

Exercise set 02

Problem 1: Production system layout of the Volund subsea satellite field;

Field Description

Volund is a subsea oil field, at 130 m water depth, located about 10 kilometers south of the Alvheim FPSO in the central part of the North Sea (see figure). The field, with reservoir depth of 2000 m, is developed as a subsea Satellite field to the Alvheim FPSO (Floating Production, Storage and Offloading vessel) and is tie-back to floating vessel. The subsea Volund field will have three horizontal subsea oil production wells producing to a subsea production manifold on a template. The wells are satellite to the template and the subsea wellhead are located a short distance from the template. The wellhead/Christmas trees are connected to the template by short pipes sections (Jumpers).

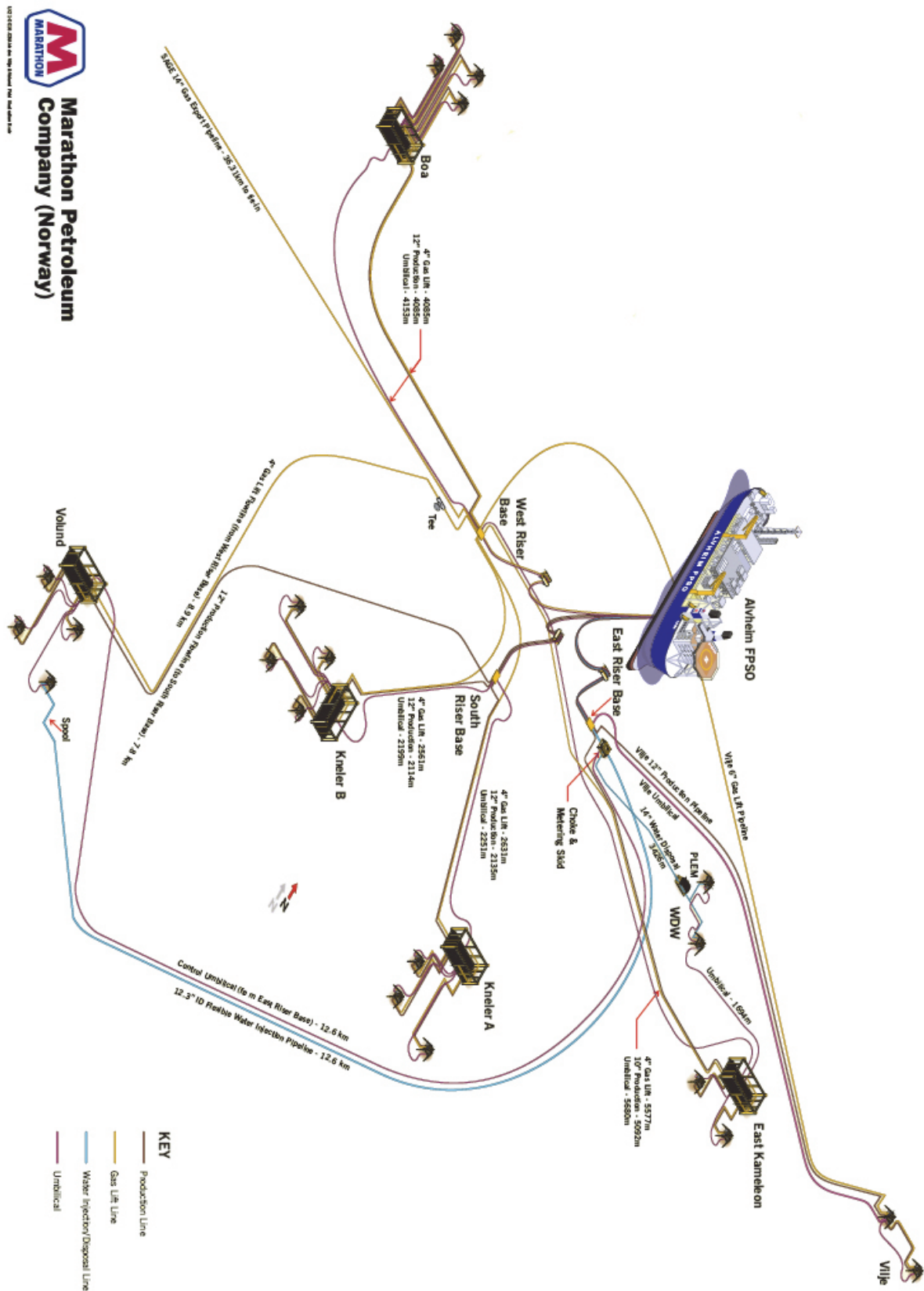
The subsea manifold on the template consists of a test and a production header which are connected by one production line and one test line to the FPSO. On the vessel there is one test separator and one production separator train dedicated entirely to the Volund field. The other fields producing to the vessel (Boa, Kneler B, Kneler A, Øst Kamelon, Vilje), have a separated testing and separation facilities and are not considered in this task.

