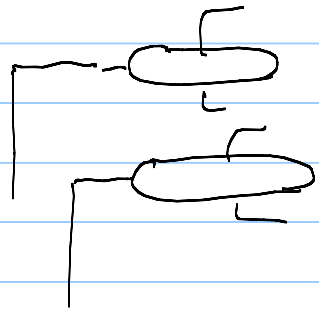
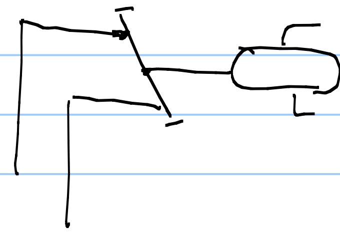
Day 4

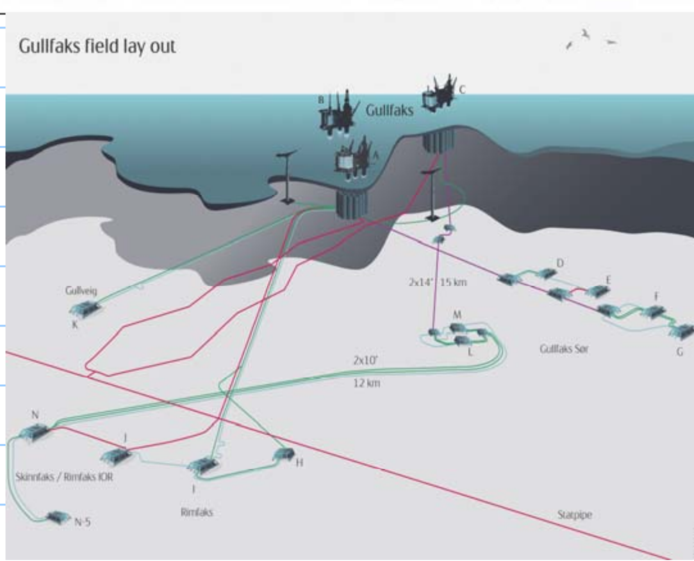
Gathering system / commingling system

Networks → collection/system of pipes, flowlines and pipelines that take production from wells to processing facilities.

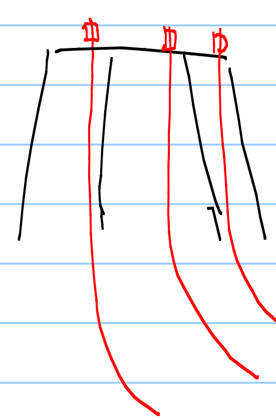


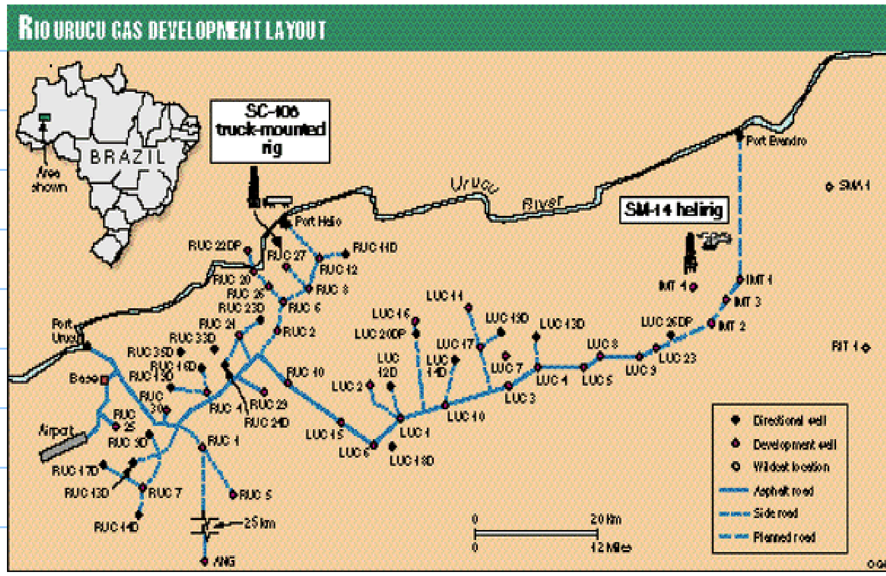


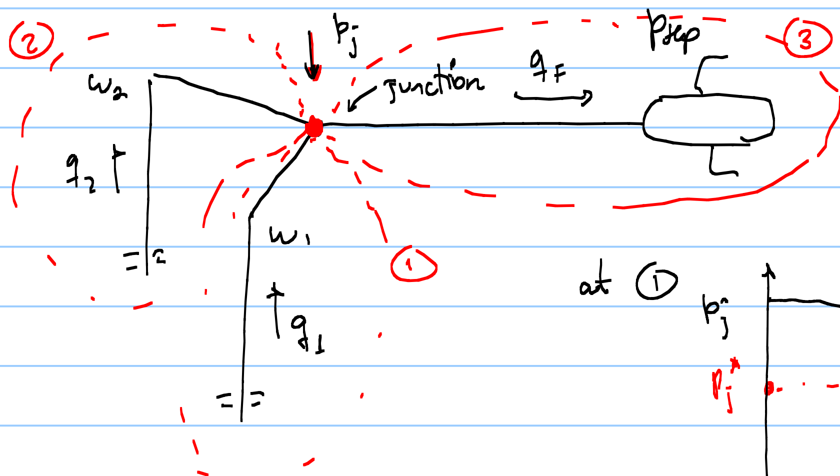
standalone wells



subsea systems







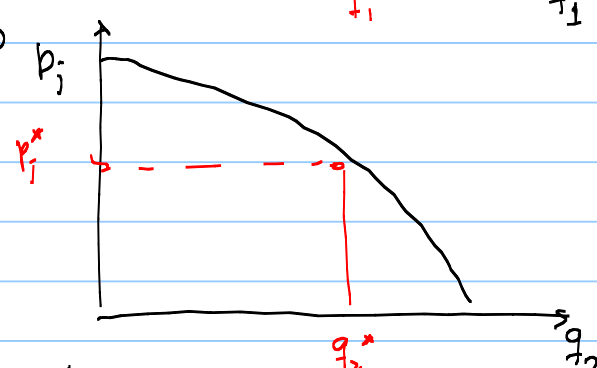
solving process

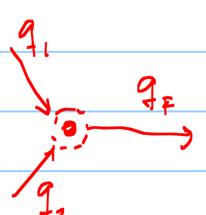
1) Assume p_j^*

in curve 1 read q_1^*

In curve 2 read q_2^*

in curve 3 read q_F^*

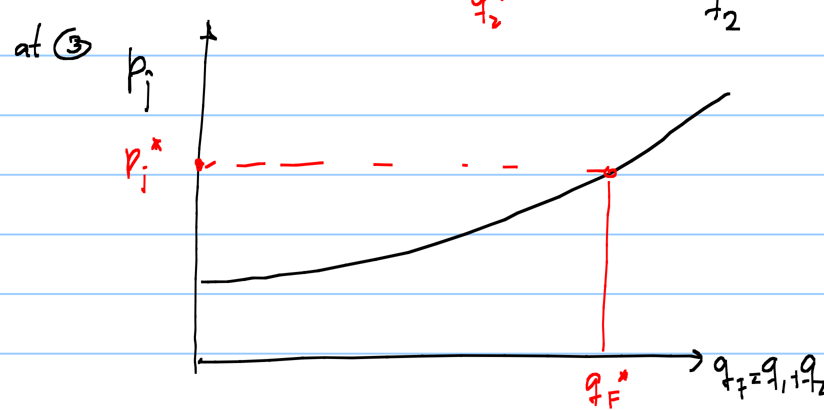




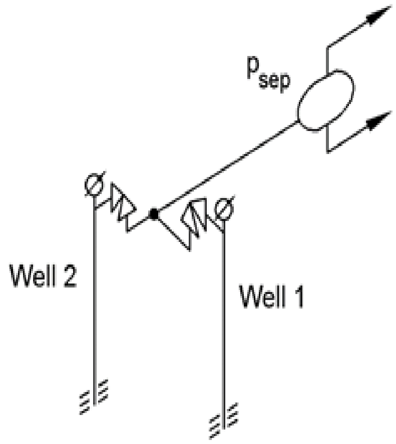
$q_F = q_1 + q_2$

verify $q_F^* = q_1^* + q_2^*$ → not → (back to 1)

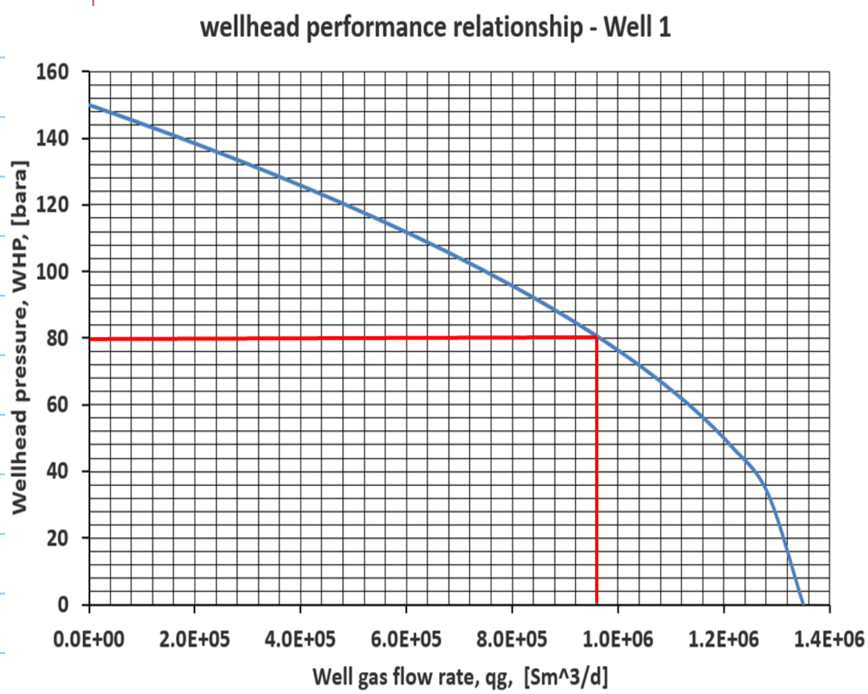
↓ yes → solution



class exercise:

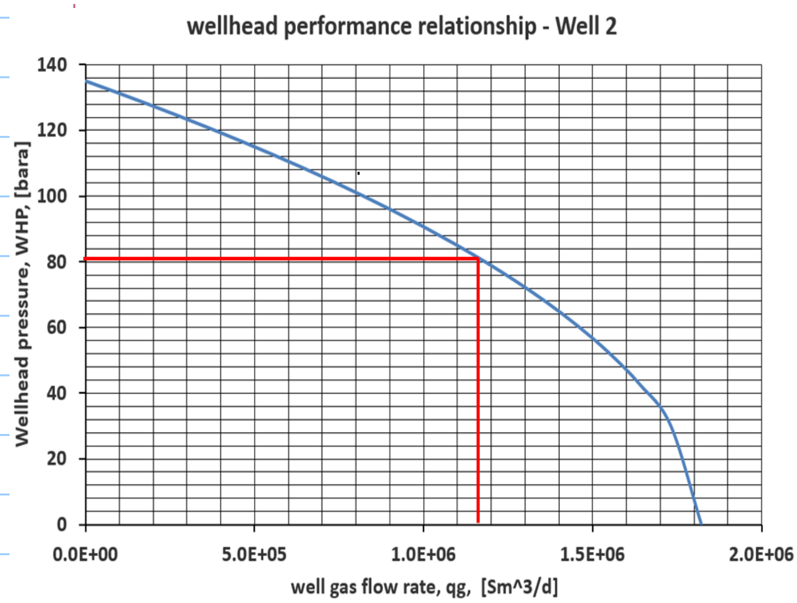


iteration 1



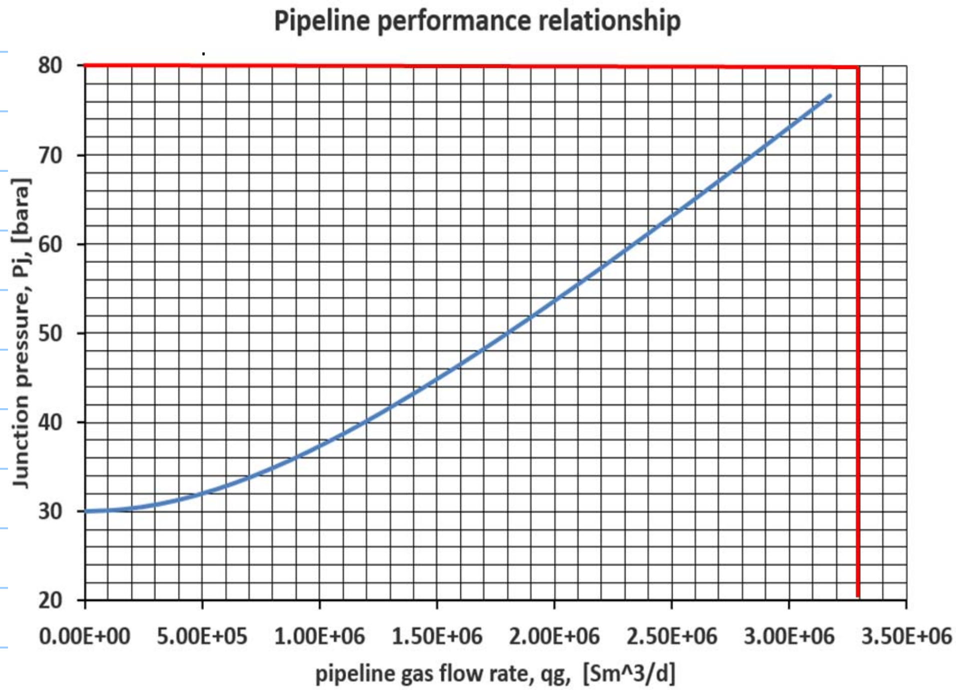
assume $p_1^k = 80$ bara

$q_1^k = 9.6\,E5$ Sm³/d



$p_1^k = 80$ bara

$q_2^k = 1.17\,E6$ Sm³/d



$p_j^* = 80$ bara

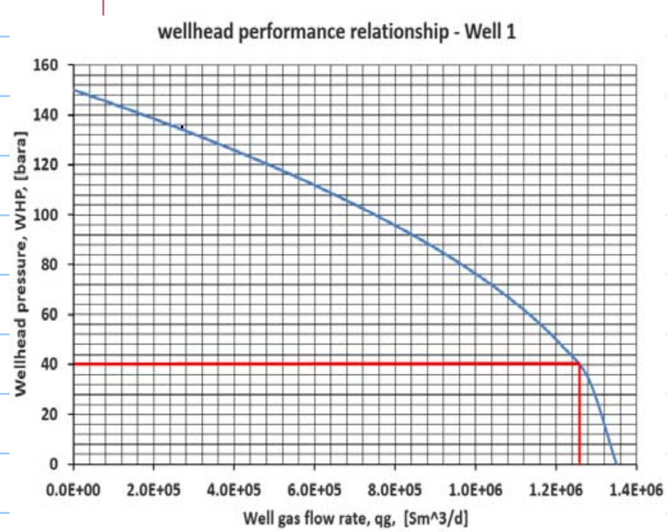
$q_F^* = 3.3E6$ Sm³/d

$9.6E5$ Sm³/d + $1.17E6$ Sm³/d $\stackrel{?}{=}$ $3.3E6$ Sm³/d

$\varepsilon = (q_F - q_1 - q_2)$

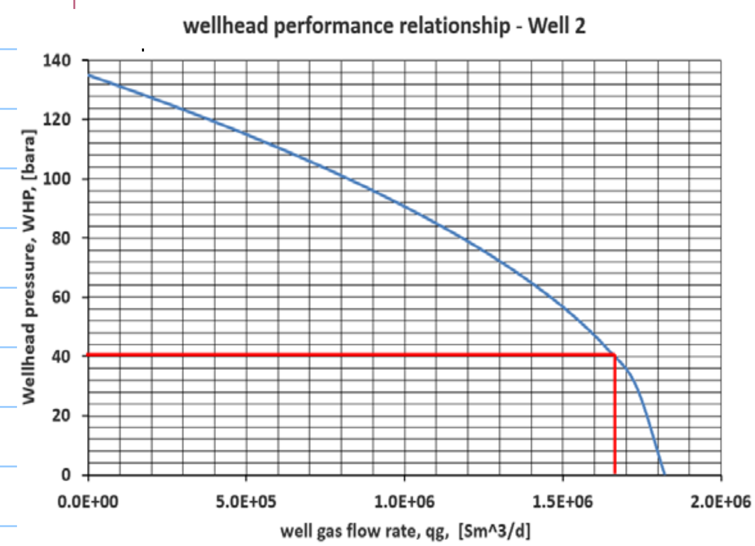
$\varepsilon^{(1)} = 1.17E6$ Sm³/d (+)

Second iteration $p_j^* = 40$ bara

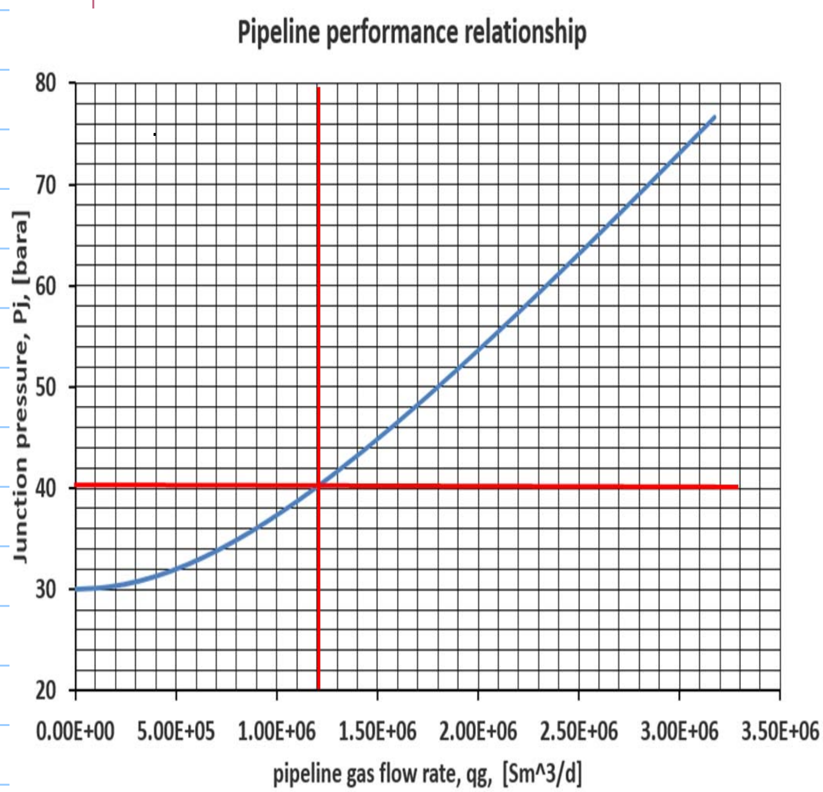


$p_j^* = 40$ bara

$q_{g1}^* = 1.25E6$ Sm³/d



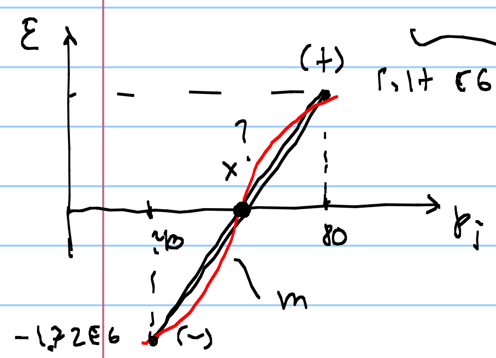
$q_2^* = 1.67\ E6\ Sm^3/d$



$q_F = 1.2\ E6\ Sm^3/d$

$q_1^* + q_2^* \stackrel{?}{=} q_F^*$

$\underbrace{1.25\ E6\ Sm^3/d + 1.67\ E6\ Sm^3/d}_{} = \underbrace{1.2\ E6\ Sm^3/d}_{}$



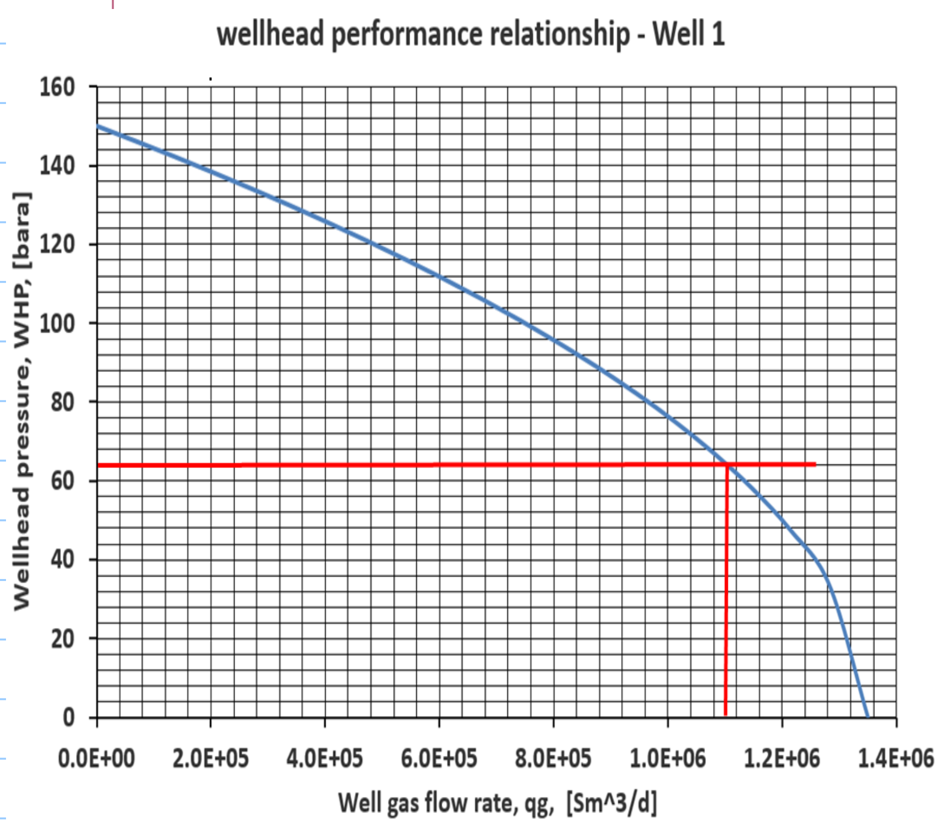
$\varepsilon^{k2} = -1.72\ E6\ Sm^3/d$

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{1.17E6 - (-1.72E6)}{80 - 40} = 0.07225\ E6$$

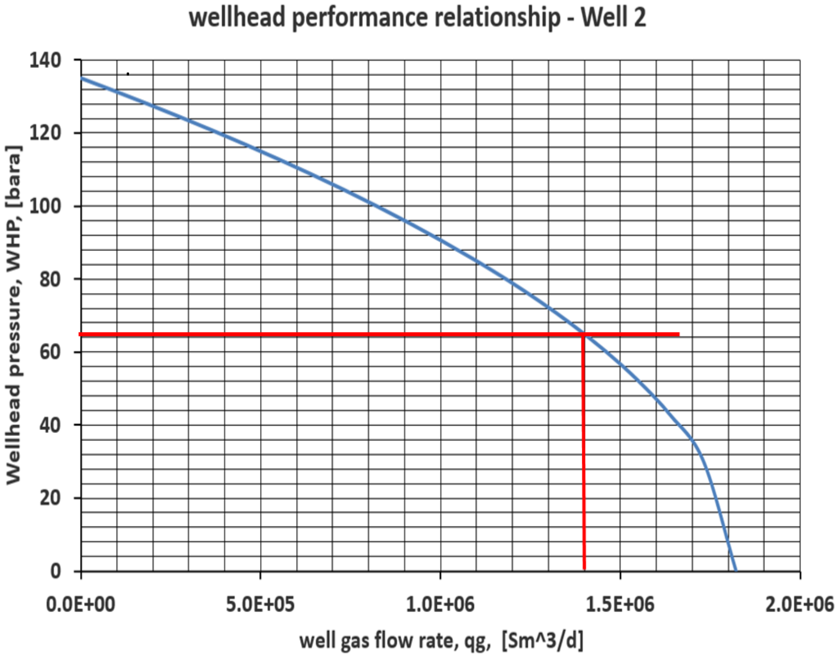
$$m = \frac{y_2 - y}{x_2 - x} = \frac{1.17E6 - 0}{80 - x} = 0.07225\ E6$$

