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Gas Innovations Inspiring Clean Energy

Optimized Gas Injection Rate for Underground Gas Storage; Sensitivity Analysis of Reservoir and Well Properties

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Outline

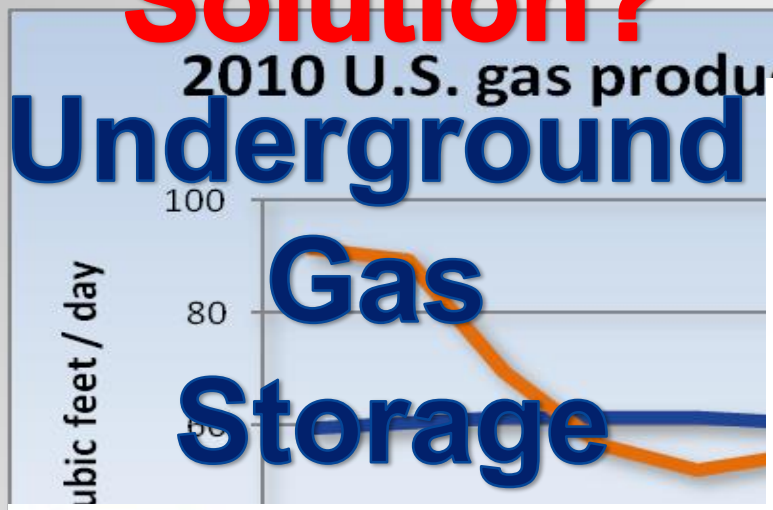
PART ONE

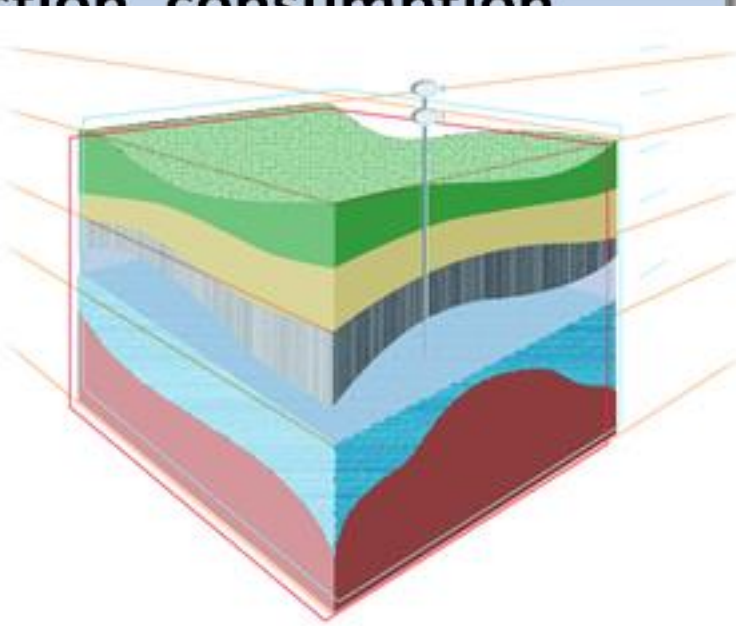
1. Introduction about Underground Gas Storage and importance of optimum injection rate
2. Effect of well's perforation's places
3. Skin factor effect
4. Effect of K_v/K_H
5. Effect of horizontal permeability (K_H)
6. Conclusion

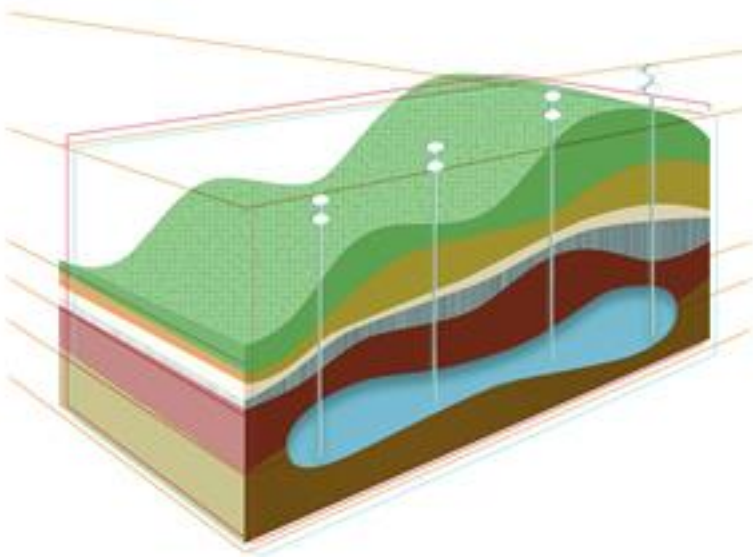
Introduction

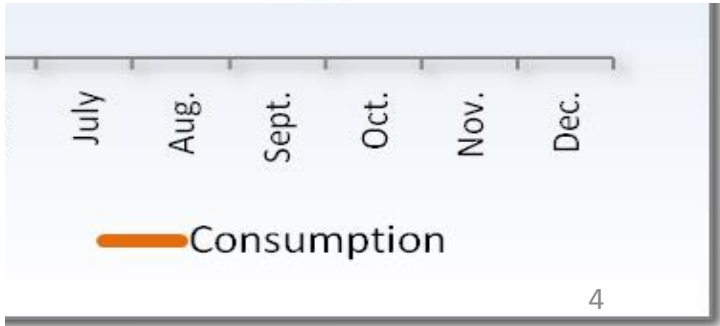
Solution?