The well-streams of Volund are commingled in the production header on the subsea template and routed through a pipeline and a flexible riser to the Alvheim FPSO for separation, processing and export. The oil is exported via an offshore buoy-loading to a shuttle tanker (not shown in the figure). The associated rich gas is separated from the condensate liquid and stripped from the NGL (Natural Gas Liquid) on the FPSO. The condensate and stripped liquids are recombined with the exported oil. The dry/lean gas is transported from the Alvheim FPSO to gas pipeline leading to the UK.

As part of preparing a development plan you need to perform the following tasks:

1. Propose a simplified P&I diagram of the subsea template of Volund production manifold with the production/testing lines to the separators on Alvheim FPSO. Show in your sketch the entire system from the wellhead to the separator. Include suggestions for pigging facilities. The production wells are satellite of the manifold template (Wellhead are not on the template but a distance away).
2. Considering that pigging is not necessary, make suggestions (using a simplified P&I diagram) for an arrangement where the testing of individual wells is done by multiphase meters (MFM) and not by test separator. Address three cases:
 - A surface single multiphase meter (MFM) on the FPSO
 - A single multiphase meter (MFM) in the subsea test manifold
 - A multiphase meter for each subsea well

Show in your diagram the main valves on the wells, the routing valves on the manifold and the arrangement of valves in the FPSO (pig launcher and receiver, separator control valves, etc).



Problem 2: Manifold design to route the production of 5 onshore wells to three separator trains

Illustrate the arrangement of the isolation valves in a production manifold that collects the production from five wells and directs it to a test separator and two production separators installed in parallel. Provide two drawings: a line diagram (process flow diagram) and an isometric diagram.

Show in your diagram the main valves on the wells and the routing valves on the manifold.

TIPS: For clarifications about the type of diagrams used in engineering, please refer to page 140 in the compendium.

Your sketches can be delivered by hand, but I recommend to use software (e.g. powerpoint, Paint, Visio, Autocad, Inkscape, Gimp, Dia) to make them. This will surely be an add-on to your engineering skills.

Problem 3: Wave statistics for the Aasta Hansteen area.

You have been invited onboard the R/V GUNNERUS, a ship that belongs to NTNU that will carry several research activities on a trip to the Norwegian Sea. The vessel will be visiting the area where the Aasta Hansteen field will be located (67° Latitude and 7° longitude). Statoil sponsors your stay and place on the ship. The ship is equipped with a buoy that measures wave elevation every 0.5 s.



Part 3.1. To show your gratitude to Statoil, you intend to process the wave elevation data that has been gathered for a period of 2047.5 s during the trip (See the excel data attached). The tasks are as follow:

- Perform an FFT of the data provided. Do this in excel and follow the instructions in the document “Frequency Domain Using Excel” written by Larry Klingenberg, from San Francisco State University. Please note that the procedure provided by Prof. Klingenberg already calculates the amplitude (wave elevation, in m), **NOT** the spectral energy.

