NTNU – Trondheim
Norwegian University of
Science and Technology

Department of Geoscience and Petroleum

Examination paper for TPG4230 – Field Development and Operations

Academic contact during examination: Prof. Milan Stanko

Phone: +47 954 40 756

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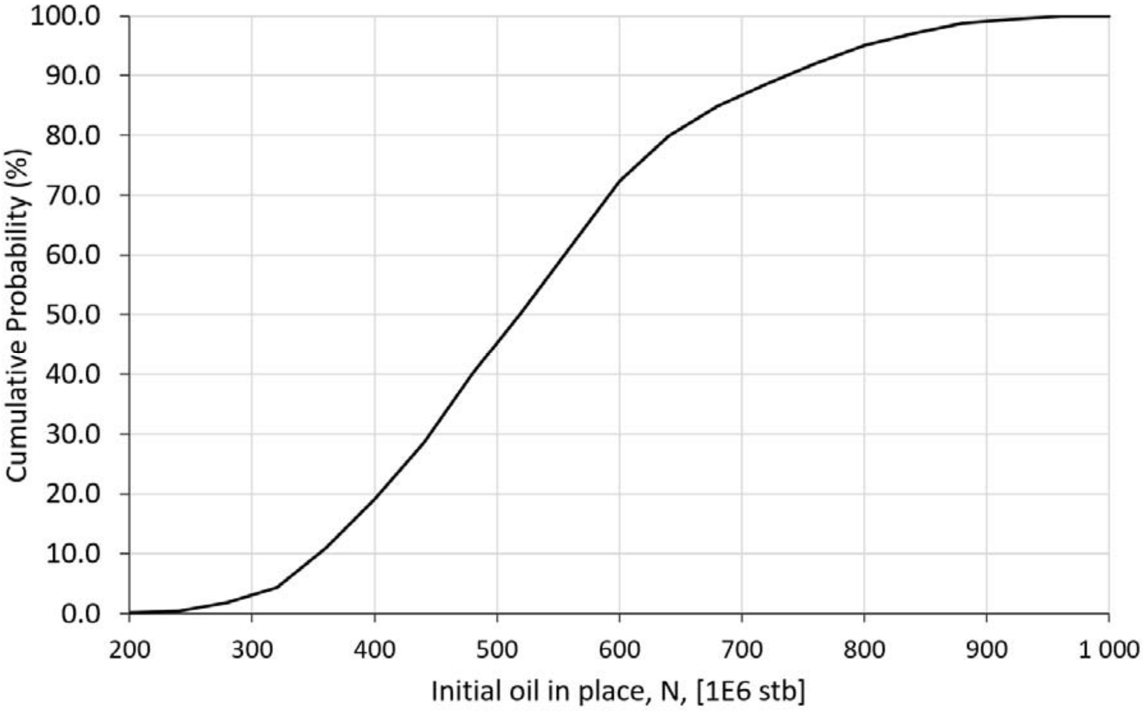
PROBLEM 1 (20 POINTS). Uncertainty quantification in early field development

Your company is deciding whether to develop or not an oil reservoir in the Norwegian Continental Shelf. They are currently in the business case identification phase. Using information from a few exploration wells, and seismic, they have calculated the following cumulative distribution function for initial oil in place:



The NPV of the project (output in million USD) can be estimated using the following formula (only oil is recovered from this field, due to lack of gas transport infrastructure):

$$NPV = P_o \cdot 0.2 \cdot N - C$$

Where:

- P_o is the price per barrel of oil [USD/bbl].
- C is the initial cost of the development, mainly representing facilities and wells [in million USD]. Given by the equation:

$$C = N \cdot 1.3 + 2002$$

- N is the original oil in place [in Million stb]. **In both equations, N must be input in million stb.**

There is a uniform uncertainty of ±40% in the cost. This can be expressed as a **multiplier to** C, with maximum value 1.4 and minimum value of 0.6.

There is an uncertainty in the oil price. Assume it exhibits a uniform probability for the range 30-60 USD/bbl

To help your company take the decision if to continue with development or not, you will quantify the effect of uncertainty using a probability tree with tree layers, considering the following factors: initial oil in place, costs, and oil price. **Each layer will have two alternatives with equal probability.**

Based on your probability tree analysis:

- Explain, in a clear, understandable way, how and what steps did you take to solve this problem
- Report the minimum NPV that the project could have and its associated probability.
- Report the maximum NPV that the project could have and its associated probability.
- Report the expected value of the project (sum of all branches of the tree weighted with their probabilities)
- Report the compound probability of the project having a total value equal or greater than 2000 MMUSD.

