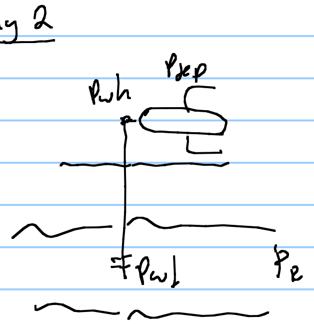
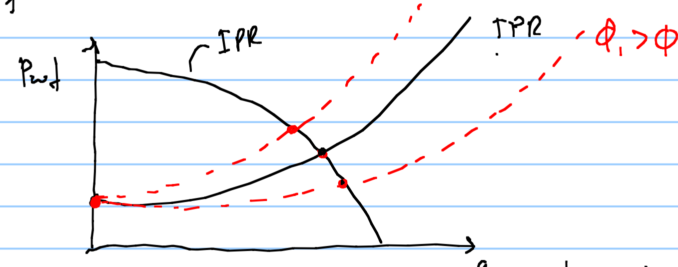
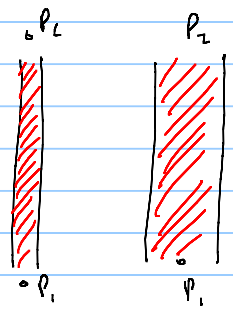
Day 2



Flow equilibrium downhole

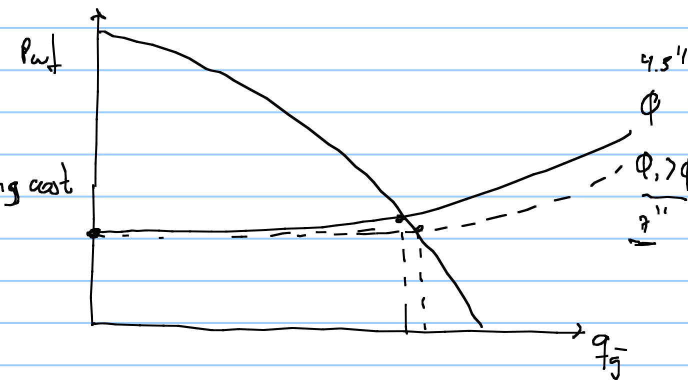




variation of tubing size "φ"

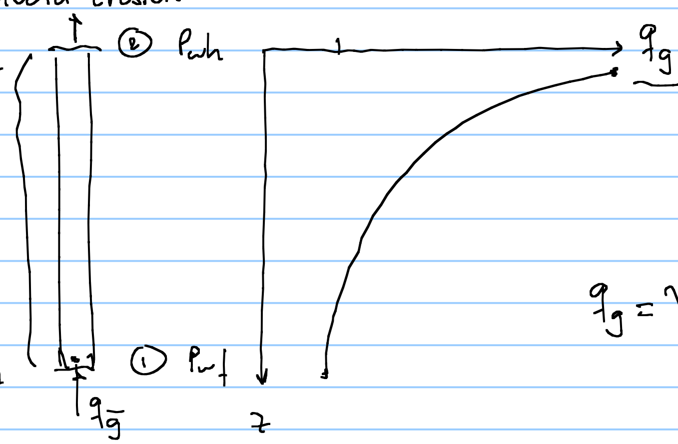
How to chose φ tubing

- minimize tubing Δp → max rate



- minimize tubing cost

- avoid erosion



$\dot{m} = \rho_{wh} \cdot q_{g2}$

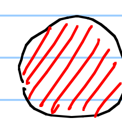
$\dot{m} = \rho_{wf} \cdot q_{g1}$

$p\tilde{V} = ZRT$

$p \frac{1}{\rho} = \frac{ZRT}{\sim}$

$\frac{p'}{ZRT} = \rho'$

$q_g = v_g \cdot A$



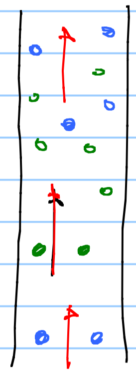
$\rho_{wf} > \rho_{wh} \rightsquigarrow q_{g1} < q_{g2}$

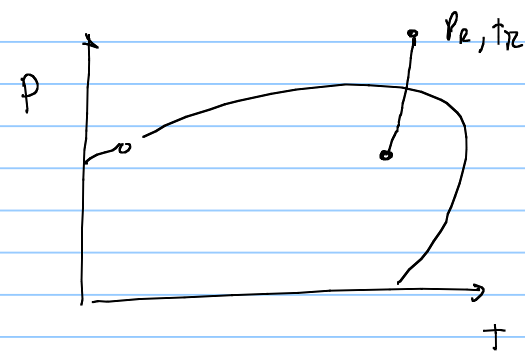
- Select φ such that we don't get erosion in tubing

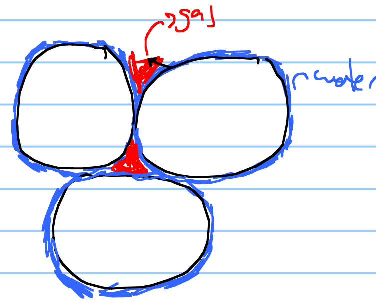
$v_g @ wh < v_{erosional} \rightsquigarrow$ API 14E

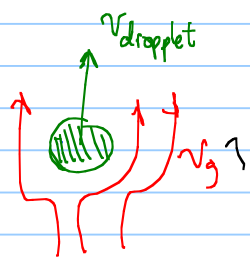
American petroleum Institute

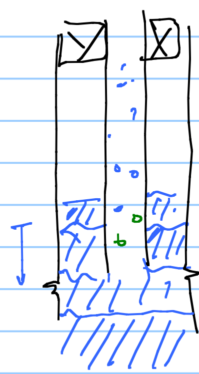
- liquid loading → condensate
  → water in solution dissolved in the gas





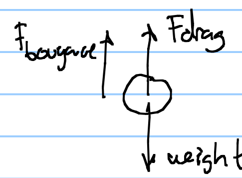






liquid loading → accumulation of liquid in wellbore
→ aditional backpressure against formation which brings $q_g \downarrow$

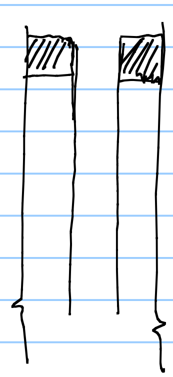
Select ϕ of tubing such that V_g is high enough to lift droplets of liquid
→ Turner

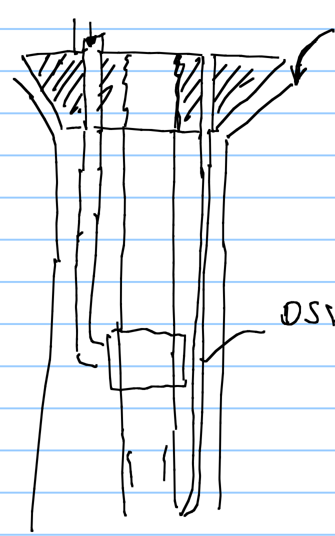


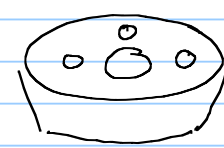
$\sim V_{gc} < V_g$

- tubing hanger

→ chemical injection (scale inhibitor)
downhole pressure gauge
power cable
landing shoulders

