SPADES: Swift Production Data Analysis and Diagnostics Engine for Shale Reservoirs

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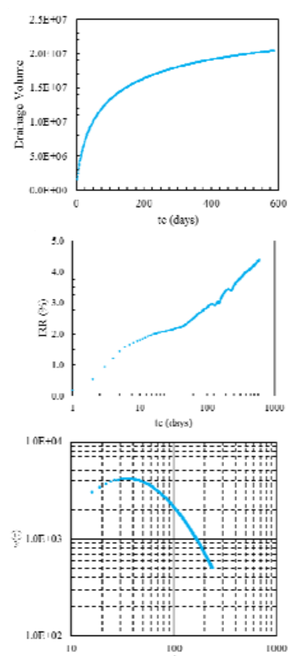
Motivation



Production data analysis software for shale gas/oil reservoirs

- Model free analysis of production data
- Better insight of flow mechanisms
- Characterization of fracture geometry and conductivity
- Refracturing candidate selection

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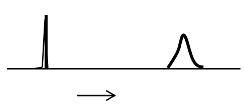
Outline

- Motivation/Background
- Methodology
  - Derive drainage volume, instantaneous recovery ratio (I.R.R.) and w(τ) from production data
  - w(τ) illustration for single infinite conductivity fracture
  - Refracturing candidate selection criteria
- Demonstration

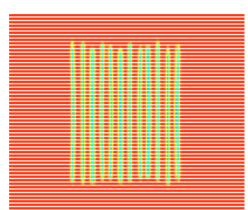
Radius of Investigation

- Radius of Investigation is the propagation distance of the 'peak' pressure disturbance for an impulse source or sink (Lee, 1982)

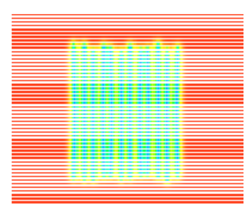
Wave Front Propagation



$$r = \sqrt{\frac{4kt}{\phi \mu c_t}}$$



Formation Linear Flow

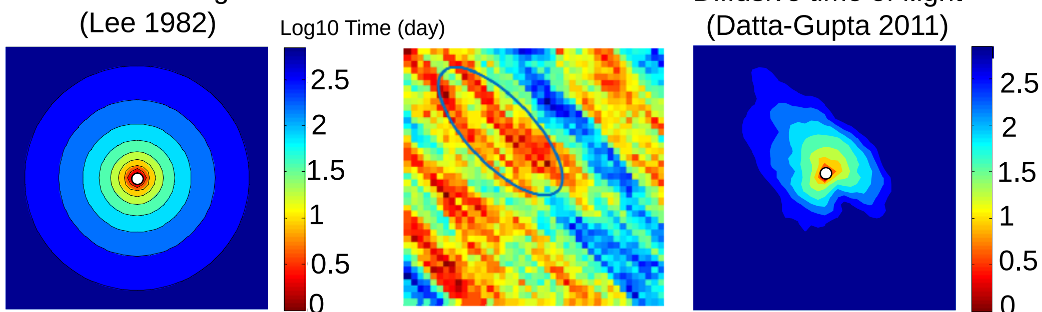


Fracture Interference

Generalization via Diffusive Time of Flight (τ)

Homogeneous
Radius of investigation
(Lee 1982)

Heterogeneous
Diffusive time of flight
(Datta-Gupta 2011)



$r = \sqrt{4\alpha t}$

Diffusivity $\alpha = \frac{k}{\phi \mu c_t}$

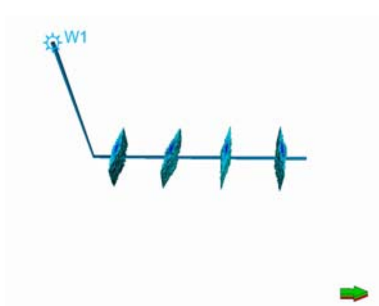
Analytical

$\sqrt{\alpha(x)}|\nabla\tau(x)|=1$

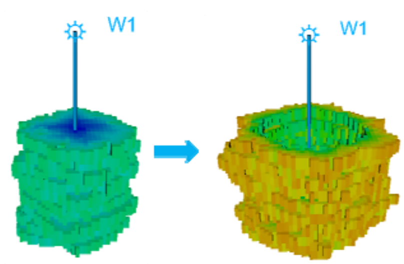
Eikonal Equation

Drainage Volume and $\mathbf{w}(\boldsymbol{\tau})$

- Visualization of the drainage volume evolution $V_p(\tau)$



- $w(\tau)$ indicates how fast $V_p(\tau)$ increases $w(\tau) = \frac{dV_p(\tau)}{d\tau}$ (drainage surface area)