Plot the wave spectrum (amplitude in m vs frequency), provide the periods with the highest amplitude on a table and report the peak spectral period (the period with the

highest amplitude). Remember that the period is the inverse of the frequency. **Is it possible with this information to reconstruct exactly the original signal?**

- Determine the average of the elevation data provided and the standard deviation. Then, assuming that the wave elevations displays a Normal distribution, **PLOT** the continuous pdf of the wave elevation using the formula provided below (already programmed in VBA beforehand).

PDF

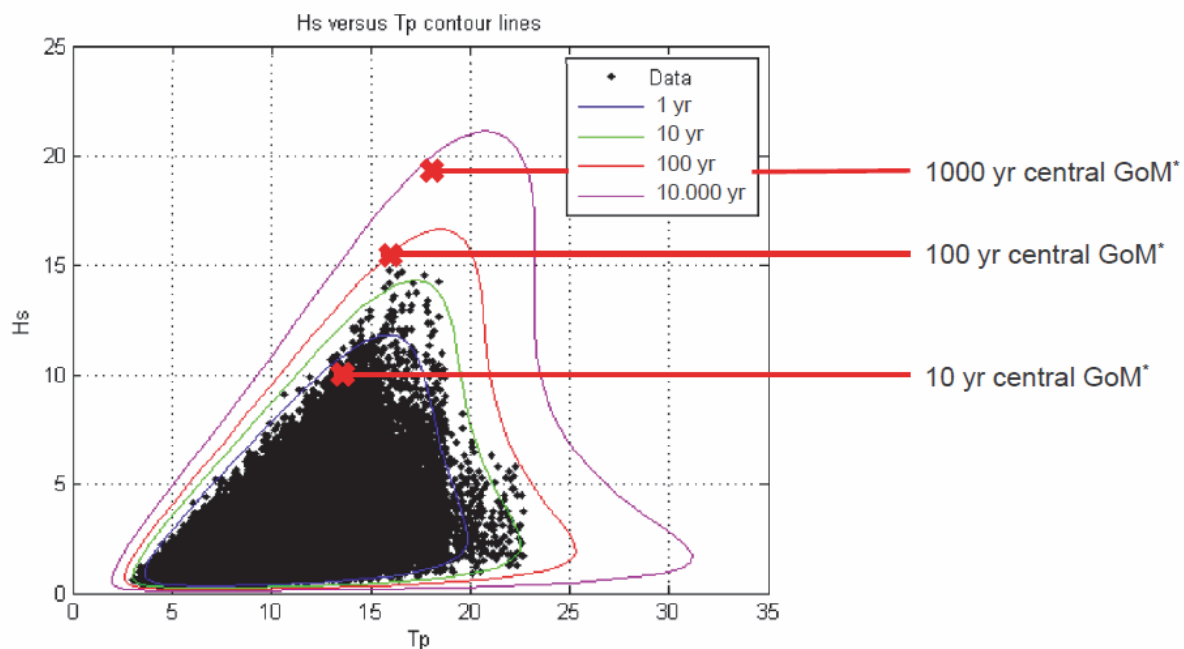
$$\frac{1}{\sqrt{2\sigma^2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Where μ is the average, σ is the standard deviation and x is the wave elevation. Please vary the wave elevation between the min and max of the data set provided.

Part 3.2. Statoil was so happy with the results delivered on the first part that they have given you the Scatter diagram of the wave statistics for a period of 15 years of the Aasta Hansteen area. (Given in the excel file).