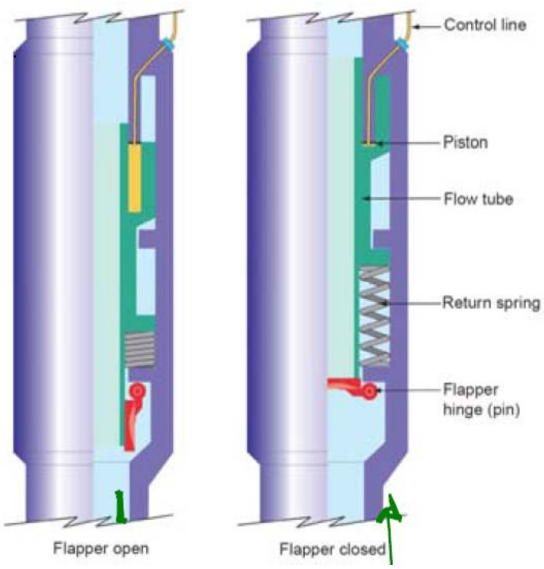




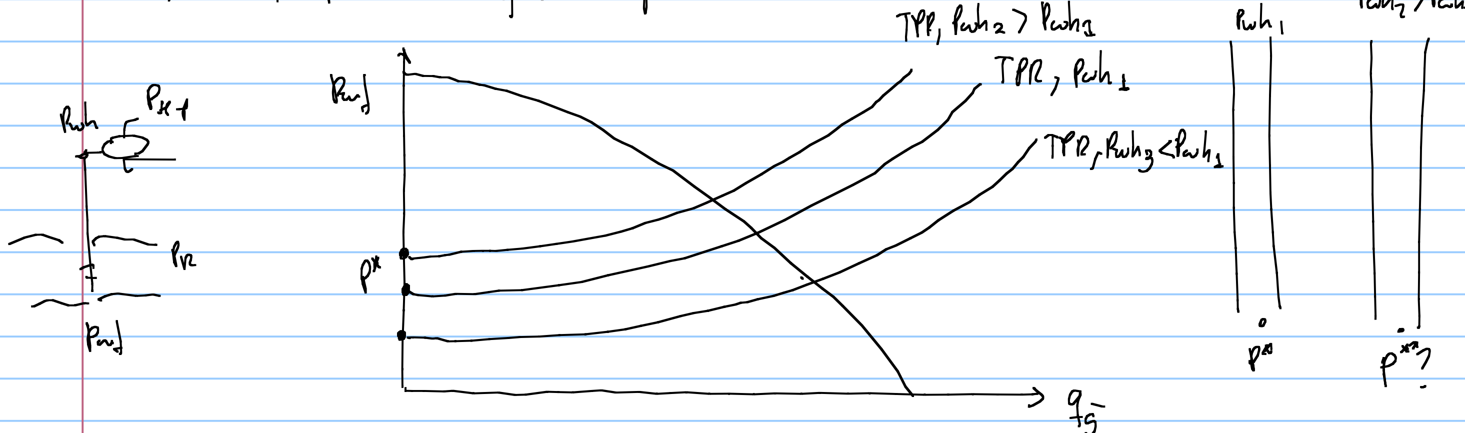


DSV downhole safety valve
100 m - 200 m below wellhead

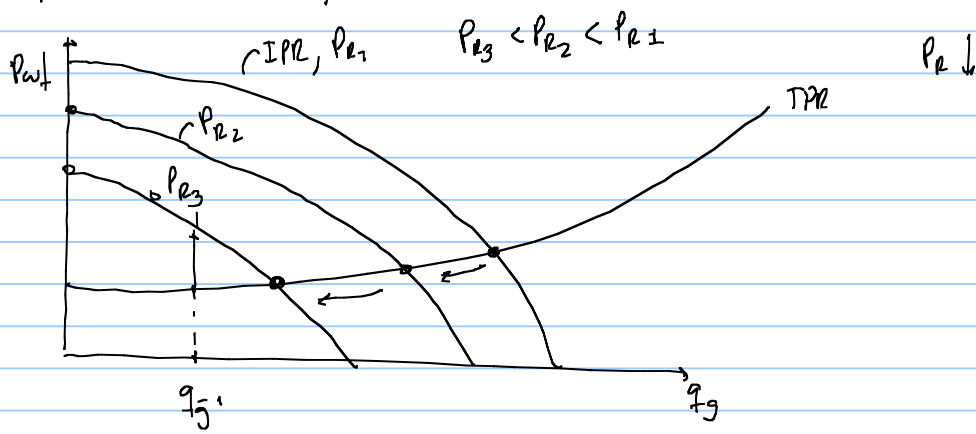
ϕ of the tubing has to be small enough to allow tubing hanger integrity



- Effect of pwh on equilibrium point

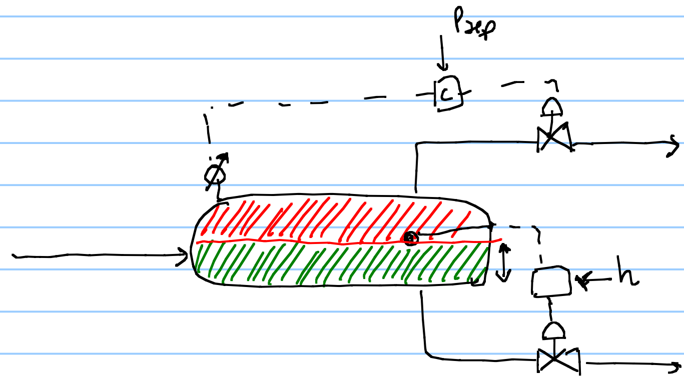


- effect of depletion on flow equilibrium



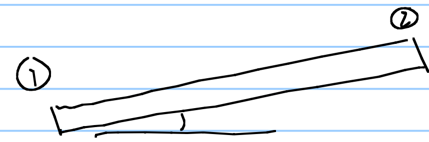
Short

Separator



flowline

$$q_g = C_T \left(\frac{P_1^2}{e^s} - P_2^2 \right)^{0.5}$$



$$q_g = C_{F2} \left(\frac{P_{in}^2}{e^s} - P_{out}^2 \right)^{0.5}$$

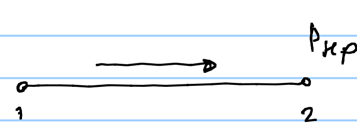
if pe is horizontal $s = 0$

$$\left(P_{in}^2 - P_{out}^2 \right)^{0.5} \qquad C_T ?$$

$$C_{F2} = \text{const} \cdot \left(\frac{s\, e^s}{e^s - 1} \right) \qquad s = 0 \qquad \frac{0 \cdot 1}{1 - 1} = \frac{0}{0} \text{ undefined !}$$

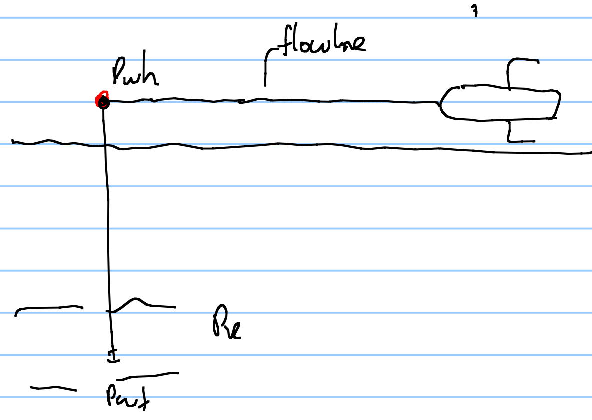
L'Hopital $\lim_{x \to 0} f(x) \Rightarrow$ undefined $\quad \lim_{x \to 0} \frac{f(x)}{g(x)} \longrightarrow \lim_{x \to 0} \frac{f'(x)}{g'(x)}$.

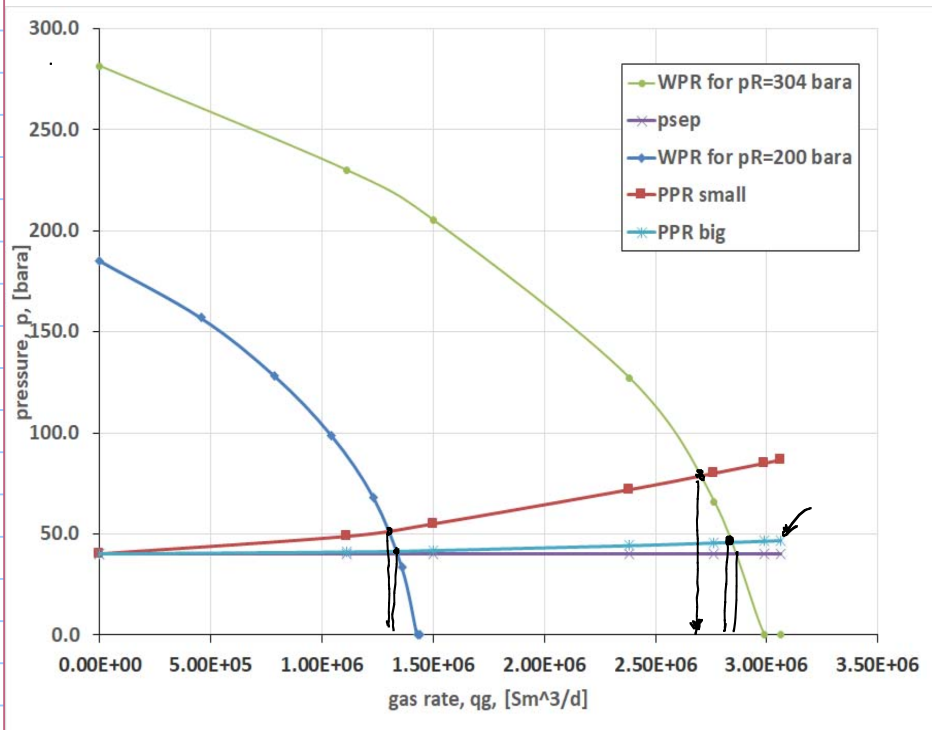
$$\frac{\frac{d}{ds}\left(s e^s\right)}{\frac{d}{ds}\left(e^s - 1\right)} = \frac{s \cdot e^s + e^s}{e^s} = \frac{1}{1} = 1$$



$$q_g = C_{F2} \left(P_{in}^2 - P_{out}^2 \right)^{0.5}$$

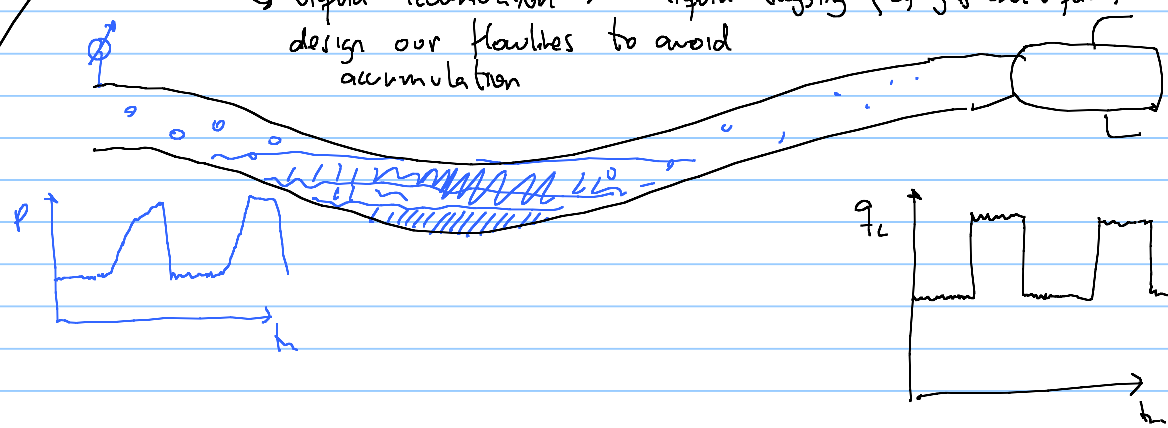
Exercise





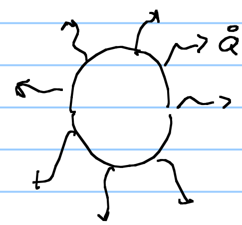
- pipeline sizing → minimize Δp, maximize rate q_g
  - → cost !
  - → erosion
  - → liquid accumulation → liquid slugging (intermittent flow of gas and liquid)