Underground Gas Storage

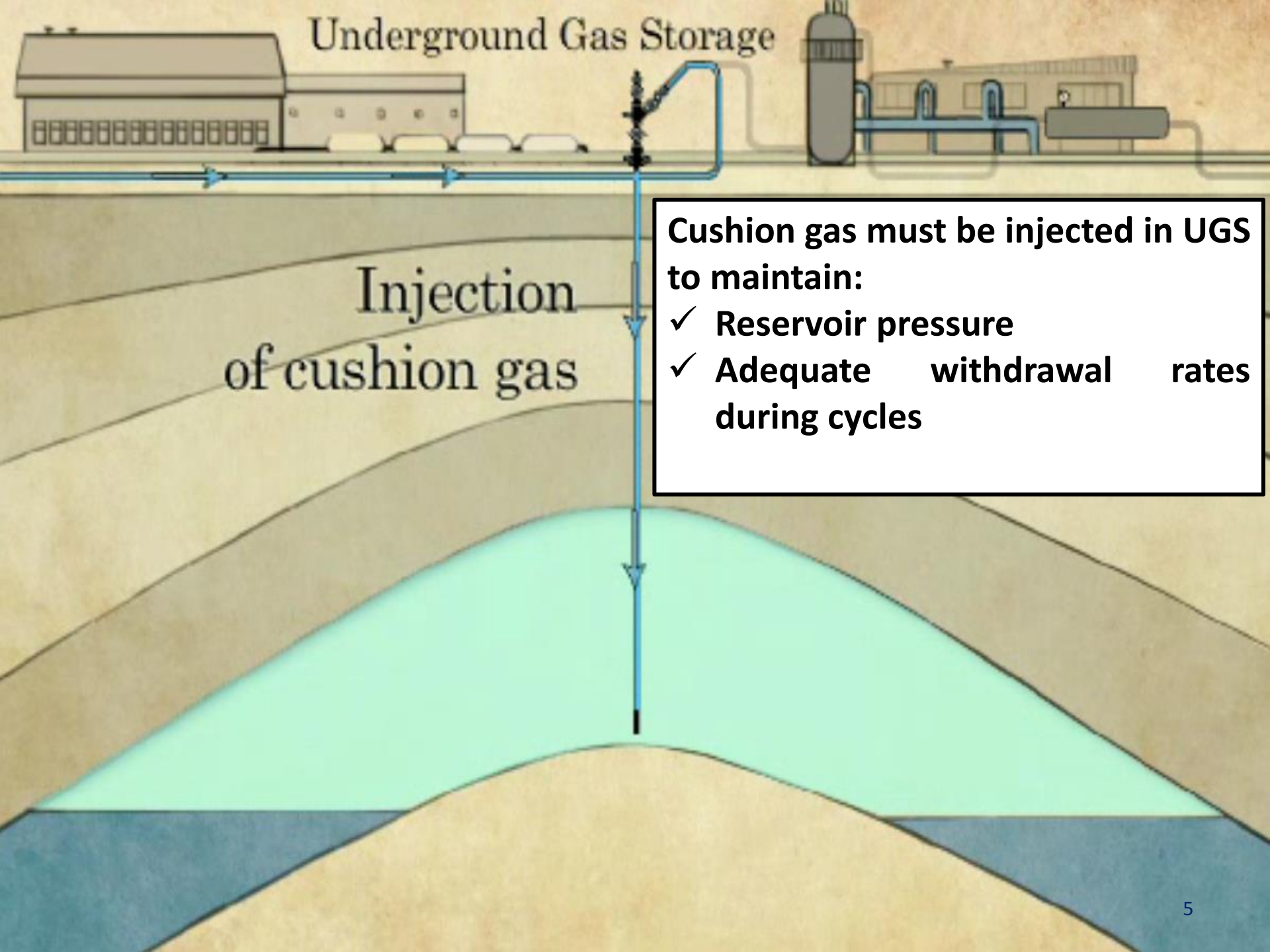








Iministration



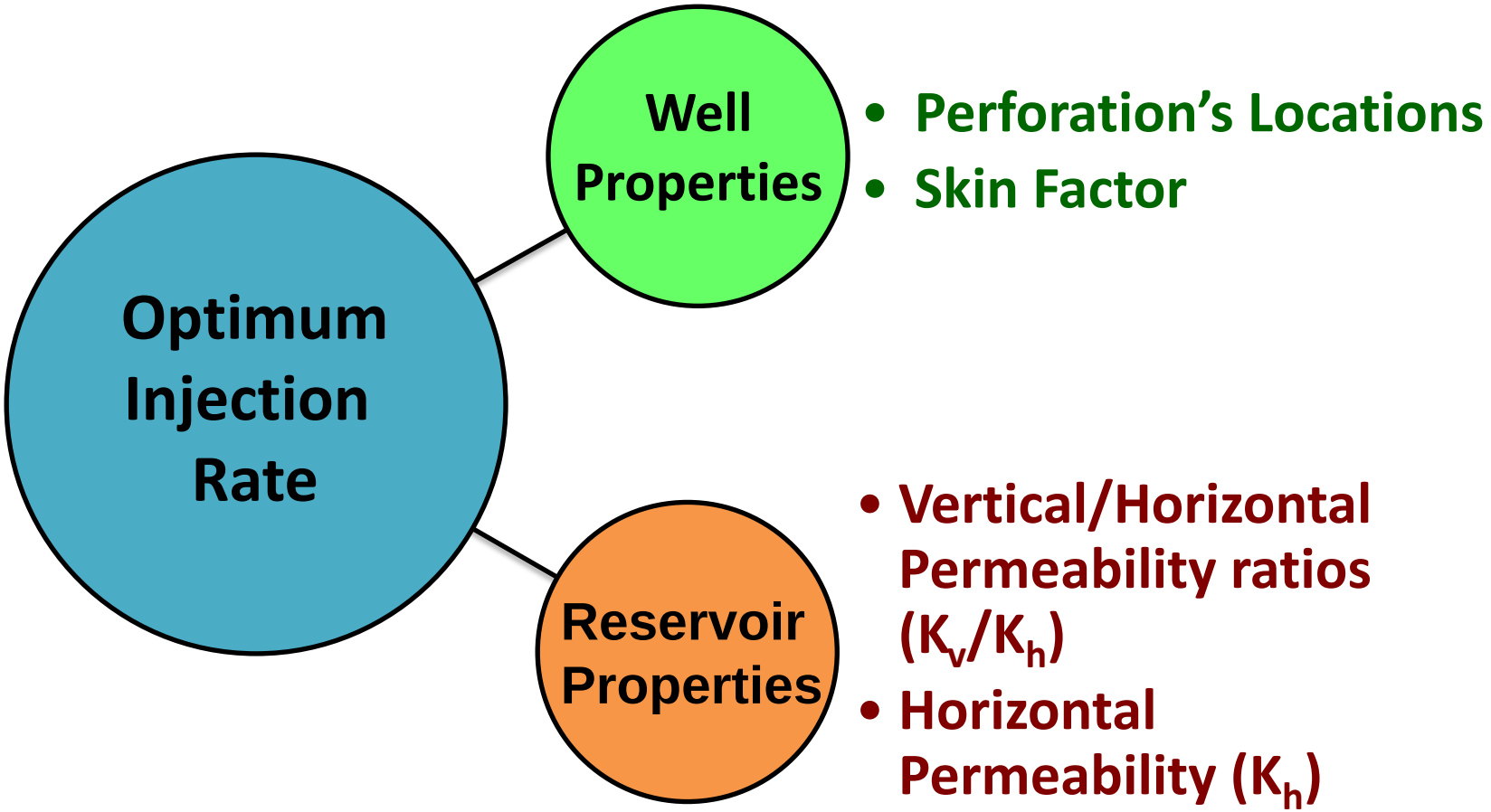
Cushion gas must be injected in UGS to maintain:

- ✓ **Reservoir pressure**
- ✓ **Adequate withdrawal rates during cycles**

- An important parameter controlling the possibility of any UGS project is the time needed to inject the cushion gas.
- The higher rate used for injecting gas, the quicker the field is prepared
- But, due to cap rock stability we can not inject with very high rates.
- As a result, It is required to find an optimum gas injection rate.

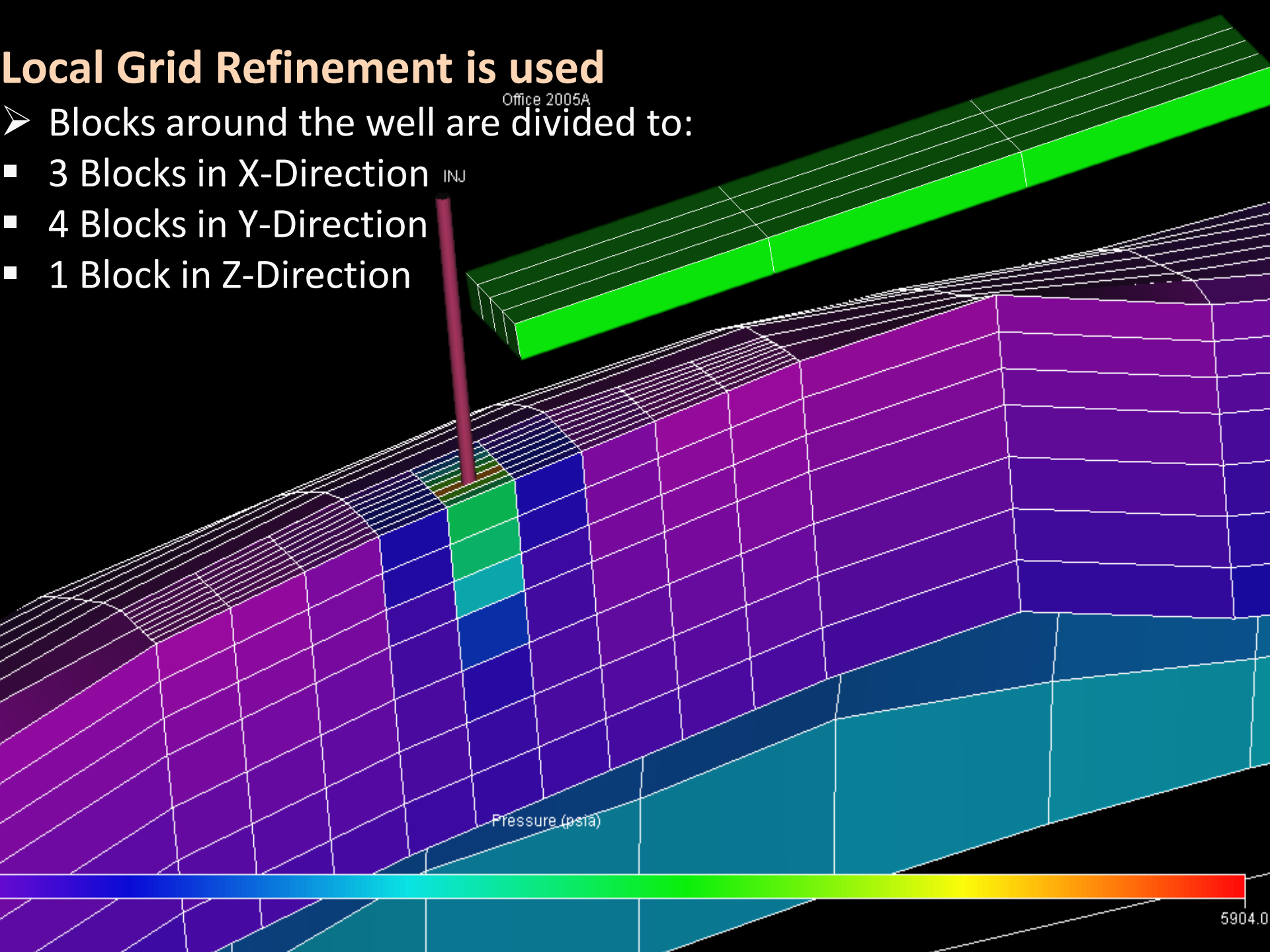
The optimum injection rate is defined to have following characteristics:

- **constant rate**
- **as much gas as possible is injected into the field (with the highest secure BHP)**


Optimum Injection Rate
Well Properties
Reservoir Properties
• Perforation's Locations
• Skin Factor
• Vertical/Horizontal Permeability ratios (K_v/K_h)
• Horizontal Permeability (K_h)

Local Grid Refinement is used

- Blocks around the well are divided to:
  - 3 Blocks in X-Direction
  - 4 Blocks in Y-Direction
  - 1 Block in Z-Direction