Additional information:

- The cumulative distribution function of a uniform probability distribution is a straight line described by:

CDF	$\begin{cases} 0 & \text{for } x < a \\ \frac{x-a}{b-a} & \text{for } x \in [a,b) \\ 1 & \text{for } x \geq b \end{cases}$

Where a is the minimum value and b is the maximum value.

- Use the following guideline to discretize a continuous cdf:

In tree analysis, we usually make a discrete approximation by setting up nonoverlapping (mutually exclusive) ranges that encompass all possible values (collectively exhaustive), by finding the probabilities that the values fall in these ranges, and by then choosing a value to represent that range. (This is the approximation.) By doing this, we have converted a continuous variable to a discrete variable and a probability density function to a probability mass function.

Given a continuous probability distribution such as the one shown in Figure 2–14, how does one perform this approximation? One widely used technique is to select the number of outcomes and the values of the probabilities you want and then draw a horizontal line at these probabilities. In Figure 2–15, we have chosen the number of outcomes to be three. We have also chosen the probabilities .25 for the lower range (line at .25), .5 for the

Figure 2–14

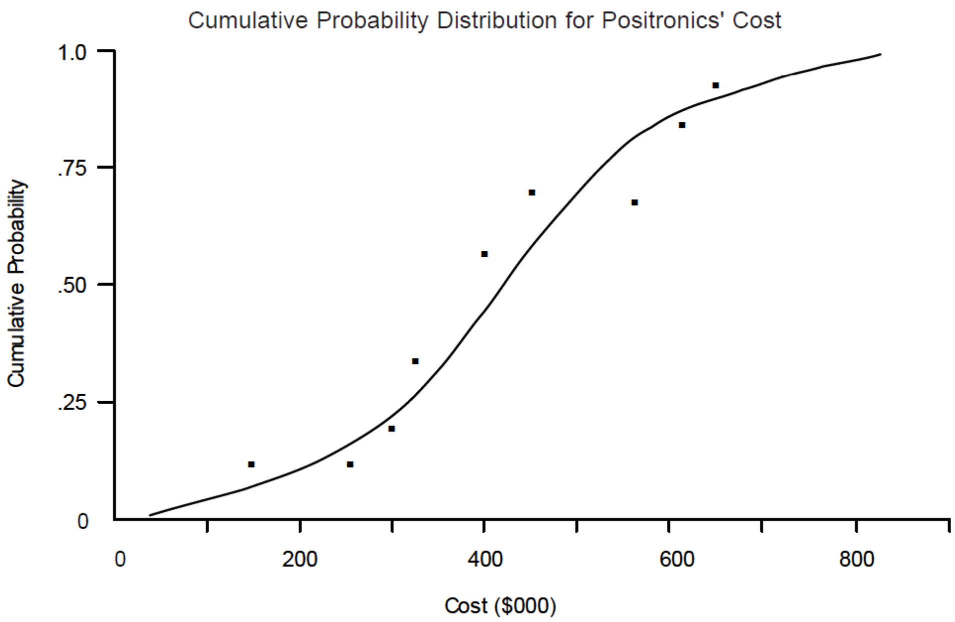
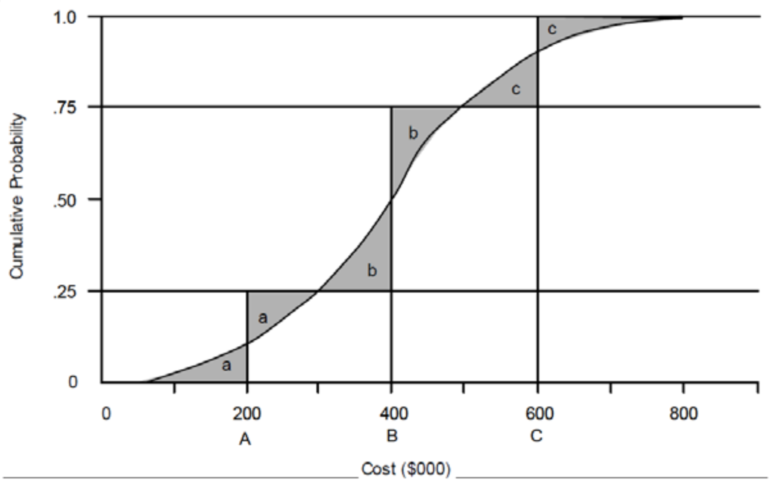


Figure 2–15

Approximation of Discrete Probability Distribution for Positronics' Cost



middle range (line at .25 + .50 = .75), and .25 for the top range (line at .25 + .5 + .25 = 1).