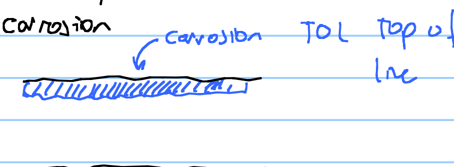
design our flowlines to avoid accumulation



→ big ϕ leads to more cooling → more oil/water condensation, more liquid accumulation

corrosion



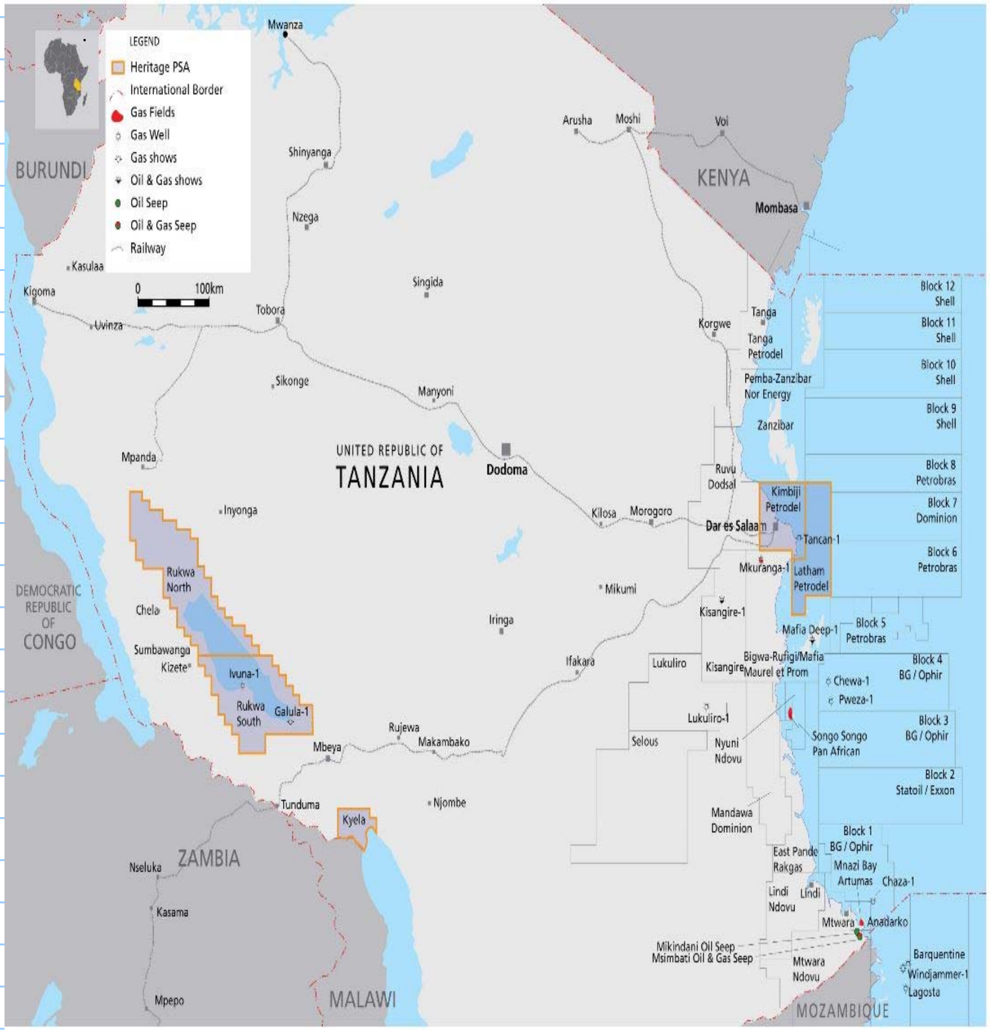


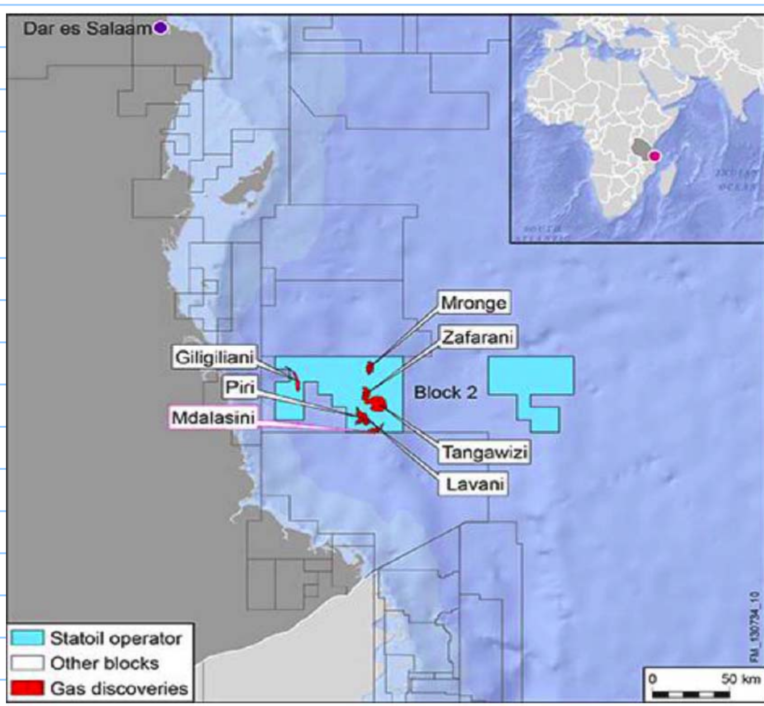
→ Hydrates if T is low

→ oil flowlines wax, $\mu\uparrow$ $\Delta p\uparrow$

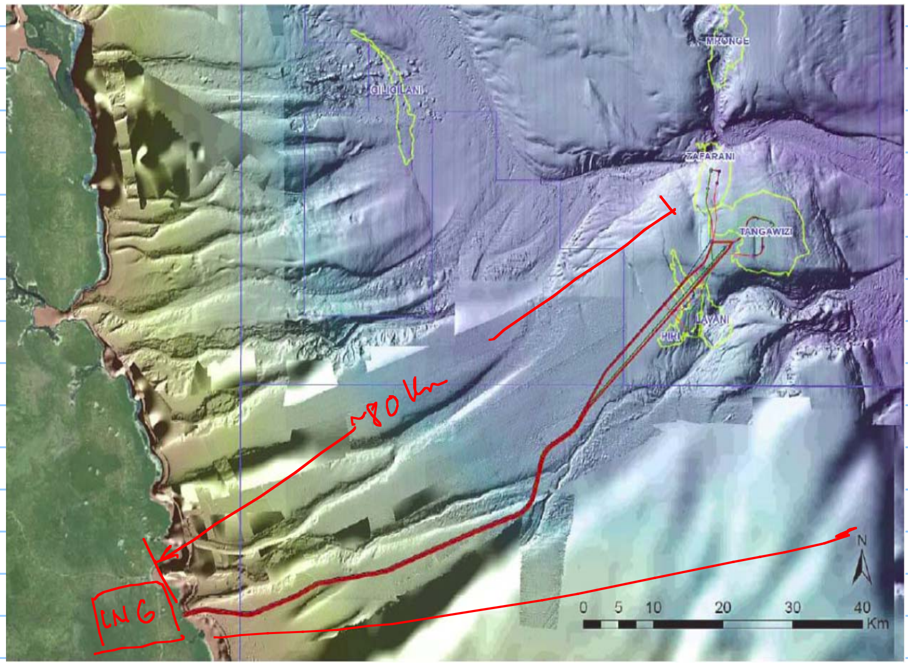
field production scheduling → define, calculate/estimate the field production profile with time

