# Resolve Horizontal and Vertical Well Skin Model Comparison with Analytical Models

Joe Eaton

Vivek Sahai

February 6, 2007

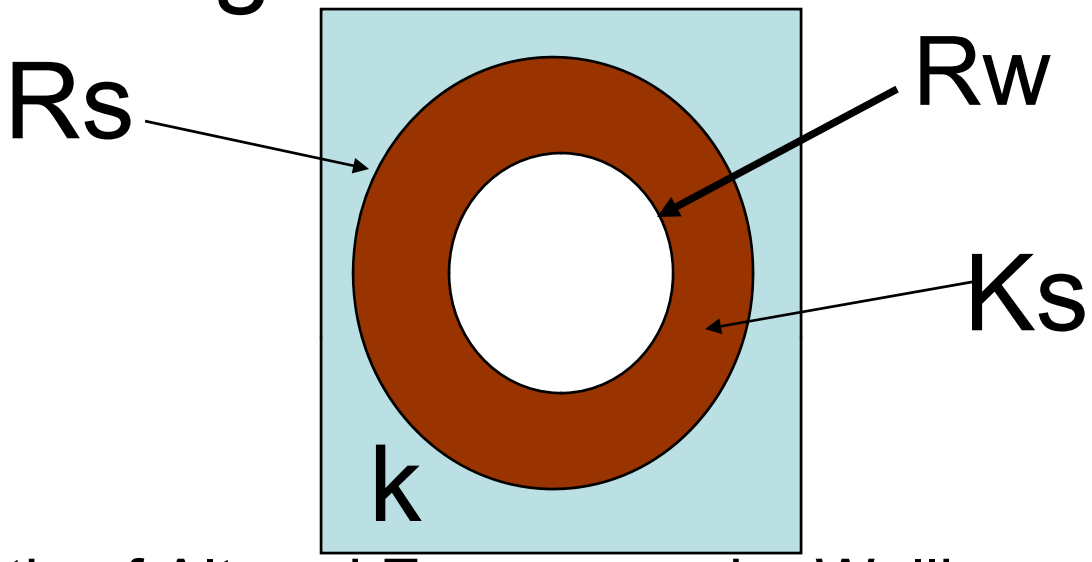


object reservoir

# Overview

- Discussion of Resolve's Skin Model
- ΔP Skin Model for Radial Flow
- Analytical Skin Model of Renard & Dupuy for Vertical and Horizontal Wells
- Results
- Conclusions – ΔP Skin Model can not capture change in flow patterns for Horizontal Wells