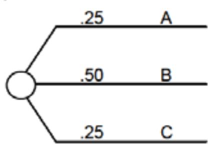
Next, we draw a vertical line at A, choosing point A so that the shaded area to the left of the vertical line is equal to the shaded area to the right. (The eye is surprisingly good at doing this.) These two areas are marked by the letter "a." Then we pick a point, B, at which to draw a vertical line with the shaded area to the right being equal to the shaded area to the left. Finally, we pick the third point, C, at which to draw the vertical line balancing the two shaded areas.

The procedure sounds much more complicated than it is in practice. The result is that we now have approximated the continuous probability distribution; the discrete probability distribution is shown in tree form in Figure 2–16. The actual values are A = 200, B = 400, and C = 600. These values are used for Positronics' cost in this chapter. In general, the values for A, B, and C will not come out evenly spaced.

The reason the procedure works is that we divided the continuous probability distribution into ranges with associated probability when we drew the horizontal lines. In Figure 2–17, we see that the first range was from negative infinity to x and had probability .25. The second range was from x to y and had a probability of .5. The third range was from y to infinity and had a probability of .25. (For this example, x = 300 and y = 500, corresponding to the ranges in Figure 2–4.) Picking point A in such a way that the shaded areas are equal is a visual way of finding the expected value, given that you are in the lowest range. (Proving that the expected value makes the shaded areas equal is a nice exercise in calculus in problem 2.15.) Choosing the expected value to represent the range is a natural approximation and is commonly used. There are, however, other possible choices.