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New Model-Free Methodology for Production Analysis

- Drainage Volume (RNP Approximation)

$$\frac{1}{V_d(t_e)} \approx c_t \frac{d}{dt_e}\left(\frac{\Delta p_{wf}(t_e)}{q_w(t_e)}\right)$$

Generalization of MBH (1954) PSS to transient flow

- Instantaneous Recovery Ratio

$$\mathrm{IRR}(t_e) = \frac{N_p(t_e)}{V_d(t_e)}$$

Impact of Rate

- Drainage Volume Geometry: w(τ)

$$V_d(t_e) = \int d\tau\, w(\tau)\, e^{-\tau^2/4t}$$

Flow Geometry (Diffusivity Equation)

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Analysis of Field Production Data

- Given Pressure & Rate Data
- Step 1: Drainage Volume

$$\frac{1}{V_d(t_e)} \approx c_t \frac{d}{dt_e}\left(\frac{\Delta p_{wf}(t_e)}{q_w(t_e)}\right)$$

- Step 2: $\mathbf{w}(\boldsymbol{\tau})$ Function

$$V_d(t_e) = \int w(\tau) \exp\left(-\frac{\tau^2}{4t}\right) d\,\tau$$

- Step 3: Instantaneous Recovery Ratio (IRR)

$$\mathrm{IRR}(t_e) = \frac{N_p(t_e)}{V_d(t_e)}$$

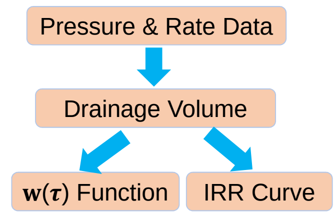

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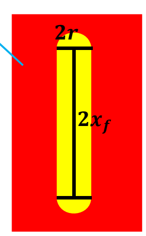
Illustration: $\mathbf{w}(\boldsymbol{\tau})$ for Single Fracture

Pillbox Shape Model



- Drainage Volume

$$V_p(r) = (4rx_f + \pi r^2)h\phi$$

$$r = \sqrt{\alpha\tau}$$

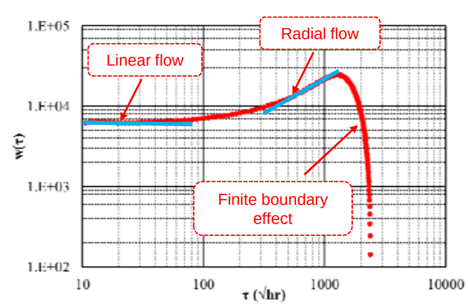
$$w(\tau) = \frac{dV_p(\tau)}{d\tau} = \left(4\sqrt{\alpha}x_f + 2\pi\alpha\tau\right)h\phi$$

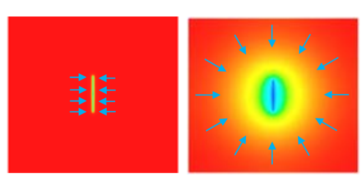
- Early Time: Fracture Area

Linear flow $w(\tau) \approx 4\sqrt{\alpha}x_f h\phi = A\sqrt{\alpha}\phi$

- Late Time: Permeability

Radial flow $w(\tau) \approx 2\pi\alpha h\phi\tau$





Linear flow   Radial flow

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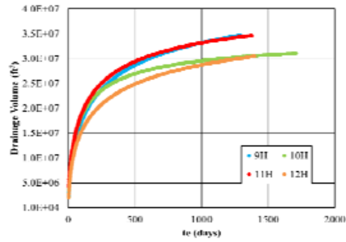
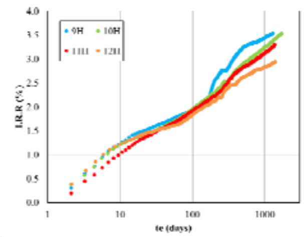
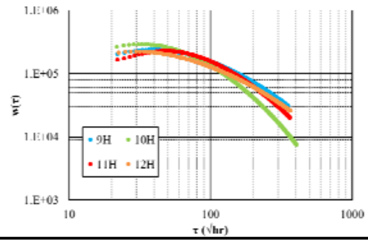
Well Performance Analysis: Eagle Ford