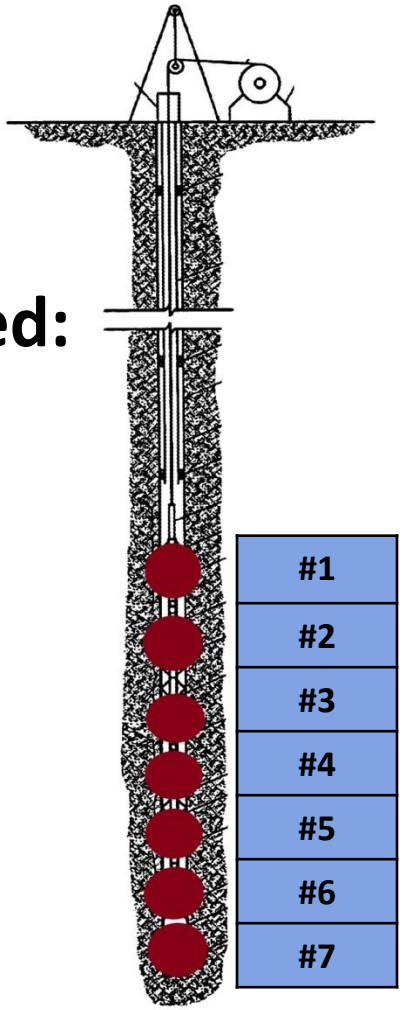


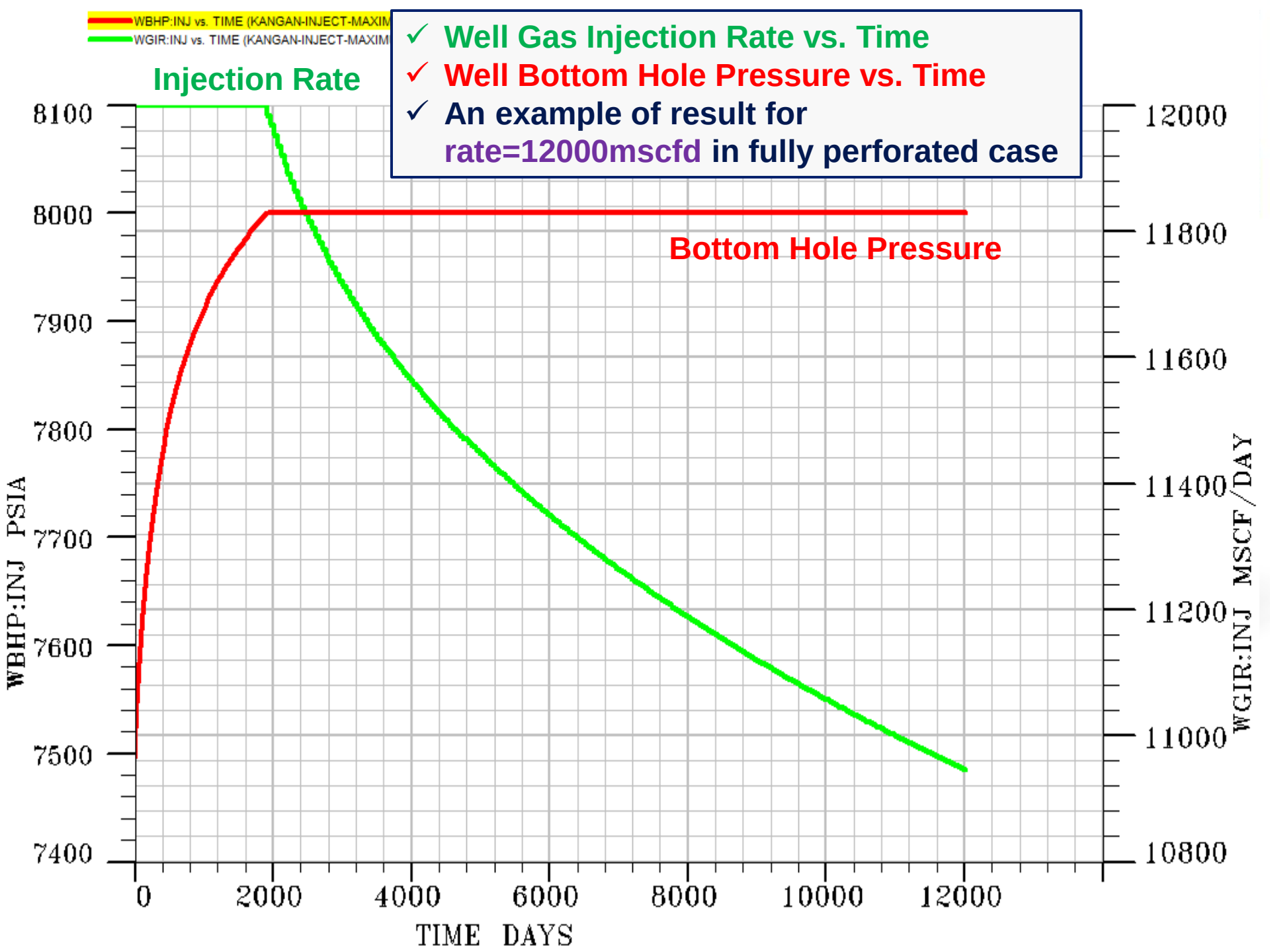
Base Case

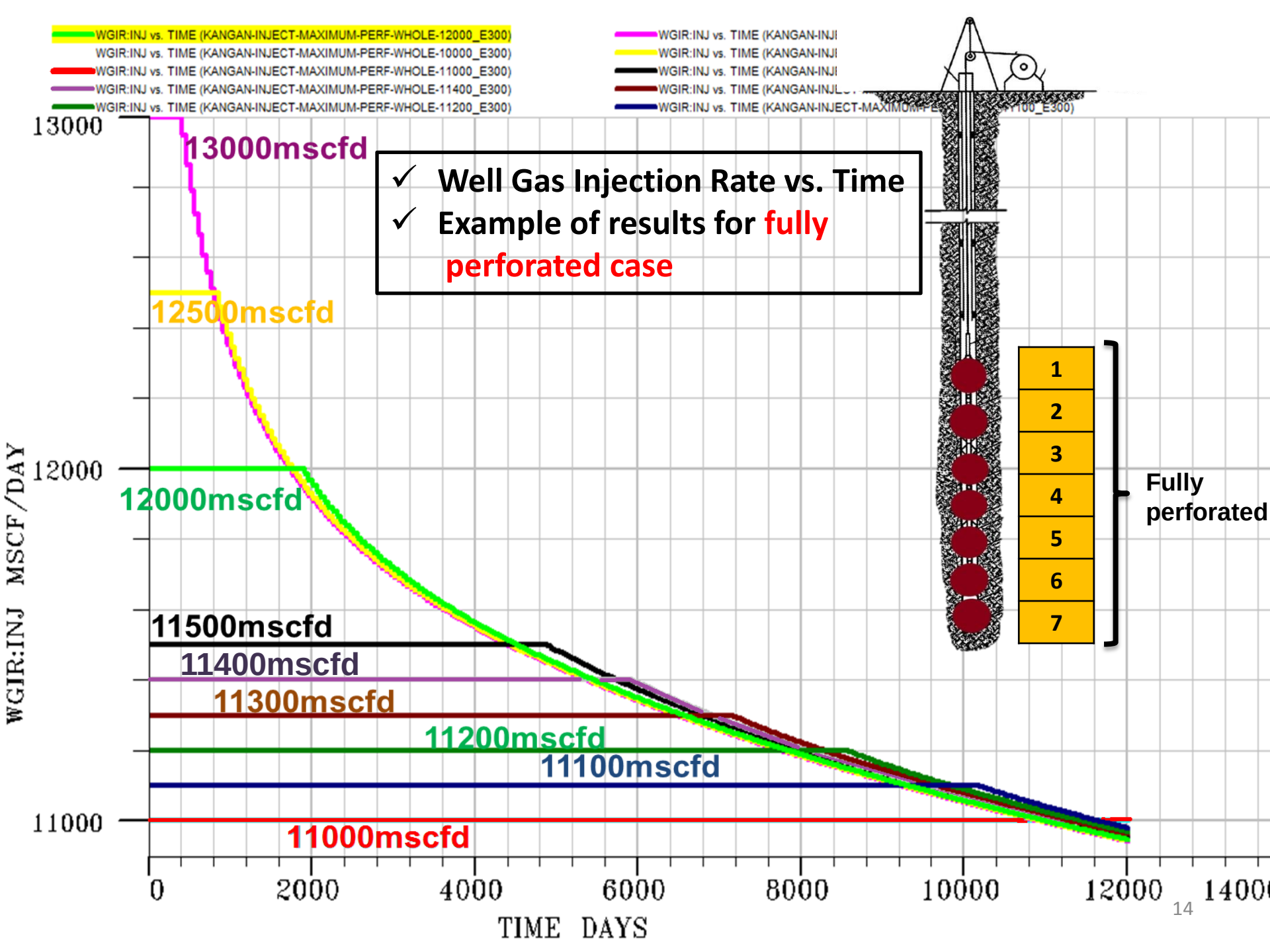
Horizontal Permeability(K_x)	0.05 mD
Horizontal Permeability(K_y)	0.05 mD
Vertical Permeability(K_z)	0.025 mD
Porosity	From Real Field Data
Well Bore ID	0.5 ft.
Control mode on BHP	8000 psi (Layer to define BHP: Layer1)
Skin Factor	0
Depth	16726’ -18214’
Pressure at Datum Depth(16736’)	4737.7 psia
Preparation's Due	During 1800-2000 days

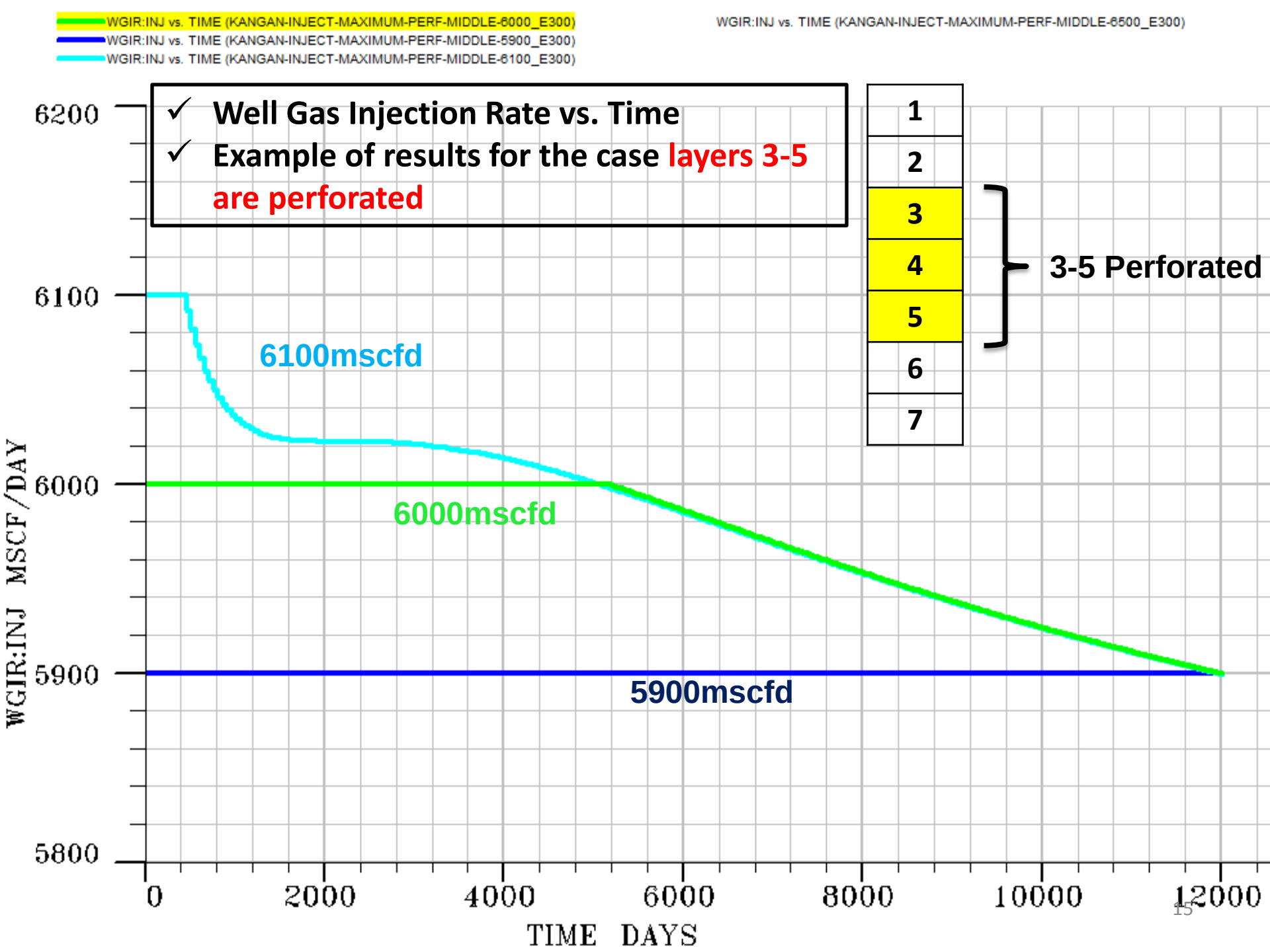
Effect of locations of well's perforations

- **The optimum rate for each case is measured:**
  - **Layers 5-7 perforated**
  - **Layers 3-5 perforated**
  - **Layers 1-3 perforated**
  - **Layers 1-7 perforated**



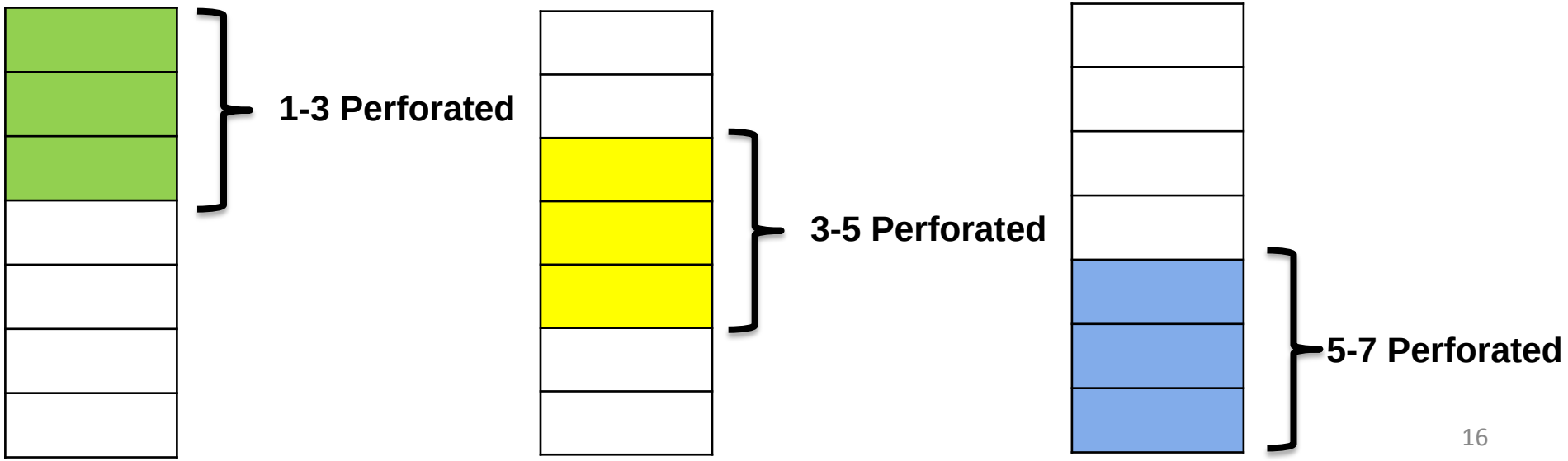

WBHP:INJ vs. TIME (KANGAN-INJECT-MAXIM
WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIM
Injection Rate
✓ Well Gas Injection Rate vs. Time
✓ Well Bottom Hole Pressure vs. Time
✓ An example of result for rate=12000mscfd in fully perforated case
Bottom Hole Pressure
8100
8000
7900
7800
7700
7600
7500
7400
WBHP:INJ PSIA
12000
11800
11600
11400
11200
11000
10800
WGIR:INJ MSCF/DAY
0
2000
4000
6000
8000
10000
12000
TIME DAYS


WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-WHOLE-12000_E300)
WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-WHOLE-10000_E300)
WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-WHOLE-11000_E300)
WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-WHOLE-11400_E300)
WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-WHOLE-11200_E300)
13000
12000
11000
WGIR:INJ MSCF/DAY
13000mscfd
12500mscfd
12000mscfd
11500mscfd
11400mscfd
11300mscfd
11200mscfd
11100mscfd
11000mscfd
✓ Well Gas Injection Rate vs. Time
✓ Example of results for fully perforated case
1
2
3
4
5
6
7
Fully perforated
0
2000
4000
6000
8000
10000
12000
TIME DAYS

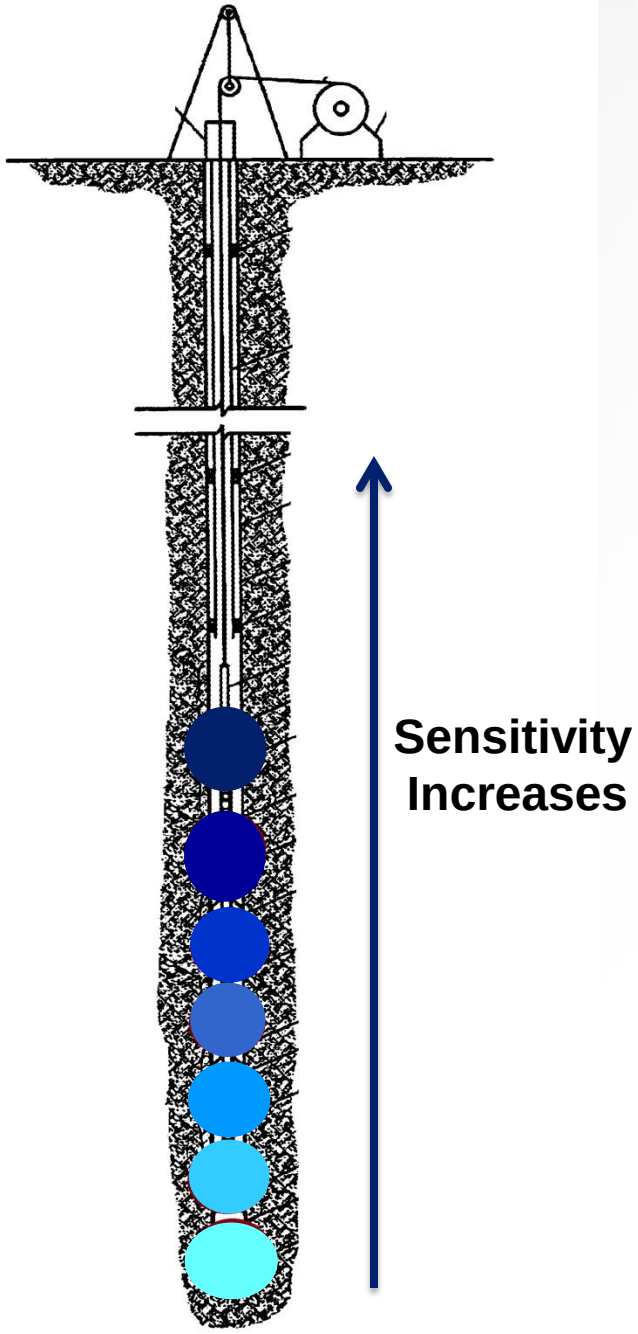

WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-MIDDLE-6000_E300)
WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-MIDDLE-5900_E300)
WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-MIDDLE-6100_E300)
WGIR:INJ vs. TIME (KANGAN-INJECT-MAXIMUM-PERF-MIDDLE-6500_E300)
✓ Well Gas Injection Rate vs. Time
✓ Example of results for the case layers 3-5 are perforated
1
2
3
4
5
6
7
3-5 Perforated
6100mscfd
6000mscfd
5900mscfd
WGIR:INJ MSCF/DAY
6200
6100
6000
5900
5800
0
2000
4000
6000
8000
10000
12000
TIME DAYS

Layers Perforated	Optimum Injection Rate (MSCFD)
1-3	4800
3-5	6000
5-7	6300
Fully Perforated	12000

1500 MSCFD Difference!
Only 300MSCFD Difference



From these results it can be concluded that sensitivity increases as higher layers are perforated.



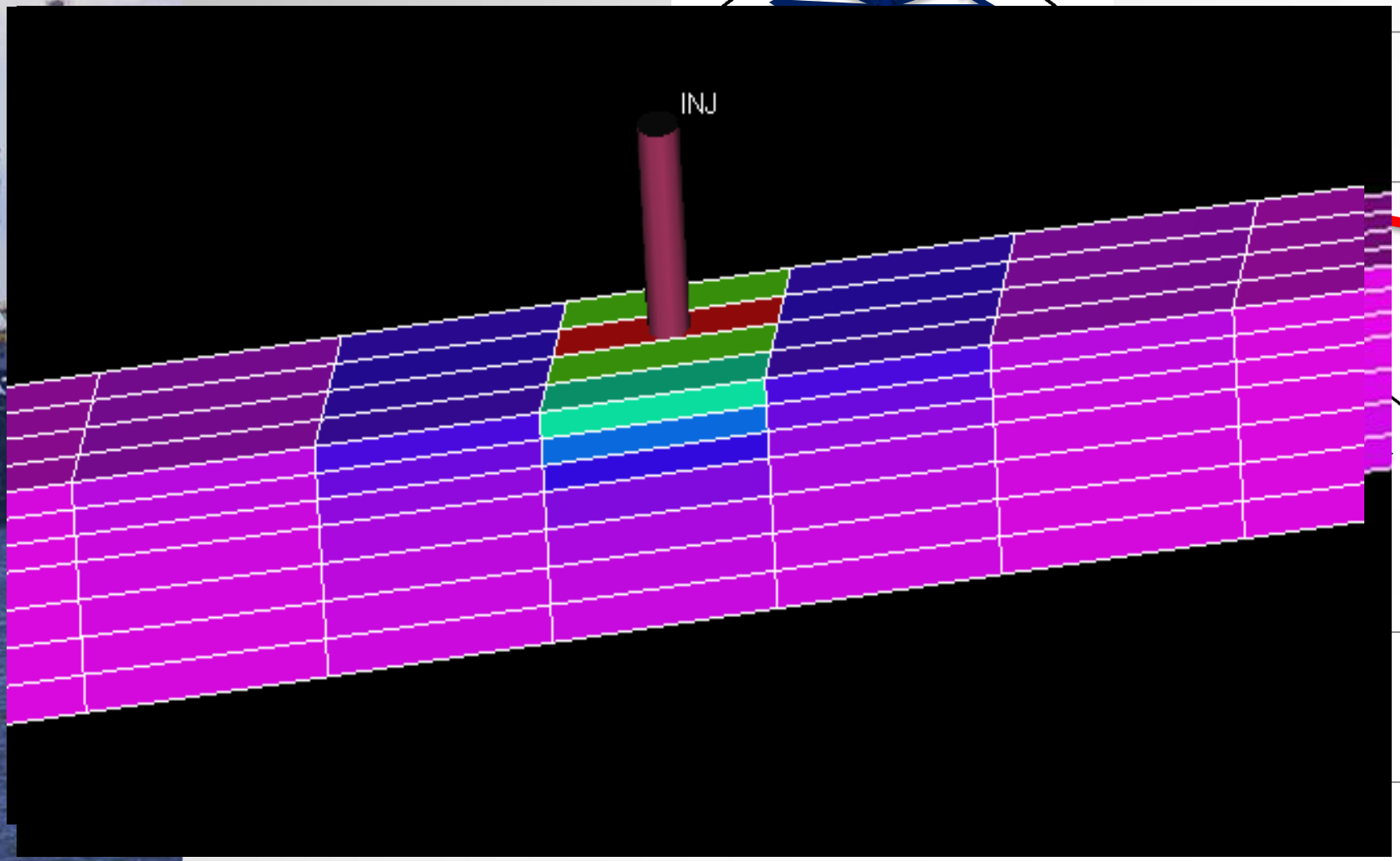
Summary of Results

Layer #	Opt. Inj. Rate(MSCFD)
1	1430
2	1502
3	1515
4	2040
5	2005
6	1960
7	1840
Summation	12292
Fully perforated(previously discussed)	12000

If we run simulation cases in each of which just one layer from layers 1 to 7 is perforated, it leads to following results:

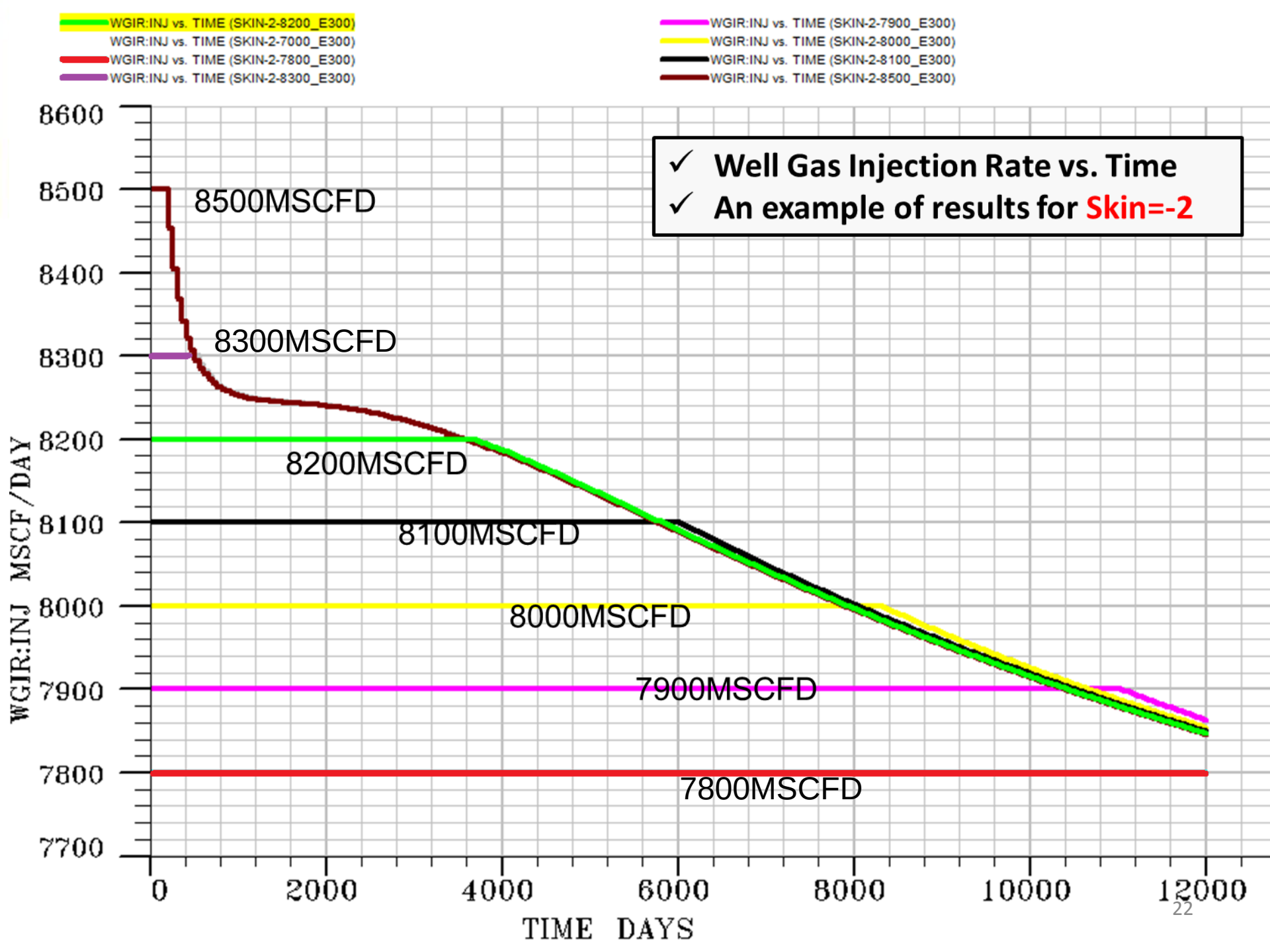
$$\text{Fully Perforated Opt. Inj. } Rate = \sum_{i=layer\ 1}^{layer\ 7} (Opt. Inj. Rate)_i$$

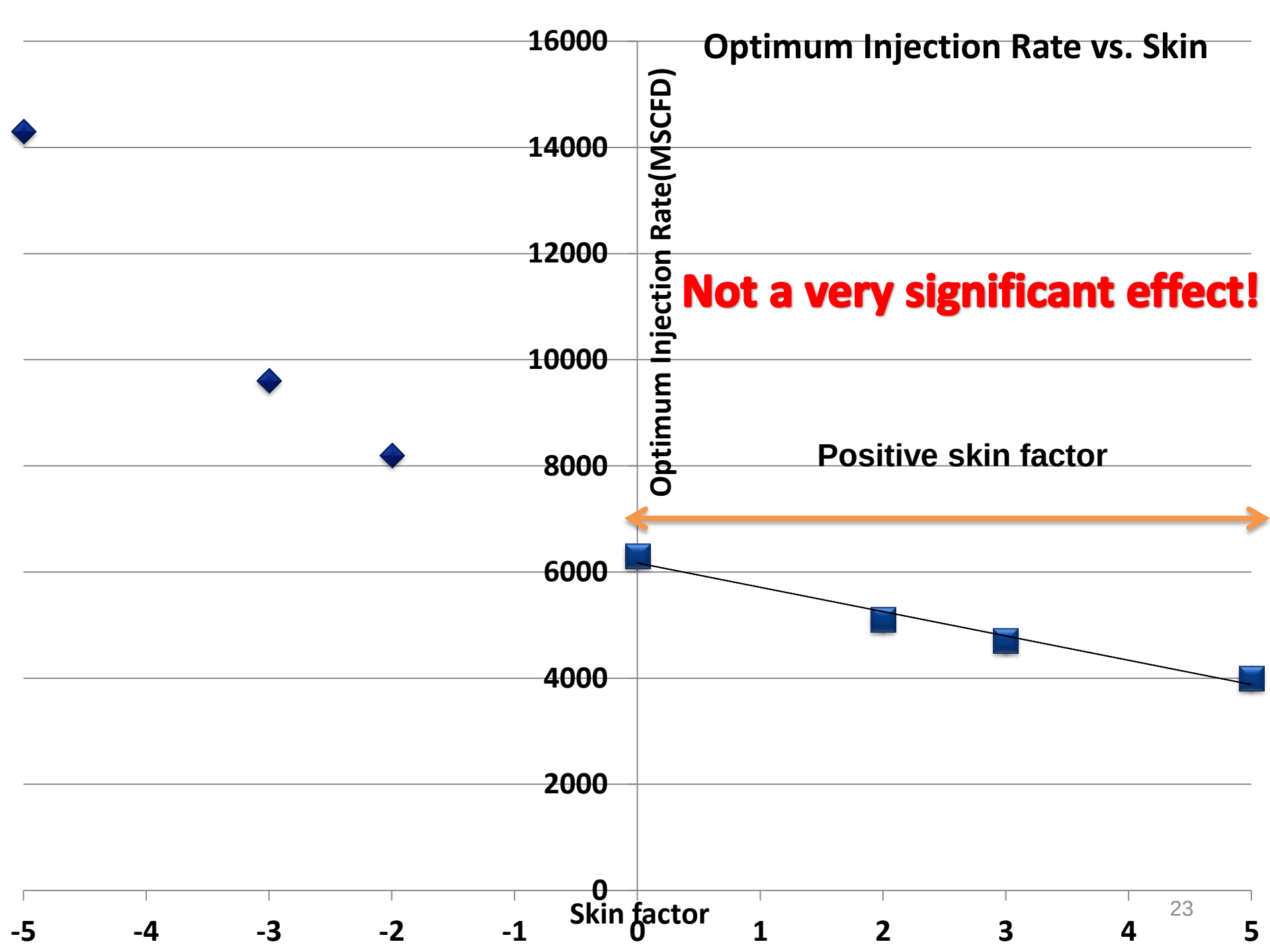
2500
2000
1500
1000
500
0
Optimum Injection rate(MSCFD)
1430
1502
1515
2040
2005
1960
1840
1
2
3
4
5
6
7
Perforated Layer Number

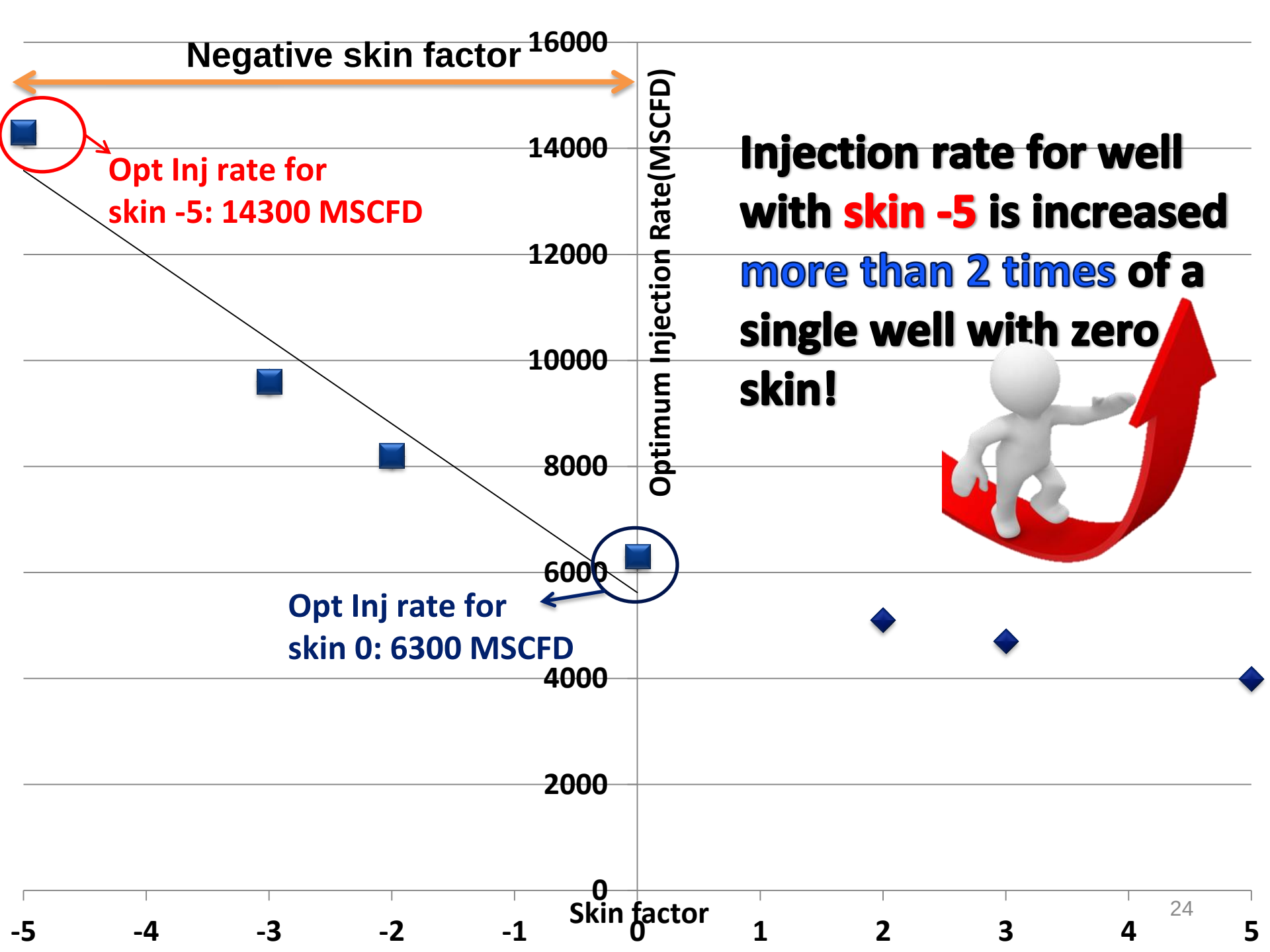


Perforated Layer Number

Effect of skin factor


WGIR:INJ vs. TIME (SKIN-2-8200_E300)
WGIR:INJ vs. TIME (SKIN-2-7000_E300)
WGIR:INJ vs. TIME (SKIN-2-7800_E300)
WGIR:INJ vs. TIME (SKIN-2-8300_E300)
WGIR:INJ vs. TIME (SKIN-2-7900_E300)
WGIR:INJ vs. TIME (SKIN-2-8000_E300)
WGIR:INJ vs. TIME (SKIN-2-8100_E300)
WGIR:INJ vs. TIME (SKIN-2-8500_E300)
✓ Well Gas Injection Rate vs. Time
✓ An example of results for Skin=-2
8500MSCFD
8300MSCFD
8200MSCFD
8100MSCFD
8000MSCFD
7900MSCFD
7800MSCFD
WGIR:INJ MSCF/DAY
TIME DAYS
8600
8500
8400
8300
8200
8100
8000
7900
7800
7700
0
2000
4000
6000
8000
10000
12000