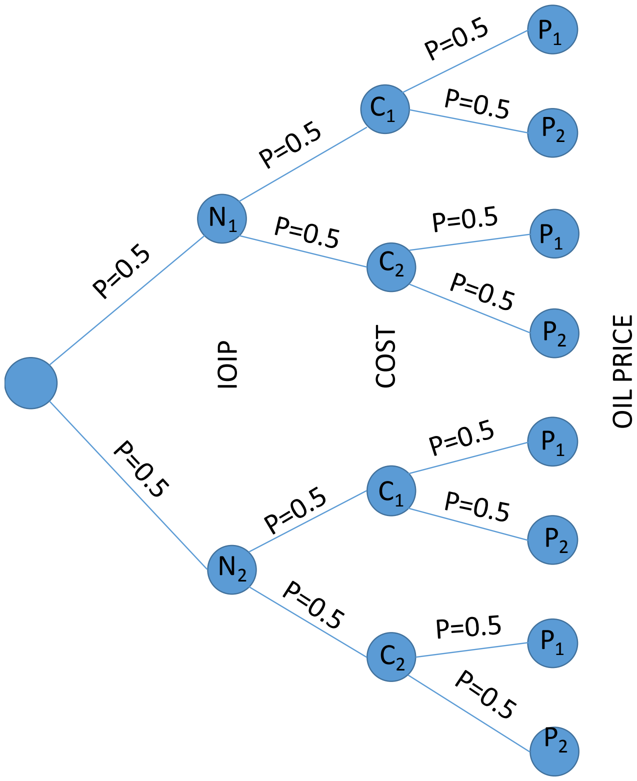
Figure 2–16

Discrete Probability Distribution in Tree Form

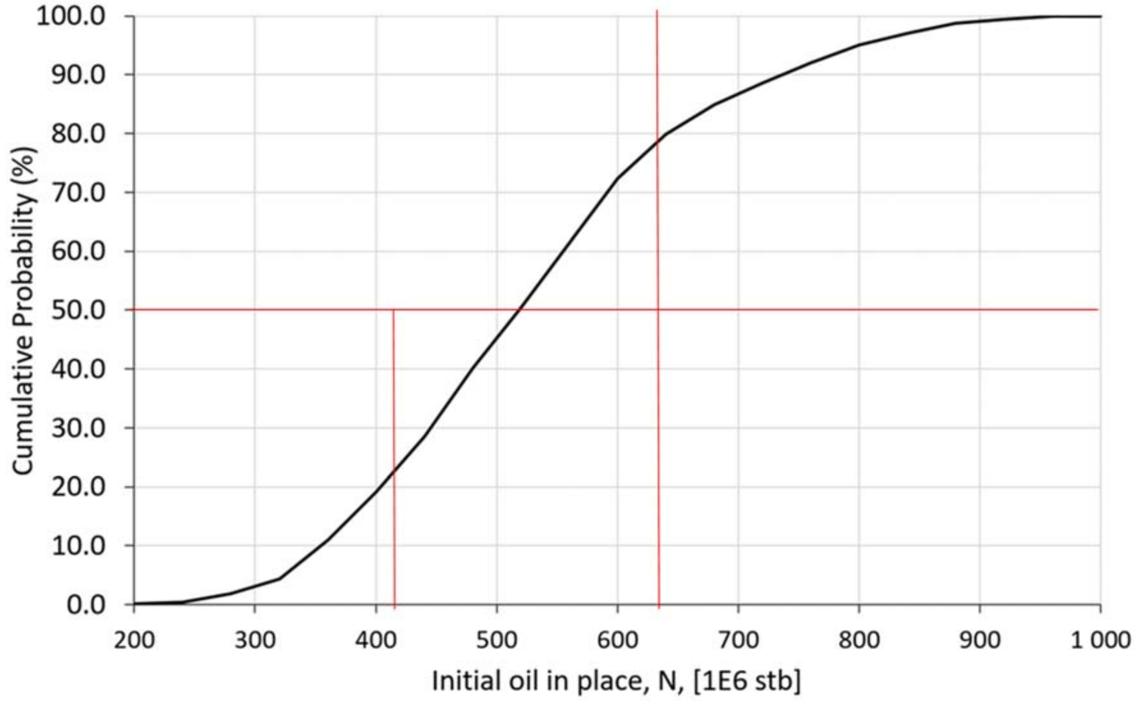


SOLUTION

The probability tree looks like this:

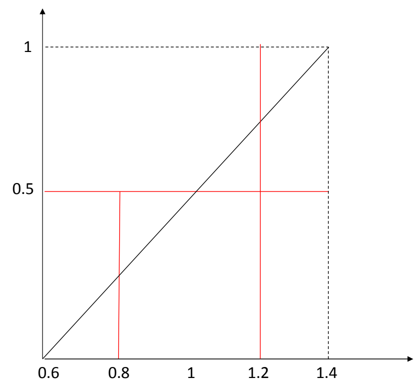


Therefore, each branch in the tree will have the same probability, i.e. 0.5*0.5*0.5= 0.125



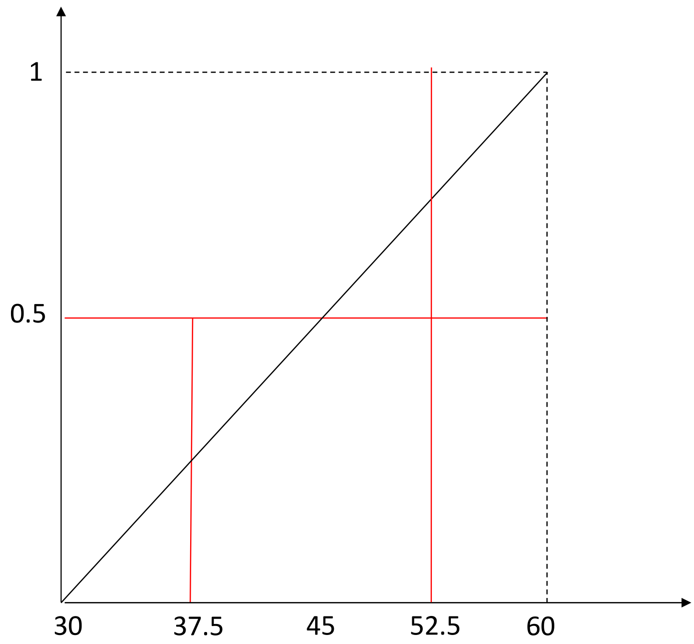
Discretizing the distribution of initial oil in place yields
N_1 = 410 MMstb
N_2 = 630 MMstb

Discretizing the distribution of the cost factor



, this yields
F_1 = 0.8
F_2 =1.2

Discretizing the distribution of the oil price



, this yields
$P_1 = 37.5$
$P_2 = 52.5$

Computing all branches in the tree:

=D4*0.2*B4-C4*(B4*1.3+2002)

N [MMstb]	Fc [-]	Price [USD/bbl]	P [-]	NPV [MMUSD]
410	0.8	37.5	0.125	=D4*0.2*B
410	0.8	52.5	0.125	2277
410	1.2	37.5	0.125	33
410	1.2	52.5	0.125	1263
630	0.8	37.5	0.125	2468.2
630	0.8	52.5	0.125	4358.2
630	1.2	37.5	0.125	1339.8
630	1.2	52.5	0.125	3229.8

- Report the minimum NPV that the project could have and its associated probability.