Hs [m]	0-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	Sum
0-1	15	290	1367	2876	3716	3527	2734	1849	1138	656	362	192	101	52	26	13	7	3	2	1	0	0	0	18927
1-2	1	81	1153	5308	12083	17323	18143	15262	10980	7053	4169	2316	1229	631	315	155	75	36	17	8	4	5	1	96348
2-3	0	2	94	1050	4532	10304	15020	15953	13457	9752	5991	3403	1795	894	426	197	88	39	17	7	3	1	1	83026
3-4	0	0	2	72	686	2782	6171	8847	9189	7493	5082	2991	1577	762	345	148	61	24	9	4	1	0	0	46246
4-5	0	0	0	2	51	433	1645	3495	4807	4750	3638	2286	1229	584	251	100	37	13	5	1	0	0	0	23327
5-6	0	0	0	0	2	39	294	1037	2069	2664	2440	1709	968	463	193	72	25	8	2	1	0	0	0	11986
6-7	0	0	0	0	0	2	32	215	692	1264	1485	1228	767	382	159	57	18	5	1	0	0	0	0	6307
7-8	0	0	0	0	0	0	2	27	157	447	730	762	555	302	130	46	14	4	1	0	0	0	0	3177
8-9	0	0	0	0	0	0	0	2	23	112	276	392	355	223	104	38	11	3	1	0	0	0	0	1540
9-10	0	0	0	0	0	0	0	0	2	19	77	160	192	148	79	31	9	2	0	0	0	0	0	719
10-11	0	0	0	0	0	0	0	0	0	2	16	50	85	85	55	24	8	2	0	0	0	0	0	327
11-12	0	0	0	0	0	0	0	0	0	0	2	12	29	40	33	18	7	2	0	0	0	0	0	143
12-13	0	0	0	0	0	0	0	0	0	0	0	2	8	15	17	12	5	2	0	0	0	0	0	61
13-14	0	0	0	0	0	0	0	0	0	0	0	0	2	5	7	6	4	1	0	0	0	0	0	25
14-15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	2	1	0	0	0	0	0	9
15-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	4
16-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	16	373	2616	9308	21070	34410	44041	46687	42514	34212	24268	15503	8892	4587	2143	921	372	146	55	22	8	6	2	292172

They have asked you to determine the significant wave height that might be reached or exceeded during a periods of 100 years ($H_{s,100}$) for the period range between 5 – 20 s. (Part of the red line in the plot below).



Your task is to reproduce partly the plot above by plotting all points of the scatter diagram and calculating part of the line with significant wave heights in 100 years in the period interval 5-20 s.

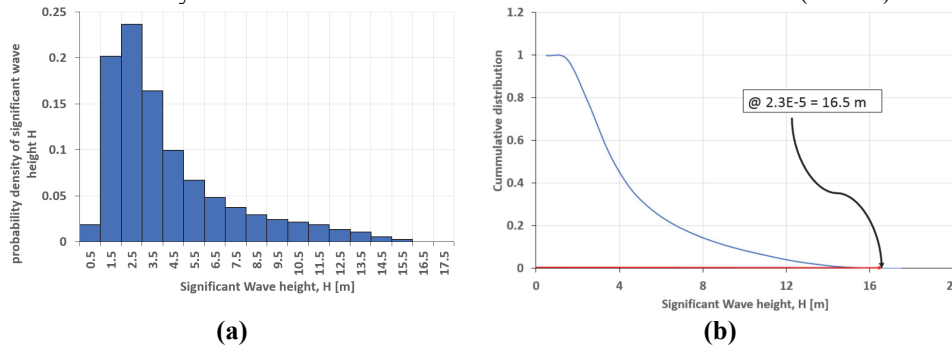
Clarifications:

As data hasn't been collected for such long periods of time, an extrapolation of the wave data collected in the scatter diagram has to be performed. The extrapolation is done using a Semi-logarithmic distribution that relates the significant wave height versus the chance of exceedance.

$$\log(P(H)) = -\frac{1}{a} H$$

The 100 year period is constituted by 292 000 “sea states” of 3 hours duration (where the significant wave height and the period can be considered constant). The 100 year wave occurs is reached or exceeded only once, thus its probability is $1/292000$ i.e. $3.4E-6$.