- 4 Eagle Ford shale oil wells are analyzed







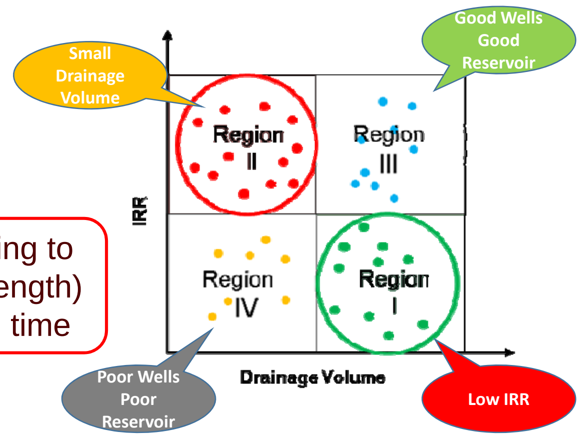
Methodology: Drainage Volume and IRR

- Well drainage volume
  - Drainage volume is calculated directly from pressure and production rate
  - The reservoir volume accessed by the well after hydraulic fracturing
    - Depends on the fracture geometry, fracture and reservoir properties
    - Independent of rate history
- Well depletion rate
  - Define Instantaneous Recovery Ratio (IRR) as the ratio of produced volume to the drainage volume
  - How effectively the accessed volume is being produced
    - Depends on rate history

Methodology: Candidate Selection Criteria

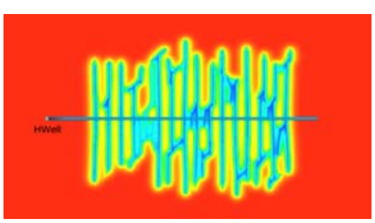
- Drainage volume looks at how much pore volume is accessed by the well
- IRR compares how efficiently the accessed pore volume is drained

We qualitatively rank wells according to their drainage volume (per lateral length) and IRR after sufficient production time

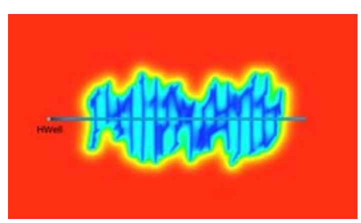


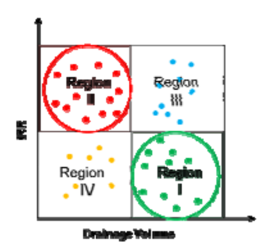
Ranking of Refracturing Candidate

Large surface area
but low conductivity (region I)



Small surface area
but high conductivity (region II)





- Region I wells are more favorable for refracturing than region II wells
  - More practical to enhance fracture conductivity with region I wells
  - Challenging to increase stimulated reservoir volume with region II wells

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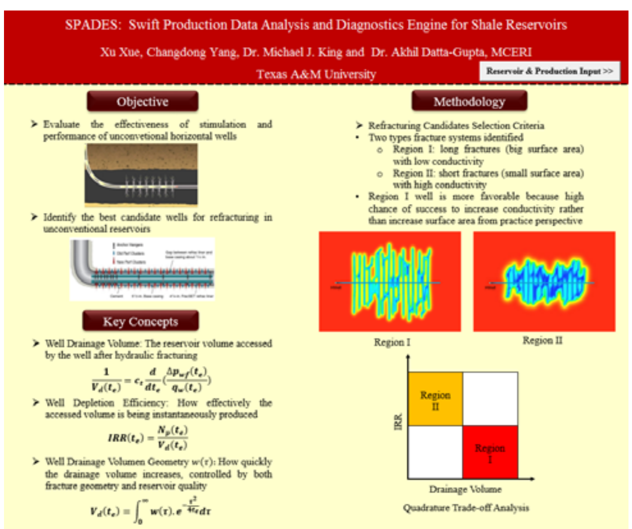
SPADES: Introduction