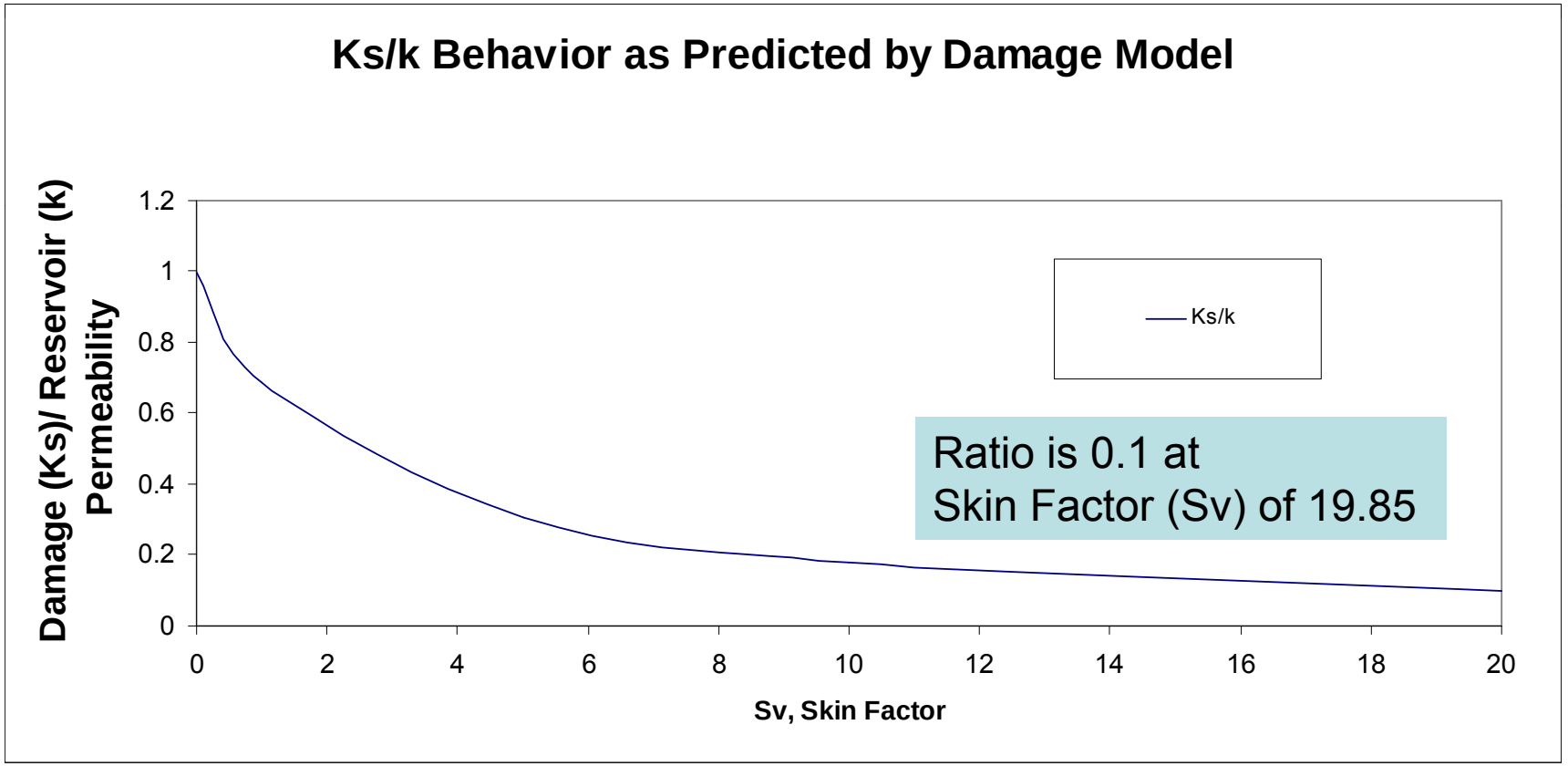
# How Resolve Models Skin (Sv) Damage Formation Model




- Schematic of Altered Zone around a Wellbore, Open Hole Damage Formation (Ks – Damage Perm.)
- Rs = Radius of Damage Formation Surrounding Wellbore Radius Rw, k = Reservoir Perm
- Skin Factor = Sv =[(k/Ks) – 1]ln(Rs/Rw) (Hawkins Formula)

Resolve Models Diffusivity Equations Around Well Without Steady State or Radial Flow Assumptions.