33 MMUSD and P= 0.125

- Report the maximum NPV that the project could have and its associated probability.

4358 MMUSD and P= 0.125

- Report the expected value of the project (sum of all al branches of the tree weighted with their probabilities)

N	Fc	Price	P	NPV	EV
[MMstb]	[-]	[USD/bbl]	[-]	[MMUSD]	[MMUSD]
410	0.8	37.5	0.125	1047	130.9
410	0.8	52.5	0.125	2277	284.6
410	1.2	37.5	0.125	33	4.1
410	1.2	52.5	0.125	1263	157.9
630	0.8	37.5	0.125	2468.2	308.5
630	0.8	52.5	0.125	4358.2	544.8
630	1.2	37.5	0.125	1339.8	167.5
630	1.2	52.5	0.125	3229.8	403.7
				EMV	2002

2002 MMUSD

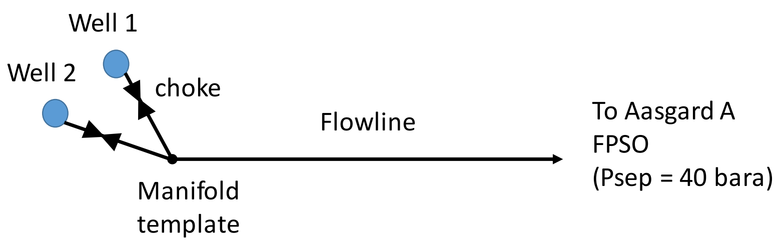
- Report the compound probability of the project having a total value greater than 2000 MMUSD.

There are 4 branches that have an NPV less than 2000 MMUSD, therefore: P=1-4*0.125=0.5

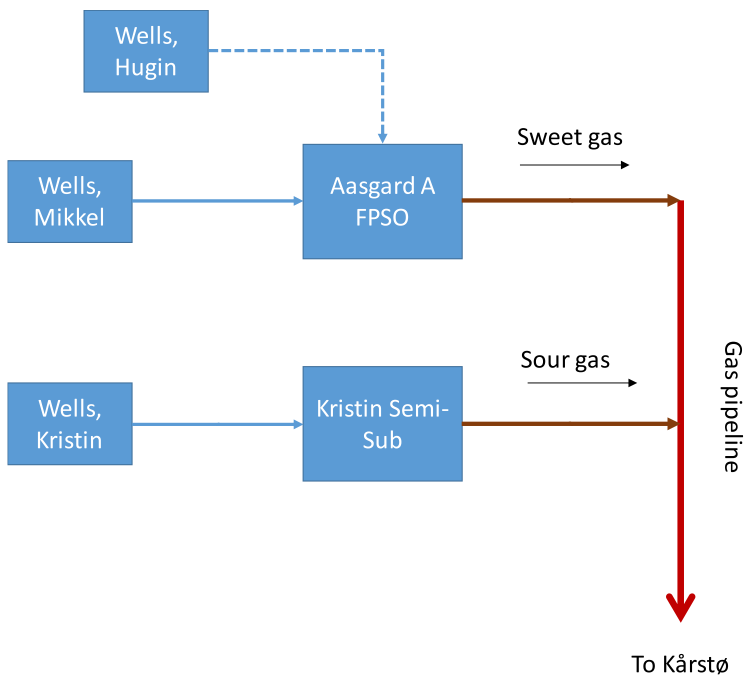
PROBLEM 2 (27 POINTS).

You are part of the field development team of a modest-size gas reservoir in the NCS called Hugin. The gas will be produced to an existing facility (the FPSO Åsgard A) and send further via a gas transport pipeline to the Kårstø processing plant. Hugin will be developed using subsea wells as shown in the figure below, although the number of wells is not defined yet. Assume that the manifold template is very close to the wells.