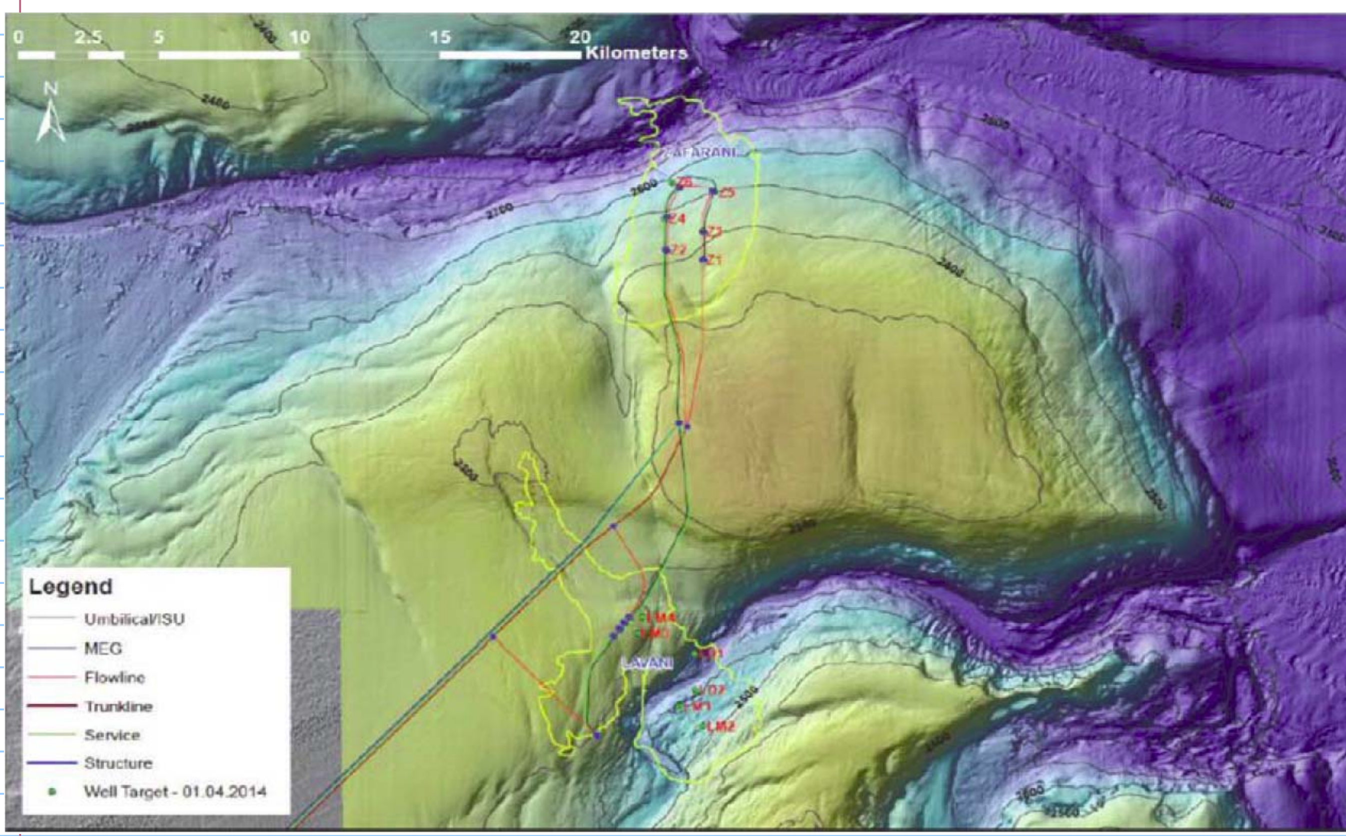
Block 2 offshore Tanzania





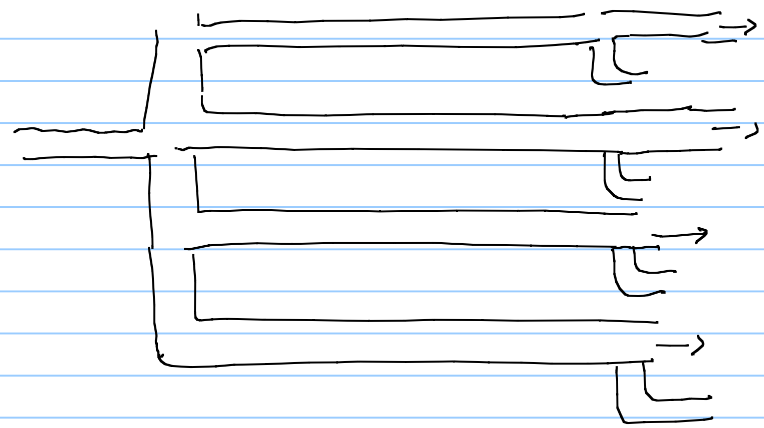
water depth 2200 - 2600 m

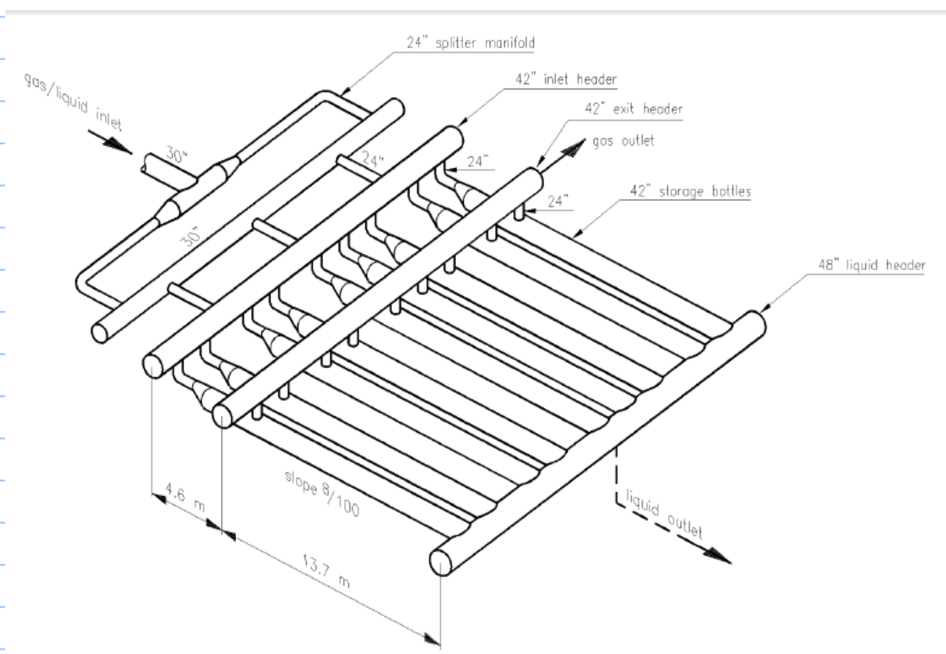




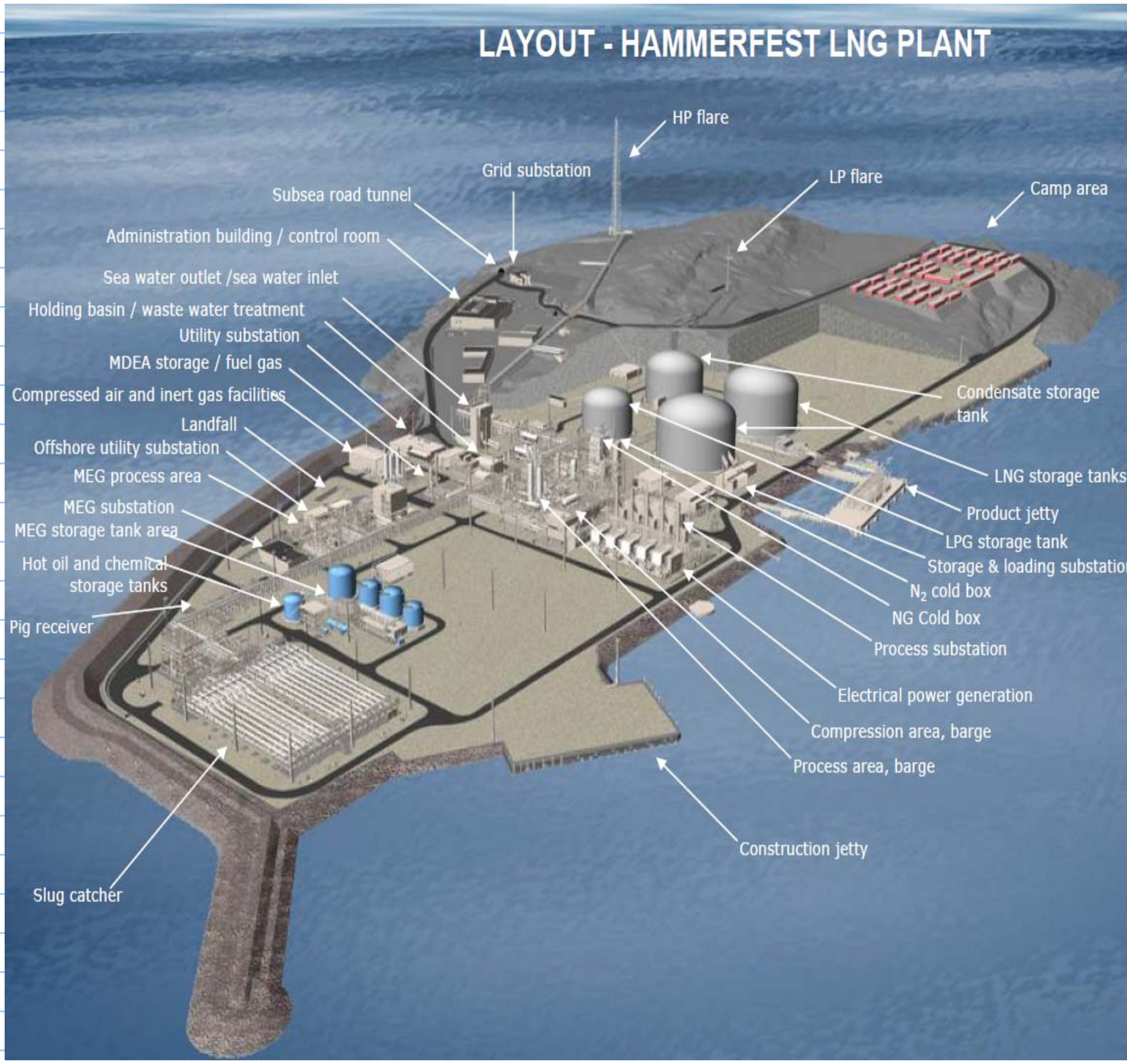
Snowhite (Snøhvit) Subsea to beach

onshore facilities : slugcatcher





LNG Plant



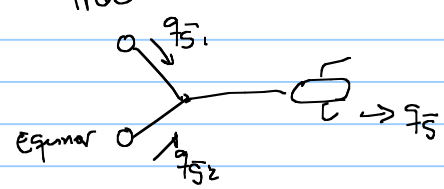
- contract for a fixed amount of gas 18 E6 Sm³/d
  - ↳ plateau length ⇝ choking mode A
  - ↳ post plateau production profile ⇝ open choke (mode B)