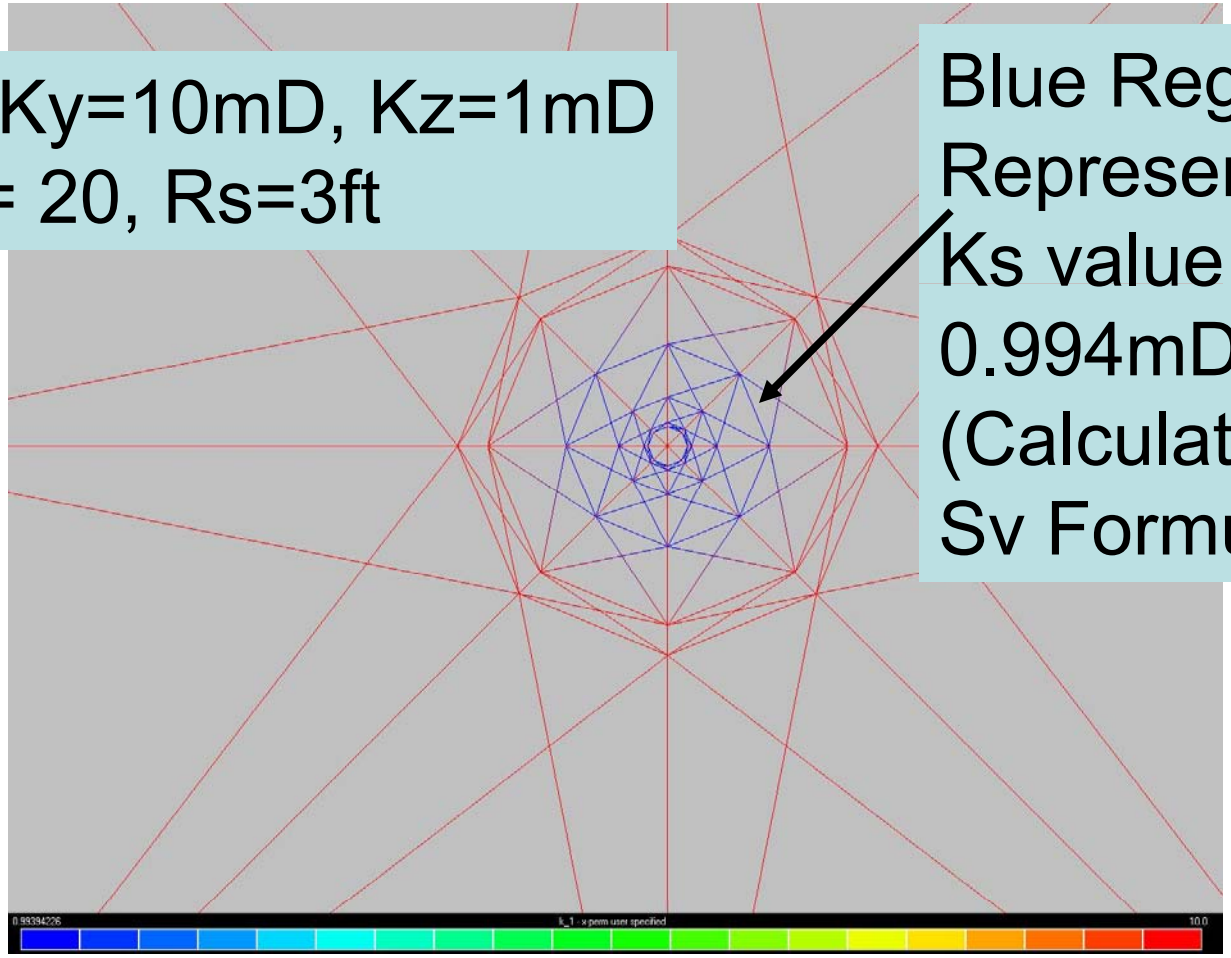
# Variation of Ks/k Ratio Predicted by Hawkins Formula




Radius of Damage Formation: Rs = 3ft
Well Bore Radius Rw = 0.33 ft
Ratio of Rs/Rw = 9.09

# Permeability Variation in Resolve

Kx=Ky=10mD, Kz=1mD
Sv = 20, Rs=3ft



Blue Region Represents Ks value of 0.994mD (Calculated by Sv Formula)

# Zero Thickness Model of Skin
# ΔP Skin - Steady State Radial Flow

- Implemented Immediately in Time as Pressure Drop:

$$\Delta Ps = Sv * (q\mu Bo / 2\pi kH)$$

Sv = Skin Factor, q = Flow Rate
Bo = FVF, k = Reservoir Perm
H = Reservoir Thickness

Used in Pan System and CMG

# Renard – Dupuy Analytical Model for Vertical Well Skin

- Derivation of Flow Efficiency (Ev) showing effect of Vertical Well Skin
- Flow Efficiency = E = PI skin / PI no skin
- Production Index = PI no skin = $q/\Delta P = 2\pi kH/\mu Bo(\ln(Re/Rw))$
- PI skin = $2\pi kH/\mu Bo(\ln(Re/Rw) + Sv)$
- $Ev = \ln(Re/Rw)/( \ln(Re/Rw) + Sv)$