Subsea layout of the Hugin Field



The production of another reservoir in the area (Kristin) is currently sent to Kårstø using the same pipeline. Kristin has a high content of CO_2 ($q_{\overline{co2}}/q_{\bar{g}} = 0.04$, i.e. "sour gas"). To avoid structural issues in the pipeline and processing problems in Kårstø, the production of Kristin is currently mixed with the production of Mikkel (another field in the area), which has low CO_2 content ("sweet" gas). However, Mikkel will be shut down soon (end of 2019). Therefore the intention is to use Hugin (from January 2020) to replace Mikkel and keep the CO_2 concentration in the gas pipeline low (below 2% in volume). The volume content of CO_2 in Hugin gas is 1%.



Your tasks are:

1. Determine the producing rates (per year) required from Hugin to provide a concentration of the total gas stream of 2% volume when mixed with Kristin gas.
1. If each Hugin well can produce a maximum of 2E06 Sm^3/d, how many wells are required?
2. Verify if it is feasible to produce the rates calculated in task 1 and estimate the well choke deltaP in each year.
3. If it is not possible for Hugin to provide the required rates at any point in time, the field development team has suggested to drill additional wells on that year. Evaluate, demonstrating with calculations, if this approach will be sufficient to provide the required rate.

For your calculations assume dry gas, all wells identical and number of producing days per year 365. Use a rectangular integration for estimating cumulative production Gp assuming the field rate at beginning of the year remains constant through the year.

Data

Material balance equation:
$p_R = p_i \cdot \left(1 - \frac{G_p}{G}\right)$ P_i = 240 bara G =45 E9 Sm^3
Inflow equation: $q_g = C_R \cdot \left(p_R^2 - p_{wf}^2\right)^n$ With C_R = 800 $Sm^3/d/bar^{2n}$ n= 0.9
Tubing equation: $q_{gsc} = C_T \cdot \left(\frac{p_{wf}^2}{e^S} - p_{wh}^2\right)^{0.5}$ C_T = 4.4 E4 $Sm^3/d/bar$ S = 0.3
Pipeline equation subsea template to FPSO: $q_{gsc} = C_{PL} \cdot \left(p_{MAN}^2 - p_{SEP}^2\right)^{0.5}$ C_{FL} = 1.4E5 $Sm^3/d/bar$ p_{sep} = 40 bara

Projected production profile for Kristin:

Time	**Projected gas Production from Kristin (at beginning of year)**
[years]	[Sm^3/d]
2020	6E06
2024	6E06
2025	5E06

The volumetric concentration of CO_2 of the gas stream in the export pipeline to Kårstø can be estimated by

$$C_{Co2,pipeline} = \frac{q_{\bar{g},Kristin} \cdot C_{Co2,Kristin} + q_{\bar{g},Hugin} \cdot C_{Co2,Hugin}}{q_{\bar{g},Kristin} + q_{\bar{g},Hugin}}$$

SOLUTION

Clearing $q_{\bar{g},Hugin}$ from the expression:

$$q_{\bar{g},Hugin} = \frac{\left(C_{Co2,pipeline} - C_{Co2,Kristin}\right) \cdot q_{\bar{g},Kristin}}{\left(C_{Co2,Hugin} - C_{Co2,pipeline}\right)}$$

This yields the following (required) production profile from Hugin:

time	qg_kristin	qg_Hugin
[years]	[Sm^3/d]	[Sm^3/d]
2020	6.00E+06	1.20E+07
2024	6.00E+06	1.20E+07
2025	5.00E+06	1.00E+07

Therefore, 6 wells are required.

Year 2020.

Gp = 0 Sm^3, pR=240 bara, With qwell = 2E06, and using the IPR equation, the pwf available is 227 bara.

With the TPR equation, qwell = 2e06 Sm^3/d and pwf = 227 bara, the pwh available is 190 bara.

With the FPR equation, qfield = 12E06 Sm^3/d, and psep = 40 bara, the pmanifold required is 94.6 bara.

Therefore, the rate for this year is feasible and deltapchoke = 95.6 bar

Year 2024

Gp = 4* 365* 12E06 = 17.5 E09 Sm^3

Material balance equation Pr = 146.6 bara

With qwell = 2E06, and using the IPR equation, the pwf available is 124.6 bara.

With the TPR equation, qwell = 2e06 Sm^3/d and pwf = 124.6 bara, the pwh available is 97 bara.