The data shown in the scatter plot has been gathered during a period of 15 years (probability of occurrence of a 15 years wave is $2.3E-5$). If one particular spectral period range is chosen (e.g. 18-19) then the probability density of the wave height and the cumulative distribution can be computed. The significant wave height that will likely occur once in 15 years is then can be read from the cumulative distribution (16.5 m).



Pdf and cd of significant wave height for spectral period range 18-19 s.

Then, it is possible to compute “a” from Eq. 2 (for the particular case $a = -3.5531$). The significant wave height of 100 years is then computed with the equation and a probability of $3.4E-6$. The 100 year wave obtained is 19.41 m for the period range 18-19 s for the particular case.

Problem 4: Determining optimum number of oil producers for the Goliat field

It is year 2008. The company ENI wishes to conduct a study to determine the optimum number of wells require to develop the Goliat field. This is part of the preparations for issuing the PDO. As explained by Haldorsen in his article: «Choosing between rocks, hard places and a lot more: the economic interface», the optimal number of wells can be determined by trying out different values, computing the production profile, the revenue and the NPV for each option and then selecting the one that exhibits the highest NPV (this is explained in detail in the text below, neglect the comments about plateau rate).

Plateau rate

Several plateau rates for a field should be tried (Fig. 21a). The number of wells should be varied for each choice of plateau rate to see how the NPV (Fig. 21b) and the recovery factor (Fig. 21c) are affected. Even if the recovery factor often increases as the number of wells is increased, a case of diminishing return is often evidenced (Fig. 21c). This is due to the fact that the last ‘new’ wells do not produce enough oil to pay for the added expense of including

them (perhaps the whole development concept must be changed from a ship to a GBS as the number of wells goes from 18 to 45). A plot of NPV against the number of wells and/or the plateau rate will often exhibit a maximum value (Fig. 21b). A plot of the recovery factor (at a fixed time, for a fixed number of wells) against plateau rate will demonstrate if rate sensitivity is a problem (Fig. 21d). If this is the case, the number of wells may be increased, which in turn will increase costs, and the search continues.