  $Ev = A /(A+Sv)$ where $A = \ln(Re/Rw)$

SPE Paper SPE 19414, 1998
Re = Drainage Radius

# Renard – Dupuy Analytical Model for Horizontal Well Skin

- Derived Flow Efficiency for Skin Due to Formation Damage for both Horizontal and Vertical Wells

$$E = \frac{A}{A + Sv}$$

Re – Drainage Radius
Rw – Well Radius
L – Horizontal Well Length
Beta – Sqrt(Kh/Kv)
X – geometric parameter
H – Layer Thickness
Rw' = Rw[(1+Beta)/2Beta]

A = ln(Re/Rw) : vertical wells (Ev)

A = (L/H*Beta)arccosh(X) + ln(H/2πRw') : horizontal wells (Eh)

Model Derives Geometrical Parameters that account for Superposition of Pseudo Radial and Boundary Dominated Flow.



object reservoir

# How Eh and Ev are Calculated for Resolve and Pan System™

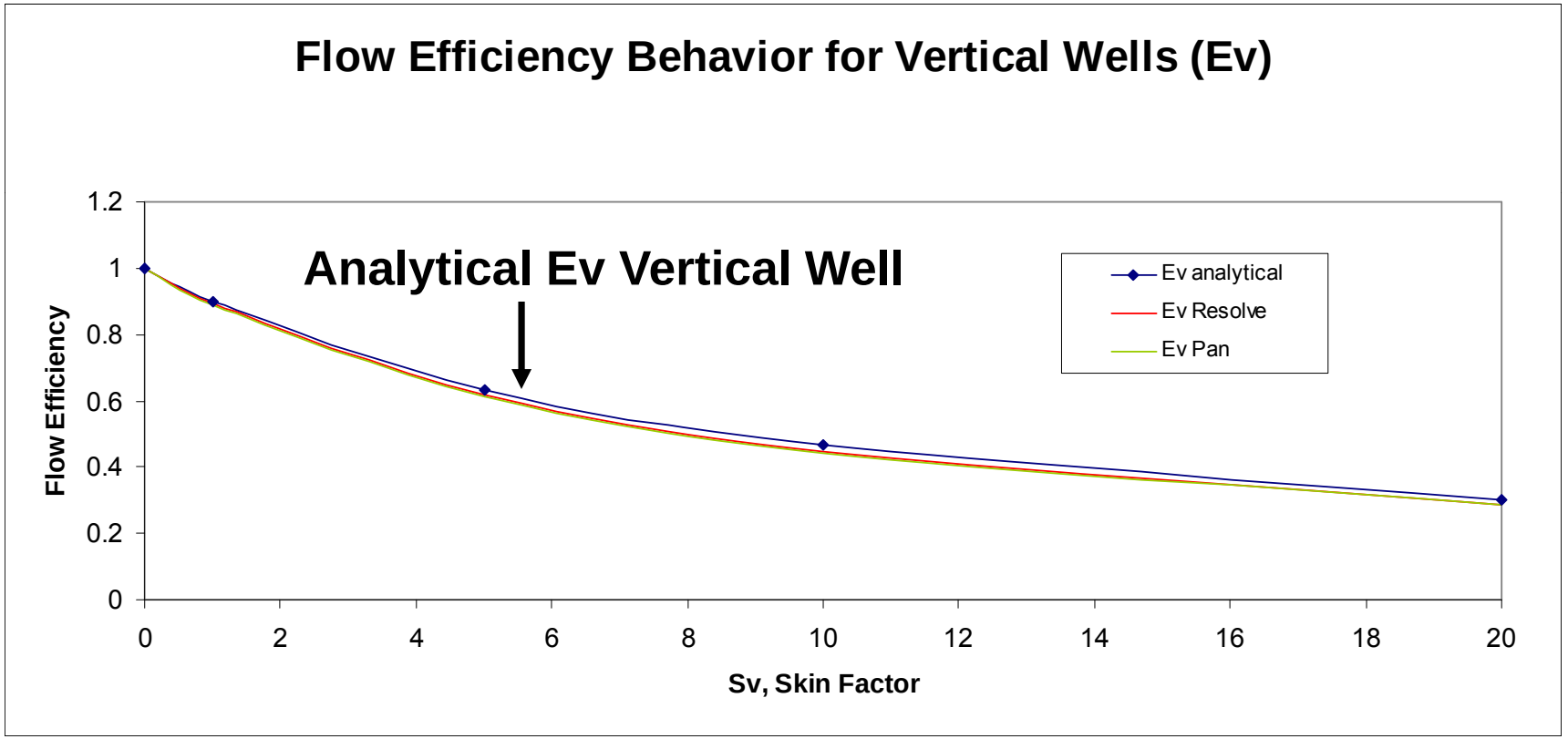
- Eh = [Q/ΔP] with skin / [Q/ΔP] no skin