$$x = 80 - \frac{1.17 E6}{0.07225\ E6} = 63.8\ \text{bara}$$

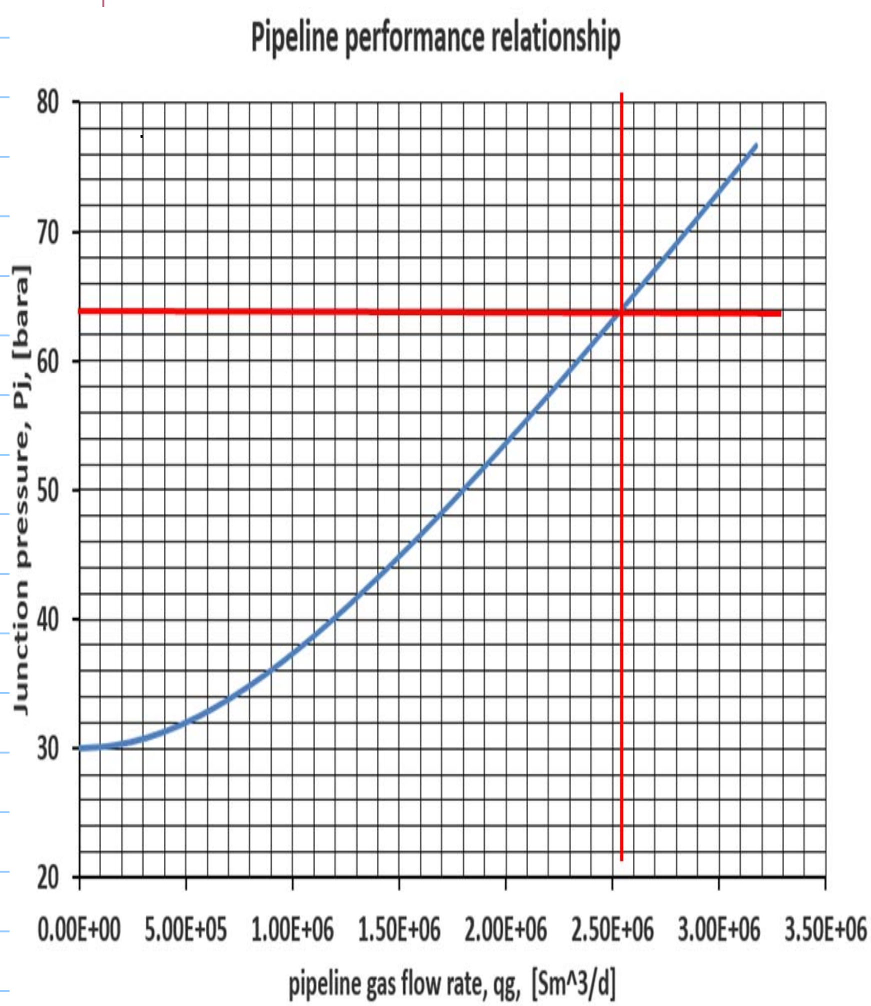
Iteration 3 $\quad p_J^* = 64$ bara



$q_1 = 1.1\ E6\ Sm^3/d$



$q_2 = 1.4 E6 \; Sm^3/d$



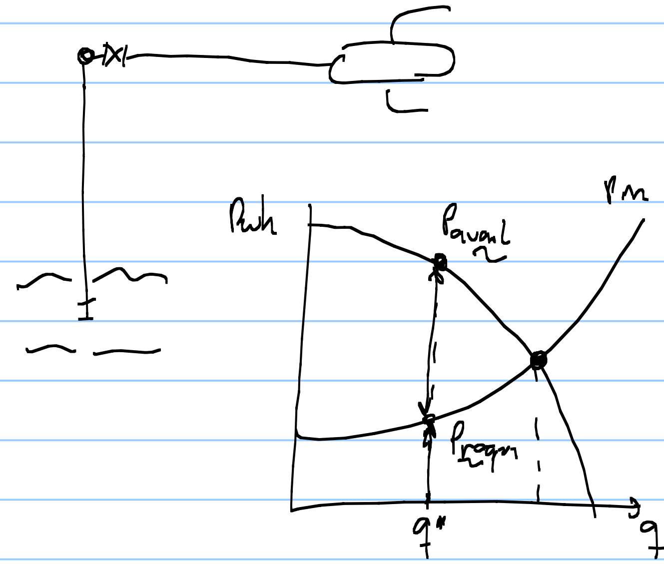
$q_F = 2.55 E6 \; Sm^3/d$

$P_J = q_F = 2.55 \; Sm^3/d$

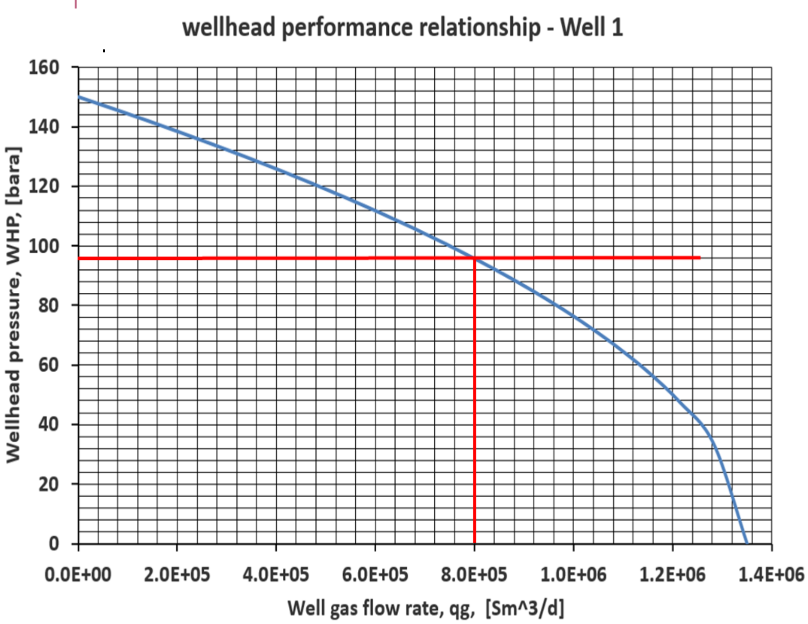
$1.1 E6 + 1.4 E6 = 2.55 E6$

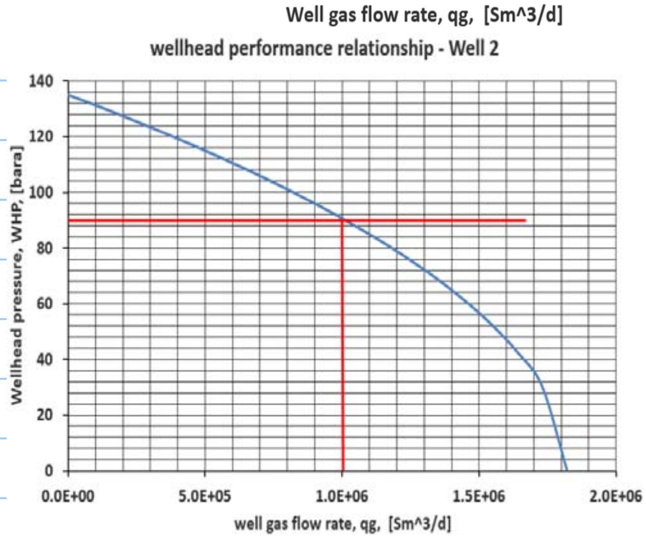
$2.5 = 2.55$

According to reservoir engineer
$8E5\ Sm^3/d > q_1$
$1E6\ Sm^3/d > q_2$

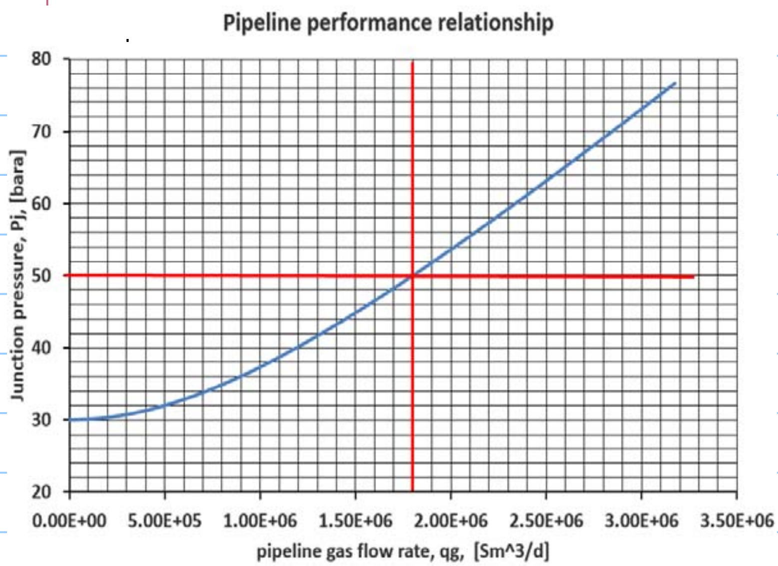


P_{wh} available (w1) = 96 bara





P_{wh} available 2 = 90 bara



$p_{in\ flowline} = 50$ bara

$P_{wh,1} = 96$ bara
$P_{wh,2} = 90$ bara
$P_{in} = 50$ bara

$P_{wh,1} > P_{in}$, $P_{wh,2} > P_{in}$ } the rates are feasible

$\Delta p_{choke,1} = 96 - 50 = 46$ bar

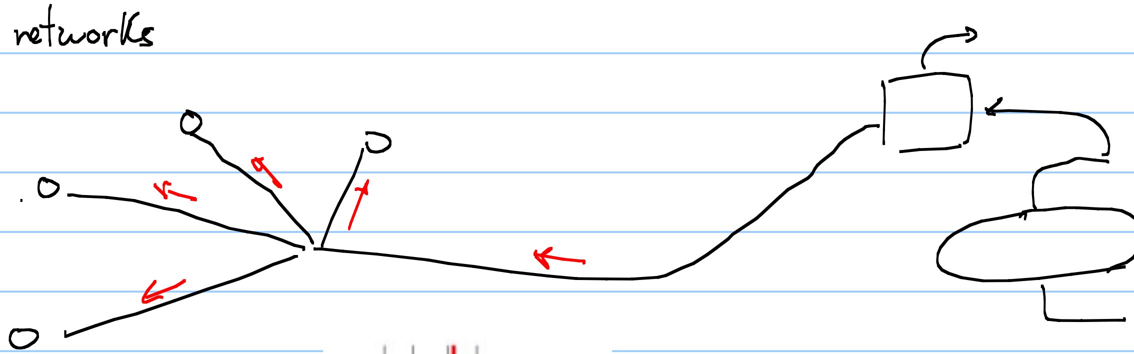
$\Delta p_{choke,2} = 90 - 50 = 40$ bar

		unknowns	equations
w1 =	$q_{g_1} = C_{R_1}(P_{R_1}^2 - P_{wf_1}^2)^{n_1}$	2	1
	$q_{g_1} = C_{T_1}\left(\frac{P_{wf_1}^2}{e^{S_1}} - P_{wh_1}^2\right)^{0.5}$	1	1
w2	$q_{g_2} = C_{R_2}(P_{R_2}^2 - P_{wf_2}^2)^{n_2}$	2	1
	$q_{g_2} = C_{T_2}\left(\frac{P_{wf_2}^2}{e^{S_2}} - P_{wh}^2\right)^{0.5}$	1	1
flowline	$q_F = C_{F_2}(P_{in}^2 - P_{sep}^2)^{0.5}$	2	1
mass balance	$q_F = q_1 + q_2$	0	1
	$P_{in} = P_{wh,1}$	0	1
	$P_{in} = P_{wh_2}$	0	1

8 equations and 8 unknowns !