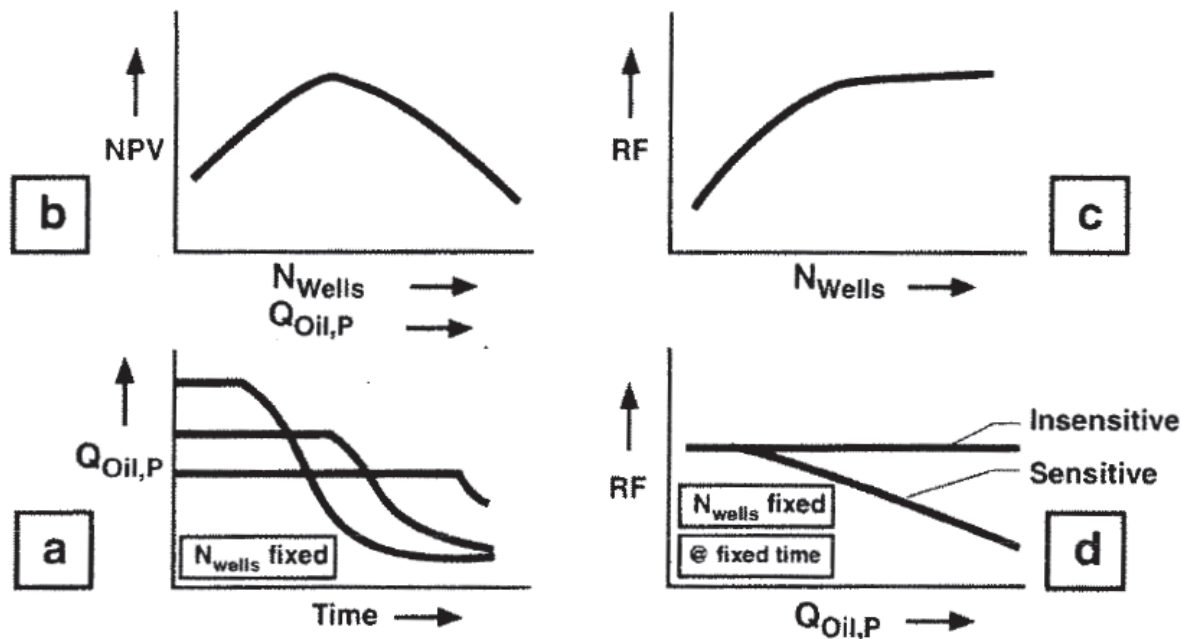


Fig. 21. Optimization methodology.

You have been asked to perform this analysis, due to your expertise in field development after taking the course at NTNU TPG4230. **Your tasks are:**

1. Perform a sensitivity analysis on the total NPV of the project by changing the number of producing wells as follows: 10, 11, 12 (keeping the field plateau constant at 15 900 Sm³/d). For each number of wells, **calculate the production profile**, annual revenues, DRILLEX, CAPEX, OPEX, total cost, cash flow, the discounted cash flow, and NPV for the Goliat field. Present your results on tables.

You should calculate the production profile using a reservoir simulator proxy (Material balance + IPR equation) **using a time step of 1 month**. The simulation should be carried out until the minimum economical rate of the field is reached (600 Sm³/d of oil). The field target rate is provided and the minimum bottom-hole pressure to use is 140 bara.

To simplify your work, the material balance expert, (a guy called Stanko) has provided you with a table that depicts reservoir pressure, producing GOR, producing WC, oil gas and water saturation as a function of cumulative oil production. He told you that, in this way, it is not necessary for you to run material balance calculations every time step. For every time step just estimate oil cumulative production at each point in time and then interpolate on the table provided to determine reservoir pressure, GOR and WC. To interpolate on the table, a VBA function has been provided (tabinterpol), check it out!.

For the oil IPR you should use the famous Vogel (1968) equation (already programmed in VBA for you):

$$\frac{q_o}{q_{o\max}} = 1 - 0.2 \cdot \left(\frac{p_{wf}}{p_R} \right) - 0.8 \cdot \left(\frac{p_{wf}}{p_R} \right)^2$$

The values that change with depletion are reservoir pressure, p_R and the $q_{o\max}$. For this particular case, Stanko has found that $q_{o\max}$ has the following trend versus reservoir pressure:

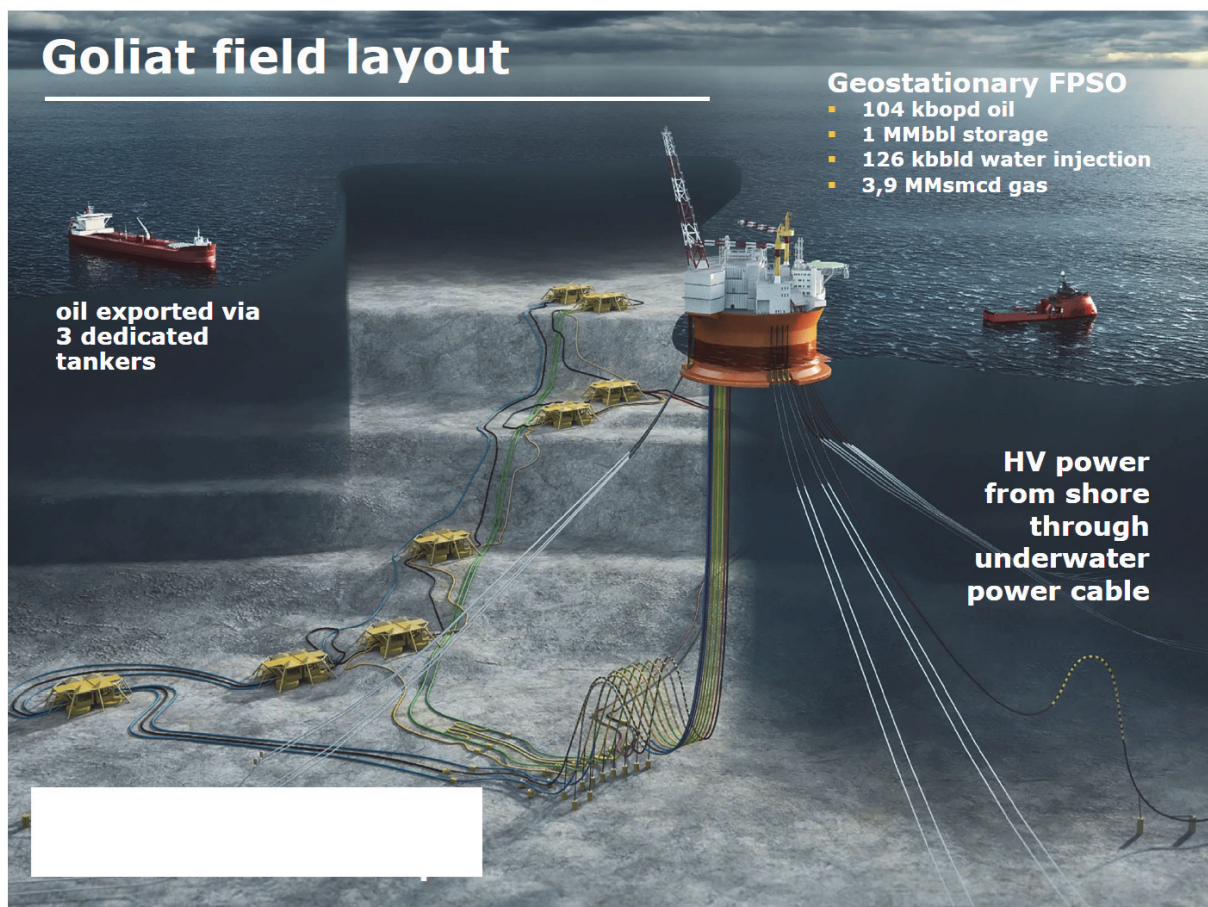
$$q_{o\max} = 38.269 \cdot p_R - 327.26 \text{ (in Sm}^3\text{/d)}.$$

Additional tasks are:

- Determine the ultimate recovery factor for each number of wells,
- Plot on the same figure the production profile for each number of wells. Is there any big change in the plateau duration?
- Plot on the same figure the GOR behavior with time for each number of wells.
- Plot on the same figure the WC behavior versus time for each number of wells.
- Plot the behavior of the IPR when reservoir pressure drops.
- Plot the gas injection rate per well for each number of wells with time. To your opinion, is this value physically feasible?
- What do you think about the statement provided by the material balance expert (Stanko). Is reservoir pressure, GOR and WC really only a function of cumulative production?

Some information about the field:

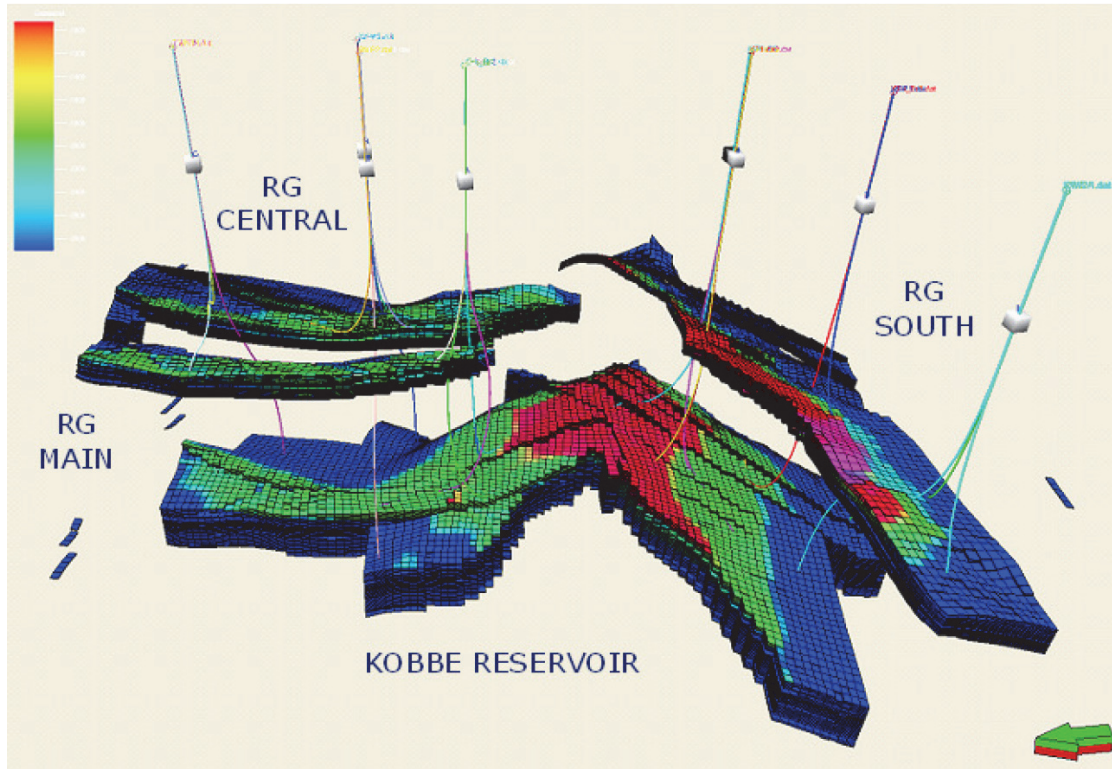
The field will be produced in plateau mode with 15 900 Sm³/d of oil and a total recoverable reserve estimated of 28 E6 Sm³ oil. The field will be produced with Subsea wells in templates and production to Sevan (circular) FPSO with risers.



The oil will be distributed to the market using tankers. The gas will be reinjected into the formation for pressure support using **two injection wells**. At the moment, **there is no solution to distribute it to the market**.

No water injection will be performed.

The main reservoir (Kobbe) has a gas cap and an underlying aquifer. For the purpose of this exercise, you are assuming that all fluids are located in a single tank. Initial reservoir pressure is 180 bara and reservoir temperature is 51.2 C. The solution GOR of the oil is 198.3 Sm³/Sm³. The horizontal permeability is 1 D. The thickness of the oil layer is, in average 60 m.



The development of the field starts in 2012. All wells will be drilled in a period of 4 years (with an average duration of drilling and completing of 2 months). The average cost per well (including completing and well equipment) is 120 E6 USD (in 2012 dollars). Usually there is a constant annual increase of 5% on this value.

The annual operating cost (OPEX) is 100 E6 USD (in 2012 dollars). Assume no change in this value with time.

The cost of the Sevan type FPSO is 1.1 E9 USD (in 2012 dollars), it will be paid upfront at the beginning of the project and the total time until delivery on site is 4 years.

Other CAPEX costs like materials and installation of the risers, umbilicals and subsea manifolds can be neglected.

All costs are given in 2012 dollars.

General assumptions for your calculations

- Neglect the buildup period of the plateau (i.e. assume that all wells enter in production at the same time).
- Oil price: 60 USD/stb
- Assume that all CAPEX is paid during the first two years of the projects.
- Assume that the project starts in 2012. Perform your NPV calculations starting from this date.
- Employ a yearly discount rate of 7%

Suggestions and recommendations:

- Calculate the cumulative production of each year using the trapezoidal rule (https://en.wikipedia.org/wiki/Trapezoidal_rule)
- The cost values given are purely referential and should be used cautiously. If an inconsistency is detected or you have obtained information from a trustworthy source, feel free to modify the input.