- The ratios are evaluated for steady-state and pseudo steady-state conditions with an incompressible fluid
- Gravity is not modeled in Pan System and turned off in Resolve.

# Compared Resolve & Pan System™ Vertical Well Skin Behavior

- Circular Reservoir 2000 ft radius (Equivalent Square Reservoir Area Set in Pan System)
- Oil with FVF = 1 RB/STB, Viscosity 0.01cp, Layer Porosity 0.12
- Anisotropic Permeability: kx=ky=kh=10mD, kz=1mD
- Rock Compressibility 0.001(1/psi) (Gas Like Compressibility was implemented)
- Initial Pressure of 4000 psi
- Rate of 400 STB/Day
- Layer Thickness 50 ft, Skin (Damage) Radius = 3ft
- Vertical Well of Radius 0.33 ft Located in Center of Reservoir, 50 ft Length
- Ran to Pseudo-Steady State Conditions (1200 days)
- 50-100 ft Radial Meshing Region, 8 sides, 12 rings

# Results of Vertical Well Flow Efficiency Behavior vs. Resolve and Pan System™




Flow Efficiency: PI skin / PI no skin
Both Resolve and Pan System Have Similar Behavior

# Effect of Skin Results For Vertical Wells

| Sv | Ev Analytical | Ev Resolve | % Diff. Analytical | % Diff. Pan | Ev Pan | % Diff. Analytical |
|---|---|---|---|---|---|---|
| 1 | .897 | .893 | 0% | 1% | .888 | 1% |
| 5 | .635 | .616 | 3% | 0% | .614 | 3% |
| 10 | .466 | .448 | 4% | 1% | .443 | 5% |
| 20 | .303 | .287 | 5% | 1% | .284 | 6% |