there are other types of network in petroleum production systems

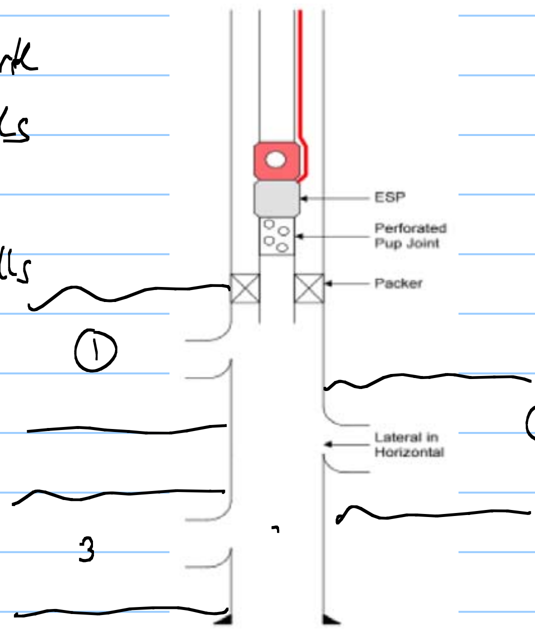
injection networks

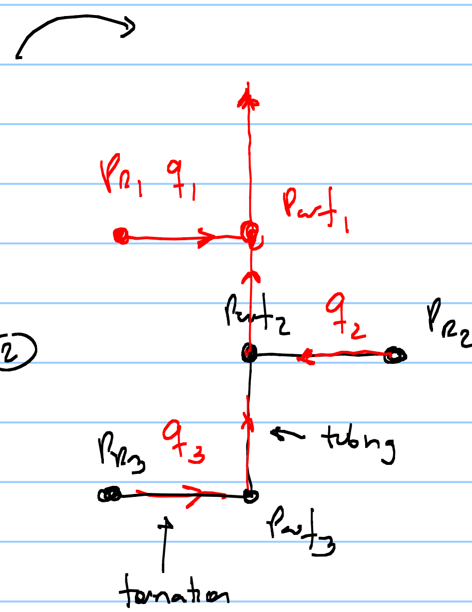


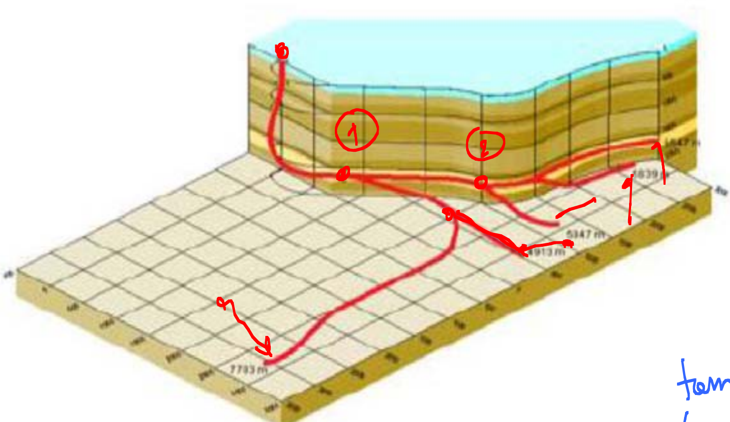
distributing network

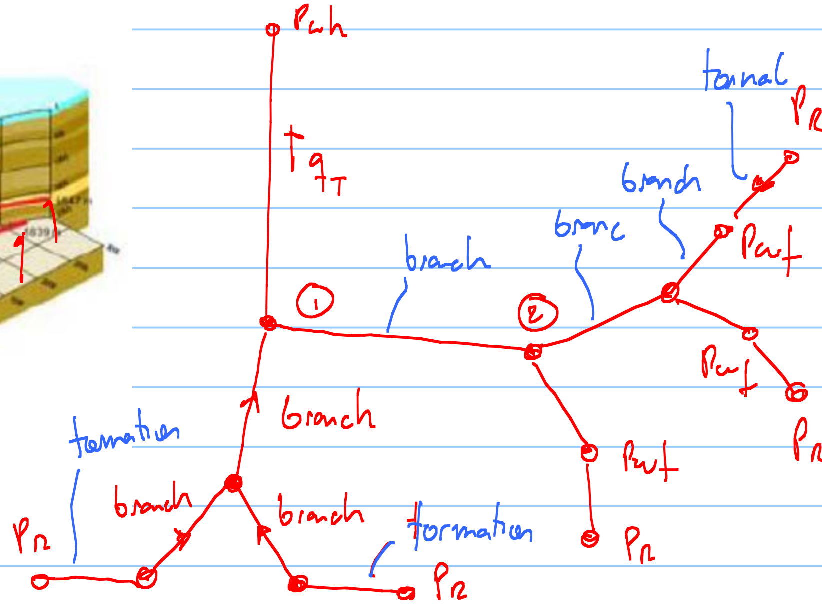
Downhole Networks

multi-zone wells









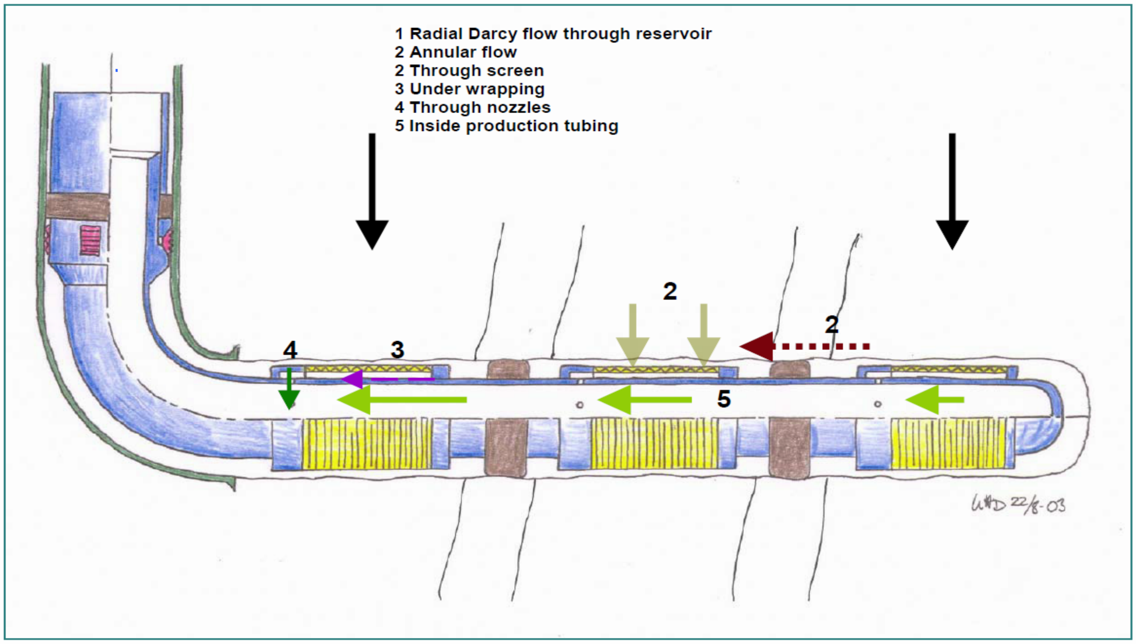
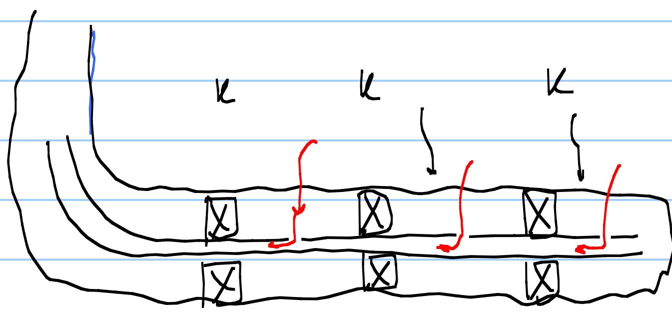
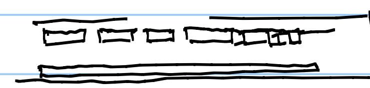
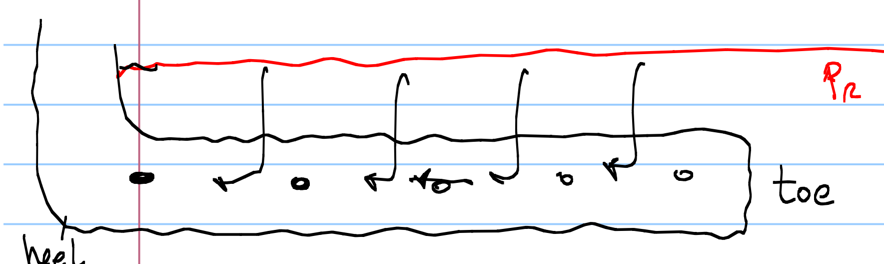
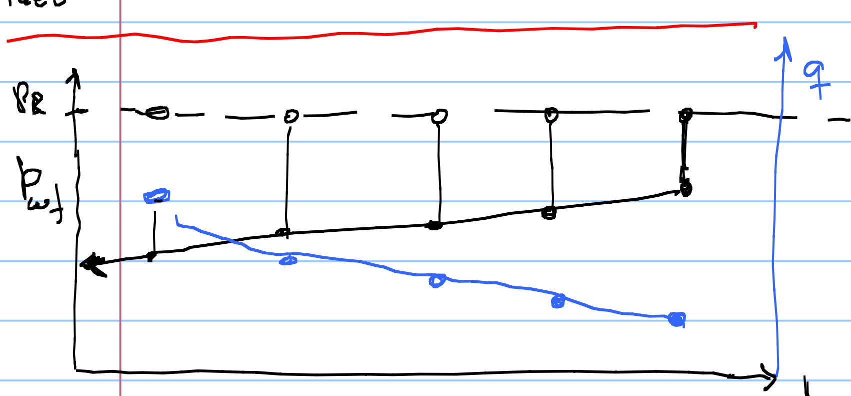


Figure-8 Functioning and interplay of an ICD completion architecture. Fluids enter the screen and flow between the axial wires and the un-perforated base pipe into the ICD housing, before passing through the nozzles and entering into the base pipe. All these flow issues are properly analyzed and put in the right perspective to achieve an optimal well completion design and solution.

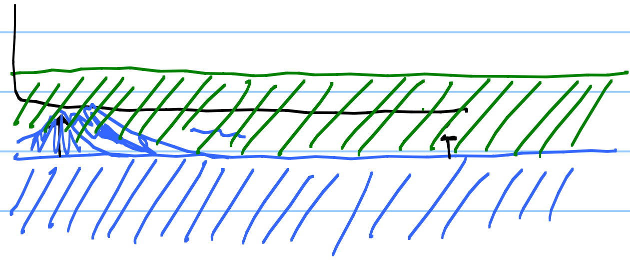


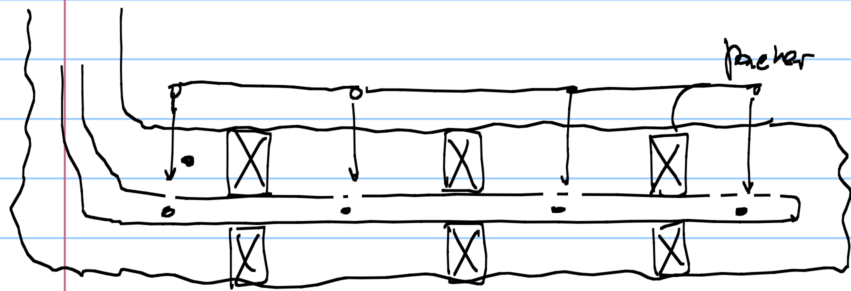


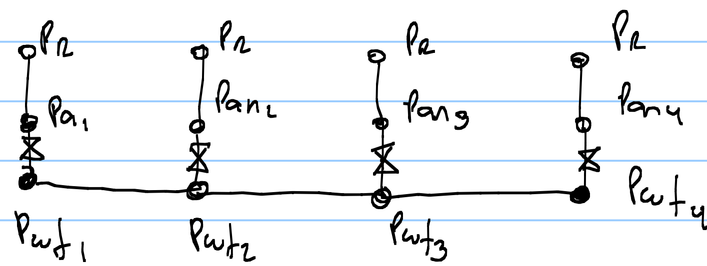


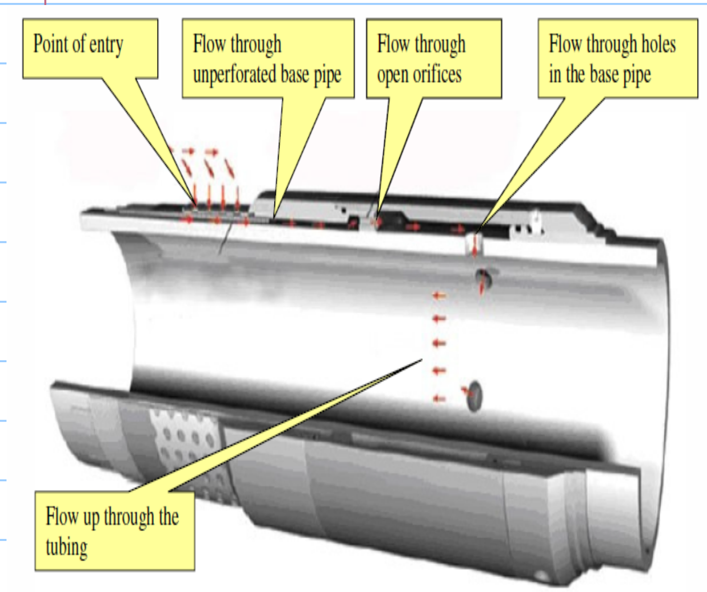


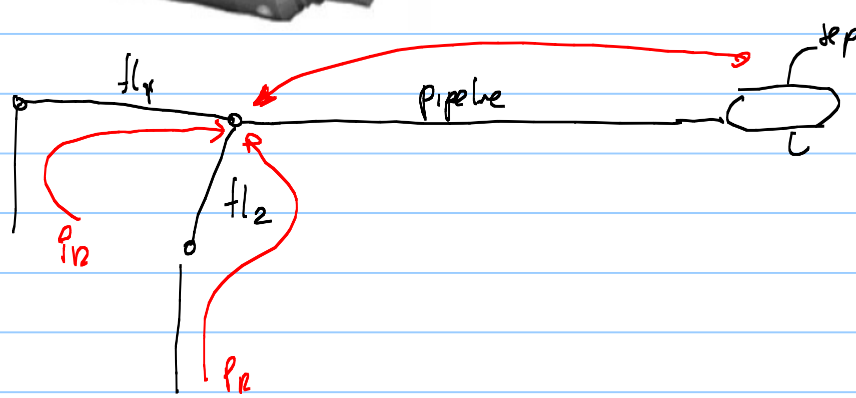
$$q_o = J\,(P_R - P_{wf})$$




packer




Point of entry
Flow through unperforated base pipe
Flow through open orifices
Flow through holes in the base pipe
Flow up through the tubing