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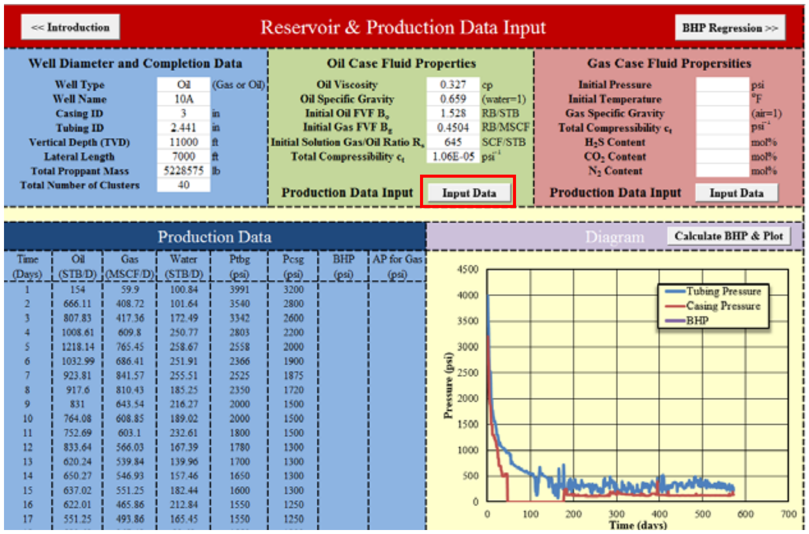
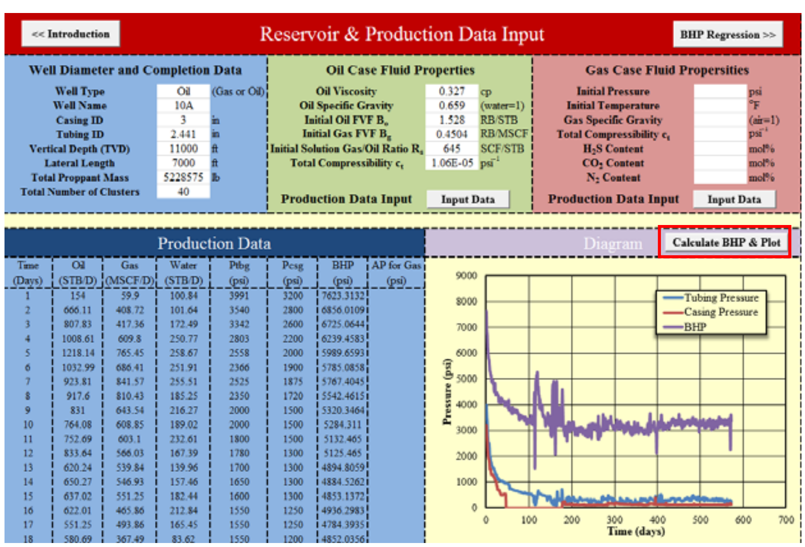
SPADES: Production Data Import