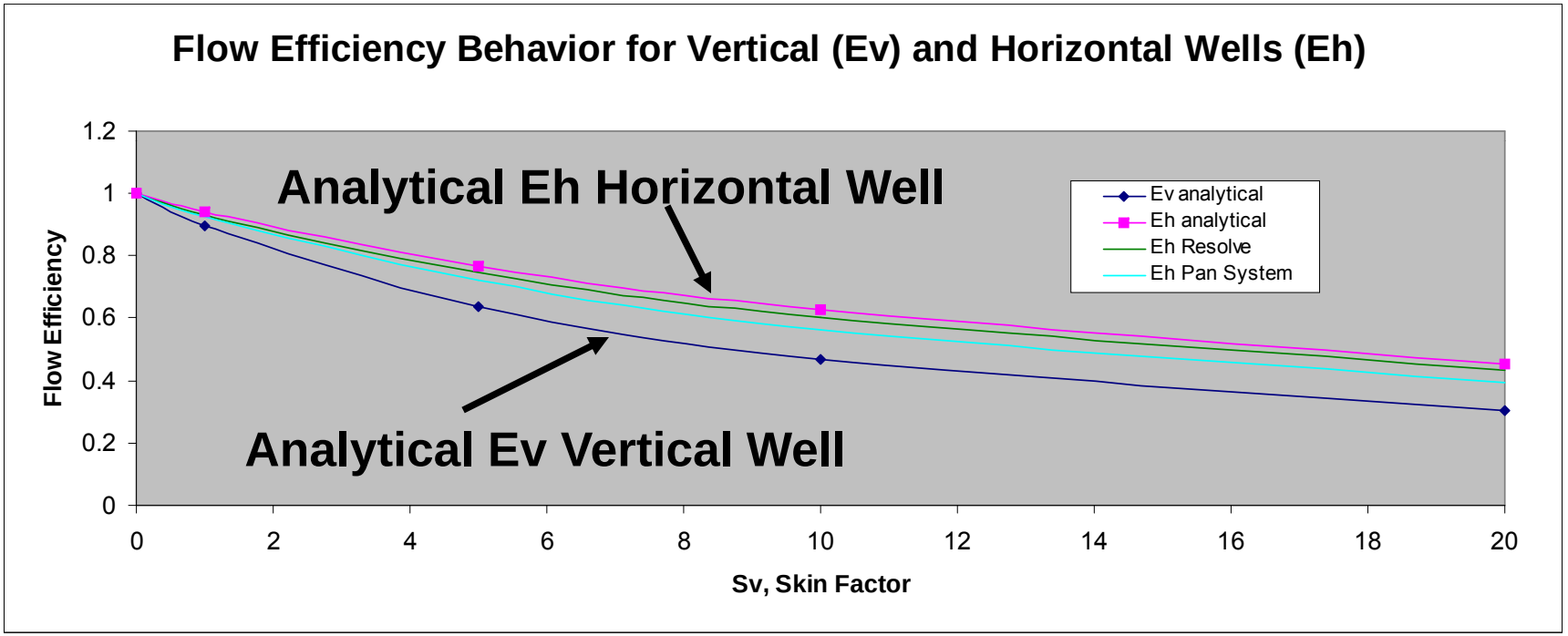
# Compared Resolve & Pan System™ Horizontal Well Skin Behavior

- Circular Reservoir 2000 ft radius (Equivalent Square Reservoir Area Set in Pan System)
- Oil with FVF = 1 RB/STB, Viscosity 0.01cp, Layer Porosity 0.15
- Anisotropic Permeability: kx=ky=kh=10mD, kz=1mD
- Rock Compressibility 0.001(1/psi) (Gas Like Compressibility was implemented)
- Initial Pressure of 3000 psi
- Rate of 400 STB/Day
- Layer Thickness 50 ft, Skin (Damage) Radius = 3ft
- Horizontal Well of Radius 0.33 ft Located in Center of Layer and Reservoir, 1000 ft Length
- Ran to Pseudo-Steady State Conditions (1000 days)
- 3 Extruded Areal Rings, 6 Radial Rings



object reservoir

# Results of Flow Efficiency Behavior vs. Resolve and Pan System™




Flow Efficiency: PI skin / PI no skin

# Effect of Skin Results For Horizontal Wells

| Sv | Ev Analytical | Eh Analytical | Eh Resolve | % Diff Analytical | %Diff Pan | Eh Pan | % Diff Analytical |
|---|---|---|---|---|---|---|---|
| 1 | .897 | .943 | .932 | 1% | 0% | .928 | 2% |
| 5 | .635 | .769 | .745 | 3% | 3% | .721 | 6% |
| 10 | .466 | .625 | .601 | 4% | 7% | .564 | 10% |
| 20 | .303 | .454 | .435 | 4% | 11% | .392 | 14% |

Ev – Vertical Well Flow Efficiency, Eh Horizontal Well Flow Efficiency

# Conclusions

- The Resolve Results for skin with horizontal and vertical wells agree within 5% of the Analytical Model Prediction
- The Analytical Model shows for steady-state flow of an incompressible fluid that up to relatively large permeability ratio values skin damage is less detrimental to horizontal wells than to vertical wells.
- ΔP Skin Model is derived for steady state radial flow so it can not handle other flow patterns around the horizontal well.