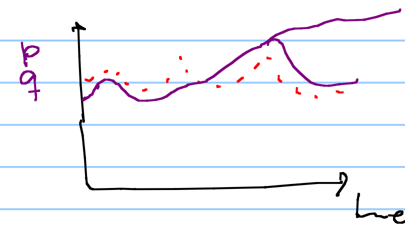
- Subsea layout / architecture

Pr

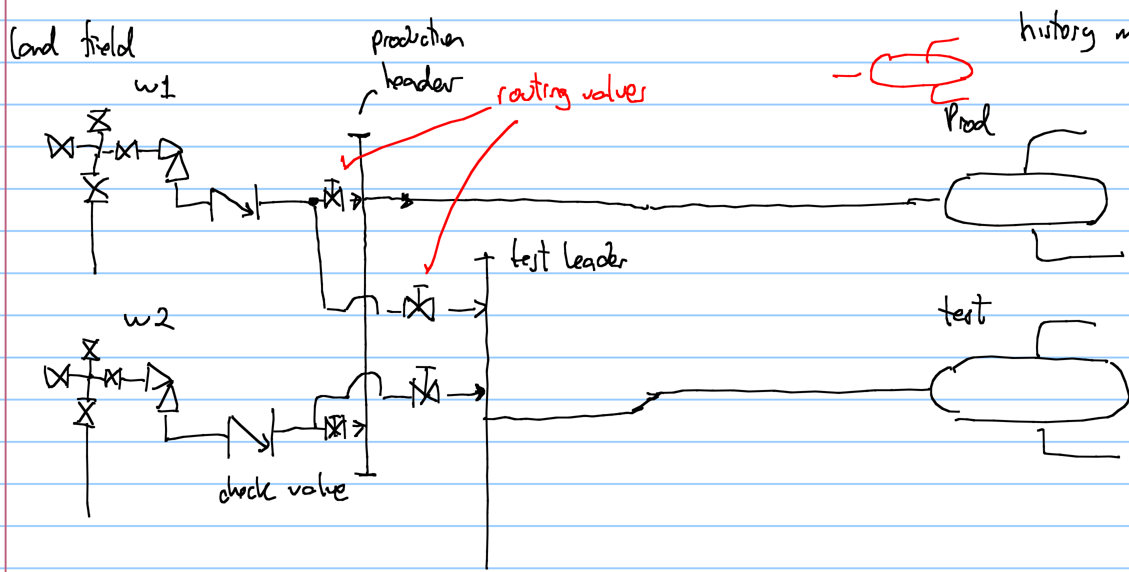
Production manifold

- route the production of wells
- test wells ⟶ allocation: determine source of gas/oil
  - ↓ split profit !
  - to improve reservoir models
  - compare model vs. data





history matching

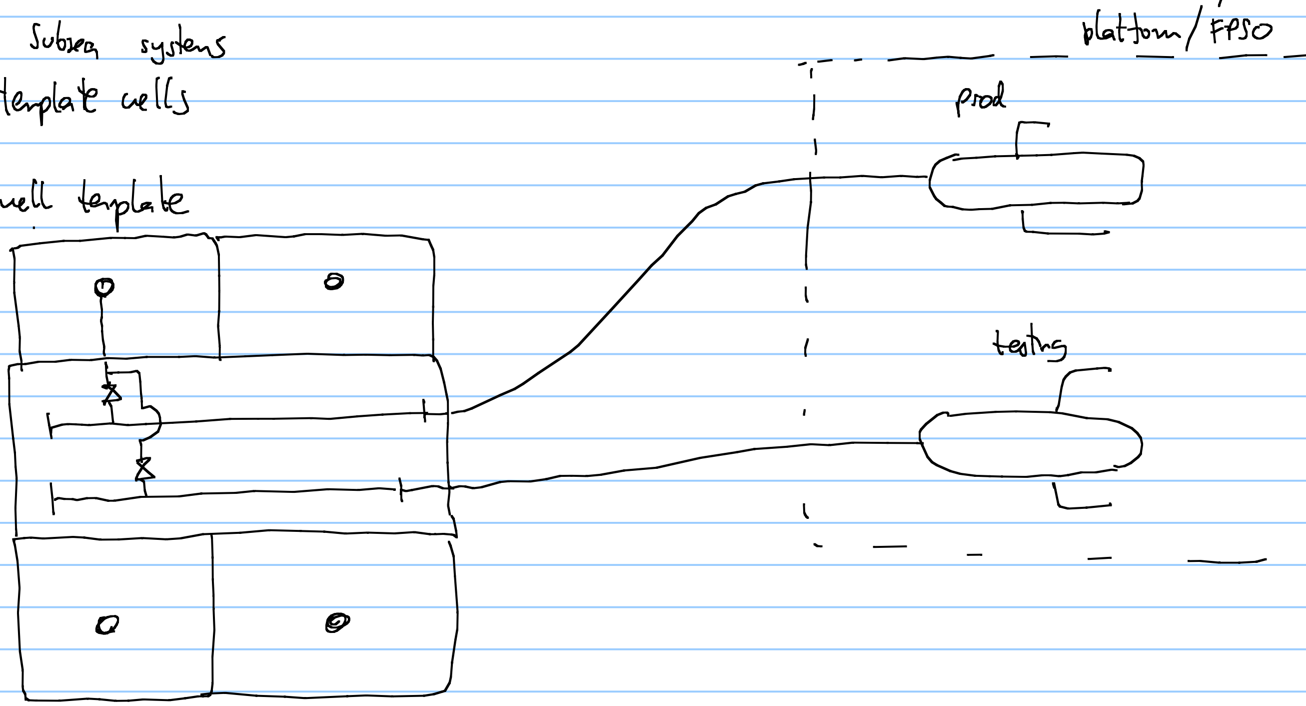


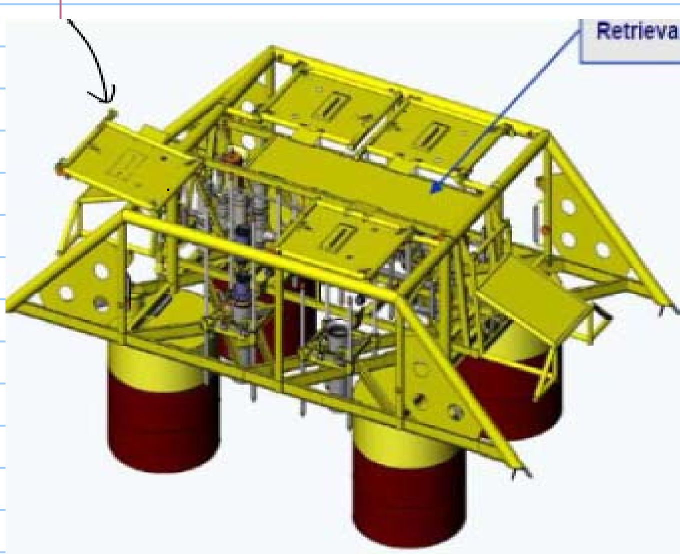
floating, production, storage offloading vessel