With the FPR equation, qfield = 12E06 Sm^3/d, and psep = 40 bara, the pmanifold required is 94.6 bara. (same as year 2020)

Therefore, the rate for this year is feasible and deltapchoke = 2.5 bar

Year 2025

Gp = 17.5 E09 Sm^3 + 1* 365* 12E06 = 21.9 E09 Sm^3

Material balance equation Pr = 123.2 bara

With qwell = 1.66 E06, and using the IPR equation, the pwf available is 101.5 bara.

With the TPR equation, qwell = 1.66 E06 Sm^3/d and pwf = 101.5 bara, the pwh available is 78.75 bara.

With the FPR equation, qfield = 10E06 Sm^3/d, and psep = 40 bara, the pmanifold required is 81.8 bara.

Therefore, the rate for this year is not feasible, because deltapchoke = -3 bar

Year 2025 with one additional well
With qwell = 1.43 E06, and using the IPR equation, the pwf available is 105.2 bara.
With the TPR equation, qwell = 1.43 E06 Sm^3/d and pwf = 105.2 bara, the pwh available is 84.6 bara.
With the FPR equation, qfield = 10E06 Sm^3/d, and psep = 40 bara, the pmanifold required is 81.8 bara. (same as before)
Therefore, the rate for this year is now feasible and deltapchoke = 2.7 bar

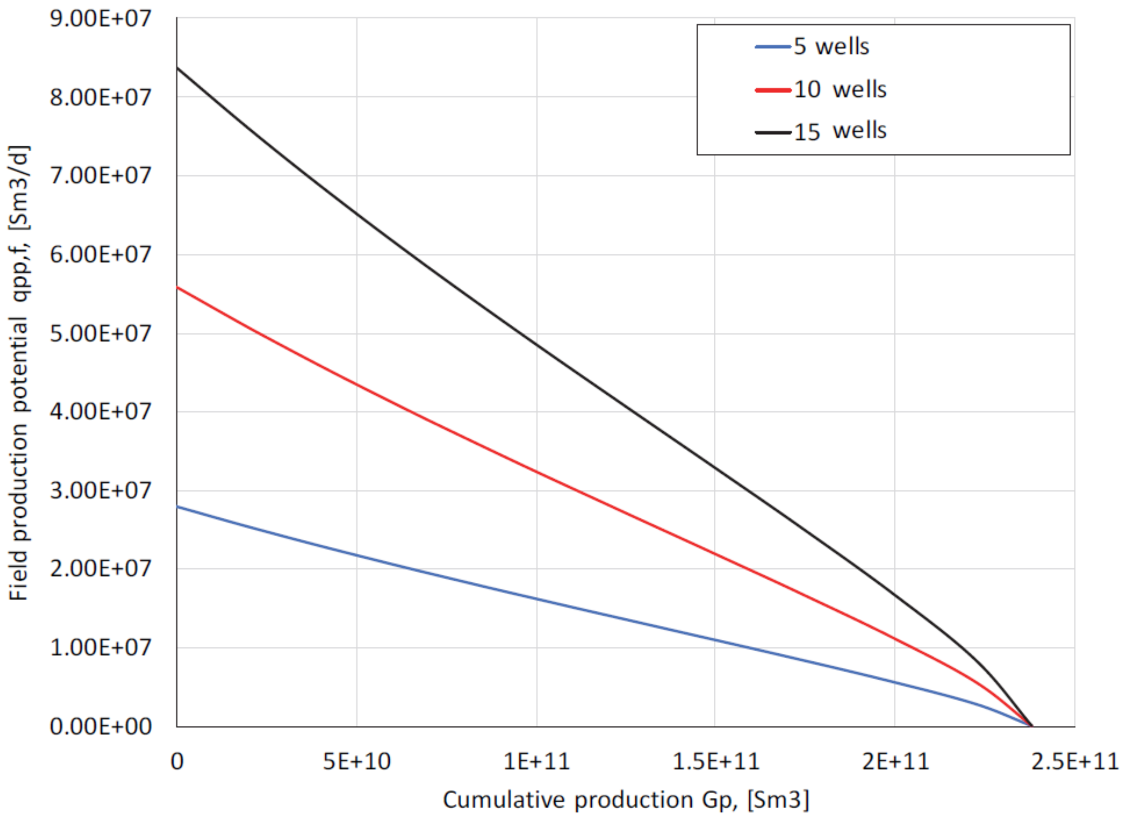
PROBLEM 3 (2 points) Which of the following activities are normally performed in the business case identification phase in field development:

- Scouting, pre-exploration, prospect identification, seismic surveys (correct)
- Preparation of the PDO
- Creation of a reservoir model
- Discovery assessment, appraisal, reserve estimation (correct)

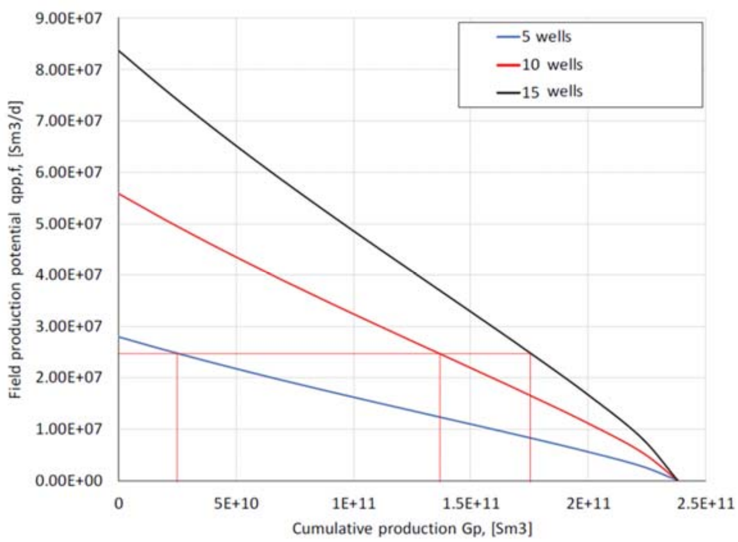
PROBLEM 4 (2 points) Which of the following statements is false?

- In plateau production, the wellhead choke is opened gradually with time
- Adding more wells for a fixed plateau rate reduces flowing-bottomhole pressure (wrong)
- The higher the plateau rate, the shorter the plateau duration
- Decline production mode is typically used for standalone projects (wrong)

PROBLEM 5 (3 points) Using the production potential curves of a gas field shown below: What is the minimum number of wells needed to provide a plateau duration of 15 years with a plateau field rate of 25 E06 Sm^3/d?. Assume 365 productive days in a year.



- 5 wells
- Between 5-10 wells
- 10 wells (correct)
- 15 wells
- More than 15 wells



For all these curves, the plateau duration:

	qplateau	[Sm^3/d]	2.50E+07	Ndays	365
Nw	Gp*	tplateau			
	[Sm^3]	[years]			
5	2.50E+10	2.7			
10	1.35E+11	14.8			
15	1.75E+11	19.2			

PROBLEM 6 (3 points). Name and explain briefly three technical aspects that are usually taken into account when selecting an offshore structure for oil and gas production.

SOLUTION:
Technical aspects:
-Water depth. Bottom supported structures (Jackup, jacket, compliant tower and GBS) can operate in water depths up to 600m. FPSO can cover the whole range, and semi-sub, SPAR and TLP are for medium to deep depths.
-Storage requirements. Only GBS and FPSO provide oil storage. This is relevant if the field is in a remote or harsh location and it might be difficult for the tankers to reach the field.
-Marine loads on the structure. Each structure is susceptible to particular periods of marine load excitation (natural frequency). You should avoid placing offshore structure in areas where the period of marine load excitation coincides to the natural period of the structure.
-Dry trees and wet trees. If dry trees are needed, due to well intervention needs, testing, reservoir spread, etc. then a bottom-supported structure or a Spar or TLP can be used. Otherwise, if it is a subsea system other structures such as FPSO and semi-sub can be used.

PROBLEM 7 (3 points). When an offshore oil and gas field requires boosting (e.g. electric submersible pumps or compressor), what operational considerations of the equipment must be taken into account when computing the production profile of the field?

Solution:
For the pump:
-the operational point DP vs q should fall within the operational map of the pump. (considering the frequency range and the minimum and maximum rate limit due to downthrust and upthrust).
-Total motor capacity
-suction pressure should be above the bubble point pressure
-The viscosity of the liquid can affect the operational map of the pump.
For the compressor:
-The operational point DP vs q should fall within the operational map of the compressor (considering the range in rotational speed, and the surge and stall limits).
-The required power should be below the motor capacity.
-Suction pressure should be kept above a minimum limit
-outlet temperature.