pipeline
sep

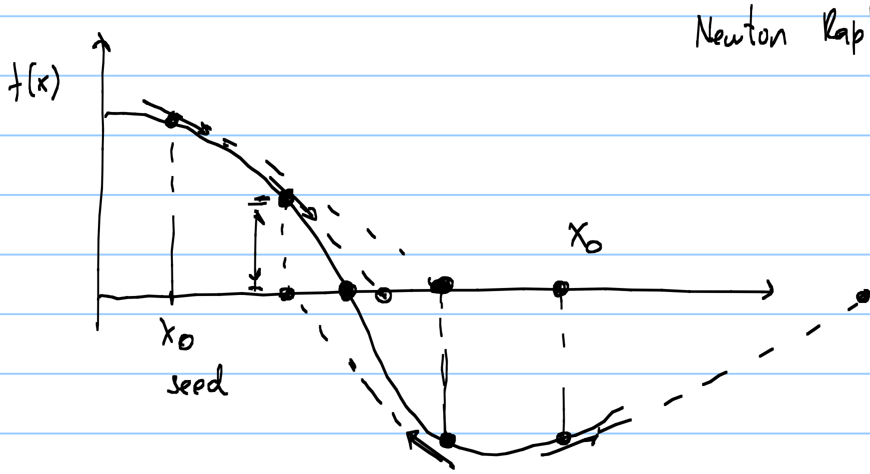
P_j	Error
P_{j1}	$(P_{j1} - P_{av})^2$
P_{j2}	$(P_{j2} - P_{av})^2$
P_{in}	$(P_{in} - P_{av})^2$
$P_{av} = \left(\frac{P_{j1} + P_{j2} + P_{in}}{3}\right)$	Σ

$$\Sigma = (P_{j1} - P_{av})^2 + (P_{j2} - P_{av})^2 + (P_{in} - P_{av})^2 \longrightarrow 0$$

$$(P_{j1} - P_{av}) + (P_{j2} - P_{av}) = 0$$

(−) +

Newton Raphson



$f(x) = 0$

$f(x) < tol$

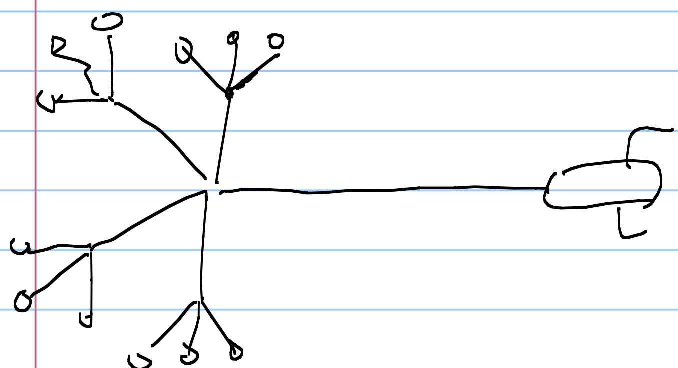
tol = 1E-3

1E-4

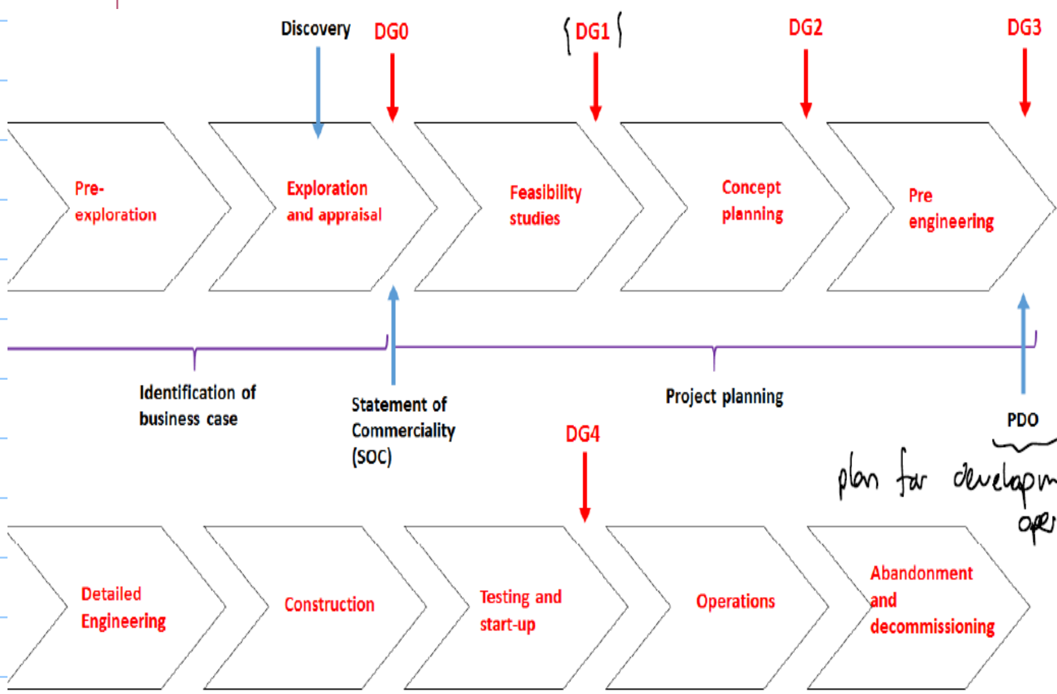
1E-10

Network of two gas wells												
		IPR		Tubing		Flowline						
Component Name	pR	C	n	S	Ct	Cfl	psep	pwf	qwell	pwh	pjunc	error
	[bara]	[Sm^3/bar^2n]			[Sm^3/bar^2]	[Sm^3/bar^2]	[bara]	[bara]	[Sm^3/d]	[bara]	[bara]	(bara^2)
W_1	120	52	0.8	0.13	7680	8673		38	1.02E+05	33	31	2E-1
W_2	120	40	0.75	0.11	8600	7563		34	4.95E+04	31	31	1E-0
Pipeline						14080	28.6		1.51E+05		31	2E-0
										Average=	31	4E-0

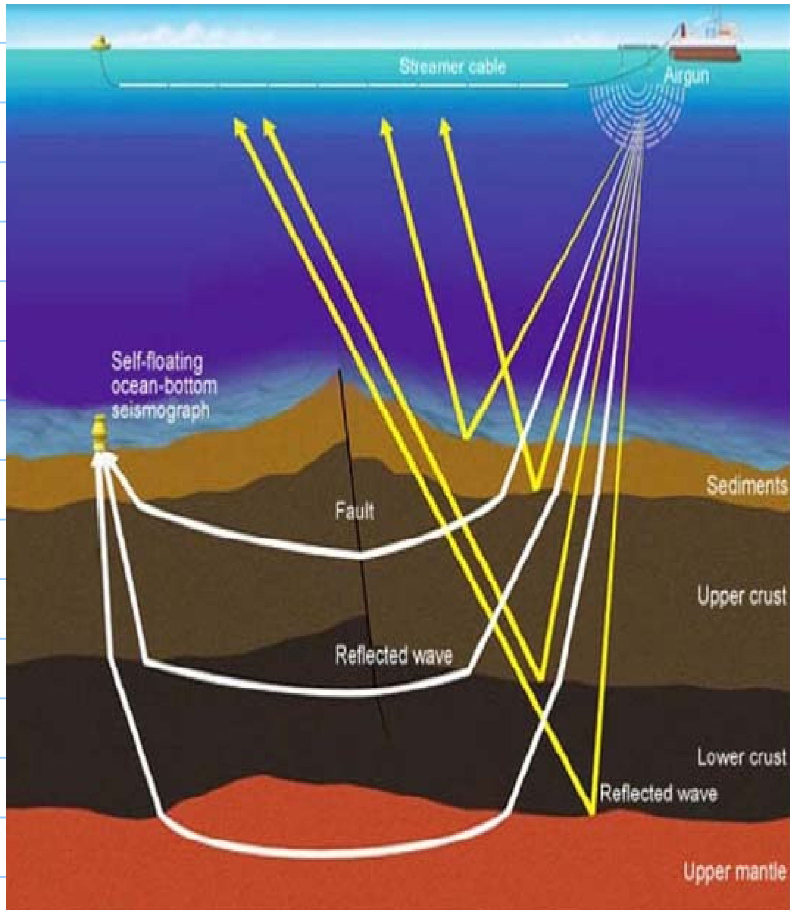
time	q field	Δp choke1, Δp choke2
0		
1		
2		

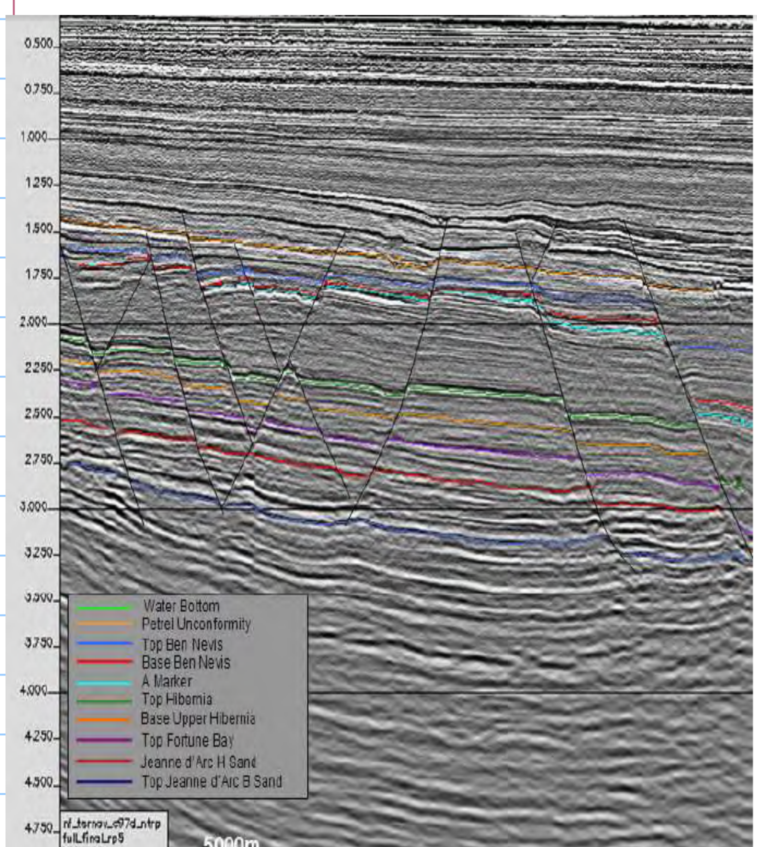


Reserve estimation → N, G OOIP, OGIP
→ Npu, Gpu TRR Total recoverable reserves

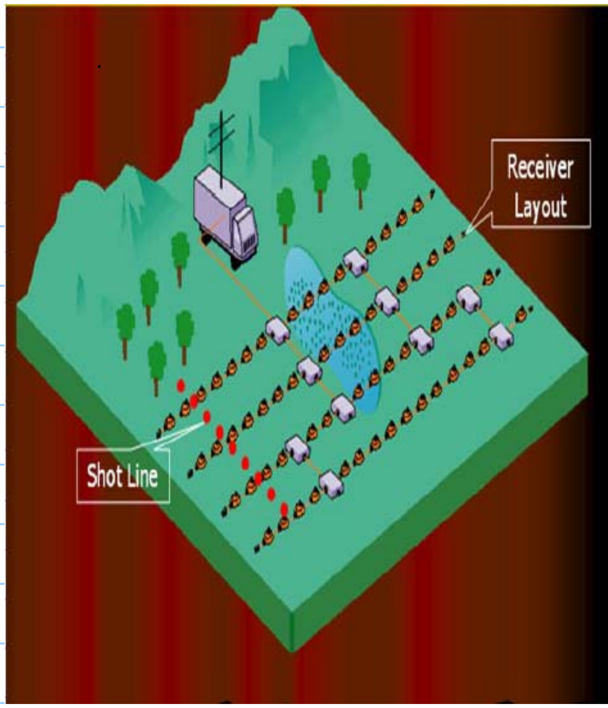


exploration seismic (offshore)





