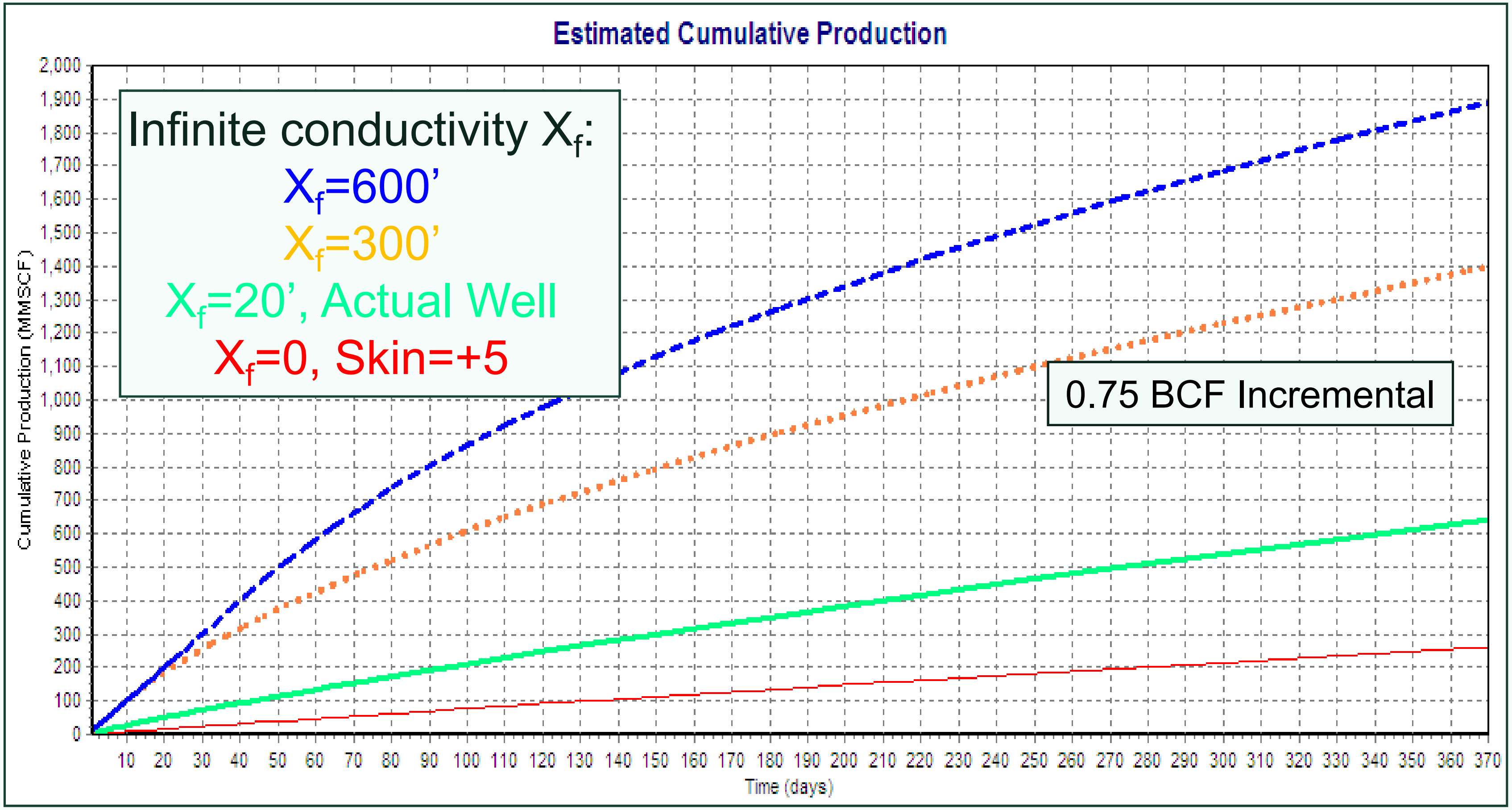
Cumulative Production: Stimulated Wells



Business Case Economic Analysis

Base case economics – first 3 years production

- Fracture half-length increased from 20’ to 300’
  - Incremental NPV@20% $6.5 MM per well
- Fracture half-length increased from 20’ to 600’
  - Incremental NPV@20% >$10.0 MM per well

Find & Fix the Problem

- Why is current Xf = 20'?
- Can a longer length be achieved?
- What must be changed to improve performance?
- Can treatment cost be decreased without loss of production?

The Challenges

- Frac geometry
  - not creating expected length
  - growth out of zone
- Proppant transport
  - prop falling out of zone
  - prop pack not connected to perfs
- Final conductivity
  - gel damage; breaker/clean-up issues
  - proppant crushing; non-Darcy flow
- Reservoir properties
  - Kh isn't what you expected
  - Drainage area less than desired

What do we need to know to …

- Define the problem
- Benchmark our performance
- Decide what to change
- Generate realistic expectations
- Optimize completion/stimulation
- Get what we want or what we should expect from our wells

Good Results Come From

- Adequate reservoir characterization
- Accurate design models
- Pre-frac diagnostics
- Post-job analysis