SPADES: BHP Calculation



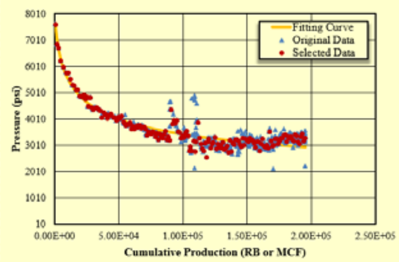
SPADES: BHP Regression

<< Reservoir & Production Input | **BHP Regression** | q_w Regression >>

BHP (psi)	Cum Prod (RB or MCF)	Regression Value $BHP=BHP_i*(1+D_i*b*t)^{(-1/b)}$	Weight	Residual	Selected Data Point	
7623.313	336.152	7610.986264	1	151.9533	7623.313	336.152
6856.011	1455.60808	7118.019023	1	68648.25	6856.011	1455.60808
6725.064	2862.46232	6678.97965	1	2123.801	6725.064	2862.46232
6239.458	4654.3884	6277.515417	1	1448.346	6239.458	4654.3884
5989.659	6774.37632	5930.293734	1	3524.267	5989.659	6774.37632
5785.086	8613.762245	5696.827611	1	7789.514	5785.086	8613.762245
5767.405	10391.52286	5510.825116	1	65832.99	5767.405	10391.52286
5542.462	12077.31319	5360.56761	1	33085.4	5542.462	12077.31319
5320.346	13611.78946	5240.758273	1	6334.269	5320.346	13611.78946
5284.311	15020.57838	5142.184436	1	20199.96	5284.311	15020.57838
5132.465	16456.27248	5051.03858	1	6630.26	5132.465	16456.27248
5125.465	17910.22522	4966.807573	1	25172.18	5125.465	17910.22522
4894.806	19060.87119	4905.10448	1	106.0608	4894.806	19060.87119
4884.526	20269.37239	4844.427555	1	1607.899	4884.526	20269.37239
4853.137	21488.40254	4787.032645	1	4369.813	4853.137	21488.40254
4936.298	22680.79829	4734.199107	1	40844.09	4936.298	22680.79829
4784.394	23750.8503	4689.297094	1	9043.33	4784.394	23750.8503
4852.036	24721.76462	4650.429285	1	40645.1	4852.036	24721.76462
4507.744	25767.76668	4610.389388	1	10536.18	4507.744	25767.76668
4822.011	26616.10492	4579.211022	1	58951.86	4822.011	26616.10492
4841.778	27635.81244	4543.159683	1	89172.84	4841.778	27635.81244
4455.923	28767.65992	4504.836128	1	2392.513	4455.923	28767.65992
4366.392	29767.9584	4472.341608	1	11225.42	4366.392	29767.9584
4468.25	30764.07561	4441.175502	0	0	#NAME?	#NAME?
4461.426	31791.9478	4410.181876	1	2625.914	4461.426	31791.9478
4454.747	32763.9293	4381.894376	1	5307.484	4454.747	32763.9293
4409.629	33809.68643	4352.499001	1	3263.865	4409.629	33809.68643
4353.576	34620.95588	4330.394964	1	537.3465	4353.576	34620.95588
4359.876	35546.58031	4305.881787	1	2915.391	4359.876	35546.58031
4080.183	36338.08602	4285.489005	1	42150.4	4080.183	36338.08602
4262.255	37361.75907	4259.852221	0	0	#NAME?	#NAME?

BHP_i	7799.960198	
D_i	0.000923099	Regression (2)
b	4.27724885	
Total Residual	9762878.239	

Resampling Interval (RB or MCF)	1100	Resample (1)



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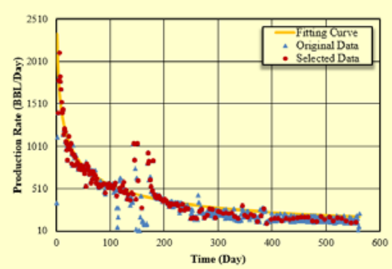
SPADES: Production Rate Regression

<< BHP Regression | **Production Rate Regression** | Single Well Analysis >>

q_w (BBL/Day)	Time (Days)	Regression Value $q_w=q_{wi}*\exp[-(t/tau)^n]$	Weight	Residual	Selected Data Point	
336.152	1	2333.440855	0	0	#NAME?	#NAME?
1119.45608	2	2058.962021	0	0	#NAME?	#NAME?
1406.85424	3	1892.772416	1	236116.5	1406.854	3
1791.92608	4	1773.255665	1	348.5844	1791.926	4
2119.98792	5	1680.040741	1	193553.5	2119.988	5
1839.385925	6	1603.765527	1	55516.97	1839.386	6
1777.760613	7	1539.327517	1	56850.34	1777.761	7
1685.790331	8	1483.632188	1	40867.91	1685.79	8
1534.476268	9	1434.658872	1	9963.513	1534.476	9
1408.788927	10	1391.014361	1	315.9352	1408.789	10
1435.694093	11	1351.697066	1	7055.501	1435.694	11
1453.952743	12	1315.962641	1	19041.27	1453.953	12
1150.645974	13	1283.242774	1	17581.91	1150.646	13
1208.501195	14	1253.093718	1	1988.493	1208.501	14
1219.030154	15	1225.162368	1	37.60405	1219.03	15
1192.395743	16	1199.163166	1	45.79802	1192.396	16
1070.052009	17	1174.861915	1	10985.12	1070.052	17
970.91432	18	1152.064178	1	32815.27	970.9143	18
1046.002068	19	1130.606774	1	7157.956	1046.002	19
848.33824	20	1110.351433	1	68650.91	848.3382	20
1019.70752	21	1091.179983	1	5108.313	1019.708	21
1131.847472	22	1072.990645	1	3464.126	1131.847	22
1000.298487	23	1055.695146	1	3068.79	1000.298	23
996.1172055	24	1039.216435	0	0	#NAME?	#NAME?
1027.872197	25	1023.486871	1	19.23109	1027.872	25
971.9814924	26	1008.446749	1	1329.715	971.9815	26
1045.757134	27	994.0431176	1	2674.339	1045.757	27
811.2694512	28	980.2287984	1	28547.26	811.2695	28