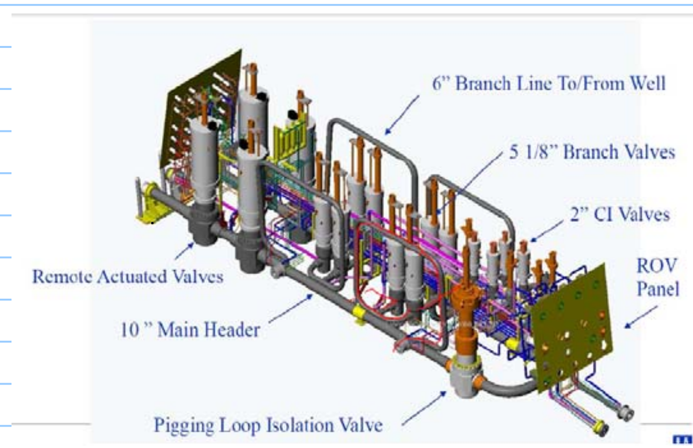
Subsea systems

template wells

4-well template

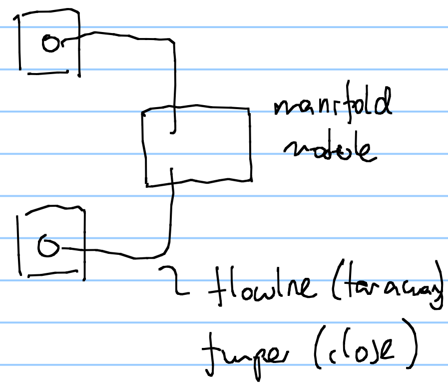


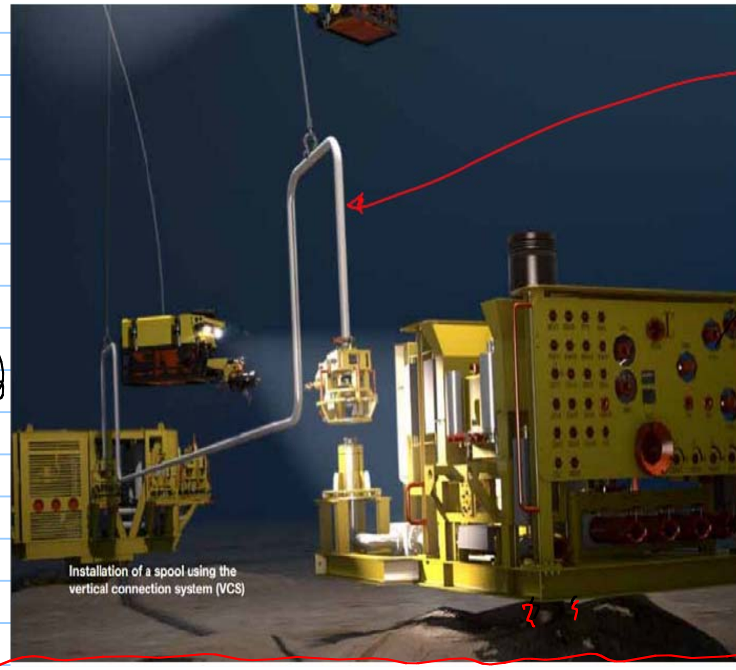




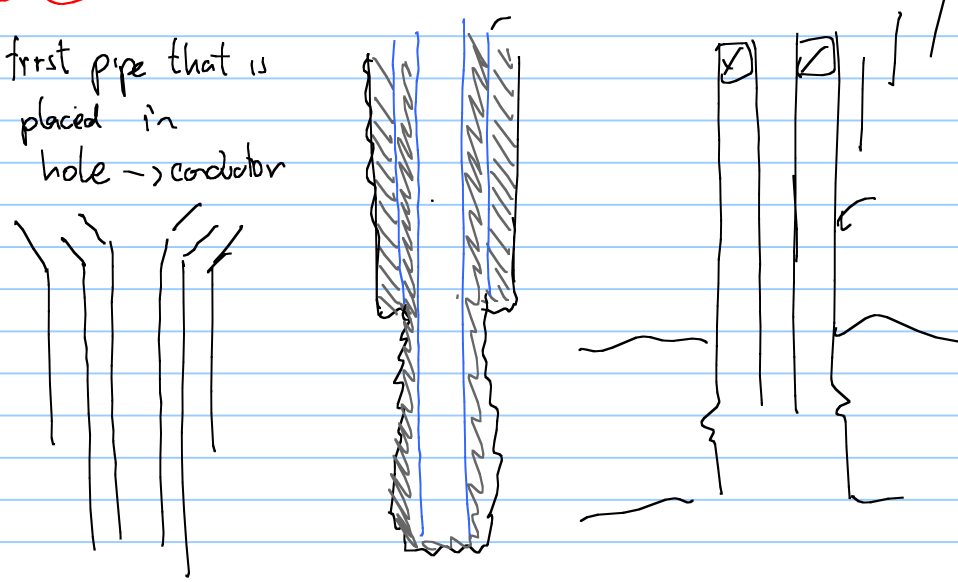
two types of subsea wells

Satellite wells

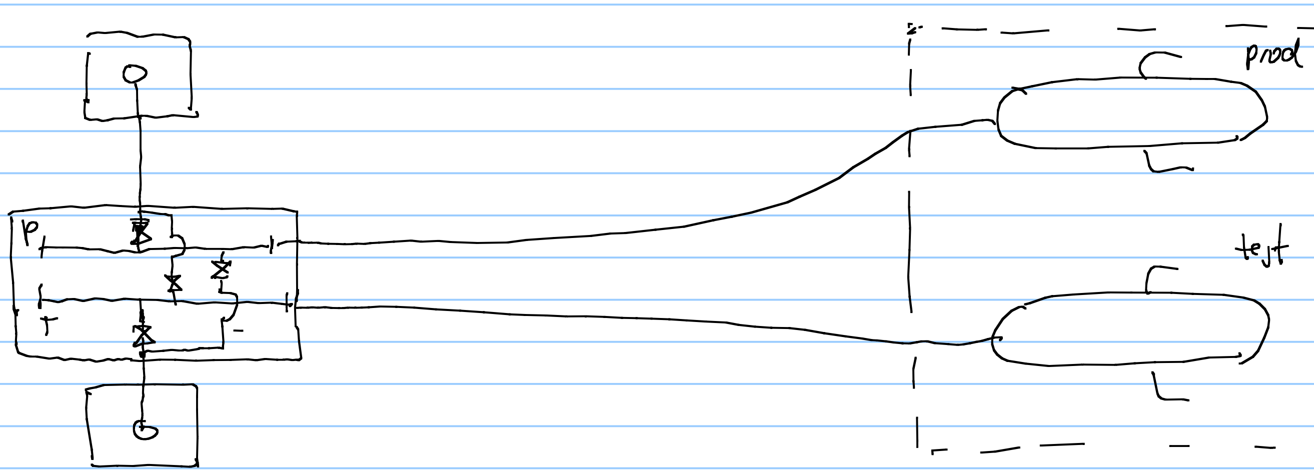


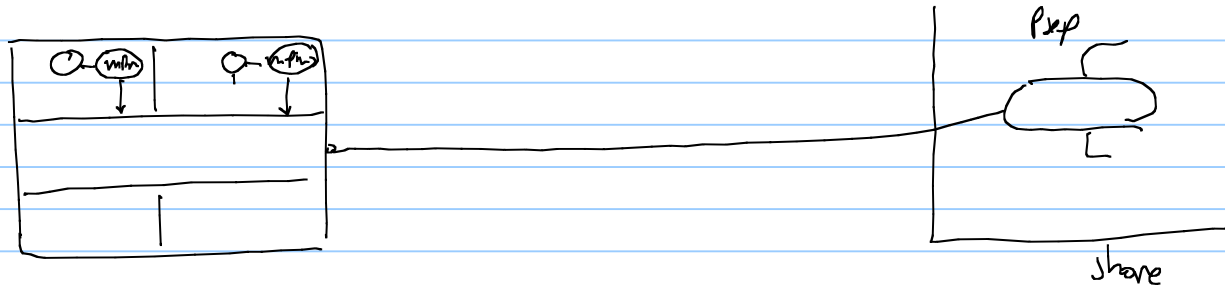


first pipe that is placed in hole -> conductor

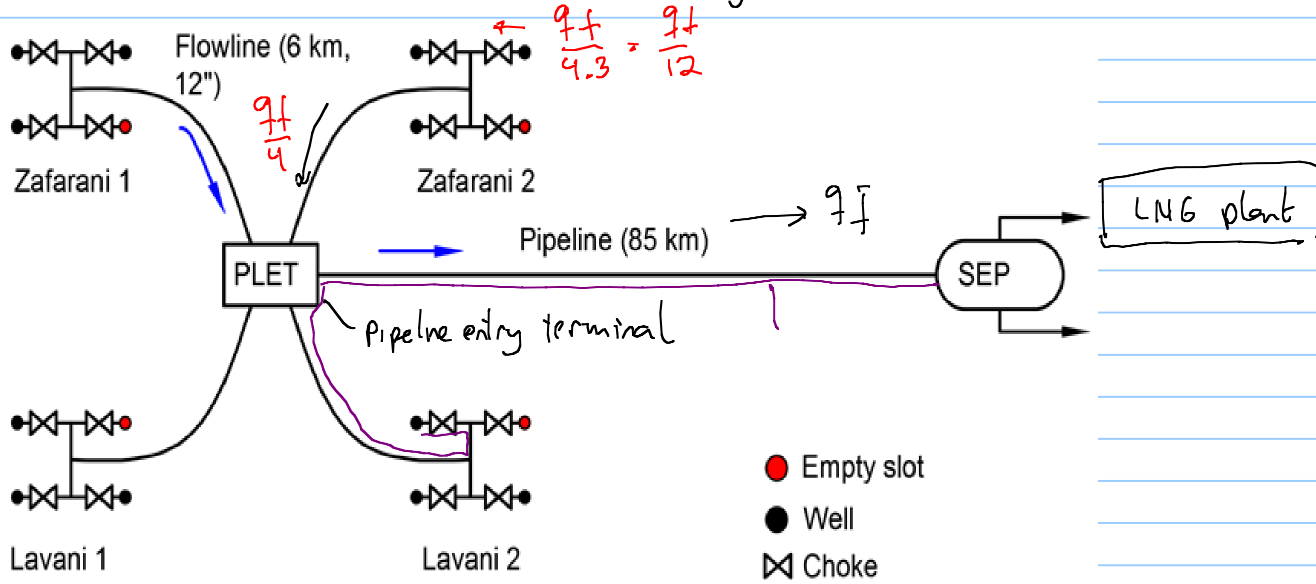


CONDUCTOR / DRILLING PROSESS





subsea gathering network



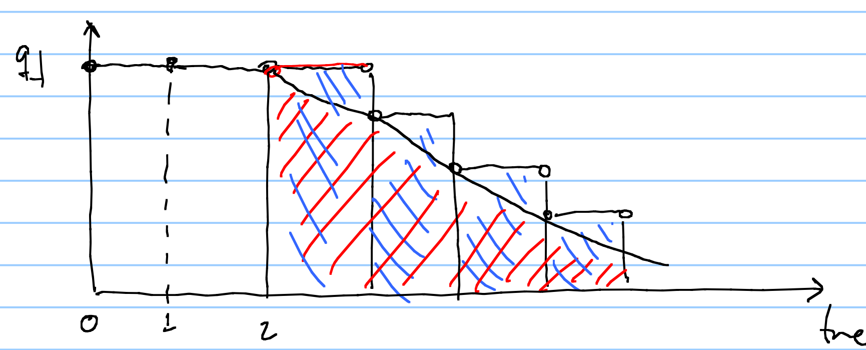
same Pat, Pwh

all well are identical

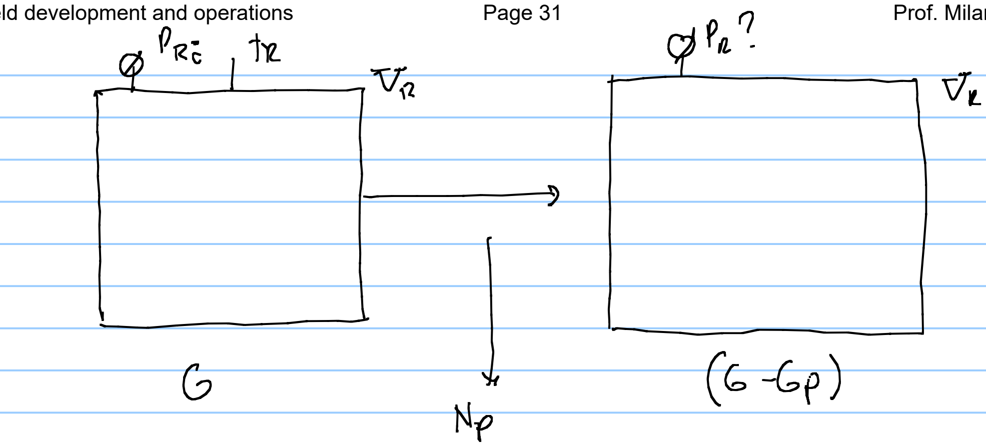
all flowlines are identical

all well drain from the same reservoir

How to calculate $P_R = f(t)$?