Optimum Injection Rate vs. Skin
Optimum Injection Rate(MSCFD)
16000
14000
12000
10000
8000
6000
4000
2000
0
Not a very significant effect!
Positive skin factor
-5
-4
-3
-2
-1
0
1
2
3
4
5
Skin factor

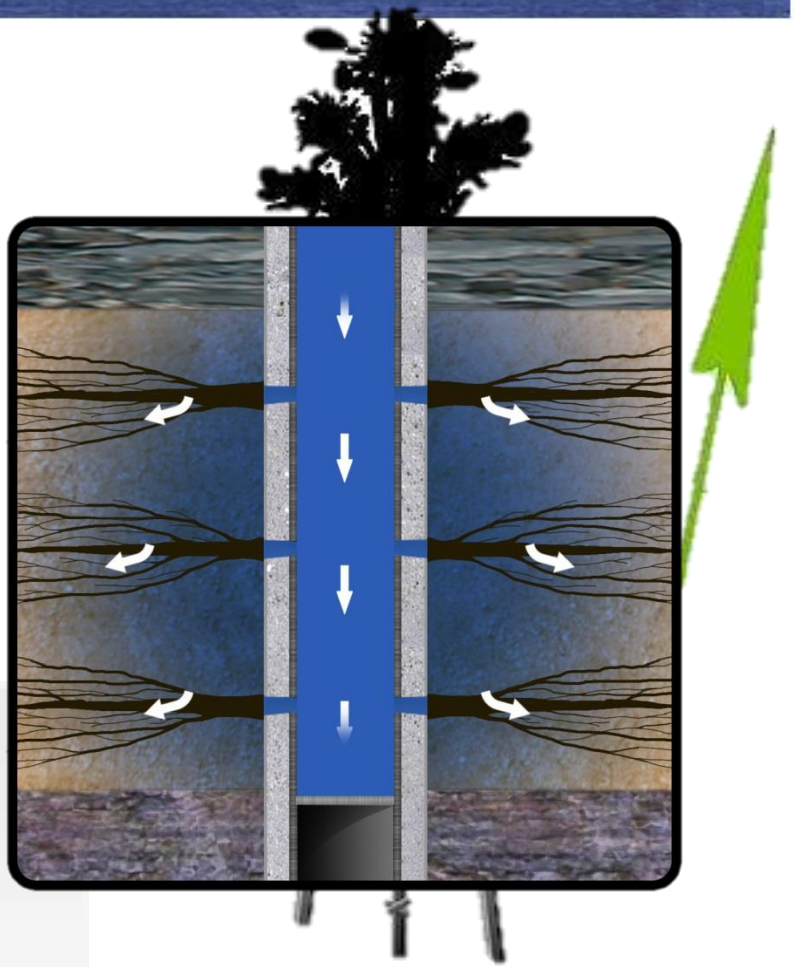

Negative skin factor
Opt Inj rate for
skin -5: 14300 MSCFD
Opt Inj rate for
skin 0: 6300 MSCFD
Optimum Injection Rate(MSCFD)
16000
14000
12000
10000
8000
6000
4000
2000
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Skin factor
Injection rate for well with skin -5 is increased more than 2 times of a single well with zero skin!

Cost of drilling one well:

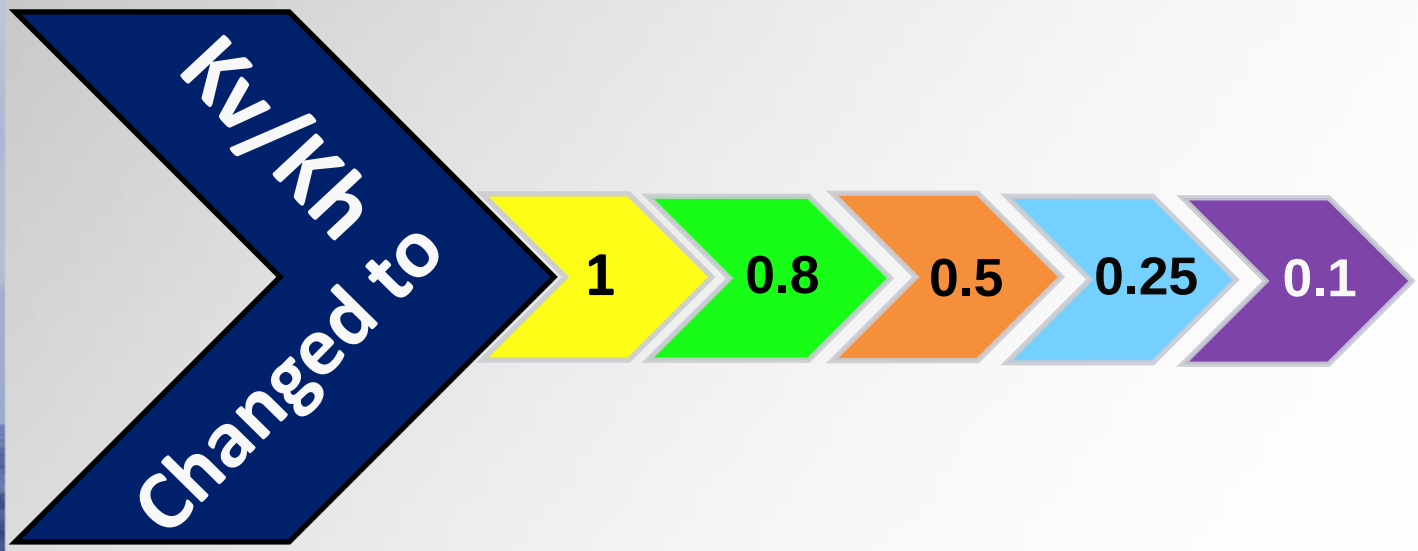
20 million dollars

Cost of Hydraulic Fracturing:

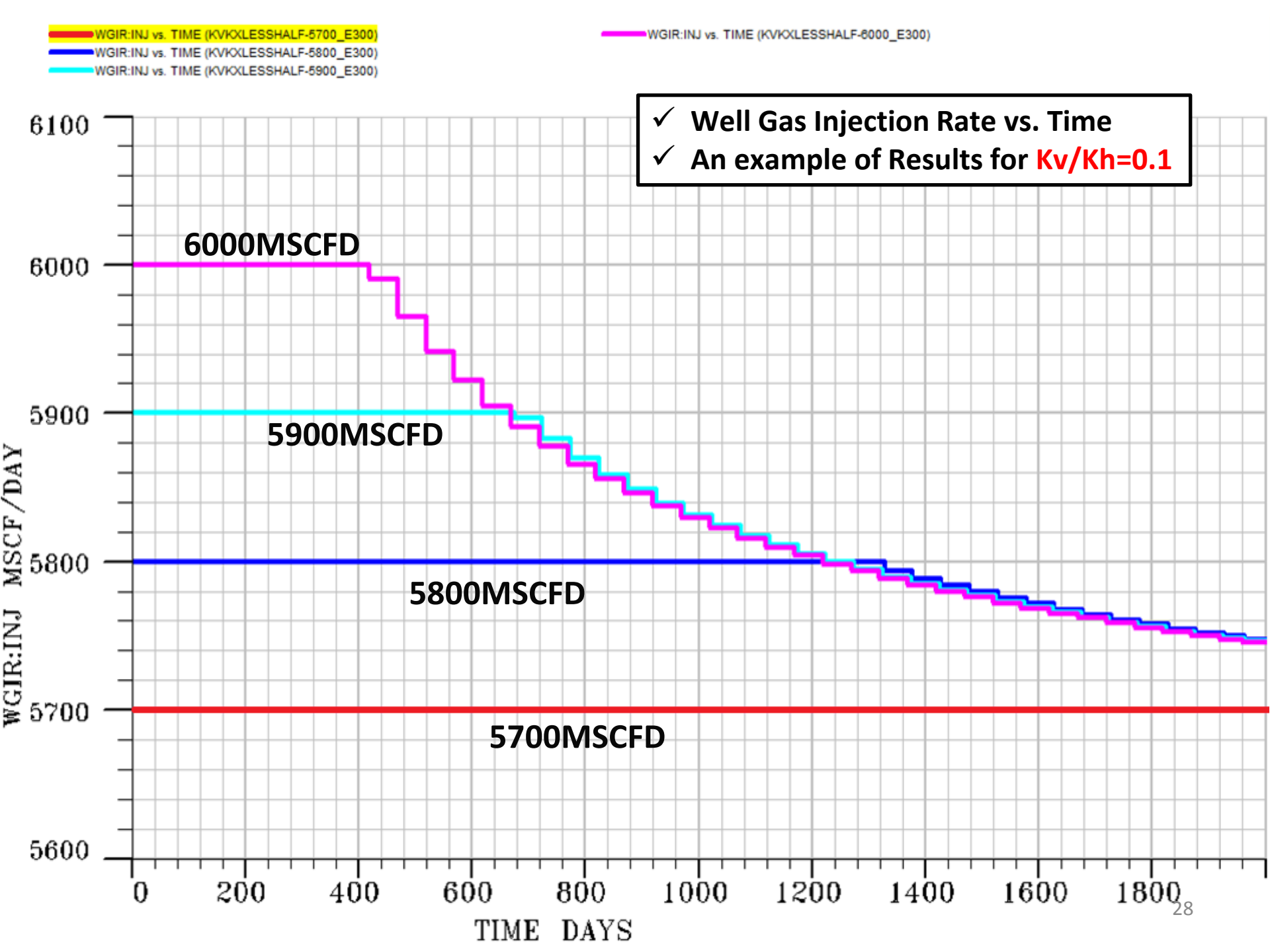
10% of drilling new well

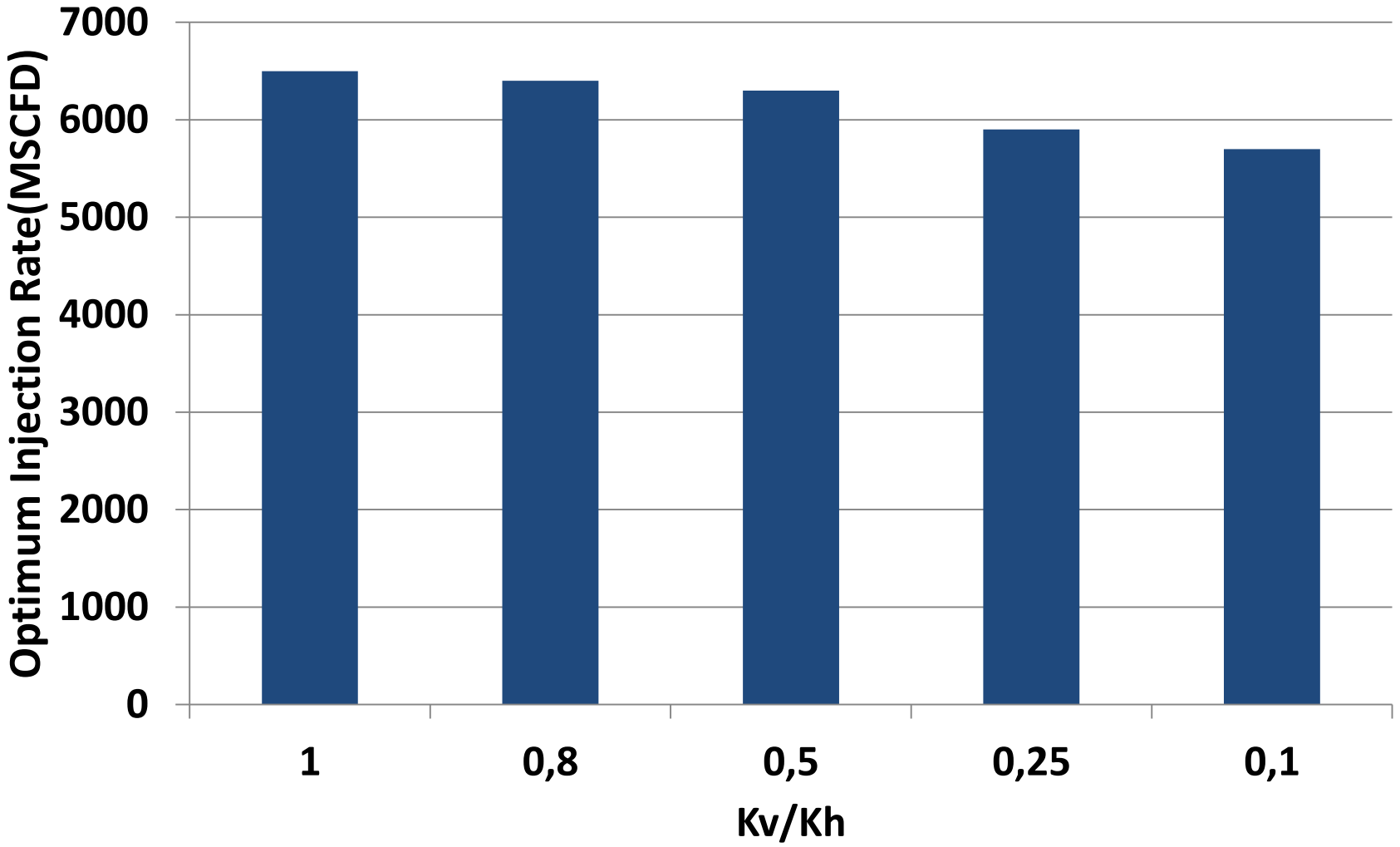


Effect of different vertical over horizontal permeability ratios (K_v/K_h)



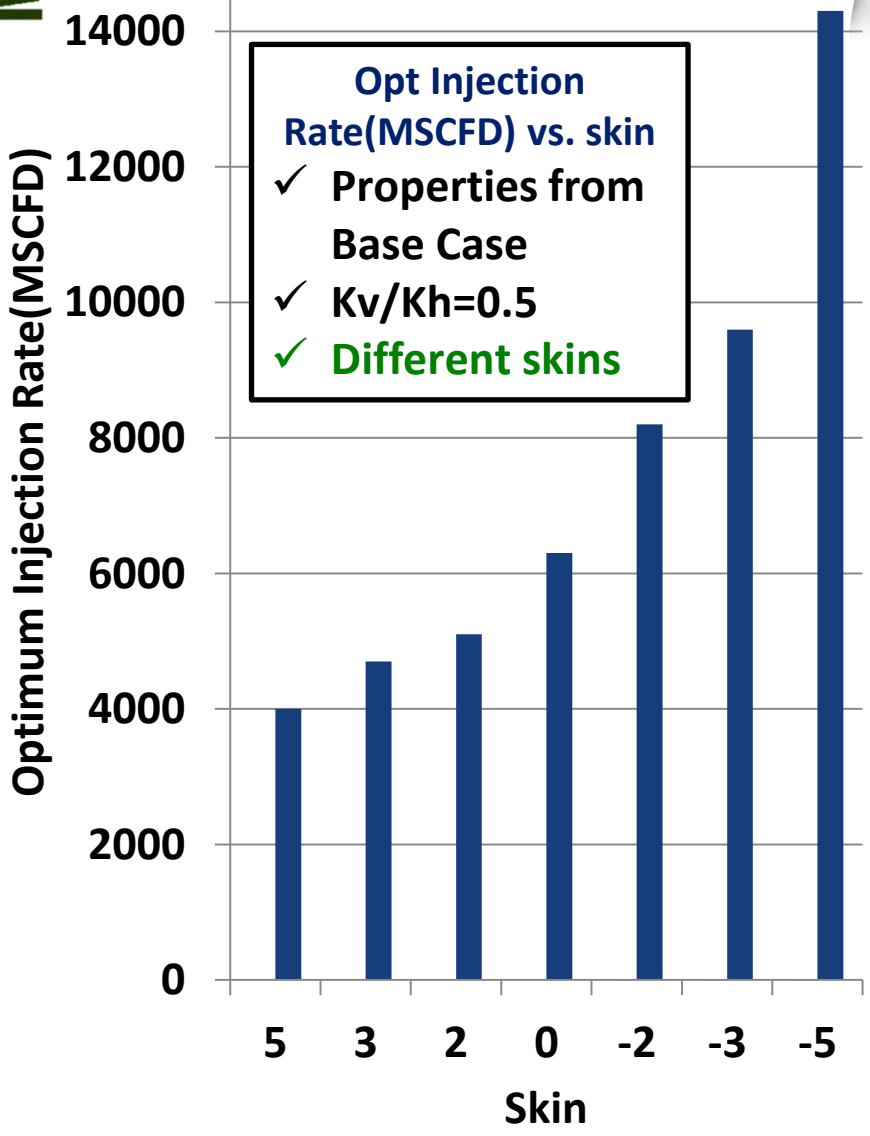
The optimum injection rate for each case is measured.

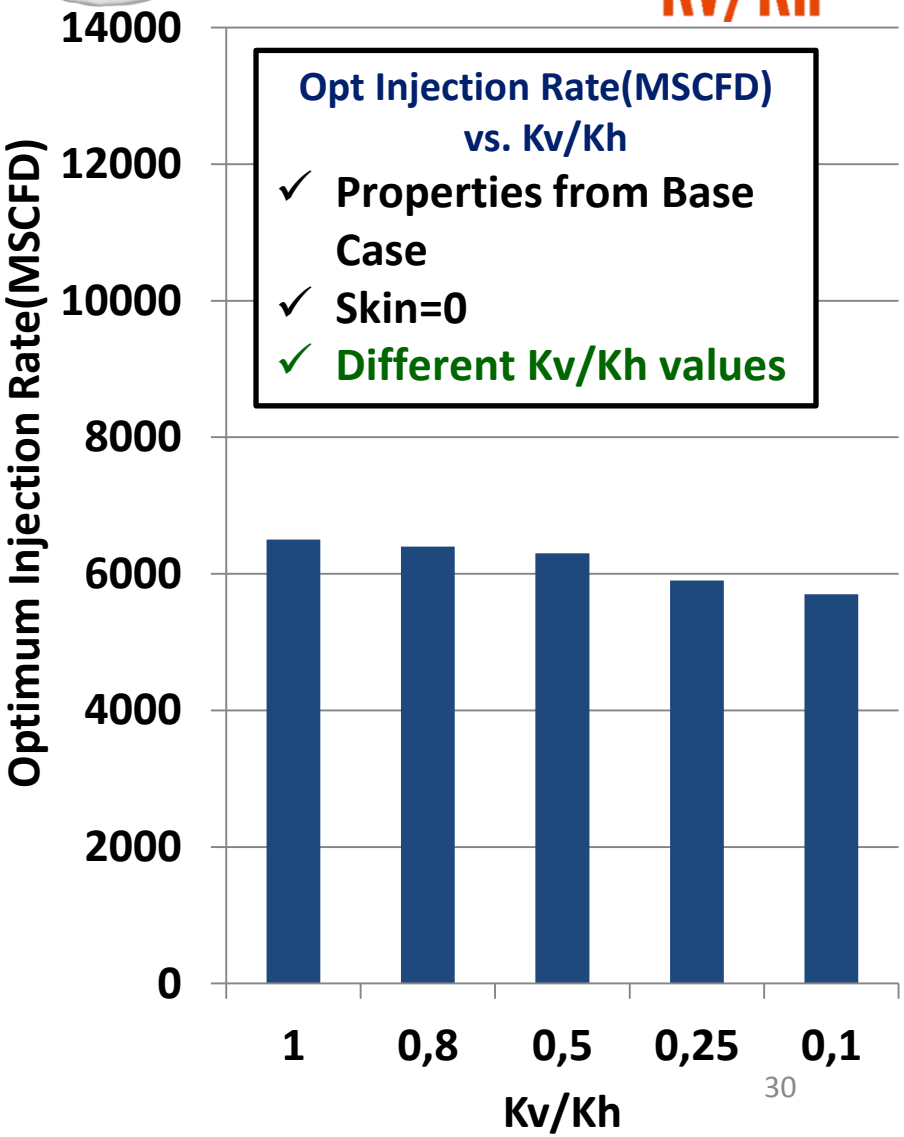

WGIR:INJ vs. TIME (KVKXLESSHALF-5700_E300)
WGIR:INJ vs. TIME (KVKXLESSHALF-5800_E300)
WGIR:INJ vs. TIME (KVKXLESSHALF-5900_E300)
WGIR:INJ vs. TIME (KVKXLESSHALF-6000_E300)
✓ Well Gas Injection Rate vs. Time
✓ An example of Results for Kv/Kh=0.1
6000MSCFD
5900MSCFD
5800MSCFD
5700MSCFD
6100
6000
5900
5800
5700
5600
WGIR:INJ MSCF/DAY
0
200
400
600
800
1000
1200
1400
1600
1800
TIME DAYS


Optimum Injection Rate(MSCFD)
7000
6000
5000
4000
3000
2000
1000
0
1
0,8
0,5
0,25
0,1
Kv/Kh

More Significant Skin Factor

Least Effect Ratio Kv/Kh





Effect of Different Horizontal Permeabilities

Horizontal Permeabilities are changed to:

0.05mD

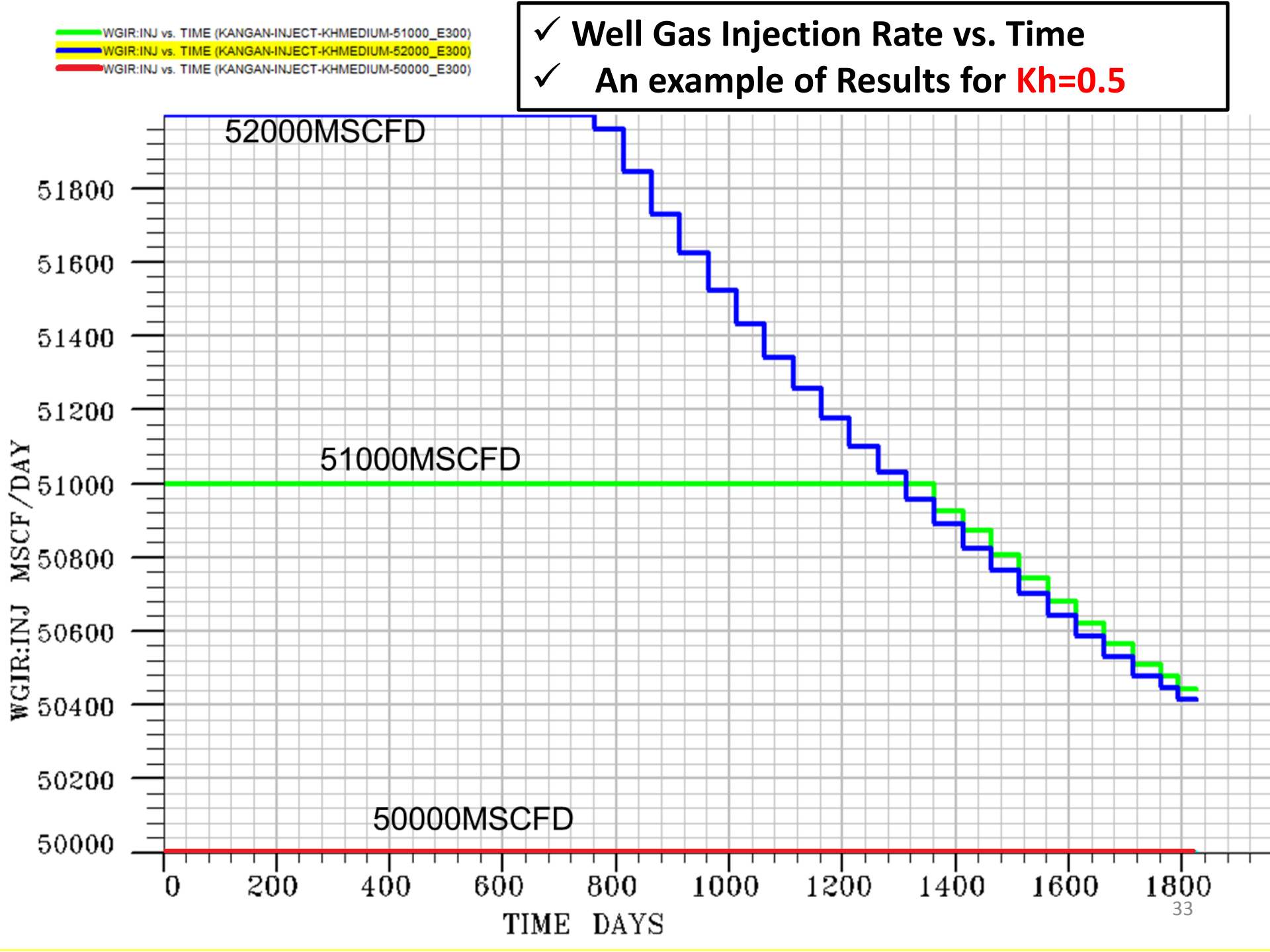
0.5 mD

5 mD

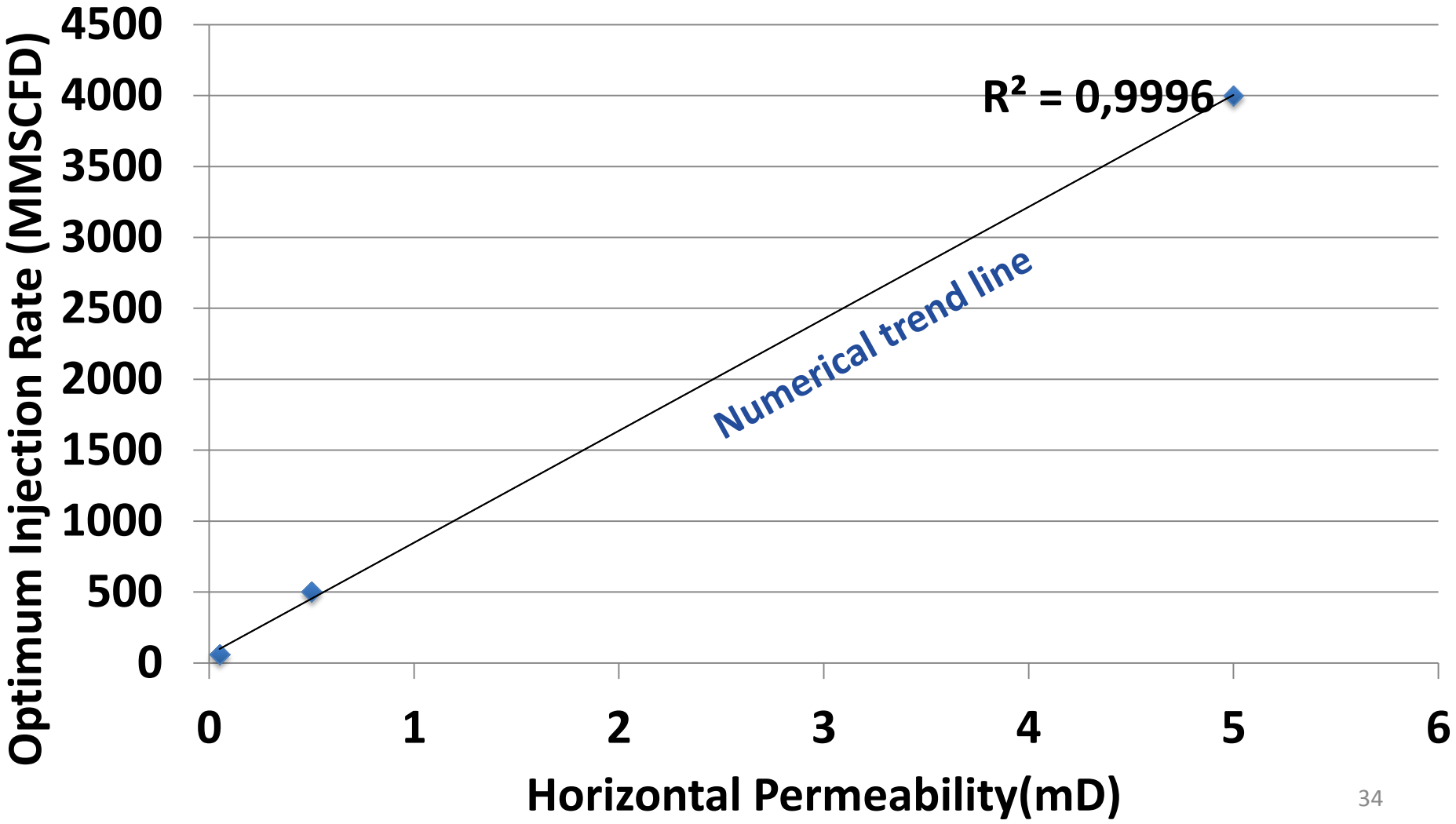
The optimum injection rate for each case is measured.

Keeping in mind that the ratio of Kv/Kh remains constant(=0.5)

- ✓ Well Gas Injection Rate vs. Time
- ✓ An example of Results for Kh=0.5



a linear relationship for the effect of horizontal permeabilities on optimum injection rate

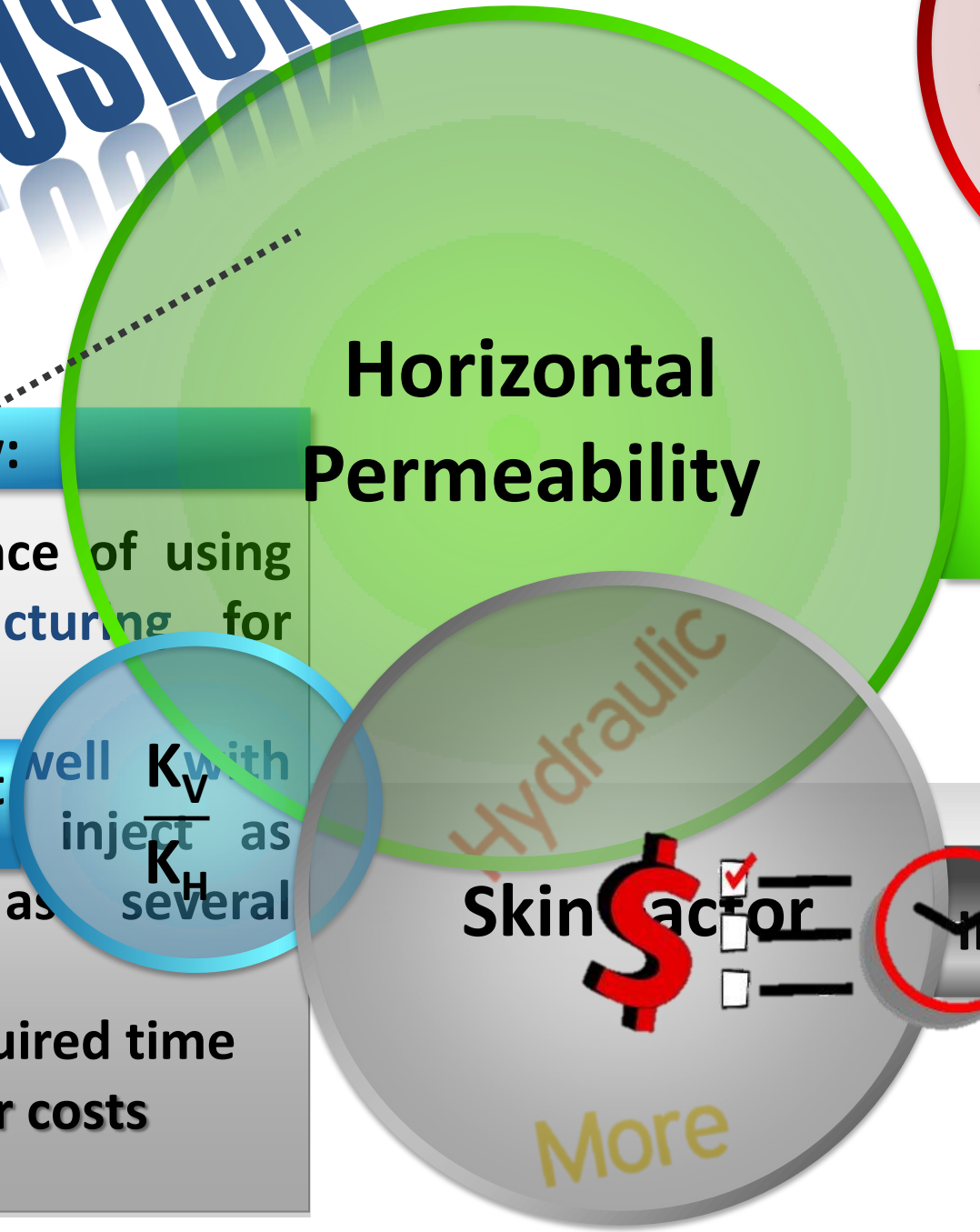


Conclusion

CONCLUSION

Results show:

- The importance of using hydraulic fracturing for the field.
- On well with $\frac{K_V}{K_H}$ Least Effect inject as much gas as several wells:
  - in the required time
  - with lower costs



Perforation's Places: Linear Relationship


Thank you for your kind attention
I would be glad to answer your questions