Geophysicist

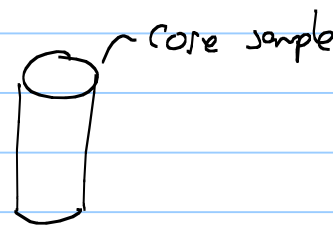


land-based seismic

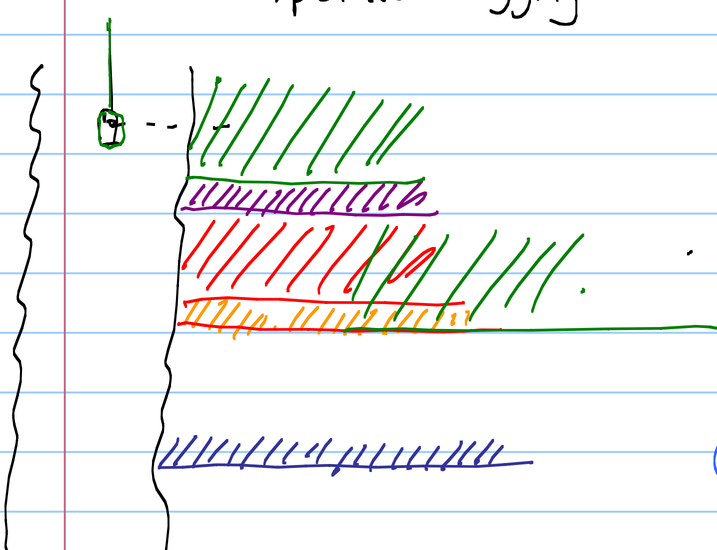
exploration drilling

porosity permeability

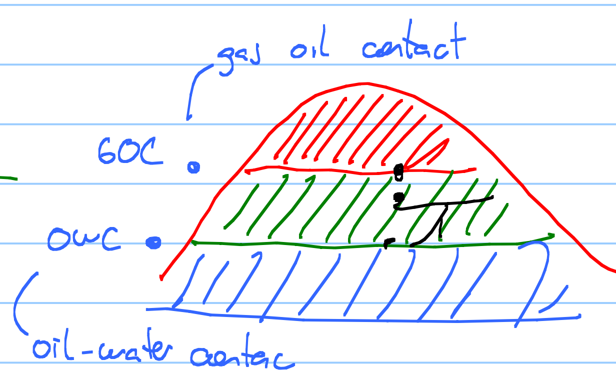
– ϕ S_w , K

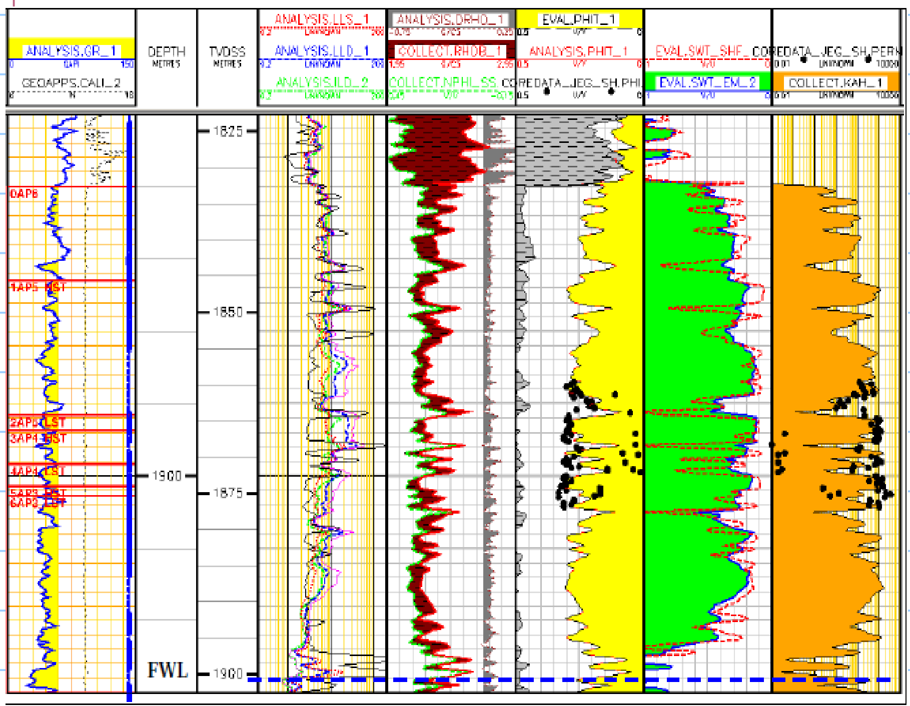


exploration Logging



S_w, detecting Hydrocarbon bearing rock



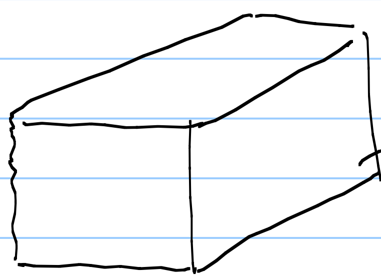


oil reservoir

connate water saturation

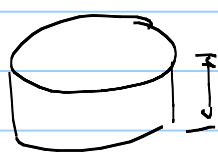
net to gross

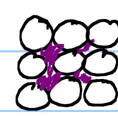
$$TRR \approx N_{pu} = \frac{\overbrace{V_R \cdot \phi}^{V_{Fluid}} \cdot \overbrace{S_o}^{(1-S_w)} \, (N_{TG})}{B_o}$$



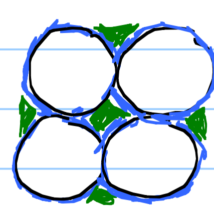
$V_R = a \cdot b \cdot c$

$\pi\, d^2 \cdot 0.25 \cdot h$





porosity $\phi = \frac{V_{cavities}}{V_R}$

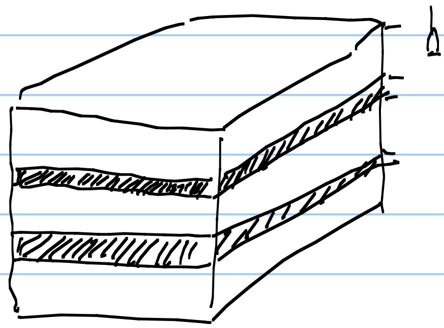


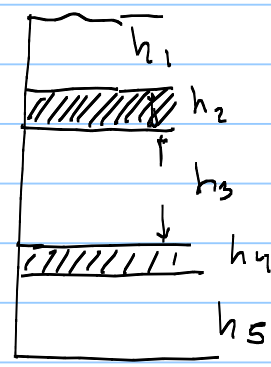
$S_w = \frac{V_{water}}{V_{cavity}}$

S_o

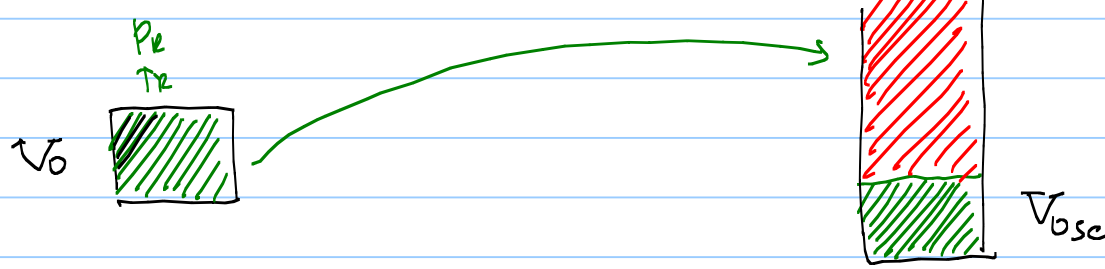
S_g

$S_w + S_o + S_g = 1$





$$(\text{Net to Gross}) = \frac{(h_1 + h_3 + h_5)}{(h_1 + h_2 + h_3 + h_4 + h_5)}$$



$V_{\bar{o}}$

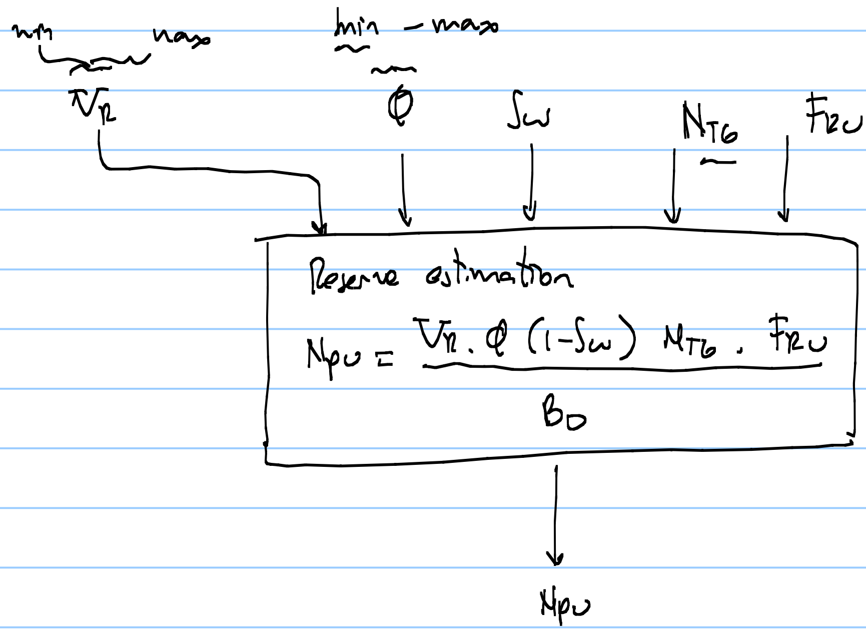
oil formation volume factor $B_o(P,T)$

$$B_o = \frac{V_o(P,T)}{V_{\bar{o}}} \simeq 1 \leadsto 2 \quad (1.2, 1.3)$$

$$N = \frac{\overbrace{(V_R \cdot \phi \cdot (1-S_w) \cdot N_{TG})}^{V_o(P_R, T_R)}}{B_o}$$

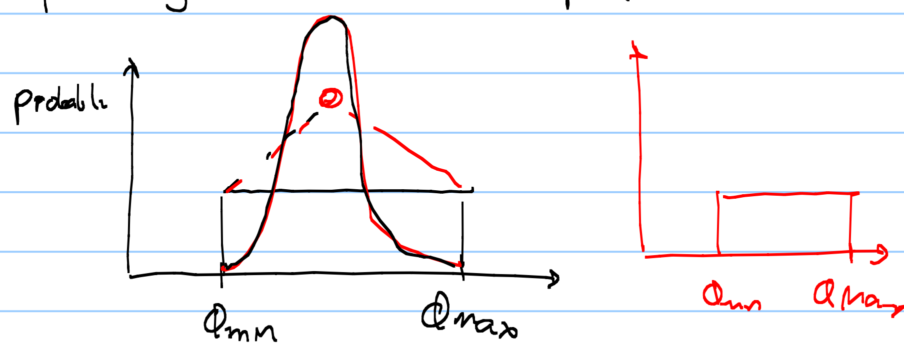
recovery factor $F_R = \frac{N_{pu}}{N}$

$$N_{pu} = TRR = \frac{V_R \cdot \phi (1-S_w) N_{TG}}{B_o} \cdot F_R$$



this calculation is NOT deterministic (one input → one output)

probability distribution function pdf



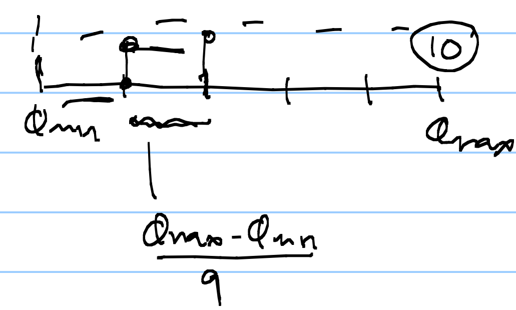
Class exercise to find pdf of porosity based on coring measurement
100