Dry gas material Balance



$$p v = R Z T_R$$

$$p \frac{V}{m} = R Z T_R$$

$$m_i = \frac{P_{Ri} V_R}{R Z_i T_R} \qquad Sm^3 \qquad kg \qquad m^* = \frac{P_R V_R}{R Z_R T_R}$$

$$G_p \approx f(m_i - m^*)$$

final equation

$$P_R = \frac{P_i Z_R}{Z_i}\left(1 - \frac{G_p}{G}\right)$$

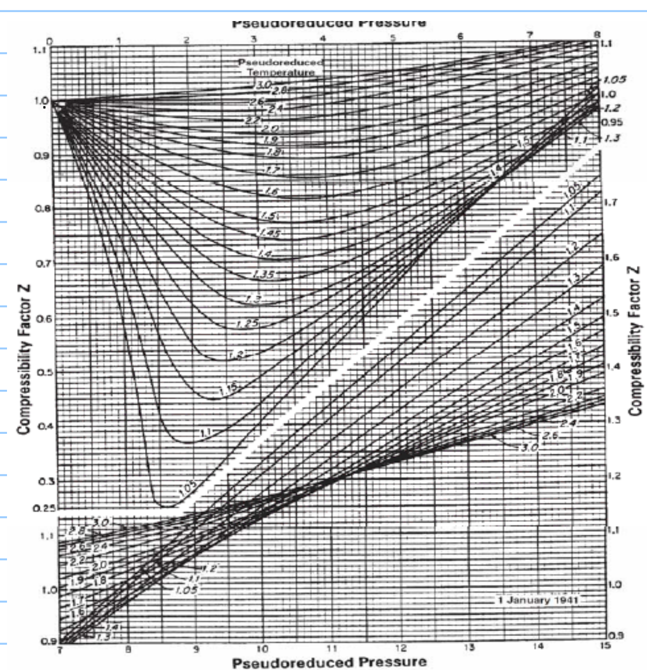
neglecting rock compressibility

Recovery factor

$$P_R = P_i \frac{Z_R}{Z_i}\left(1 - RF\right)$$

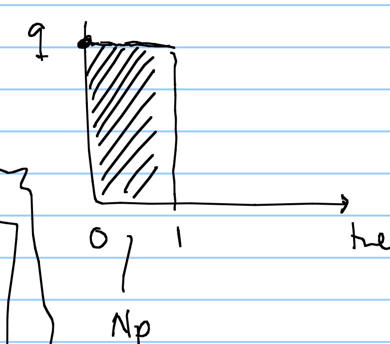
0 — q field

1 — q field



$$Z_R = f(T_R, P_R)$$

assume $P_{R\,assumed}$
↓
calculate Z_R
↓
equation calcula P_R
↓
is $P_{R\,assumed} = P_{R\,calc}$?
↳ yes