q_{wi}	4451.894306	
tau	66.3809098	Regression
n	0.25546746	
Total Residual	3504679.134	



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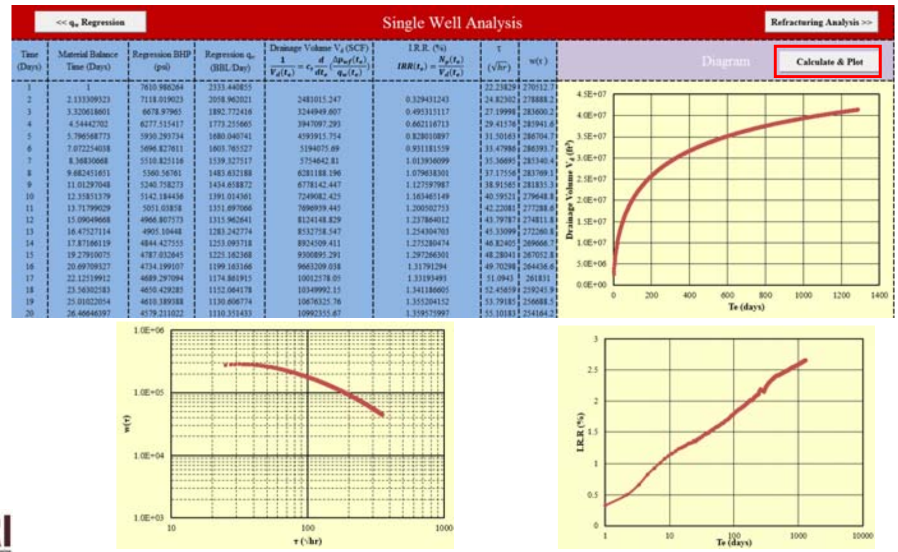
SPADES: Single Well Analysis



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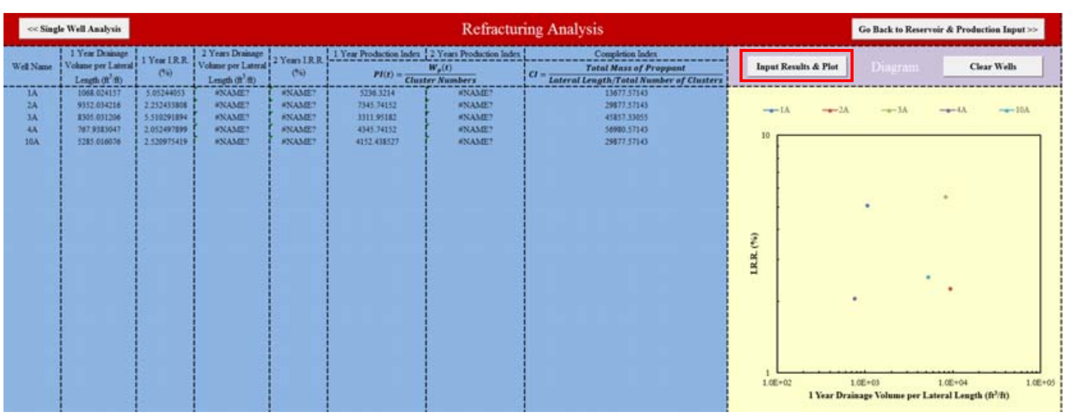
SPADES: Refracturing Candidate Selection



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