06_Porosity_distribution xls 30 720 03.12.2018 06:21 -a--

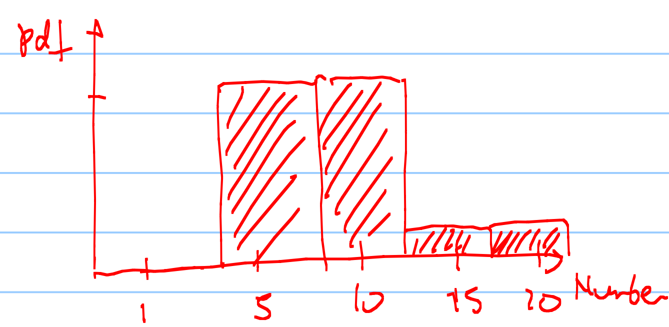
		por_min	[-]	0.182
		por_max	[-]	0.344
Measurement nr.	**Porosity value**			
1	0.344			
2	0.250			
3	0.321			
4	0.232			
5	0.235			
6	0.239			
7	0.205			
8	0.324			
9	0.260			
10	0.205			
11	0.221			
12	0.290			
13	0.260			
14	0.303			
15	0.208			
16	0.288			
17	0.260			
18	0.233			
19	0.220			

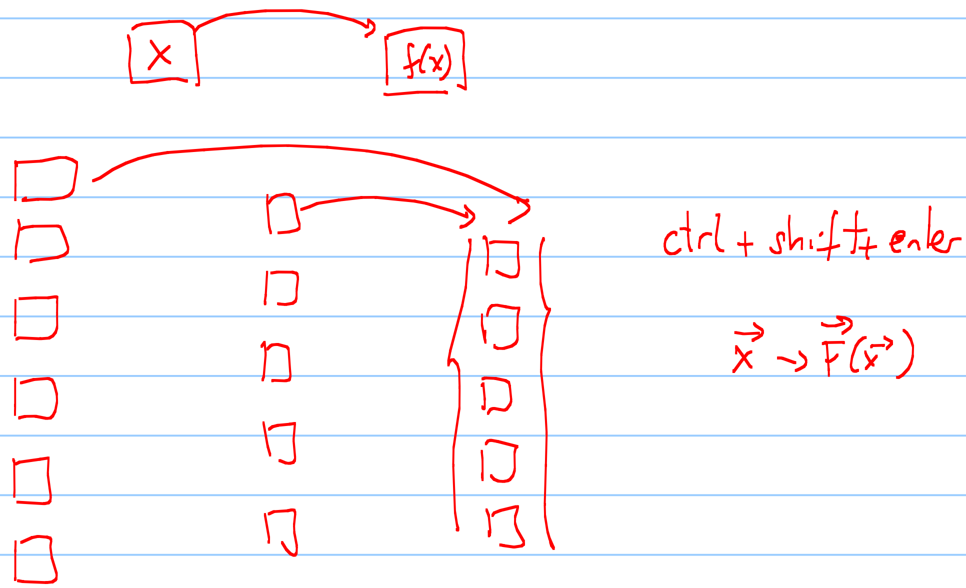
ϕ min, $-\phi_1$, $-\phi_2$, $-\phi_3$, $-\phi_4$, $-\phi_5$, max

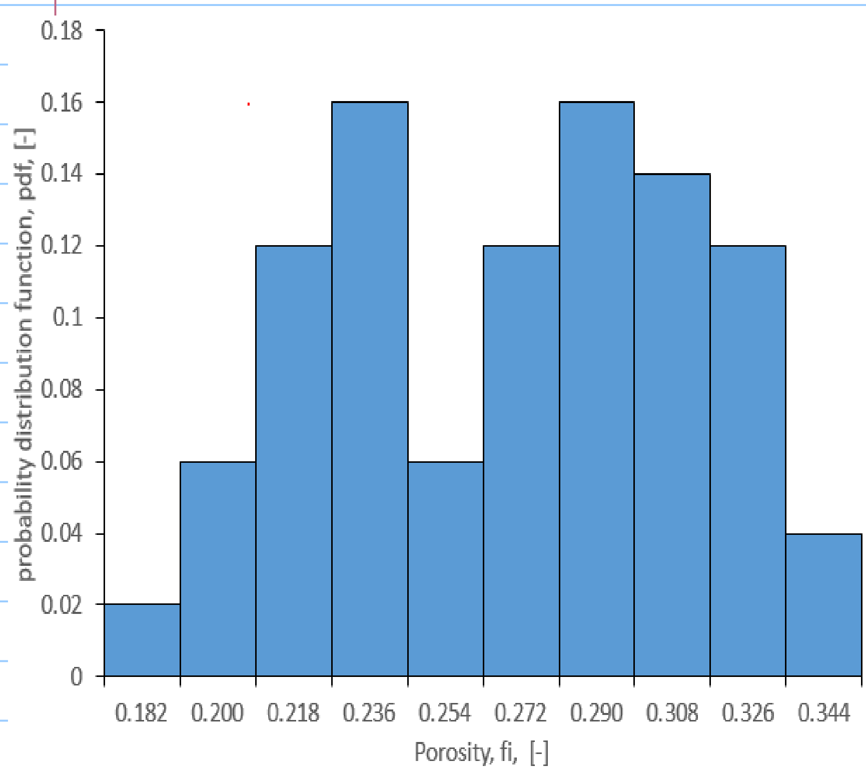
ϕ_{min} $+ \frac{(\phi_{max}-\phi_{min})}{N_{points}-1}$



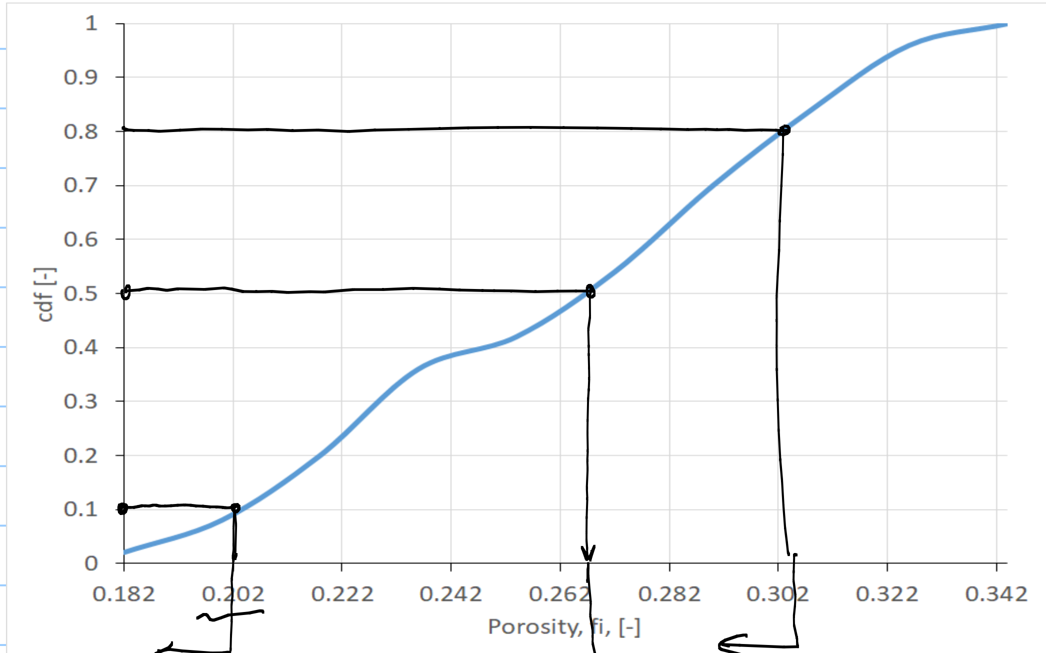
bin	
1	0
5	4
10	4
15	1
20	1







cdf cumulative distribution function

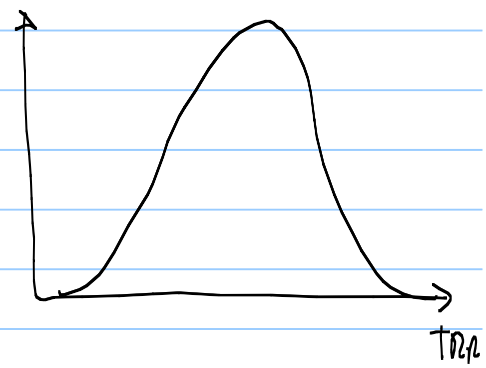


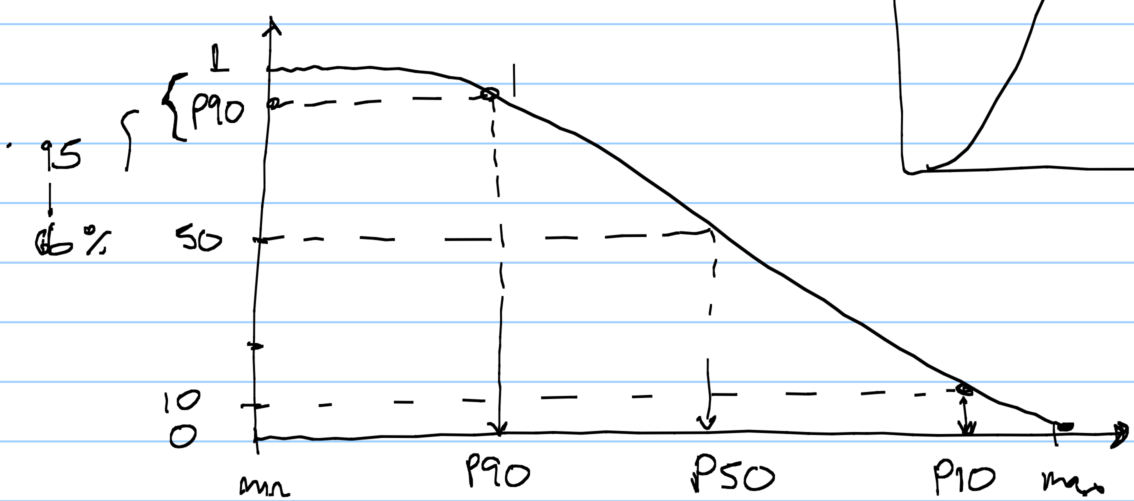
10% of samples have a porosity of 0.202 or lower

50% of sample have a porosity of 0.27 or lower

80% of the samples have a porosity of 0.302 or lower

TRR are plotted using cdf

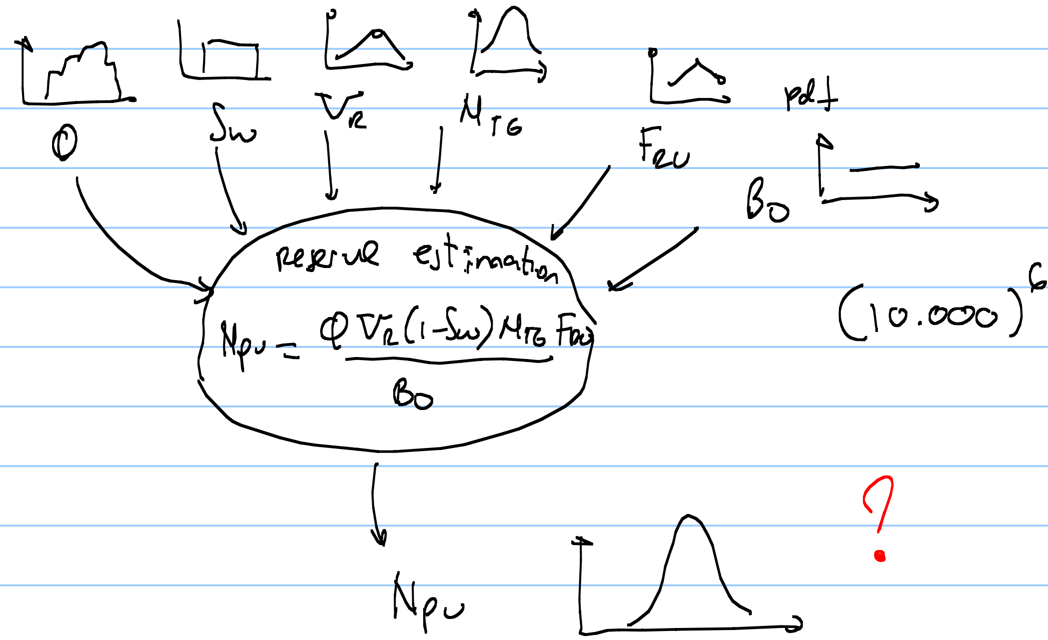




there is a 90% probability that reserves are equal of higher than P90

there is a 50% probability that reserves will be equal or higher than P50

there is a 10% probability that reserver will be equal or higher than P10



Los Alamos laboratory

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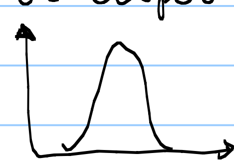
THE MONTE CARLO METHOD