time	p_R
t_1	p_{R_1}
t_2	p_{R_2}
t_3	p_{R_3}
⋮	⋮

$p_{R_1} \rightarrow p_{R_2}$ slow changing

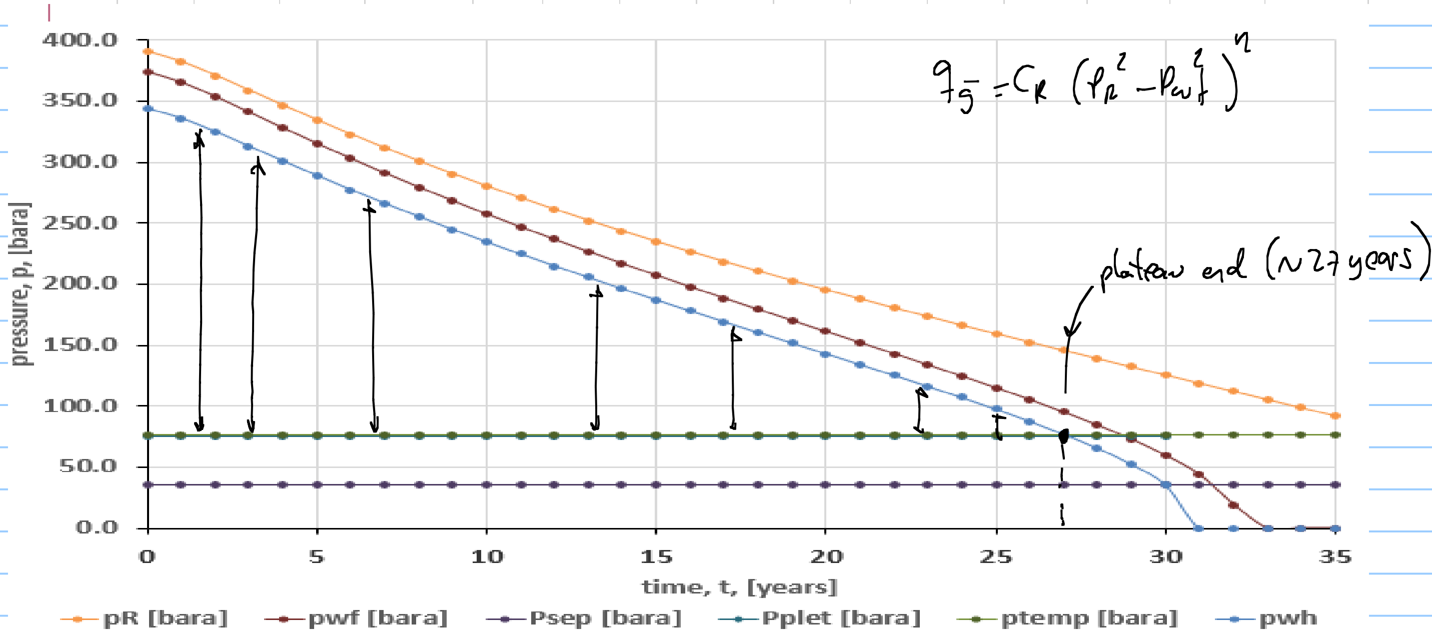
Z_{R_2} with $(p_{R_1}$

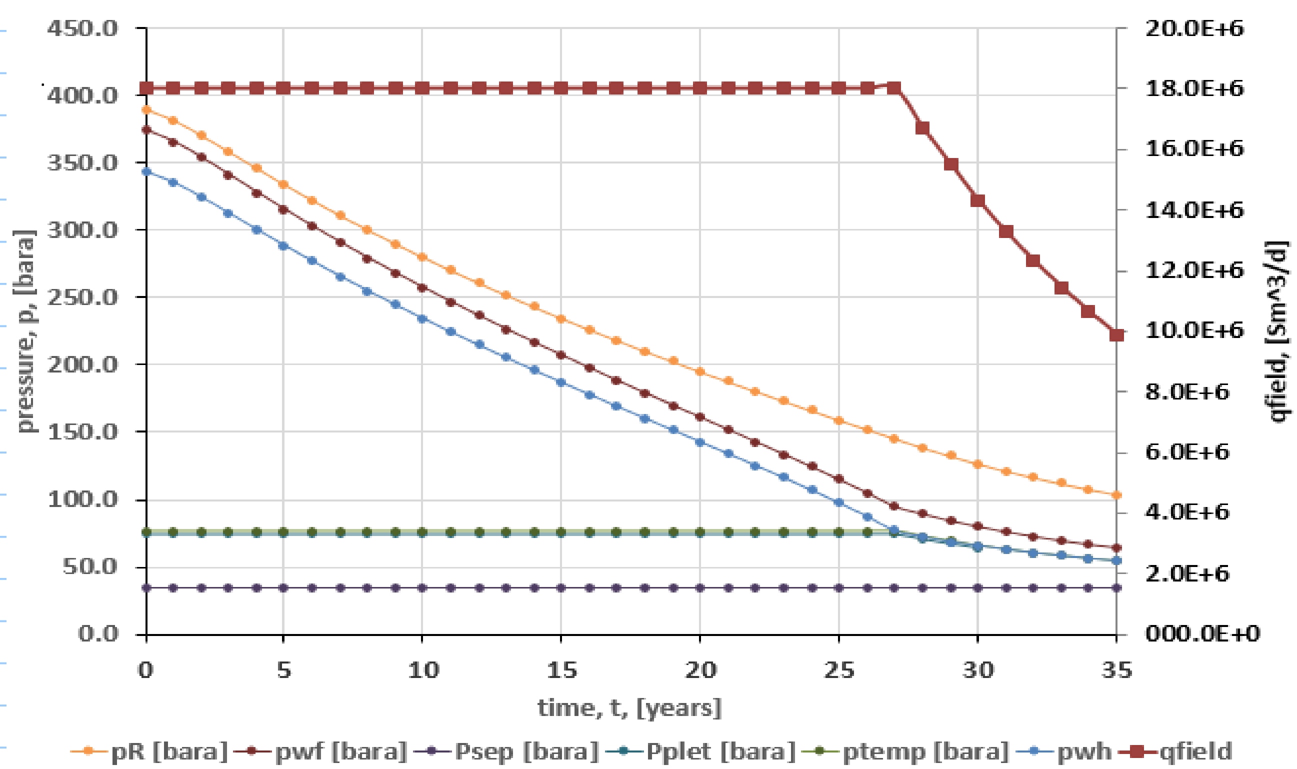
Z_{R_i} with $p_{R_{i-1}}$

Sm³/d, years, $t_i - t_{i-1}$, $\frac{\text{Ndays}}{\text{year}} \sim$ uptime

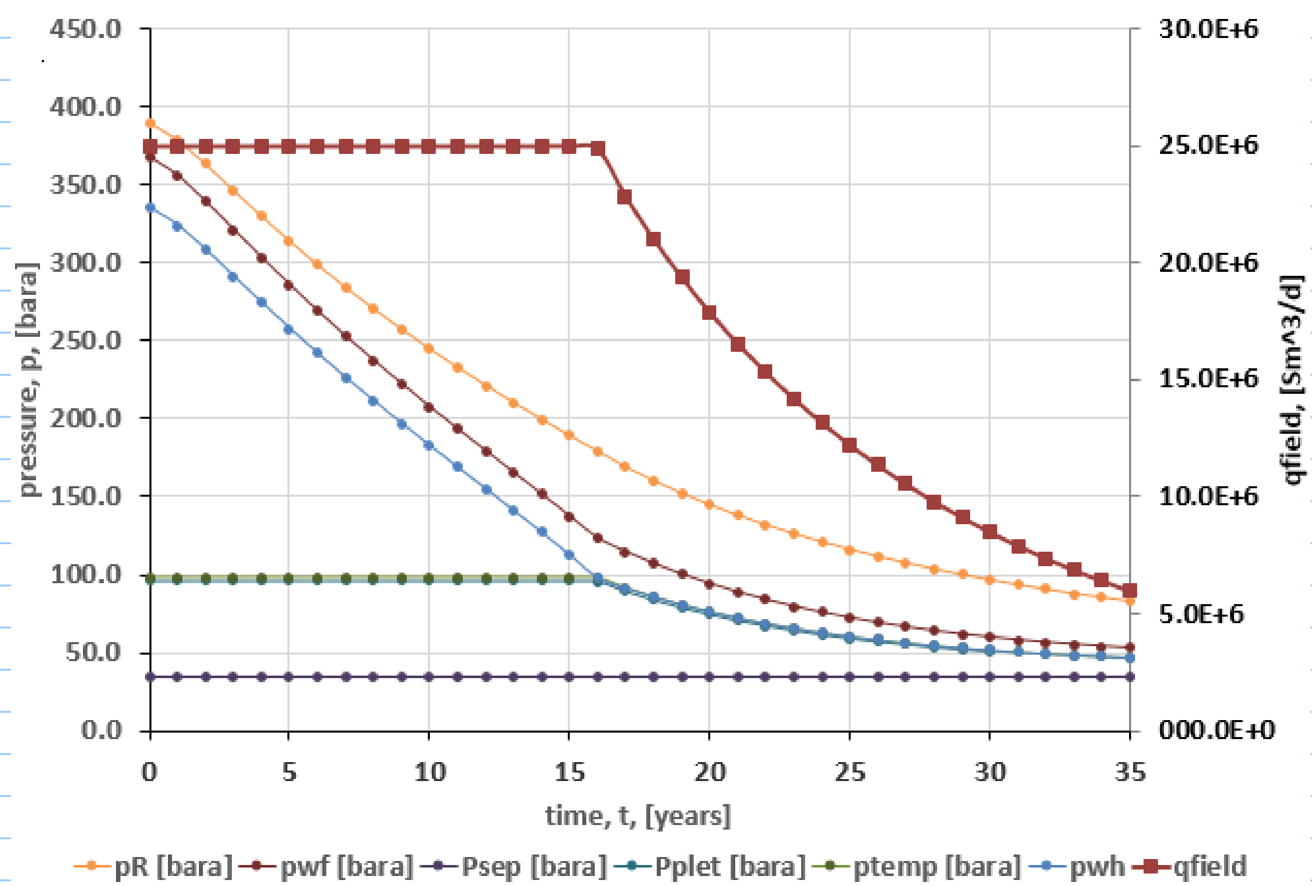
$\Delta G_p = q_{year}(1-0) \cdot \text{uptime}$

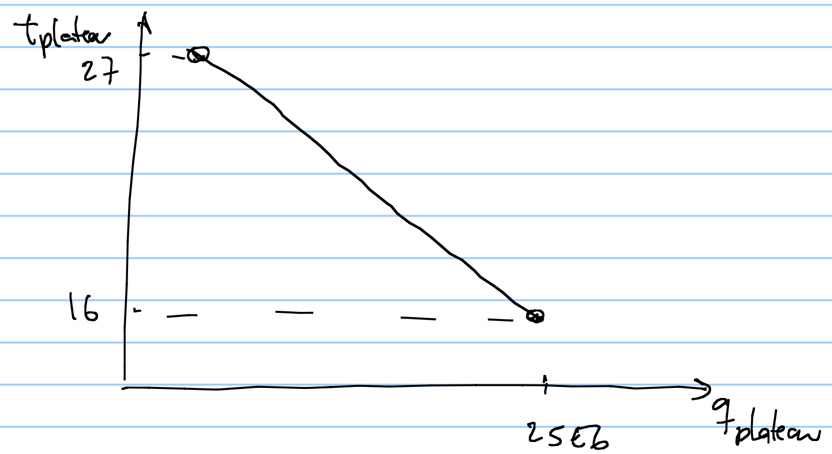
time	qwell	qfield	ΔGp	Gp	RF	pR	Z	pwf	pwh	Psep	Pplet	qtemp	ptemp	Deltpchoke	time
[years]	[Sm^3/d]	[Sm^3/d]	[Sm^3]	[Sm^3]	[-]	[bara]	[-]	[bara]	[bara]	[bara]	[bara]	[Sm^3/d]	[bara]	[bara]	[years]
0	1.50E+06	18.0E+6	6.5E+9	000.0E+0	0.00	390.0	1.045	374.0	343.6	35.0	75.1	4.50E+06	76.7	267	0
1	1.50E+06	18.0E+6	6.5E+9	6.5E+9	0.02	381.9	1.036	365.6	335.7	35.0	75.1	4.50E+06	76.7	259	1
2	1.50E+06	18.0E+6	6.5E+9	13.0E+9	0.04	370.6	1.024	353.8	324.7	35.0	75.1	4.50E+06	76.7	248	2
3	1.50E+06	18.0E+6	6.5E+9	19.4E+9	0.06	358.4	1.012	340.9	312.7	35.0	75.1	4.50E+06	76.7	236	3
4	1.50E+06	18.0E+6	6.5E+9	25.9E+9	0.08	346.1	0.999	328.0	300.6	35.0	75.1	4.50E+06	76.7	224	4
5	1.50E+06	18.0E+6	6.5E+9	32.4E+9	0.10	334.0	0.987	315.3	288.7	35.0	75.1	4.50E+06	76.7	212	5
6	1.50E+06	18.0E+6	6.5E+9	38.9E+9	0.13	322.4	0.976	302.9	277.1	35.0	75.1	4.50E+06	76.7	200	6
7	1.50E+06	18.0E+6	6.5E+9	45.4E+9	0.15	311.2	0.966	291.0	265.9	35.0	75.1	4.50E+06	76.7	189	7
8	1.50E+06	18.0E+6	6.5E+9	51.8E+9	0.17	300.4	0.957	279.4	255.1	35.0	75.1	4.50E+06	76.7	178	8
9	1.50E+06	18.0E+6	6.5E+9	58.3E+9	0.19	290.0	0.948	268.2	244.6	35.0	75.1	4.50E+06	76.7	168	9
10	1.50E+06	18.0E+6	6.5E+9	64.8E+9	0.21	280.0	0.940	257.3	234.4	35.0	75.1	4.50E+06	76.7	158	10
11	1.50E+06	18.0E+6	6.5E+9	71.3E+9	0.23	270.4	0.933	246.8	224.5	35.0	75.1	4.50E+06	76.7	148	11
12	1.50E+06	18.0E+6	6.5E+9	77.8E+9	0.25	261.0	0.926	236.5	214.8	35.0	75.1	4.50E+06	76.7	138	12
13	1.50E+06	18.0E+6	6.5E+9	84.2E+9	0.27	252.0	0.920	226.5	205.3	35.0	75.1	4.50E+06	76.7	129	13
14	1.50E+06	18.0E+6	6.5E+9	90.7E+9	0.29	243.2	0.915	216.7	196.0	35.0	75.1	4.50E+06	76.7	119	14
15	1.50E+06	18.0E+6	6.5E+9	97.2E+9	0.31	234.7	0.910	207.1	186.9	35.0	75.1	4.50E+06	76.7	110	15
16	1.50E+06	18.0E+6	6.5E+9	103.7E+9	0.33	226.4	0.906	197.6	178.0	35.0	75.1	4.50E+06	76.7	101	16
17	1.50E+06	18.0E+6	6.5E+9	110.2E+9	0.35	218.3	0.902	188.3	169.1	35.0	75.1	4.50E+06	76.7	92	17
18	1.50E+06	18.0E+6	6.5E+9	116.6E+9	0.38	210.4	0.899	179.1	160.3	35.0	75.1	4.50E+06	76.7	84	18
19	1.50E+06	18.0E+6	6.5E+9	123.1E+9	0.40	202.7	0.897	170.0	151.6	35.0	75.1	4.50E+06	76.7	75	19





for higher plateau 25E6 Sm^3/d





cost (CAPEX + OPEX)
capital expenditures operational expenditures

NPV calculations Net present value ← Revenue

year	ΔGp	Revenue	Pg
	□	ΔGp.Pg	□

ΔGp Pg