NICHOLAS METROPOLIS AND S. ULAM
Los Alamos Laboratory

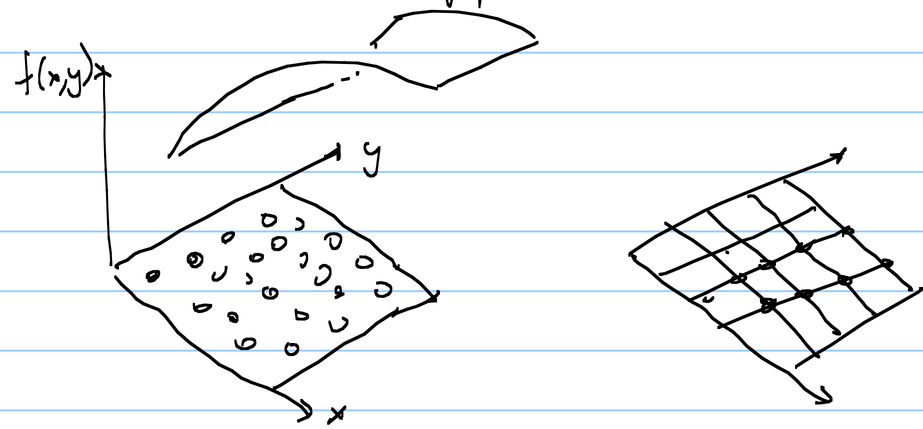
- 1) assume a random number for each parameter (be inside distribution)
- 2) Compute Npu
- 3) Repeat for many, many, many times

MC iteration	Npu
1	Npu_1
2	Npu_2
3	Npu_3
4	

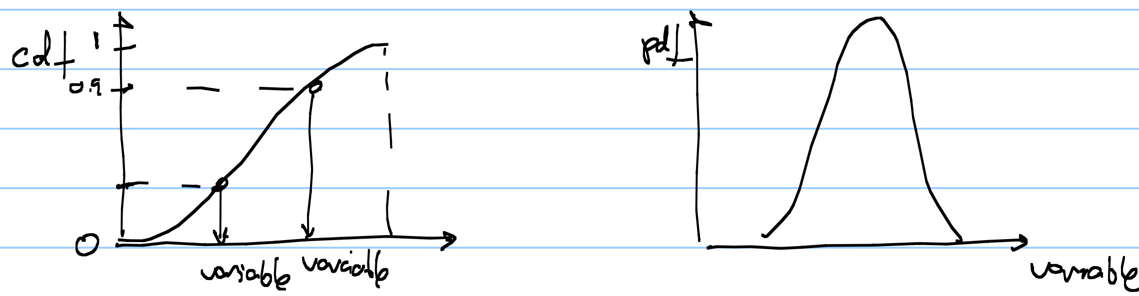
(4) ~ apply a frequency analysis on the output values !



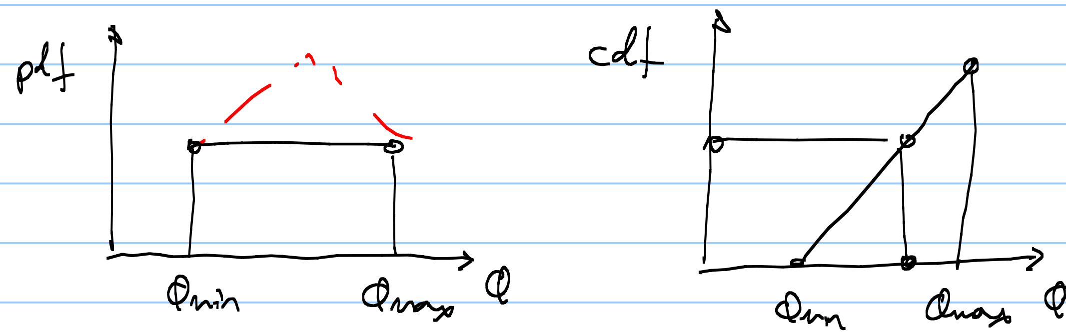
Monte carlo is a sampling method
to find a representative sample of
the whole population



How to generate the random values of input?

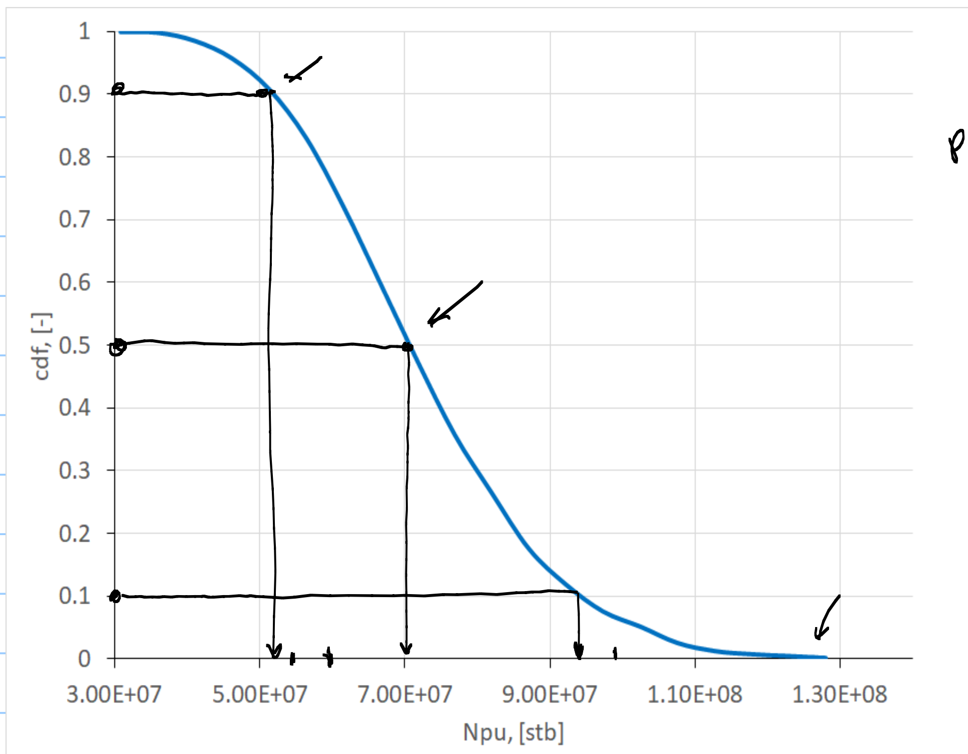


use for our input only uniform distribution



$$\phi = \phi_{min} + \underbrace{RAND()}_{0-1} (\phi_{max} - \phi_{min})$$

Class example TPG4230, Michael Golan and Milan Stanko							
			Net to Gros	Oil Saturation	Formation Volume	Ultimate Recovery Factor	
	Rock volume	Porosity	N/G	So=(1-Sw)	Bo	Fr	
	bbl	fraction	fraction	fraction	Res bbl/STB	fraction	
Min	2.00E+09	0.18	0.3	0.8	1.35	0.42	
Max	2.50E+09	0.3	0.5	0.9	1.6	0.65	
MC it	**Rock volume**	**Porosity**	**N/G**	**So=(1-Sw)**	**Bo**	**Fr**	**Npu**
[-]	bbl	fraction	fraction	fraction	Res bbl/STB	fraction	[stb]
1	2.07E+09	2.00E-01	3.84E-01	8.37E-01	1.38E+00	5.79E-01	5.60E+07
2	2.41E+09	2.47E-01	3.34E-01	8.66E-01	1.47E+00	4.83E-01	5.66E+07
3	2.19E+09	2.20E-01	4.33E-01	8.80E-01	1.45E+00	5.36E-01	6.81E+07
4	2.04E+09	2.53E-01	4.98E-01	8.85E-01	1.42E+00	5.74E-01	9.20E+07
5	2.30E+09	1.98E-01	3.31E-01	8.65E-01	1.46E+00	6.15E-01	5.49E+07
6	2.01E+09	2.27E-01	4.51E-01	8.46E-01	1.45E+00	5.46E-01	6.57E+07

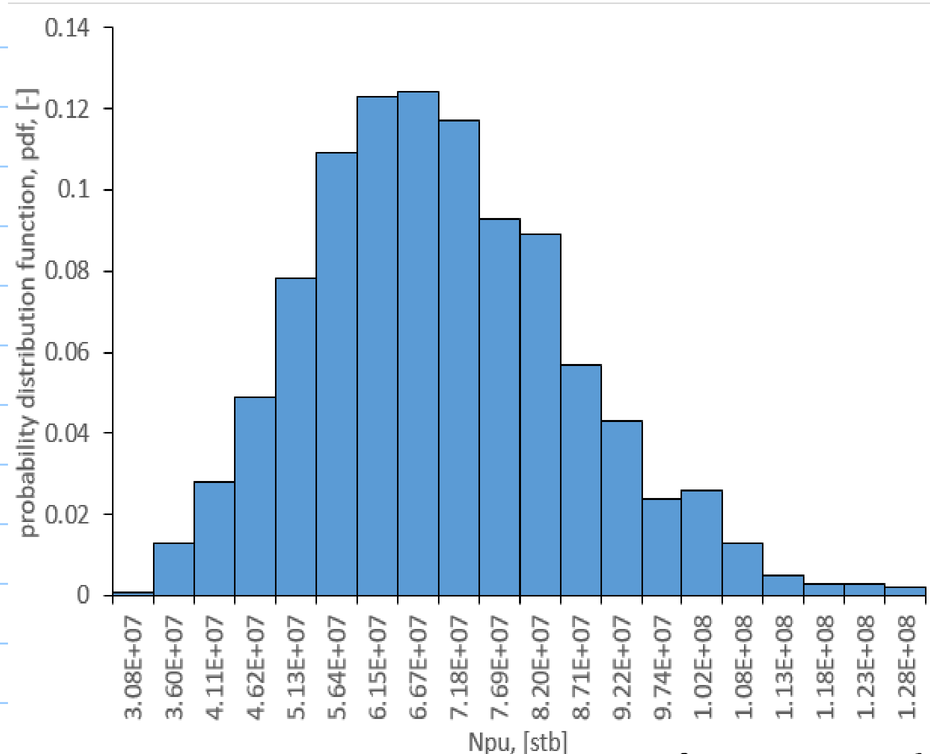


P50 is usually used for production profile forecasting

P10 = 95 E6 stb

P50 = 70 E6 stb

P90 = 52 E6 stb



~P10 P50 P90

Hebron Ben Nevis Oil	Upside Volumes		Best Estimate Volumes		Downside Volumes	
	MBO	Mm³	MBO	Mm³	MBO	Mm³
D-94 Fault Block	1601	255	1328	211	1077	171
I-13 Fault Block	252	40	187	30	141	22
Total Hebron Ben Nevis	1870	297	1515	241	1204	191
Total Hebron Ben Nevis Gas	**Upside Volumes**		**Best Estimate Volumes**		**Downside Volumes**	
	GCF	* GSm³	GCF	GSm³	GCF	GSm³
Solution Gas D-94 Block	112	3.2	145	4.1	189	5.4
Solution Gas I-13 Block	10	0.3	14	0.4	22	0.6
Non-associated Gas	n/a	n/a	n/a	n/a	n/a	n/a
Gas Cap D-94 Block only	0	0	0	0	31	0.9

* GSm³ = 10⁹ cubic meters

from Hebron PDO

- when the simulation takes long time } production profiles, Cost estimation, NPV calculation

Monte Carlo is impractical (too long running times) → use probability trees.